Distribution and Abundance of Young-of-the-Year Striped Bass, *Morone saxatilis*, in Relation to River Flow in the Sacramento-San Joaquin Estuary[1]

JERRY L. TURNER AND HAROLD K. CHADWICK
Anadromous Fisheries Branch, California Department of Fish and Game, Stockton, California 95205

ABSTRACT

Annual distribution and abundance of young-of-the-year striped bass were measured from 1959 to 1970 in the Sacramento-San Joaquin estuary. Annual abundance of young bass in late summer was closely related to the amount of river flow in June–July into the estuary ($r = 0.89$). Highly significant correlations existed between striped bass abundance and salinity and water diverted from the estuary, both of which were mutually related to the amount of river flow. Six mechanisms which may control these relationships are discussed. Annual striped bass distribution in the estuary was also related to river flow ($r = -0.93$) and salinity ($r = 0.88$) with bass being farther upstream in years of low runoff and high salinity.

INTRODUCTION

The summer abundance of young striped bass in the Sacramento-San Joaquin estuary has been monitored since 1953 to determine the environmental factors responsible for year class abundance. Knowledge of the effects of changes in the environment on the young bass population would be extremely helpful in guiding and modifying water development plans, both now and in the future, to maximize striped bass production.

We changed procedures for monitoring young bass abundance several times between 1953 and 1959 (Chadwick, 1964). Basic survey procedures have remained unchanged since 1959. Early surveys had several serious biases, so only surveys from 1959 through 1970 are analyzed in this paper. No survey was made in 1966.

DESCRIPTION OF STUDY AREA

The major striped bass population in California inhabits the estuary of the Sacramento-San Joaquin system (Fig. 1) and the adjacent coastal area (Chadwick, 1967). The area from eastern San Pablo Bay upstream through the Sacramento-San Joaquin Delta is the nursery area for young striped bass. The Delta is the network of channels forming a triangular area upstream from the confluence of the two rivers.

The estuary is subjected to tidal fluctuations with a mean of about 4 feet in San Francisco Bay and about 3 feet in the western Delta. The runoff from 46,500 square miles of the central valley of California drains into the estuary, primarily from the Sacramento and San Joaquin rivers. The flows from both rivers are extremely variable and are partially controlled by an extensive series of reservoirs throughout the watershed.

Throughout the study period, the U. S. Bureau of Reclamation pumping plant at Tracy (Fig. 1) exported water from the Delta, and starting in 1968 additional amounts were exported at the nearby State of California pumping plant. These exports ranged from about 20 to 40% of total Delta inflow during June and July of most study years. A similar proportion of the inflowing water is diverted for irrigation in the Delta and for smaller exports. The Delta irrigation demand is met through hundreds of small diversions.

San Francisco Bay is usually nearly as saline as the Pacific Ocean. The gradient from sea to fresh water generally begins in San Pablo Bay and extends some 50 miles upstream to the western Delta. This estuary is well mixed vertically. Kelley (1966) described the estuary in more detail.

METHODS

We selected thirty-four stations and sampled the major nursery area of striped bass as ex-

