1964
Calif. Fish and Game
50(2): 69-99

SLATER
Striped bass

ERRATUM

Abramson, Norman J., Estimating the number of angling license purchasers, vol. 48, no. 4, pp. 253-255.

The expression following the equal sign on line 3, page 254 should read

$$N - \frac{N(N-1)}{n(n-1)}x_2 \quad \text{rather than} \quad \frac{N(N-1)}{n(n-1)}x_2 .$$

The author is indebted to Maurice I. Gershenson, California Division of Labor Statistics and Research, for noting this error.

ANNUAL ABUNDANCE OF YOUNG STRIPED BASS, *ROCCUS SAXATILIS*, IN THE SACRAMENTO-SAN JOAQUIN DELTA, CALIFORNIA[1]

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INTRODUCTION

A reliable index of striped bass spawning success would serve two important management purposes. First, it would enable us to determine if recruitment is directly related to spawning success. If it is, we could predict important changes in the fishery three years in advance.

Second, it would give insight into environmental factors responsible for good and poor year-classes. Besides increasing our understanding of the bass population, this knowledge might be used to improve recruitment by modifying water development plans in the Sacramento-San Joaquin Delta under the State Water Resources Development System.

Fyke net samples provided the earliest information on young bass distribution (Hatton, 1940). They were not promising for estimating abundance, and subsequent sampling of eggs and larvae with plankton nets also had important limitations (Calhoun and Woodhull, 1948; Calhoun, Woodhull, and Johnson, 1950).

An exploratory survey with tow nets in the early summer of 1947 (Calhoun and Woodhull, 1948) found bass about an inch long distributed throughout the lower Sacramento-San Joaquin River system except in the Sacramento River above Isleton. This suggested the best index of spawning success would be the abundance of bass about an inch long, measured by tow netting.

In 1948 and 1949 extensive tow net surveys were made to measure the relative abundance of young bass in the Delta between Rio Vista and Pittsburg (Erkkila *et al.*, 1950). In 1951, the actual size of the young bass population was estimated twice during the summer (Calhoun, 1953). Since 1953, the Department has made more limited surveys annually.

This paper reports results of these annual surveys for 1953 through 1962. It also reports results of two types of studies to evaluate their accuracy. First, more intensive surveys (Delta-wide surveys), exploratory tow net sampling, and beach seining were used to learn if annual surveys accurately measured abundance throughout the nursery grounds, and throughout the time when young bass were vulnerable to the tow net. Second, the net's size selectivity, the vertical and horizontal distribution of young bass, the effects of tidal stage on catch, and the

[1] Submitted for publication September 1963. This work was performed as part of Dingell-Johnson Project California F-9-R, "A Study of Sturgeon and Striped Bass," supported by Federal Aid to Fish Restoration funds.

relationship between water transparency and net efficiency were examined to determine how accurately tow netting measures abundance in the immediate water mass being sampled.

DESCRIPTION OF STUDY AREA

California's only large striped bass population inhabits the estuary of the Sacramento-San Joaquin River system (Figure 1) and adjacent coastal waters. Tidal movement dominates the estuary, with flow reversal occurring in summer up to Courtland on the Sacramento River and above Mossdale on the San Joaquin River. However, the Delta is essentially fresh water, with salinities seldom exceeding 1,000 ppm chlorides a few miles above the confluence of the two rivers. Downstream, salinity increases rapidly, sometimes approaching 90 percent of seawater in San Pablo Bay in late summer

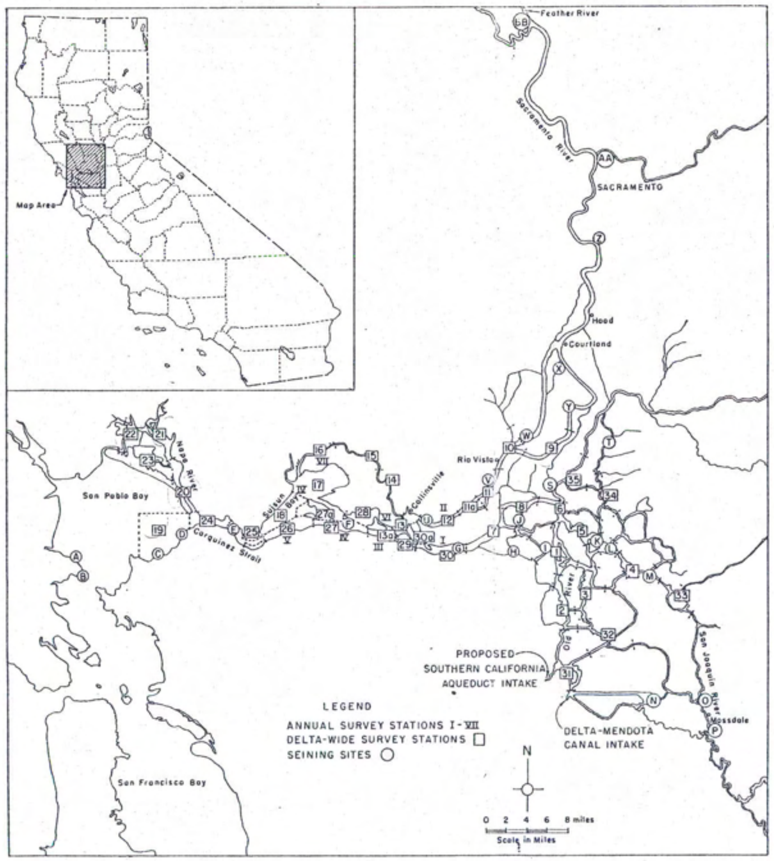

FIGURE 1. The study area showing tow net and seining stations and areas represented by Delta-wide survey stations.

Waters throughout the Delta are turbid, with Secchi disk readings seldom over a foot, except in the Sacramento River above Rio Vista. In the bays west of Pittsburg the water is clearer.

METHODS

Description of Nets

Most sampling was with a tow net mounted on skis, as described by Calhoun (1953). The net cone was made of ½-inch stretched mesh #6 medium-laid cotton webbing, and nylon bobbinet with openings approximately 0.1 inches in diameter (Pattern No. 281, Marion Textiles, Inc., New York). A 9-foot cone of cotton webbing was attached directly to the frame, and a 7-foot nylon bobbinet cone was sewed to the cotton webbing, so that the cotton webbing formed a 2-foot fyke inside the bobbinet. The overall length of the net was approximately 14 feet. A quart Mason jar was tied in the apex of the bobbinet cone.

Size selectivity, vertical distribution, and some horizontal distribution measurements were determined with modified nets. In measuring size selectivity, the bobbinet of the standard net was replaced with bobbinet having holes approximately 0.04 inches in diameter (Pattern 1400, Marion Textiles).

In measuring vertical distribution, we used circular nets, 3 feet in diameter. These had an 8-foot cone of the same cotton webbing joined to a 6½-foot cone of No. 281 bobbinet to form a 2-foot fyke inside the bobbinet. One of these nets was mounted on skis to measure horizontal distribution during 1961.

Fishing Procedures

The standard net was towed from the 28-foot research boat *Striper*, on a ¼-inch steel cable passing from a winch amidship through a block suspended from an "A" frame at the stern (Figure 2).

All samples were taken towing into the current at 1,000 rpm engine speed giving a velocity through the water of approximately 2.7 feet per second. Calhoun found this an efficient speed (Calhoun and Warren, 1949).

Fishing depth was estimated from the length of cable released. The relationship between fishing depth and cable length was established by measuring cable deflection angle, and from readings made with Moeller Chemical Sounding Tubes suspended by rubber stoppers inside an aluminum tubing capsule attached to the net frame.

Three circular nets were fished simultaneously to measure vertical distribution. Each was attached with a swivel safety hook to a swivel clamped on the towing cable. A 2-foot-square wooden kite weighted with concrete blocks was attached to the end of the cable to depress it, so less cable was needed to fish a given depth. The nets could be retrieved so rapidly that the difference between fishing times of the top and bottom nets was less than 5 percent.

Lateral distribution of small bass in various channels was measured during 1961 with a circular net mounted on skis, towed from a 40 hp outboard skiff.

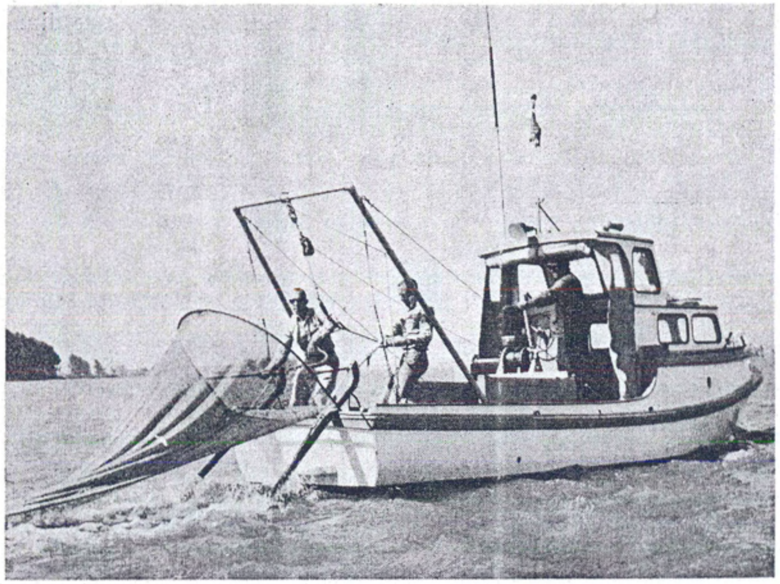

FIGURE 2. Tow net being pulled aboard *Striper* at end of a tow. *Photograph by William Heubach, July 1962.*

Annual Survey Procedures

In 1953, stations were selected in the lower San Joaquin River (I), and in the Sacramento River several miles above and below the mouth of the San Joaquin River (II and III); in 1954, two stations were added in Suisun Bay (IV and V) (Figure 1). We believed these stations represented the area inhabited by almost 90 percent of the estimated young bass population in early July 1951 (Calhoun, 1953).

