STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF FISH AND GAME

FISH BULLETIN 136

ECOLOGICAL STUDIES OF THE SACRAMENTO-SAN JOAQUIN DELTA

PART II
Fishes of the Delta

Compiled by
JERRY L. TURNER D. W. KELLEY

1966

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FOREWORD

In July 1961 the Delta Fish and Wildlife Protection Study began an investigation of the ecology of the Sacramento-San Joaquin estuary in California. Our investigations were designed to answer specific questions raised by water development plans proposed for the estuary, and to provide a background of information that could be used to evaluate these plans.

We have annually prepared a progress report, and more recently published the first volume of our ecological studies; a series of eight papers on fishes of San Pablo and Suisun bays, and of zooplankton and zoobenthos of the Delta and San Pablo and Suisun bays.

This is the second volume of our ecological studies. It consists of 12 individual papers about the distribution, relative abundance, food and spawning habits of fishes in the Sacramento-San Joaquin Delta.

All investigations of the Delta Fish and Wildlife Protection Study have been financed with funds made available through the California Department of Water Resources by the California Water Bond Act. The practical result is that those who will profit by water development have paid for investigations needed to protect fish and wildlife resources dependent upon that water.

In 1965, after evaluation of four alternative Delta water transfer concepts, the peripheral canal plan was selected as the only plan with the opportunity to both protect and enhance these resources. Our present studies are being directed toward learning how to operate the peripheral canal to use these opportunities.

Acknowledgments

The success of any undertaking of this size is dependent on the cooperation, advice, and participation of many people.

The Delta Studies Section of the California Department of Water Resources provided us with much of the information regarding physical conditions in the Delta. Special thanks are expressed to Cyril McRae, Glenn Twitchell, Roy Nelson, and August Mueller.

Clarkson E. Blunt, Jr., helped to organize the fish study and directed the first year of the investigation.

David Ganssle organized and conducted the 1963 survey of striped bass eggs and larvae distribution.

Vincent Catania made many helpful suggestions concerning our operations and captained the trawl-netting boat at all times. Elvn Gunderson kept our gill-net boat in operation and spent many unrewarded hours in the field. Ratzi Mercurio made and repaired most of our nets.

John Pierce assisted in our field program and did the laboratory analysis of food habits of threadfin shad. Numerous others assisted in our field work. Armand Croft, Dennis Knowles, and Brad Wood deserve special acknowledgment.

Mrs. Janet Boranian and Mrs. Marlene Oehler handled our office work and typed the manuscripts of this bulletin.

Credit for drafting and lettering the illustrations goes to Don Wolf.

Special thanks go to Robert L. Jones, former Leader of the Delta Fish and Wildlife Study, who solved our administrative problems and gave much encouragement and advice.

To all of the above and the many others who helped in so many ways, go our appreciation and thanks.

JERRY L. TURNER
D. W. KELLEY

INTRODUCTION TO FISHERIES STUDIES IN THE SACRAMENTO-SAN JOAQUIN DELTA

JERRY L. TURNER

DESCRIPTION OF THE DELTA

The Sacramento-San Joaquin Delta is at the confluence of the Sacramento and San Joaquin rivers and receives all the flows draining the 26,000 square miles of the Central Valley of California. It is a reclaimed tidal marsh which consists of some 30 large farmed islands protected by high earthen levees and surrounded by 700 miles of sloughs and river channels. Most of these channels are subject to tidal action twice a day with a mean fluctuation of from 2 to 3 feet. Controlled river flows from upstream storage usually maintain the saline water below the Delta. During late summer and early fall, brackish water sometimes intrudes into the extreme western portion of the Delta. Kelley (1966) described the geography and physical-chemical environment of the Delta in detail.

Striped bass, *Roccus saxatilis,* king salmon, *Oncorhynchus tshawytscha,* white sturgeon, *Acipenser transmontanus,* green sturgeon, *A. medirostris,* steelhead trout, *Salmo gairdnerii,* American shad, *Alosa sapidissima,* white catfish, *Ictalurus catus,* black crappie, *Pomoxis nigromaculatus,* and a number of other species depend upon the Sacramento-San Joaquin Delta for part or all of their life cycle. The extent of both commercial and recreational fishing has been reported by Pelgen (1955), Skinner (1955, 1962), Wendler (1960), and Chadwick (1962).

PURPOSE OF STUDY

Development of the California Water Plan will create considerable environmental changes in the Sacramento-San Joaquin Delta. Major changes will occur in amount and pattern of water flow, water quality and salinity incursion. A knowledge of the major factors affecting fish distribution and abundance is essential if we are to protect and enhance, if possible, the fishery resources of the Delta with the development of the California Water Plan. The purpose of this study was to add to our understanding of the factors affecting the present distribution, relative abundance, spawning and food habits of fishes in the Delta. This bulletin is a report of our investigations on fish during the past several years.

The methods used and manner of presenting the data are included in this introductory paper so that authors of individual papers will not have to repeat descriptions of their own. The one exception is the paper on striped bass spawning by Timothy C. Farley. The sampling techniques were quite different and have been reported in his paper.

METHODS

Fish collections were made each month over a 12-month period from September 1963 to August 1964 in order to obtain a seasonal picture of fish abundance and distribution. As a result of some preliminary sampling, a total of 16 stations were located throughout the Delta on the Sacramento, San Joaquin, and Mokelumne rivers as well as some adjacent sloughs (Figure 1). One day each month was spent at each sampling station.

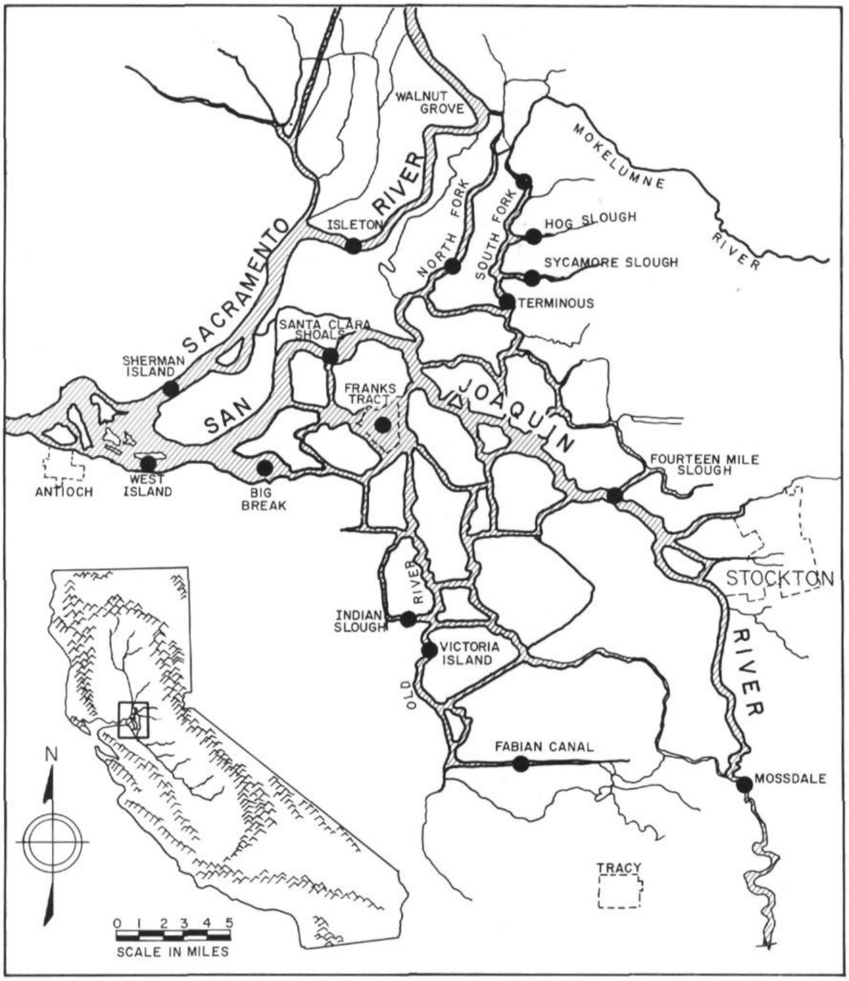

FIGURE 1. Location of sampling stations in the Sacramento-San Joaquin Delta.

Sampling Gear

Some exploratory sampling with various types of fishing gear was made prior to commencing a regular sampling program. We wanted to find a fishing gear that would (i) sample all sizes of fish present in

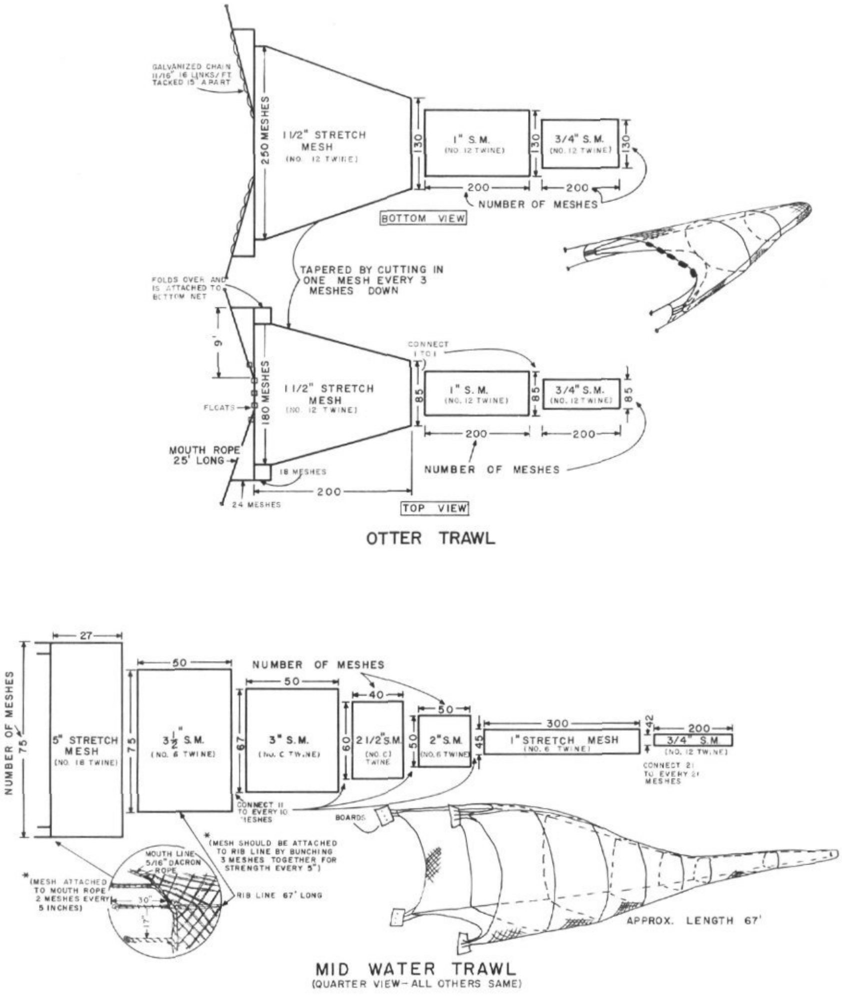

FIGURE 2. Diagram showing construction of otter trawl and midwater trawl used in this study.

the Delta, (ii) sample in the complete range of water flows and depths, and (iii) be easy to operate under most field conditions. We were unable to find one gear that met all the requirements but a combination of several did fulfill our needs.

The fishing gears tested were the lampara net, beam trawl, midwater trawl, otter trawl, and set gill net. Two sizes of lampara nets, 360 and 650 feet long, were fished in the Delta. These nets caught small fish but required extensive open areas of quiet waters, free from snags and obstructions. The beam and otter trawl both caught small fish on the bottom in all ranges of water flows, but the beam trawl was much more difficult to handle. The midwater trawl caught small fish in the mid-depths, was easy to use, and sampled in both swift and slow currents.

The set gill net caught large fish at all depths, was relatively simple to manage but was difficult to set in swift water.

We finally decided to use gill nets to sample large fish, an otter trawl to sample small fish on the bottom, and a midwater trawl to sample small fish in the mid-depths.

Our otter trawl was a semi-balloon trawl that sampled a cross sectional area of water on the bottom approximately 15 feet wide and 5 feet deep. The midwater trawl sampled a cross sectional area of water near the surface approximately 10 feet by 10 feet. Varying sizes of leading mesh in both nets guided the fish to a $\frac{3}{4}$-inch-stretch mesh in the cod end of the nets (Figure 2).

All trawling tows were 10 minutes long, not including time to retrieve the trawl. When possible, six otter and four midwater trawls were made at each station. The otter and midwater trawls were made over the same area at each station except in the shoal areas at the West Island and Santa Clara stations, where only otter trawl tows could be made. All samples were taken towing with the current at a velocity through the water of approximately 2.9 feet per second.

Each "gill net unit" was composed of two nets: one 250 feet long, 12 feet deep, and made up of five 50-foot sections of webbing, the meshes of which (stretched measure, inches) were $2\frac{1}{2}$, 3, $3\frac{1}{2}$, 4 and $4\frac{1}{2}$; and one 200 feet long, 12 feet deep, and made up of four 50-foot sections of webbing, the meshes of which were 5, $5\frac{1}{2}$, 6 and 7. Two "gill net units" were set overnight at each station except on the North and South Fork of the Mokelumne River and at Isleton on the Sacramento River where only one set was made. Each net was set in a stationary position on the bottom by anchors. Nets were set as near perpendicular to the current as possible. In narrow channels the nets had to be laid out at an angle. The shallow as well as deep areas were sampled.

Each overnight gill net set was considered to be a standard fishing unit even though actual fishing times varied somewhat. Van Oosten, Hile and Jobes (1946) found while netting in the Great Lakes that small differences in time in overnight gill net sets had little effect on the total catch.

Fish Analysis

All fish caught in each unit of gear were identified, counted, and recorded. All were measured in centimeters from the tip of the snout to the notch in the tail fin of fork-tailed fish or to the center of fin when the tail was not forked (fork length). Subsamples were measured when unusually large numbers of a particular species were caught.

The stomach contents of most species were examined whenever possible. All food organisms were counted and identified on the boat at the time of collection. Unknown food organisms taken were preserved and placed in jars for later analysis in the laboratory.

Gonads were examined when time permitted. Since there are difficulties in field determination of male sexual maturity, it was assumed that the male breeding cycle paralleled that of the female, and no attempt was made to distinguish the stages in male sexual maturity other than by noting the presence of obviously ripe males. The stages of sexual maturity of the female were determined by gross examination and the following criteria:

A. Immature (I): No eggs visible macroscopically in the ovary: ovary generally small.
B. Developing (D): The eggs are visible in the ovary but not loose and free flowing.
C. Ripe (R): The eggs are large and loose and flow from the fish when the abdomen is squeezed. The ovaries are soft and greatly enlarged.
D. Spent (S): The ovaries are flabby and only a few large eggs remain, scattered through the ovaries.

Environmental Measurements

A series of environmental measurements were made at the same time that the fish population was being sampled. Surface water temperature was measured with a bucket thermometer, turbidity with a Secchi disc, surface salinity with a hydrometer, and water depth with the depth finder aboard the boat. A sample of water was obtained for a measurement of its specific conductance.

From September 1963 to February 1964, information was obtained from Turner (1966) and Turner and Heubach (1966) on the concentration of zooplankton at each sampling station. From March to August 1964, a zooplankton sample was taken each month at each station during our regular fish sampling program in the same manner as described by Turner (1966). The Department of Water Resources furnished us with a monthly average of net flow and cross sectional area at each of our sampling stations.

PRESENTATION OF RESULTS

The first five papers of this bulletin are devoted to striped bass. There is one paper on adults, one on their spawning areas, one on young-of-the-year, one on juveniles, and one on the food habits of all age groups. American shad and king salmon are each described in individual papers. All reports of other anadromous fish are combined into one paper.

There are three papers on the resident families, Centrarchidae, Cyprinidae and Ictaluridae. All resident fish not in these three families and some limited information on crayfish have been combined into the final paper.

Catches of fish by otter and midwater trawl are expressed as the daily mean number of each species of fish per 10 minutes of towing. All counts of gill net catches are expressed as the mean number of each species per overnight "gill net unit". Monthly catches are an average of all the tows or sets made at one station in a particular month. Season catches are an average of the mean monthly tows or sets at one station over a 3-month period. Seasons are defined as fall (September through November), winter (December through February), spring (March through May), and summer (June through August).

Most types of fishing gear are selective for one or more kinds of fish and for various sizes of the same species of fish. To minimize this problem, our comparison of catches between stations and between seasons was usually limited to a single fishing gear and to individual age groups of a single species or for all age groups of a species when we were unable to separate age groups based on the length frequency of catch.

We have assumed that the catch of each species of fish per unit of effort is a rough estimate of the concentration of the fish at that station for that month. The dangers of such assumptions are well known. Anything that changes the ability of the fish to sense or avoid the oncoming trawl will affect the catch even though the population remains the same. All we really know about this is that large fishes are more successful in avoiding the trawl than small ones. We therefore do not use trawl catches to quantitatively compare fish of different year-classes.

Our gill nets were anchored in place so that the catches depended upon the movement of fish. Thus anything that affects movement must greatly affect the catch. We suspect that rate of movement is much less during the winter than at other times, but we have no measure of this. The only solution to this problem is to use the catch data with caution, recognizing that errors exist even though they are seldom definable.

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DISTRIBUTION OF ADULT AND SUBADULT STRIPED BASS, *ROCCUS SAXATILIS*, IN THE SACRAMENTO-SAN JOAQUIN DELTA

LARRY D. RADTKE

The number of adult striped bass in the Sacramento-San Joaquin Delta varies widely throughout the year for, being anadromous fish, they spend a large part of their lives in San Francisco, San Pablo, and Suisun bays or in the Pacific Ocean.

This report describes the distribution of adult (1960 and earlier year-classes) and subadult (1961 year-class) striped bass in the Delta for the period of September 1963 through August 1964. It is based on an analysis of gill net catches made once a month at 16 stations. Roughly 6,000 bass were caught.

Relatively few striped bass were found in the Delta during the fall and winter. Large numbers of mature adults entered the Delta in the spring, a large run of males preceding the females. Bass in the northern Delta migrated rapidly up the Sacramento River, while those in the central Delta concentrated in the lower San Joaquin River during the spawning period. High concentrations of total dissolved solids at and upstream from Stockton appear to have blocked the spawning migration up the San Joaquin River.

METHODS

The sampling techniques and the location of sampling stations are described in the introductory paper of this bulletin. The interpretation of gill net catches and determination of sexual maturity are also described there.

The year-classes of striped bass were identified by length-frequency analysis of the gill net catch (Figure 1). Fish of the 1960 or earlier year-classes are called *adults* in this paper. Gonad examination revealed that most were capable of spawning in 1964. Only a portion of the 1961 year-class was capable of spawning in 1964. Members of this group are referred to as *subadults*.

Gonads were examined to determine how sex and maturity were related to distribution. When possible at least 10 adults and 10 subadults were examined at each station each month. Sample sizes were too small to estimate sex ratios reliably for each station each month. The ratios used in the analysis were obtained by combining the samples of fish sexed at similar and nearby stations and calculating the sex ratio for the group. The groups included stations in (i) the Sacramento River, (ii) the Mokelumne River, (iii) Hog and Sycamore sloughs, (iv) Franks Tract and Big Break, (v) San Joaquin River below the City of Stockton, (vi) the San Joaquin River above Stockton (Mossdale), Old River, Fabian and Bell Canal, and Indian Slough (Figure 2A).

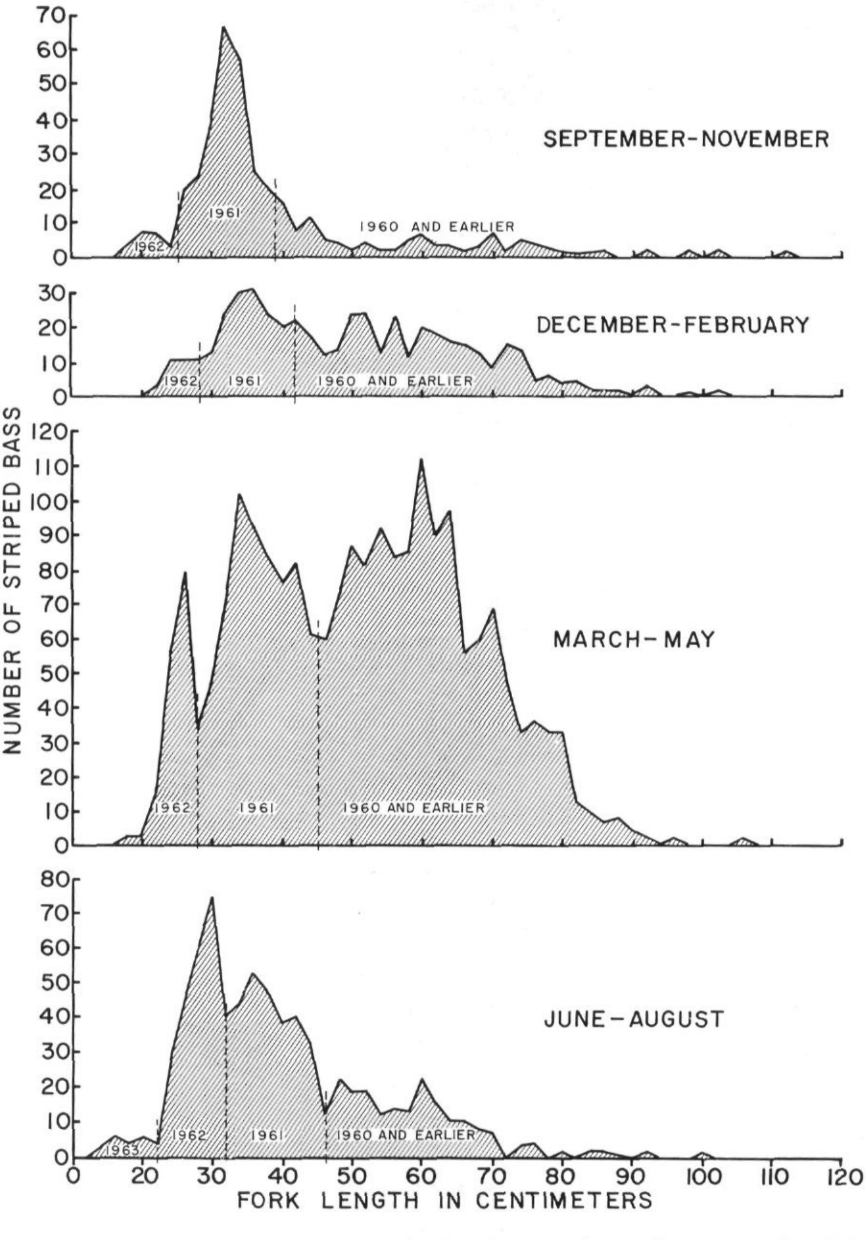

FIGURE 1. Length-frequency distribution of striped bass caught in gill nets. Year-class divisions are indicated by dotted lines.

DISTRIBUTION OF ADULTS IN FALL AND WINTER

Catches of adult striped bass were low at nearly all stations from September through February (Figure 2B, C, D). The only exception

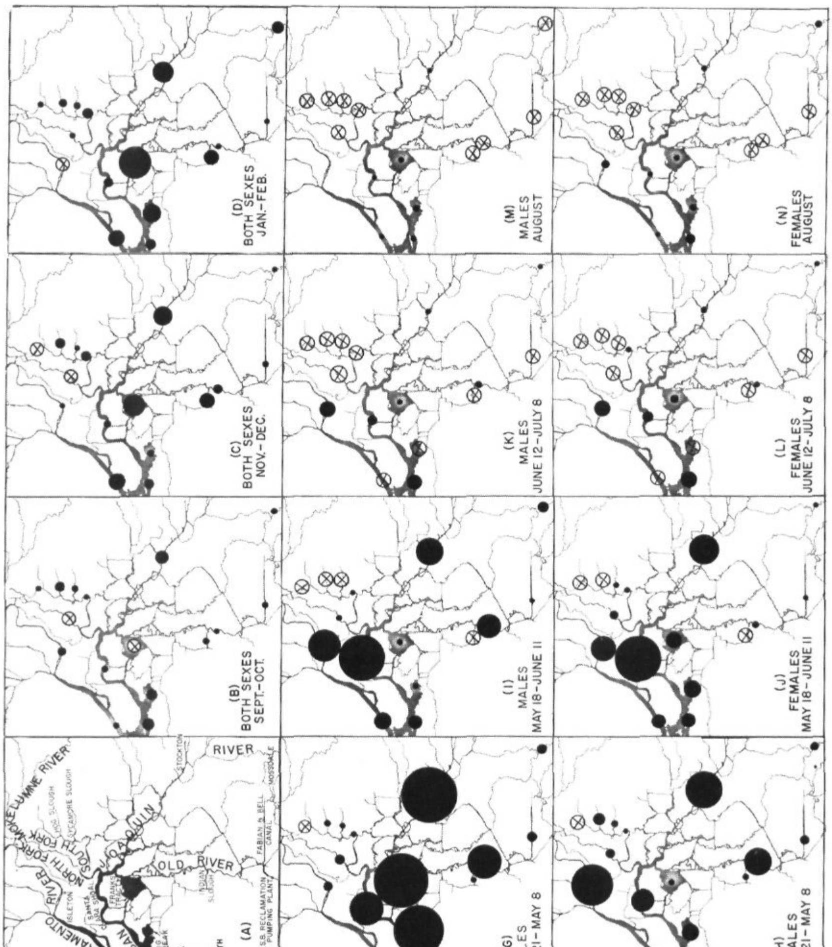

FIGURE 2. Distribution of adult striped bass in the Delta. The area of each circle is proportional to the catch per gill net unit. (A) shows locations mentioned in the text. Circles in (B) through (D) represent averages of two monthly samples at each station. Circles in (E) through (N) represent one sample at each station during each period.

was Franks Tract where catches increased from zero in September and October to 24.5 fish per gill net unit on January 22 and 57.5 per unit on February 19. The generally low catches probably indicate that there were few adults in the Delta during this period.

The higher catches at Franks Tract in January and February may be the result of a population increase there, although why this would happen is unknown. Temperature was essentially the same there as in the surrounding waterways. A food habits investigation in the Delta concurrent with the present study indicates that the percentage of adult bass stomachs containing food was higher in fall and winter than during spring (see Stevens, p. 76). But other areas of the Delta had higher concentrations of forage fish than Franks Tract during this time (see Sasaki, p. 48; see Turner, p. 160). Therefore, it is doubtful that food alone attracted adult bass to Franks Tract. Perhaps the relative stillness of the water, with only tidal currents, attracted them.

DISTRIBUTION OF ADULTS IN SPRING AND SUMMER

Catches during late March and early April suggest a migration primarily of males up the Sacramento River and into the western San Joaquin Delta (Figure 2E, F).

Catches during late April and early May indicate that most males in the Sacramento River had migrated upstream (Figure 2G). There were many males in the San Joaquin River below Stockton, in the central Delta, and in part of the southern Delta.

Females migrated into the Sacramento River during late April and early May (Figure 2H). Females were also present in the San Joaquin River below Stockton and in part of the southern Delta.

During late May and early June, the heaviest concentration of males in the San Joaquin Delta was in the Santa Clara Shoal area of the San Joaquin River (Figure 2I). Catches declined in most other areas of the San Joaquin Delta. Virtually all males were ripe.

Calhoun (1946) reported high numbers of ripe male bass caught by anglers in Franks Tract in mid April 1946. He found that in the latter half of April, the catch in Franks Tract dropped sharply, while catches of ripe males in the main San Joaquin increased and remained high through most of May. This pattern of movement is similar to that indicated by the present study.

Females in the Sacramento River migrated upstream during late May and early June (Figure 2J). Those in the San Joaquin River concentrated mainly in the Santa Clara Shoal area. Farley (see p. 34) found evidence of heavy spawning in the lower portion of the San Joaquin River, including Santa Clara Shoal, in mid May 1964. He found little evidence of spawning in other areas of the San Joaquin Delta.

Although adult males and females entered the San Joaquin River in large numbers during the spring, few migrated upstream beyond Stockton or into Fabian and Bell Canal.

Catches of both sexes were low from early June to early July (Figure 2K, L). Eighty percent of the females caught were spent. Most bass had spawned and left the Delta by this time. By August, very few remained (Figure 2M, N).

DISTRIBUTION OF SUBADULTS

Few subadults were caught, compared to adults. This may be partly explained by the fact that several year-classes were included in the adult classification while only the 1961 year-class made up the subadults.

Few subadults were caught from September through February (Figure 3A, B, C). From mid March to early June, the distribution pattern of subadult males resembled that of adult males; i.e., those in the Sacramento River migrated upstream, while those in the San Joaquin remained in the central and western Delta (Figure 3D, F, H). Approximately 65 percent of the subadult males caught from mid May to early June were ripe; they probably spawned with the adults. During the summer they migrated into the bay (Figure 3J, L).

The few subadult females caught during spring and summer (Figure 3E, G, I, K, M) were immature. Few female striped bass mature before their fourth year (Scofield, 1931), and few migrate from the bay into the Delta before this time (Chadwick, 1967).

GEOGRAPHICAL POPULATION DIFFERENCES

The Delta is a maze of channels that vary in width from a few hundred feet to a mile. While gill net catches are comparable expressions of *concentration,* they are not comparable expressions of the *relative numbers* or *abundance* of fish in different parts of the Delta. The entire fish population could be contained in the wide channels of the western Delta with a concentration (and therefore a net catch) only a fraction of that which would result from containing the same population in the smaller channels of the eastern Delta. To achieve an index of relative abundance in various parts of the Delta, stations were grouped on the basis of river system and flow and delineated into zones. Sasaki, (see p. 52) illustrates these geographical areas and the stations in them. The mean seasonal catch of bass in each zone (*index of concentration*) was multiplied by the percent of the Delta's surface area represented by each zone. The resulting figures are *population indices* for each zone, which I converted to percent of total bass in the Delta (Tables 1 and 2). The population indices of the zones were totaled to obtain population indices for the entire Delta each season *(quarterly population indices).*

The quarterly population indices suggest that the number of adult bass in the Delta increased greatly from fall to spring and decreased from spring to summer (Table 1). While these changes in the index are probably due primarily to migration, the magnitude of change was undoubtedly influenced by the effects of various factors on the gill net catches. For instance, from fall to winter the actual population of adult bass in the Delta may have increased by much more than is indicated. Low temperatures probably caused a decrease in fish activity, resulting in disproportionately low catches and an underestimate of the increase. The increase in the index from winter to spring is probably disproportionately large due to increased fish activity caused by rising temperature and approaching sexual maturity.

During the fall, winter, and spring, most adult bass in the Delta were located in the flooded islands, the Sacramento River, and the lower and

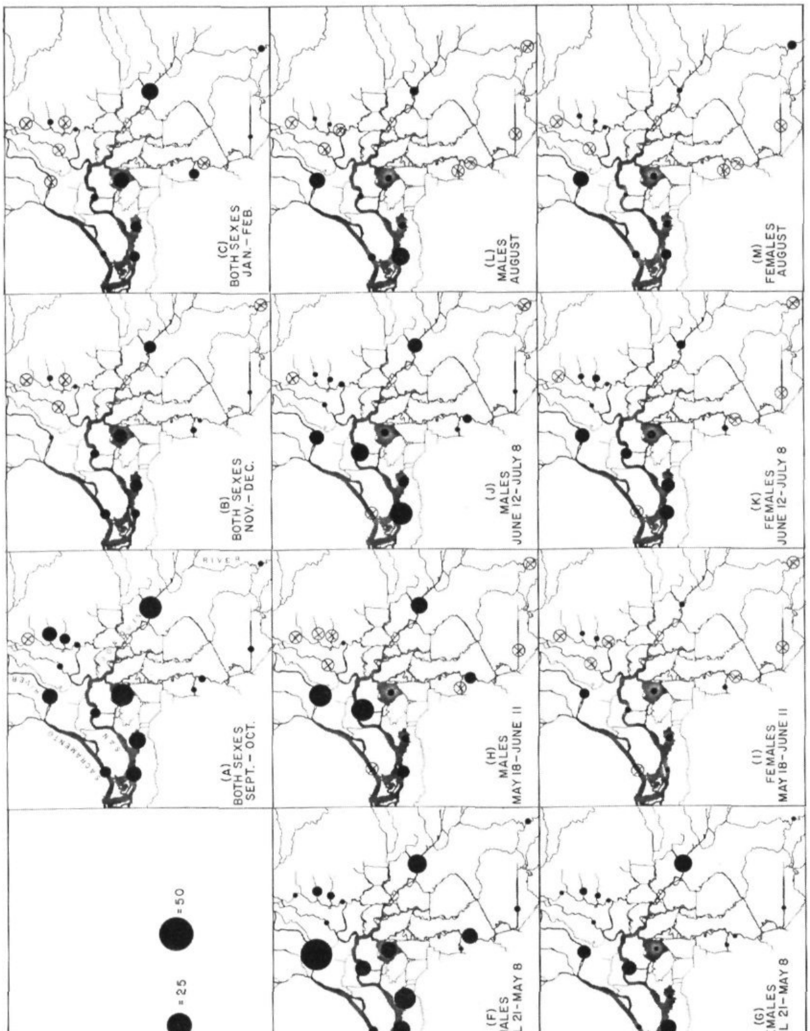

FIGURE 3. Distribution of subadult striped bass in the Delta. The area of each circle is proportional to the catch per gill net unit. Circles in (A) through (C) represent averages of two monthly samples at each station. Circles in (D) through (M) represent one sample at each station during each period.

TABLE 1

Relative Abundance of Adult Striped Bass in Zones of the Delta

Zones	Percent of Delta Area	Fall			Winter			Spring			Summer		
		Index of concen-tration	Pop. index	Percent of pop. in zone	Index of concen-tration	Pop. index	Percent of pop. in zone	Index of concen-tration	Pop. index	Percent of pop. in zone	Index of concen-tration	Pop. index	Percent of pop. in zone
Lower San Joaquin River	24.6	3.4	83.4	16.3	6.2	153.3	10.6	102.2	2,515.9	32.0	9.4	231.3	21.5
Middle San Joaquin River	12.4	9.3	115.3	22.5	15.5	192.2	13.2	82.9	1,027.9	13.2	2.0	24.8	2.3
Upper San Joaquin River	2.1	1.3	2.7	0.5	3.8	8.0	0.5	5.7	12.0	0.2	1.0	2.1	0.2
Sacramento River	15.3	4.5	68.9	13.5	12.2	186.7	12.8	72.7	1,112.3	14.3	36.0	550.8	51.2
Mokelumne River	5.4	2.0	10.8	2.1	4.8	25.9	1.8	41.2	222.5	2.9	2.1	11.3	1.1
South Delta	15.7	2.2	34.5	6.7	3.0	47.1	3.2	43.1	676.7	8.7	1.3	20.4	1.9
Flooded Islands	17.6	7.8	137.3	26.8	43.2	760.3	52.3	122.7	2,159.5	27.7	13.2	232.3	21.6
Dead-end Sloughs	6.9	8.5	58.7	11.5	11.7	80.7	5.5	11.1	76.6	1.0	0.3	2.1	0.2
Quarterly population indices	---------	---------	511.6	---------	---------	1,454.2	---------	---------	7,803.4	---------	---------	1,075.1	---------

TABLE 2

Relative Abundance of Subadult Striped Bass in Zones of the Delta

Zones	Percent of Delta Area	Fall			Winter			Spring			Summer		
		Index of concen-tration	Pop. index	Percent of pop. in zone	Index of concen-tration	Pop. index	Percent of pop. in zone	Index of concen-tration	Pop. index	Percent of pop. in zone	Index of concen-tration	Pop. index	Percent of pop. in zone
Lower San Joaquin River	24.6	6.9	170.7	16.1	6.8	168.2	25.6	30.6	751.6	36.3	21.5	530.9	39.1
Middle San Joaquin River	12.4	16.5	204.6	19.2	12.5	155.0	23.5	16.2	200.9	9.7	9.5	117.8	8.7
Upper San Joaquin River	2.1	0.7	1.5	0.1	1.3	2.7	0.4	2.3	4.8	0.2	1.3	2.7	0.2
Sacramento River	15.3	11.7	179.0	16.8	3.2	49.0	7.4	29.1	445.2	21.5	24.3	371.8	27.4
Mokelumne River	5.4	2.3	12.4	1.1	0.5	2.7	0.4	6.3	34.0	1.6	1.3	7.0	0.5
South Delta	15.7	2.8	44.0	4.3	0.3	4.7	0.7	8.0	141.6	6.8	1.3	20.4	1.5
Flooded Islands	17.6	21.2	373.1	35.1	13.8	242.9	36.7	24.6	432.9	20.9	15.3	269.3	19.8
Dead-end Sloughs	6.9	11.3	78.0	7.3	5.0	34.5	5.3	9.0	62.1	3.0	6.2	37.8	2.8
Quarterly population indices			1,063.3			659.7			2,073.1			1,357.7	

middle San Joaquin River. During the summer approximately half the Delta population was in the Sacramento River.

Quarterly population indices for subadults suggest an overall decrease in numbers in the Delta from fall to winter, followed by a large increase in spring and a decrease in summer (Table 2). Again, these indices undoubtedly reflect, in part, the influences of temperature and spawning activity. The distribution of the subadult population among the various zones of the Delta was similar to that of the adults. The most notable exception was in summer when a substantially higher percentage of subadults was in the lower San Joaquin River and a lower percentage was in the Sacramento River.

WHY DO STRIPED BASS AVOID THE UPPER SAN JOAQUIN RIVER?

Although large numbers of adult and subadult striped bass were caught in all other areas of the Delta in the spring, few were taken in the San Joaquin River above Stockton or in the extreme south Delta. In attempting to explain this, various environmental factors such as food, temperature, flow, and total dissolved solids were considered.

Food

An extensive study of their food habits indicates that few adult bass fed during the spawning migration (see Stevens, p. 76), and because of this, it is doubtful that food availability had much influence on their distribution during this time.

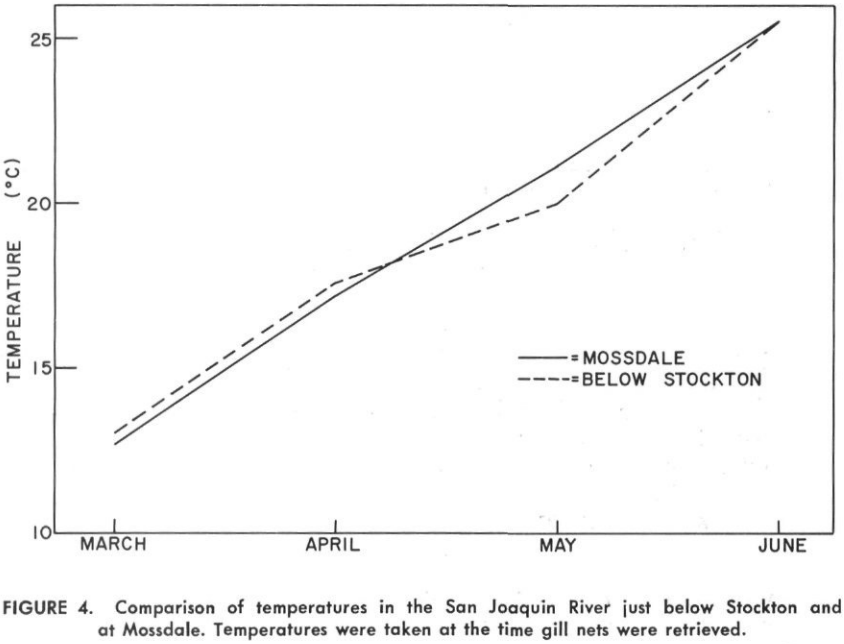

FIGURE 4. Comparison of temperatures in the San Joaquin River just below Stockton and at Mossdale. Temperatures were taken at the time gill nets were retrieved.

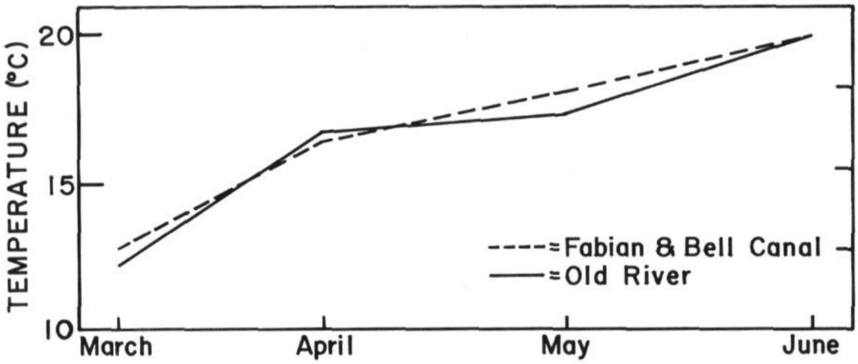

FIGURE 5. Comparison of temperatures in Old River and Fabian and Bell Canal. Temperatures were taken at the time gill nets were retrieved.

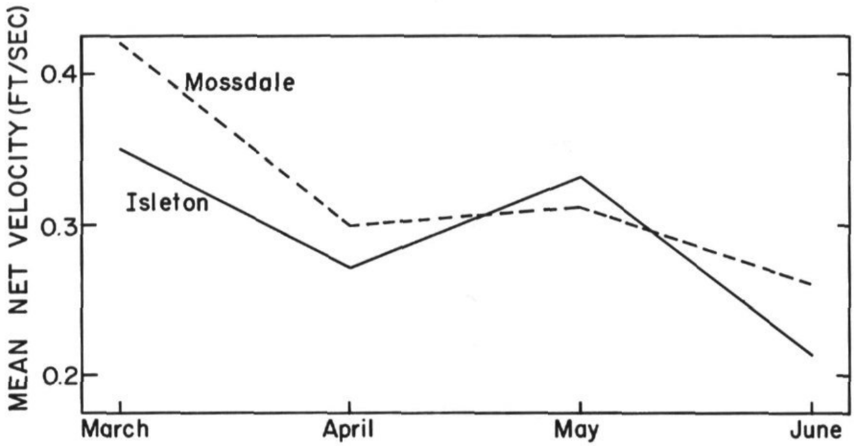

FIGURE 6. Comparison of mean net velocity of flow in the Sacramento River at Isleton and in the San Joaquin River at Mossdale, based on monthly net flows estimated by the California Dept. of Water Resources.

Temperature

Temperature does not appear to have prevented the migration up the San Joaquin River. Just below Stockton, where many bass were caught, temperatures taken during the spawning migration were similar to those taken at Mossdale, where few bass were caught (Figure 4).

In Old River, where large numbers of bass were taken, temperatures differed little from those in the adjacent Fabian and Bell Canal, where very few bass were caught (Figure 5).

Flow

Current velocity in the upper San Joaquin River was not unfavorable for striped bass migration. Mean net velocities [1] at Isleton on the Sac-

[1] Mean net velocity (in feet per second) $= \frac{\text{Net flow (in cubic feet per second)}}{\text{cross sectional area of channel (in sq. ft.)}}$
Turner (1966) discusses this measurement and how it applies to flows in the Delta.

ramento River and at Mossdale on the San Joaquin River were similar during the spring of 1964 (Figure 6). Although this does not mean that actual velocities at these stations were necessarily similar, it does indicate that at both places water moved toward the ocean at about the same rate. If this were the controlling factor, comparable concentrations of striped bass would be expected at both stations during the spawning migration. However, catches indicate that in the spring of 1964, very few went up the San Joaquin, while many went up the Sacramento River.