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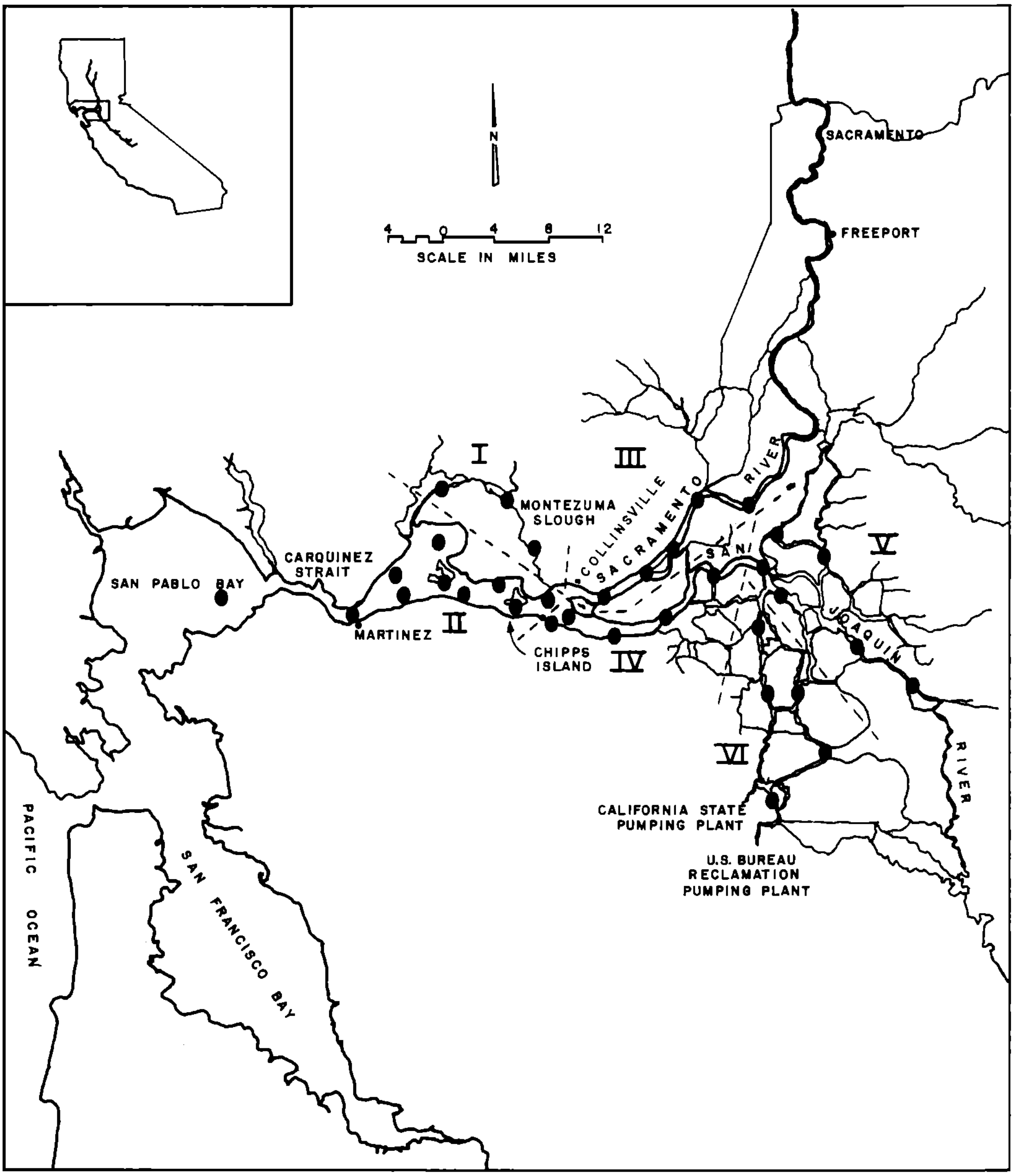

FIGURE 1.—The study area showing location of sampling stations.

tensively as possible in 5 days with one boat (Fig. 1). Three 10-minute tows were taken at each station every other week. Days of least tidal fluctuations were sampled which minimized any biases associated with tidal stage. Sampling was conducted from the time substantial numbers of bass over 0.7 inches long appeared until the mean bass size approached 2.0 inches.

Sampling was with a tow net mounted on skis (Calhoun, 1953). We took samples by towing into the current at 1,000 rpm engine speed, which resulted in a velocity through the water of approximately 2.7 feet per second.

TABLE 1.—*Summary of striped bass catches in the Sacramento-San Joaquin estuary*

Year	First survey	Second survey	Third survey	Fourth survey	Fifth survey
1963					
Date	6/14–19	6/28–7/2	7/12–16	7/26–30	8/9–13
Total Catch	837	10,316	11,210	5,205	1,430
Percentage 0.7–2.0 in.	18	55	95	98	81
Mean length[1]	0.5	0.7	1.0	1.3	1.7
1964					
Date	6/16–20	6/30–7/3	7/14–17	7/28–8/1	
Total Catch	3,028	10,048	6,042	2,732	
Percentage 0.7–2.0 in.	23	75	91	83	
Mean length[1]	0.6	0.8	1.1	1.5	
1965					
Date	6/21–25	7/6–10	7/20–24	8/2–7	
Total Catch	7,688	9,205	6,374	3,175	
Percentage 0.7–2.0 in.	30	89	98	88	
Mean length[1]	0.7	0.9	1.2	1.6	
1967					
Date	6/27–7/1	7/13–17	7/27–31	8/10–14	8/24–28
Total Catch	599	5,732	6,080	3,240	1,485
Percentage 0.7–2.0 in.	71	59	93	94	63
Mean length[1]	0.8	0.7	1.0	1.5	1.9
1968					
Date	6/17–21	7/1–5	7/15–19	7/26–30	
Total Catch	13,137	4,925	2,189	1,145	
Percentage 0.7–2.0 in.	57	88	92	44	
Mean length[1]	0.7	0.9	1.4	2.1	
1969					
Date	7/5–9	7/19–23	8/2–6	8/16–22	
Total Catch	7,840	6,689	3,386	734	
Percentage 0.7–2.0 in.	47	93	91	63	
Mean length[1]	0.7	0.9	1.3	2.0	
1970					
Date	6/24–29	7/9–14	7/22–27	8/5–9	
Total Catch	11,057	4,749	1,975	984	
Percentage 0.7–2.0 in.	86	96	87	68	
Mean length[1]	.9	1.3	1.7	1.9	

[1] Fork length in inches.