These localities were sampled during the week of minus tides (water height at low tide at Golden Gate, San Francisco, below mean sea level) closest to the time that young bass at Antioch reached a mean length of 1-inch. This was to compensate for annual variations in spawning time and growth rate. Stations were sampled in numerical order—one station a day—on successive days. Fifteen 15-minute samples were taken at each station during the minus ebb tide. At the start of each tow, 185 feet of cable was released and it was retrieved during odd-minute intervals, thus all depths to about 30 feet were sampled equally.

Procedures were changed in 1957. Stations III, IV, and V were dropped, and stations were selected in Spoonbill Slough (VI) and Montezuma Slough (VII) (Figure 1). The same minus tides were sampled, but each station was sampled on three different days with five, 15-minute tows per day. Stations I and II were sampled during ebb tides on days 1, 3, and 5, and 2, 4, and 6, respectively. Stations VI and VII were sampled during flood tides on days 1, 3, and 5, and 2, 4, and 6, respectively. Sampling started 2½, 2, ½, and 1 hour after slack water

at Stations I, II, VI, and VII, respectively, and subsequent samples were taken at ½-hour intervals, so any correlation between catch and tidal stage would not bias the results. Only 100 feet of cable were released at Station VI; it was shortened to 75 and 50 feet after 5 and 10 minutes, since the water was considerably shallower there. Other procedures remained the same.

Delta-wide Survey Procedures

Thirty stations (Stations 1-30, Figure 1) were selected to sample the area between upper San Pablo Bay and Isleton on the Sacramento River and Mossdale on the San Joaquin River as extensively as could be done in 5 days with one boat. Three 10-minute samples were taken at each station every other week. Days of least tidal fluctuation were sampled to minimize 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 inches.

Previous work indicated most bass were in the top 10 feet of water (U. S. Dept. of Interior, 1957); hence, towing procedures were designed to sample equally all depths to 12 feet. This was done by releasing 100 feet of cable at the start of each tow, and retrieving 25 feet at 3-minute intervals. Data collected in 1960 showed the vertical distribution of bass was not constant, so in 1961 towing procedures were modified to sample all depths equally. We released enough cable to reach the bottom at the start of towing and pulled in 25 feet at appropriate intervals. Selected stations had a 30-foot maximum depth, since deeper water could not be sampled with available gear. During 1961, one tow at each station was made in the old manner each period, so a ratio of catches by the new method (diagonal tows) to the old method (surface tows) could be calculated.

In 1961, Stations 9, 19, 21, 22, and 24 were abandoned, because few fish had been caught there, and five stations (31-35) were added to cover the San Joaquin Delta more thoroughly. In 1962, Stations 20, 23, and 32 were abandoned so Stations 11a, 13a, 27a, and 30a could be added to increase sampling in areas of greatest water volume.

Seine Survey Procedures

Seine collections were made with a 100- by 6-foot, ⅜-inch stretched mesh beach seine during October or November 1956-1959. Sites were selected wherever suitable beaches were found from western San Pablo Bay to the mouth of the Feather River on the Sacramento River and about 10 miles above Mossdale on the San Joaquin River (Stations A-BB, Figure 1). Up to three hauls were made at each station.

Procedures Used to Evaluate Accuracy of Local Abundance Estimates

The minimum size selectivity of the standard tow net was measured by comparing lengths of bass caught in the standard net with lengths of bass caught in the net with the Pattern 1400 bobbinet cod end.

We measured vertical distribution at several localities having water depths of approximately 30 feet, by fishing the three circular nets simultaneously at 5, 15, and 25 feet.

Between 1957 and 1959, we measured horizontal distribution by comparing catches next to shore and at mid-river on alternate tows. Shore tows were in water less than 10 feet deep with 75 feet of cable, so the net rode on the bottom except at Stations 1 and 5, where the water was 20 to 30 feet deep adjacent to shore. Mid-river tows were taken following annual survey procedures. In 1961, comparisons were made by simultaneously taking a sample next to shore with the small tow net pulled by a skiff and a sample at mid-river using the procedure designed to measure vertical distribution. The mean catch of the three nets fished in mid-river was compared with the catch near shore.

Statistical Methods

Catches were analyzed with standard statistical procedures. In most experiments variables were analyzed by factorial design analysis of variance, which requires normally distributed measurements. It was impossible to determine the type of distribution of sample catches, since the population sampled was constantly changing because of tidal movement and fish behavior. However, trawl net catches generally have some type of contagious distribution, so the logarithms of the catches, or the catches plus one in samples with zero catches, are suitable for most statistical analyses (Gulland, 1956). Logarithmic transformations have been used commonly in other similar studies (Winsor and Clarke, 1940; Silliman, 1946; and Bagenal, 1958), and I used them in all analyses.

For the annual surveys, simple aggregate indices of abundance were calculated by dividing the sum of the mean catches per tow at several stations during a given year by the sum of the mean catches per tow at those stations during the base year. This gives each station an importance proportional to the magnitude of its catch. This is preferable to other ways of calculating indices, since the fraction of the population present at each station cannot be estimated.

A simple aggregate index was also calculated for the Delta-wide surveys. In addition, a weighted index was calculated by multiplying the catch at each station by the water volume represented by the station (Appendix A). These volumes were determined by setting boundaries midway between stations or at a distance of 2.5 miles from stations on the area's periphery and estimating the water volume present at mean half-tide to the nearest 1,000 acre-feet.

Striped bass were measured to the nearest 0.1-inch, fork length.

RESULTS

Annual Surveys

1953-1956 Surveys

Catches during 1953 and 1954 were considerably greater than those during 1955 and 1956, and catches were generally greatest at Stations I and II (Table 1).

The 1954-1956 results were analyzed by analysis of variance to test the hypothesis that these stations sampled the population adequately. The 1953 results were not included, since only three stations were sampled. I assumed the first tow each day was made at the same tidal stage, and the other tows followed at equal time intervals. Thus, the catches of any given tow were indicative of a certain time during the tide. The first order interactions, year x time and time x station, were not significantly different at the 95 percent level from the second order interaction, so the three were combined to estimate sampling error (Table 2).

TABLE 1

Summary of Striped Bass Catches Made During Annual Surveys

Station		Date									
		7/26-28 1953	6/28-7/2 1954	7/4-8 1955	7/19-23 1956	7/13-16 1957	7/26-8/1 1958	6/20-25 1959	7/6-11 1960	6/26-7/1 1961	7/1-6 1962
I	Catch/tow	85.0	117.1	73.5	48.9	*23.9	37.6	13.1	42.1	157.8	*277.8
	Mean length†	1.0	1.0	1.1	1.0	1.2	1.1	1.5	1.3	1.1	0.9
II	Catch/tow	110.7	96.2	35.5	21.3	*27.3	17.9	9.3	117.3	235.6	417.9
	Mean length	1.0	1.0	1.0	1.0	1.3	1.3	1.4	1.2	0.9	1.1
III	Catch/tow	64.5	57.0	4.9	20.5						
	Mean length	1.1	1.1	1.0	1.3						
IV	Catch/tow	--	51.3	5.8	30.3						
	Mean length	--	1.2	1.2	1.5						
V	Catch/tow	--	6.7	10.9	9.7						
	Mean length	--	1.3	1.2	1.4						
VI	Catch/tow	--	--	--	--	*58.9	54.7	30.7	129.1	362.1	*462.8
	Mean length	--	--	--	--	1.1	1.0	1.3	1.1	0.9	1.0
VII	Catch/tow	--	--	--	--	*50.5	116.9	10.0	49.6	87.5	*235.5
	Mean length	--	--	--	--	1.4	1.2	1.6	1.7	1.3	1.1

* Sampling limited to two days and 10 samples.
† Fork length in inches.

TABLE 2

Analysis of Variance of 1954-1956 Tow Net Surveys

Variable	*Degrees of Freedom*	*Sum of Squares*	*Mean Square*
Year	2	4.252	2.126
Station	4	8.281	2.070
Time	14	0.949	0.068
Year x station	8	2.485	0.311
Error	196	6.618	0.034
Total	224	22.585	

Three important results of this analysis are: (i) differences among yearly catches are highly significant ($F = 62.53$ with $F_{.01} = 4.70$); (ii) differences among mean catches at the stations are highly significant ($F = 60.88$ with $F_{.01} = 3.85$), clearly indicating an unequal distribution of bass in the area sampled; (iii) the year x station interaction is significant ($F = 9.15$ with $F_{.01} \cong 2.85$), indicating significant annual differences in geographical distribution.

To test the hypothesis that these stations sampled the population in many miles of river due to fish being carried by the relatively fast-moving water during minus ebb tides, the relationship between the catches at Stations I, II, III, and V was examined. Float studies

(Calif. Div. of Water Resources, 1952) indicated that water moves from Station III to Station V in approximately 3 hours. Hence, early catches at Station III should be similar to late catches at Station V. Such a relationship was evident only in 1956 (Table 3). Catches at Stations I and II also failed to show a relationship to those at Station III.