Dissolved Solids

In the spring of 1964 adult striped bass passed through a 50-mile long section of decreasing salinities in the bays before they reached the fresh water of the Delta. Those that entered the San Joaquin River continued upstream until confronted with increasing total dissolved solids just below Stockton (Figure 7). The bass that migrated into Old River encountered a similar situation at Fabian and Bell Canal in the south Delta. In both instances, migration appeared to cease.

In years of low natural runoff, such as 1964, the San Joaquin River contains relatively high concentrations of sodium chloride during the spring and summer, due to the influence of irrigation water returned to the river from farmlands in the San Joaquin Valley (Calif. Dept. of Water Resources, 1961). A *reverse salinity gradient* is caused by the mixture of San Joaquin and Sacramento River waters as they are drawn to the Delta-Mendota Canal by the U. S. Bureau of Reclamation pumping plant.

During the journey from salt to fresh water, adult striped bass necessarily undergo certain osmoregulatory changes, as do all anadromous fishes during their spawning migrations. Changes in endocrine activity usually accompany or precede changes in osmoregulatory mechanisms, indicating hormonal control. The pituitary, the thyroid, and the gonads are concerned with physiological changes prior to and during migrations. Their secretions may initiate osmoregulatory processes. Lagler, Bardach, and Miller (1962) mention that pituitary and gonadal changes often lead to appetitive behavior, such as the stickleback's, *Gasterosteus*, preference for fresh water when preparing to spawn.

Black (1957) reviewed the literature dealing with osmoregulation in anadromous fishes and cited evidence than anadromous fishes are adjusted to either the freshwater or the saltwater phase of their life cycles and cannot change abruptly from one to the other. For example, the sea lamprey, *Petromyzon marinus,* after having entered fresh water, cannot tolerate even half sea water salinities. It can regulate body fluids until this time but becomes stenohaline upon beginning its anadromous migration.

The physiological effects of the salinity gradient in the San Joaquin River near Stockton and in the south Delta on striped bass are not known. But it seems reasonable to hypothesize that, having been in fresh water for several weeks, their osmoregulatory systems had thoroughly adapted to the freshwater environment. They were probably sensitive to increases in salinity and were able to detect the relatively high salinity of the water from the upper San Joaquin River. When they encountered it, they did not continue upstream.

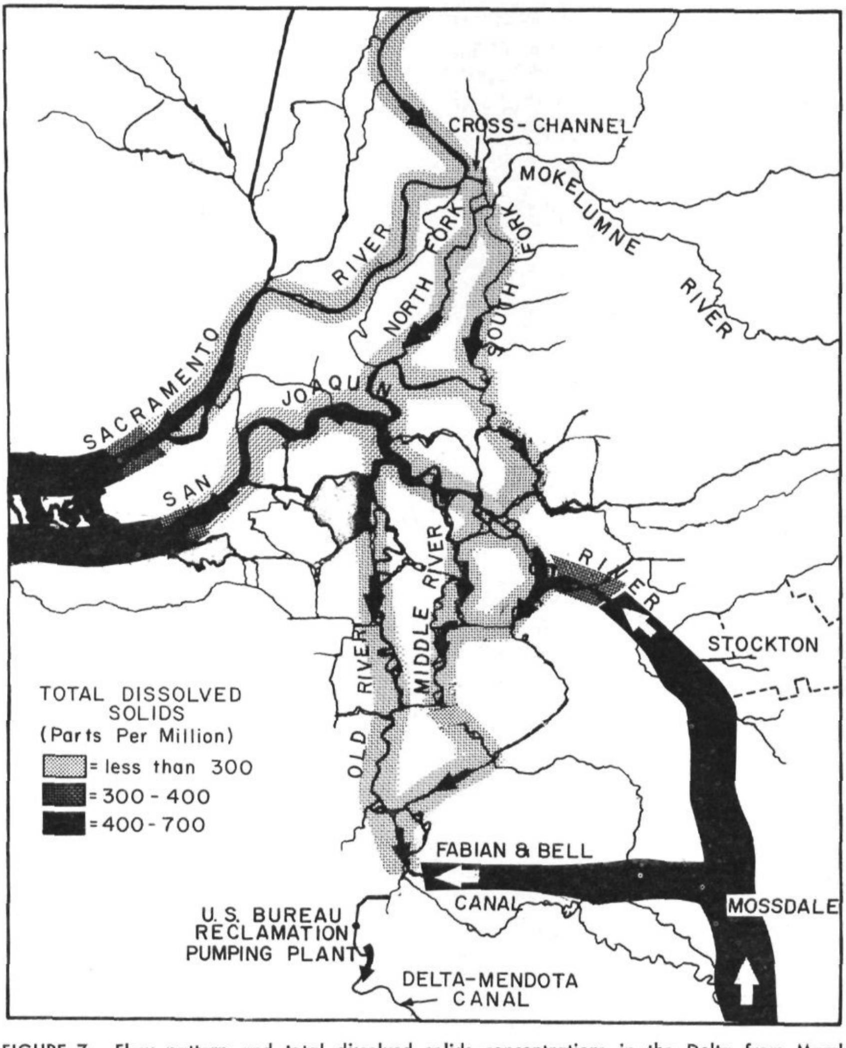

FIGURE 7. Flow pattern and total dissolved solids concentrations in the Delta from March through June 1964. Arrows indicate the direction of net flow, based on monthly flows estimated by the California Dept. of Water Resources. Shaded areas represent ranges of total dissolved solids, based on water samples collected during fish sampling.

Striped bass apparently always spawn in fresh water and, except for a few isolated populations located entirely in fresh water, they migrate from essentially sea water through a salinity gradient to do so (Morgan and Gerlach, 1950; Tresselt, 1952; Rathjen and Miller, 1957). I believe that when the San Joaquin River above Stockton has a high concentration of dissolved solids, striped bass will not migrate upstream to spawn. In years when high flows occur in the San Joaquin River due to natural runoff, the dissolved solids concentration is much lower and striped bass probably migrate upstream. Farley (see p. 37) reviewed the literature on striped bass spawning in the Delta and found that in years when there was evidence of spawning in the upper San Joaquin River, the dissolved solids concentration was low. According to his data, bass spawned there in the spring of 1963 but not in 1964.

SUMMARY

From September 1963 through August 1964, gill nets were set in the Sacramento-San Joaquin Delta to obtain information on the distribution and abundance of adult and subadult striped bass. Few adult or subadult striped bass were caught in the Delta during fall and winter except in the flooded island, Franks Tract. The major spawning migration of adult striped bass occurred during the spring, with a large run of males preceding the females. The bass that entered the northern Delta migrated upstream in the Sacramento River, while those in the central Delta concentrated in the lower San Joaquin River. Few migrated into the upper San Joaquin River or the extreme south Delta.

Most of the subadult males (3 years old) were mature in the spring and their migration pattern resembled that of adult males. Female subadults were not mature at that time and very few migrated into the Delta.

Relatively high concentrations of total dissolved solids apparently blocked the spawning migration of striped bass into the upper San Joaquin River.

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STRIPED BASS, *ROCCUS SAXATILIS*, SPAWNING IN THE SACRAMENTO-SAN JOAQUIN RIVER SYSTEMS DURING 1963 AND 1964

TIMOTHY C. FARLEY

This paper is the result of 2 years' work to determine where striped bass spawn in the Sacramento and San Joaquin River systems and why they spawn where they do. Plankton nets were used to collect striped bass eggs and larvae from various locations in the Delta and its tributaries. The geographic origins of eggs and larvae were estimated by determining the ages of individuals and calculating how far, and from where, they could have been carried by the river currents since they were spawned. Some eggs and larvae were traced back to or found newly spawned in almost every area in the Delta and tributaries, but there were three areas in 1963 and two areas in 1964 where most eggs and larvae originated. These are defined as the main spawning areas.

The onset of spawning in the spring was correlated with spring warming of the water to about 15°C. There is evidence to support the hypothesis that the later the water reaches this temperature, the farther up the Sacramento River bass will migrate to spawn.

No significant amount of spawning occurred in areas where the total dissolved solids content of the water was above 180 parts per million; in 1964 TDS values above that level prevented bass from migrating above Stockton in the San Joaquin River.

EGG SAMPLING

In 1963 eggs and larvae were sampled at 26 stations every 2 to 5 days from April 2 to June 28 (Figure 1). In 1964, 33 stations were sampled from April 13 to June 12; all the stations south of Courtland on the Sacramento River were covered each Monday, Wednesday, and Friday and those north of Courtland on Tuesdays and Thursdays.

Eggs were collected in plankton nets, 18 inches in diameter at the mouth, made of a 40-inch cone of 23 mesh per inch bolting cloth. The eggs and larvae were concentrated in a small screen bucket attached to the small end of the net. In 1964 pygmy-type flow meters were mounted in the mouths of the nets to measure the amount of water strained during each tow.

At most stations two nets were towed behind a power boat at a speed of 3.0 to 3.5 feet per second relative to the water current. One net was fished at the surface. A 10-pound weight was attached to the towing line on the other net to make it fish 15 to 25 feet deep. In 1964 only surface tows were made in the San Joaquin River above Stockton and in Old River near Bacon Island due to the shallowness of those areas.

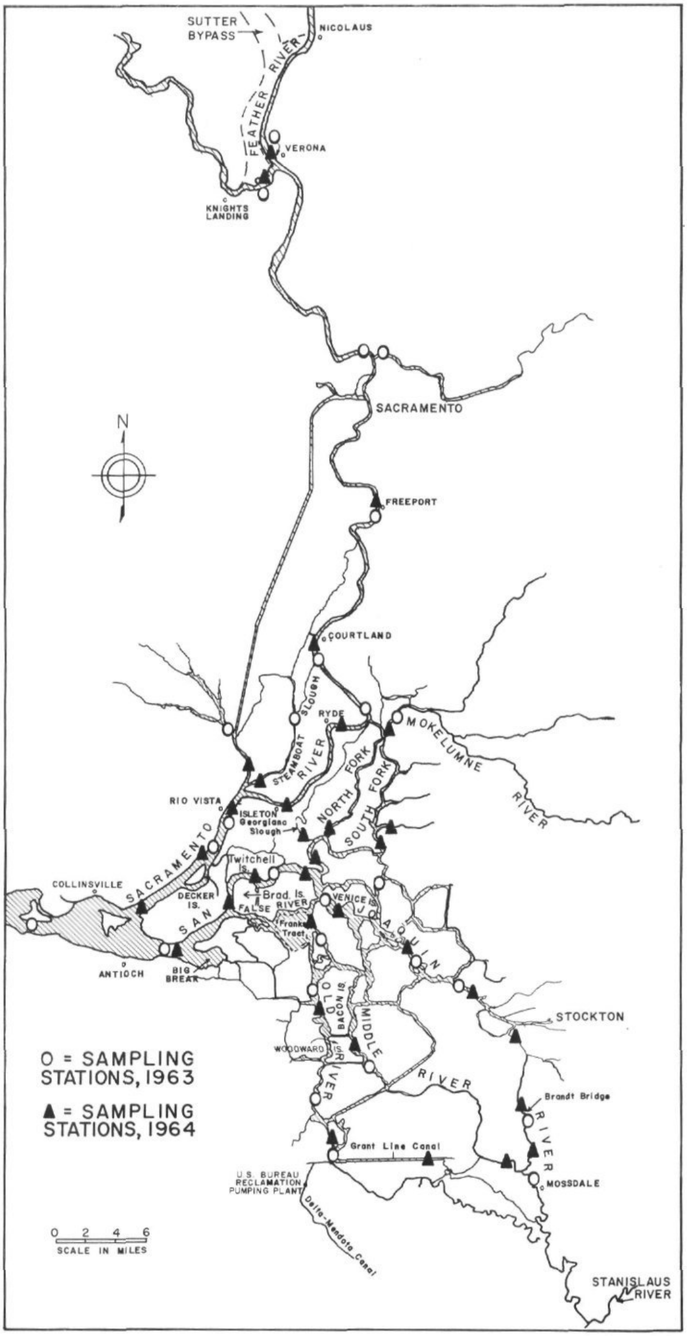

FIGURE 1. Striped bass egg and larva sampling stations.

In both years surface samples were collected from the highway bridges at Courtland and Freeport. The stations above Sacramento were sampled from an anchored skiff.

In all cases 10-minute tows were made.

During each tow, physical and chemical measurements of the water were made (e.g., bottom and surface temperatures, turbidity, water velocity, tidal stage). In 1964 a water sample was collected at each station for analysis of total dissolved solids (TDS) in the laboratory.

The contents of each tow were preserved in 5 to 7 percent formalin to which rose bengal dye had been added. When the sample was emptied into a white enamel laboratory pan, the stained eggs and larvae were easily seen.

1963 Collections

Few eggs and no larvae were collected during April (Figure 2). In the first half of May the numbers of eggs and larvae increased in the collections in both the Sacramento and San Joaquin rivers. From May 16 to May 31 the catches (numbers of eggs and larvae in the samples) in the San Joaquin River from Antioch to Venice Island and above Stockton increased to their highest values there for the sampling period. Catches in the Sacramento River continued to increase in the latter part of May, but did not reach a peak until the first half of June. San Joaquin River catches declined greatly by mid June. During the latter half of June, most catches had declined and consisted almost entirely of larvae.

Although some eggs were collected at almost every station, the areas of highest egg and larvae catches were in the San Joaquin River from Antioch to Venice Island and above Stockton, and in the Sacramento River above Sacramento.

1964 Collections

Low to moderate numbers of eggs and larvae were caught from April 13 to May 1 in 1964 (Figure 3). From May 4 to May 8 no eggs and only a few larvae were caught; this cessation of spawning followed a storm which caused a drop in water temperature of 1.1 to 3.3°C. in most areas of the Delta. From May 11 to May 29 high numbers of eggs were caught in the lower San Joaquin River and the upper Sacramento River. High numbers of larvae were caught in the lower Sacramento and San Joaquin rivers from May 11 until June 12, the end of the survey.

LOCATING THE SPAWNING AREAS

The ages of eggs and larvae were determined by examining each individual under a dissecting microscope and comparing the stage of development with those described by Mansueti (1958). The geographic origin of each egg and larva collected in the Sacramento River was then estimated by multiplying its age by the average river velocity upstream from the collection site; for example, a 36-hour old egg collected below a stretch of river with a 2-mile per hour mean velocity was estimated to have been spawned 72 miles upstream. Such a calculation assumes that striped bass eggs travel at the same rate as the river flow. Since bass eggs are pelagic, this assumption was reasonable for a rough estimation of the location of spawning.

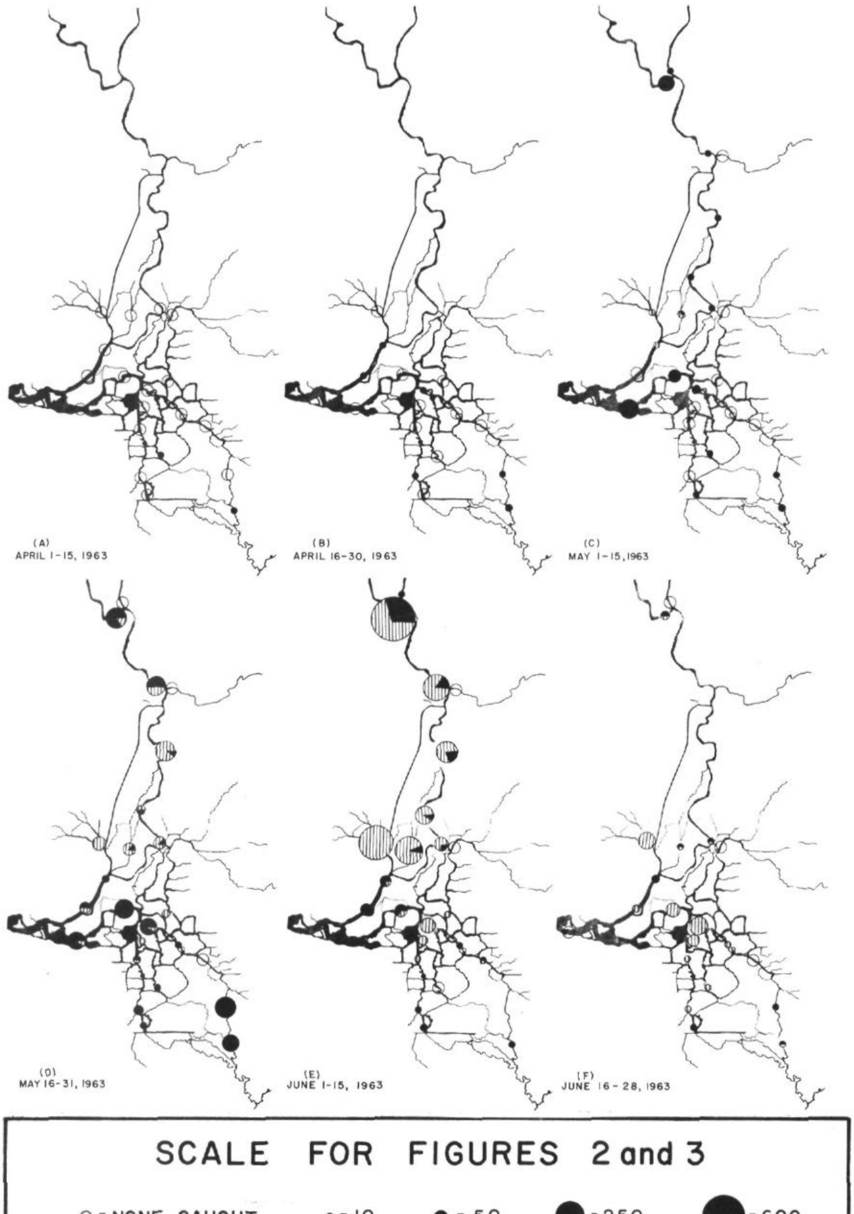

FIGURE 2. Semi-monthly mean eggs and larvae per tow in 1963.

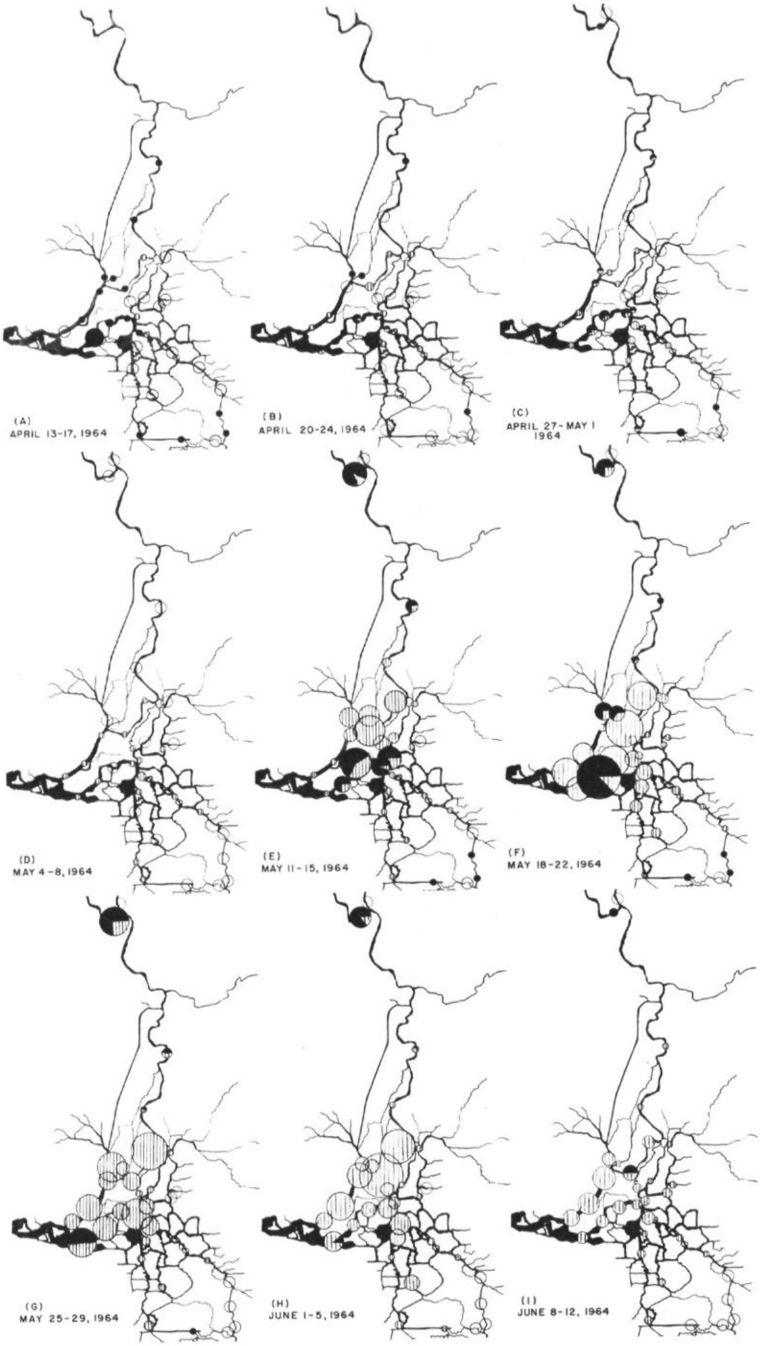

FIGURE 3. Weekly mean eggs and larvae per tow in 1964. For scale and legend see Figure 2.

Mansueti (op. cit.) described the growth rate and development of striped bass eggs and larvae in temperatures from 17.2 to 17.8°C.; at this range of temperature, the eggs hatch in from 36 to 48 hours. We collected eggs and larvae in temperatures from 14.4 to 22.2°C. Because egg development and larval growth rate vary with temperature, there was some error in some of the estimates of the ages of eggs and larvae. In many instances it was necessary to assign broad age estimates to eggs and larvae; e.g., 12 to 20 hours old, 3 to 5 days old. This increased the possible area from which such individuals could have originated.

Back-tracking eggs and larvae collected in the confined channel of the Sacramento River above the Delta was relatively easy since travel time down stretches of that river had already been calculated for various levels of outflow (Calif. Dept. Water Resources, 1962).

Because of the complex current pattern in the San Joaquin River and in the Delta, it was impossible to determine accurately the origin of older eggs and larvae collected there. Therefore, eggs from there were not back-tracked and the spawning areas in the San Joaquin River and Delta are defined as those areas where eggs less than 24 hours old were consistently caught. This is reasonable since water there moves back and forth with the tide, and net flows were low throughout the spawning season (Table 1).

TABLE 1

Net Flows and Net Velocities in the Lower San Joaquin River in 1963 and 1964 [1]

Location and Month	Cross Section (ft^2)	Net Flow (ft^3/sec)	Net Velocity (ft/sec)	Net Downstream Movement in 24 Hours (in miles)
1963				
San Joaquin River—Between Bradford and Twitchell Islands				
April	71,000	12,100	0.17	2.8
May	71,000	11,000	0.15	2.5
June	71,000	6,860	0.10	1.6
San Joaquin River—at Antioch				
April	85,800	31,380	0.37	6.1
May	84,200	23,340	0.28	4.6
June	82,000	11,430	0.14	2.3
1964				
San Joaquin River—Between Bradford and Twitchell Islands				
April	71,000	1,700	0.02	0.3
May	71,000	1,660	0.02	0.3
June	71,000	230	0.003	0.1
San Joaquin River—at Antioch				
April	81,125	3,390	0.04	0.7
May	81,100	3,580	0.04	0.7
June	81,050	940	0.01	0.2

[1] Cross-section and net flow information supplied by California Department of Water Resources, Delta Studies Section.

1963 Spawning Areas

Most eggs caught in the Sacramento River were spawned in the stretch of river from 70 to 160 miles above the junction of the Sacramento and San Joaquin rivers at Collinsville (Figure 4). This section of the river is from 200 to 300 feet wide and 10 to 15 feet deep. Tidal action affected water levels as far upstream as Verona (mile 80), but did not cause flow reversal above Freeport during the spawning period.

During the peak spawning period the flow in the river above Verona was from 8,000 to 9,000 cubic feet per second (Calif. Dept. Water Resources, August 1963). This amount of outflow causes the water to flow 2 to 3 feet per second (Calif. Dept. Water Resources, 1962).

In the Delta the main spawning areas were in the San Joaquin River from Antioch to Venice Island and from Stockton to above Mossdale (Figure 4). Between Antioch and Venice Island, the river is from 1,500 to 4,500 feet wide. Thirty percent of the total water area is made up of shoals less than 10 feet deep (see Sasaki, p. 54). In a few places the water is up to 75 feet deep, but most of the river is maintained as a deep-water ship channel averaging 30 to 40 feet deep. This area is directly affected by tides; the current reverses direction with each ebb and flood of the tide. The river narrows at Venice Island and again at Stockton, so that above Stockton it is only 200 to 300 feet wide. The average depth of the river above Stockton was about 15 feet during the spawning season. Although the water level rose and fell due to tidal action, the flow above Stockton was always downstream during the spawning period.

1964 Spawning Areas

In the Sacramento River most eggs and larvae were spawned from 10 to 60 miles above Collinsville (Figure 4). This is considerably downstream from where the major spawning occurred in 1963. The width of the river below Sacramento varies from 250 to 800 feet, generally becoming wider as it flows downstream. This section of the river was influenced by tidal action. On several occasions the river was observed flowing upstream with the flood tide at Freeport. The flow ranged from 9,000 to 15,000 cubic feet per second from April to June, and the average river velocity was probably near 1 foot per second during the spawning season. At a flow of 10,000 cubic feet per second at Sacramento, the river velocity averages slightly less than 1 foot per second (Calif. Dept. Water Resources, 1962).

Again large numbers of eggs were spawned in the lower San Joaquin River, but the upper San Joaquin River was not a major spawning area as it had been in 1963. The apparent reason for this is discussed in a later section of this paper describing the effect of total dissolved solids on spawning.

THE EFFECT OF WATER TEMPERATURE ON SPAWNING

In both years the onset of bass spawning occurred when the water temperature reached 14.4 to 15.0°C. In 1963 the first egg was collected in Middle River opposite Woodward Island on April 11, 9 days after the survey began; the water temperature was 14.4°C. In 1964 the first eggs were collected on April 13 at Antioch and near the mouth of False River, where the water temperatures were 15.0 and 14.4°C respectively. Although April 13 was the first day of regular sampling, I believe very little spawning took place before that time because we caught only a very small number of larvae during the entire first week of the survey.

In both years the greatest numbers of eggs were collected near the spawning areas when the water temperature was between 16.1 and 20.6°C (Table 2).

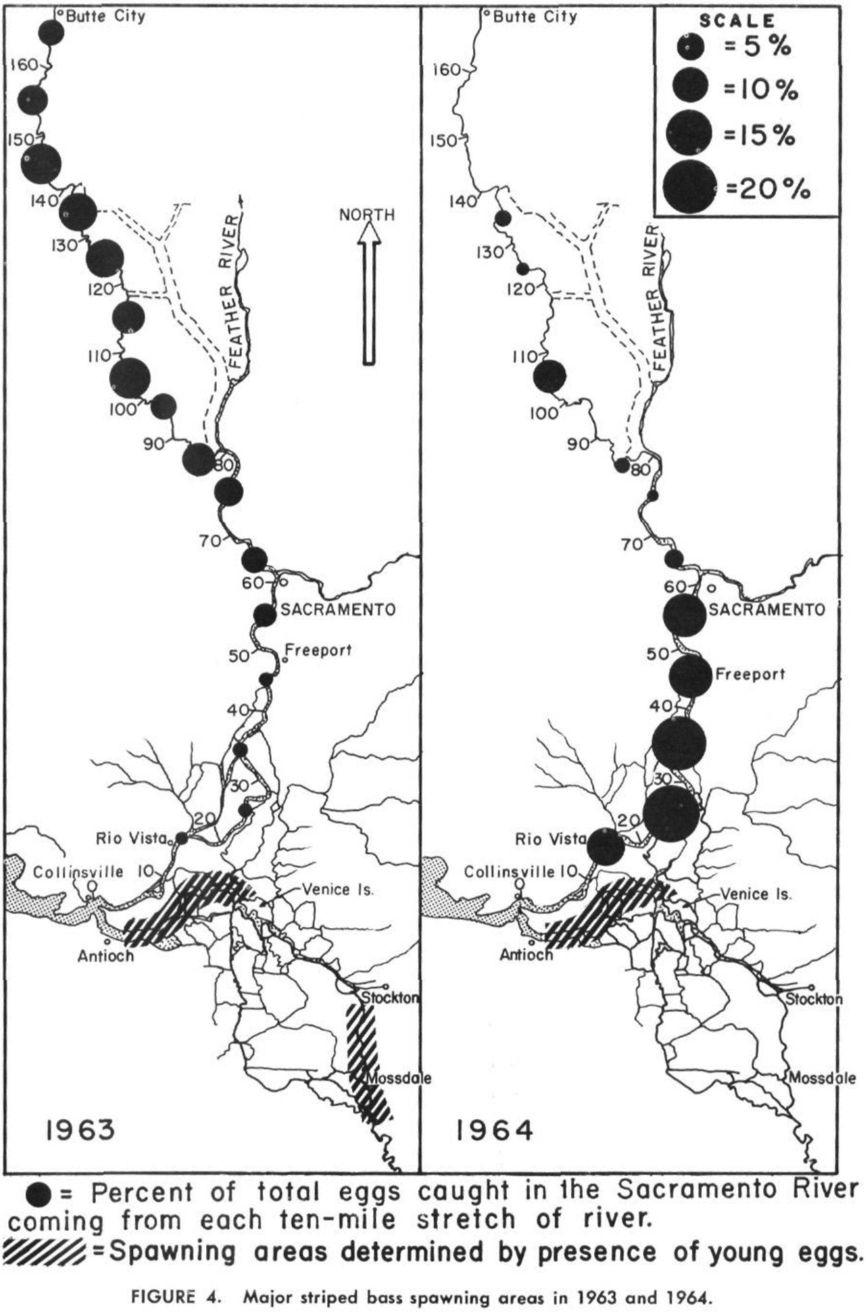

FIGURE 4. Major striped bass spawning areas in 1963 and 1964.

Bass ceased spawning temporarily when the water temperature fell below 15.6°C, or when there was a sudden drop in water temperature even though it remained above 15.6°C. This was clearly demonstrated

TABLE 2

Mean Eggs Per Tow and Water Temperature Near the Spawning Areas in 1963 and 1964

		April			May			June		
		1–10	11–20	21–30	1–10	11–20	21–30	31–9	10–19	20–29
1963										
San Joaquin River above Stockton	C°	13.9	13.3	15.0	15.6	17.8	—	17.8	20.0	21.1
	Eggs/Tow	0	0.5	8.5	11.0	81.0	—	9.0	2.5	2.5
San Joaquin River from Webb Tract to Venice Island	C°	13.3	13.3	13.5	16.7	17.2	17.8	18.3	19.4	20.8
	Eggs/Tow	0	0	0	45.0	70.0	4.0	3.0	9.0	0
Sacramento River above Verona	C°	—	—	—	16.1	16.7	18.9	19.4	20.6	20.0
	Eggs/Tow	—	—	—	84.0	50.0	90.0	95.0	250.0	3.0
1964										
San Joaquin River at the Mouth of False River	C°	—	16.1	16.1	15.0	16.7	18.3	18.3	18.3	—
	Eggs/Tow	—	57.0	27.0	14.0	374.0	160.0	83.0	42.0	—
Sacramento River above Verona[1]	C°	—	16.1	16.1	15.0	18.3	18.9	20.0	18.3	—
	Eggs/Tow	—	4.0	4.0	1.5	163.0	426.0	312.0	6.0	—

[1] Most spawning in the Sacramento River took place below this point. However, the catches above Verona were composed primarily of eggs 16–20 hours old, and the catches delimiting the lower spawning area were composed primarily of larvae. Since the catches above Verona were closer in time to the actual spawning events, the water temperature that they were caught in was considered more representative of the water temperature when spawning occurred.

in 1964 in the Sacramento River above the mouth of the Feather River when the water temperature dropped following cold weather from May 1 to May 5 and from June 4 to June 11 (Figure 5). The drop in water temperature in the first week of May was widespread and caused spawning to cease throughout the Delta (see Figure 3d).

Previous studies of striped bass spawning have shown a close relationship between water temperature and spawning. Although eggs have been found in a range of temperature from 10.0 to 23.9°C, the onset of spawning usually occurs at 14.4 to 15.6°C (May and Fuller, 1962; Chadwick, 1958), and the peak of spawning has usually been at about 18.3°C (Mansueti and Hollis, 1963). The cessation of spawning due to a sudden drop in temperature has been observed in several instances (Calhoun, Woodhull and Johnson, 1950; Chadwick, 1958; Mansueti and Hollis, 1963).

In addition to the relationship of certain temperatures to the onset and peak of spawning and the starting and stopping effect caused by fluctuating temperatures, some biologists believe that temperature may affect the location of spawning. Calhoun, Woodhull and Johnson (1950) theorized that bass continue to migrate up the river until the water becomes warm enough for spawning, so in years when the Delta and rivers remain cool in spring (years of heavy runoff), bass migrate farther up river than they do in years when the water is relatively warm in spring (years of low runoff).

The results of my sampling in the Sacramento River in 1963 and 1964 support this theory. In 1963 (a wet spring), the water temperature did not reach 15.6°C at Rio Vista until May 17; most spawning in the Sacramento River was between river mile 50 and river mile 170. In 1964, a relatively dry spring, the water reached 15.6°C on April 13 and most spawning took place below river mile 60.

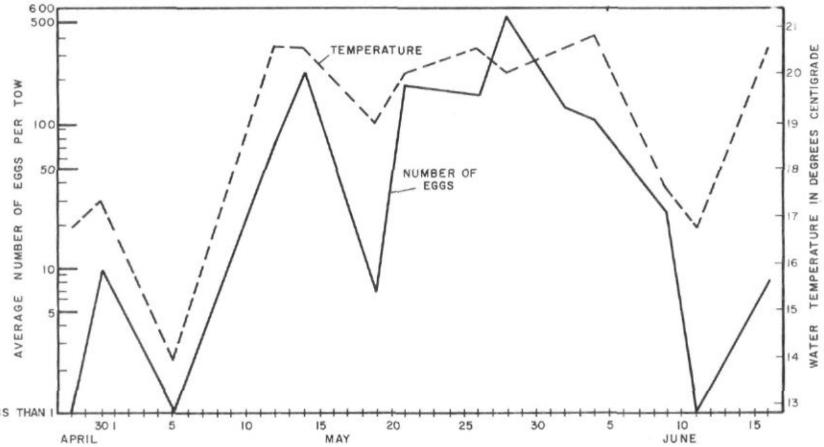

FIGURE 5. The relationship of water temperature to spawning activity in the Sacramento River above the mouth of the Feather River in 1964.

THE EFFECT OF TOTAL DISSOLVED SOLIDS ON SPAWNING

I know of no documented case of striped bass spawning in brackish or saline water, although eggs have been collected there. In California, Chadwick (1958) collected three eggs in Suisun Slough, a tributary to Suisun Bay, in 1957. The salinity was 1.3‰. In some short Chesapeake Bay tributaries, striped bass eggs have been found in salinities greater than 3‰; in 1959 eggs were collected in the Blackwater River in salinities from 4.72 to 11.28% (Edgar Hollis, pers. commun.). In both of these instances, it is possible that spawning took place in fresh water upstream from the collection site.

TABLE 3

Concentration of Total Dissolved Solids at or Near Striped Bass Spawning Areas in 1963 and 1964 [1]

Location	April	May
1963		
San Joaquin River at Mossdale	171	73
San Joaquin River at Antioch	179	113
Sacramento River at Freeport	56	73
1964		
San Joaquin River at the Mouth of False River	153	120
Sacramento River at Ryde	96	112

[1] 1963 TDS information from Calif. Dept. of Water Resources (June 1963, July 1963). 1964 TDS information obtained directly from water samples collected when sampling for eggs and larvae.

In both 1963 and 1964 most spawning in the Sacramento-SanJoaquin River system occurred in water with a total dissolved solids (TDS) content below 180 ppm (Table 3). In 1963 water throughout the Delta and tributaries was relatively fresh during the spawning period due to a heavy spring runoff, and bass migrated far up the Sacramento and San Joaquin rivers to spawn. In 1964 the San Joaquin River at and above Stockton averaged between 650 and 1,000 ppm TDS concentration, and very little spawning took place there. Radtke (see p. 17) found a heavy concentration of adult bass 5 miles below Stockton in April. He concludes (see p. 26) that these fish did not migrate farther up the river because of the high TDS concentration there.

In three previous studies (Table 4), bass eggs were found to have originated in the San Joaquin River above Stockton. The TDS concentration was less than 250 ppm during May in each of those years.

TABLE 4

Presence or Absence of Spawning in the San Joaquin River Above Stockton in Years When Spawning Surveys Were Made There. TDS Measurements Taken at Mossdale

Year	Spawning	TDS in May (ppm)
1948	Yes[1]	120[4]
1949	Yes[1]	250[5]
1952	Yes[2]	61[6]
1963	Yes[3]	73[7]
1964	No[3]	661[3]

[1] Erkkila, et al (1950).
[2] U.S. Dept. of the Interior (1957).
[3] Results of this Survey.
[4] Calif. Div. of Water Resources (1949).
[5] Calif. Div. of Water Resources (1950).
[6] Calif. Div. of Water Resources (1953).
[7] Calif. Dept. of Water Resources (June, 1963).

THE RELATIVE AMOUNT OF SPAWNING IN THE SACRAMENTO AND SAN JOAQUIN RIVER SYSTEMS

Measurement of the amount of water strained during each tow in 1964 allowed an estimation of the relative importance of the Sacramento and San Joaquin rivers as spawning areas. The mean weekly catch of eggs and larvae per tow at Steamboat Slough, Isleton, Georgiana Slough and the North Fork of the Mokelumne River was used to estimate the total amount of eggs and larvae from the Sacramento River. These stations represent all major locations where Sacramento River water enters the Delta (Figure 6), and my estimates assume that all eggs spawned in the Sacramento River in 1964 passed these points. For a comparable estimate of eggs spawned in the San Joaquin River and Delta, the stations at Grant Line Canal, Old River near Bacon Island, Middle River, and an average of the catch at Antioch and the mouth of False River stations in the San Joaquin River were used (Figure 6). The Grant Line Canal station provided a measure of the few eggs and larvae originating there and also any eggs or larvae present in the upper San Joaquin River water as it was drawn across to the U. S. Bureau of Reclamation pumping plant. The other three stations represented the possible directions that eggs and larvae could have been transported from the lower San Joaquin River spawning area. The Antioch and mouth of False River stations were averaged because the Antioch station was always sampled early in the morning and the False River station was sampled in mid afternoon; averaging the catches gave a better estimate of the eggs passing through that stretch of river throughout the day. It is assumed that all eggs and larvae spawned in the San Joaquin River system passed these points; although due to low net flows in the river at the time, it is possible

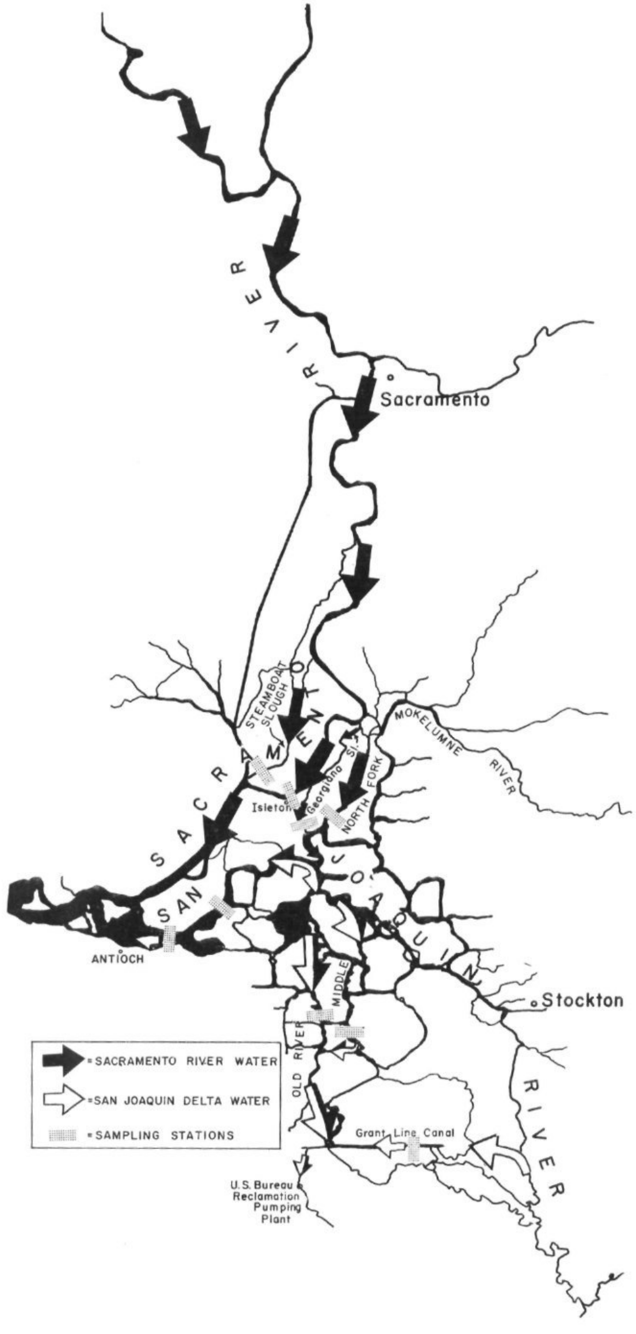

FIGURE 6. Direction of water flow from the major spawning areas in 1964.

that some eggs and larvae were retained upstream from the sampling stations.

The estimate of eggs produced was made by applying the following formula to the 1964 egg catches for each of the nine index stations during each week of the survey:

$$E = \frac{e}{w} \times f \text{ where,}$$

E = number of eggs and larvae flowing past the station in a week

e = mean number of eggs and larvae per tow at the station during the week

w = mean volume of water strained during each tow

f = net volume of water flow past the station during the week

The sum of the estimates of the total number of eggs passing the index stations each week is an estimate of the total eggs surviving to these points. Some bias could be introduced into the calculations if the average age of eggs and larvae caught at the index stations of one system differed significantly from the average age of eggs and larvae caught at the index stations of the other system. All other things being equal, the oldest eggs and larvae probably would have suffered a higher natural mortality than the younger ones; this could result in an underestimate of the relative number of eggs produced in the system where the average age was highest. Detailed knowledge of the survival rate versus age of striped bass eggs and larvae is needed before this factor can be accounted for in future calculations.

Assuming that egg survival is equal in both rivers, the Sacramento River contributed approximately 66 percent of the total and those from the San Joaquin Delta made up 34 percent of the total (Table 5).

HYPOTHESES ABOUT THE LOCATION OF BASS SPAWNING

A hypothesis of what causes striped bass to spawn where they do brings together some of the important results of this paper. Some adults spend the winter in the Delta, but most of the spawning population migrates upstream from the bay in the spring (see Radtke, p. 18). As the bass reach the confluence of the Sacramento and San Joaquin rivers, they can go up either river. What causes them to choose one river or the other is a matter of conjecture although there is some evidence that bass tend to return to the river where they spawned the previous year (Chadwick, 1967). Fish that choose the Sacramento River keep migrating upstream until the water temperature approaches that necessary for the onset of spawning (14.4 to 15.6°C). When water temperatures remain cool in spring, as they did in 1963, bass migrate farther up the river to spawn than when the water warms early in the spring, as it did in 1964.