Except in 1959 and 1960, diagonal tows were made to sample all depths equally. Surface tows were made in 1959 and 1960, and catches were adjusted to correct biases caused by variations in vertical distribution (Chadwick, 1964).

Water samples were collected during sampling in 1969 and 1970 and specific conductance measured in the laboratory with a Wheatstone Bridge.

Striped bass were measured to the nearest 0.1 inch, fork length. The weighted catch of striped bass for each survey was calculated by multiplying the catch at each station by the water volume represented by the station and totaling the various stations. An annual weighted density of each year class of striped bass was calculated by multiplying the percent of total catch residing in six large geographical areas by the catch per tow in that area and summing the results. Chadwick (1964) described water volumes and sampling procedures in more detail.

INDEX OF ABUNDANCE

Four or five surveys were made annually, with the timing and number of surveys dependent on the time that most young bass were 0.7 to 2.0 inches long (Table 1 and Chadwick, 1964, Table 6). This size range was selected because it is the approximate range within which the net catches bass most efficiently. The lower limit of this range has been defined clearly by experimental evidence, but the upper limit has not been established experimentally (Chadwick, 1964).

Catches often increased through the second or third surveys, reflecting recruitment into the vulnerable size range. Subsequently, catches declined rapidly, presumably reflecting mortality in the population and declining vulnerability to the net. Significant emigration from the survey region is unlikely, since few bass are caught in sampling outside the survey area.

Initially an annual index of abundance was developed from the mean abundance of bass

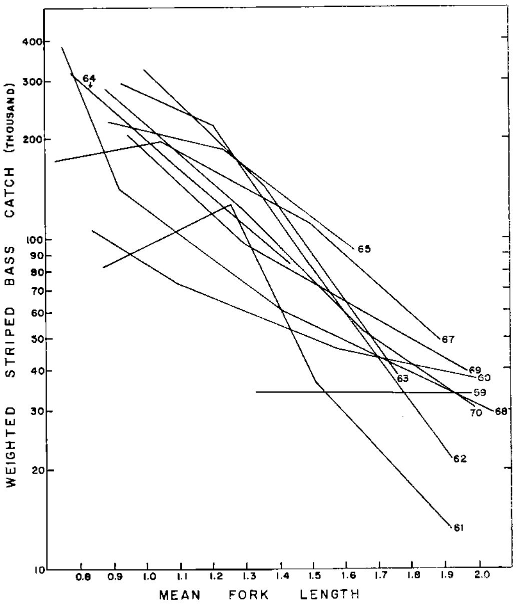

FIGURE 2.—Relationship between weighted number and mean fork length in inches of young striped bass population for 11 year classes. Numbers on figure designate years.

during the 5-week period when the greatest percentage of the population was 0.7 to 2.0 inches long (Chadwick, 1964). This approach has proved to have serious deficiencies. The most important deficiency results from mortality rates commonly over 50% during the 2 weeks between surveys. Since surveys can vary in time from year to year by as much as a week, mean abundance estimates have a significant bias from this source.

To overcome this, abundance was estimated when the fish reached selected mean lengths. This was done by plotting abundance against mean length for each survey (Fig. 2) and interpolating abundance for the selected mean length.

Relative abundance when the mean length in the population is 1.5 inches was selected as the primary measure of survival through the first few months of life. Sampling was always continued at least until this mean length was reached, and it was well within the range of maximum net efficiency.

Differences in the variance of the length frequency distributions and in growth rates still bias these indices. Variations in length frequency distributions presumably result primarily from differences in the duration of effective spawning. Such variations are appreciable (Chadwick, 1964, Fig. 3), but there does not appear to be any way to evaluate quantitatively the significance of the resulting bias.

The index of abundance when the population mean length is 1.5 inches has varied by a factor of 3.4 during the 11 years being examined (Table 2).