TABLE 3

Total Catches of Striped Bass at Stations III and V During Comparable Periods of Sampling

	Station III Tows 1-5	*Station V Tows 10-15*
1954	230	67
1955	9	104
1956	91	81

1957-1962 Surveys

Boat breakdowns prevented 1 day of sampling at each station in 1957 and 1 day at three stations in 1962. The 1959 results are aberrant because the survey was 2 weeks late. This occurred because young bass reached a 1-inch mean length a month earlier than in any other year.

Annual catches were relatively low from 1957 through 1959 and then increased sharply to a 10-year high in 1962 (Table 1).

Appreciable variations in catches on different days at the same station have occurred during some years (Table 4).

TABLE 4

Variability in Catch of Striped Bass at Station I During Annual Surveys

	Mean catch per tow		
Year	*Series I*	*Series II*	*Series III*
1957	33.6	14.2	
1958	43.8	37.8	31.2
1959	14.0	17.0	8.2
1960	50.8	37.4	38.0
1961	160.2	219.6	93.6
1962	350.2	--	205.2

Indices of Abundance

The only measure of abundance possible for all years is an index of abundance at Stations I and II (Table 5, Annual survey A), since these were the only stations sampled every year. Broader based indices were calculated for 1957 through 1962 from catches at Stations I, II, VI, and VII (Table 5, Annual survey B), and for 1954 through 1956 from catches at Stations I through V (Table 5, Annual survey C); 1960 is the base year used for the first two indices. The last index was calculated using 1954 as a base and multiplying each annual abundance index by 1.34 to put them on the same scale as the other indices.

The indices agree closely with each other. They show a decline in abundance from a 1953-54 peak to a low in 1959, and then a sharp increase through 1962, with abundance being greatest in 1961 and 1962.

TABLE 5

Indices of Annual Abundance of Striped Bass Fry in the Sacramento-San Joaquin Delta [1]

	Year									
Index	*1953*	*1954*	*1955*	*1956*	*1957*	*1958*	*1959*	*1960*	*1961*	*1962*
Annual survey A [2]	1.23	1.34	0.68	0.44	0.32	0.35	0.14	1.00	2.47	4.36
Annual survey B [3]					0.48	0.67	0.19	1.00	2.49	4.12
Annual survey C [4]		1.34	0.54	0.54						
Delta-wide survey A [5]							0.49	1.00	1.40	3.20
Delta-wide survey B [6]							0.38	1.00	1.04	2.60
Delta-wide survey C [7]							0.44	1.00	1.20	3.34
Delta-wide survey D [8]									1.00	2.42

[1] Underlining indicates best estimates of relative abundance.
[2] Sum of mean catches per tow at Stations I and II divided by the 1960 sum.
[3] Sum of mean catches per tow at Stations I, II, VI, and VII divided by the 1960 sum.
[4] Sum of the mean catches per tow at Stations I, II, III, IV, and V, divided by 1954 sum, and multiplied by 1.34 to equate it to other indices.
[5] Total number of bass collected at Stations 1-30 during three surveys when more than 70 percent of all bass were between 0.7 and 2.0 inches long, adjusted for annual differences in survey procedures, and divided by 1960 total.
[6] Similar to Delta-wide survey A except that catch at each station was multiplied by the thousands of acre-feet of water present at the station and stations with "a" suffixes included in 1962 in addition to stations 1-30.
[7] Similar to Delta-wide survey B except that catches during four surveys were included (Survey No. 1 excluded in 1961) and only 1.0-1.4 inch bass were included, except during first survey, when those larger than that were included, and fourth survey, when those smaller than that were included.
[8] Similar to Delta-wide survey B but includes stations 31, 33, 34, and 35, and excludes stations 9, and 19-24.

Delta-wide Surveys

Length Composition of Catch

Four Delta-wide surveys were made annually in 1959, 1960, and 1962, and five were made in 1961 (Table 6). The 1960, 1961, 1962 catches

TABLE 6

Summary of Striped Bass Catches During Delta-wide Surveys *

Year	*First survey*	*Second survey*	*Third survey*	*Fourth survey*	*Fifth survey*
1959					
Date	6/13-18	6/27-7/1	7/11-15	7/25-29	
Total catch	556	824	640	272	
Percentage 0.7-2.0 inches	91	72	70	66	
Mean length †	1.1	1.1	1.5	1.9	
1960					
Date	6/16-20	6/30-7/4	7/13-18	7/28-8/1	
Total catch	1,737	1,329	758	280	
Percentage 0.7-2.0 inches	82	89	85	55	
Mean length †	0.8	1.1	1.5	2.1	
1961					
Date	6/5-9	6/19-23	7/4-10	7/17-21	7/31-8/3
Total catch	1,061	3,736	4,428	1,152	335
Percentage 0.7-2.0 inches	55	81	82	91	64
Mean length †	0.7	0.8	1.0	1.4	1.9
1962					
Date	6/26-29	7/8-12	7/23-27	8/6-10	
Total catch	10,814	8,099	3,103	733	
Percentage 0.7-2.0 inches	85	96	88	64	
Mean length †	0.9	1.2	1.5	1.9	

* Catches are not comparable in all years due to changes in survey procedures and stations described in text.
† Fork length in inches.

showed similar patterns, with mean length increasing from 0.8 or 0.9 inches to about 2 inches over a period of four surveys. The bulk of the catch was made during the first three of these surveys, when over 80 percent of the bass were 0.7 to 2.0 inches long. In 1959, bass were larger during the first survey and the size range was greater, and only about 70 percent of the catch was in the 0.8 to 2.0-inch range, except during the first period.

Length frequency distributions of the catches are not as similar as the means (Figure 3). Three modes progress through the fishery in 1959, while there were two modes in 1960 and 1961, and only one in 1962. The modes probably indicate either periodicity in spawning or periodicity in survival. The modes on successive surveys generally coincided during 1959 and 1960, and the modes at 0.7 inches coincided in 1961.

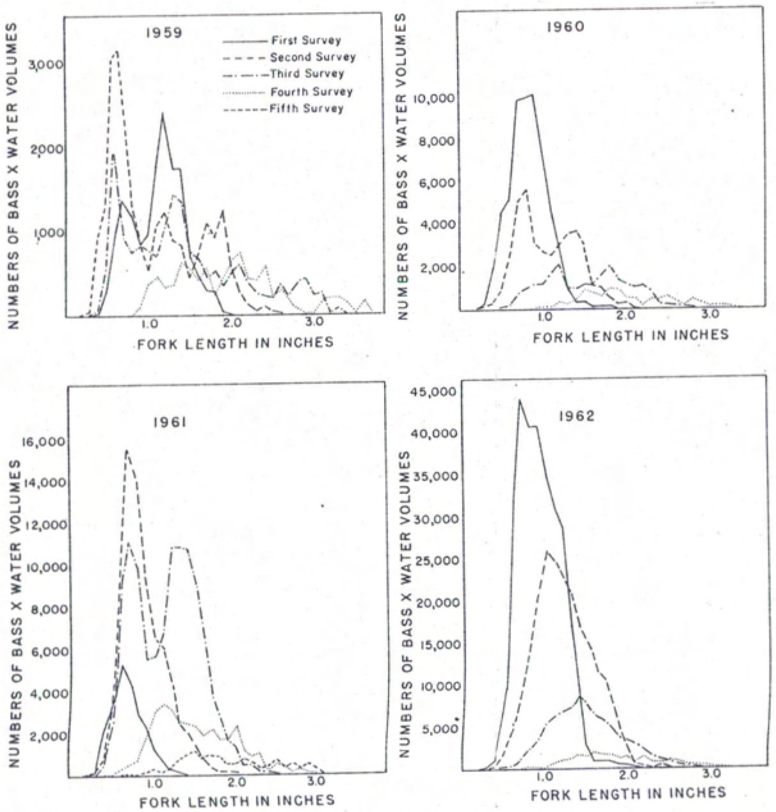

FIGURE 3. Length frequencies of striped bass caught during Delta-wide surveys.

Geographical Distribution

Appreciable annual variations occurred in the geographical distribution of young bass (Table 7). Distribution was similar in 1959 and

1961, with about 60 percent of the bass in the lower Delta and most of the rest in the San Joaquin Delta. The 1960 distribution was similar, but even more bass were in the lower Delta and fewer in the San Joaquin Delta. The population was generally farther downstream in 1962.

TABLE 7

Relative Distribution of Young Striped Bass in the Sacramento-San Joaquin Delta

Stations	*Percentage of Total Catch* *			
	1959	*1960*	*1961*	*1962* †
San Joaquin Delta				
1, 2 and 3	16	7	12	4
4, 5, 6, and 8	16	8	14	7
Lower Delta				
7 and 30	13	16	13	21
9, 10, 11, and 12 ‡	41	25	32	18
13 and 29	8	37	21	17
Suisun Bay Area				
14, 15, and 16	4	4	5	11
26, 27, and 28	2	2	3	19
17, 18, and 25	1	1	1	3
San Pablo Bay Area				
20 and 23	Trace	0	0	–

* Percentage of total catch weighted by water volume during the three Delta-wide Surveys with over 70 percent of bass between 0.7 and 2.0 inches.
† Stations with "a" suffixes tabulated with station of same number. Part of station 13 included in station 30a.
‡ Station 9 not sampled in 1961 and 1962.