In some years bass spawn in the Feather River. In 1948 Calhoun, Woodhull, and Johnson (1950) found many eggs in the Feather River when they sampled off the highway bridge at Nicolaus. I found no evidence of spawning in the Feather River in either 1963 or 1964. In 1963, when many bass migrated past the mouth of the Feather River

TABLE 5

The Relative Amount of Striped Bass Spawning in the Sacramento and San Joaquin River Systems in 1964 [1]

	Sacramento River System				San Joaquin River System			
	Steam-boat Slough	Sacra-mento River at Isleton	Georgiana Slough	North Fork of the Mokel-umne River	Grantline Canal	Middle River	Old River at Bacon Island	San Joaquin River at Antioch[2]
April 12-18	2.8	5.0	0.0	0.0	0.4	0.1	0.4	57.3
April 19-25	1.0	27.3	0.2	0.8	0.0	0.0	0.5	11.6
April 26–May 2	4.7	0.6	0.2	0.3	3.5	1.8	1.3	25.7
May 3-9	0.5	6.1	1.7	1.1	0.0	1.6	0.2	22.4
May 10-16	239.9	685.0	123.6	81.5	1.1	2.5	0.7	49.8
May 17-23	150.0	1,156.2	42.6	19.1	2.0	7.9	52.3	972.4
May 24-30	102.2	199.8	20.0	27.7	1.1	3.6	31.8	525.1
May 31–June 6	65.7	582.1	63.0	11.3	0.2	16.8	5.1	85.5
June 7-13	13.6	116.1	42.9	4.9	0.0	6.9	36.7	50.6
Station totals	580.4	2,778.2	294.2	146.7	8.3	41.2	129.0	1,800.4

Sacramento River System total = 3,799.5 San Joaquin Delta total = 1,978.9

Total for Both Areas = 5,778.4

$$\text{Sacramento River System} = \frac{3{,}799.5}{5{,}778.4} = 66\% \text{ of all Spawning}$$

$$\text{San Joaquin River System} = \frac{1{,}978.9}{5{,}778.4} = 34\% \text{ of all Spawning}$$

[1] All values are in millions of eggs and larvae.
[2] An average of the Antioch and False River stations.

to spawn in the upper Sacramento River, flow and temperature characteristics in the Feather River and Sacramento River were similar to the conditions existing there in 1948. Therefore, bass avoided the Feather River for some other reason.

The behavior of fish that choose to move up the San Joaquin River depends on the amount of runoff in the spring season, which in turn affects the total dissolved solid concentration of the water in the river. In wet springs, the TDS is low (below 250 ppm), and some fish migrate upstream past Stockton. In dry springs, the TDS is high and bass are blocked by a TDS "barrier" some place below Stockton; these fish then return to the lower San Joaquin River area to spawn. Radtke (see p. 24) concludes that current velocity conditions alone did not prevent bass from moving into the upper San Joaquin River in 1964 since the mean net velocities at Isleton and Mossdale were similar and bass moved past Isleton but not Mossdale.

In both wet and dry springs some spawning occurs in the lower San Joaquin River. Some bass that spawn there may consist of fish which have over-wintered in the nearby flooded islands. Large concentrations of bass over-winter in Big Break and Franks Tract (see Radtke, p. 17), and both Radtke and Calhoun (1946) have demonstrated a movement of ripe fish out of Franks Tract in April and May into the San Joaquin River nearby. The extensive shoals in that area of the river may be somehow attractive to bass waiting to spawn. I have no evidence that this is or is not true, except that I know bass do not necessarily select shallow water for spawning. I observed a large school of bass spawning in the San Joaquin River near False River on May 11, 1964. There is a shallow area near the north shore, but these fish were spawning throughout the full width of the river.

SUMMARY

Striped bass eggs and larvae were collected from 26 stations in 1963 and 33 stations in 1964 in the Sacramento-San Joaquin Delta and its tributaries. In the Sacramento River spawning areas were determined by back-tracking eggs and larvae to the place where they were spawned. This was accomplished by multiplying the age of an egg or larva by the river velocity upstream from the sampling stations. In the San Joaquin Delta the spawning areas were defined as those areas where young eggs were consistently caught.

In 1963 the main spawning areas in the San Joaquin River were from Antioch to Venice Island and upstream from Stockton. In the Sacramento River most spawning occurred above Sacramento.

In 1964 the main areas were the Sacramento River below Sacramento and the San Joaquin River from Antioch to Venice Island. No spawning took place in the upper San Joaquin River.

No significant amount of spawning occurred in water with a TDS content greater than 180 ppm, and in 1964 the migration up the San Joaquin River was blocked by a concentration exceeding that level. In both 1963 and 1964, spawning began when the water temperature reached 14.4 to 15.0°C.

Most spawning occurred when water temperatures were between 16.1 and 20.6°C.

A sudden drop in water temperature caused bass to cease spawning until the temperature rose again.

There is evidence that water temperature affects the location of spawning in the Sacramento River. In 1963 the river warmed up slowly and bass spawned from river mile 50 to river mile 170. In 1964 the river warmed up quickly and most bass spawned below river mile 60.

In general no evidence was found that bass prefer a particular type of environment for spawning other than it be flowing, fresh water. The location of spawning appears to depend upon water temperature and water quality conditions, which in turn depend upon the weather and the amount of spring runoff.

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DISTRIBUTION OF YOUNG STRIPED BASS, *ROCCUS SAXATILIS*, IN THE SACRAMENTO-SAN JOAQUIN DELTA

SHOKEN SASAKI

Young striped bass (1963 year-class) were sampled in the Sacramento-San Joaquin Delta with a midwater trawl and an otter trawl from September 1963 to August 1964. They were most abundant in the Delta during the fall. There was evidence that large numbers of young bass migrated from the Delta downstream to San Pablo Bay area during the fall and winter of 1963. Concentrations of young bass in the Delta remained low through the following spring and summer. The concentrations were almost always greatest over the shoals in the lower San Joaquin River. This region was the most important nursery area in the Delta for young bass.

DEFINITION OF "YOUNG" STRIPED BASS

In this paper the term "young" striped bass applies to the 1963 year-class. Members of this year-class were identified by analyzing the length frequencies of the bass caught in both the otter and midwater trawls (Figure 1). These bass grew from a range of 5 to 12 cm (FL) in September 1963 to a range of 12 to 23 cm in August 1964.

THE INDEX OF CONCENTRATION

The description of the distribution of young striped bass in this paper is based on an "index" of concentration. This index is an approximation which considers the catch of bass by both the otter and midwater trawls and the relative volume of the Delta channel represented by the catch of each.

In the channels, the otter trawl sampled the water within 5 feet of the bottom. The midwater trawl sampled the water within 10 feet of the surface. Large numbers of young striped bass were caught in both the otter trawl and the midwater trawl. Neither gear was adequate by itself. Concentrations of bass near the bottom were missed with the midwater trawl and concentrations near the surface were missed by the otter trawl.

A valid index of concentration of young striped bass must therefore be based on the catch of both gears so that all depths and levels in the channel are represented. Since the vertical distribution of the bass can be expected to change with the season and to be different in different areas, and since the two nets could not be expected to catch fish equally well, the catch data of the two gears could not simply be added or averaged. These catch data were adjusted (i) with an estimate of the efficiency of the two nets and (ii) by weighting the mean catch of each gear according to the relative amount of "midwater" and "bottom" water at the sampling station. Only after this adjust-

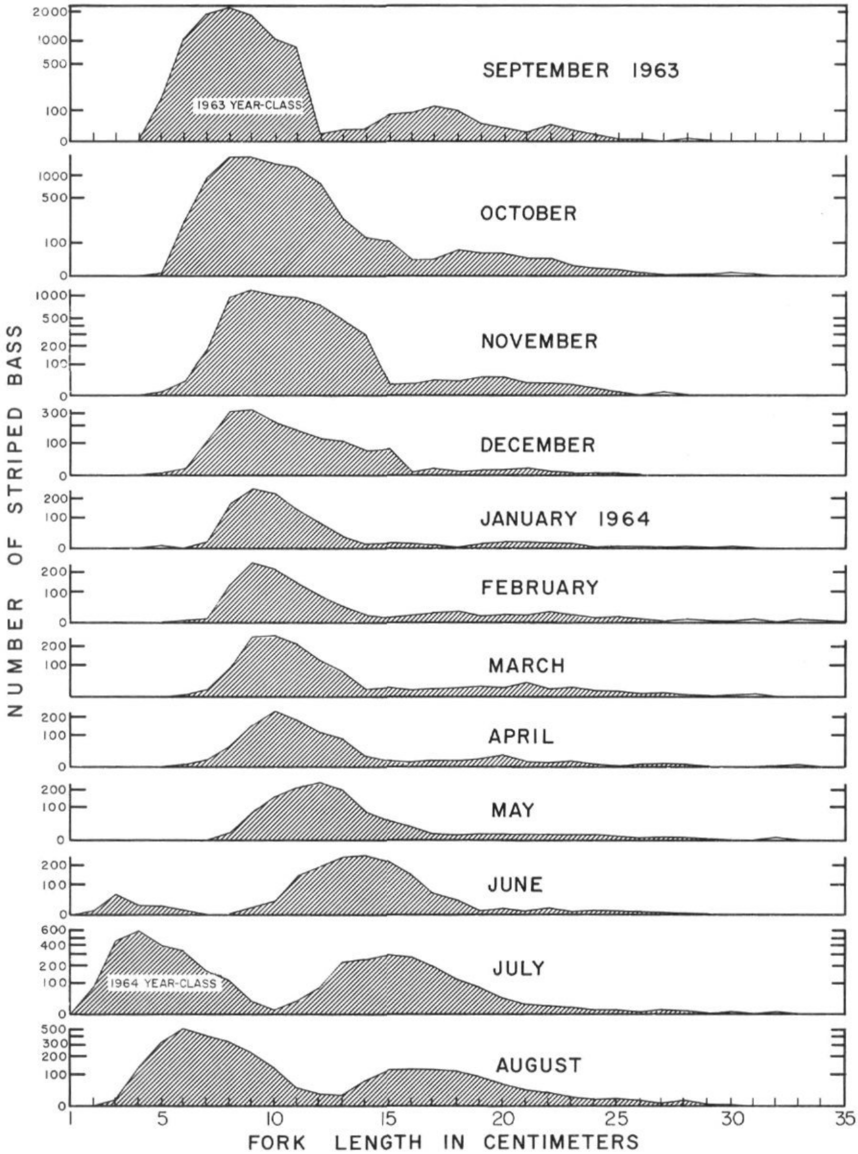

FIGURE 1. Length frequency of striped bass taken with the otter and midwater trawls from September 1963 to August 1964.

ment could the catch data be combined and valid comparisons made of indices of concentration from one station or time to another.

Relative Efficiency of Otter Trawl and Midwater Trawl

The relative efficiency of the otter trawl and the midwater trawl was estimated by fishing each trawl along with a third kind of gear, a floating gill net that collected the same size striped bass as the trawls.

On November 17, 1964, three 1-hour drifts were made with a 150 foot by 10 foot gill net with a stretch mesh of $\frac{5}{8}$ inch. The net was floated at the surface in deep water in the San Joaquin River near West Island. At the same time, nine 10-minute tows were made with the midwater trawl in the path of the gill net. The mean gill net catch was 19.7 bass per hour drift while the mean midwater trawl catch was 13.6 bass per tow (Table 1). Since the midwater trawl strains an area of 100 square feet (see Turner, p. 12), the mean midwater trawl catch was 0.136 bass per square foot.

TABLE 1

Comparison of the Efficiency of the Otter and Midwater Trawls. Figures are Numbers of Young Striped Bass Per Trawl Tow or Per Hour Drift

Midwater trawl	Gill net drifting near surface in deep water	Gill net drifting at bottom in shallow water	Otter trawl
35	23.2	136.0	279
11	18	86.6	275
10	18		166
16			421
11			222
16			
9			
4			
11			
Sample mean...13.6	19.7	111.3	272.4

On November 20, 1964, two 1-hour drifts were made with the gill net on the shoals near West Island in water where the lead line dragged on the bottom. The depth was about 4 to 10 feet. While these drifts were being made, five 10-minute hauls of the otter trawl were made in the path of the gill net. The mean catch of young striped bass in the otter trawl was 272.4 per tow while the mean gill net catch was 111.3 per hour drift (Table 1). The otter trawl strains an area of 75 square feet (see Turner, p. 12), so the mean otter trawl catch was 3.632 bass per square foot.

It was assumed that the drifting gill net fished in the deep water with the same efficiency that it did while fishing over the shoal area. Therefore, we increased the gill net catch in the deep area by a factor of 5.65 to equal that of the gill net catch in the shoal area and increased the midwater trawl catch proportionately. The adjusted midwater trawl catch was 0.768 bass per square foot, therefore the otter trawl was 3.632/0.768 or roughly 4.7 times more efficient than the midwater trawl. Accordingly, for the analysis in this paper, the midwater trawl catches were multiplied by a factor of 4.7.

Vertical Distribution of Young Striped Bass

A comparison of otter trawl catches with adjusted midwater trawl (x 4.7) catches demonstrated that the vertical distribution of young bass varied considerably from station to station during fall and winter but there was a tendency for young bass to be concentrated on the bottom at most stations (Table 2). During the spring, more bass were found in the midwaters. In the summer, young bass were definitely more concentrated in the midwaters.

TABLE 2

Seasonal Comparison of Mean Otter Trawl Catches with Mean 4.7 Midwater Trawl Catches of the 1963 and 1964 Year-Class of Striped Bass at Various Stations from September 1963 to August 1964

	Mean Otter Trawl Catch/Mean 4.7 Midwater Trawl Catch				
	1963 year class				1964 year class
Stations	Fall	Winter	Spring	Summer	Summer
Sacramento River—Isleton	34.3	1.0	5.7	1.0	0.8
Sacramento River—Sherman Island	0.2	1.2	0.09	0.4	0.2
San Joaquin River—Mossdale	34.9	27.5	3.2	0.1	2.1
San Joaquin River—Fourteen Mile Slough	0.3	2.4	0.9	0.1	1.2
San Joaquin River—Santa Clara Shoal—Deep	0.01	0.8	0.06	0.08	0.4
San Joaquin River—West Island—Deep	0.1	0.8	0.6	0.1	0.2
Mokelumne River—North Fork	7.5	----	0.9	0.5	0.4
Mokelumne River—South Fork	12.1	----	2.5	2.0	3.3
Mokelumne River—Terminous	14.9	4.2	7.7	1.1	18.8
Old River—Fabian and Bell Canal	2.1	4.2	2.3	0.2	0.2
Old River—Victoria Island	5.5	3.3	0.6	0.3	0.1
Dead-end Slough—Sycamore Slough	36.6	2.2	0.6	0.03	0.1
Dead-end Slough—Hog Slough	32.8	----	0.2	0.1	0.3
Dead-end Slough—Indian Slough	0.4	0.5	0.1	0.1	0.03

The 1964 year-class of striped bass appeared in the catch in large numbers in July and August of 1964. These bass were most concentrated in the midwaters at most stations (Table 2).

Because of these differences in the vertical distribution, the numbers of bass caught in the otter trawl could not simply be averaged with the numbers caught in the midwater trawl (x 4.7) for an index of the concentration of bass at each station. Each adjusted catch of bass in the midwater trawl was weighted by the proportion of the channel

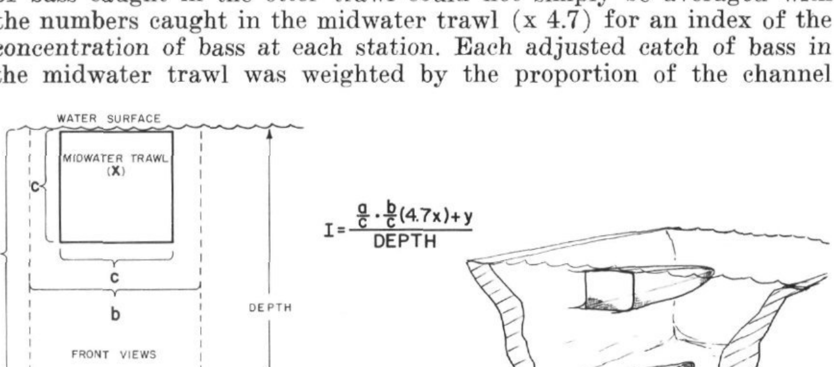

FIGURE 2. Index of concentration "I" where:
a = the depth of water represented by the midwater trawl.
b = the width of water represented by the midwater trawl.
This width is equal to width of otter trawl.
x = the mean catch of bass in the midwater trawl.
c = the depth and width of water actually sampled by the midwater trawl.
y = the mean catch of bass in the otter trawl in a constant 5-foot depth from the bottom.

from 5 feet off the bottom to the surface before adding it to the otter trawl catch. This total catch was then divided by the station water depth to derive the index of concentration of bass for each station (Figure 2).

GEOGRAPHICAL DIFFERENCES IN POPULATION DENSITY

Striped bass spawned in and above the Delta during late May and early June 1963 (see Farley, p. 30), and personnel of the California Department of Fish and Game started to collect large numbers of 1.8–5.0 cm long young striped bass in late June with a tow net having a bobbinet cod end with 2.5 mm diameter openings.

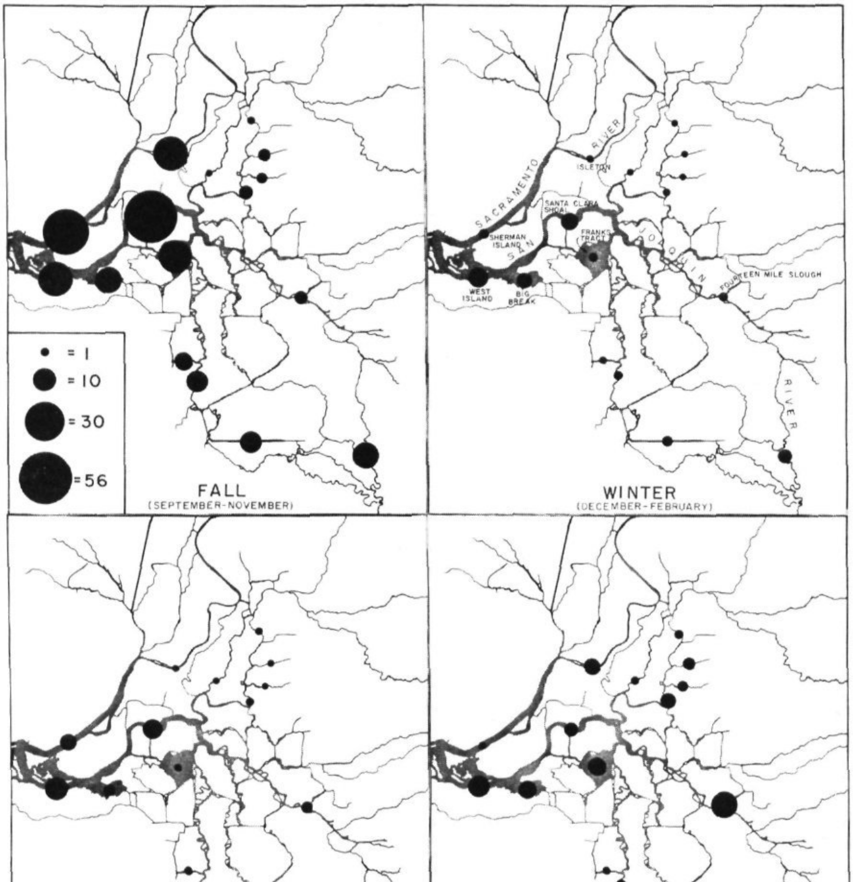

FIGURE 3. Distribution of 1963 year-class striped bass, September 1963 to August 1964. The area of each circle represents the index of concentration (see text, page 44).

These young bass were abundant in the Delta when we started sampling in September 1963 (Figure 3). They were most concentrated in the western Delta. Concentrations were especially high in the San Joaquin River at West Island and Santa Clara Shoal, in the Sacramento River at Sherman Island and Isleton, and in flooded islands (Big Break and Franks Tract).

By winter the concentrations of young bass in the Delta had declined. A sudden and large drop in catches occurred between November and December (Figure 4). Ganssle (1966) reported that catches in San Pablo Bay increased from almost nothing in September to almost 150 bass per tow in November (Figure 4). Since striped bass do not spawn in San Pablo Bay (see Farley, p. 33), these young bass must have emigrated from the Delta to San Pablo Bay in the fall. Fall catches of young bass in San Pablo Bay were very low in 1964 suggesting a possible difference in emigration pattern that year (Ganssle, 1966).

Other biologists have also suggested that young bass migrate toward the ocean when they are a few months old. Scofield and Bryant (1926) based their belief on age and growth studies which showed a large "sea growth" in the second year and also in the high catches of young striped bass in the fall and winter by shrimp nets fishing on the ebb tide between San Pablo and San Francisco bays. Erkkila, *et al.* (1950), sampling in the Sacramento-San Joaquin Delta, found increasing numbers of young bass in the lower San Joaquin River and Sacramento River along with a decreasing number of bass in the central and southern Delta during late summer. On the East Coast, Mansueti (1954) based his belief on finding young bass farther downstream toward the lower rivers and bay as time progressed after the spawning period.

Concentrations of young bass in the Delta were never high after the fall migration (Figure 3).

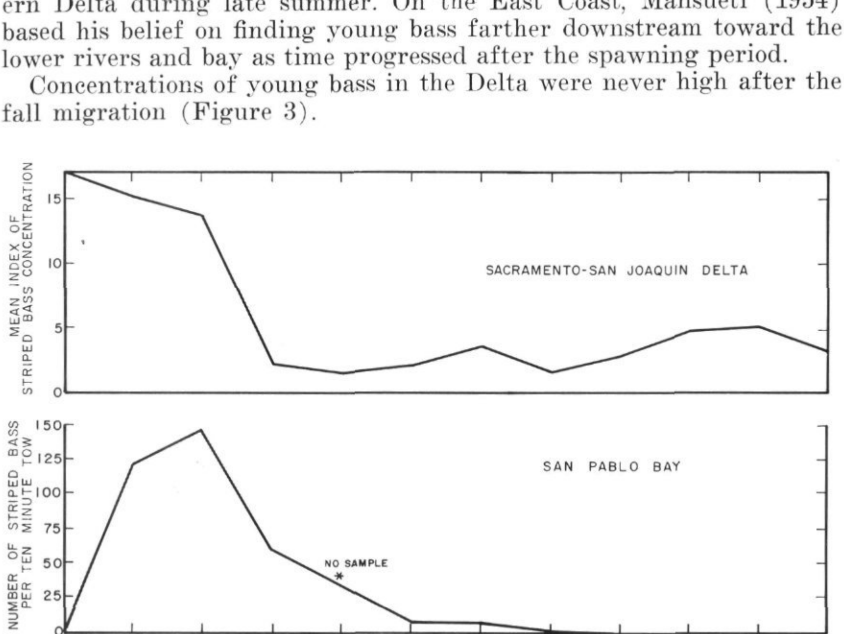

FIGURE 4. Comparison of the monthly mean index of concentration (see text, p. 44) in the Delta and the monthly average otter trawl catches in San Pablo Bay (Ganssle, 1966) of the 1963 year-class striped bass, September 1963 to August 1964.

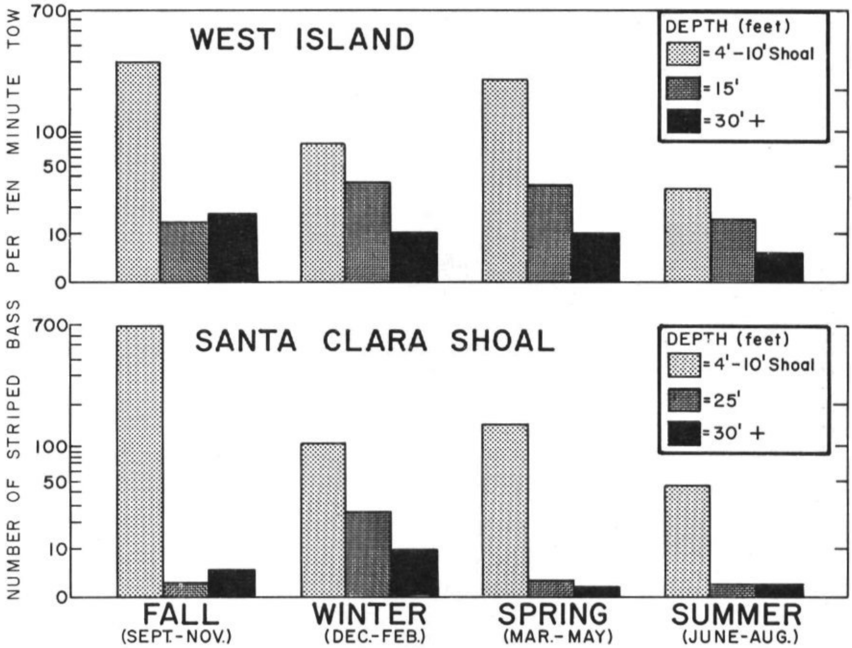

FIGURE 5. Average catch by season of the 1963 year-class striped bass taken at various bottom depths by otter trawl at West Island and Santa Clara Shoal on the San Joaquin River during 1963–1964.

The concentration of young striped bass did increase in the San Joaquin River near Fourteen Mile Slough during the summer of 1964. Stevens (see p. 93) believes that this increase may have been caused by young bass moving down into the Delta from the upper river areas.

Young bass in the lower San Joaquin River were always more concentrated over the shoal areas than in the deeper water (Figure 5).

Large numbers of the new (1964) year-class of striped bass were collected in July and August 1964 (Figure 1). These bass were too small to be trapped by the $\frac{3}{4}$ inch stretch mesh on the cod end of the trawls before July. The largest concentrations were in the flooded islands, in the lower San Joaquin River at West Island and in the Sacramento River at Sherman Island (Figure 6).

GEOGRAPHICAL DIFFERENCES IN TOTAL POPULATION

Delta channels vary a great deal in size so the index of concentration (Figure 2), a measure of population *density,* does not indicate (i) what proportion of the population of young bass in the Delta is in different areas of the Delta or (ii) the *changes* in *total* numbers of young striped bass in the Delta from season to season. To do this the weighted catch in a column of water at each station (the numerator of the index of concentration formula, Figure 2) must be adjusted by the surface area of that portion of the Delta it represents. The Delta was divided into eight environmental zones based largely on river systems and flow.

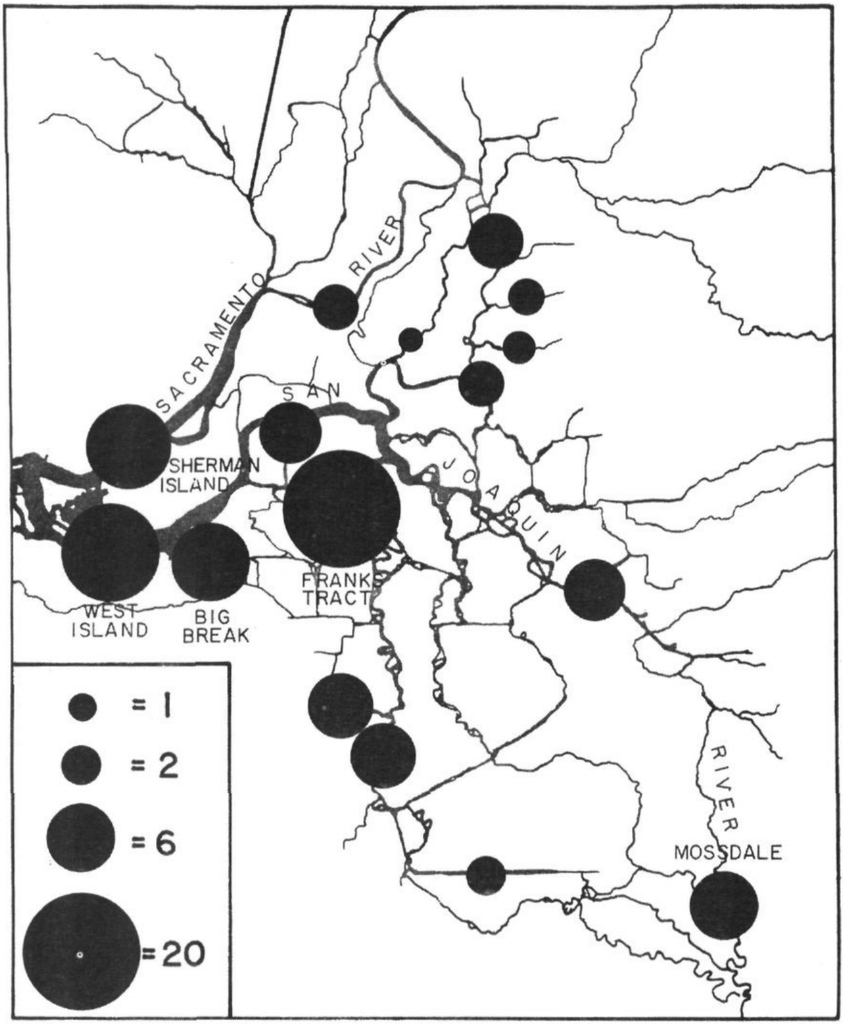

FIGURE 6. Distribution of 1964 year-class striped bass in summer (June, July, and August) 1964. The area of each circle represents the index of concentration (see text, p. 44).

These zones are the Sacramento River, Mokelumne River, the upper, middle, and lower San Joaquin River, south Delta, flooded islands, and dead-end sloughs (Figure 7). The mean weighted catch of bass in each zone was multiplied by the percent of the Delta area represented by each zone (Table 3). The products are population indices useful to compare the proportion of the Delta population in different parts of the Delta and to describe changes in the relative abundance of young striped bass from season to season (Figure 8).

In the fall of 1963, 79 percent of the young striped bass in the Delta were in the lower San Joaquin (I) and Sacramento River (II) environmental zones (Table 3). About 10 percent were in the flooded islands (III).

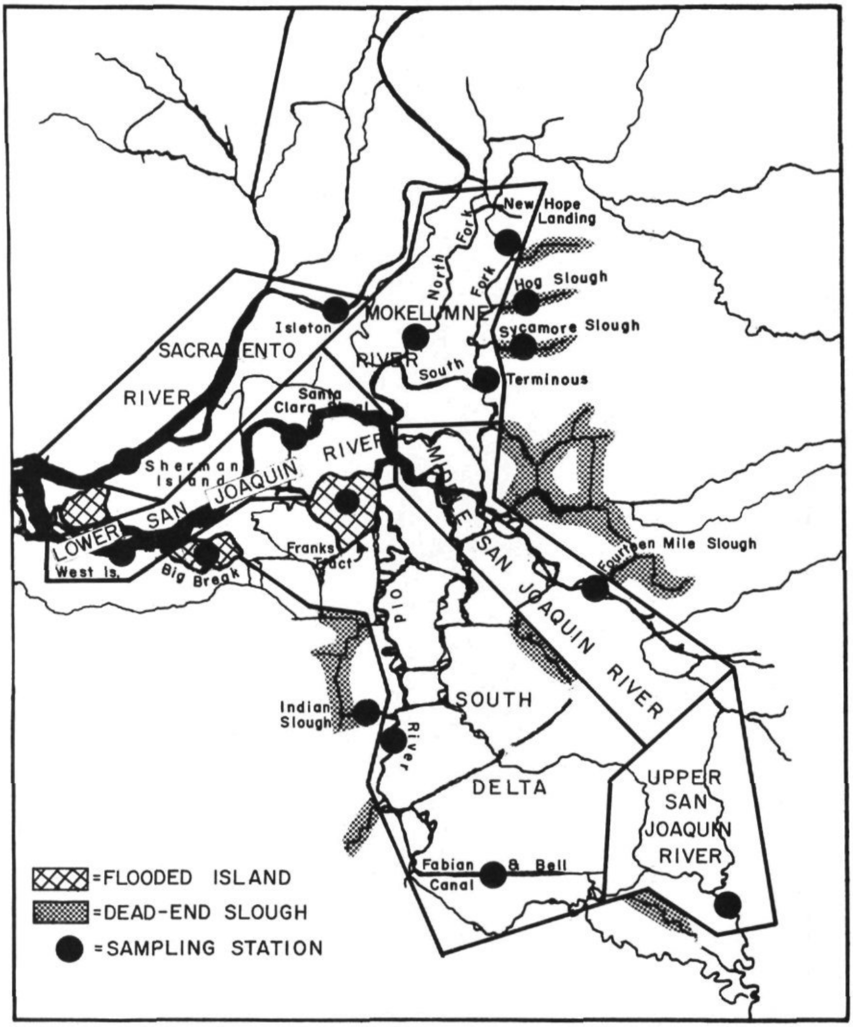

FIGURE 7. Location of sampling stations and areas of similar environments in the Sacramento-San Joaquin Delta.

During the winter, the population of young striped bass in the Delta was reduced to about one-ninth of what it was in the fall. Evidence has already been presented that leads me to believe most of these young striped bass migrated downstream into the bay portion of this estuary.

The population of young striped bass in the Delta remained low until the following summer when it about doubled. This increase was almost entirely due to a build-up in the concentration of young bass in the middle San Joaquin River zone (V) and to a lesser extent in the flooded island zone (III). The increase in population in the middle San Joaquin River may have been a result of some young bass over-wintering above the Delta in the San Joaquin River and migrating

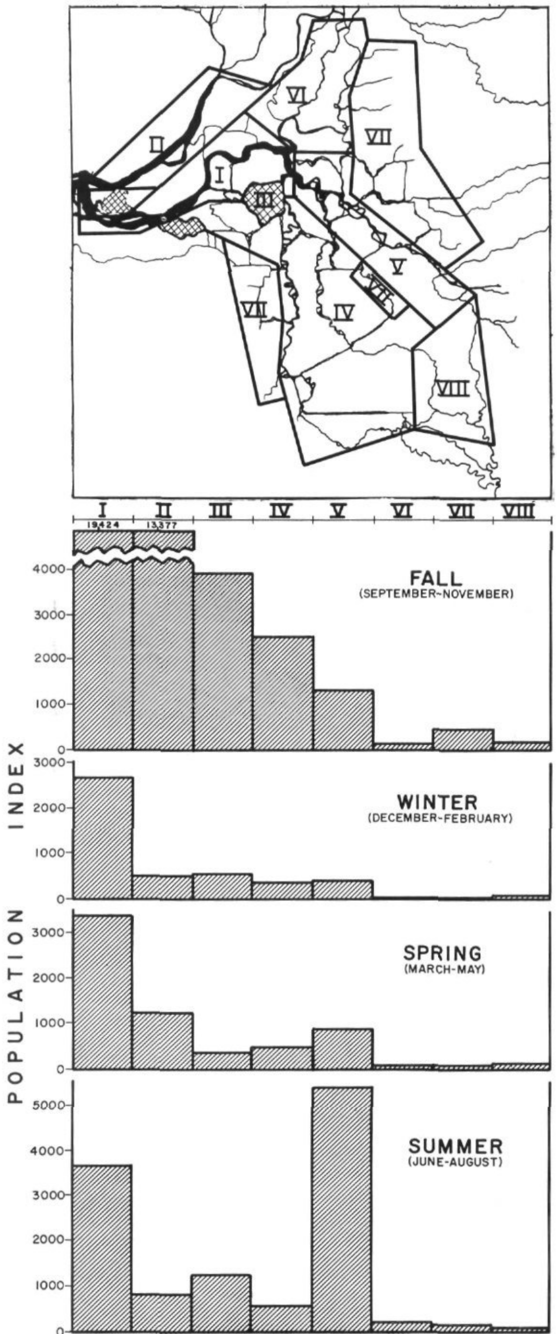

FIGURE 8. Population indices of 1963 year-class striped bass, 1963–1964.

TABLE 3

Relative Abundance of Young Striped Bass in the Environmental Zones of the Delta During 1963–1964

Environmental zones	Percent of Delta Area	Fall			Winter			Spring			Summer		
		Mean weighted catch	Pop. index	Percent of pop. in zone	Mean weighted catch	Pop. index	Percent of pop. in zone	Mean weighted catch	Pop. index	Percent of pop. in zone	Mean weighted catch	Pop. index	Percent of pop. in zone
I Lower San Joaquin River—Deep	18.9	871.1	16,464	46.9	117.7	2,224	58.2	125.8	2,378	51.8	184.9	3,495	30.6
I Lower San Joaquin River—Shoals	5.7	519.0	2,960		89.9	512		182.0	1,038		36.9	210	
V Middle San Joaquin River	12.4	104.6	1,297	3.1	32.0	397	8.4	73.3	909	13.8	435.6	5,401	44.7
VIII Upper San Joaquin River	2.1	124.7	262	0.6	36.7	77	1.6	40.1	84	1.3	55.0	116	1.0
II Sacramento River	15.3	874.3	13,377	32.3	33.7	515	11.0	83.8	1,282	19.4	46.1	705	5.8
VI Mokelumne River	5.4	24.9	134	0.3	3.5	19	0.4	8.7	47	0.7	37.5	202	1.7
IV South Delta	15.7	164.7	2,586	6.2	24.5	385	8.2	29.8	468	7.1	37.7	592	4.9
III Flooded Islands	17.6	223.0	3,925	9.5	30.5	537	11.4	20.0	352	5.3	67.3	1,184	9.8
VII Dead-end Sloughs	6.9	63.5	438	1.1	5.4	37	0.8	5.8	40	0.6	26.4	182	1.5
Quarterly population indices			41,443			4,703			6,598			12,087	

down to the Delta during their second summer (see p. 50 and Stevens, p. 93).

Population indices were also calculated for the 1964 year-class striped bass in the Delta (Table 4) during the summer of 1964. Eighty-seven percent of these bass were in the middle San Joaquin River, the lower San Joaquin River, the flooded islands, and the Sacramento River environmental zones (Figure 9).

TABLE 4

Relative Abundance of 1964 Year-Class Striped Bass in the Environmental Zones of the Delta During Summer 1964

Environmental Zones	Percent of Delta Area	Mean Weighted Catch	Pop. Index	Percent of Pop. in Zone
I Lower San Joaquin River—Deep	18.9	245.6	4,642	35.6
I Lower San Joaquin River—Shoals	5.7	58.9	336	
V Middle San Joaquin River	12.4	134.7	1,670	11.9
VIII Upper San Joaquin River	2.1	67.2	141	1.0
II Sacramento River	15.3	123.5	2,598	18.6
VI Mokelumne River	5.4	39.5	213	1.5
IV South Delta	15.7	70.7	1,110	7.9
III Flooded Islands	17.6	168.4	2,964	21.2
VII Dead-end Sloughs	6.9	46.0	317	2.3

EFFECT OF ENVIRONMENT ON CONDITION AND GROWTH OF YOUNG STRIPED BASS

To determine whether environment might have some effect on condition of young striped bass, the coefficient of condition (K_{fl}) was calculated for 113 young striped bass collected over a 6-day period with the otter trawl from the three zones in the San Joaquin River during August 1964.

The young bass were selected from a small size range (16.6 cm to 19.1 cm) to minimize the effects of fish length on condition. The bass from the lower San Joaquin River were in better condition than those from the middle San Joaquin at Fourteen Mile Slough and the upper San Joaquin River at Mossdale (Table 5). Differences in the mean coefficients of condition were significant at the one percent level.

TABLE 5

Comparison of Mean Coefficients of Condition of 1963 Year-Class Striped Bass Caught in August 1964 from Three Environmental Zones of the San Joaquin River

Environmental zones and mean coefficients of conditions	t Value	Degrees of freedom	Level of significance
Lower River vs. Middle River 1.19 1.12	4.79	81	0.01
Lower River vs. Upper River 1.19 1.13	3.75	80	0.01

Mean fork lengths were also calculated for 532 young striped bass similarly collected from the same three zones. The mean fork length of young bass from the lower San Joaquin River was 20.2 cm and that of bass collected from middle and upper San Joaquin River was

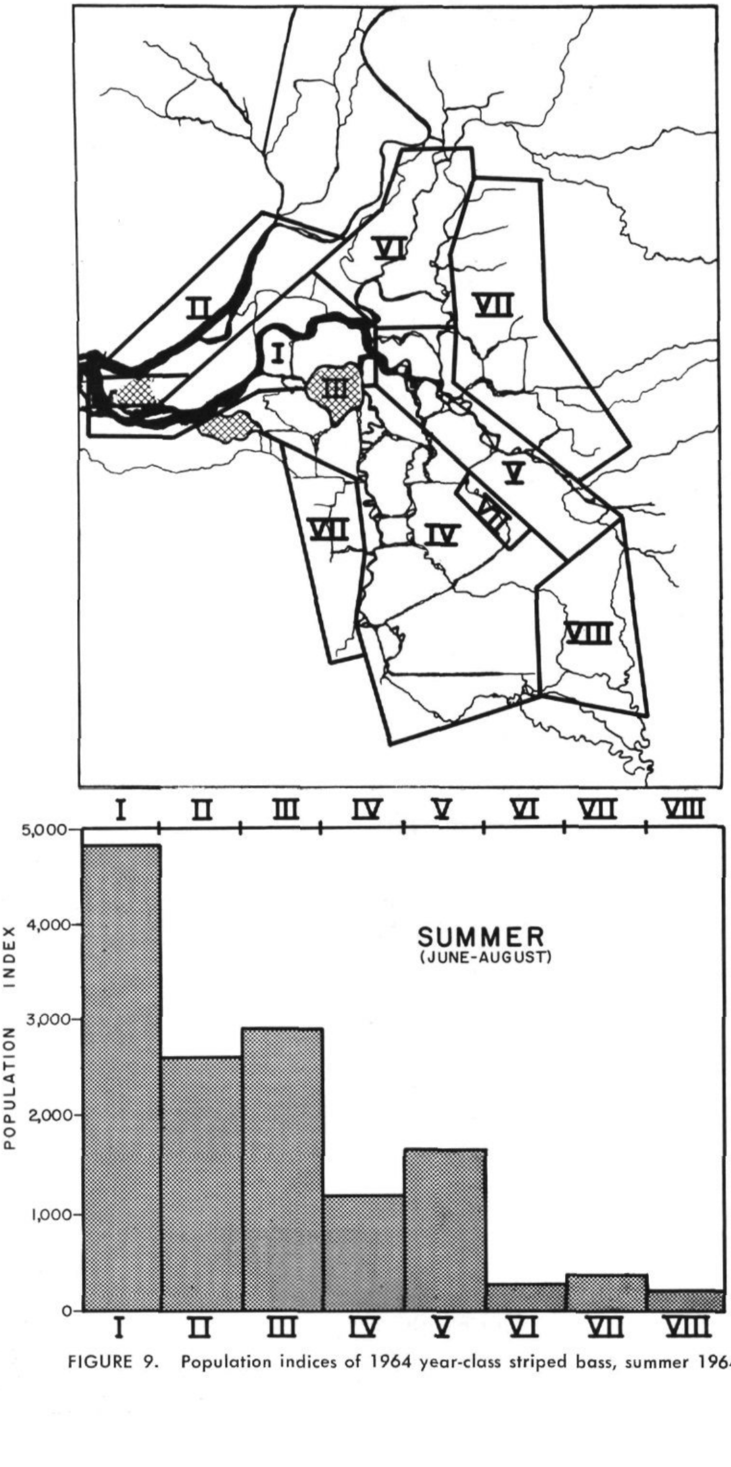

FIGURE 9. Population indices of 1964 year-class striped bass, summer 1964.