TABLE 2.—*Relationship between abundance of young bass and various environmental factors*

Year	Abundance of young bass	Water temperature[1]	River inflow[2]	River outflow[3]	Salinity[4]	Percent of inflow diverted[5]	Bass catch at Tracy[6]
1959	34	72.2	9,830	1,460	326	.85	7.9
1960	50	72.7	11,130	2,570	192	.77	10.2
1961	38	*	10,980	2,080	248	.81	15.2
1962	83	71.8	14,710	6,140	75	.58	14.0
1963	91	71.4	20,350	12,040	25	.41	12.1
1964	74	72.4	12,480	3,850	147	.69	26.8
1965	116	70.6	19,200	10,750	40	.44	10.8
1967	111	72.2	49,470	42,560	1	.14	1.3
1968	55	72.2	12,060	3,390	172	.72	2.7
1969	75	71.5	35,430	28,710	5	.19	.7
1970	76	71.8	13,350	4,500	*	.66	10.8
Correlation coefficient		−.645	+.846	+.889	−.887	−.904	+.09

[1] Mean June–July water temperature at Contra Costa PG&E steam plant, Antioch.

[2] Mean calculated daily inflow into Delta during June and July in cubic feet per second. From Calif. Dept. Water Resources Water Supervision and Water Flow bulletins. Correlation coefficient is calculated from log value of inflow.

[3] Mean calculated daily outflow past Chipps Island during June and July in cubic feet per second. From Calif. Dept. Water Resources Water Supervision and Water Flow bulletins. Correlation coefficient is calculated from the log value of outflow.

[4] Average salinity in parts of chlorides per 100,000 parts of water during June and July at Collinsville on the Sacramento River. Measurements taken 1½ hours after high-tide at 4-day intervals. From Calif. Dept. Water Resources Water Supervision and Water Flow bulletins.

[5] Percent of total inflow to Delta in June and July that is diverted in the Delta and at Tracy Pumping Plant. From Calif. Dept. Water Resources Water Supervision and Water Flow bulletins.

[6] Total striped bass catch at Tracy Fish Collection Facility for June and July in millions. From records of Tracy Fish Collection Facility.

* Data unavailable.

TABLE 3.—*Relationship between index of year class abundance of young striped bass and Delta outflow for various time periods. Numbers are curvilinear correlation coefficients for 11 years of data*

Month	One Month Period	Two Month Period	Three Month Period	Four Month Period
April	.680			
		.757		
May	.839		.793	
		.856		.817
June	.844		.877	
		.889		
July	.772			

RELATION OF ABUNDANCE TO ENVIRONMENTAL FACTORS

The annual indices of young bass abundance were correlated with water temperature, river inflow and outflow from the Delta, the proportion of Delta inflow which is diverted for local consumption and export, salinity, and the catch of bass at the Tracy Fish Collection Facility which is a louvered fish screen at the intake of the Bureau of Reclamation's Delta Mendota Canal (Table 2). Curvilinear correlations between bass abundance and inflow, outflow, percent diverted, and salinity are all significant at the 1% level. The correlations with water temperature are significant at the 5% level. The correlation with bass catch at Tracy is not significant.

All of the significant correlations presumably reflect the same basic cause because the independent variables are interrelated. This is true because the amount of water diverted in the Delta is relatively constant each year, so inflow and outflow parallel each other and the percentage of inflow diverted is inversely related to them. Salinity is also inversely related to water flow, because increasing flow decreases salinity intrusion from the ocean. Although not as closely related, water temperature in the Delta is also affected by the amount of inflow.

Indices of young bass abundance when the fish in the population reached various mean lengths were also correlated with river outflow to determine the time when the relationship becomes significant (Fig. 3). The relationship is highly significant when the mean length of the population is 1.0 inches and remains significant at all larger sizes.

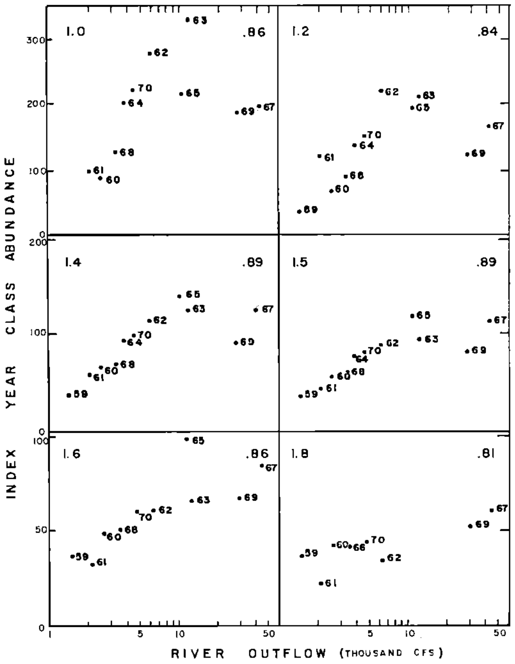

FIGURE 3.—Relationship between year class abundance of young bass for various mean lengths of the population and river outflow during June and July. Mean fork length in inches is in upper left corner of each square and correlation coefficient is in upper right corner. Numbers on figure designate years. Sample size differs for different mean lengths because the population size each year was not measured throughout the entire size range from 1.0 to 1.8 inches.