Indices of Abundance

Four indices of abundance were calculated from the Delta-wide surveys (Table 5). Delta-wide survey indices A and B were based on catches during the three surveys each year when over 70 percent of the bass caught were 0.7 to 2.0 inches long (Table 6). Both were adjusted by depth correction factors during 1959 and 1960, and for 1961 because only two diagonal tows were made at most stations that year. The depth correction factors were calculated by grouping similar stations and dividing the sum of the average diagonal tow catches by the sum of the surface tow catches (Table 8). Index A was calculated by dividing the total catch during the three surveys in each year by the 1960 total catch. Index B was calculated by weighing the catch at each station by the appropriate water volume (Appendix A), summing the weighted totals, and dividing each year's total by the 1960 total.

TABLE 8

Comparison of Diagonal Tows and Surface Tows During the First Four 1961 Delta-wide Surveys

Stations	*Total catch* *		*Ratio*
	Diagonal tows	*Surface tows*	
1+2+3	467.5	430	1.1
4+5+6+8	504.5	511	1.0
7+30	162	108	1.5
29	104.5	165	0.6
11	185.5	55	3.4
12	195.5	18	10.9
13	165.5	67	2.5
15+16	135	67	2.0
25+26+27	18.5	22	0.8

* Catches include only fish 0.7-2.0 inches long. Catches from diagonal tows were divided by two, since two diagonal tows and only one surface tow were made at each station.

Delta-wide survey Index C estimates bass fry abundance as they pass through the size interval 1.0 to 1.4 inches. Modal lengths (Figure 3) indicate this interval is approximately equal to bass growth during a 2-week period. Thus, each group would be sampled only once. This index was calculated by using the total catch of 1.0- to 1.4-inch bass, weighted by water volumes, during four surveys (Survey 1 excluded in 1961). In addition, the weighted catches of bass larger than this on the first survey and smaller than this on the fourth survey were included.

Delta-wide survey D was calculated similarly to Index B, but Stations 9 and 19-24 were excluded and Stations 31, 33, 34, and 35 were included.

All three indices show similar trends of increasing abundance during 1959 through 1962.

A weighted index comparable to Index B was calculated for each of five size groups of bass (Table 9). Annual differences are smallest in the largest and smallest groups, and greatest in the middle group.

TABLE 9

Index of Abundance of Various Sizes of Striped Bass

Length group	*1959*	*1960* *	*1961*	*1962*
0.0-0.5	45	100	60	112
0.6-0.9	28	100	84	208
1.0-1.4	41	100	118	328
1.5-1.9	50	100	109	215
2.0+	116	100	57	99

* Base year.

Growth Rates

Distances between modal lengths in subsequent surveys are probably accurate measures of growth for 2-week periods. The distances between pronounced modes in tenths of inches are: 1959—0.5, 0.6, 0.7; 1960—0.4, 0.4, 0.6; 1961—0.4, 0.6; 1962—0.3, 0.4 (Figure 3).

Exploratory Tow Net Sampling

Considerable exploratory tow netting was done between 1954 and 1958. Most sampling in areas covered later by the Delta-wide surveys contributed nothing additional to our knowledge of young bass distribution. However, sampling in the Sacramento River above Rio Vista, in San Pablo Bay, and in the Napa River and adjacent sloughs contributed substantially.

On August 7 and 8, 1957, eight tow net samples were taken at scattered locations from the south end of Steamboat Slough (Station W) to the mouth of the Feather River. The only bass was collected near Station X. At the same time, seine collections caught 13 bass at Station W in two hauls, 18 at Station AA in three hauls, and 3 at Station BB in one haul.

On July 7, 1958, no bass were caught in five tow net samples between Stations W and AA.

On July 17, 1957, one bass was caught in six tow net collections in the Napa River between the mouth and Napa.

The Napa River was sampled on three occasions in 1958. On June 19, 26 bass were caught in four samples between the mouth and Station 21. On June 26, 429 bass were caught in eight samples in the river and adjacent sloughs in the general area covered by Stations 20-23. On July 22, 227 bass were caught in seven samples in this area and three in the main river between Station 21 and Napa.

The only sampling in San Pablo Bay consisted of 12 tow net hauls on June 25, 1958 at scattered localities throughout the Bay. Only nine bass were taken in the eastern part of the Bay. In contrast, the remainder of the catch was composed of Sacramento smelt, *Spirinchus thaleichthys*, 7; smelt, *Hypomesus* spp., 110; anchovy, *Engraulis mordax*, 1, 157; splittail, *Pogonichthys macrolepidotus*, 24; threespine stickleback, *Gasterosteus aculeatus*, 3; unknown goby, 208.

Seine Surveys

Fall seine surveys collected young bass in appreciable numbers from eastern San Pablo Bay to Ryde on the Sacramento River and Mossdale on the San Joaquin River (Table 10).

TABLE 10

Catches of Young-of-the-Year Striped Bass Made in Fall Seine Collections

		Number of young-of-the-year striped bass per seine haul			
Station	*Location*	*1956*	*1957*	*1958*	*1959*
A	San Pablo Bay at China Camp	–	0	0	0
B	San Pablo Bay at Pt. San Pedro	–	0	0	0
C	San Pablo Bay at Pt. Wilson	–	5	4	0
D	San Pablo Bay at Rodeo	19	9	53	1
E	Carquinez Strait at Port Costa	76	80	10	3
F	Sacramento R. at Middle Grounds	53	16	7	101
G	San Joaquin R. at Antioch	300	20	133	6
H	Taylor Slough	–	5	1	2
I	Sand Mound Slough at Piper Slough	–	–	50	3
J	Fishermen's Cut	–	0	0	1
K	San Joaquin R. at Medford Island	550	82	129	172
L	San Joaquin R. at Headreach Island	600	22	37	10
M	San Joaquin R. at Roberts Island	200	128	82	436
N	Salmon Slough at Doughty Cut	8	3	14	3
O	San Joaquin R. ½ mi. below Mossdale	8	2	–	–
P	San Joaquin R. 1 mi. above Mossdale	–	86	1	2
Q	San Joaquin R. 3 mi. above Mossdale	–	–	0	–
R	San Joaquin R. 10 mi. above Mossdale	–	–	3	–
S	Mokelumne R. at Highway 12	62	12	1	2
T	South Fork Mokelumne R. above Hog Slough	2	7	1	1
U	Sacramento R. at Sherman Island	77	38	82	3
V	Sacramento R. below Rio Vista	90	163	51	10
W	Steamboat Slough, south end	15	17	12	1
X	Steamboat Slough, north end	–	44	7	4
Y	Sacramento R. at Ryde	25	13	23	5
Z	Sacramento R. above Freeport	5	7	2	3
AA	Sacramento R. at American R.	5	0	1	+
BB	Sacramento R. at Feather R.	2	–	15	0

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Accuracy of Measurement of Local Abundance

Size Selectivity

Ratios of bass catches in the standard-mesh net to those in the fine-mesh net during two pairs of tows at Station 14 and three pairs at Station I indicated the standard net's efficiency increases sharply as bass size increases from 0.5 to 0.7 inches and reaches 100 percent at approximately 0.8 inches (Table 11). This is supported by the fact that of 42 bass fry gilled in the standard bobbinet during 1958, the percentages of 0.6-, 0.7-, and 0.8-inch fry were 12, 76, and 12, respectively.

TABLE 11

Comparison of the Lengths of Striped Bass Fry Caught in Standard Tow Net and Tow Net with Small Mesh Cod End

Length *	*Standard Net*	*Small Cod End Net*	*Ratio*
0.2	0	63	0.00
0.3	4	151	0.03
0.4	14	102	0.14
0.5	36	198	0.18
0.6	175	326	0.54
0.7	283	346	0.82
0.8	150	128	1.17
0.9	36	39	0.92
1.0	3	6	–
1.1	0	5	–
1.2	1	0	–
1.3	1	0	–
1.4	0	1	–

* Fork length in inches.

Striped bass become less vulnerable to the net as they grow, presumably because of increased swimming ability. The limit of vulnerability is about 3.5 inches, since virtually no larger ones were caught, even though they occurred in the areas sampled. However, no satisfactory method was found to measure accurately the decline in vulnerability. During the Delta-wide surveys, annual modal length varied from 0.7 to 0.9 inches and the catch of larger fish generally declined sharply (Figure 3). This resulted from a combination of mortality and declining vulnerability, and no facts are available to measure the contribution of each. However, the small catch of bass longer than 2 inches (11.4 percent of the catch in 1959, and half or less of this in other years) suggested the net was quite inefficient for bass of this size.

Vertical Distribution

During 1960 and 1961, vertical distribution was sampled at nine localities (Tables 12 and 13). In the western part of the Delta (Stations 7-30), bass were generally concentrated near the bottom, while in the eastern part (Stations 1-5) they were more evenly distributed, with greatest concentration frequently near the surface.

Bass showed a general tendency to raise off the bottom during flood tides. This was more pronounced and general in the western localities. This tendency was particularly pronounced and closely correlated with tidal stage at Station 12 in both 1960 (Figure 4) and 1961.