16.9 cm. The differences were statistically significant at the one percent level (Table 6). Also, throughout most of the year young bass from the upper and middle San Joaquin River were consistently shorter than those from the lower San Joaquin River.

TABLE 6

Comparison of Mean Fork Lengths of 1963 Year-Class Striped Bass Caught in August 1964 From Three Environmental Zones of the San Joaquin River and From Suisun Bay

Environmental zones and mean fork lengths	t Value	Degrees of freedom	Level of significance
Suisun Bay vs. Lower River 20.6 20.2	0.8	345	Not significant
Lower River vs. Middle River 20.2 16.9	10.38	409	0.01
Lower River vs. Upper River 20.2 16.9	9.27	386	0.01
Suisun Bay vs. Middle River 20.6 16.9	8.73	142	0.01
Suisun Bay vs. Upper River 20.6 16.9	8.28	119	0.01

The mean fork length of young striped bass collected by Ganssle (1966) in Suisun Bay during August 1964 was 20.6 cm. This length was not significantly greater than the mean length of those bass I collected from the lower San Joaquin River at the same time, but it was significantly greater than the mean length of bass collected from the middle and upper San Joaquin River.

Stevens (see p. 92) has related these differences in condition and mean length to food supply.

SUMMARY AND DISCUSSION

Young striped bass were abundant in the Delta when we started sampling in September 1963. The data suggest that in October and November, large numbers of these bass migrated downstream from the Delta. A small part of the population remained in the Delta throughout the year.

It is not known why these young bass migrated seaward. Mansueti (1954) suggested that endocrine changes may force the young striped bass to seek water with a higher salt content.

Young striped bass were most concentrated over the shoal areas in the lower San Joaquin River. They may prefer shoal areas because of the lower water velocities there. Kerr (1953) observed that fish (striped bass included) invariably sensed and sought lower uniform current velocities.

A large percentage of those young bass in the Delta were usually in the western portion (lower and middle San Joaquin River, Sacramento River, and flooded islands). Under existing environmental conditions this region is the most important nursery for young bass in the Delta.

Young bass of the 1963 and 1964 year-classes were never abundant in either fork of the Mokelumne River, the south Delta, the upper San Joaquin River, or the dead-end sloughs. Farley (see p. 32) collected few eggs or larvae in the south Delta and in Sycamore Slough, a dead-end slough. He believed that in these areas the flows, or water quality, or both, were not conducive for spawning by adult bass. He found that a number of adults spawned in the upper San Joaquin River in 1963. Most of the young bass produced in this area were probably swept downstream to the more "quiet" western Delta before they were large enough to control their distribution. Farley also collected a number of eggs and larvae in the Mokelumne River which were probably washed to the western Delta. These areas did not attract young bass after they were able to control their distribution probably because concentrations of their primary food *Neomysis awatschensis* (see Stevens, p. 72) were low there (Turner and Heubach, 1966).

Although the Mokelumne River and upper San Joaquin River are not important nursery areas, their importance as migration routes for young bass should not be overlooked.

During August 1964, young bass were longer and in better condition in the lower San Joaquin River than they were in the middle and upper San Joaquin River. Stevens (see p. 92) has related this to differences in the intensity of feeding by bass from the same zones.

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DISTRIBUTION OF JUVENILE STRIPED BASS, *ROCCUS SAXATILIS*, IN THE SACRAMENTO-SAN JOAQUIN DELTA

SHOKEN SASAKI

Juvenile striped bass (1962 year-class) were collected from the Sacramento-San Joaquin Delta with an otter trawl, a midwater trawl, and gill nets from September 1963 to August 1964. They were found in relatively high concentrations in many areas of the Delta during the fall. There was also evidence that they were migrating from the Delta to the bays below the Delta during this same season. The population of juvenile bass in the Delta was relatively low through the winter, but it appeared to increase in late spring and summer.

Usually these bass were most concentrated in the shoal areas in the western Delta. Many of the males were sexually mature in the spring while all of the females were immature.

The lower San Joaquin River appeared to be the most important nursery area in the Delta for juvenile striped bass.

METHODS

The term "juvenile" striped bass is applied throughout this paper to the 1962 year-class. Striped bass of this year-class were identified by length frequency analysis (Figure 1). These bass grew from a range

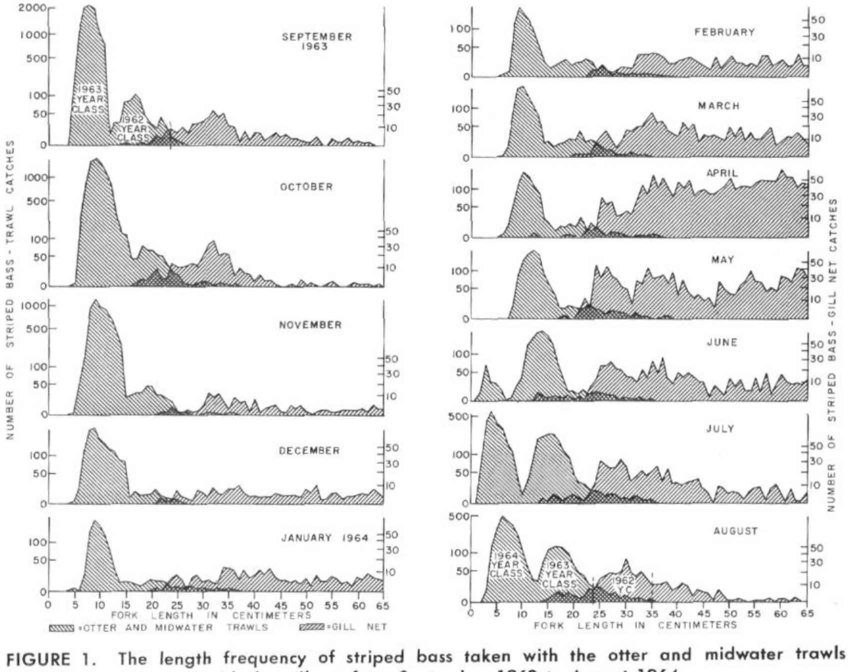

FIGURE 1. The length frequency of striped bass taken with the otter and midwater trawls and with the gill net from September 1963 to August 1964.

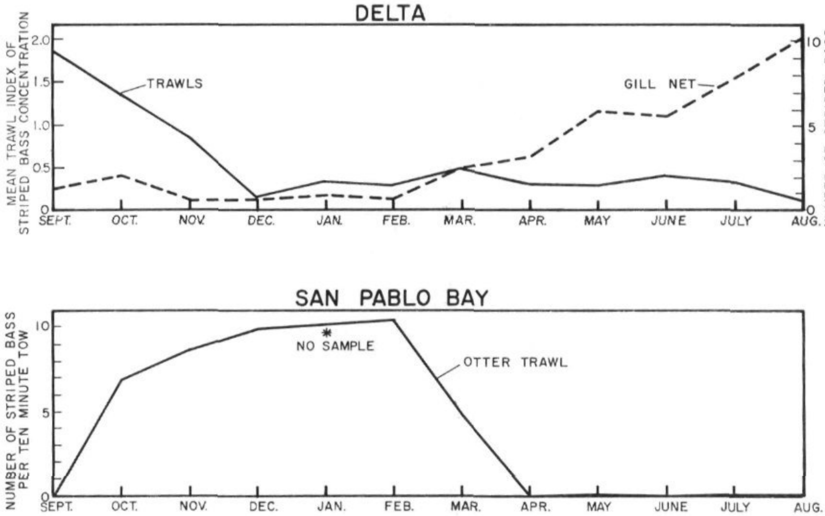

FIGURE 2. Comparison of the mean index of concentration (see Sasaki, p. 44) in the Delta, the mean gill net catch in the Delta and the mean otter trawl catch in San Pablo Bay (Ganssle, 1966) of the 1962 year-class striped bass, September 1963 to August 1964.

of 13 to 25 cm (FL) in September 1963 to a range of 24 to 35 cm in August 1964.

In the fall of 1963 large numbers of juvenile striped bass were captured in the trawls but few were caught in the gill nets because the mesh was too large. As the juveniles grew larger, they became less vulnerable to the trawls and more vulnerable to the gill net (Figure 2). A switch was made from the trawl data to the gill net data for analysis of their distribution after February 1964.

The otter trawl and midwater trawl catch data was combined for the purpose of analysis in the manner and for the reasons described for the young striped bass (see Sasaki, p. 44).

The population index, a figure representing the relative abundance of fish, was used to compare the numbers of juveniles in the various environmental zones of the Delta. These environmental zones and the method used to compute the population index figures have been explained in the paper on young striped bass (see Sasaki, p. 50).

DISTRIBUTION OF JUVENILE STRIPED BASS

In September 1963 the catches of juvenile striped bass in the trawls were high (Figure 2). These catches were highest in the middle and lower San Joaquin River areas (Figure 3). The catches in the Delta steadily decreased in the fall while Ganssle (1966) reported that trawl catches of juveniles in San Pablo Bay increased during this same period (Figure 2). This suggests that a downstream movement of juvenile bass from the Delta occurred at this time. The concentration of juveniles remained low in the Delta through the winter but they were still high in San Pablo Bay (Figure 2). Concentration in the Delta was highest in the lower San Joaquin River area (Figure 3).

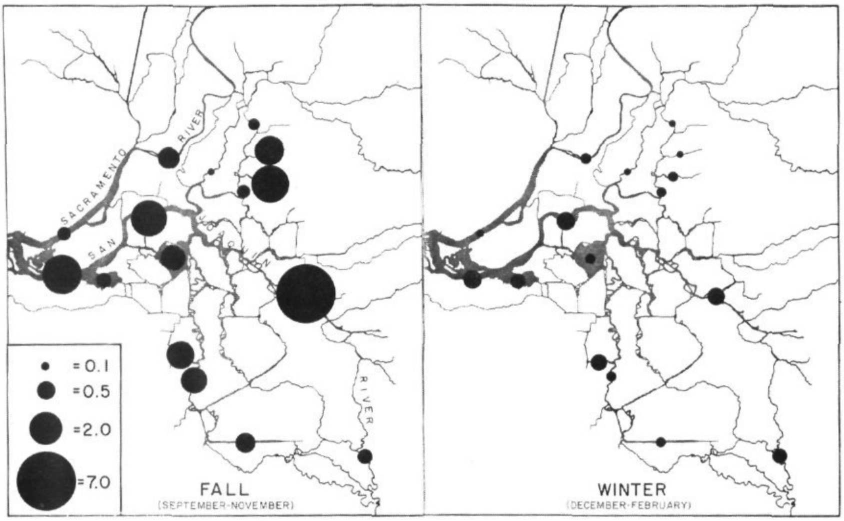

FIGURE 3. Distribution of 1962 year-class striped bass, September 1963–February 1964. The area of each circle represents the index of concentration (see Sasaki, p. 44).

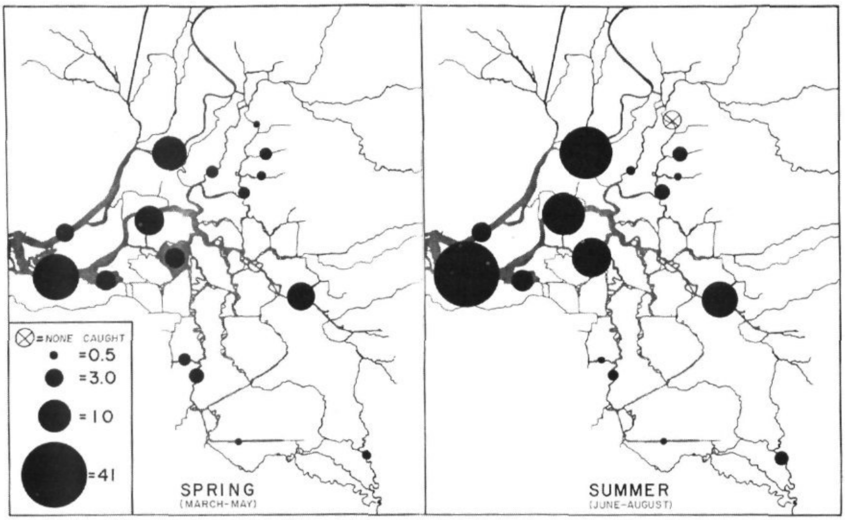

FIGURE 4. Distribution of 1962 year-class striped bass, March 1964–August 1964. The area of each circle represents the average gill net catch.

What happened to the juveniles in the Delta from winter to spring cannot be determined because the trawl catch data were used for analysis in winter, and gill net catch data were used for analysis in spring.

The numbers of juvenile striped bass caught in the gill nets increased in the late spring and summer especially in the western Delta (Figure 4). This increase could be a direct result of an increasing number of juveniles growing large enough to be caught, an increase in their ac-

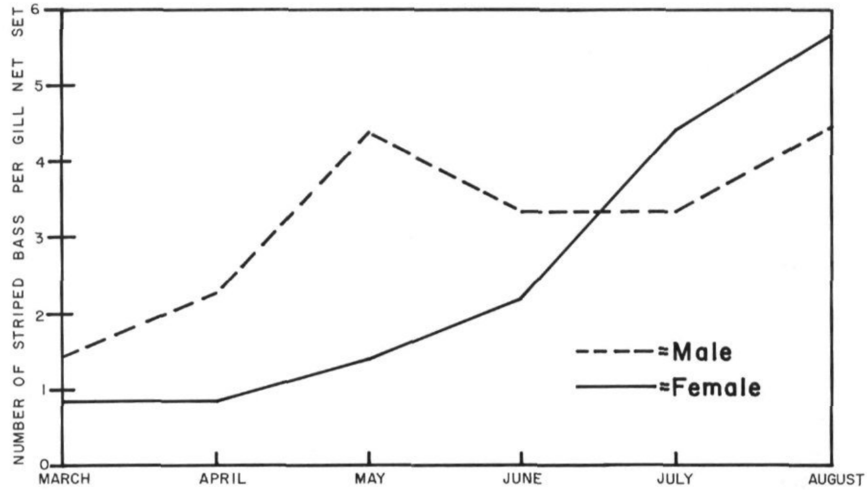

FIGURE 5. Comparison of the average catch of male and female 1962 year-class striped *bass from March to August 1964.*

tivity due to the warming water, or an increase in their population in the Delta.

Undoubtedly some increase in the gill net catches resulted from an increase in the size or activity of the juvenile bass but I also believe that some bass moved into the Delta. I base this belief on the changing ratio of male to female juvenile bass in the catch (Figure 5). If the increase in catch from spring to summer was only caused by the bass increasing in size and becoming more active, then the ratio of males to females should have remained the same assuming that both sexes grew and increased their activity at about the same rate. Robinson (1960) found that male and female striped bass grow at the same rate for the first 3 years of life. Since the ratio changed as the catch increased, some of this increase must have been caused by an increase in the numbers of juveniles in the Delta.

Like the young striped bass, the juveniles in the western Delta were usually more concentrated over the shoals than in deep areas (Figure 6).

Most of the juvenile striped bass in the Delta during the spring were males (Figure 5). The number of females in the Delta increased with the approach of summer and by July there were more females than males.

SEXUAL MATURITY

The testes of many of the juvenile males were ripe in the spring, but all of the females examined had immature ovaries (Table 1). Other biologists have also found that males mature younger than females. On the Atlantic Coast, Merriman (1941) found that most male striped bass matured at 2 years and all had matured at 3. He also examined hundreds of females from 1 to 3 years old in the spring and all had immature ovaries. Morgan and Gerlach (1950) found that in Coos Bay, Oregon, some male striped bass as young as 1 year were mature. They did not find any mature 1- or 2-year-old females.

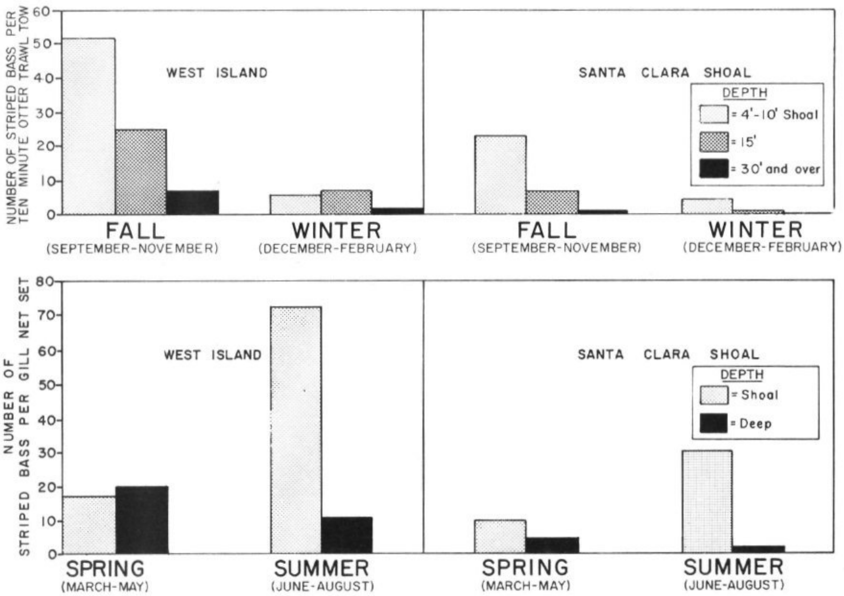

FIGURE 6. Average catch by season of the 1962 year-class striped bass taken at various depths at West Island and Santa Clara Shoal on the San Joaquin River during 1963–1964.

TABLE 1

Percentage of Sexually Mature Striped Bass of the 1962 Year-Class Observed in 1964

Month	Number of males examined	Number of males with ripe testes	Percent of ripe males	Number of females examined	Number of females with ripe ovaries
March	29	0	0	15	0
April	49	18	36.7	18	0
May	67	51	74.6	23	0
June	53	15	28.3	33	0
July	48	1	2.1	62	0
August	69	0	0	86	0

GEOGRAPHICAL DIFFERENCES IN TOTAL POPULATION

Population indices (see Sasaki, p. 50) were computed for each environmental zone of the Delta in order to compare the numbers of juvenile striped bass in these different zones (Figure 7).

These indices were also used to compare the number of juveniles in the Delta from fall to winter and from spring to summer. Fall and winter indices were not compared with spring and summer indices because they were based on samples collected with different types of nets.

In the fall, 56 percent of the juvenile striped bass in the Delta were in the middle San Joaquin River, and 25 percent were in the lower San Joaquin River (Table 2). In the winter the number of juveniles in the Delta was about one seventh of what it was in the fall. The evidence already presented leads me to believe that most of these juveniles

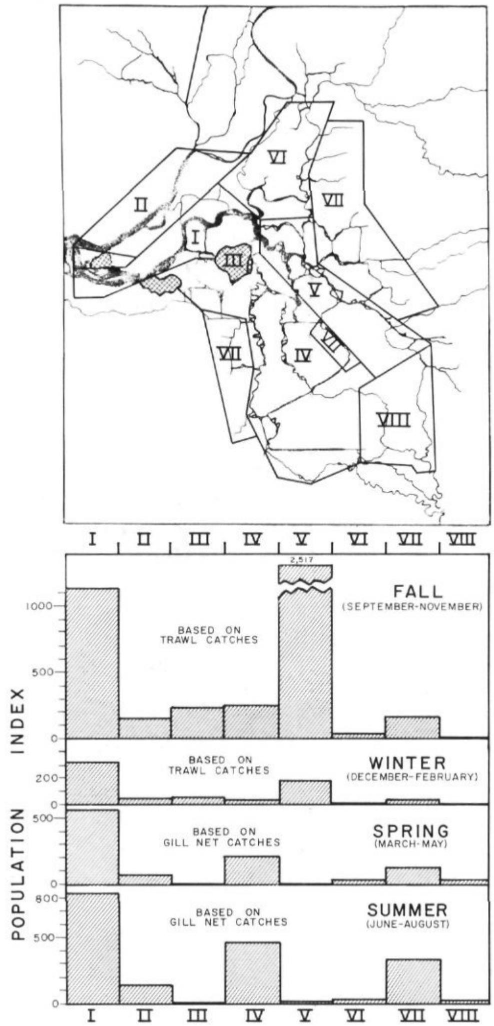

FIGURE 7. Population indices of 1962 year-class striped bass, 1963–1964.

migrated from the Delta to the San Pablo Bay area. Forty-eight percent of those bass left in the Delta during the winter were in the lower San Joaquin River.

In the spring, about 85 percent of the juveniles in the Delta were in the western portion (lower San Joaquin River, Sacramento River, flooded islands). The number of juveniles in the Delta almost doubled from spring to summer. As in the spring, most of these juveniles were in the western Delta.

The lower San Joaquin River is considered to be the most important nursery area in the Delta for juvenile striped bass because the lower San Joaquin River generally had the highest numbers of bass through-

TABLE 2

Relative Abundance of Juvenile Striped Bass in the Environmental Zones of the Delta During 1963–1964

Environmental zones	Percent of Delta Area	Indices based on trawl catches						Indices based on gill net catches					
		Fall			Winter			Spring			Summer		
		Mean weighted catch	Pop. index	Percent of pop. in zone	Mean weighted catch	Pop. index	Percent of pop. in zone	Mean catch	Pop. index	Percent of pop. in zone	Mean catch	Pop. index	Percent of pop. in zone
I Lower San Joaquin River—Deep	18.9	46.9	886	25.4	15.1	285	47.8	25.0	472	54.6	13.0	246	45.8
I Lower San Joaquin River—Shoals	5.7	44.2	252		4.6	26		17.0	97		103.3	589	
V Middle San Joaquin River	12.4	203.0	2,517	56.2	14.7	182	28.0	6.8	84	8.1	11.2	139	7.6
VIII Upper San Joaquin River	2.1	1.2	2	0.1	1.5	3	0.5	0.7	2	0.6	1.7	4	0.2
II Sacramento River	15.3	9.2	141	3.1	2.9	44	6.8	13.5	206	19.8	30.3	464	25.4
VI Mokelumne River	5.4	2.6	14	0.3	0.9	5	0.8	2.8	15	1.4	2.5	14	0.8
IV South Delta	15.7	16.3	256	5.7	2.5	39	6.0	1.8	28	2.7	1.3	20	1.1
III Flooded Islands	17.6	12.6	222	5.0	2.6	46	7.0	6.3	111	10.6	18.8	331	18.2
VII Dead-end Sloughs	6.9	27.4	189	4.2	2.9	20	3.1	3.3	23	2.2	2.5	17	0.9
Quarterly population indices			4,479			650			1,038			1,824	

out most of the year. Juvenile bass were never abundant in the Mokelumne River, upper San Joaquin River, south Delta, or dead-end sloughs so these environmental zones may not be important to them as nursery areas now.

SUMMARY AND DISCUSSION

The collections of juvenile striped bass lead me to believe there was a migration of juvenile striped bass from the Delta to San Pablo Bay area during the fall. Sexually maturing male juveniles moved into the Delta during the spring. They were followed by immature females in the summer. Usually the juveniles in the lower San Joaquin River were most concentrated over the shoal areas. This region also was the most important nursery in the Delta for juvenile bass.

Why the juvenile striped bass moved out of the Delta in the fall is not known. Perhaps the juveniles were seeking warmer water, or were following their food supply, or both. In the winter, water in the lower bays (San Pablo Bay) and the ocean was warmer than water in the Delta, and the center of abundance of *Neomysis awatschensis,* their primary food source, (see Stevens, p. 73) shifted toward the bay (Turner and Heubach, 1966).

In the spring, sexually mature juvenile males migrate into the Delta to spawn. The juvenile females are not sexually mature. They migrated into the Delta in late spring and summer, perhaps in response to a warming of the water in the Delta, to the upstream movement of *N. awatschensis* (Turner and Heubach, 1966), or to other stimuli that have not yet been defined.

The observations of juvenile striped bass migrations do not agree with published reports from other areas. Vladykov and Wallace (1938) tagged striped bass in Chesapeake Bay; they concluded that striped bass under 2 years of age were not migratory. Massmann and Pacheco (1961) working in the Chesapeake Bay region stated that almost all striped bass shorter than 12 inches in length remained in the river system in which they were tagged. Mansueti (1961) thought that bass hatched in the Potomac River remain there during the first 3 or 4 years of their life. He also believed that the exchange between bay and river populations of Maryland striped bass was not very great. Merriman (1941) found little evidence that striped bass younger than 2 years undertook migrations along the Atlantic Coast.

Clark (1936) tagged more than 1,500 striped bass in the Sacramento-San Joaquin Delta. Most of these bass were juveniles (shorter than 13 inches). The tag returns revealed that the bass simply diffused away from the tagging site; no distinct migration patterns were evident.

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FOOD HABITS OF STRIPED BASS, *ROCCUS SAXATILIS*, IN THE SACRAMENTO-SAN JOAQUIN DELTA

DONALD E. STEVENS

This paper describes the food habits of striped bass older than three months, in the Delta of the Sacramento and San Joaquin rivers. Most of the older descriptions (Smith, 1896; Scofield, 1910; Scofield and Coleman, 1910; Scofield and Bryant, 1926; Scofield, 1928, 1931; Shapovalov, 1936; Hatton, 1940; Johnson and Calhoun, 1952) of striped bass food habits in the Sacramento-San Joaquin estuary are merely qualitative or fragmentary. More recently, Heubach, Toth, and McCready (1963) examined a large number of stomachs of bass younger than 6 months from the Delta, but they examined few stomachs of older bass. Ganssle (1966) has described striped bass food habits in the estuary between the Delta and the lower end of San Pablo Bay, and Thomas (1967) has studied the diet of striped bass from the Sacramento and San Joaquin rivers above the Delta down to San Francisco Bay. To avoid duplication of my work, Thomas did not attempt Delta-wide coverage.

This paper is based on an analysis of stomach contents of 8,628 striped bass from eight types of Delta environments. The stomachs were collected from September 1963 through August 1964. The mysid shrimp, *Neomysis awatschensis*, and the amphipods, *Corophium stimpsoni* and *Corophium spinicorne*, were the most important foods of young bass. As bass grew their diet shifted to forage fishes, primarily small striped bass and the threadfin shad, *Dorosoma petenense*. The composition of the diet varied by season and area.

There is some evidence that *N. awatschensis* was a preferred food of young bass. Stomach contents differed for bass collected by different sampling gear. The amount of food in stomachs of year-old bass decreased significantly from the lower to the middle to the upper San Joaquin River. Differences in the length and coefficient of condition of bass from these same zones may be a direct result of the differences in food intake.

METHODS

Collecting methods are described by Turner (see p. 12). Stomachs were examined on the boat as the fish were removed from the nets. Most food organisms were counted and measured at this time. Only those food organisms that could not be identified on the boat were taken to the laboratory for analysis.

The data were analyzed by percent frequency of occurrence in the stomachs and percent of diet by volume. Volumes of the food organisms were not measured directly. For the most common foods, mean volumes were determined and they were multiplied by the number of organisms eaten (Table 1). These means were determined from the volume of water displaced by a known number of each food organism freshly collected from the Delta. Volumes of foods eaten infrequently were visually estimated.

Variations in the digestion rates of food organisms were not compensated for in the analysis. In their study of young-of-the-year striped bass food habits, Heubach, *et al.* (1963) found under controlled conditions that *Neomysis mercedis* (now *N. awatschensis*) was recognizable 6 hours after ingestion whereas *Corophium spinicorne* could be identified after 8 hours. Large organisms, such as forage fishes, are probably recognizable longer after consumption than most small invertebrates, so the value of invertebrates as compared with forage fishes may be underestimated in the analysis by frequency of occurrence. This error was probably reduced in the volume analysis, since when making that analysis, each food item was considered to be at pre-ingestion size.

TABLE 1

Mean Volume Displacement (cc) of Food Organisms of Striped Bass

Food Organisms										
Invertebrates										
Cladocerans and Copepods	0.0005									
Amphipods, *Corophium stimpsoni and Corophium spinicorne*	0.0034									
Tendipedids	0.0030									
Mysid Shrimp, *Neomysis awatschensis* (Length mm)	1–5	6–8	9–11	11–14	15–20					
	0.0010	0.0028	0.0079	0.0152	0.0332					
Fishes (Length cm)	2	3	4	5	6	7	8	9	10	11
Threadfin shad, *Dorosoma petenense*	—	0.25	0.8	1.5	2.8	4.4	7.2	10.5	14.0	19.0
American shad, *Alosa sapidissima*	—	0.25	0.5	1.1	2.4	3.6	5.1	7.3	9.9	13.7
Pond smelt, *Hypomesus transpacificus*	0.1	0.25	0.4	0.8	1.4	2.4	4.0	—	—	—
Striped bass, *Roccus saxatilis*	0.3	0.5	0.9	1.4	2.3	3.7	6.0	9.1	12.4	—

To be considered important, a food must be eaten by a significantly large proportion of the bass in significantly large amounts. No objective limits to what is and what is not "significantly large" were set, so my classification of a food as important is a matter of my own judgment after reviewing its frequency of occurrence in bass stomachs and the volume with which it was found.

In this paper, the diet of bass of different sizes during each season of the year is described first. Then local variations in diet that are essential to an understanding of the ecology of the Delta are described. After these seasonal and geographic differences in food habits are documented, this information is reviewed and conclusions are drawn about the individual important foods of striped bass. These sections are followed by sections on food selectivity, differences in stomach contents of bass caught by different sampling gear, and the growth of bass as related to their food intake.

GENERAL DELTA-WIDE FOOD HABITS

To obtain Delta-wide coverage of the food habits of each of four age-groups of bass, an attempt was made to examine 20 stomachs from bass of each age-group collected with each of three types of net at each station each month. Most of the time, that many bass of each age-group were not caught with each type of net at each station, so the sample was somewhat smaller. Yet, the sample was still stratified, so to portray the diet with reasonable accuracy, the result from each stratum was weighted by the proportion of the total Delta bass population that it represented.

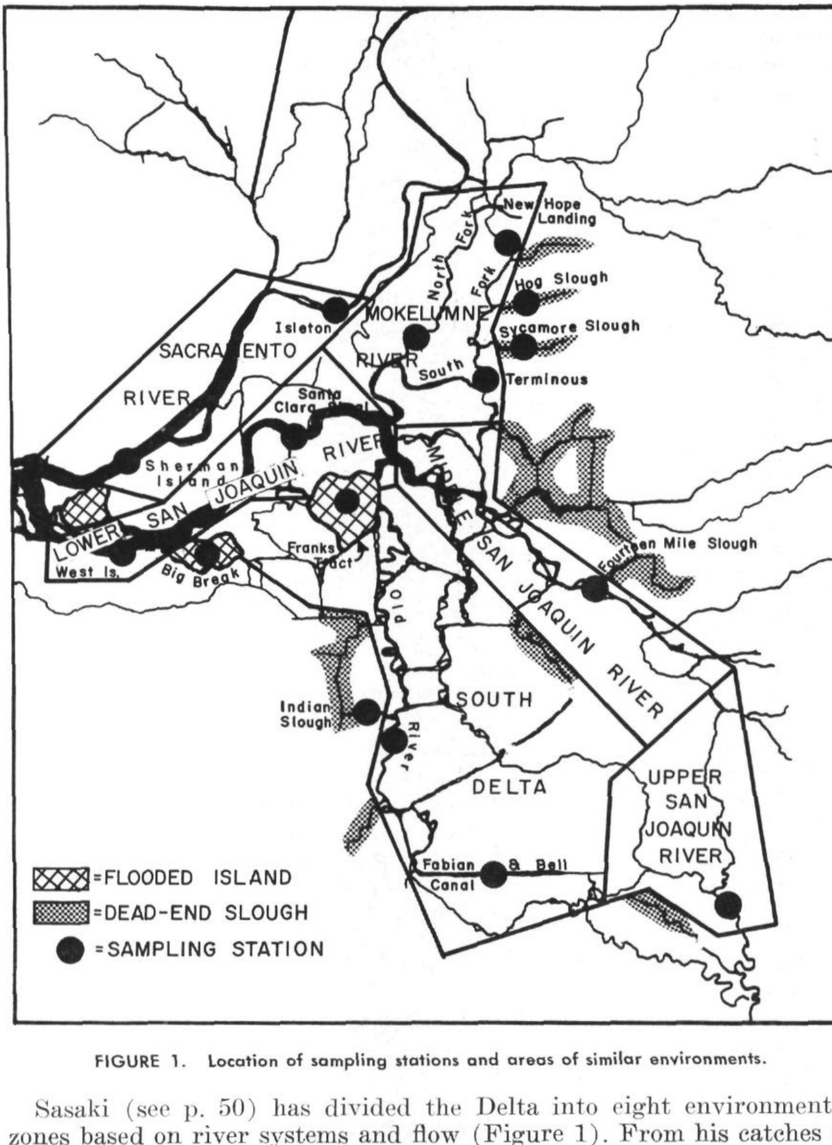

FIGURE 1. Location of sampling stations and areas of similar environments.

Sasaki (see p. 50) has divided the Delta into eight environmental zones based on river systems and flow (Figure 1). From his catches of young bass and the area of each of these zones, he has estimated the percentage of the total population of young bass in the Delta in each zone during each season (see p. 54). He has done the same for juvenile bass (see p. 65), and Radtke has done it for subadult and adult bass (see pp. 22 and 21). My analysis of the Delta-wide food habits of each age-group of striped bass is based on food habit data from each of these zones weighted by the percent of the total population found there.

The percentage of the population of bass in the Delta utilizing a food item was estimated by multiplying the percentage of the total Delta population of bass in each zone by the percent occurrence of the food item in the stomachs of bass in the appropriate zones and summing the products of these calculations (Table 2).

TABLE 2

Method of Estimating Percentage of Bass Population Utilizing a Food Organism

Environmental Zone	Percentage of Population		Percent Frequency of Occurrence of Food Item in Stomach		
Lower San Joaquin River	42.7	×	96.3	=	41.1
Middle San Joaquin River	3.0	×	50.0	=	1.5
Upper San Joaquin River	1.0	×	0.0	=	0.0
Sacramento River	31.8	×	88.2	=	28.0
Mokelumne River	0.5	×	8.3	=	0.0
South Delta	6.2	×	42.9	=	2.7
Flooded Islands	13.1	×	66.7	=	8.7
Dead-end Sloughs	1.7	×	75.0	=	1.2
	Percentage of Population Utilizing Food Item			=	83.2

The percentage of the total diet volume formed by a food item was estimated in a similar manner. First the percentage of the total Delta population of bass in each zone was multiplied by the mean volume of that food item in the stomachs of bass from the appropriate zone, and the products were summed to obtain a total weighted mean volume

TABLE 3

Method of Estimating the Total Weighted Mean Volume of a Food Item

Environmental Zone	Percentage of Population		Mean Volume (cc) of Food Item A in Stomachs		Weighted Mean Volumes of Food A
Lower San Joaquin River	42.7	×	0.0317	=	0.135
Middle San Joaquin River	3.0	×	0.0171	=	0.005
Upper San Joaquin River	1.0	×	0.0000	=	0.000
Sacramento River	31.8	×	0.0444	=	0.141
Mokelumne River	0.5	×	0.0042	=	0.000
South Delta	6.2	×	0.0067	=	0.004
Flooded Islands	13.1	×	0.0198	=	0.026
Dead-end Sloughs	1.7	×	0.0701	=	0.012
	Total of Weighted Mean Volumes of Food A			=	0.323

(Table 3). Then, to obtain the percentage of total volume formed by that food item, the total weighted mean volume was divided by the sum of the total weighted mean volumes of all food items (Table 4).

The estimates resulting from these calculations are presented in Tables 5 through 8 for all food organisms.

TABLE 4

Method of Estimating the Percentage of Total Diet Volume Formed by a Food Item

Food Item	Total of Weighted Mean Volume of Food Items[1]				Percent of Total Volume
Food A	0.323	÷	.855	=	38
Food B	0.129				15
Food C	0.403				47
Sum	0.855				

[1] See Table 3 for method of estimating total of weighted mean volumes.

Diet of Young Bass

Young bass are defined by Sasaki (see p. 44) as the 1963 year-class. They were hatched about 3 months before this study started in the fall of 1963 and were a few months past 1-year old when the study terminated in the summer of 1964. During this period, they grew from a range of 5 to 12 cm in September 1963 to a range of 12 to 23 cm in August 1964.

N. awatschensis was their most important food (Table 5). This mysid was the only organism consumed in quantity by a large percentage of the young bass during every season.

Significant amounts of the amphipods, *C. stimpsoni* and *C. spinicorne,* were eaten by about a third to a half of the young bass. I judge *Corophium* to be the second most important food of young bass.

A very few of the young bass ate small threadfin shad as early as the fall of 1963 when threadfins were abundant (see Turner p. 160), and the bass themselves were only a few months old. During the winter and spring, the bass were larger, but small fish were not abundant and were rarely eaten. In the summer, the bass were even larger, and they fed occasionally on the new crops of threadfin shad and small striped bass.

During the winter, a few young bass fed extensively on pieces of sardine and anchovy bait discarded by anglers or stolen from their hooks.

In the fall, cladocerans and copepods were eaten by less than one percent of the young bass. In contrast, Heubach, *et al.* (1963) found that these plankton were eaten quite frequently by young bass during this season. The difference in my results could be due to differences in food availability from one year to another, but I believe the difference really reflects differences in food selection by bass of different sizes. The bass collected by Heubach, *et al.*, were all shorter than 11 cm (2.0-4.5 in). Because stomachs of bass shorter than 11 cm are too small to handle expediently in the field, most of the bass in my samples were longer than that length.

TABLE 5

Stomach Contents of Young Striped Bass in the Delta [1]

Food Items	Fall		Winter		Spring		Summer		Average	
	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol
Annelids										
Polychaete (*Neanthes limnicola*)	--	--	--	--	--	--	Tr	Tr	Tr	Tr
Unidentified Annelid	--	--	--	--	Tr	Tr	--	--	Tr	Tr
Crustaceans										
Cladocerans and/or Copepods	Tr	Tr	3	Tr	2	Tr	1	Tr	2	Tr
Mysid shrimp (*Neomysis awatschensis*)	85	36	84	44	86	81	65	30	80	48
Isopod (*Exosphaeroma oregonensis*)	--	--	Tr	1	--	--	--	--	Tr	Tr
Unidentified Isopod	--	--	--	--	--	--	Tr	Tr	Tr	Tr
Amphipods (*Corophium*)	39	13	30	5	37	7	56	7	40	8
Crayfish (*Pacifastacus leniusculus*)	--	--	--	--	Tr	Tr	Tr	Tr	Tr	Tr
Unidentifiable shrimp	--	--	--	--	Tr	2	Tr	Tr	Tr	1
Insects										
Tendipedids	2	Tr	2	Tr	2	Tr	8	Tr	4	Tr
Other insects	--	--	Tr	Tr	--	--	--	--	Tr	Tr
Molluscs										
Asiatic clam (*Corbicula fluminea*)	Tr	1	Tr	1	--	--	Tr	Tr	Tr	Tr
Fishes										
Threadfin shad (*Dorosoma petenense*)	1	45	--	--	--	--	6	41	2	22
American shad (*Alosa sapidissima*)	--	--	--	--	1	2	Tr	2	Tr	1
Unidentifiable Clupeids	--	--	--	--	--	--	Tr	Tr	Tr	Tr
Pond smelt (*Hypomesus transpacificus*)	--	--	--	--	--	--	Tr	Tr	Tr	Tr
White catfish (*Ictalurus catus*)	--	--	--	--	--	--	Tr	Tr	Tr	Tr
Striped bass (*Roccus saxatilis*)	--	--	--	--	--	--	7	19	2	5
Starry flounder (*Platichthys stellatus*)	--	--	--	--	Tr	Tr	--	--	Tr	Tr
Unidentifiable fishes	--	--	--	--	Tr	3	Tr	1	Tr	1
Fish eggs	--	--	--	--	Tr	Tr	--	--	Tr	Tr
Sardine and anchovy bait	1	6	3	49	Tr	4	Tr	Tr	1	15
Stomachs examined	320		946		1,303		1,274			
Percent containing food	85		73		84		81			

[1] Stomach content data for young bass in each of the eight environmental zones in the Delta were weighted by the percent of the total Delta population of young bass found there and summed (see text, p. 71).

Diet of Juvenile Bass

Juvenile bass are the 1962 year-class (see Sasaki, p. 59). They were slightly more than 1 year old at the start of the study and had passed the end of their second year at the end of the study. Their lengths varied from 13 to 25 cm in September 1963 to 24 to 35 cm in August 1964.

N. awatschensis was a very important food each season (Table 6). It was especially important in the winter and spring.

Juvenile bass often fed on fishes. In the fall, the distribution of the juveniles was such that a large percentage were in areas where threadfin shad were abundant; as a result threadfins were eaten by about one quarter of the population and by volume made up most of the diet. In the winter and spring, small fishes were scarce in the Delta and only a few were eaten. Large numbers of small striped bass of the new year-class became available in the summer (see Sasaki, p. 47); they were preyed upon by about one-quarter of the juveniles.

About one-quarter to one-third of the juveniles fed on some *Corophium* each season, but they consumed relatively small quantities, so *Corophium* were not really too important.

In the winter and spring, about 10 percent of the juveniles ate portions of sardine and anchovies which had been used for bait by anglers.

TABLE 6

Stomach Contents of Juvenile Bass in the Delta [1]

Food Items	Fall		Winter		Spring		Summer		Average	
	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol
Annelids										
Polychaete (*Neanthes limnicola*)	Tr	Tr	--	--	--	--	--	--	Tr	Tr
Crustaceans										
Cladocerans and/or Copepods	--	--	Tr	Tr	Tr	Tr	--	--	Tr	Tr
Mysid shrimp (*Neomysis awatschensis*)	39	2	84	11	79	29	64	11	66	13
Isopod (*Exosphaeroma oregonensis*)	--	--	--	--	Tr	Tr	--	--	Tr	Tr
Amphipods (*Corophium*)	22	Tr	27	Tr	31	Tr	31	2	28	1
Crayfish (*Pacifastacus leniusculus*)	Tr	Tr	--	--	Tr	1	Tr	Tr	Tr	Tr
Crab (*Rhithropanopeus harrisii*)	1	1	--	--	--	--	--	--	Tr	Tr
Unidentifiable shrimp	--	--	1	Tr	--	--	1	1	Tr	Tr
Insects										
Tendipedids	9	Tr	--	--	1	Tr	3	Tr	3	Tr
Other insects	--	--	1	Tr	--	--	--	--	Tr	Tr
Molluscs										
Asiatic clam (*Corbicula fluminea*)	Tr	Tr	--	--	--	--	Tr	Tr	Tr	Tr
Fishes										
Unidentified Ammocoete	--	--	--	--	Tr	Tr	Tr	Tr	Tr	Tr
Threadfin shad (*Dorosoma petenense*)	27	72	3	38	1	11	2	4	8	31
American shad (*Alosa sapidissima*)	2	3	--	--	--	--	1	4	1	2
King salmon (*Oncorhynchus tshawytscha*)	--	--	--	--	1	1	1	3	Tr	1
Pond smelt (*Hypomesus transpacificus*)	--	--	--	--	1	3	2	8	1	3
White catfish (*Ictalurus catus*)	--	--	--	--	--	--	Tr	Tr	Tr	Tr
Striped bass (*Roccus saxatilis*)	4	7	1	8	Tr	1	26	55	8	18
Unidentifiable fishes	15	14	1	7	5	29	6	11	7	15
Sardine and anchovy bait	2	1	13	36	9	24	Tr	Tr	6	15
Stomachs examined	655		365		544		473			
Percent containing food	69		71		70		61			

[1] Stomach content data for juvenile bass in each of the eight environmental zones in the Delta were weighted by the percent of the total Delta population of juvenile bass found there and summed (see text, p. 71).