The equation for the relationship between numbers of striped bass at 1.5 inches and log of the river outflow is: Index year class abundance $= -865.3 + 441.7 \log \text{outflow} - 50.5 (\log \text{outflow})^2$. This equation indicates that survival increases rapidly as mean June–July outflows increase from 2,000 to 10,000 cfs, but survival changes little at flows above 10,000 cfs.

Indices of young bass abundance were also correlated with Delta outflow during various periods from April to July (Table 3). All correlations are significant at the 1% level except for the individual month of April which is significant at the 5% level. The June–July 2-month period had the highest correlation coefficient ($r = 0.889$). The general significance of all of these correlations is not surpris-

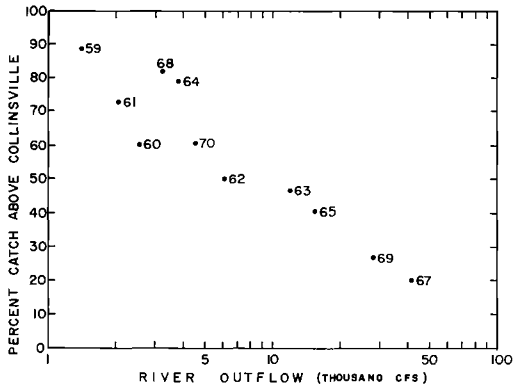

FIGURE 4.—Relationship between river outflow during June and July and the percent of young striped bass above Collinsville.

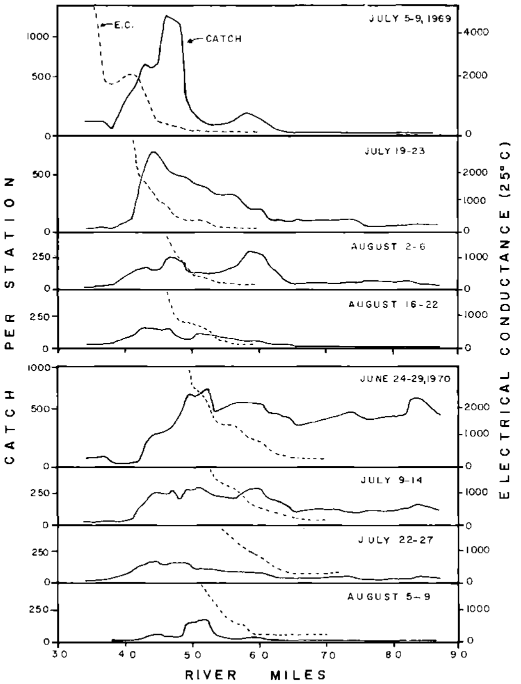

FIGURE 5.—Relationship between catch of young striped bass, electrical conductance, and river miles from Golden Gate during sampling periods in 1969 and 1970. Catches and electrical conductances are running averages for three stations.

ing, since flows throughout the spring are interrelated. The generally higher correlations with later flows suggest that flows in June and July or May, June and July are more important than flows early in the period.

RELATION OF DISTRIBUTION TO RIVER OUTFLOW

Considerable annual differences occur in the geographical distribution of young bass (Table 4). Generally the bulk of the population is near Collinsville.

The percentage of the young striped bass population upstream from Collinsville is correlated with Delta outflow ($r = -0.93$, $p < .01$) (Fig. 4). The relationship of distribution to salinity at Collinsville is also highly significant ($r = 0.88$). These results show that young bass are farther upstream during years of high salinity and low outflow than in years of low salinity and high outflow. Chadwick (1964) demonstrated a similar relationship from 1957 to 1962.