TABLE 12

Vertical Distribution of Striped Bass During Ebb Tides

Station	*Date*	*Number of tows*	*Mean catches per tow at various depths below surface* † *5 feet*	*15 feet*	*25 feet*
15	6/14/60	10	4.2	17.1 **	15.0
14a	7/25/60	10	2.1	8.3	14.1 **
12	6/15/61	7	1.6	15.7	20.5 **
12	7/23/60	10	1.4	16.9	65.1 **
12	7/27/61	7	0	18.5	70.8 **
12	8/ 2/60	5	8.2	12.0	94.6 **
30	6/27/60	10	16.5	32.5 **	24.0
7	6/16/61	7	0.4	23.5	28.3 **
7	7/13/61	7	2.6	34.5	104.8 **
5	6/14/61	7	38.8 **	25.2	9.0
5	7/12/61	7	19.8	32.1 **	29.1
1	6/24/60	10	29.5	33.5 **	13.9
1	7/21/60	10	13.3 **	7.0	3.2
3	6/13/61	7	38.4 **	21.2	7.3
3	7/11/61	7	21.8	81.6 **	23.5

† In this and subsequent tables, single asterisks denote differences significant at 95 percent levels and double asterisks denote differences significant at 99 percent levels.

TABLE 13

Vertical Distribution of Striped Bass During Flood Tides

Station	*Date*	*Number of tows*	*Mean catches per tow at various depths below surface* *5 feet*	*15 feet*	*25 feet*
16	7/20/61	7	1.0	0.7	7.8 **
14a	7/25/60	5	2.4	10.0	11.4 **
12	6/15/61	7	0.9	21.8 **	12.9
12	7/23/60	5	2.8	14.4	34.5 **
12	7/27/61	7	0.6	44.8	64.0 **
12	8/ 2/60	10	2.4	38.9 **	24.9
30	6/27/60	5	9.2	23.0	32.0 **
7	6/16/61	7	6.7	42.0	45.4 **
7	7/13/61	7	10.0	27.8	68.0 **
5	6/14/61	5	27.5 **	15.4	2.8
5	7/12/61	7	23.5	45.2 **	24.1
1	6/24/60	5	28.8	16.8	18.4
1	7/21/60	5	6.6 **	1.0	2.5
3	6/13/61	7	50.5 **	36.5	17.8
3	7/11/61	7	14.7	23.1	28.2 **

TABLE 14

Mean Lengths of Striped Bass Caught at Different Depths

Station	*Date*	*Mean lengths at various depths* *5 feet*	*15 feet*	*25 feet*
15	6/14/60	0.8	0.8	0.7
14a	7/25/60	1.8	1.7	1.7
12	6/15/61	0.6	0.7	0.6
12	7/23/60	1.9	1.5	1.6
12	7/27/61	1.9	1.6	1.8
12	8/ 2/60	2.4	2.1	2.0
30	6/27/60	1.0	1.1	1.1
7	6/16/61	0.7	0.7	0.8
7	7/13/61	1.2	1.1	1.1
5	6/14/60	0.7	0.8	0.7
5	7/12/61	1.0	1.0	1.0
1	6/24/60	0.9	1.0	1.0
1	7/21/60	1.4	1.4	1.5
3	6/13/61	0.7	0.7	0.7
3	7/11/61	0.9	0.9	0.9

Mean length of bass and depth were not correlated except at Station 12, where fish near the surface were larger late in the season (Table 14).

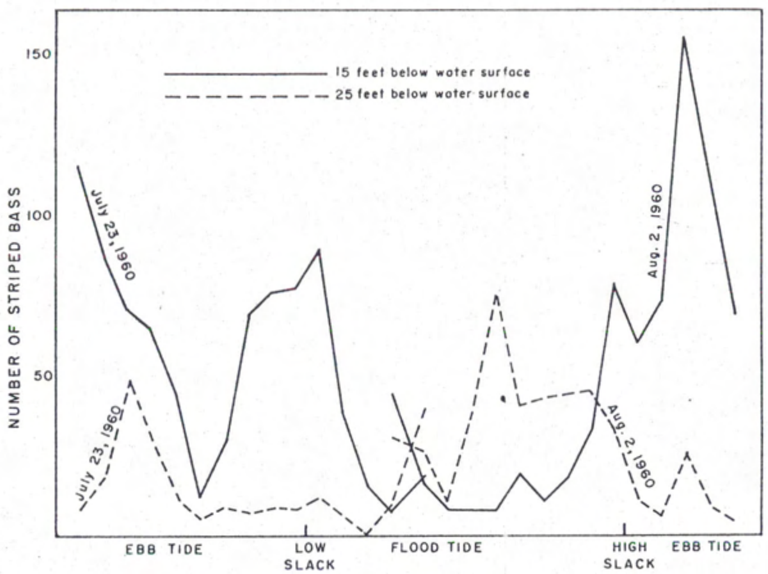

FIGURE 4. Relationship between striped bass tow net catches at different depths and tidal stage.

Horizontal Distribution

Horizontal distribution was measured between 1957 and 1961 (Tables 15 and 16).

Huge concentrations of small bass were found along the shore in the western Delta. As they grew, their distribution became more even, and in several instances significantly more of the larger bass were caught at mid-river.

Bass were more evenly distributed at Stations 1, 3, and 5, but some mid-river catches were significantly greater at Stations 3 and 5.

Variations Due to Tidal Stage

Evidence of significant vertical distribution variations related to tide was presented earlier. A comparison of the ratios of bass caught near shore to bass caught in mid-river during ebb tides with comparable ratios during flood tides (Table 17) indicates that differences were not consistent, even though they were sometimes great.

TABLE 15

Horizontal Distribution of Striped Bass During Ebb Tides

			Mean catches per tow					
		Number	Bass to 0.8 inches		Bass 0.9-1.4 inches		Bass 1.5 inches or more	
Station	Date	of tows	Near shore	Mid-river	Near shore	Mid-river	Near shore	Mid-river
16	6/28/57	7	461 **	145	34	26	0	0
16	6/20/58	8	68 **	12	20 **	5	0	0
16	7/ 3/58	8	157 **	34	38 **	6	3 **	+
16	8/ 1/58	8	24 *	6	49	71	2	35 **
16	7/20/61	7	0	0	2	+	18 **	0
14a	7/22/59	8	0	0	3	9 *	6	27 **
III	7/27/57	7	0	0	0	0	5	8
30	7/26/57	7	0	0	0	0	4	11
30	7/13/58	7	14	12	4	8	0	0
30	7/16/58	8	23	18	5	8	0	0
30	7/24/58	8	28 *	10	20 **	6	4	2
12	6/15/61	6	282 **	12	7 **	1	0	0
12	7/27/61	7	6 **	+	11	9	1	21 **
7	6/16/61	5	225 **	11	25 **	4	0	+
7	7/13/61	7	10	7	8	34 **	1	7 **
1	6/23/60	8	27	13	14	21	+	+
3	7/11/61	7	14	19	11	19	+	1
5	6/14/61	6	8	21 *	2	4	0	0
5	7/12/61	7	4	7 *	8	18 **	1	2 *

TABLE 16

Horizontal Distribution of Striped Bass During Flood Tides

			Mean catches per tow					
		Number	Bass to 0.8 inches		Bass 0.9-1.4 inches		Bass 1.5 inches or more	
Station	Date	of tows	Near shore	Mid-river	Near shore	Mid-river	Near shore	Mid-river
16	6/20/58	4	34 *	15	21	7	0	0
16	7/ 3/58	4	127	29	41	8	0	0
16	7/20/61	6	6	0	6 *	1	18	9
14a	7/22/59	4	0	0	5	3	18	13
30	7/13/58	4	35 *	9	15 *	4	0	0
30	7/16/58	4	14	19	9	9	0	0
12	6/15/61	7	350 **	11	10 **	1	0	0
12	7/27/61	7	7 **	+	11	11	5	25 **
7	6/16/61	7	145 **	25	18	6	0	0
1	6/23/60	4	18	5	32 *	11	+	+
3	7/11/61	7	6	8	7	12 *	+	1
5	6/14/61	7	5	13 **	1	3 *	0	0
5	7/12/61	7	7	6	1	23 **	1	2

However, mid-river catches made on comparable tows before and following slack tide were greater on ebb tides more often than on flood tides (Table 18). Most differences were not statistically significant, but because of small samples the analysis of variance test was not very sensitive in most cases. On the other hand, the equal division of significantly larger catches between ebb and flood tides, and the lack of consistent pronounced differences at any location suggest there was no general difference in catches at different tidal stages.