Diet of Subadult Bass

Subadult bass are defined by Radtke (see p. 15) as the 1961 year-class. These bass were 2 years old several months before the start of the study; they were 3 years of age shortly before the study terminated. In September, subadults were 26 to 37 cm long; by August they were 36 to 47 cm long.

Subadults fed primarily on fishes (Table 7). In the fall, threadfin shad and small striped bass were abundant in the Delta and both were consumed by more than one-third of the subadult bass. In the winter, even though numbers of threadfin shad and small striped bass in the Delta decreased, they still made up most of the diet. The percentage of the subadults that ate small bass did decrease somewhat; however, the percentage of the subadults that fed on threadfins increased slightly. By spring, there were few threadfin shad and striped bass of a size suitable for food in the Delta. Correspondingly, the occurrence of these fishes in stomachs of subadults decreased appreciably. In the summer, when the new year-classes of striped bass and threadfin shad became available, they were preyed upon more frequently. Small bass were especially prevalent in the summer diet of the subadults.

A significant percentage of the subadults fed on *N. awatschensis* in the winter, spring, and summer, and on *Corophium* in the spring; but because the amounts that were consumed were relatively small, I consider these crustaceans to be of minor importance.

TABLE 7

Stomach Contents of Sub-Adult Bass in the Delta [1]

Food Items	Fall		Winter		Spring		Summer		Average	
	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol
Crustaceans										
Mysid shrimp (*Neomysis awatschensis*)	6	Tr	22	Tr	37	2	34	2	25	1
Amphipods (*Corophium*)	2	Tr	5	Tr	21	Tr	13	Tr	10	Tr
Crayfish (*Pacifastacus leniusculus*)	1	Tr	Tr	Tr	2	6	Tr	Tr	1	2
Unidentifiable shrimp	Tr	Tr	2	Tr	--	--	--	--	1	Tr
Insects										
Other insects	--	--	--	--	--	--	1	--	Tr	Tr
Fishes										
Unidentified Ammocoete	--	--	--	--	Tr	Tr	--	--	Tr	Tr
Threadfin shad (*Dorosoma petenense*)	36	67	39	68	5	13	12	25	23	43
American shad (*Alosa sapidissima*)	3	2	1	1	--	--	--	--	1	1
Pacific herring (*Clupea pallasi*)	--	--	--	--	1	Tr	--	--	Tr	Tr
Unidentifiable Clupeids	Tr	Tr	6	2	--	--	3	4	2	2
King salmon (*Oncorhynchus tshawytscha*)	Tr	1	--	--	4	10	--	--	1	3
Pond smelt (*Hypomesus transpacificus*)	1	Tr	1	1	2	4	--	--	1	1
Carp (*Cyprinus carpio*)	Tr	Tr	--	--	--	--	--	--	Tr	Tr
White catfish (*Ictalurus catus*)	Tr	Tr	--	--	--	--	--	--	Tr	Tr
Striped bass (*Roccus saxatilis*)	39	23	20	22	14	41	42	54	29	35
Unidentifiable Centrarchids	--	--	--	--	--	--	Tr	Tr	Tr	Tr
Unidentifiable fishes	21	4	6	3	15	20	12	15	14	10
Sardine and anchovy bait	4	1	9	3	7	5	--	--	5	2
Stomachs examined	455		234		312		241			
Percent containing food	47		58		29		36			

[1] Stomach content data for sub-adult bass in each of the eight environmental zones in the Delta were weighted by the percent of the total Delta population of sub-adult bass found there and summed (see text, p. 71).

Diet of Adult Bass

All bass older than 3 years in the fall of 1963 were classified as adult bass (see Radtke, p. 15). In the summer of 1964, at the end of the study, they were all older than 4 years. In September 1963, these bass were 38 cm or longer; in August 1964 they were 48 cm or longer.

The diet of adults was almost entirely fishes, especially small bass and threadfin shad (Table 8). In the fall, small bass were eaten by almost one-half of the adults and threadfin shad were eaten by about one-quarter of the adults. In the winter, the percentage of the adults that fed on small bass decreased somewhat, but the percentage of adults that preyed upon threadfin shad increased; so both of these fishes were eaten by about one-third of the adults.

In the spring, when few threadfin shad and small bass were in the Delta, they were each eaten by about one-quarter of the adult bass. The occurrence of threadfin shad in the stomachs of adults decreased to 6 percent and that of small bass increased to 50 percent in the summer; however, only 21 stomachs with food were examined so these percentages may not be very meaningful.

Sardine and anchovy bait occurred in about one-sixth of the stomachs during the fall, winter, and summer. Bait did not occur in any stomachs in the spring sample.

TABLE 8

Stomach Contents of Adult Bass in the Delta [1]

Food Items	Fall		Winter		Spring		Summer		Average	
	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol
Crustaceans										
Mysid shrimp (*Neomysis awatschensis*)	--	--	--	--	16	Tr	--	--	4	Tr
Amphipods (*Corophium*)	--	--	--	--	7	Tr	--	--	2	Tr
Crayfish (*Pacifastacus leniusculus*)	Tr	Tr	--	--	Tr	Tr	--	--	Tr	Tr
Crab (*Rhithropanopeus harrisii*)	--	--	1	Tr	--	--	--	--	Tr	Tr
Unidentifiable shrimp	--	--	1	Tr	--	--	10	1	3	Tr
Fishes										
Unidentified Ammocoete	--	--	Tr	Tr	1	Tr	--	--	Tr	Tr
Threadfin shad (*Dorosoma petenense*)	24	15	34	56	24	27	6	4	22	26
American shad (*Alosa sapidissima*)	8	12	4	6	--	--	--	--	3	4
Unidentifiable Clupeids	--	--	14	2	--	--	--	--	4	Tr
King salmon (*Oncorhynchus tshawytscha*)	--	--	--	--	6	3	5	1	3	1
Pond smelt (*Hypomesus transpacificus*)	--	--	Tr	Tr	2	Tr	--	--	1	Tr
Carp (*Cyprinus carpio*)	--	--	Tr	1	--	--	--	--	Tr	Tr
Goldfish (*Carassius auratus*)	--	--	Tr	Tr	--	--	--	--	Tr	Tr
Sacramento blackfish (*Orthodon microlepidotus*)	--	--	--	--	Tr	Tr	--	--	Tr	Tr
Sacramento hitch (*Lavinia exilicauda*)	--	--	--	--	Tr	Tr	--	--	Tr	Tr
Striped bass (*Roccus saxatilis*)	44	56	32	26	25	56	50	43	38	45
Bluegill (*Lepomis macrochirus*)	Tr	1	--	--	1	5	--	--	Tr	2
Black crappie (*Pomoxis nigromaculatus*)	--	--	Tr	Tr	Tr	Tr	--	--	Tr	Tr
Three-spined stickleback (*Gasterosteus aculeatus*)	--	--	Tr	Tr	--	--	--	--	Tr	Tr
Unidentifiable fishes	30	9	8	4	18	9	12	3	17	6
Sardine and anchovy bait	18	7	17	5	--	--	16	49	13	15
Stomachs examined	223		574		531		174			
Percent containing food	41		37		12		12			

[1] Stomach content data for adult bass in each of the eight environmental zones in the Delta were weighted by the percent of the total Delta population of adult bass found there and summed (see text, p. 71).

In both the spring and early summer, only a very small percentage of the stomachs contained food. Although few small fishes were available at this time, I do not believe that the scarcity of food in the stomachs was a result of poor forage conditions. If it was merely a lack of suitable forage that caused the reduced food intake, angler catches should be rather large in the Delta in the spring since adult bass are so abundant in the Delta during that season (see Radtke, p. 17; Calhoun, 1952). However, catches by anglers are actually quite small. The mean catch of bass on sport-fishing party boats in the Delta was not above 0.14 per angler hour during any spring between 1961 and 1964, and a creel census conducted by the California Department of Fish and Game, indicated that the catch on many days was as low as 0.05 bass per angler hour (Thomas Doyle, pers. commun.). A suggestion (Hollis, 1952) that striped bass do not feed heavily when they near spawning is relevant. Bass spawn in the Delta during April, May, and June (see Farley, p. 30), and most of the stomachs examined during the spring and summer were collected during these months.

GEOGRAPHICAL VARIATIONS IN DIET

In this section, the diet and abundance of bass and the abundance of their food organisms in each environmental zone of the Delta are reviewed.

Lower San Joaquin River (Table 9)

This zone was one of the most important nursery areas in the Delta for young bass (see Sasaki, p. 57); it was also a very important nursery for juvenile bass (see Sasaki, p. 64). The large quantities of *N. awatschensis* that were consumed by these bass reflected the large concentrations of *N. awatschensis* that were present (Turner and Heubach, 1966). Stomachs of the young bass contained as many as 100 or 150 individual *N. awatschensis*. Stomachs of the juvenile bass often held 200 to 300 *N. awatschensis*. *Corophium* were of some importance to young bass in the fall, but only small amounts were consumed by young bass during the rest of the year. The abundant young bass provided most of the forage for large bass.

Middle San Joaquin River (Table 10)

During the fall, winter, and spring, *N. awatschensis* was the most important invertebrate eaten by bass in this zone; however, only a small percentage of the young bass in the Delta were here until the summer (see Sasaki, p. 52) when concentrations of *N. awatschensis* in the environment (Turner and Heubach, 1966) had decreased from the relatively high winter and spring levels, and *Corophium* had become a more important food.

The large numbers of threadfin shad which were eaten here in the fall and winter reflected the extreme concentrations of this species in the environment (see Turner, p. 161). Stomachs of adult bass contained as many as 24 threadfins averaging 10 cm FL. In the fall, the threadfin shad was the most important food of juvenile bass, and in that season about one-half of the juveniles in the Delta were in this zone (Sasaki, p. 63). The bass in this area also ate a few of their own young.

Upper San Joaquin River (Table 11)

The upper San Joaquin River was not an important zone for bass of any age-group. Each season only a very small percentage of the bass in the Delta were here (see Sasaki, pp. 54 and 65; Radtke, pp. 21 and 22). The few young bass inhabiting this area fed primarily on *Corophium*. A significant percentage of these bass also fed on the tendipedid larvae and pupae which were fairly abundant in the bottom sediments (Hazel and Kelley, 1966). *N. awatschensis* was scarce (Turner and Heubach, 1966), and was consumed in quantity only by juvenile bass in the fall. Much of the diet of juveniles was formed by *Corophium* and sardine and anchovy bait. The threadfin shad was the most common forage fish in stomachs of large bass. It was consumed most frequently in the winter and spring.

South Delta (Table 12)

Relatively few bass of any size inhabited the south Delta (see Sasaki, pp. 54 and 55; Radtke, pp. 21 and 22). The young bass in this area usually fed on *Corophium*, although in the winter *N. awatschensis* was a more important food. *N. awatschensis* was never particularly abundant in the environment (Turner and Heubach, 1966), but it was still the most important food of juvenile bass.

TABLE 9

Stomach Contents of Striped Bass in the Lower San Joaquin River

Food Items	Young Bass: Fall % Freq Occ	Fall % by Vol	Winter % Freq Occ	Winter % by Vol	Spring % Freq Occ	Spring % by Vol	Summer % Freq Occ	Summer % by Vol
Crustaceans								
Cladocerans and Copepods	--	--	--	--	1	Tr	--	--
Mysid shrimp (*Neomysis awatschensis*)	96	82	89	94	95	89	98	80
Unidentified Isopod	--	--	--	--	--	--	1	Tr
Amphipods (*Corophium*)	30	18	28	6	29	4	32	2
Unidentifiable shrimp	--	--	--	--	Tr	2	--	--
Insects								
Tendipedids	--	--	--	--	--	--	1	Tr
Molluscs								
Asiatic clam (*Corbicula fluminea*)	--	--	--	--	--	--	--	--
Fishes								
Unidentified Ammocoete	--	--	--	--	--	--	--	--
Threadfin shad (*Dorosoma petenense*)	--	--	--	--	--	--	--	--
American shad (*Alosa sapidissima*)	--	--	--	--	1	2	--	--
Pacific herring (*Clupea pallasi*)	--	--	--	--	--	--	--	--
King salmon (*Oncorhynchus tshawytscha*)	--	--	--	--	--	--	--	--
Carp (*Cyprinus carpio*)	--	--	--	--	--	--	--	--
Striped bass (*Roccus saxatilis*)	--	--	--	--	--	--	7	18
Unidentifiable fishes	--	--	--	--	Tr	1	Tr	1
Sardine and anchovy bait	--	--	--	--	Tr	2	--	--
Stomachs examined	105		292		279		211	
Percent containing food	75		63		78		85	

Food Items	Juvenile Bass: Fall % Freq Occ	Fall % by Vol	Winter % Freq Occ	Winter % by Vol	Spring % Freq Occ	Spring % by Vol	Summer % Freq Occ	Summer % by Vol
Crustaceans								
Cladocerans and Copepods	--	--	--	--	1	Tr	--	--
Mysid shrimp (*Neomysis awatschensis*)	95	34	82	12	93	58	83	16
Unidentified Isopod	--	--	--	--	--	--	--	--
Amphipods (*Corophium*)	21	1	24	Tr	34	Tr	23	Tr
Unidentifiable shrimp	--	--	1	Tr	--	--	--	--
Insects								
Tendipedids	--	--	--	--	--	--	--	--
Molluscs								
Asiatic clam (*Corbicula fluminea*)	1	1	--	--	--	--	--	--
Fishes								
Unidentified Ammocoete	--	--	--	--	--	--	1	1
Threadfin shad (*Dorosoma petenense*)	1	8	1	35	--	--	--	--
American shad (*Alosa sapidissima*)	--	--	--	--	--	--	--	--
Pacific herring (*Clupea pallasi*)	--	--	--	--	--	--	--	--
King salmon (*Oncorhynchus tshawytscha*)	--	--	--	--	--	--	--	--
Carp (*Cyprinus carpio*)	--	--	--	--	--	--	--	--
Striped bass (*Roccus saxatilis*)	1	24	1	16	--	--	21	68
Unidentifiable fishes	2	22	--	--	4	32	8	14
Sardine and anchovy bait	2	11	12	38	4	9	--	--
Stomachs examined	174		132		164		185	
Percent containing food	87		70		79		66	

Food Items	Sub-Adult Bass: Fall % Freq Occ	Fall % by Vol	Winter % Freq Occ	Winter % by Vol	Spring % Freq Occ	Spring % by Vol	Summer % Freq Occ	Summer % by Vol
Crustaceans								
Cladocerans and Copepods	--	--	--	--	--	--	--	--
Mysid shrimp (*Neomysis awatschensis*)	30	2	35	Tr	46	4	50	5
Unidentified Isopod	--	--	--	--	--	--	--	--
Amphipods (*Corophium*)	6	Tr	6	Tr	11	Tr	5	Tr
Unidentifiable shrimp	2	Tr	6	Tr	--	--	--	--
Insects								
Tendipedids	--	--	--	--	--	--	--	--
Molluscs								
Asiatic clam (*Corbicula fluminea*)	--	--	--	--	--	--	--	--
Fishes								
Unidentified Ammocoete	--	--	--	--	--	--	--	--
Threadfin shad (*Dorosoma petenense*)	--	--	12	9	4	9	5	11
American shad (*Alosa sapidissima*)	11	12	--	--	--	--	--	--
Pacific herring (*Clupea pallasi*)	--	--	--	--	4	Tr	--	--
King salmon (*Oncorhynchus tshawytscha*)	2	10	--	--	11	25	--	--
Carp (*Cyprinus carpio*)	2	1	--	--	--	--	--	--
Striped bass (*Roccus saxatilis*)	53	70	41	85	18	46	40	60
Unidentifiable fishes	6	5	--	--	7	7	10	24
Sardine and anchovy bait	2	1	12	5	14	8	--	--
Stomachs examined	82		35		59		52	
Percent containing food	57		49		48		38	

Food Items	Adult Bass: Fall % Freq Occ	Fall % by Vol	Winter % Freq Occ	Winter % by Vol	Spring % Freq Occ	Spring % by Vol	Summer % Freq Occ	Summer % by Vol
Crustaceans								
Cladocerans and Copepods	--	--	--	--	--	--	--	--
Mysid shrimp (*Neomysis awatschensis*)	--	--	10	Tr	20	Tr	--	--
Unidentified Isopod	--	--	--	--	--	--	--	--
Amphipods (*Corophium*)	--	--	--	--	--	--	--	--
Unidentifiable shrimp	--	--	--	--	--	--	--	--
Insects								
Tendipedids	--	--	--	--	--	--	--	--
Molluscs								
Asiatic clam (*Corbicula fluminea*)	--	--	--	--	--	--	--	--
Fishes								
Unidentified Ammocoete	--	--	5	1	--	--	--	--
Threadfin shad (*Dorosoma petenense*)	--	--	16	16	10	11	--	--
American shad (*Alosa sapidissima*)	14	12	--	--	--	--	--	--
Pacific herring (*Clupea pallasi*)	--	--	--	--	--	--	--	--
King salmon (*Oncorhynchus tshawytscha*)	--	--	--	--	20	16	--	--
Carp (*Cyprinus carpio*)	--	--	--	--	--	--	--	--
Striped bass (*Roccus saxatilis*)	68	69	58	81	40	67	67	30
Unidentifiable fishes	36	17	--	--	10	7	--	--
Sardine and anchovy bait	4	3	10	2	--	--	33	70
Stomachs examined	37		38		81		55	
Percent containing food	60		50		12		5	

TABLE 10

Stomach Contents of Striped Bass in the Middle San Joaquin River

	Young Bass								Juvenile Bass								Sub-Adult Bass								Adult Bass							
	Fall		Winter		Spring		Summer		Fall		Winter		Spring		Summer		Fall		Winter		Spring		Summer		Fall		Winter		Spring		Summer	
Food Items	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol
Crustaceans																																
Cladocerans and Copepods	--	--	--	--	5	Tr	2	Tr	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Mysid shrimp (*Neomysis awatschensis*)	50	1	94	14	81	69	40	5	14	Tr	82	12	56	3	21	2	--	--	20	Tr	40	Tr	--	--	--	--	7	Tr	--	--	--	--
Isopod (*Exosphaeroma oregonensis*)	--	--	--	--	--	--	--	--	--	--	--	--	5	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Amphipods (*Corophium*)	50	1	33	1	53	19	68	9	17	Tr	37	Tr	46	1	29	3	--	--	6	Tr	40	Tr	14	Tr	--	--	2	Tr	--	--	--	--
Crayfish (*Pacifastacus leniusculus*)	--	--	--	--	--	--	--	--	--	--	--	--	2	6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Crab (*Rhithropanopeus harrisii*)	--	--	--	--	--	--	--	--	2	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Insects																																
Tendipedids	--	--	--	--	1	Tr	14	Tr	12	Tr	--	--	--	--	12	Tr	5	Tr	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Fishes																																
Threadfin shad (*Dorosoma petenense*)	25	98	--	--	--	--	14	75	43	76	4	36	5	22	21	30	84	95	69	93	--	--	21	42	61	84	90	87	100	100	--	--
American shad (*Alosa sapidissima*)	--	--	--	--	--	--	--	--	2	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	13	3	2	12	--	--	--	--
Unidentifiable Clupeids	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	21	19	--	--	--	--	--	--	--	--
Pond smelt (*Hypomesus transpacificus*)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4	2	--	--	--	--	--	--	--	--	--	--	--	--
White catfish (*Ictalurus catus*)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Striped bass (*Roccus saxatilis*)	--	--	--	--	--	--	5	11	5	5	--	--	2	4	4	42	6	1	3	2	--	--	21	19	12	13	5	1	--	--	67	95
Unidentifiable fishes	--	--	--	--	--	--	--	--	24	14	2	14	7	33	12	21	26	3	9	3	60	100	21	20	--	--	--	--	--	--	33	5
Sardine and anchovy bait	--	--	27	85	1	12	--	--	--	--	12	37	26	30	--	--	--	--	3	Tr	--	--	--	--	--	--	--	--	--	--	--	--
Stomachs examined	14		37		92		143		98		64		61		64		90		68		32		59		44		92		41		17	
Percent containing food	57		89		86		78		43		77		70		38		54		52		16		24		59		46		24		18	

TABLE 11

Stomach Contents of Striped Bass in the Upper San Joaquin River

Young Bass

Food Items	Fall % Freq Occ	Fall % by Vol	Winter % Freq Occ	Winter % by Vol	Spring % Freq Occ	Spring % by Vol	Summer % Freq Occ	Summer % by Vol
Annelids								
Unidentified Annelid	--	--	--	--	1	2	--	--
Crustaceans								
Cladocerans and Copepods	--	--	20	2	2	Tr	--	--
Mysid shrimp (*Neomysis awatschensis*)	--	--	8	1	36	10	5	Tr
Amphipods (*Corophium*)	86	3	92	43	89	38	87	9
Insects								
Tendipedids	14	Tr	23	2	39	8	52	1
Molluscs								
Asiatic clam (*Corbicula fluminea*)	--	--	--	--	--	--	--	--
Fishes								
Threadfin shad (*Dorosoma petenense*)	--	--	--	--	--	--	7	42
Carp (*Cyprinus carpio*)	--	--	--	--	--	--	--	--
Striped bass (*Roccus saxatilis*)	--	--	--	--	--	--	7	42
Unidentifiable fishes	--	--	--	--	1	39	--	--
Fish eggs	--	--	--	--	1	2	--	--
Sardine and anchovy bait	29	97	3	52	--	--	1	6
Stomachs examined	7		63		113		105	
Percent containing food	100		97		94		72	

Juvenile Bass

Food Items	Fall % Freq Occ	Fall % by Vol	Winter % Freq Occ	Winter % by Vol	Spring % Freq Occ	Spring % by Vol	Summer % Freq Occ	Summer % by Vol
Annelids								
Unidentified Annelid	--	--	--	--	--	--	--	--
Crustaceans								
Cladocerans and Copepods	--	--	20	Tr	5	Tr	--	--
Mysid shrimp (*Neomysis awatschensis*)	85	49	40	2	16	4	12	Tr
Amphipods (*Corophium*)	8	Tr	20	Tr	84	5	88	4
Insects								
Tendipedids	54	5	10	Tr	10	Tr	25	Tr
Molluscs								
Asiatic clam (*Corbicula fluminea*)	8	Tr	--	--	--	--	--	--
Fishes								
Threadfin shad (*Dorosoma petenense*)	--	--	10	20	5	34	12	62
Carp (*Cyprinus carpio*)	--	--	--	--	--	--	--	--
Striped bass (*Roccus saxatilis*)	--	--	--	--	--	--	--	--
Unidentifiable fishes	--	--	--	--	--	--	--	--
Fish eggs	--	--	--	--	--	--	--	--
Sardine and anchovy bait	8	46	60	77	16	57	12	33
Stomachs examined	13		17		38		11	
Percent containing food	100		59		50		73	

Sub-Adult Bass

Food Items	Fall % Freq Occ	Fall % by Vol	Winter % Freq Occ	Winter % by Vol	Spring % Freq Occ	Spring % by Vol	Summer % Freq Occ	Summer % by Vol
Annelids								
Unidentified Annelid	--	--	--	--	--	--	--	--
Crustaceans								
Cladocerans and Copepods	--	--	--	--	--	--	--	--
Mysid shrimp (*Neomysis awatschensis*)	--	--	--	--	--	--	--	--
Amphipods (*Corophium*)	33	Tr	--	--	--	--	--	--
Insects								
Tendipedids	--	--	--	--	--	--	--	--
Molluscs								
Asiatic clam (*Corbicula fluminea*)	--	--	--	--	--	--	--	--
Fishes								
Threadfin shad (*Dorosoma petenense*)	--	--	100	100	100	100	--	--
Carp (*Cyprinus carpio*)	--	--	--	--	--	--	--	--
Striped bass (*Roccus saxatilis*)	67	100	--	--	--	--	--	--
Unidentifiable fishes	--	--	--	--	--	--	--	--
Fish eggs	--	--	--	--	--	--	--	--
Sardine and anchovy bait	--	--	--	--	--	--	--	--
Stomachs examined	9		9		15		2	
Percent containing food	33		89		27		0	

Adult Bass

Food Items	Fall % Freq Occ	Fall % by Vol	Winter % Freq Occ	Winter % by Vol	Spring % Freq Occ	Spring % by Vol	Summer % Freq Occ	Summer % by Vol
Annelids								
Unidentified Annelid	--	--	--	--	--	--	--	--
Crustaceans								
Cladocerans and Copepods	--	--	--	--	--	--	--	--
Mysid shrimp (*Neomysis awatschensis*)	--	--	--	--	--	--	--	--
Amphipods (*Corophium*)	--	--	--	--	--	--	--	--
Insects								
Tendipedids	--	--	--	--	--	--	--	--
Molluscs								
Asiatic clam (*Corbicula fluminea*)	--	--	--	--	--	--	--	--
Fishes								
Threadfin shad (*Dorosoma petenense*)	--	--	100	97	--	--	--	--
Carp (*Cyprinus carpio*)	--	--	--	--	100	100	--	--
Striped bass (*Roccus saxatilis*)	100	100	7	3	--	--	--	--
Unidentifiable fishes	--		--	--	--	--	--	--
Fish eggs	--	--	--	--	--	--	--	--
Sardine and anchovy bait	--	--	--	--	--	--	--	--
Stomachs examined	6		22		31		2	
Percent containing food	33		64		3		0	

TABLE 12

Stomach Contents of Striped Bass in the South Delta

Food Items	Young Bass								Juvenile Bass								Sub-Adult Bass								Adult Bass							
	Fall		Winter		Spring		Summer		Fall		Winter		Spring		Summer		Fall		Winter		Spring		Summer		Fall		Winter		Spring		Summer	
	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol
Annelids																																
Polychaete (*Neanthes limnicola*)	--	--	--	--	--	--	1	Tr	2	Tr	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Crustaceans																																
Cladocerans and Copepods	--	--	10	2	Tr	Tr	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Mysid shrimp (*Neomysis awatschensis*)	43	6	75	31	58	20	58	12	39	6	83	49	59	24	80	62	--	--	33	8	100	100	--	--	--	--	--	--	57	Tr	--	--
Isopod (*Exosphaeroma oregonensis*)	--	--	1	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Amphipods (*Corophium*)	99	26	51	17	78	23	81	18	46	1	44	3	59	2	80	9	--	--	33	Tr	--	--	33	Tr	--	--	--	--	--	--	--	--
Crayfish (*Pacifastacus leniusculus*)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	33	65	--	--	--	--	--	--	--	--	--	--	--	--
Insects																																
Tendipedids	14	1	3	Tr	14	1	18	1	32	2	--	--	19	Tr	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Molluscs																																
Asiatic clam (*Corbicula fluminea*)	--	--	1	23	--	--	2	1	2	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Fishes																																
Unidentified Ammocoete	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	14	2	--	--
Threadfin shad (*Dorosoma petenense*)	--	--	--	--	--	--	1	1	--	--	--	--	--	--	--	--	17	57	33	26	--	--	--	--	--	--	92	19	--	--	--	--
Unidentifiable Clupeids	--	--	--	--	--	--	1	6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Pond smelt (*Hypomesus transpacificus*)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8	Tr	--	--	--	--
Striped bass (*Roccus saxatilis*)	--	--	--	--	--	--	6	37	2	40	--	--	--	--	20	29	50	27	--	--	--	--	67	100	100	100	8	80	--	--	100	100
Bluegill (*Lepomis macrochirus*)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	14	90	--	--
Unidentifiable fishes	--	--	--	--	1	28	3	22	2	16	--	--	3	9	--	--	33	16	--	--	--	--	--	--	--	--	8	Tr	14	8	--	--
Sardine and anchovy bait	7	66	1	23	Tr	28	1	4	11	33	6	48	12	64	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Stomachs examined	17		128		210		157		59		23		50		8		10		4		31		7		9		19		72		5	
Percent containing food	82		88		87		74		75		78		64		62		60		75		3		43		22		63		10		20	

Few stomachs of the older bass had food. Threadfin shad were the most important forage fish. They were present in 11 of the 22 stomachs of adult bass, and 2 of the 13 stomachs of subadult bass that contained food. All except one were eaten during the winter. In the fall, winter, and summer, a few of the stomachs contained small bass.

Sacramento River (Table 13)

In the fall, about one-third of the young bass in the Delta were in the Sacramento River, but during the rest of the year this proportion was much smaller (see Sasaki, p. 54). The proportion of the juvenile bass in this area was quite small in the fall, but it increased each season until the summer when it peaked at about one-quarter of the population in the Delta (see Sasaki, p. 65). *N. awatschensis* was quite abundant in the environment (Turner and Heubach, 1966) and was the most important food of these age-groups. These bass also consumed a fair number of *Corophium*. Young striped bass were the predominant forage fish.

Mokelumne River (Table 14)

The Mokelumne River was of small importance as a nursery area for young and juvenile bass (see Sasaki, pp. 58 and 66). Turner and Heubach (1966) found that *N. awatschensis* was scarce here in all seasons, but this mysid was the most important food of the juveniles from this area and of those young bass here in the winter and spring. In the fall and summer, young bass fed more often on *Corophium*.

Only a few stomachs from the older bass contained food. The threadfin shad was the most common of the forage fishes in them.

Flooded Islands (Table 15)

The proportion of the Delta population of young and juvenile bass in flooded islands varied seasonally from 5 to 18 percent. These bass fed largely on *N. awatschensis* in the winter and spring. In the fall and summer, *Corophium* were a more important food source. In contrast, Turner and Heubach (1966) did not collect any *N. awatschensis* in these areas during the winter, but they did collect a few in the other seasons.

Depending on season, from 20 to 52 percent of the subadult and adult bass in the Delta inhabited the flooded islands (see Radtke, pp. 21 and 22). These bass preyed primarily on small striped bass and threadfin shad.

Dead-end Sloughs (Table 16)

Few bass of any size populated the dead-end sloughs (see Sasaki, pp. 54 and 65; Radtke, pp. 21 and 22). *N. awatschensis* was the most important invertebrate utilized as food, although it was never abundant in the environment (Turner and Heubach, 1966). *Corophium* were only of small importance as a food. The threadfin shad, which was so abundant in these sloughs (see Turner, p. 161) was, by far, the most important forage fish. Stomachs of adult and subadult bass often contained more than 10 threadfins. Juvenile bass in these sloughs also consumed a substantial number of threadfins. A few individuals of many other species of fishes were also eaten by the larger bass.

TABLE 13

Stomach Contents of Striped Bass in the Sacramento River

Food Items	Young Bass: Fall % Freq Occ	Fall % by Vol	Winter % Freq Occ	Winter % by Vol	Spring % Freq Occ	Spring % by Vol	Summer % Freq Occ	Summer % by Vol
Annelids								
Unidentified Annelid	--	--	--	--	1	6	--	--
Crustaceans								
Cladocerans and Copepods	--	--	--	--	18	Tr	--	--
Mysid shrimp (*Neomysis awatschensis*)	88	79	51	54	75	70	86	55
Isopod (*Exosphaeroma oregonensis*)	--	--	3	6	--	--	--	--
Amphipods (*Corophium*)	31	21	38	6	30	10	33	2
Crayfish (*Pacifastacus leniusculus*)	--	--	--	--	1	7	--	--
Unidentifiable shrimp	--	--	--	--	--	--	1	Tr
Insects								
Tendipedids	3	Tr	14	2	4	Tr	--	--
Other Insects	--	--	1	2	--	--	1	Tr
Fishes								
Threadfin shad (*Dorosoma petenense*)	--	--	--	--	--	--	--	--
American shad (*Alosa sapidissima*)	--	--	--	--	1	7	4	10
King salmon (*Oncorhynchus tshawytscha*)	--	--	--	--	--	--	--	--
Pond smelt (*Hypomesus transpacificus*)	--	--	--	--	--	--	1	2
Striped bass (*Roccus saxatilis*)	--	--	--	--	--	--	12	30
Unidentifiable fishes	--	--	--	--	--	--	1	1
Sardine and anchovy bait	--	--	1	31	--	--	--	--
Stomachs examined	75		129		145		140	
Percent containing food	91		57		77		89	

Food Items	Juvenile Bass: Fall % Freq Occ	Fall % by Vol	Winter % Freq Occ	Winter % by Vol	Spring % Freq Occ	Spring % by Vol	Summer % Freq Occ	Summer % by Vol
Annelids								
Unidentified Annelid	--	--	--	--	--	--	--	--
Crustaceans								
Cladocerans and Copepods	--	--	--	--	--	--	--	--
Mysid shrimp (*Neomysis awatschensis*)	53	13	36	7	53	4	57	10
Isopod (*Exosphaeroma oregonensis*)	--	--	--	--	--	--	--	--
Amphipods (*Corophium*)	38	5	27	Tr	18	Tr	17	Tr
Crayfish (*Pacifastacus leniusculus*)	--	--	--	--	--	--	--	--
Unidentifiable shrimp	--	--	--	--	--	--	2	2
Insects								
Tendipedids	9	Tr	--	--	--	--	5	Tr
Other Insects	--	--	9	2	--	--	--	--
Fishes								
Threadfin shad (*Dorosoma petenense*)	2	31	--	--	3	25	--	--
American shad (*Alosa sapidissima*)	--	--	--	--	--	--	2	7
King salmon (*Oncorhynchus tshawytscha*)	--	--	--	--	3	3	2	10
Pond smelt (*Hypomesus transpacificus*)	--	--	--	--	3	11	7	23
Striped bass (*Roccus saxatilis*)	6	30	--	--	--	--	38	42
Unidentifiable fishes	2	5	9	30	9	24	5	7
Sardine and anchovy bait	6	16	27	60	18	34	--	--
Stomachs examined	64		27		60		62	
Percent containing food	83		41		57		68	

Food Items	Sub-Adult Bass: Fall % Freq Occ	Fall % by Vol	Winter % Freq Occ	Winter % by Vol	Spring % Freq Occ	Spring % by Vol	Summer % Freq Occ	Summer % by Vol
Annelids								
Unidentified Annelid	--	--	--	--	--	--	--	--
Crustaceans								
Cladocerans and Copepods	--	--	--	--	--	--	--	--
Mysid shrimp (*Neomysis awatschensis*)	--	--	10	Tr	30	1	27	1
Isopod (*Exosphaeroma oregonensis*)	--	--	--	--	--	--	--	--
Amphipods (*Corophium*)	--	--	--	--	30	Tr	--	--
Crayfish (*Pacifastacus leniusculus*)	5	5	--	--	10	29	--	--
Unidentifiable shrimp	--	--	10	3	--	--	--	--
Insects								
Tendipedids	--	--	--	--	--	--	--	--
Other Insects	--	--	--	--	--	--	--	--
Fishes								
Threadfin shad (*Dorosoma petenense*)	--	--	--	--	--	--	20	14
American shad (*Alosa sapidissima*)	5	6	20	28	--	--	--	--
King salmon (*Oncorhynchus tshawytscha*)	--	--	--	--	--	--	--	--
Pond smelt (*Hypomesus transpacificus*)	5	1	--	--	10	21	--	--
Striped bass (*Roccus saxatilis*)	65	75	20	25	20	43	67	78
Unidentifiable fishes	20	4	--	--	--	--	7	7
Sardine and anchovy bait	10	9	40	44	10	6	--	--
Stomachs examined	52		18		39		27	
Percent containing food	38		56		26		56	

Food Items	Adult Bass: Fall % Freq Occ	Fall % by Vol	Winter % Freq Occ	Winter % by Vol	Spring % Freq Occ	Spring % by Vol	Summer % Freq Occ	Summer % by Vol
Annelids								
Unidentified Annelid	--	--	--	--	--	--	--	--
Crustaceans								
Cladocerans and Copepods	--	--	--	--	--	--	--	--
Mysid shrimp (*Neomysis awatschensis*)	14	Tr	3	Tr	29	2	--	--
Isopod (*Exosphaeroma oregonensis*)	--	--	--	--	--	--	--	--
Amphipods (*Corophium*)	--	--	6	Tr	--	--	--	--
Crayfish (*Pacifastacus leniusculus*)	14	3	--	--	--	--	--	--
Unidentifiable shrimp	--	--	3	Tr	--	--	22	3
Insects								
Tendipedids	--	--	--	--	--	--	--	--
Other Insects	--	--	--	--	--	--	--	--
Fishes								
Threadfin shad (*Dorosoma petenense*)	--	--	12	9	--	--	--	--
American shad (*Alosa sapidissima*)	--	--	12	8	--	--	--	--
King salmon (*Oncorhynchus tshawytscha*)	--	--	--	--	--	--	11	5
Pond smelt (*Hypomesus transpacificus*)	--	--	3	Tr	14	3	--	--
Striped bass (*Roccus saxatilis*)	43	79	62	79	14	42	44	80
Unidentifiable fishes	--	--	9	2	43	53	22	13
Sardine and anchovy bait	29	18	3	1	--	--	--	--
Stomachs examined	18		74		63		40	
Percent containing food	39		43		11		22	

TABLE 14

Stomach Contents of Striped Bass in the Mokelumne River

Food Items	Young Bass								Juvenile Bass							
	Fall		Winter		Spring		Summer		Fall		Winter		Spring		Summer	
	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol
Crustaceans																
Cladocerans and Copepods	--	--	--	--	--	--	5	1	--	--	--	--	--	--	--	--
Mysid shrimp (*Neomysis awatschensis*)	8	2	98	55	74	43	47	13	76	46	88	41	71	5	41	3
Isopod (*Excsphaercma oregonensis*)	--	--	--	--	--	--	1	Tr	--	--	--	--	--	--	--	--
Amphipods (*Corophium*)	92	18	12	1	54	19	70	11	24	3	4	Tr	32	Tr	35	1
Crayfish (*Pacifastacus leniusculus*)	--	--	--	--	--	--	2	8	--	--	--	--	3	Tr	6	9
Insects																
Tendipedids	4	Tr	--	--	3	Tr	17	Tr	--	--	--	--	--	--	12	Tr
Molluscs																
Asiatic clam (*Corbicula fluminea*)	8	80	--	--	--	--	--	--	--	--	--	--	--	--	6	6
Fishes																
Unidentified Ammocoete	--	--	--	--	--	--	--	--	--	--	--	--	3	3	--	--
Threadfin shad (*Dorosoma petenense*)	--	--	--	--	--	--	1	7	--	--	--	--	3	25	--	--
American shad (*Alosa sapidissima*)	--	--	--	--	--	--	6	40	--	--	--	--	--	--	6	3
King salmon (*Oncorhynchus tshawytscha*)	--	--	--	--	--	--	--	--	--	--	--	--	3	24	--	--
White catfish (*Ictalurus catus*)	--	--	--	--	--	--	2	2	--	--	--	--	--	--	--	--
Striped bass (*Roccus saxatilis*)	--	--	--	--	--	--	2	18	--	--	--	--	--	--	24	49
Black crappie (*Pomoxis nigromaculatus*)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Starry flounder (*Platichthys stellatus*)	--	--	--	--	1	6	--	--	--	--	--	--	--	--	--	--
Unidentifiable fishes	--	--	--	--	--	--	--	--	--	--	--	--	--	--	12	30
Sardine and anchovy bait	--	--	2	44	1	31	--	--	6	51	12	59	21	42	--	--
Stomachs examined	28		70		120		153		35		34		47		19	
Percent containing food	86		83		80		80		49		74		70		90	

Food Items	Sub-Adult Bass								Adult Bass							
	Fall		Winter		Spring		Summer		Fall		Winter		Spring		Summer	
	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol
Crustaceans																
Cladocerans and Copepods	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Mysid shrimp (*Neomysis awatschensis*)	--	--	--	--	--	--	--	--	--	--	--	--	25	Tr	--	--
Isopod (*Excsphaercma oregonensis*)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Amphipods (*Corophium*)	17	Tr	--	--	--	--	--	--	--	--	--	--	25	Tr	--	--
Crayfish (*Pacifastacus leniusculus*)	--	--	--	--	12	30	50	10	--	--	--	--	--	--	--	--
Insects																
Tendipedids	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Molluscs																
Asiatic clam (*Corbicula fluminea*)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Fishes																
Unidentified Ammocoete	--	--	--	--	38	9	--	--	--	--	--	--	--	--	--	--
Threadfin shad (*Dorosoma petenense*)	17	14	--	--	12	18	50	30	--	--	75	86	25	59	--	--
American shad (*Alosa sapidissima*)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
King salmon (*Oncorhynchus tshawytscha*)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
White catfish (*Ictalurus catus*)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Striped bass (*Roccus saxatilis*)	17	18	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Black crappie (*Pomoxis nigromaculatus*)	--	--	--	--	--	--	--	--	--	--	25	14	--	--	--	--
Starry flounder (*Platichthys stellatus*)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Unidentifiable fishes	50	68	--	--	25	20	100	60	100	100	--	--	25	41	100	100
Sardine and anchovy bait	--	--	--	--	25	24	--	--	--	--	--	--	--	--	--	--
Stomachs examined	16		0		22		10		11		25		56		8	
Percent containing food	38		--		38		20		18		16		7		25	

TABLE 15

Stomach Contents of Striped Bass in Flooded Islands

Food Items	Young Bass								Juvenile Bass							
	Fall		Winter		Spring		Summer		Fall		Winter		Spring		Summer	
	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol
Crustaceans																
Cladocerans and Copepods	5	Tr	--	--	6	4	--	--	--	--	--	--	2	Tr	--	--
Mysid shrimp (*Neomysis awatschensis*)	67	40	99	58	96	83	71	17	29	1	69	11	89	35	47	6
Amphipods (*Corophium*)	87	59	8	2	23	3	76	11	61	5	8	Tr	24	2	70	16
Crab (*Rhithropanopeus harrisii*)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Unidentifiable shrimp	--	--	--	--	--	--	--	--	--	--	4	3	--	--	--	--
Insects																
Tendipedids	--	--	1	Tr	--	--	3	Tr	--	--	--	--	--	--	6	Tr
Fishes																
Threadfin shad (*Dorosoma petenense*)	--	--	--	--	--	--	--	--	10	36	--	--	--	--	--	--
American shad (*Alosa sapidissima*)	--	--	--	--	--	--	Tr	8	3	11	--	--	--	--	2	11
Unidentifiable Clupeids	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Striped bass (*Roccus saxatilis*)	--	--	--	--	--	--	11	64	3	14	4	25	--	--	32	66
Unidentifiable fishes	--	--	--	--	1	10	Tr	Tr	5	20	--	--	4	54	2	Tr
Sardine and anchovy bait	--	--	2	40	--	--	--	--	10	13	23	61	2	9	--	--
Stomachs examined	63		148		188		200		124		33		63		87	
Percent containing food	100		78		94		92		75		79		86		61	