Salinity was measured during sampling only in 1969 and 1970. Running averages of catches and salinity were plotted against river miles from the Golden Gate for each sampling survey in 1969 and 1970 (Fig. 5). These years are representative of the two general types of distributions that have been observed for the 11 year-classes of striped bass. One type

TABLE 4.—*Percent of young striped bass occurring in various sections of the Sacramento-San Joaquin estuary*

Year	Montezuma Slough	Sacramento River-Collinsville downstream	Sacramento River-Collinsville upstream	San Joaquin River-Seven Mile Slough to mouth	Remainder of Delta	Old-Middle Rivers
1959	3.1	8.0	53.2	12.6	10.3	12.8
1960	4.6	35.3	32.4	15.1	6.1	6.5
1961	2.9	24.1	32.5	16.1	11.1	13.3
1962	10.9	38.2	18.3	22.2	5.3	5.1
1963	16.4	36.0	26.8	14.4	2.9	3.5
1964	3.4	17.6	46.1	21.0	5.4	6.5
1965	15.1	43.9	18.2	17.0	2.8	3.0
1967	15.1	64.2	9.8	9.8	0.4	0.7
1968	3.8	13.8	55.2	18.2	4.4	4.6
1969	17.9	54.6	10.6	13.3	1.8	1.8
1970	6.1	32.8	22.7	21.2	8.4	8.8
Mean	9.0	33.6	29.6	16.4	5.3	6.1

TABLE 5.—*Growth and survival rates of 10 year classes of young striped bass in the Sacramento-San Joaquin estuary*

Year	Growth rate inches/day	Daily loss rate percentage
1960	.0315	4.6
1961	.0250	3.0
1962	.0214	7.7
1963	.0272	7.5
1964	.0250	4.7
1965	.0272	3.5
1967	.0315	4.0
1968	.0400	6.0
1969	.0333	5.6
1970	.0272	5.4
Mean	.0289	5.2

occurs during high outflow years when the population generally has a single peak of abundance throughout the entire sampling period (1969 in Fig. 5). The second type of distribution occurs during low outflow years when the population during the early part of the season is more evenly concentrated from the area of initial mixing of fresh and salt water upstream into the freshwater portion of the estuary (June 24–29, 1970). As the season progresses in low flow years, there is a decline in the relative concentration of striped bass in the freshwater portion of the system, so that by the end of the summer during both high and low outflow years, the center of the striped bass population is near the zone of mixing.

The geographical location of the midpoint of the bass population in river miles was correlated with the density of bass in the section of estuary where the middle 50% of the population occurred. The relationship is almost significant ($r = 0.54$, $r_{.95} = 0.55$) with densities being greater when the population is located farther downstream.

GROWTH AND SURVIVAL

The daily growth rate for each year class was calculated by determining the time in days required for the mean length of the population to increase from 1.0 to 1.6 inches (Table 5). The growth rate varied from about 0.02 to 0.04 inches per day, which is about the same range estimated from modal lengths (Chadwick, 1964). Growth rates were compared with bass density at 1.0 inches, survival rates, river outflow, and mean water temperature during the same time period. None were significantly related.

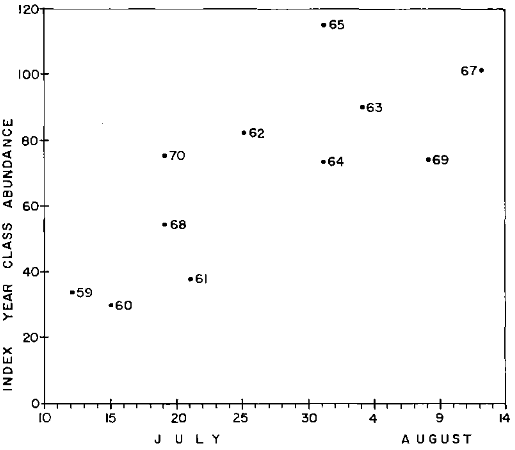

FIGURE 6.—Relationship between year class abundance of young bass and the estimated time the mean length of the population reaches 1.5 inches. Numbers on figure designate years.

The percentage of the population lost each day was calculated from the equation: $b = \log(1 - y)$ (Pearcy, 1962). In this equation, b is the slope of the line for the plot of number of young against time, and y is the percent loss per day. The line for calculating b was plotted from interpolated numbers (Fig. 2) and times when the population mean length was 1.0 and 1.6 inches. The average daily loss rate varied from 3.0 to 7.7% (Table 5).

The average daily loss rate is probably an overestimate of mortality, because some of the loss is due to increasing ability to escape the net. Escapement is probably a constant function of size though, so loss rates probably provide a reasonable index to annual variations in survival.

The survival rate of each year class was compared with the density of bass at 1 inch, log of the river outflow, and numbers of striped bass caught at Tracy. The only significant single correlation coefficient was a positive one between rate of survival and density of bass at 1 inch ($r = 0.61$, $r_{.95} = 0.55$). High density is unlikely to favor increased survival, so this correlation probably just reflects better environmental conditions.