TABLE 17

Ratios of Striped Bass Catch Near Shore to Catch in Mid-River During Ebb and Flood Tides

		Bass to 0.8 inches		*Bass 0.9 -1.4 inches*		*Bass 1.5 or more inches*	
Date	*Station*	*Ebb*	*Flood*	*Ebb*	*Flood*	*Ebb*	*Flood*
6/20/58	16	5.6	2.3	4.0	3.0	–	–
7/ 3/58	16	4.6	4.4	6.3	5.1	–	–
7/22/59	14a	–	–	0.3	1.6	0.2	1.4
7/13/58	30	1.2	3.9	0.5	3.8	–	–
7/16/58	30	1.3	0.7	0.6	1.0	–	–
6/15/61	12	23.5	31.8	7.0	10.0	–	–
7/27/61	12	20.7	36.8	1.2	1.0	0.04	0.4
6/16/61	7	20.5	5.8	6.3	3.0	–	–
6/23/60	1	2.1	3.6	0.7	2.9	–	–
7/11/61	3	0.7	0.8	0.6	0.6	–	–
6/14/61	5	0.3	0.4	0.5	0.3	–	–
7/12/61	5	0.6	1.2	0.4	0.04	–	–

TABLE 18

Catches of Striped Bass During Ebb and Flood Tides

			Mean catch per tow	
Station	*Date*	*No. pairs of tows*	*Ebb*	*Flood*
16	6/20/58	4	15	22
16	6/27/57	6	174	151
16	7/ 3/58	4	52	39
16	7/20/61	7	+	9 **
14a	7/22/59	4	35	23
14a	7/25/60	5	30	24
VI	6/26/57	5	195	215
VI	7/24/57	6	16	13
12	6/15/61	7	38	36
12	7/23/60	5	65	52
12	7/27/61	7	89	109
12	8/ 2/60	5	115	77
30	6/27/60	5	75	64
30	7/ 3/58	4	15	13
30	7/16/58	4	19	28
30	7/25/57	5	8	4
30	8/ 7/56	5	11	13
7	6/16/61	7	52	94 *
7	7/13/61	7	142	106
5	6/14/61	7	73 **	46
5	7/12/61	7	81	93
1	6/23/60	4	28 **	16
1	6/24/60	5	56	64
1	7/21/60	5	13 **	10
3	6/13/61	7	67	105 **
3	7/11/61	7	127 **	66

Relationship of Efficiency to Water Transparency

Trawl net efficiency is generally closely related to water transparency, so tow net efficiency should be similarly related. Unfortunately, no method has been found to measure this, since there is no way of obtaining an absolute measure of bass abundance in any area, or of holding abundance constant and observing the effect of varying water transparency on catches.

Most areas inhabited by young bass are quite turbid, with turbidity declining somewhat as summer progresses. For example, Secchi disk readings at 27 stations between June 19 and 23, 1961 varied from 3 to 17 inches and averaged 11.2 inches, while on July 31 to August 3 they varied from 7 to 31 inches and averaged 13.3 inches. Changes were generally small and increases exceeded 5 inches at only five stations.

During the June 19-23 period, total catches gave no indication of relationship to turbidity at stations with Secchi disk readings less than 13 inches (Figure 5). Where readings were over 13 inches, low catches probably reflected scarcity rather than decreased net efficiency, since five of these stations were at the area's western periphery, and the two stations closest to these had readings of 3 and 11 and catches of 3 and 4. Catches were uniformly low from July 31-August 3, so they could not be related to turbidity.

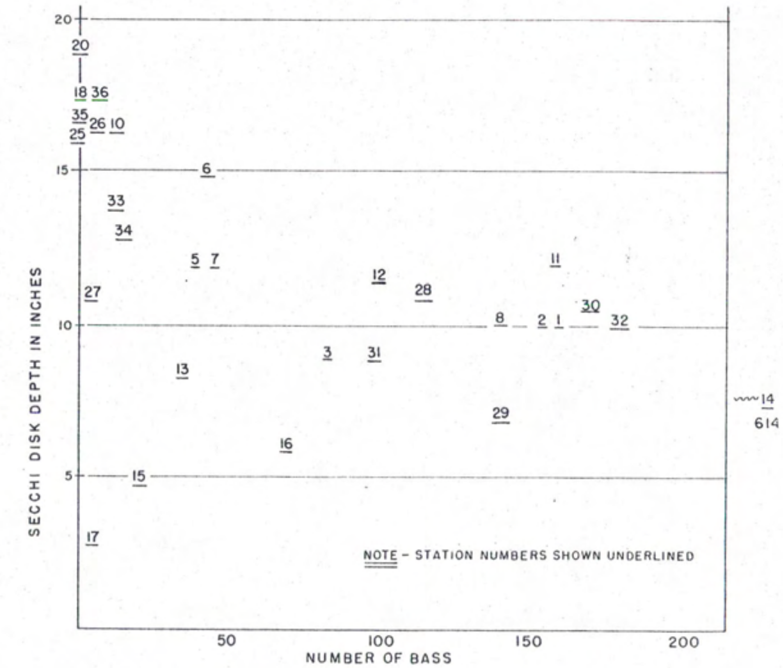

FIGURE 5. Relationship between striped bass tow net catches and water transparency during June 19-23, 1961 Delta-wide survey.

DISCUSSION

Evaluation of Indices

Accuracy of Measurements of Local Abundance

The tow net's size selectivity limited the size range of bass caught efficiently. The lower limit of the size range is clearly defined as 0.7-0.8 inches. The upper limit is not clearly defined, but apparently bass over 2.0 inches are sampled inefficiently.

Vertical distribution measurements showed that previous sampling results in Old River, which indicated 70 to 92 percent of all bass were in the top 10 feet of water (U.S. Dept. of Interior, 1957), are not universally applicable. However, those results were qualitatively similar to ours at Stations 1-5.

The varying vertical distribution of young bass is a potential source of bias, but it can be overcome by sampling all depths equally. The fact that diagonal tow catches in the Delta-wide surveys were as much as 10 times the surface tow catches (Table 8) illustrates this bias' potential importance.

The uneven horizontal distribution presents a more serious problem than does vertical distribution, since it is impractical to eliminate this bias by sampling all portions of the cross-sectional area equally. It causes estimates of abundance to be biased downwards in the areas where concentrations occur near shore. However, this bias' importance is minimized, since it occurs when the bass are relatively small, since it does not occur in all areas, and since the shallow shelf next to shore constitutes only 2 to 4 percent of the river's cross-sectional area. I estimated the error it causes by assuming bass abundances in waters less than and more than 10 feet deep were uniformly equal to concentrations indicated by shore and mid-river samples. The average underestimate was about 15 percent for bass 0.7 inches and larger on the 4 days when the greatest concentrations were near shore at Stations 7, 12, and 16. The range of the underestimates was 6 to 37 percent.

There do not appear to be any biases associated with tidal stage.

The importance of differences in water transparency is not fully known. However, general high turbidity throughout the area, the lack of correlation between catch and turbidity, and the occasional good catches at Stations 10, 18, and 26, where turbidity was lower, suggest it was not serious in the area covered by the Delta-wide surveys.

Thus, while several factors bias catches, I believe tow net samples give reasonably accurate measures of local abundance of 0.7- to 2.0-inch bass, so long as all water depths are sampled equally.

Relationship of Water Movement to Young Bass Movement

The basic premise in planning the annual surveys was an hypothesis that bass abundance in a few areas would reflect abundance over a wide area, because water moving past any locality during a large ebb tide would carry bass from a considerable distance upstream past that locality. This hypothesis was based on measurements showing water moved as much as 13 miles during large ebb tides (Calif. Div. of Water Resources, 1952). While it is evident that water flow greatly affects the movement and distribution of young striped bass, several sources of information indicate this hypothesis should be modified.

The large concentrations of young bass found along shorelines and near the bottom in some areas clearly demonstrate that bass have considerable control over their movement at an early age. While these bass are too small to maintain their position in mid-water during periods of maximum tidal movement, they apparently seek favorable areas during periods of low water velocity, so their movement cannot be assumed to be directly correlated to water flow.

Diurnal catch fluctuations at the Tracy Fish Collection Facility also indicate that young bass have considerable control over their movement. Louver screens there collect fish from water entering the Delta Mendota Canal. Catches of striped bass are typically much greater at night than during the day (Bates *et al.*, 1960, Figure 15), indicating bass tend to maintain their position during the day and move voluntarily at night.

More recent information indicates water generally moves much less than 13 miles during a tide. For example, a float we placed in the San Joaquin River at the mouth of False River at the beginning of an ebb tide on July 29, 1957 moved a little over 7 miles downstream, and a float we placed in the Sacramento River at Three-Mile Slough about an hour after the start of an ebb tide on July 30, 1957, moved 5½ miles downstream. The tidal variations at the Golden Gate on these dates were +6.1 to —0.5 and +5.5 to —0.1. The Department of Water Resources estimated the maximum tidal movements from the Sacramento River at Stations 13a and 10, and from the San Joaquin River at Station 6 on August 20, 1959 were 8, 6, and 7 miles, respectively (Carl Warner, letter). On that day, tidal variation at the Golden Gate was +5.7 to +0.1. These water movements were at mid-river; movements near the channel's periphery are appreciably less.

Hence, it is not surprising that catches at annual survey stations did not reflect catches at stations farther upstream.

Temporal Distribution of Young Bass

The annual surveys can be biased by differences in temporal distribution even though they are made at approximately the same time in relation to bass size at Antioch. One cause of this is that survey time could vary as much as a week in relation to bass size at Antioch since minus tides occur only every other week. The rapid changes in bass abundance, indicated by differences in daily catches during the 1957-1962 annual surveys and by the differences between successive Delta-wide surveys, indicate this bias is important.

Bias also occurs because successful spawning is not distributed through the season in a similar manner each year. In years such as 1962, when the distribution was unimodal, a single survey during the peak of abundance would sample the population more efficiently than in years such as 1959, when there were several modes.

The Delta-wide surveys minimized this bias by taking several samples each season. Some differences between Delta-wide and annual survey results are partially due to this bias and show its importance. For example, the annual survey indicated the difference in abundance between 1959 and 1962 was about 20 times, while the Delta-wide survey indicated only a sixfold difference.

Geographical Distribution of Young Bass

Annual surveys would measure abundance accurately only if geographical distribution remained the same each year. When analysis of the 1954-1956 surveys showed that geographical distribution varied, the survey stations were changed to try to sample the most densely populated areas to minimize the bias. The surveys and exploratory sampling indicated this could best be done by retaining Stations I and II and selecting additional stations in Spoonbill Slough and Montezuma Slough, where large numbers of bass had been caught regularly. However, the magnitude of geographical distribution variations shown by the Delta-wide surveys (Table 7) indicates that no group of four or five stations can give an accurate indication of annual abundance.