Food Items	Sub-Adult Bass								Adult Bass							
	Fall		Winter		Spring		Summer		Fall		Winter		Spring		Summer	
	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol	% Freq Occ	% by Vol
Crustaceans																
Cladocerans and Copepods	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Mysid shrimp (*Neomysis awatschensis*)	2	Tr	18	Tr	31	Tr	31	Tr	--	--	--	--	--	--	--	--
Amphipods (*Corophium*)	2	Tr	4	Tr	40	Tr	54	Tr	--	--	--	--	22	Tr	--	--
Crab (*Rhithropanopeus harrisii*)	--	--	--	--	--	--	--	--	--	--	2	Tr	--	--	--	--
Unidentifiable shrimp	--	--	--	--	--	--	--	--	--	--	2	Tr	--	--	--	--
Insects																
Tendipedids	--	--	--	--	--	--	8	Tr	--	--	--	--	--	--	--	--
Fishes																
Threadfin shad (*Dorosoma petenense*)	33	51	22	24	10	10	15	32	12	9	10	9	--	--	33	36
American shad (*Alosa sapidissima*)	--	--	--	--	--	--	--	--	6	23	--	--	--	--	--	--
Unidentifiable Clupeids	--	--	18	12	--	--	--	--	--	--	29	6	--	--	--	--
Striped bass (*Roccus saxatilis*)	44	41	30	50	20	74	38	55	59	46	38	47	44	88	33	45
Unidentifiable fishes	24	6	7	8	10	15	15	13	35	6	12	16	33	12	--	--
Sardine and anchovy bait	5	2	11	6	--	--	--	--	59	16	33	22	--	--	33	19
Stomachs examined	128		57		64		45		44		234		125		46	
Percent containing food	43		47		16		29		39		20		7		7	

TABLE 16

Stomach Contents of Striped Bass in Dead-End Sloughs

Young Bass

Food Items	Fall % Freq Occ	Fall % by Vol	Winter % Freq Occ	Winter % by Vol	Spring % Freq Occ	Spring % by Vol	Summer % Freq Occ	Summer % by Vol
Crustaceans								
Cladocerans and Copepods	--	--	--	--	2	Tr	--	--
Mysid shrimp (*Neomysis awatschensis*)	75	39	93	95	88	97	82	8
Amphipods (*Corophium*)	12	6	26	5	24	3	19	Tr
Crayfish (*Pacifastacus leniusculus*)	--	--	--	--	--	--	--	--
Insects								
Tendipedids	--	--	--	--	2	Tr	6	Tr
Molluscs								
Asiatic clam (*Corbicula fluminea*)	--	--	--	--	--	--	--	--
Fishes								
Unidentified Ammocoete	--	--	--	--	--	--	--	--
Threadfin shad (*Dorosoma petenense*)	12	55	--	--	--	--	13	78
American shad (*Alosa sapidissima*)	--	--	--	--	--	--	3	3
Unidentifiable Clupeids	--	--	--	--	--	--	--	--
Pond smelt (*Hypomesus transpacificus*)	--	--	--	--	--	--	1	2
Carp (*Cyprinus carpio*)	--	--	--	--	--	--	--	--
Goldfish (*Carassius auratus*)	--	--	--	--	--	--	--	--
Hitch (*Lavinia exilicauda*)	--	--	--	--	--	--	--	--
Sacramento blackfish (*Orthodon microlepidotus*)	--	--	--	--	--	--	--	--
White catfish (*Ictalurus catus*)	--	--	--	--	--	--	1	1
Striped bass (*Roccus saxatilis*)	--	--	--	--	--	--	7	6
Bluegill (*Lepomis macrochirus*)	--	--	--	--	--	--	--	--
Black crappie (*Pomoxis nigromaculatus*)	--	--	--	--	--	--	--	--
Unidentifiable Centrarchids	--	--	--	--	--	--	--	--
Three-spined stickleback (*Gasterosteus aculeatus*)	--	--	--	--	--	--	--	--
Unidentifiable fishes	--	--	--	--	--	--	2	2
Sardine and anchovy bait	--	--	--	--	--	--	--	--
Stomachs examined	11		79		156		169	
Percent containing food	73		87		78		62	

Juvenile Bass

Food Items	Fall % Freq Occ	Fall % by Vol	Winter % Freq Occ	Winter % by Vol	Spring % Freq Occ	Spring % by Vol	Summer % Freq Occ	Summer % by Vol
Crustaceans								
Cladocerans and Copepods	--	--	--	--	--	--	--	--
Mysid shrimp (*Neomysis awatschensis*)	16	Tr	68	2	54	7	38	2
Amphipods (*Corophium*)	13	Tr	4	Tr	20	Tr	6	Tr
Crayfish (*Pacifastacus leniusculus*)	3	1	--	--	--	--	--	--
Insects								
Tendipedids	--	--	--	--	--	--	--	--
Molluscs								
Asiatic clam (*Corbicula fluminea*)	3	2	--	--	--	--	--	--
Fishes								
Unidentified Ammocoete	--	--	--	--	5	8	--	--
Threadfin shad (*Dorosoma petenense*)	50	70	36	98	3	21	44	57
American shad (*Alosa sapidissima*)	--	--	--	--	--	--	--	--
Unidentifiable Clupeids	--	--	--	--	--	--	--	--
Pond smelt (*Hypomesus transpacificus*)	--	--	--	--	--	--	6	25
Carp (*Cyprinus carpio*)	--	--	--	--	--	--	--	--
Goldfish (*Carassius auratus*)	--	--	--	--	--	--	--	--
Hitch (*Lavinia exilicauda*)	--	--	--	--	--	--	--	--
Sacramento blackfish (*Orthodon microlepidotus*)	--	--	--	--	--	--	--	--
White catfish (*Ictalurus catus*)	--	--	--	--	--	--	--	--
Striped bass (*Roccus saxatilis*)	5	9	--	--	3	10	--	--
Bluegill (*Lepomis macrochirus*)	--	--	--	--	--	--	--	--
Black crappie (*Pomoxis nigromaculatus*)	--	--	--	--	--	--	--	--
Unidentifiable Centrarchids	--	--	--	--	--	--	--	--
Three-spined stickleback (*Gasterosteus aculeatus*)	--	--	--	--	--	--	--	--
Unidentifiable fishes	18	17	--	--	13	40	19	13
Sardine and anchovy bait	3	1	--	--	8	14	6	3
Stomachs examined	88		35		61		37	
Percent containing food	43		80		62		43	

Sub-Adult Bass

Food Items	Fall % Freq Occ	Fall % by Vol	Winter % Freq Occ	Winter % by Vol	Spring % Freq Occ	Spring % by Vol	Summer % Freq Occ	Summer % by Vol
Crustaceans								
Cladocerans and Copepods	--	--	--	--	--	--	--	--
Mysid shrimp (*Neomysis awatschensis*)	4	Tr	20	Tr	13	Tr	5	Tr
Amphipods (*Corophium*)	4	Tr	--	--	13	Tr	10	1
Crayfish (*Pacifastacus leniusculus*)	--	--	--	--	--	--	--	--
Insects								
Tendipedids	--	--	--	--	--	--	--	--
Molluscs								
Asiatic clam (*Corbicula fluminea*)	--	--	--	--	--	--	--	--
Fishes								
Unidentified Ammocoete	--	--	--	--	--	--	--	--
Threadfin shad (*Dorosoma petenense*)	71	83	77	97	70	91	60	81
American shad (*Alosa sapidissima*)	--	--	--	--	--	--	--	--
Unidentifiable Clupeids	7	2	--	--	--	--	5	4
Pond smelt (*Hypomesus transpacificus*)	--	--	--	--	--	--	--	--
Carp (*Cyprinus carpio*)	--	--	--	--	--	--	--	--
Goldfish (*Carassius auratus*)	--	--	--	--	--	--	--	--
Hitch (*Lavinia exilicauda*)	--	--	--	--	--	--	--	--
Sacramento blackfish (*Orthodon microlepidotus*)	--	--	--	--	--	--	--	--
White catfish (*Ictalurus catus*)	4	1	--	--	--	--	--	--
Striped bass (*Roccus saxatilis*)	7	7	3	1	--	--	10	7
Bluegill (*Lepomis macrochirus*)	--	--	--	--	--	--	--	--
Black crappie (*Pomoxis nigromaculatus*)	--	--	--	--	--	--	--	--
Unidentifiable Centrarchids	--	--	--	--	--	--	10	5
Three-spined stickleback (*Gasterosteus aculeatus*)	--	--	--	--	--	--	--	--
Unidentifiable fishes	18	8	6	2	13	8	10	3
Sardine and anchovy bait	--	--	--	--	4	1	--	--
Stomachs examined	68		43		50		39	
Percent containing food	41		81		46		51	

Adult Bass

Food Items	Fall % Freq Occ	Fall % by Vol	Winter % Freq Occ	Winter % by Vol	Spring % Freq Occ	Spring % by Vol	Summer % Freq Occ	Summer % by Vol
Crustaceans								
Cladocerans and Copepods	--	--	--	--	--	--	--	--
Mysid shrimp (*Neomysis awatschensis*)	--	--	7	Tr	--	--	--	--
Amphipods (*Corophium*)	6	Tr	2	Tr	4	Tr	--	--
Crayfish (*Pacifastacus leniusculus*)	--	--	--	--	4	1	--	--
Insects								
Tendipedids	--	--	--	--	--	--	--	--
Molluscs								
Asiatic clam (*Corbicula fluminea*)	--	--	--	--	--	--	--	--
Fishes								
Unidentified Ammocoete	--	--	--	--	--	--	--	--
Threadfin shad (*Dorosoma petenense*)	36	31	79	73	54	37	--	--
American shad (*Alosa sapidissima*)	--	--	--	--	--	--	--	--
Unidentifiable Clupeids	--	--	5	Tr	--	--	--	--
Pond smelt (*Hypomesus transpacificus*)	--	--	--	--	4	1	--	--
Carp (*Cyprinus carpio*)	--	--	2	11	--	--	--	--
Goldfish (*Carassius auratus*)	--	--	7	7	--	--	--	--
Hitch (*Lavinia exilicauda*)	--	--	--	--	4	2	--	--
Sacramento blackfish (*Orthodon microlepidotus*)	--	--	--	--	4	20	--	--
White catfish (*Ictalurus catus*)	--	--	--	--	--	--	--	--
Striped bass (*Roccus saxatilis*)	21	47	7	8	--	--	--	--
Bluegill (*Lepomis macrochirus*)	6	13	--	--	--	--	--	--
Black crappie (*Pomoxis nigromaculatus*)	--	--	--	--	8	35	--	--
Unidentifiable Centrarchids	--	--	--	--	--	--	--	--
Three-spined stickleback (*Gasterosteus aculeatus*)	--	--	2	Tr	--	--	--	--
Unidentifiable fishes	29	9	17	1	17	4	--	--
Sardine and anchovy bait	--	--	--	--	--	--	--	--
Stomachs examined	54		70		62		1	
Percent containing food	26		60		39		0	

IMPORTANCE OF INDIVIDUAL FOODS

In any season, only five items ever occurred in more than 10 percent of the stomachs of bass of any age. These items were *N. awatschensis, Corophium*, small striped bass, threadfin shad, and discarded or stolen sardine and anchovy bait. In this section their importance to each of the four age groups of bass is reviewed.

Neomysis awatschensis

N. awatschensis was by far the most important food of young bass. During the fall, winter and spring, it was consumed by more than 84 percent of the young bass. In the summer, even though concentrations of *N. awatschensis* peaked in the environment (Turner and Heubach, 1966), its occurrence in the stomachs of young bass decreased to 65 percent. This decrease reflected a change in the relative abundance and distribution of the young bass. In the fall, winter and spring, a large percentage of the young bass in the Delta inhabited the lower San Joaquin River where concentrations of *N. awatschensis* were high. In the summer, the percentage of the bass in this area decreased considerably and the percentage increased in the middle San Joaquin River (see Sasaki, p. 54) where *N. awatschensis* was not as available.

N. awatschensis was also a very important food of juvenile bass. In the winter and spring, more than 79 percent of the juveniles consumed *N. awatschensis*. During the fall and summer, when forage fishes were readily available, fewer juveniles fed on *N. awatschensis*.

N. awatschensis was eaten by a few subadult and adult bass, but it was not an important part of their diet.

Corophium

Corophium were eaten by large numbers of young and juvenile bass, especially by young bass in those areas of the Delta where *N. awatschensis* was scarce. They were consumed by a few subadult and adult bass also. These amphipods are too small to be a very important food of any but the young bass.

Small Striped Bass

Young striped bass were one of the important foods of adult and subadult bass. In the fall, they were eaten by about two-fifths of the subadults and adults. In the winter and spring, as the young bass became less abundant and larger (see Sasaki, p. 49), they were eaten less frequently. In the summer, when the new year-class of young bass became available, there was a sharp increase in the percentage of the subadults and adults that had eaten small bass. These new young-of-the-year bass were also of importance as a food of juvenile bass.

Threadfin Shad

Threadfin shad were also a very important food source for subadult and adult bass. They were especially important in the fall when they were extremely abundant in the middle San Joaquin River and the dead-end sloughs, and in the winter when their numbers were decreasing (see Turner, p. 164). In the winter, numbers of small bass also decreased (see Sasaki, p. 49), so the threadfins were still one of the more available forage species. In the fall, the threadfins were also quite prominent in the diet of juvenile bass. They were eaten by only a very few young bass.

Sardine and Anchovy Bait

A surprisingly large percentage of the adult bass had eaten quantities of sardine and anchovy bait which had either been discarded by anglers or stolen from their hooks. In the winter and spring, bait was also consumed by a small but significant percentage of the juvenile bass. It was eaten by relatively few young or subadult bass.

FOOD SELECTIVITY

Some organisms in the Delta that were of a size suitable for food were seldom eaten. For example, small American shad were very abundant during the summer and fall (see Stevens, p. 101), but few were consumed by bass. Similarly, Hazel and Kelley (1966) collected zoobenthos from the Delta belonging to 35 taxa; they found that the two species of *Corophium*, tendipedids, *Corbicula fluminea*, and oligochaetes were abundant; however, bass stomachs contained benthic organisms belonging to only 8 taxa and *Corophium* were the only benthos utilized in appreciable quantity.

Young bass seem to prefer *N. awatschensis* over *Corophium* (Table 17). Indices of concentrations of *N. awatschensis* and *Corophium* in the environment when compared with the frequency of occurrence of these organisms in the stomachs of young bass, show that young bass fed primarily on *Corophium* only if *Corophium* were abundant and *N. awatschensis* was scarce. If *N. awatschensis* and *Corophium* were abundant, if *N. awatschensis* was abundant and *Corophium* were not, and if *N. awatschensis* and *Corophium* were scarce, young bass fed primarily on *N. awatschensis*.

TABLE 17

Occurrence of *Neomysis awatschensis* and *Corophium* in Stomachs of Young Striped Bass Compared with the Abundance of *N. awatschensis* [1] and *Corophium* [2] in the Environment

Area	Mean Seasonal Percent Frequency of Occurrence of N. *awatschensis* in Stomachs of Young Bass	Mean Seasonal Percent Frequency of Occurrence of *Corophium* in Stomachs of Young Bass	Abundance of N. *awatschensis* in Environment	Abundance of *Corophium* in Environment
Lower San Joaquin River	94.8	29.5	A	A
Dead-End Sloughs	84.3	20.4	S	S
Sacramento River	75.2	32.8	A	A
Franks Tract	73.3	55.5	S	S
Middle San Joaquin River	66.1	51.3	A	S
North Fork of Mokelumne River and South Fork of Mokelumne River at New Hope Landing	59.7	45.1	S	S
Old River-Fabian and Bell Canal	58.4	72.0	S	A
Mokelumne River at Terminous	52.3	65.2	S	A
Upper San Joaquin River	12.3	88.2	S	A

[1] Based on mean season catch of N. *awatschensis* with a Clarke-Bumpus plankton net (Turner and Heubach, 1966).
A = abundant (28–75 N. *awatschensis* per cubic meter of water).
S = scarce (0– 6 N. *awatschensis* per cubic meter of water).
[2] Based on mean numbers of *Corophium* caught with a Peterson dredge by Hazel and Kelley (1966).
A = abundant (30–57 *Corophium* per square foot).
S = scarce (6–20 *Corophium* per square foot).

Small bass and threadfin shad were eaten at a rate more directly related to their density in the environment. Turner (see p. 161) indicates that threadfin were most concentrated in the middle San Joaquin River and dead-end sloughs, and in these areas large bass preyed on them heaviest. Sasaki (see p. 49) has shown that the greatest concentrations of small bass occurred in the lower San Joaquin River, Sacramento River, and flooded islands, and they were utilized by large bass more frequently in these areas than in the rest of the Delta.

EFFECT OF SAMPLING GEAR ON RESULTS

It has been shown in this paper that bass stomach contents differed in the various environmental zones of the Delta. These differences are probably an effect of differences in the availability of foods in the different zones, and food preferences.

There were also differences in the availability of different kinds of food organisms within each zone, particularly at different depths of the channels. *N. awatschensis* (Turner and Heubach, 1966) and *Corophium* are generally most abundant near the bottom of the channels, the vertical distribution of small striped bass is quite variable (Chadwick, 1964; see Sasaki, p. 46), and threadfin shad are most abundant at the surface (see Turner, p. 160). Because the otter trawl collected bass from near the bottom of the channels and the midwater trawl collected bass from near the surface, it was possible to compare the stomach contents of bass collected at different depths, and consequently determine if the results of this study might have been influenced by the proportion of the sample collected by each type of trawl. Chi square, two-way classification tests were used to determine if in the summer of 1964 the proportion of young bass utilizing each of the important food organisms was significantly different from each type of trawl.

The tests indicated three major differences in stomach contents (Table 18). The proportion of the stomachs that contained threadfin shad was significantly larger in the sample from the midwater trawl than in the sample from the otter trawl, and the proportions of the stomachs that contained *N. awatschensis* and *Corophium* were significantly larger in the sample from the otter trawl than in the sample from the midwater trawl.

TABLE 18

Frequency of Important Foods Compared for Stomachs of Young Striped Bass Collected in the Midwater and Otter Trawls in Summer, 1964 in All Environmental Zones

Food Item	Midwater Trawl		Otter Trawl		X^2	Percentile (1 d.f.)
	Obs. Freq.	Exp. Freq.	Obs. Freq.	Exp. Freq.		
N. awatschensis	213	236	433	410	10.13	0.995
Corophium	183	211	393	365	13.38	0.995
Threadfin Shad	31	13	5	22	37.32	0.995
Striped Bass	25	27	48	46	0.09	—
Stomachs Containing Food	360		624			

These differences in stomach contents could have resulted directly (i) from bass caught at different depths having fed on different organisms or (ii) from bass caught in the midwater trawl having formed a larger than normal proportion of the sample from zones where threadfin shad were most available and/or from bass caught in the otter trawl having formed a larger than normal proportion of the sample from zones where *N. awatschensis* and *Corophium* were most available.

Further inspection of the data revealed that in the two zones, (middle San Joaquin River and dead-end sloughs) where threadfin shad were most densely distributed, the proportion of the sample formed by bass caught in the midwater trawl was, in fact, large. Bass caught in the midwater trawl formed 47 percent of the trawl-caught sample in these two zones; whereas they made up only 37 percent of the trawl-caught sample for all zones combined. Therefore, the proportion of bass utilizing each food organism was also compared for the midwater and otter trawl samples from the middle San Joaquin River and dead-end sloughs only. Chi square tests indicated that the same three differences in stomach contents were significant (Table 19).

TABLE 19

Frequency of Important Foods Compared for Stomachs of Young Striped Bass Collected in the Midwater and Otter Trawls in Summer, 1964 in Middle San Joaquin River and Dead-end Sloughs

Food Item	Midwater Trawl		Otter Trawl		X^2	Percentile (1 d.f.)
	Obs. Freq.	Exp. Freq.	Obs. Freq.	Exp. Freq.		
N. awatschensis	50	60	80	70	6.42	0.975
Corophium	22	44	74	52	34.91	0.995
Threadfin Shad	26	13	3	16	23.91	0.995
Striped Bass	8	6	5	7	0.78	—
Stomachs Containing Food	99		117			

On the basis of the chi square tests, I have concluded that the results of this food habits study were influenced by the proportion of the sample collected with each type of trawl. The validity of the results of this study might have been increased if it were possible to weight accurately the sample from each trawl according to the proportion of the population in the strata of water that it represented. However, the catch data indicate that the vertical distribution of young bass varied considerably over time and between sampling stations (see Sasaki, Table 2, p. 47), and only fragmentary data were available on the vertical distribution of other age groups; therefore, it was not possible to estimate meaningful weight factors.

The proportion of the stomachs that contained food also varied with the sampling gear (Figure 2). To demonstrate this point it was necessary to compare proportions representing each gear for only one age-group of bass because the proportion of the stomachs containing food varied with the age of the bass (Tables 5-8) and each gear caught a different proportion of the total sample of each age-group. Large numbers of individuals from only the juvenile age-group were caught by all three types of gear so this group was selected.

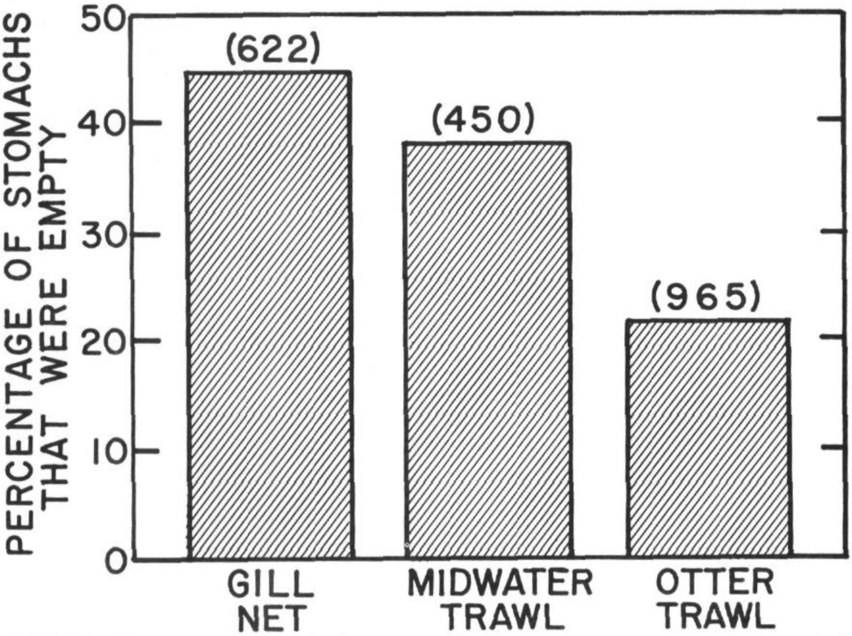

FIGURE 2. Percentage of juvenile bass stomachs that were empty compared to method by which the bass were collected. Numbers of stomachs examined are in parentheses.

Two-way classification chi square tests indicated that the proportion of bass stomachs that contained food for each type of gear was significantly different from the proportion for each of the other two types of gear (Table 20). The proportion of the bass with empty stomachs that were caught in the midwater trawl was larger than the proportion of the bass with empty stomachs from the otter trawl, and the proportion of bass with empty stomachs that were caught in the gill net was larger than that proportion for both the otter trawl and midwater trawl samples. The former difference probably reflected a greater abundance of food near the bottom, and the latter difference probably resulted from some of the stomachs' content being digested while the bass were in the net and unable to feed.

TABLE 20

Frequency of Empty Stomachs Compared for Juvenile Bass Collected by Three Types of Sampling Gear

Comparison	Midwater Trawl		Otter Trawl		Gill Net		X^2	Percentile (1 d.f.)
	Tot. Stomachs = 450		Tot. Stomachs = 965		Tot. Stomachs = 622			
	Obs. No. Empty Stomachs	Exp. No. Empty Stomachs	Obs. No. Empty Stomachs	Exp. No. Empty Stomachs	Obs. No. Empty Stomachs	Exp. No. Empty Stomachs		
Midwater Trawl vs. Otter Trawl	173	120	204	257	—	—	46.14	0.995
Midwater Trawl vs. Gill Net	173	189	—	—	278	261	3.93	0.950
Otter Trawl vs. Gill Net	—	—	204	293	278	189	98.12	0.995

FOOD INTAKE AND BASS GROWTH

In the summer of 1964 there was a progressive change in the composition of the stomach contents of year-old bass from the lower to the middle to the upper San Joaquin River. In the lower river (Table 9), *N. awatschensis* occurred in almost all stomachs, *Corophium* were in about one-third of the stomachs, and tendipedids occurred in almost no stomachs. In the middle river (Table 10), only two-fifths of the stomachs contained *N. awatschensis, Corophium* occurred in more than two-thirds of the stomachs and were the most common food item, and tendipedids were in 14 percent of the stomachs. In the upper river (Table 11), *N. awatschensis* was in almost no stomachs, but seven-eighths of the stomachs contained *Corophium*, and more than one-half contained tendipedids. These changes in diet almost certainly reflected a change in the kinds of food available (see p. 88).

There was not only the progressive change in diet composition, but there was also a corresponding progressive change in the intensity of food consumption. The amount of food in bass stomachs decreased significantly from the lower to the middle to the upper river (Table 21). This decrease suggests that the total food availability decreased from the lowermost to the uppermost zone. In regard to this hypothesis, Ellis and Gowing (1957) found that the amount of food in stomachs of brown trout, *Salmo trutta,* was directly related to the amount of food in the section of the stream from which the trout were collected; and in a series of experiments, Ivlev (1961, pp. 19–40) found that the amount of food consumed by fishes depended on the mean concentration and degree of aggregation of food in the environment.

TABLE 21

Comparison of Mean Volumes of Food in Stomachs of Striped Bass from Three Environmental Zones of the San Joaquin River [1]

Environmental Zones and Mean Volumes of Food (cc)	t Value	Degrees of Freedom	Percentile
Lower River vs. Upper River 0.1875 0.0172	3.61	82	0.99
Lower River vs. Middle River 0.1875 0.0845	2.47	98	0.98
Middle River vs. Upper River 0.0845 0.0172	3.28	80	0.99

[1] Bass were 14.5 to 16.5 cm FL and were collected during August 1964. Bass were selected from this size range to minimize variations in stomach capacities and to maximize the sample size without using effort additional to the regular sampling program.

Sasaki (see p. 55) describes differences in the mean length and mean coefficient of condition of year-old bass from the same three environmental zones. It seems reasonable to expect that these differences were related to the food intake. In support of this theory the mean length and mean coefficient of condition of the bass from the lower river was greater than that of the bass from the middle and upper river (Figure 3). However, the trends in food intake, fork length, and coefficient of condition of bass from the middle to the upper river do not agree. The mean fork length of bass from the middle river was the same as that of bass from the upper river, and the mean coeffi-

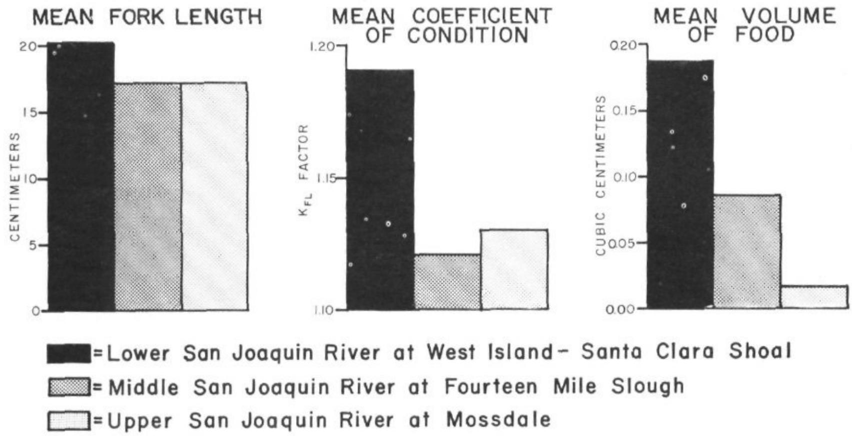

FIGURE 3. Mean volume of food per stomach, mean length, and mean coefficient of condition of year-old bass from the three environmental zones of the San Joaquin River during the summer of 1964.

cient of condition of bass from the middle river was smaller, although not significantly smaller, than bass from the upper river; whereas the food intake was higher in the middle river than in the upper river. However, it should be noted here that there was a large increase in Sasaki's catches of year-old bass in the middle river from spring to summer (see p. 52); therefore, bass must have migrated there from another area. They may have come from upstream too recently to have put on growth consistent with their increased food intake. It is relevant that in the study by Ellis and Gowing (1957) the coefficient of condition of brown trout was highest in the section of the stream in which the food supply and food intake was highest.

DISCUSSION AND SUMMARY

The bass stomachs contained more than 30 different foods, but only 5 of these foods, *N. awatschensis, Corophium,* small striped bass, threadfin shad, and bait, were eaten by an appreciable percentage of bass during any season.

Young bass entered their first fall, feeding almost entirely on invertebrates (Figure 4). They continued to do so through the winter and spring. In their second summer of life, they began feeding on small fish, primarily new young-of-the-year striped bass and threadfin shad.

In the second fall of their life, the bass, now juveniles, fed nearly half on fish and half on invertebrates. During this period, threadfin shad and small striped bass were abundant and at the proper size. In the winter and spring when many of the small bass had moved

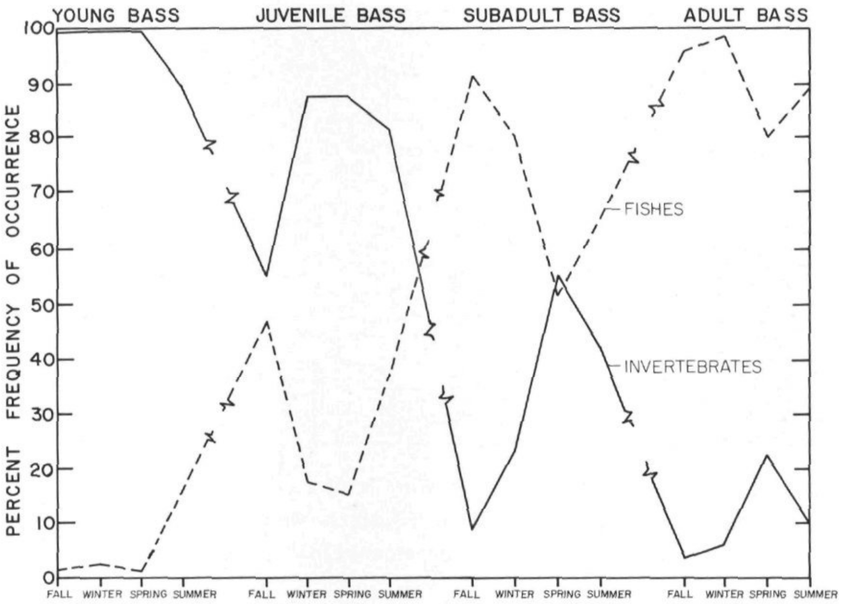

FIGURE 4. Percent frequency of occurrence of fishes and invertebrates in stomachs of striped bass of different ages from fall 1963 through summer 1964.

down into the bays below the Delta (see Sasaki, p. 49; and Ganssle, 1966), and the threadfin shad had died out (see Turner, p. 164), the juvenile bass returned to a diet formed largely by invertebrates. When the new crop of young-of-the-year bass and threadfin shad became available in the summer, the juveniles turned again toward a diet of small fish.

In the fall, the abundant small striped bass and threadfin shad comprised nearly the entire diet of the subadult bass. Like the juveniles, the subadults consumed less fish and more invertebrates in the winter and spring when small fishes were less numerous. The subadults returned to an almost exclusive fish diet when the new crops of small bass and threadfin shad arrived in the summer.

Adult bass fed primarily on small bass and threadfin shad. In the spring and early summer the adults reduced their food intake. This reduction was probably related to their spawning activities.

The shift from the diet of young bass which consisted primarily of invertebrates to the diet of the adult bass which was formed predominately by fishes was obviously a result of selective feeding by bass of different sizes. This shift in diet was not unexpected in view of findings of many other studies and conforms with the results of Ivlev's (1961, pp. 82–91) experiments showing that predators prefer to devour victims of the largest possible size.

Corophium were the only zoobenthos that bass utilized in significant amounts. These amphipods were the most abundant of the macroorganisms collected from the bottom of the Delta channels by Hazel and Kelley (1966). *Corophium* also are often found on the substrate rather than in it, so are probably more available than those less abundant benthic animals which live in the substrate.

Few bass stomachs contained small king salmon. *Oncorhynchus tshawytscha*. Several biologists (Scofield, 1931; Shapovalov, 1936; Hatton, 1940) have speculated on how much striped bass prey upon seaward migrating salmon. Hatton (1940) analyzed stomach contents of 224 adult bass from the Delta during the salmon migration primarily to determine the extent of this predation. He found no salmon in the stomachs and concluded that they were not an important food source. Adult bass are spawning during the salmon migration; therefore, they would not be serious predators because they do not feed heavily then.

Recently, Thomas (1966) reported that juvenile bass consumed quantities of small salmon in the spring and summer in the Sacramento River above the Delta. This suggests that salmon are more available there than in the Delta. This availability may be a direct result of the greater clarity and/or small width of the river. The small salmon are necessarily more concentrated when in the relatively narrow river than when in the broad and diverging channels of the Delta. The availability of small salmon to striped bass in the Delta during the summer might also be low because other forage fishes, particularly young-of-the-year striped bass, act as a buffer against predation on the salmon.

Relatively few small American shad were eaten by striped bass, even during the summer when small shad were quite abundant. Thomas (1966) did not find many American shad in the stomachs of striped bass either. Why more bass did not prey upon this species is unknown.

Sardine and anchovy bait were consumed with surprising frequency by juvenile and adult bass. These baits may have either been discarded by anglers or stolen from their hooks.

Young bass grew best in the lower San Joaquin River where the mysid, *N. awatschensis,* was extremely abundant. A decrease in the concentration of *N. awatschensis* here would almost certainly reduce the rate of growth and perhaps the survival of these bass. Since this zone is the most important nursery area in the Delta for young bass (see Sasaki, p. 44), such a reduction would probably seriously affect the structure of the entire bass population.

Suitable forage fishes for striped bass were scarce in the Delta during the winter and spring. Both juvenile and subadult bass fed on invertebrates during this period. The rate of growth and survival of these bass might be improved if small forage fishes were more available at this time.

Because the availability of food organisms varied with depth, bass stomach contents varied with the depth at which the bass were collected. Different sampling gear was used to collect bass at different depths; therefore, the results of this study were influenced to some extent by the proportion of the sample collected by each type of gear.

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DISTRIBUTION AND FOOD HABITS OF THE AMERICAN SHAD, *ALOSA SAPIDISSIMA*, IN THE SACRAMENTO-SAN JOAQUIN DELTA

DONALD E. STEVENS

This paper describes the distribution, migrations and food habits of the American shad in the Sacramento-San Joaquin Delta. The description is based on catches of shad in gill nets and trawls, on the estimation of gonad maturation in adult shad, and on the examination of contents of 269 stomachs of adult shad.

Adult shad were abundant in the Delta only during their spawning migration. The Sacramento and Mokelumne River systems supported larger runs than the San Joaquin River. There is evidence that while most shad spawned far upstream, some spawned in several areas in the Delta itself. The catch and gonad maturation data suggest that a large percentage of the adults die shortly after spawning, although there is also evidence that some spent shad do migrate seaward. Adult shad fed primarily on a mysid, *Neomysis awatschensis*, and copepods and cladocerans. Percentages of stomachs containing food were directly related to concentrations of food organisms in the environment.

Young shad were abundant in the Delta from July through November. Greatest concentrations occurred in the Sacramento River, Mokelumne River, dead-ends sloughs tributary to the Mokelumne River, and the San Joaquin River below the mouth of the Mokelumne River. Most of the young shad in the latter area probably originated in the Sacramento and Mokelumne rivers.

Some migrations of young shad within the Delta appeared to be related to the food supply.

METHODS

The trawling and gill netting procedures, locations of the sampling stations, and the method of estimating gonad maturation are described by Turner (see p. 12). Procedures used in the food habits analysis are the same as those described for striped bass by Stevens (see p. 68).

ADULT SHAD

Catch Analysis

Adult shad ranging in size from 20 to 55 cm FL were collected with gill nets from September 1963 through August 1964. They were abundant in the Delta only in the spring during their spawning migration (Figure 1). Catches at most stations, but especially at those stations in the Sacramento River, Mokelumne River and tributary sloughs, and Fabian and Bell Canal, increased very significantly during April and May. The catches generally decreased during June and were at prespawning season level after June.

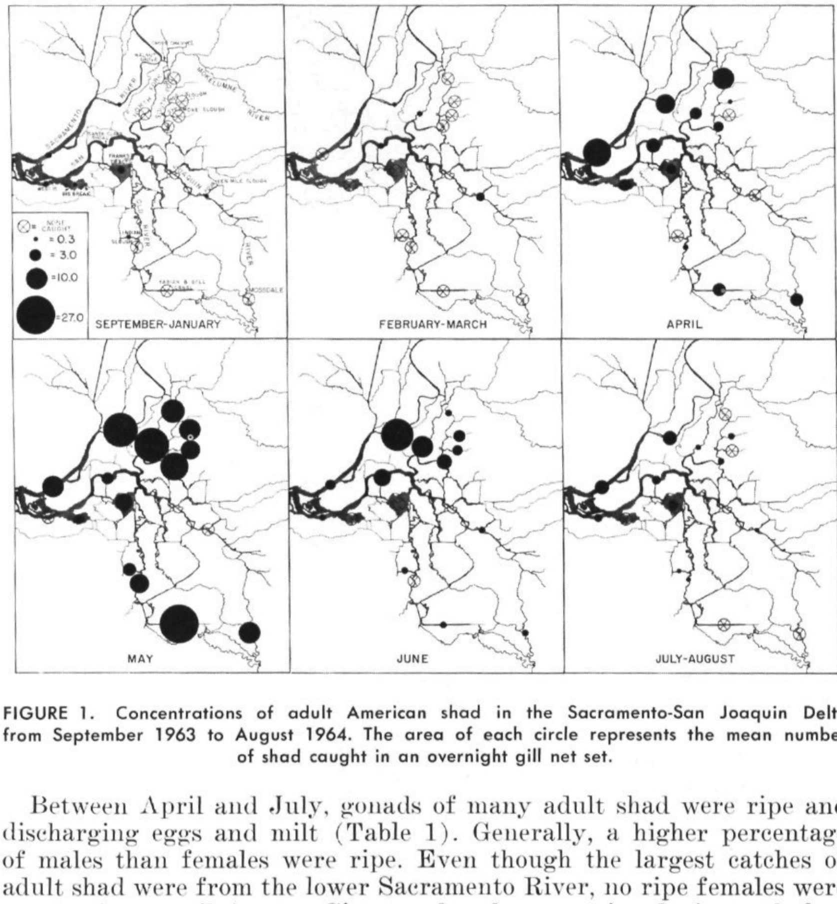

FIGURE 1. Concentrations of adult American shad in the Sacramento-San Joaquin Delta from September 1963 to August 1964. The area of each circle represents the mean number of shad caught in an overnight gill net set.

Between April and July, gonads of many adult shad were ripe and discharging eggs and milt (Table 1). Generally, a higher percentage of males than females were ripe. Even though the largest catches of adult shad were from the lower Sacramento River, no ripe females were caught there until August. Since no females were ripe during or before

TABLE 1

Sexual Maturity of Adult American Shad by Area from April to July, 1964 [1]

Area	Stage of Maturity							
	Females					Males		
	Immature	Developing	Ripe	Spent	Sample Size	Not Ripe	Ripe	Sample Size
Sacramento River	--	90.0	--	10.0	20	48.3	51.7	29
Mokelumne River	--	69.2	28.2	2.6	39	51.7	48.3	29
Old River	--	75.0	25.0	--	8	--	100.0	2
Fabian and Bell Canal	--	21.4	78.6	--	14	60.0	40.0	5
Franks Tract and Big Break	--	100.0	--	--	5	71.4	28.6	7
Hog, Sycamore and Indian Sloughs	15.0	50.0	35.0	--	20	16.0	84.0	25
San Joaquin River at Mossdale	--	33.3	66.7	--	9	25.0	75.0	8
San JoaquinRiver at West Island, Santa Clara Shoal, and Fourteen Mile Slough	--	50.0	--	50.0	8	100.0	--	11

[1] Values for stage of maturity are percentages.

the peak of this run, I believe that the shad caught in the lower Sacramento River were on their way to spawning areas upstream. Many shad spawn in the rivers tributary to the Sacramento River above the Delta. In the Feather, Yuba, and American rivers there is an excellent sport fishery on the spawning grounds. Conversely, a large percentage of the female shad caught in Fabian and Bell Canal and in the upper San Joaquin River at Mossdale were ripe, and I believe that these shad were spawning in the Delta proper. A significant but not large percentage of the female shad in the Mokelumne River and adjacent dead-end sloughs were also ripe. I believe that some of these shad spawned in the vicinity of these sampling stations, but most were on their way to the Mokelumne River above the Delta or to the Sacramento River via the cross channel at Walnut Grove.

The large catches of adult shad in Fabian and Bell Canal suggest that the south Delta may be an important producer of shad; however, few young shad were caught in this region (Figures 4 and 5). My analysis of the differences in adult shad gonad maturation between areas as related to their migrations and spawning helps to explain this disagreement. If most of the adult shad caught at the Sacramento and Mokelumne River stations were on their way upstream, a much larger percentage of the shad entering the Delta would have ascended the Sacramento and Mokelumne rivers than is indicated merely by the numbers caught there. The catches of adults in the Sacramento River, and to a lesser extent the catches of adults in the Mokelumne River, would primarily be indices of the concentrations passing by the sampling stations each night; whereas, the numbers of adults caught in the south Delta would reflect the size of the concentrations accumulating there for spawning.

The small catches of adult shad during July and August (Figure 1) suggest that a large percentage of those adults that spawn in the upper rivers succumb shortly after spawning. This suggestion is supported by the large numbers of dead, spent shad present in Sacramento River tributaries during July (Calif. Dept. of Fish and Game, unpublished). However, there is also evidence that some shad do migrate seaward after spawning. During August, I caught 5 spent female shad in the Sacramento River at Sherman Island; and in Suisun Bay in September 1963, Ganssle (1966) caught 11 spent adults. These areas are below all known spawning grounds.

Food Habits

Adult shad fed primarily on zooplankton. The mysid shrimp, *Neomysis awatschensis,* was the most important of these plankton. It occurred in stomachs more frequently than any other organism and it formed most of the total food volume (Table 2). The stomach of one adult shad contained more than 4,000 *N. awatschensis*. Copepods and cladocerans were the only other food of importance. Some stomachs contained an estimated 3,000 of these plankters. The amphipods, *Corophium stimpsoni* and/or *Corophium spinicorne*, occurred in a significant percentage of the stomachs; however, no stomach contained more than 10 individuals and I conclude that *Corophium* were not really important to adult shad.

TABLE 2

Stomach Contents of Adult American Shad

Food Item	Percent Frequency of Occurrence: Fall	Winter	Spring	Summer	Average	Percent of Total Volume
Copepods and Cladocerans	37.5	--	38.3	11.1	31.5	13.3
Mysid shrimp (*Neomysis awatschensis*)	62.5	100.0	61.7	96.3	70.1	86.6
Amphipod (*Corophium* spp.)	--	33.3	17.3	25.9	17.3	0.1
Asiatic clam (*Corbicula fluminea*)	--	--	7.4	--	4.7	--
Unidentified fish larvae	--	--	1.2	--	0.8	--
Seed	--	--	1.2	--	0.8	--
Stomachs examined	25	4	180	60	269	
Stomachs containing food	16	3	81	27	127	

The occurrence of zooplankton in stomachs of adult shad was directly related to concentrations of zoöplankton in the environment (Figure 2). Zooplankton were collected from the environment with a Clarke-Bumpus net towed for 10 minutes on the days the stomachs were collected. During April and May, stomachs of shad from the upper San Joaquin River at Mossdale, the Mokelumne River and Old River were generally empty. Zooplankton populations in these areas were low. Food was generally present in the stomachs of shad from the Sacramento River and Sycamore, Hog and Indian sloughs. Zooplankton concentrations were high in these areas. There was no relationship between the occurrence of food in stomachs and gonad maturation.