SPAWNING TIME

The index of year class abundance was related to the time the various year classes reach a mean length of 1.5 inches (Fig. 6). The amount of outflow partially determined the time of striped bass spawning by affecting water temperature, particularly in the Sacramento River above the Delta. Previous studies have shown a relationship between water temperature and time of striped bass spawning in California with most of the spawning occurring in May (Calhoun, Woodhull and Johnson, 1950; Erkkila, Moffett, Cope, Smith and Nielson, 1950; Chadwick, 1958; Farley 1966). The two major spawning areas of striped bass are in the Sacramento River above the Delta and in the lower San Joaquin River in the Delta. The correlation coefficient between the mean inflow and mean water temperature in May at Freeport on the Sacramento River above the Delta is –0.93 from 1961 to 1970 which is highly significant. The correlation coefficient for mean inflow from all rivers entering the Delta and the mean temperature in May at the Contra Costa steam plant at Antioch in the lower San Joaquin River is –0.34 from 1959 to 1970 which is not significant.

POSSIBLE MECHANISMS RESPONSIBLE FOR RELATIONSHIPS

We do not know the mechanisms responsible for the correlations between flow parameters and the abundance of young bass, but six explanations have varying degrees of supporting evidence. These explanations are that flow controls the abundance of bass by affecting either: 1) the distribution of young bass, 2) the supply of detritus and nutrients, 3) the time of spawning, 4) predation, 5) loss to diversions, or 6) toxicity from various effluents. The first three mechanisms would all act by influencing the available food supply. The mechanisms vary in their relationship to the flow parameters, so identification of the controlling mechanism is essential to decisions on water development alternatives. The available evidence is reviewed in the following sections.

Distribution

Young bass abundance typically peaks in the zone where fresh and salt water mix initially, presumably indicating better conditions for survival there. Massmann (1963) referred to this as the "critical zone" in estuaries, because it is the principal nursery area for many fish.

At flows associated with better survival, the zone is located in the Suisun Bay area. The high proportion of shallow embayments there probably enhances productivity. In the summer of 1966 the standing crop of phytoplankton in the shallow embayments was about twice the crop in the adjacent channel (Calif. Dept. Fish and Game, unpublished data). Primary productivity is greater in the Suisun Bay region than either upstream or downstream from there (Bain and McCarty, 1966). Painter (1966) found larger zooplankton populations in one shallow embayment in Suisun Bay than in the adjacent channel, but the reverse was true in the second embayment in the region.

Detritus and Nutrient Supply

A variety of evidence suggests that high flows may increase estuarine productivity by increasing the supply of detritus and inorganic nutrients.

Detritus-feeding invertebrates are important in estuarine food chains (Darnell, 1967). The input of detritus into the estuary is probably a direct function of flow, because the annual input of total suspended solids is a direct function of river discharge (Krone, 1966), and limited evidence indicates that the percentage of organic material in total suspended solids varies little with flow (U. S. Geol. Surv., unpublished data). If the organic material is entrapped in the low salinity portion of the estuary, the organic detritus base of the food chain is presumably a function of flow. Significantly, Briggs (1970) concluded that over 90% of the organic particulate matter in upper Chesapeake Bay (where fresh and salt water initially mix) was derived from material carried in from the river.

The only direct evidence of such an effect influencing striped bass in the Sacramento-San Joaquin estuary is that the rate of decrease in larval bass abundance was closely related to the concentration of small *Neomysis awatschensis* in various areas of the estuary in 1970 (Turner, unpublished data). The rate of decrease in bass abundance may have been a biased measure of survival because of migration between areas. There have been only small differences between years in the mean number of *N. awatschensis* per bass stomach and the catch per effort of *N. awatschensis* in the estuary (Turner, unpublished data).

Evidence from other estuaries suggests a relationship between invertebrate production and flow.

Heinle (1969) found evidence suggesting that the production of *Eurytemora affinis* in the Patuxent River estuary increased greatly following the addition of organic detritus to the estuary during high spring flows. *E. affinis* is the principal food of striped bass less than 15 mm long in the low salinity zone of the Sacramento-San Joaquin estuary (Heubach *et al.*, 1963; Turner, unpublished data).

Shrimp production in estuaries has often been related to rainfall or river discharge (Hildebrand and Gunter, 1953; Thomson, 1956; Chapman, 1966). This relationship has usually been attributed to the resulting amount of habitat of suitable salinity for shrimp, but nutrient input has also been suggested as a cause (Kutkuhn, 1966).