The Delta-wide survey stations used during 1962 did not cover the whole area inhabited by young bass. Young bass probably occurred in the unsampled portions of the southeastern San Joaquin Delta in concentrations about equal to their abundance in the adjacent sampled areas (Erkkila *et al.*, 1950; Calhoun, 1953). However, the water volume there forms only a small fraction of the total volume in the Delta.

The exploratory tow net sampling and the fall seining indicated few young bass occur in the Sacramento River above Station 10. This substantiated earlier findings (Calhoun and Woodhull, 1948), so this omission was probably not important.

The omission of the western part of Carquinez Strait, San Pablo Bay, and the Napa River may have seriously biased the survey results. Appreciable bass concentrations certainly occurred in the Napa River in 1958, but this may have been a fairly unusual occurrence, since virtually no bass were caught there in 1957, 1959, 1960, or 1961. This and the fact that the water volume at the four Napa River stations included in the 1959 and 1960 surveys amounted to less than three percent of the water volume of the area now surveyed indicates omission of these stations probably causes little bias.

Some young bass are present in Carquinez Strait and San Pablo Bay, and the water is relatively clear there, so low net efficiency might cause poor catches. However, the small bass catches there in 1958, when many bass were caught in the Napa River and when many other fish were caught in San Pablo Bay, tends to refute this. We have observed schools of bass in sheltered places along the shore in this area, which may indicate they seek sheltered areas in clear water and are thus unavailable to the tow net. The water volume here is great, so the presence of a few bass could significantly bias the survey. However, I believe the bias is small, since this is certainly the periphery of the bass' range.

Comparison of Annual and Delta-wide Surveys

The three annual survey indices show similar trends, although some appreciable differences in magnitude occur, with Index A having greatest variability. This was to be expected, since it is based on more limited sampling, and it indicates that Indices B and C are superior.

While all Delta-wide survey indices had similar trends, there are appreciable differences in magnitude among indices. The differences in magnitude between Indices A and B reflect annual geographical differences in distribution and the unequal volumes of water at various stations. For example, the difference between 1960 and 1961 is due primarily to the fact that 28 percent of the 1960 catch was made at stations with water volumes over 60,000 acre-feet, while 42 percent of the 1961 catch was made at these stations. These variations indicate that weighing by volume is necessary, and that Index A is unsatisfactory.

Theoretically, Index C should be superior to Index B, since biases due to temporal variations in annual distribution would be less. The size range 1.0 to 1.4 inches has additional advantages in that the net had close to maximum efficiency in this range and few bass were either larger during the first survey or smaller during the last survey.

However, survey C was not as good as survey B, because the catches in the limited size range were affected more by chance variation than was the total catch. This is exemplified by differences in the relative abundance within different size groups (Table 9). Annual variations in growth and mortality rates would also tend to make Index B more accurate. Therefore, Index B is superior for 1959-1962 and Index D should be used in the future, since its stations cover the Delta better.

For the 1959-1962 period, both the Delta-wide and annual survey indices exhibit similar trends. However, differences in magnitude exceeded 100 percent primarily because of the annual survey's greater biases, but also because of its greater sampling variability, associated with its more limited nature. Therefore, Delta-wide surveys are preferable, not only because of their greater accuracy, but also because they provide additional information on geographical distribution.

The best estimate of relative abundance during the 10-year period can be made by combining "Annual Survey" Index A for 1953-1956, "Annual Survey" Index B for 1957 and 1958, and Delta-wide survey Index B for 1959-1962 (Table 5).

Comparison of Surveys and Catches at Tracy Fish Collection Facility

Fish in the water entering the Delta Mendota Canal are screened out by louvers at the Tracy Fish Collection Facility (Bates *et al.*, 1960). Striped bass catches there should be proportional to the abundance of bass in the sloughs south of the San Joaquin River. Delta-wide survey stations 1, 2, and 3 sampled part of this area and catches there were similar to the relative annual catches at Tracy (Table 19). This supports the accuracy of the Delta-wide surveys.

TABLE 19

Comparison of Relative Annual Abundance of Striped Bass at Stations 1, 2, and 3 with June and July Catches at Tracy Fish Collection Facility

Year	*Weighted catch at Stations 1, 2, 3*	*Ratio to 1959 abundance*	*Tracy*[1] *catch*	*Ratios to 1959 catch*
1959	13,591	1.00	8,860	1.00
1960	15,847	1.17	10,246	1.16
1961	28,333	2.08	15,166	1.71
1962	26,426	1.94	14,032	1.58

[1] To nearest thousand bass.

Causes of Uneven Local Distribution

The causes for the variability in vertical distribution are not obvious. The concentration of fish near the bottom in the western Delta was probably related to the lower water velocities there, since bass have been shown to seek areas of lowered velocity (Kerr, 1953). The upwards movement during flood tide in the western Delta may also have been related to velocities, since velocities are less during flood tides than ebb tides. However, the fact that bass generally remain near the bottom during low slack tide, come up during peak flood tide flows, and then go back down as high slack tide approaches (Figure 4) indicates it is not a simple reaction to velocity.

The differences between the eastern and western Delta are even more difficult to explain. A possible explanation is eastern Delta waters generally carry a heavy load of finely divided plant detritus. This is most dense near the bottom and could either cause bass to avoid this area or cause inaccurate sampling results by clogging the net. However, this hypothesis was discounted by the distribution at Station 7, where there also was a heavy load of plant detritus, and by the lack of any substantial change at eastern Delta stations during slack tide, when virtually all plant detritus settles to the bottom.

Another possible explanation is that water velocities are generally greater in the western Delta. However, again this cannot be a simple reaction to velocity, since there was no common distribution when velocity approaches zero at slack tide.

A reasonable hypothesis for the cause of differences in horizontal distribution between the eastern and western areas is that western areas had shallow shelves with growths of sedges (*Scirpus* sp.) extending into the water, while at eastern stations the banks dropped abruptly to 20 or more feet. The shallow areas near shore would attract fish, since water velocities would be lower, especially where the sedge growths extended into the water.

Causes of Abundance and Distribution Variations

A primary purpose of this work was to relate the abundance and distribution estimates with observations of physical and biological environmental changes, to try to identify conditions controlling spawning success. Physical factors such as salinity (Bishai, 1961), and water currents (Bishai, 1960) have been directly or indirectly related to the survival of pelagic fish eggs and larvae, and light is deleterious to trout eggs (Leitritz, 1959).

A relationship between water temperature and egg and larval bass survival would not be surprising, since striped bass spawning is closely related to water temperatures. Peak spawning usually occurs at temperatures between 60° and 67°F. (Raney, 1952), and spawning frequently ceases during periods of decreasing water temperatures in the Sacramento-San Joaquin River system (Calhoun, Woodhull and Johnson, 1950; Chadwick, 1958; Albrecht, unpublished data).

Air temperature is the only environmental factor previously shown to be related to striped bass abundance. The mean February to May air temperature in Washington, D. C. had a —0.354 correlation with the commercial catch of adult striped bass 2 years later along the Atlantic Coast from 1884-1937 (Merriman, 1941). This correlation is significant at the one percent level. Presumably, air temperature was related to egg or larval survival indirectly through other environmental factors, such as water temperature.

Correlation coefficients for the relationships between young bass abundance and water temperature, water temperature fluctuations, runoff, salinity, and light (sky cover) (Table 20) were not significantly different from 0. However, significant relationships may still exist, since correlation coefficients are quite variable for small samples (Snedecor, 1956). Estimates of bass abundance are not precise, and the most desirable environmental measurements are not available in all cases. Moreover, while one factor may affect egg and larval survival, overall survival is probably controlled by a combination of factors, so a high correlation between one factor and young fish abundance is unlikely (Ricker, 1958).

Spawning stock size is a biological factor which might determine abundance of young. While no marked relationship generally exists between the size of an adult stock and the number of recruits (Beverton and Holt, 1957), Radovich (1962) has shown that the Pacific sardine

TABLE 20

Relationship Between Abundance of Young Striped Bass and Various Environmental Factors

Year	*Abundance of young bass*	*Water temperature* [1]	*Water temperature fluctuations* [2]	*Runoff* [3]	*Salinity* [4]	*Sky cover* [5]
1953	1.23	61.1	11	659	22	158
1954	1.34	64.2	11	640	148	107
1955	0.68	61.8	15	320	112	92
1956	0.44	62.4	10	866	8	127
1957	0.48	63.6	15	503	84	165
1958	0.67	63.9	7	1,749	4	104
1959	0.38	65.3	12	224	326	95
1960	1.00	63.9	18	301	192	134
1961	1.04			259	248	130
1962	2.60				76	131
Correlation coefficient		—.24	+.04	—.09	—.13	+.17

[1] Mean April-May water temperature at Contra Costa P.G. & E. Steam Plant, Antioch.

[2] Sum of decreases in mean temperatures between successive days from the day that the mean temperature first reaches 60° F. to the end of May at the Contra Costa Steam Plant.

[3] Total measured flow to the Delta during April, May, and June in ten thousands of acre feet. From Calif. Dept. of Water Resources Water Supervision and Water Flow Bulletins.

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

[5] Sum of daily sunrise-sunset sky cover in 10ths during May at Sacramento Airport. From records of U.S. Dept. of Commerce, Weather Bureau.