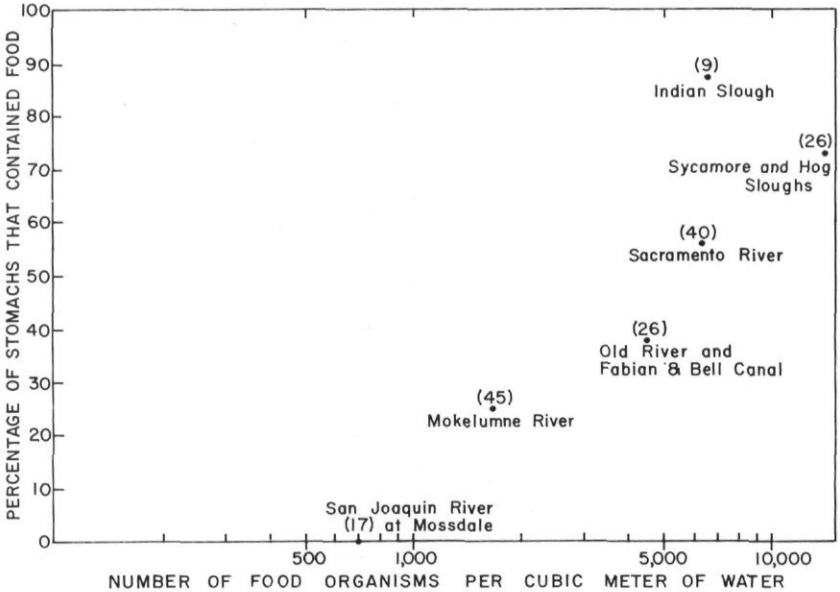

FIGURE 2. Concentrations of food in the environment compared with percentages of stomachs of adult American shad that contained food during April and May 1964. Comparisons are only for areas where more than five stomachs were examined. Numbers of stomachs examined are in parentheses.

Contrary to my findings, other biologists (Smith, 1896; Brice, 1898; Leim, 1924; Hildebrand and Schroeder, 1928; Hatton, 1940) have reported that adult shad do not actively feed while in fresh water. Mansueti and Kolb (1953) have reported that shad in the northern waters of the East Coast begin to feed soon after spawning. Atkinson (1951) has attributed the absence of food in stomachs of shad from fresh water to the size of freshwater plankton, since many freshwater plankton are probably too small to be filtered and retained by the gill rakers.

YOUNG SHAD

Catch Analysis

Shad of the 1963 and 1964 year-classes were collected with midwater and otter trawls. The mean number of shad younger than 1 year caught with the midwater trawl was 57.3 and with the otter trawl, the mean number was 3.1. The otter trawl is more efficient (see Sasaki, p. 46), so the difference in the magnitude of these catches indicates that young shad occurred primarily near the surface. In a study of the vertical distribution of fishes at the U. S. Bureau of Reclamation pumping plant in the south Delta, the U. S. Department of the Interior (1957) also found that young shad occurred primarily at the surface.

Because young shad were most concentrated at the surface, the otter trawl catch varied greatly depending on the depth of the sampling station. In deep areas the otter trawl seldom caught shad. When it was towed over shoals, the otter trawl caught as many as 233 young shad, but there it was actually straining water near the surface. Since the otter trawl fished at variable distances below the surface and the catches were generally small, only the catches of shad in the midwater trawl were analyzed in determining the abundance, distribution, and movements of young shad.

In order to follow the migration of one year-class of young shad through the Delta, data collected during July 1963 were included in my analysis of the distribution and movements of the 1963 year-class. Some exploratory trawls preceding the inception of the regular sampling program were made during that month.

Shad of the 1963 year-class were abundant in the midwater trawl catches through November 1963 (Figure 3). During July the greatest concentrations of young shad occurred in the South Fork of the Mokelumne River, and young shad were also numerous in the Sacramento River at Isleton, and in the North Fork of the Mokelumne River (Figure 4). They were fairly well concentrated in the San Joaquin River at Santa Clara Shoal, the first station below the mouth of the Mokelumne River, but concentrations at West Island, a more seaward station in the San Joaquin River, were quite low. A seaward movement of this year-class was evident in September and October. During these months large concentrations of young shad appeared in the Sacramento River and in the San Joaquin River below the mouth of the Mokelumne River. Young shad were also numerous in both forks of the Mokelumne River and sloughs tributary to the South Fork of the Mokelumne River. By November, significant numbers of young shad were caught only in the Sacramento River and in the San Joaquin River below the Mokelumne River.

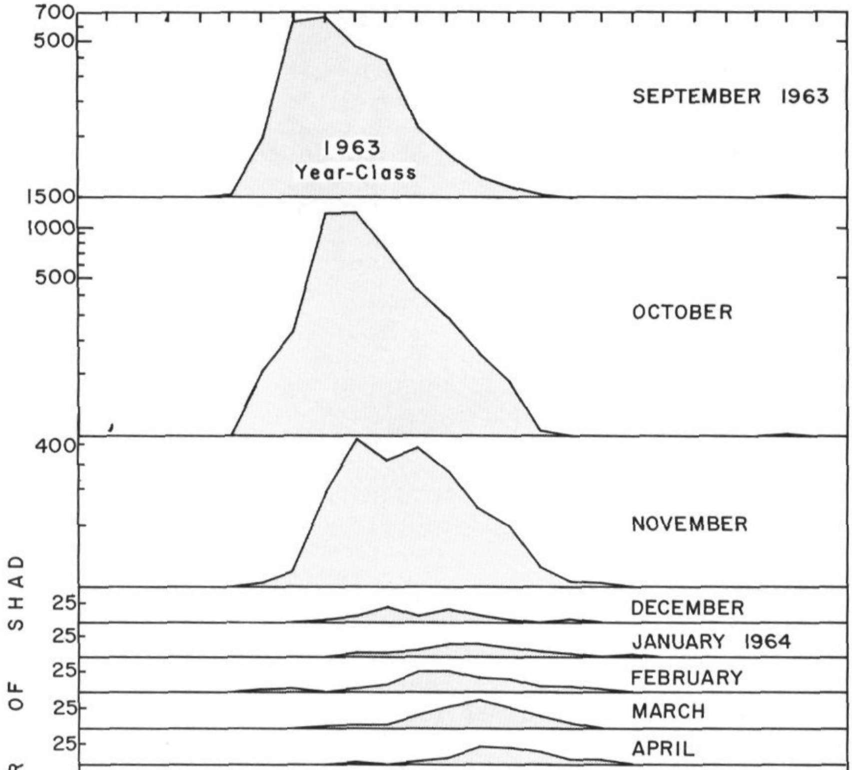

FIGURE 3. Length frequency distribution of American shad caught in the midwater trawl.

Ganssle (1966) presents further evidence that the center of the population was moving seaward. He made his largest catches of shad of the 1963 year-class in the estuary below the Delta during November

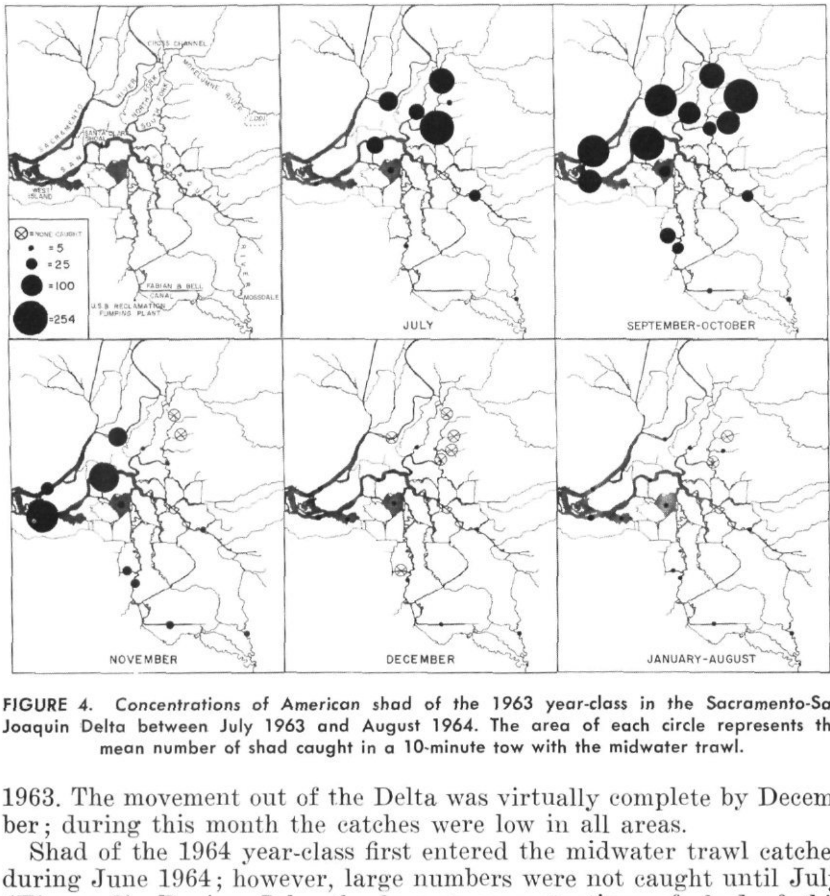

FIGURE 4. *Concentrations of American shad of the 1963 year-class in the Sacramento-San Joaquin Delta between July 1963 and August 1964. The area of each circle represents the mean number of shad caught in a 10-minute tow with the midwater trawl.*

1963. The movement out of the Delta was virtually complete by December; during this month the catches were low in all areas.

Shad of the 1964 year-class first entered the midwater trawl catches during June 1964; however, large numbers were not caught until July (Figure 3). During July, the largest concentrations of shad of this year-class occurred in the South Fork of the Mokelumne River and tributary sloughs (Figure 5). Young shad were also numerous in the San Joaquin River below the mouth of the Mokelumne River. Concentrations in the Sacramento River and in the North Fork of the Mokelumne River were relatively small. In August, the catch of young shad increased in the Sacramento River, the North Fork of the Mokelumne River, and the San Joaquin River below the Mokelumne River; however, the largest concentrations still occurred in the South Fork of the Mokelumne River where the catches of young shad also increased.

Young shad were abundant only in areas receiving the seaward flow of the Sacramento and Mokelumne rivers. During the period when they were abundant, all of the flow in the North Fork of the Mokelumne River came from the Sacramento River via the cross channel at Walnut Grove (Figure 4). No water from the Mokelumne River above the Delta was flowing down the North Fork (Calif. Dept. Water Res., Delta Studies Section, pers. commun.); therefore, all of the young shad

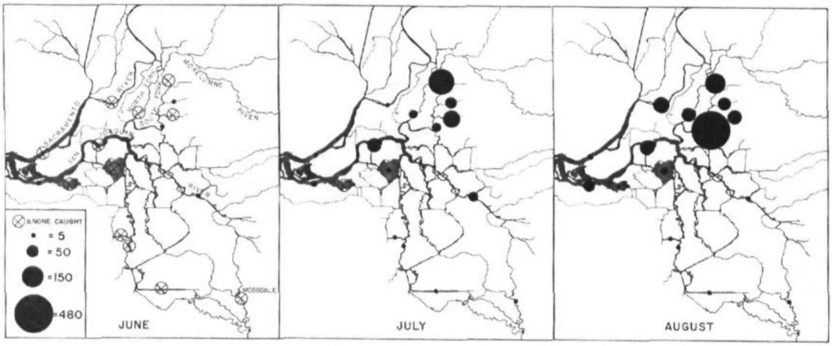

FIGURE 5. Concentrations of American shad of the 1964 year-class in the Sacramento-San Joaquin Delta between June 1964 and August 1964. The area of each circle represents the mean number of shad caught in a 10-minute tow with the midwater trawl.

caught in the North Fork were probably downstream migrants from the Sacramento.

The flow from the Mokelumne River above the Delta was small, and much of the flow in the South Fork of the Mokelumne River also came from the Sacramento River, so some of the young shad in the South Fork of the Mokelumne River were probably from the Sacramento River.

Because catches of young shad in the South Fork of the Mokelumne River during the summer were considerably larger than catches in either the Sacramento River or North Fork of the Mokelumne River during the summer (Figures 4 and 5), I believe that most of the shad caught in the South Fork were spawned in the Mokelumne River. If they had been spawned in the Sacramento River, the catches there and in the North Fork of the Mokelumne River (where the water was entirely from the Sacramento River) should have been as high or higher than the catches in the South Fork of the Mokelumne River.

It is reasonable to expect shad spawned in the Mokelumne River to arrive in the Delta earlier than shad from the Sacramento River. Any spawning in the Mokelumne River must occur close to the Delta. A dam at Lodi prevents adult shad from migrating up the Mokelumne River more than 20 or 25 miles above my sampling stations on the South Fork. The most important of the known spawning areas in the Sacramento River system is much farther above the Delta.

Food Habits

A detailed study of feeding habits of young shad was not attempted. The few stomachs that were examined contained cladocerans and copepods. Atlantic Coast studies on young shad food habits (Maxfield, 1953; McHugh, 1955; Walburg, 1956; Massmann, 1963) have shown that small crustaceans and insects are the common foods. Maxfield (1953) and Walburg (1956) thought that young shad utilized those food items which were most readily available.

SUMMARY AND DISCUSSION

Adult Shad

Between September 1, 1963 and August 31, 1964, indices of concentrations of adult American shad in various areas of the Sacramento-San Joaquin Delta were obtained with set gill nets. These indices indicated that adult shad were abundant in the Delta only in the spring during their spawning migration. By supplementing information about the numbers of adult shad caught in the gill nets with data on their gonad maturation, I interpreted similar catches in different areas to have different meanings. The numbers of shad ascending the Sacramento and Mokelumne rivers were judged to be much larger than numbers of shad ascending the San Joaquin River or entering the Delta south of the San Joaquin River.

Biologists on the Atlantic Coast (Leach, 1925; Bigelow and Schroeder, 1953; Talbot, 1954; Massmann and Pacheco, 1957) have suggested that migrations of adult shad are influenced by water temperature, but the range of temperatures at which the heaviest migrations have been reported is wide (7.7° to 18.9°C). In the spring of 1963, the California Department of Fish and Game found that the migration of adult shad into the Yuba River (a tributary of the Sacramento River system) started when minimum daily water temperatures were 10.0°C (unpublished). During my study, most of the adult shad were in the Delta while water temperatures were between 11.1° and 21.1°C.

Radtke (see p. 25) has suggested that adult striped bass on their spawning migration reacted negatively to high concentrations of dissolved solids in water originating in the San Joaquin River. Since a number of shad nearing spawning condition was caught in Fabian and Bell Canal, an area with water originating in the San Joaquin River, it appears that shad do not react negatively to this water.

A large percentage of the shad that spawn in the upper rivers apparently die after spawning. A high mortality of spent shad occurs in many other river systems. On the East Coast, almost all shad in streams south of Chesapeake Bay die after their initial spawning run (Talbot and Sykes, 1958).

Adult shad fed primarily on the mysid, *Neomysis awatschensis*, and cladocerans and copepods. The frequency of occurrence of these plankton in stomachs of shad was directly related to the degree of concentration of these plankton in the environment.

Young Shad

Indices of concentration of young shad were obtained with a midwater trawl. These indices indicated that young shad were abundant only in the Sacramento River, Mokelumne River and tributary sloughs, and in areas of the San Joaquin River receiving the seaward flow of the Sacramento and Mokelumne rivers. In 1963 and again in 1964, large numbers of young shad first entered the catch in July.

Data presented by Ganssle (1966) and my own data are evidence that young shad migrated downstream out of the Delta in September, October, and November.

Sykes and Lehman (1957) described the fall downstream migration of juvenile shad from the Delaware River. They found that the migration was dependent on the lowering of the water temperature, or an increase in water flow, or both of these factors.

Results of an unpublished study by the California Department of Fish and Game on the Yuba River suggest that the timing of the seaward migration of young shad may not be determined by temperature and/or flow. This study indicated that young shad commence their seaward migration as soon as they are hatched. Therefore, the period of the migration of young shad through the Delta may depend largely on time and area of spawning.

Some movements of young shad within the Delta may be related to local food abundance. During the fall, large concentrations of young shad were present in the dead-end sloughs tributary to the Mokelumne River (Figure 4). Turner (1966) has indicated that cladocerans and copepods were scarce in the Mokelumne River whereas they were numerous in the dead-end sloughs.

Erkkila, *et al.* (1950) sampled shad in the Delta from June through December in 1948. They reported an extensive downstream migration of young shad in late June and July, but they caught few shad after August 1. In 1963, I caught large numbers of young shad through November. The difference between my results and theirs is almost surely attributable to a difference in the efficiency of our nets. The shad caught in their nets in 1948 were smaller than those caught in the midwater trawl during 1963 (Table 3). So I believe that the tow nets used by Erkkila, *et al.*, were less efficient than the midwater trawl for sampling the larger young shad that were abundant in the fall, and the midwater trawl was less efficient in capturing the smaller shad that were abundant in the summer. I conclude that the migration of young shad through the Delta starts in late June and extends through November.

TABLE 3

Mean Lengths and Mean Numbers of Shad Caught in Tow Nets Used by Erkkila, et al. in 1948 and in the Midwater Trawl in 1963

Sampling Gear	Month		
	July	September	November
Tow net used by Erkkila, *et al.* 5 foot diameter, ¼ inch stretch mesh	3 towing cycles July 2–August 3, 1948: 2.2, 2.5, 3.3 cm; 69.5 shad per tow	2 towing cycles September 6–29, 1948: 5.9, 7.0 cm; 7.0 shad per tow	1 towing cycle November 9–12, 1948: 7.4 cm; 0.9 shad per tow
Midwater trawl—10 foot by 10 foot, cod end—¾ inch stretch mesh	July 1963: 4.6 cm; 54.0 shad per tow	September 1963: 8.5 cm; 75.4 shad per tow	November 1963: 10.6 cm; 40.6 shad per tow

In 1963 and 1964, few young shad were caught either in the upper San Joaquin River at Mossdale or in the south Delta. In 1948 and 1949, Erkkila, *et al.*, also found that shad were much more abundant in the Mokelumne and Sacramento rivers than in the San Joaquin River. No good evidence is available to explain the scarcity of shad in the San

Joaquin River drainage, but there is one obvious possibility. The shad run may be limited by irrigation diversions. A large percentage of the young shad migrate down the Sacramento and Mokelumne rivers to the Delta during the summer and early fall. In the 55-mile section of the San Joaquin River between the mouth of the Merced River and Mossdale, unscreened irrigation diversions remove much of the flow during this period. In recent years, the entire stream has been diverted during the summer by a sand dam a few miles above Mossdale. A large portion of the shad run is probably removed along with the flow.

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DISTRIBUTION AND FOOD HABITS OF KING SALMON, *ONCORHYNCHUS TSHAWYTSCHA*, AND STEELHEAD RAINBOW TROUT, *SALMO GAIRDNERII*, IN THE SACRAMENTO-SAN JOAQUIN DELTA

SHOKEN SASAKI

Young king salmon from the Sacramento River system moved downstream toward the sea through all channels of the north Delta. Most of the young king salmon caught in the south Delta probably also originated from the Sacramento River.

The downstream migration of young king salmon through the Delta peaked in May and June in 1964. There is some, but not conclusive, evidence that this migration is later now than it was in past years.

The adult king salmon and steelhead did not feed while in the Delta, but the young of both fed primarily on adult insects during their downstream journey.

KING SALMON

Adults

Adult king salmon pass through the Delta en route to their spawning grounds in the upper rivers and tributaries. They are abundant in the Delta only when this movement is in progress.

Our nets were neither designed nor set to take adult king salmon and only 50 were taken during the entire year of sampling. All were caught in the gill nets. The highest catches were in the Sacramento River during the fall when the large fall run of king salmon is migrating up the Sacramento River to spawn.

Migration of king salmon in the Sacramento-San Joaquin River system has been found at one time to occur in two distinct runs, fall and spring (Rutter, 1903; Needham, *et. al.*, 1940; Hallock, *et al.*, 1957). There was some evidence that a small winter run occurred, overlapping that of the spring (Needham, *et al.*, 1940; Hallock, *et al.*, 1957) but in recent years the winter run has expanded and its importance has increased (Dept. Fish and Game, Marine Resources Branch, pers. commun.). Hallock, *et al.* (1957) found peak numbers of king salmon at Fremont Weir on the Sacramento River above the Delta in September 1953. Van Woert (1955) reported highest numbers of adult king salmon at Fremont during the months of September and October 1954.

Forty-six of the 47 adult king salmon stomachs examined were empty. The stomach of one collected in lower San Joaquin River during July of 1964 contained eight *Neomysis awatschensis*.

Young

After spawning in the tributaries above the Delta, the adult king salmon die. The young hatch and eventually migrate downstream. These are the fish that were caught as they passed through the Delta on their way to the sea.

No young king salmon were taken in the gill nets. The smallest mesh used in the gill nets (2½″ stretch mesh) was too large to catch them.

Only 67 young king salmon were caught with the otter trawl, but 1,205 were collected with the midwater trawl. Since the midwater trawl fishes about the upper 10 feet of water, this indicates that young king salmon migrate downstream near the surface. Hallock and Van Woert (1959) found in their sampling of fingerling king salmon in the Sacramento River near Red Bluff that the greatest numbers occurred only 2 to 4 feet under the surface. Hatton (1940), sampling at Hood in the Sacramento River, found the young to occur in the upper 8 feet of water.

The largest concentrations of young king salmon occurred at Mokelumne River, Sacramento River, and lower San Joaquin River stations (Figure 1). King salmon were found throughout the year at these stations but most were taken during May and June (Figures 1 and 2). It is suspected that the majority of the king salmon taken at the Mokelumne River stations, the lower San Joaquin River stations and even the stations in Old River and Indian Slough were from the Sacramento River system. At that time of the year (May–June) the cross channel at Walnut Grove was open and most of the water in the North Fork, and about half of the water in the South Fork of the Mokelumne River, came from the Sacramento River (Dept. of Water Resources, Delta Studies Section, pers. commun.). At this time, water in Old River was also Sacramento River water flowing south (upstream) to the U. S. Bureau of Reclamation pumping plant.

Concentrations of young salmon were very low in the southern and eastern parts of the Delta (Figure 1). Almost all of the few king salmon that were caught in these areas were taken in April, May, and June.

The peak downstream movement of king salmon through the Delta occurred in May and June (Figure 2). This peak appears to occur later than it did in the past (Table 1). Rutter (1903), Hatton (1940), and Erkkila, *et al.* (1950) reported that the peak migration occurred in March. The U. S. Bureau of Reclamation fish collection facility, which screens water entering the Delta-Mendota Canal from Old River, reported peak catches of fingerling king salmon in April during 1957, 1959, and 1960, and in May during 1961, 1962, and 1964. Data from the Carquinez Strait (Messersmith, 1966) and that of our study show peak catches in May and June of 1962 and 1964, respectively.

These apparent changes may only reflect the sampling gear used. King salmon young that migrate downstream in May and June are larger, and this size fish may have avoided the nets used in the earlier studies. Evidence from Tracy fish collection facility is contrary to this. The peaks of king salmon collection there have been progressively later in recent years.

The increased average length of king salmon (Table 1) and the fact that they appear to migrate downstream later than they did several years ago do not suggest any change in the timing of the adult spawning, but rather a delay in the young moving downstream.

Hatchery king salmon releases may also affect the size of the salmon and time of runs although we do not know if the number of young

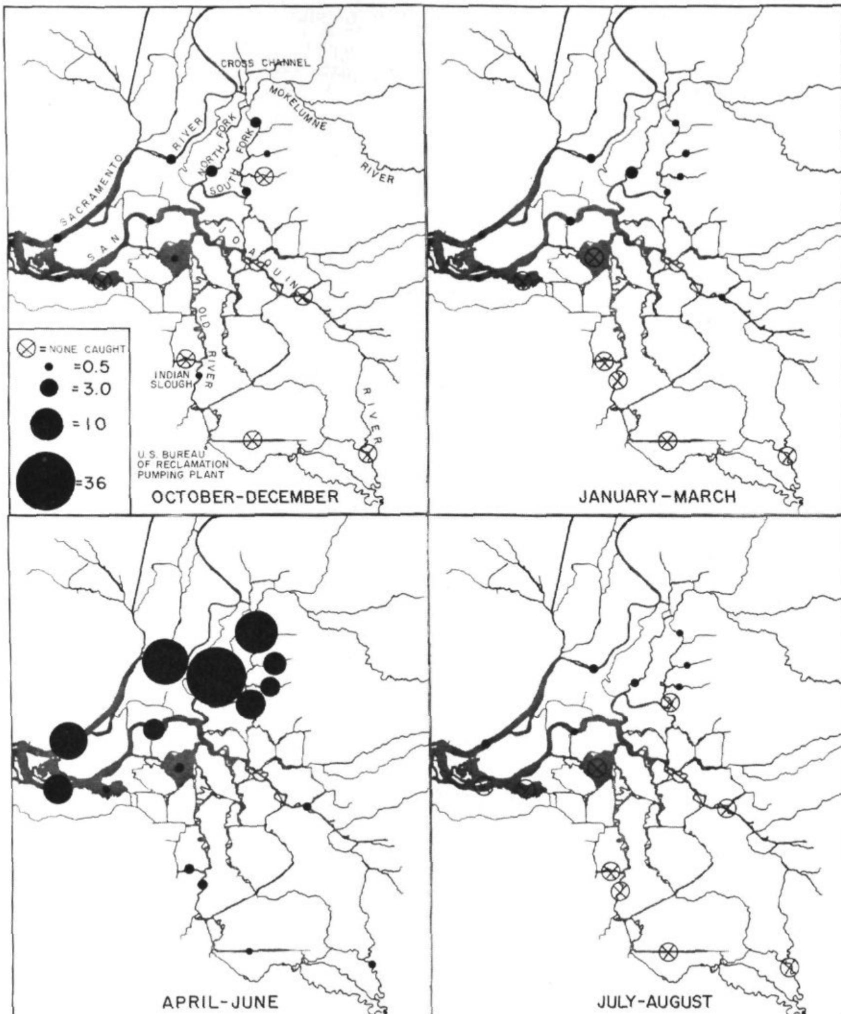

FIGURE 1. Average midwater trawl catches of king salmon downstream migrants in the Sacramento-San Joaquin Delta during 1963–1964.

salmon released from hatcheries could cause changes in the natural migration picture.

The concentration of the San Joaquin River king salmon downstream migrants was very low in comparison to that of the Sacramento River migrants in 1964 (Figure 3).

Erkkila, *et al.* (1950) collected young king salmon migrating down both the Sacramento and the San Joaquin Rivers in 1949 (Figure 3). The migration down the San Joaquin River was one to two months later than that in the Sacramento. Our catches are not comparable to

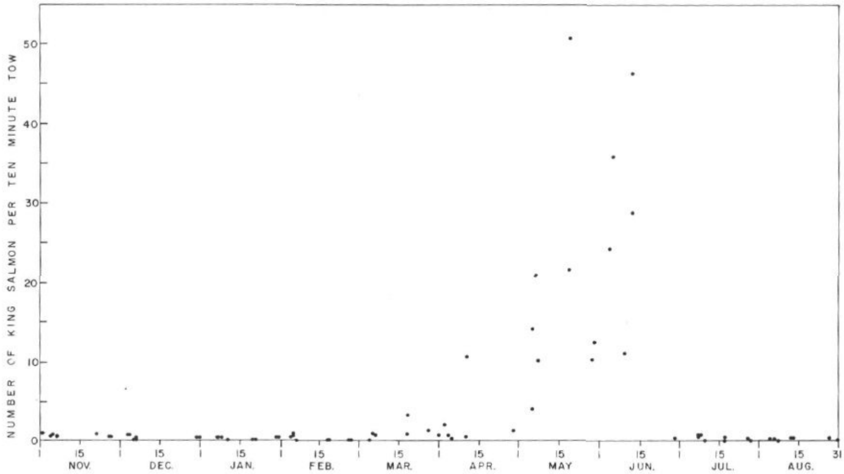

FIGURE 2. Average midwater trawl catches of king salmon downstream migrants in the Sacramento River, Mokelumne River, and lower San Joaquin River from November 1, 1963 to August 31, 1964.

Erkkila's, but the proportion of fish taken in the two rivers each year is comparable. The catch of young king salmon in the San Joaquin River during 1949 was much higher compared to that of the Sacramento River catch than it was in 1964. This reflects the well documented decline (Table 2) of the San Joaquin River runs of adult king salmon.

TABLE 1

Comparison of Peak Migration of Young King Salmon Migrants for Different Years Through the Sacramento-San Joaquin Delta

Year	Reference	Sampling Gear	Mesh Size	Station Location	Peak Migration Period	Ave. Length During Peak
1899	Rutter (1903)	Circular bag, 4 feet in diameter	½″ stretch	Walnut Grove	March	4.4 cm TL
1939	Hatton (1940)	Fyke net, 5 feet in diameter	½″ stretch	Hood	March	3.9 cm TL
1949	Erkkila, et al. (1950)	Tow net, 5 feet in diameter at mouth	½″ stretch	Five stations on Sacramento River from Walnut Grove to Pittsburg	March	3.8 cm FL
1957	U.S. Bureau of Reclamation fish collecting facility (unpub. records)	Louver screen at pumping plant	------	Old River at U.S. Bureau of Reclamation pumping plant	April	------
1959	"	"	------	"	April	------
1960	"	"	------	"	April	------
1961	"	"	------	"	May	------
1962	"	"	------	"	May	------
1962	Messersmith (1966)	25′ x 25′ midwater trawl	½″ stretch	Carquinez Strait	May-June	8.5 cm
1964	U.S. Bureau of Reclamation fish collecting facility (unpub. records)	Louver screen at pumping plant	------	Old River at U.S. Bureau of Reclamation pumping plant	May	------
1964	Delta Study	15′ x 15′ midwater trawl	¾″ stretch	Two stations on Sacramento River	May-June	8.3 cm FL

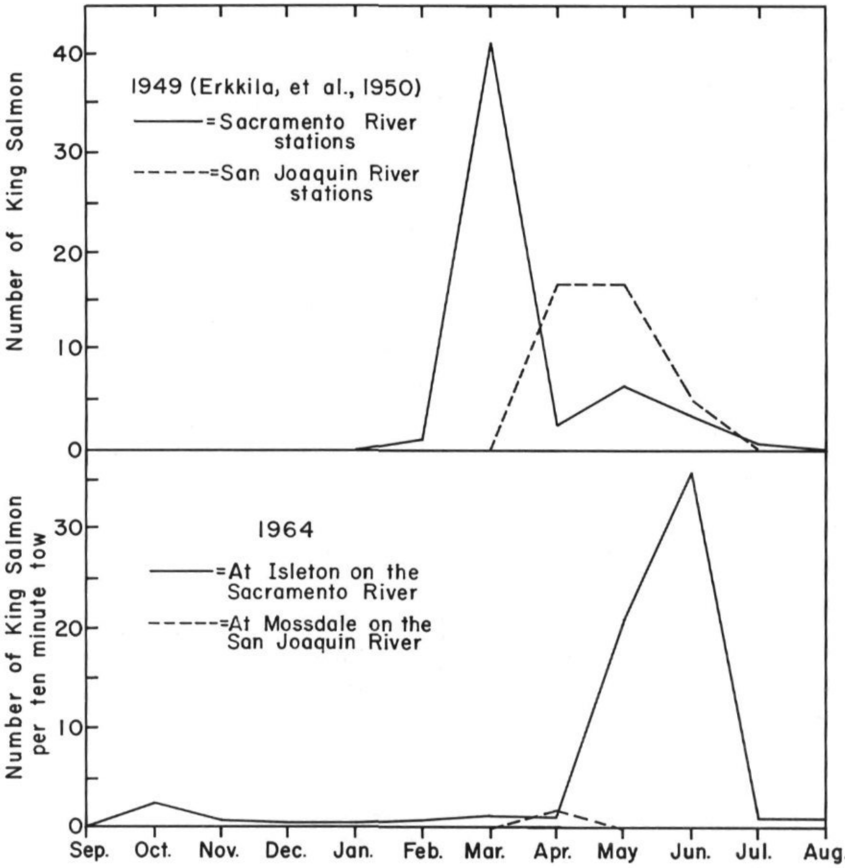

FIGURE 3. King salmon downstream migrants in the Sacramento and San Joaquin rivers for 1949 and 1964.

TABLE 2

Fall Run Adult King Salmon Population Estimates for San Joaquin River Tributaries above Mossdale in Thousands of Fish [1]

Year	Stanislaus	Tuolumne	Merced	Total
1953	35	45	*	80
1954	22	40	4	66
1955	7	20	*	27
1956	5	6	*	11
1957	4	8	*	12
1958	6	32	*	38
1959	4	46	*	50
1960	8	45	*	53
1961	2	0.5	*	2.5
1962	*	*	*	0.5
1963	*	*	*	*
1964	4	2	*	6

* Less than 500.
[1] Compiled by Marine Resources Branch, Calif. Dept. of Fish and Game.

Out of 469 young king salmon stomachs examined, 322 contained food. Insects were the primary food of young king salmon. They were found in 74 percent of the stomachs containing food (Table 3). No aquatic organism was in more than 19 percent of the stomachs. Aquatic organisms were of some local importance, however, especially tendipedid larvae and pupae in the Sacramento River at Isleton, *Neomysis awatschensis* in the lower Sacramento River, lower San Joaquin River and flooded islands, and *Corophium* spp. in the lower San Joaquin River and flooded islands. Rutter (1903) and Scofield (1913) also found insects to be the most important food item of young king salmon.

TABLE 3

Stomach Contents of Young King Salmon

Food Item	Percent Frequency of Occurrence					
	Sacramento River at Isleton	Sacramento River at Sherman Isl.	Lower San Joaquin River	Flooded Islands	Other Areas	Average and Total
Microplankton	5.0	--	10.9	22.2	0.7	5.0
Mysid shrimp (*Neomysis awatschensis*)	5.0	31.4	31.2	61.1	0.7	14.0
Amphipods (*Corophium*)	16.7	8.6	34.4	61.1	11.0	18.9
Terrestrial Arachnids	1.7	2.9	4.7	--	--	3.1
Tendipedids	46.7	2.9	6.2	11.1	9.7	16.1
Other insects	70.0	60.0	67.2	33.3	89.0	73.9
Fishes	--	8.6	1.6	--	2.1	1.9
Seeds	--	--	--	--	0.7	0.3
Stomachs examined	75	68	88	22	216	469
Stomachs containing food	60	35	64	18	145	322

STEELHEAD RAINBOW TROUT

As with the king salmon, the steelhead young and adults are only present in the Delta when they are migrating to or from the sea. Only 30 adult steelhead were caught, all with the gill net, and 15 young steelhead, mostly with the midwater trawl, during the entire year of sampling in the Delta.

Past work indicates that peak runs of adult steelhead in the Sacramento River occur in the fall as they migrate upstream to spawn (Van Woert, 1955; Hallock, *et al.*, 1957). Yearling steelhead migrate through the Delta in the largest numbers during spring. The Marine Resources Branch trawl operations in Carquinez Strait in 1961 and 1962 show peak numbers in April and May, indicating a downstream migration at that time (Messermith, 1966).

Adult steelhead probably do not feed in the Delta. Eighteen stomachs out of 19 examined were empty. The stomach of one steelhead caught in Big Break (a flooded island) contained two *Corophium* spp. Only 5 of 14 stomachs of yearling steelhead examined contained food. Of these five stomachs, four contained adult insects, two contained tendipedid larvae and pupae, and one contained a *Corophium* spp.

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DISTRIBUTION OF SMELT, JUVENILE STURGEON, AND STARRY FLOUNDER IN THE SACRAMENTO-SAN JOAQUIN DELTA WITH OBSERVATIONS ON FOOD OF STURGEON

LARRY D. RADTKE

SMELT

Two species of smelt occur in the Sacramento-San Joaquin Delta. They are the pond smelt, *Hypomesus transpacificus,* and the Sacramento smelt, *Spirinchus thaleichthys.* The former is found along the Pacific Coast from San Francisco to Alaska and Japan. The latter occurs primarily in the San Francisco Bay area and the lower Sacramento-San Joaquin Delta. Fish of both species move into the Delta in the winter and spring to spawn.

Pond Smelt

A total of 1,960 pond smelt was caught in the midwater trawl and 461 in the otter trawl during our year of sampling. A single size group, probably the 1963 year-class, dominated the catch from September through May (Figure 1). From June through August, this group diminished and young-of-the-year (1964 year-class) began to enter the catch.

In the fall of 1963, we caught few pond smelt except in the Sacramento River at Sherman Island (Figure 2). During the winter, catches at Sherman Island were lower than they had been in the fall but catches at most other stations were higher. In the spring, pond smelt were caught at all stations. Pond smelt had apparently become widely distributed in the Delta during the winter and remained so during the spring. This movement may be associated with spawning. A total of 11 ripe females were caught in February, 6 in March, 24 in April, and 8 in May. One spent female was caught in March, 6 in April, and 3 in May. In Japan, Shiraishi (1952) found that a lacustrine population of pond smelt ascended tributaries from January to March to spawn. Sato (1950) states that in the spring, pond smelt along the coast of Alaska, Siberia, and Japan ascend estuaries as far as fresh water to spawn.

In the summer catches were low except for the station in the Sacramento River at Sherman Island. About 70 percent of the pond smelt caught during June, July, and August were young of the year (Figure 1).

Sacramento Smelt

A total of 45 Sacramento smelt was caught in the midwater trawl and 51 in the otter trawl. Like pond smelt, the fish caught from December to May were predominantly of a single size group, probably the 1963 year-class (Figure 3). During the summer, the number of older fish diminished and young-of-the-year (1964 year-class) entered the catch.

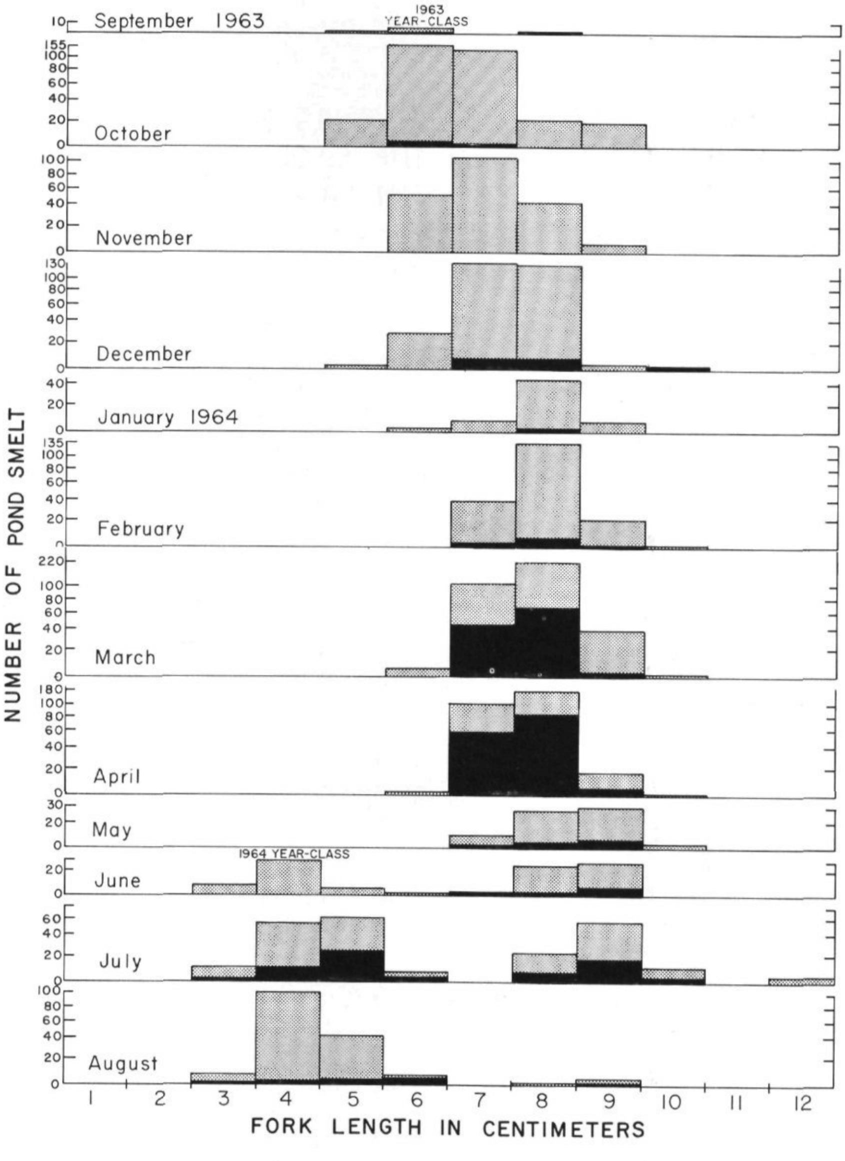

FIGURE 1. Length-frequency distribution of pond smelt caught in the Delta with midwater trawl (black) and otter trawl (shaded) from September 1963 through August 1964.

No Sacramento smelt were caught in the Delta in the fall (Figure 4). Highest catches during the rest of the year were in the western Delta.

The spawning season appears to extend from midwinter to early spring. Two ripe females were taken in December, four in January, eight in February, four in March, and one in April. One spent female

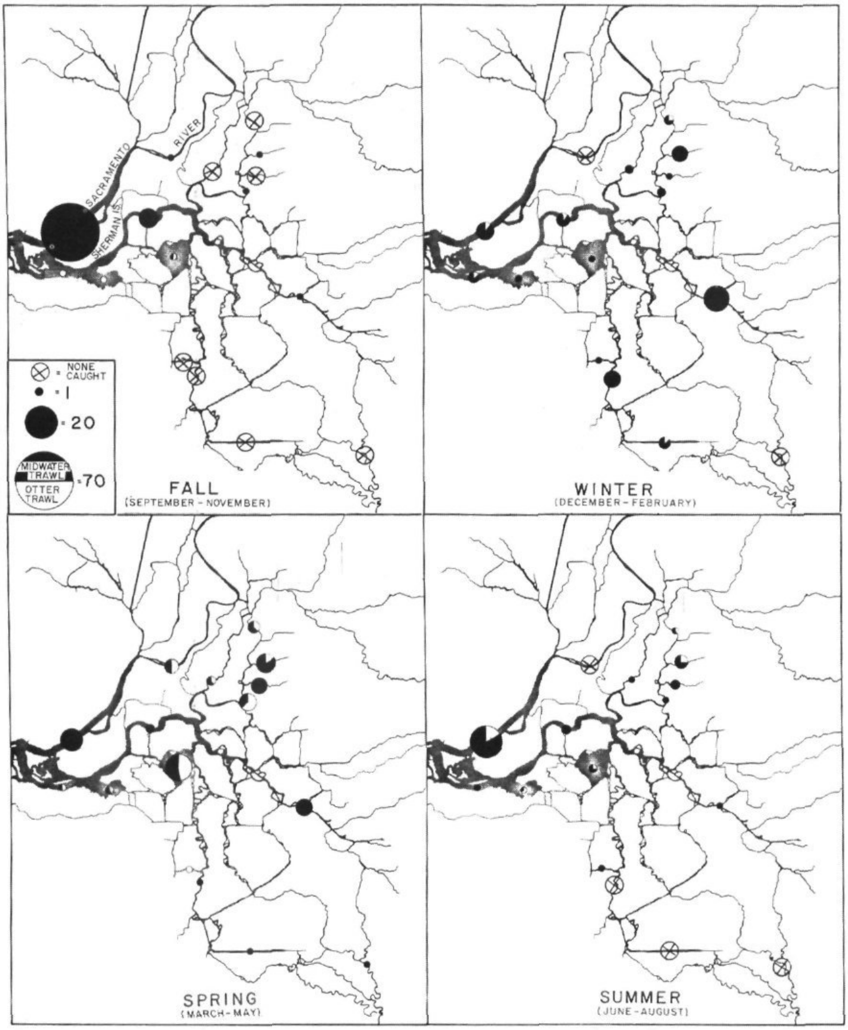

FIGURE 2. Distribution of pond smelt in the Delta. The area of each circle represents the sum of mean midwater and otter trawl catches.

was found in March. Ganssle (1966) found ripening Sacramento smelt below the Delta in San Pablo and western Suisun bays in March and April 1963.