Spawning Time

As previously mentioned, there is a general pattern of high outflow depressing water temperatures, which results in late spawning, which is then associated with greater year class abundance. Later spawning may result in greater availability of food when the young bass start to feed. Heubach (1969) found a rapid increase in numbers of small *Neomysis awatschensis* from March through midsummer. Turner (1966) and Painter (1966) reported a rapid increase in the standing crop of crustacean zooplankton from June through midsummer in the Sacramento-San Joaquin estuary.

Some evidence indicates that peak densities of *N. awatschensis* are delayed by high flow.

Predation

High outflow might influence predation indirectly by controlling turbidity, which is also highest in the zone of low salinity. As previously mentioned, the annual input of total suspended solids into the estuary is positively correlated with river discharge (Krone, 1966). However, limited measurements of light penetration in 1966 and 1967 indicate that mean light penetration was greater throughout the estuary in 1967, a high outflow year, than in 1966, a low outflow year (Chadwick, unpublished). Turbidities increased markedly during peak flow periods in the winter, but this did not persist into the moderate flow periods in spring and summer. Few of these measurements were made in the region downstream from Collinsville during the time when striped bass were so numerous there in 1967 (Table 4), but they indicate it is improbable that high outflows increase turbidity and hence reduce predation.

Loss to Diversions

The fifth possible mechanism is the loss of striped bass in water diverted from Delta channels. The primary diversions during the period of study were the Delta Mendota Canal and Delta agricultural diversions. Diversions could be important in determining survival even though the canal intake has a louvered fish screen, because the louvers do not save eggs and newly hatched larvae and salvage only about 50% of young bass approximately an inch long (Heubach, unpublished data). Also, neither Delta agricultural diversions nor the smaller export canals (Contra Costa and City of Vallejo canals) are screened.

The possibility that water diversions determine survival is supported by the fact that the percentage of the water entering the Delta which is diverted is closely correlated with the observed abundance of young bass. Again though, the meaning of this correlation is not clear, because there is also a high inverse relationship ($r = -0.997$) between the Delta outflow and the proportion of Delta inflow diverted. Hence, this correlation would exist even if some other mechanism controlled survival.

Several things suggest that water diversions are not the primary mechanism determining survival. One is that the percentage of the striped bass population in the San Joaquin Delta within the immediate influence of the canal intake was small in most years (Table 4). In 1959 and in 1961 about 25% of the population was there. In all other years it was less than 20% and in 1968, a poor year for bass survival, it was less than 10%. Moreover, during the 2-month period covered by surveys each summer, the geographical distribution of bass usually remained quite constant, and in the instances when the distribution did change, there was no consistent pattern suggesting that the fish were moving toward the canal intake.

While this distribution pattern indicates that losses in diversions are not likely to be the major factor determining survival, it does not eliminate the possibility. The steady diversion of eggs and larvae as they move downstream through the area influenced by the pumps, and the return of some young toward the pumps by tidal diffusion could result in the observed distribution pattern even though losses at the pumps were the dominant factor determining mortality.

Another consideration indicating that losses in water diversions are unlikely to be the primary mechanism controlling survival is that many bass are lost through Carquinez Strait in high outflow years (Stevens, unpublished data). His best observations of this phenomenon were made in 1967, and they indicated that very few of young carried through the Strait survived. Few young bass remained in the Delta after spawning was completed in the San Joaquin River and a major percentage of spawning in the Sacramento River had occurred. This loss in all probability was comparable to the loss in diversions in the driest of years; yet survival from late spawning in the Sacramento River was so great that the best survivals in the 11-year period occurred that year and in 1965.

Toxicity

A final possible mechanism is toxicity. The San Francisco Bay-Delta Water Quality Control Program has concluded that toxicity from municipal and industrial effluents is significant in the estuary and that about 20% of the toxicity in the system is discharged in the region where young striped bass are most numerous (Kaiser Engineers, 1969). The relationship between waste dilution and outflow, good estimates of toxic waste loadings over the study period, and better evidence of the effects of toxic wastes are necessary to evaluate the importance of this mechanism. None of these are available.

SUMMARY AND CONCLUSIONS

The almost fourfold (3.4 variation in the number of young striped bass surviving when the population mean length was 1.5 inches during the 11 summers of the study is clearly a direct function of water flow in the system. The time of spawning and the distribution of young bass are also functions of flow, with spawning taking place later and the young being farther downstream when flows are high. Young bass abundance is greatest in the low salinity zone which is typically the most productive zone for young fish in estuaries.

Several hypotheses have been advanced to explain the observed flow-survival relationship. None can be eliminated with the available evidence. We feel though that the supply of available food reflecting some combination of effects of bass distribution, detritus-nutrient input and spawning time is the most probable mechanism.

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