(*Sardinops caeruleus*) population fits a model describing the relationship of stock size and environment to production of young.

Available long-term indices of adult bass abundance are based on catch statistics of limited accuracy (Chadwick, 1962), and none of these provides a suitable measure of spawing stock. The best available index of bass spawning stock is angler success in the Delta during the springs of 1959 through 1962 (Albrecht and Chadwick, m.s.). The mean catches per hour there during these springs were 0.118, 0.085, 0.074, and 0.050. These have a definite negative relationship with the index of abundance of young for these years, but the significance of this cannot be judged from so few measurements.

The distribution of young bass might also be affected by environmental conditions. Water flow and salinity are the environmental conditions most likely to affect distribution, since bass eggs and larvae are pelagic and since bass seek fresh water for spawning (Raney, 1952). In the Sacramento-San Joaquin Delta, the effects of water inflow and salinity cannot be differentiated, since they are mutually controlled. For correlation purposes, relative distribution of young bass was measured by both the percentage of the annual survey total catch made at Stations I, II, and VI for the years 1957-1962 and the proportion of the total bass catch taken above the confluence of the Sacramento and San Joaquin rivers during the two extensive 1951 surveys (Calhoun, 1953) and during the 1959-1962 Delta-wide surveys. The correlation coefficients between distribution and runoff and salinity are quite high (Table 21). The correlations with our annual survey distribution are significant at the 10 percent level and 1 percent level, respectively. While evidence based on so few years is not conclusive, it strongly indicates that young bass are farther upstream during years of high salinity and low runoff than in years of low salinity and high runoff. This could reflect either the distance adults migrate upstream to spawn

TABLE 21

Relationship Between Distribution of Young Bass and Salinity at Collinsville and Runoff to Delta

Year	*Proportion of bass catch above confluence of Sacramento and San Joaquin rivers*	*Proportion of Annual Survey total catch caught at Stations I, II, and VI*
1951	81	
1957		68
1958		49
1959	94	84
1960	94	85
1961	91	90
1962	67	83
Correlation with salinity *	+.74	+.76
Correlation with runoff †	—.78	—.93

* See Table 20 for salinity measurements. 1951 salinity = 8.
† See Table 20 for runoff measurements. 1951 runoff = 502.

or how far eggs and larvae are carried downstream by water currents. Facts necessary to determine the relative role of each are not available.

Relation of Recruitment to Abundance of Young

The second purpose of this study was to determine if recruitment to the fishery is related to abundance of young-of-the-year bass. This has never been measured for any striped bass population. However, good fishing on the Atlantic Coast has been related to dominant year-classes, which have been recognized in their third year by rough quantitative observations (Merriman, 1941). Dominant year-classes have not been recognized in California's striped bass population.

Striped bass enter the fishery as 3-year-olds. Good measurements of annual recruitment are not available. At present, the best measure is the angler catch per hour for 3-year-old bass in the Delta during April and May of 1959 through 1962 (Albrecht and Chadwick, m.s.). This essentially measures the relative abundance of males, since 3-year-old females are immature and do not migrate to the Delta (Chadwick, unpublished data). The respective catches per hour were 0.034, 0.033, 0.016, and 0.016. These would be recruitment indices for the 1956-1959 year-classes. Except for 1958, they parallel the abundance of young indicated by our annual surveys.

While annual recruitment cannot be measured from the total angler catch, the total catch does reflect trends in recruitment. The fall party boat fishery in Carquinez Strait-San Pablo Bay gives the best available measure of overall bass abundance (Chadwick, 1962), and has the added advantage of being largely composed of bass at the end of their third and fourth growing seasons.

The catches per hour there were 0.24, 0.35, 0.23, 0.24, 0.20 for 1957 through 1961. If recruitment is related to the abundance of young bass, these catches per hour should reflect trends indicated by spawning success surveys three or four years earlier and, except for 1957, they do. While these data suggest a direct relationship between bass recruitment and abundance of young during their first summer, the data are so limited I consider this to be a tentative hypothesis.

Growth and Survival

The 2-week growth increments of 0.3 to 0.7 inches are smaller than comparable growth increments of 0.5 to 1.1 inches reported in the Patuxent River (Mansueti, 1958). As a result, Patuxent River bass average over 2 inches long in early July, while bass in the Delta average 1.0 to 1.5 inches long then, despite the fact that peak spawning occurs during May in both places.

Growth increments were greatest in 1959 and smallest in 1962, suggesting that growth may be negatively correlated with abundance.

The relationship between bass size and net efficiency precludes accurate survival estimates from tow net catches. However, the coincidence of modes in our 1959 and 1960 Delta-wide surveys indicates biweekly cycles in spawning time or survival, since surveys were taken at 2-week intervals. Tidal stage is the only environmental factor having an obvious 2-week cycle, so survival or spawning intensity may be related to tidal stage.

The decreasing annual variations in abundance indices as bass size increased from 1-inch to over 2 inches (Table 9) could be caused by density dependent mortality. However, the small annual variations among 0.3- to 0.5-inch bass would not be expected if this were true. Hence, the small annual variations were probably chance similarities among the small catches within the largest and smallest size groups.

ACKNOWLEDGMENTS

Thanks are expressed to the many members of the Department of Fish and Game who contributed to the success of this program. These include George McCammon, John Skinner, and Arnold Albrecht, who supervised the 1953, 1954-1956, and 1962 surveys, respectively. John Robinson, Robert Toth, and William Heubach also assisted in carrying out parts of the field work. All of these and Frederick Meyer assisted in tabulating and analyzing the data. Vincent Catania made all of the nets, contributed many ideas, and captained the boat at all times. Donald Fry, Jr., contributed the basic ideas for the method of fishing the three nets to measure vertical distribution.

I thank the California Department of Water Resources for calculating water volumes, and the Pacific Gas and Electric Company for providing the water temperature measurements.

SUMMARY

We sampled young-of-the-year striped bass to measure their relative abundance throughout their range in the Sacramento-San Joaquin River system. We did this to obtain a measure of annual abundance which could be used to determine: (i) if spawning success and recruitment are correlated, and (ii) which environmental factors control spawning success.

Sampling was done with a fixed frame tow net, which earlier studies had shown was efficient for sampling young bass. The sampling included: (i) various experiments to determine if the tow netting accurately measured abundance in the immediate area of sampling; (ii) annual surveys consisting of one series of samples at a few stations to try to develop an annual index of abundance; (iii) Delta-wide sur-

veys consisting of repeated sampling at many stations throughout the bass' range to develop an index of abundance suitable for determining if our annual surveys accurately measured abundance; and (iv) limited exploratory tow netting and seining to determine the range of young-of-the-year bass.

Experiments to determine if tow netting accurately measured local abundance showed that it did measure the abundance of 0.7- to 2.0-inch bass reasonably accurately, at least within our Delta-wide survey area. Accuracy requires sampling all depths equally because the vertical distribution of bass is not uniform and is also variable. Variations in horizontal distribution biased sampling of smaller bass in some areas, but this bias appeared to be relatively insignificant. The effects of water transparency were not thoroughly evaluated, but the available evidence indicates it was not a serious problem in the survey area.

The uneven distribution is largely unexplained, but behavioral characteristics partially related to tidal stage and water velocity are important. These behavioral characteristics indicate that even very young bass have considerable control over their distribution and movement.

Our annual and Delta-wide surveys showed important annual geographical and temporal differences in bass distribution, although the Delta-wide surveys showed that most of the population was in the Sacramento and San Joaquin rivers within a few miles of their confluence. Marked changes in abundance at given localities occurred within 2 days, and overall abundance in the Delta changed significantly within 2 weeks.

Biases associated with these differences were the primary cause of substantial errors in our annual survey abundance estimates. These errors tended to magnify annual variations. Delta-wide surveys provided more accurate measures of annual abundance, although they were also somewhat biased, because tow netting and seining showed they did not cover the entire nursery area, and there were biases in the accuracy of local measurements.

Our annual surveys indicated that young bass declined in abundance from a 1953-54 peak to a 1959 low and then increased to a 10-year high in 1962. The Delta-wide surveys showed a similar 1959-1962 trend.

No relationships were detected between young bass abundance and water temperature, water temperature fluctuations, runoff, salinity, light, or spawning stock size. However, the available data are inadequate for a definitive evaluation. The data do show their distribution probably has a relationship to salinity and water runoff to the Delta, with bass being farther upstream in years of greater salinity intrusion and lower runoff.

The results also suggest a direct relationship between abundance of young-of-the-year bass during the summer, and year-class recruitment. They also indicate that growth of young bass is slower here than in the Patuxent River, and is negatively related to abundance.

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APPENDIX A

Water Volumes[1] of Delta Segments Represented by Delta-wide Survey Stations

Station	*1959-61 volume*	*1962 volume*	*Station*	*1959-61 volume*	*1962 volume*
1	23		19	213	
2	15		20	14	
3	15		21	5	
4	11		22	1	
5	21		23	3	
6	40		24	113	
7	56		25	13	
8	22		26	46	
9	5		27	81	60
10	32		27a		49
11	52	35	28	15	
11a		27	29	9	
12	63	53	30	62	52
13	90	43	30a		26
13a		31	31	11	
14	4		32	5	
15	15		33	8	
16	20		34	10	
17	44		35	22	
18	84	70			

[1] Volumes in thousands of acre feet at mean half-tide with an estimated reliability of ± 15 percent. Estimates made by Delta Branch, California Department of Water Resources.