About 87 percent of the fish caught in the Delta during June, July, and August 1964 were young-of-the-year (Figure 3).

Discussion

Our catches suggest that both species of smelt migrated upstream from the bay into the Delta during the winter. Ganssle (op. cit.) found concentrations of both pond and Sacramento smelt just below the Delta in Suisun Bay in the fall of 1963. The comparatively large catch

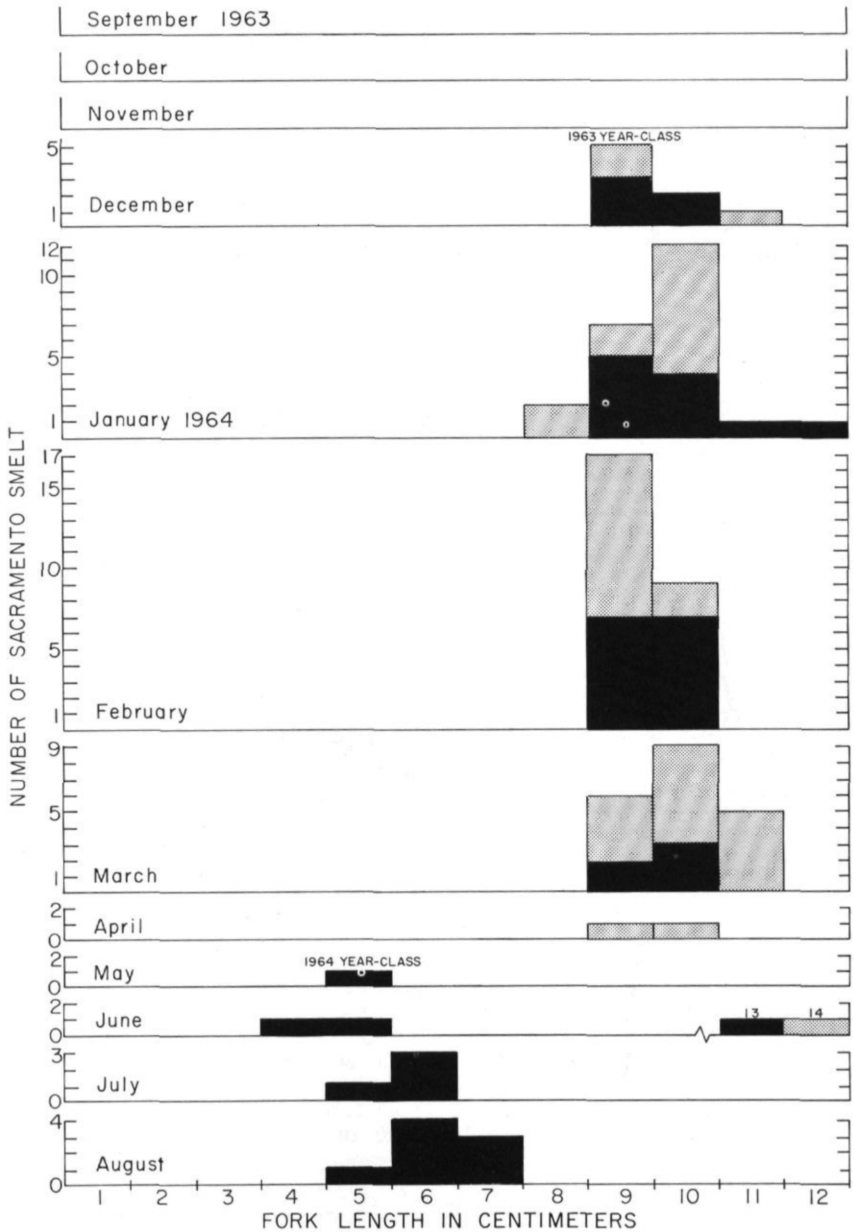

FIGURE 3. Length-frequency distribution of Sacramento smelt caught in the Delta with mid-water trawl (black) and otter trawl (shaded) from December 1963 through August 1964. None were caught from September through November.

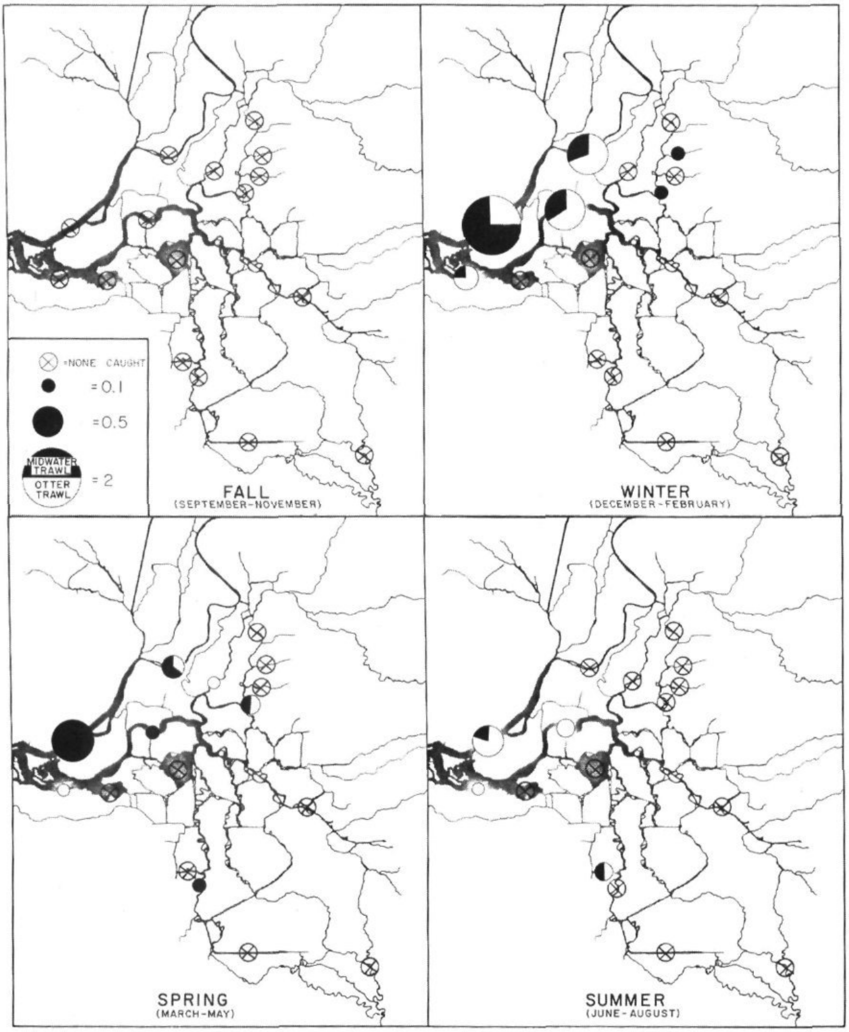

FIGURE 4. Distribution of Sacramento smelt in the Delta. The area of each circle represents the sum of mean midwater and otter trawl catches.

of pond smelt in the Sacramento River at Sherman Island in the fall probably represents part of the same concentration Ganssle found in Suisun Bay.

The fact that catches of both species of smelt were predominantly of single size groups during the spawning migration suggests that heavy adult mortality occurs sometime during the year. Few large smelt were caught in the Delta in the summer of 1964, and Ganssle (op. cit.) found few large smelt below the Delta in Suisun Bay then, although he caught many small fish. Erkkila, et al. (1950) report high numbers of young pond smelt in the Sacramento River near Sherman Island in July and August 1948. They found few adults in the Delta at that time. If most smelt lived to spawn more than once, larger size groups, or at least a wider size range, should have been found during the spawning migration and adult fish should have been caught in the Delta or bay after the spawning season.

Hart and McHugh (1944) state that there is evidence that the eulachon, *Thaleichthys pacificus,* and the surf smelt, *Hypomesus pretiosus,* die after spawning. Pond and Sacramento smelt are closely related to these species and may undergo similar mortality.

STURGEON

Two species of sturgeon are found in the Sacramento-San Joaquin Delta. They are the white sturgeon, *Acipenser transmontanus,* and the green sturgeon, A. *medirostris.* Both species are generally regarded as being anadromous, but little is known about the time or location of spawning in the Sacramento-San Joaquin River systems.

This paper deals with distribution of juvenile sturgeon only, because we did not catch adults. Juvenile sturgeon were present throughout the year in the Delta. Both species were most common in the western Delta. The major food items of both were the mysid shrimp, *Neomysis awatschensis,* and the amphipod, *Corophium.*

White Sturgeon

A total of 75 white sturgeon was caught in gill nets and 35 in the otter trawl. Three size groups were distinguishable in the catch (Figure 5). The largest individual was a 102 cm male taken in the San Joaquin near Mossdale in April. According to the growth rates measured by Pycha (1956), fish of the three distinguishable size groups were 1, 2, and 4 years old, and the largest individual was about 11 years old. No ripe sturgeon were caught. All but the largest fish were probably juveniles.

Juvenile white sturgeon were caught in most areas of the Delta, but the catches did not indicate a systematic movement (Figure 6). Over 60 percent of the total were caught in the Sacramento River.

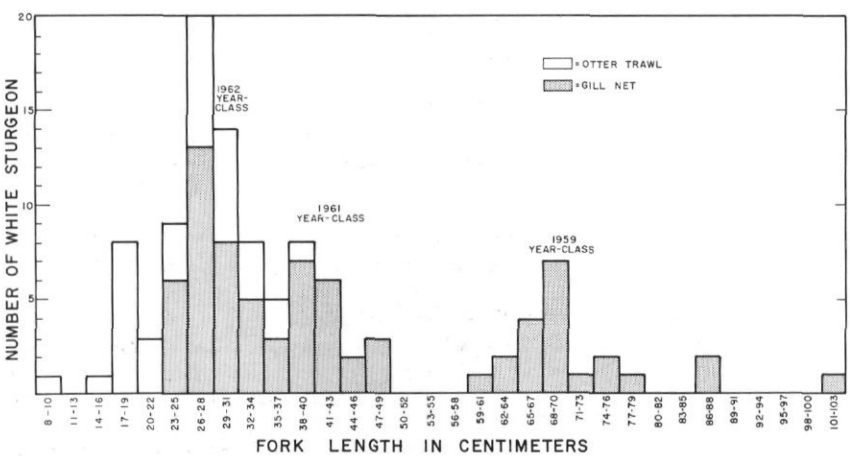

FIGURE 5. Length-frequency distribution of white sturgeon caught in the Delta with gill nets and otter trawl from September 1963 through August 1964.

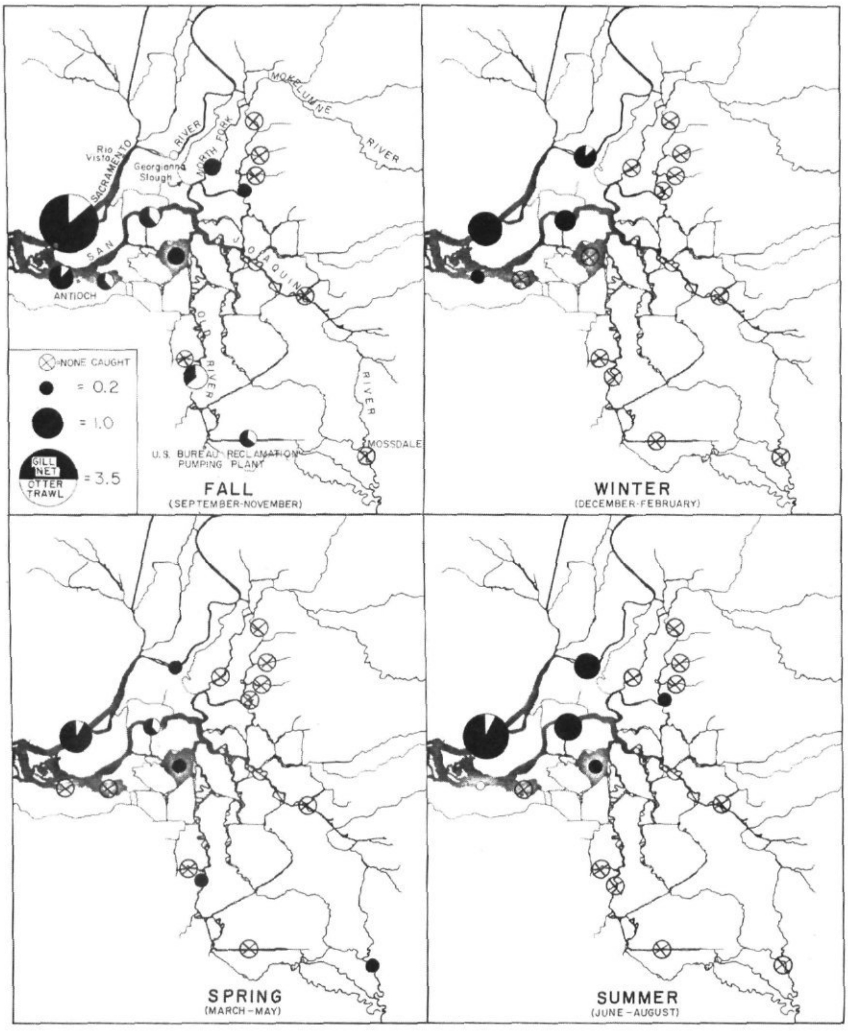

FIGURE 6. Distribution of juvenile white sturgeon in the Delta. The area of each circle represents the sum of mean gill net and otter trawl catches.

In May 1965, William Heubach (pers. commun.) caught two very small white sturgeon in a plankton net towed on the bottom at a depth of about 35 feet. One was 22 mm TL, caught in the North Fork of the Mokelumne River near its junction with Georgiana Slough, and the other was 62 mm TL, caught in the Sacramento River near Rio Vista. Turner (see page 141) reports the occurrence of sturgeon roe in the stomach of a white catfish caught in the lower San Joaquin River in April 1964.

Food Habits

Food habits of white sturgeon were determined by examining stomach contents of 105 fish caught with gill nets and the otter trawl. *Corophium* and *Neomysis awatschensis* were probably the most important foods of smaller white sturgeon (Table 1). Other foods of smaller sturgeon were polychaete worms, tendipedids, and small American shad, *Alosa sapidissima*.

Larger white sturgeon (40-102 cm) utilized *N. awatschensis* heavily throughout the year. *Corophium* were found in their stomachs in winter, spring, and summer. The only other foods found were the shrimp, *Paleomon macrodactylus,* and the Asiatic clam, *Corbicula fluminea;* both were found only in the fall.

Green Sturgeon

We caught 138 green sturgeon in gill nets and 28 in the otter trawl. Two size groups were distinguishable in the catch (Figure 7). Little is known about the growth characteristics of green sturgeon, but all those taken were probably juveniles.

Few juvenile green sturgeon were caught until summer when fairly large catches were taken with gill nets in the San Joaquin River at Santa Clara Shoal (10.5 per gill net unit on June 25, 35.5 on July 22, and 20.5 on August 26; Figure 8). Nearly all of these were caught in a shoal area where the water was about 3 to 8 feet deep.

Food Habits

Food habits were determined by examining 74 green sturgeon caught with the gill nets and the otter trawl. *Corophium* appeared to be the most important food of smaller green sturgeon. It was the only item found in the eight smaller green sturgeon (19-39 cm) examined in the fall (Table 2). None were examined in the winter. All those examined in the spring and summer had eaten *Corophium,* which made up over half the volume of their diet during these seasons. *N. awatschensis* was also utilized heavily during spring and summer. One fish examined in the spring had eaten shrimp that we could not identify.

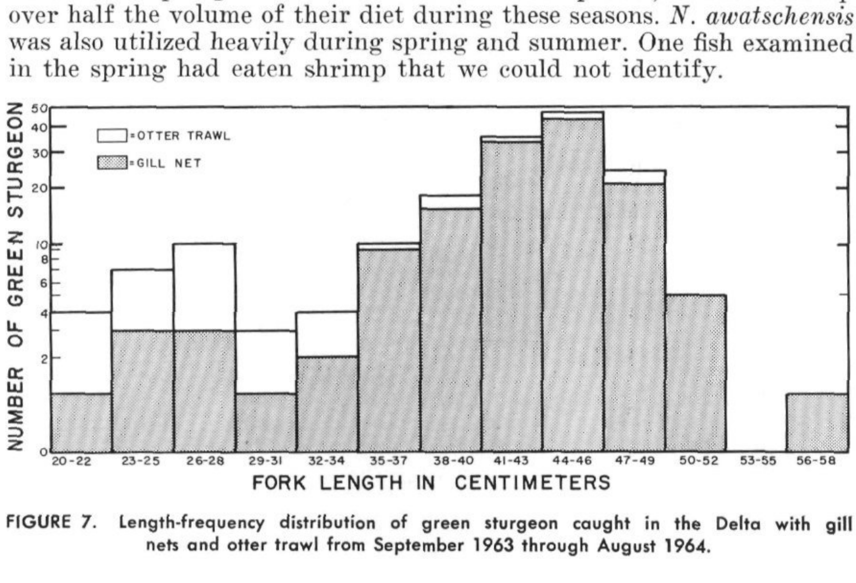

FIGURE 7. Length-frequency distribution of green sturgeon caught in the Delta with gill nets and otter trawl from September 1963 through August 1964.

TABLE 1

Stomach Contents of White Sturgeon

Food Item	19–39 cm White Sturgeon										40–102 cm White Sturgeon									
	Fall		Winter		Spring		Summer		All year		Fall		Winter		Spring		Summer		All year	
	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.
Polychaetes	--	--	20.0	7.8	--	--	--	--	1.8	0.5	--	--	--	--	--	--	--	--	--	--
Mysid shrimp (*Neomysis awatschensis*)	17.2	41.2	60.0	35.1	61.5	33.6	100.0	92.9	44.6	45.9	80.0	96.4	100.0	76.7	85.7	79.5	100.0	71.6	92.0	83.7
Amphipods (*Corophium*)	96.6	58.8	100.0	57.1	76.9	51.0	44.4	7.1	83.9	50.9	--	--	25.0	23.3	71.4	20.5	22.2	28.4	32.0	14.7
Oriental shrimp (*Paleomon macrodactylus*)	--	--	--	--	--	--	--	--	--	--	20.0	3.5	--	--	--	--	--	--	4.0	1.6
Tendipedids	--	--	--	--	7.7	0.1	--	--	1.8	Tr.	--	--	--	--	--	--	--	--	--	--
Asiatic clam (*Corbicula fluminea*)	--	--	--	--	--	--	--	--	--	--	20.0	0.1	--	--	--	--	--	--	4.0	Tr.
American shad (*Alosa sapidissima*)	--	--	--	--	7.7	15.3	--	--	1.8	2.7	--	--	--	--	--	--	--	--	--	--
Stomachs examined	35		7		18		11		71		7		6		9		12		34	
Stomachs containing food	29		5		13		9		56		5		4		7		9		19	

TABLE 2

Stomach Contents of Green Sturgeon

Food Item	19–39 cm Green Sturgeon										40–57 cm Green Sturgeon									
	Fall		Winter		Spring		Summer		All year		Fall		Winter		Spring		Summer		All year	
	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.	Pct. Freq. Occ.	Pct. Tot. Vol.
Mysid shrimp (*Neomysis awatschensis*)	--	--	--	--	40.0	38.3	75.0	43.0	50.0	33.2	--	--	--	--	100.0	99.0	78.4	86.6	78.0	86.4
Amphipods (*Corophium*)	100.0	100.0	--	--	100.0	54.7	100.0	57.0	100.0	63.9	100.0	100.0	--	--	33.3	1.0	81.1	13.4	78.0	13.6
Unidentified shrimp	--	--	--	--	10.0	7.0	--	--	3.8	2.8	--	--	--	--	--	--	--	--	--	--
Stomachs examined	8		0		10		12		30		1		0		3		40		44	
Stomachs containing food	4		0		10		12		26		1		0		3		37		41	

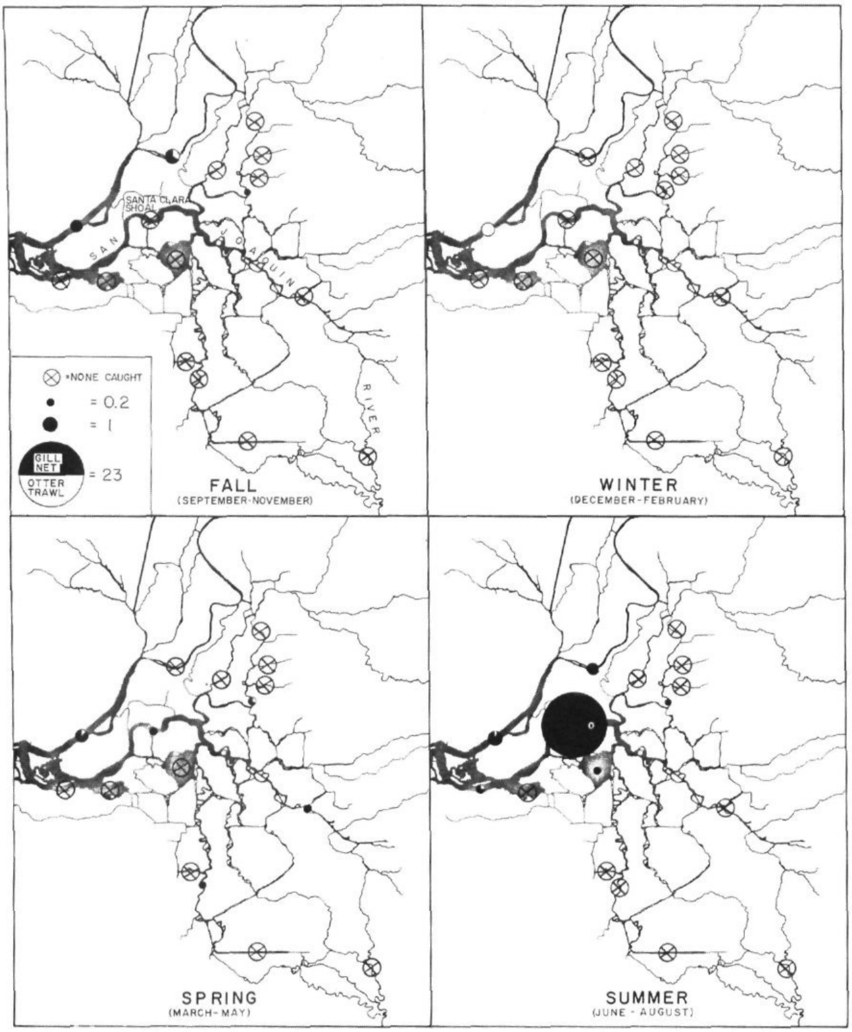

FIGURE 8. Distribution of juvenile green sturgeon in the Delta. The area of each circle represents the sum of mean gill net and otter trawl catches.

Only one green sturgeon of the larger size group (40-57 cm) was examined in the fall; it had eaten only *Corophium*. None were examined in the winter. *N. awatschensis* was utilized by all fish examined in the spring, and it made up nearly the entire bulk of their diet. In the summer more fish had eaten *Corophium* than had eaten *N. awatschensis,* but the latter made up a much greater volume of the diet than the former.

Discussion

Juvenile white sturgeon were present in the Delta all year. They were particularly common in the lower Sacramento River. Ganssle (1966) found that white sturgeon in Suisun Bay, just below the Delta, were generally smaller than those in San Pablo Bay. Pycha (op. cit.) states that white sturgeon less than 40 inches long seem to be present throughout the Delta the year round.

Bajkov (1951) analyzed tag returns and catch records from the commercial and sport fisheries in the Columbia River from Bonneville Dam to the mouth. He concluded that small and medium-size fish migrate upstream during fall and early winter and downstream during late winter and spring. He suggests that the upstream movement is a feeding migration related to the availability of salmon and lamprey carcasses in the upstream areas, and the downstream movement is associated with an abundance of smelt in the lower river during late winter and spring.

The relatively high catch of green sturgeon in the San Joaquin River at Santa Clara Shoal in the summer suggests an abrupt movement into this area. These fish probably moved upriver from the bay, perhaps to feed.

In general, bottom feeders such as sturgeon utilize food items most readily available to them. The general lack of organisms larger than *Neomysis awatschensis* in the diet in the Delta is probably due to a lack of suitable larger organisms in the environment (Hazel and Kelley, 1966). However, the Asiatic clam, which is abundant over most of the Delta, was nearly absent from our samples. In other areas, where large food organisms are available, sturgeon utilize them. For example, Ganssle (op. cit.) found larger invertebrates such as clams, *Macoma* sp., and the isopod, *Synidotea laticauda,* to be the important foods of sturgeon in San Pablo Bay, and anglers have found the bay shrimp, *Crago franciscorum,* an effective bait for sturgeon in San Pablo and Suisun bays.

The only previous study of sturgeon food habits in the Delta above the City of Antioch is that by Schreiber (1962). He collected 30 young-of-the-year white sturgeon averaging 20.3 cm FL, at the fish screens of the Bureau of Reclamation pumping plant on Old River (see Figure 6) during August, September, and October of 1956 and 1958. Of 21 stomachs containing food, *Corophium spinicorne* were in 90 percent, *Neomysis mercedis* (now *N. awatschensis*) in 10 percent, tendipedid larvae in 19 percent, and tendipedid adults in 5 percent.

STARRY FLOUNDER

The starry flounder, *Platichthys stellatus,* occupies the bays, inlets, and sounds of the Pacific Coast from the Santa Ynez River, California, to the Alaskan Peninsula. It is common in San Pablo and Suisun bays below the Sacramento-San Joaquin Delta. The role of this species in the Delta appears to be a minor one. It is euryhaline and probably ranges into the Delta from the bay area. Some spawning may occur in the Delta, and there is evidence that striped bass feed upon some of the young there (see Stevens, p. 73).

A total of 273 starry flounder was caught in the otter trawl and 2 in the gill net. Assuming that the growth rate of the fish in the Delta was similar to that of fish in Monterey Bay (Orcutt, 1950), the fish caught in the Delta from October through April were probably 1 or 2 years old. None were sexually mature.

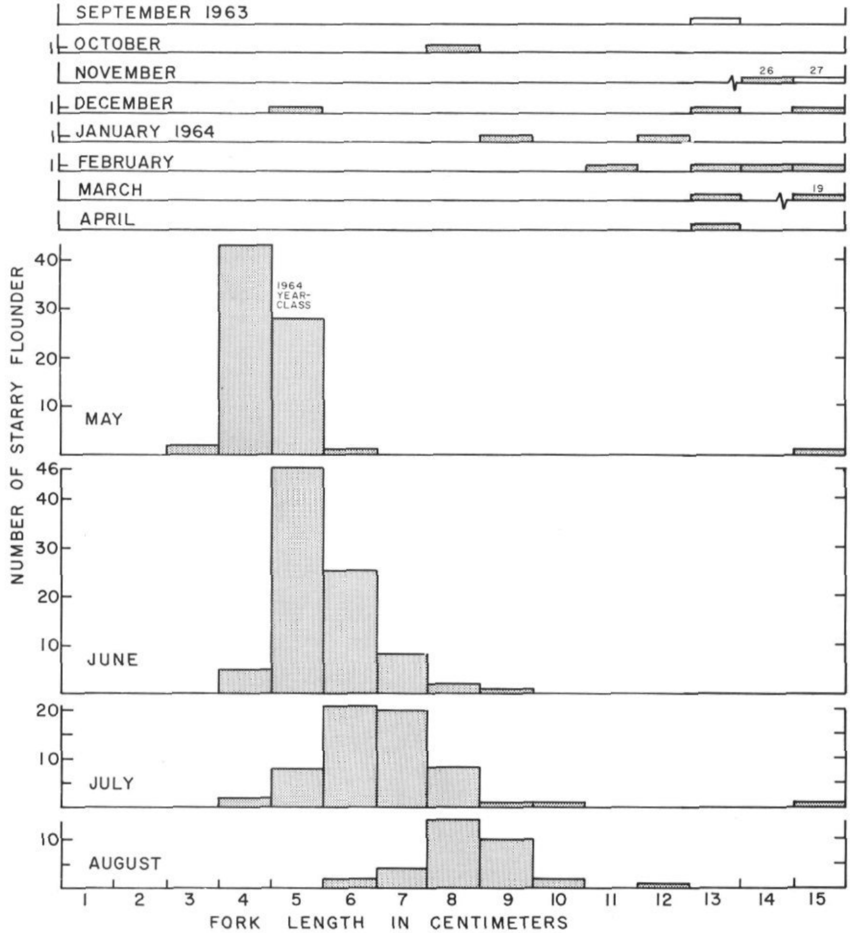

FIGURE 9. Length-frequency distribution of starry flounder caught in the Delta with otter trawl (shaded) and gill net (white) from September 1963 through August 1964.

From May through August a group of smaller fish, ranging from 3 to 10 cm TL, dominated the catch (Figure 9). Since starry flounder spawn in the winter, these were probably young-of-the-year (1964 year-class). Starry flounder occurred in most parts of the Delta, but most were taken in the San Joaquin River, the Sacramento River, the South Fork of the Mokelumne River at Terminous, and in the flooded islands, Franks Tract and Big Break in spring and summer (Figure 10). Timothy C. Farley (pers. commun.) collected some very small juveniles (8-15 mm TL) in plankton nets while towing for striped bass eggs and larvae in the lower San Joaquin River in April and May 1963 and 1964.

The starry flounder has long been regarded as being euryhaline. It is common below the Sacramento-San Joaquin Delta in Suisun and San Pablo bays (Ganssle, op. cit.) where salinities range from nearly

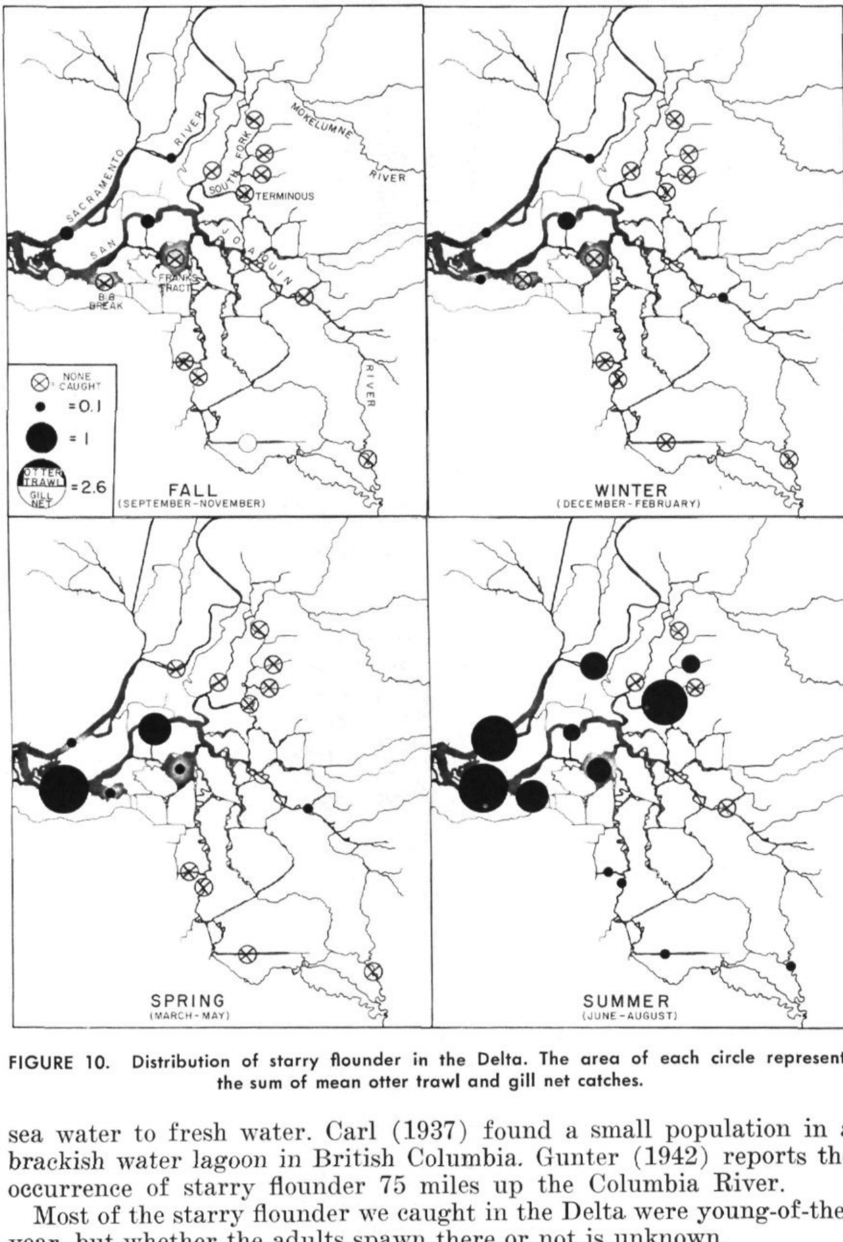

FIGURE 10. Distribution of starry flounder in the Delta. The area of each circle represents the sum of mean otter trawl and gill net catches.

sea water to fresh water. Carl (1937) found a small population in a brackish water lagoon in British Columbia. Gunter (1942) reports the occurrence of starry flounder 75 miles up the Columbia River.

Most of the starry flounder we caught in the Delta were young-of-the-year, but whether the adults spawn there or not is unknown.

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DISTRIBUTION AND FOOD HABITS OF ICTALURID FISHES IN THE SACRAMENTO-SAN JOAQUIN DELTA

JERRY L. TURNER

The number of catfish anglers in California ranks second only to those who catch trout (Ryan, 1959). The Sacramento-San Joaquin Delta is particularly important because it provides over half the catfish caught by anglers in the State. The white catfish is the most numerous species of catfish in the Delta.

This report is a description of the distribution and food habits of the four species of the Ictaluridae or catfish family that were caught during 12 months of sampling in the Sacramento-San Joaquin Delta. The catfish taken were brown bullhead, *Ictalurus nebulosus,* black bullhead, *Ictalurus melas,* channel catfish, *Ictalurus punctatus,* and white catfish, *Ictalurus catus.* None are native fish.

Each species of catfish occupies a different environment in the Delta. Both the brown and black bullheads were taken in greatest numbers in quiet waters of the dead-end sloughs. Channel catfish were concentrated in swifter water in the river channels upstream from the central Delta. Adult white catfish were most abundant in dead-end sloughs, flooded islands, and the San Joaquin River below Stockton while their young were taken in channels in the southern and eastern Delta.

All the catfish were omnivorous, feeding on whatever was available on the bottom. *Corophium, Neomysis* and tendipedids were the most frequent food items for all sizes of catfish. The importance of larger food items such as fishes and crayfish increased as the size of the catfish increased.

The growth rate of white catfish in the Delta is slow, a condition which could be due to a limited or unavailable food supply, particularly for the larger catfish.

TOTAL CATCH

Catfish were taken with the otter and midwater trawls and with set gill nets. Most of the brown bullheads, black bullheads, channel catfish and white catfish were taken with the otter trawl (Table 1). A number of older white catfish was also caught with the gill net and midwater trawl.

TABLE 1

Total Numbers of Various Ictalurids Taken With Gill Nets, Otter and Midwater Trawls

Species	Gill net	Otter trawl	Midwater trawl	Total number
Brown bullhead	7	76	6	89
Black bullhead	7	*86*	7	*100*
Channel catfish	24	540	7	571
Young-of-the-year white catfish	--	14,472	86	14,558
Juvenile and adult white catfish	2,366	7,776	576	10,718

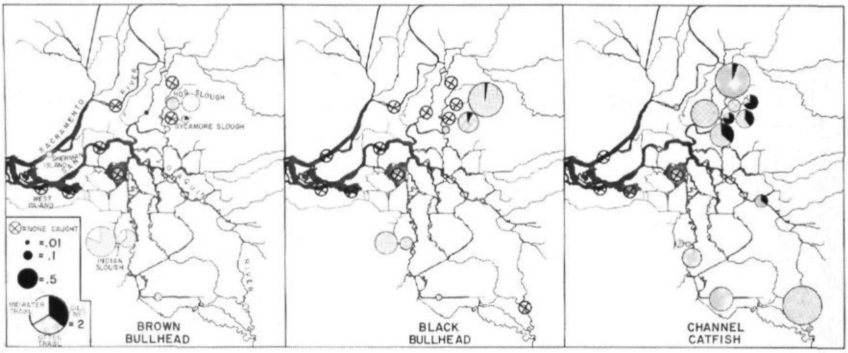

FIGURE 1. Distribution of brown bullheads, black bullheads, and channel catfish. The area of each circle is proportional to the sum of the mean catch of fish taken with the otter trawl, midwater trawl, and gill net.

The white catfish made up over 97 percent of our total catch with all types of gear.

BROWN AND BLACK BULLHEADS

Out of 189 brown and black bullheads caught in the Delta, 161 were taken from the dead-end sloughs—Hog, Sycamore, and Indian (Figure 1). Three-fourths of these were caught at the stations farthest from the mouth of the sloughs. Brown bullheads were not taken in the western Delta except for one fish caught at Sherman Island on the Sacramento River. No black bullheads were caught in the western Delta.

The brown bullheads ranged in fork length from 8 to 31 cm with an average length of 21.1 cm. The black bullheads ranged in fork length from 12 to 29 cm with an average length of 21.2 cm.

Our analysis of the stomachs of 56 brown bullheads and 60 black bullheads disclosed that they consumed a variety of benthic organisms. The most frequently found food was the amphipod, *Corophium*. They were found in 80 percent of the brown bullhead and 92 percent of the black bullhead stomachs examined (Table 2). It also made up 16.7 percent of the volume of food found in the brown bullhead and 19.3 percent of the volume of food in the black bullhead. The mysid shrimp, *Neomysis awatschensis,* and a variety of other foods including unidentified dragonfly nymphs; unidentified fishes, tendipedid larvae and pupae; crayfish, *Pacifastacus leniusculus*; amphipod, *Gammarus*; isopod, *Exosphaeroma oregonensis;* were less frequently found in the brown and black bullhead stomachs. However, dragonfly nymphs made up 40 percent of the volume of brown bullhead stomach contents, and fishes made up 40 percent of the volume of black bullhead stomach contents.

CHANNEL CATFISH

Most of the 571 channel catfish taken were caught in areas of fast water in rivers and channels upstream from the central Delta (Figures 1 and 2). No channel catfish were taken in the western Delta (Sherman Island on the Sacramento River and West Island on the San Joaquin River).

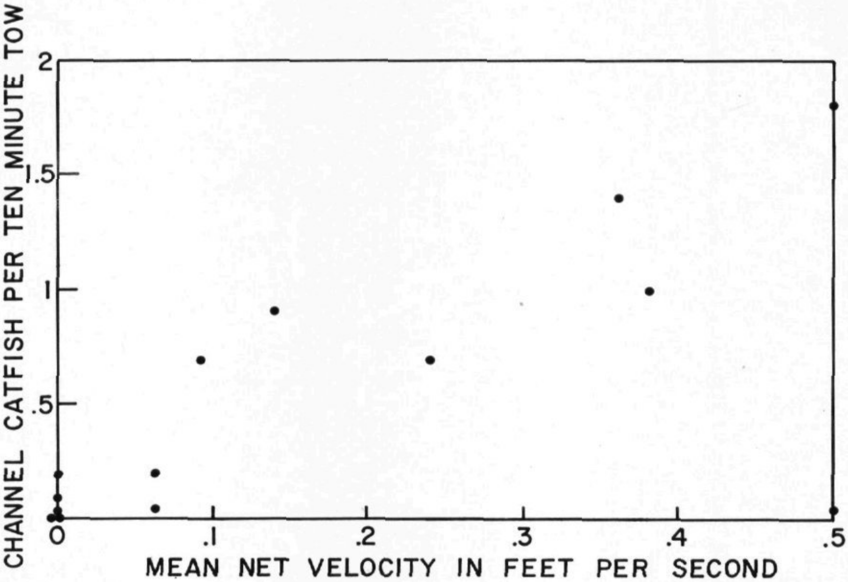

FIGURE 2. Comparison of the mean annual catch of channel catfish taken by otter trawl with the mean annual net velocity of flow at our sampling stations. Radtke (see p. 24) describes net velocity of flow.

TABLE 2

Stomach Contents of Brown and Black Bullheads

Food item	Brown Bullhead		Black Bullhead	
	Percent frequency occurrence	Percent volume	Percent frequency occurrence	Percent volume
Annelids				
Unidentified Annelids	--	--	2.1	.7
Crustaceans				
Mysid shrimp (*Neomysis awatschensis*)	31.8	2.0	52.1	3.6
Isopod (*Exosphaeroma oregonensis*)	4.5	9.1	2.1	16.5
Amphipod (*Corophium*)	79.5	16.7	91.7	19.3
Amphipod (*Gammarus*)	2.3	1.2	--	--
Crayfish (*Pacifastacus leniusculus*)	6.8	16.8	2.1	3.3
Insects				
Unidentified dragonfly nymphs	9.1	40.3	2.1	1.3
Tendipedids	9.1	.2	27.1	1.5
Other insects	4.5	2.2	2.1	.3
Molluscs				
Asiatic clam (*Corbicula fluminea*)	4.5	--	2.1	--
Unidentified snails	4.5	8.8	2.1	10.6
Fishes				
Unidentified fishes	2.3	.7	8.3	39.7
Fish eggs	2.3	1.8	--	--
Miscellaneous				
Seeds	--	--	4.2	3.3
Peat (Percent of total stomachs examined)	5.4	--	3.3	--
Stomachs examined	56		60	
Stomachs containing food	44		48	

The channel catfish ranged in size from 4 to 53 cm FL. Most were less than 15 cm in length with an average length of 12.1 cm.

Corophium was the most important food of channel catfish under 20 cm long. We found them in 94 percent of the 203 stomachs examined (Table 3). They made up 85 percent of the total volume of the stomach contents. Tendipedidae larvae and *Neomysis awatschensis* were of much lesser importance.

TABLE 3

Stomach Contents of Channel Catfish

Food item	Catfish less than 20 cm.		Catfish 20 cm. and longer	
	Percent frequency occurrence	Percent volume	Percent frequency occurrence	Percent volume
Crustaceans				
Mysid shrimp (*Neomysis awatschensis*)	13.8	3.2	13.3	0.1
Isopod (*Exosphaeroma oregonensis*)	1.1	2.5	--	--
Amphipod (*Corophium*)	93.9	85.1	80.0	1.3
Crayfish (*Pacifastacus leniusculus*)	--	--	20.0	55.0
Insects				
Tendipedids	26.5	4.6	6.7	--
Other insects	4.4	4.2	6.7	0.1
Molluscs				
Asiatic clam (*Corbicula fluminea*)	0.6	--	20.0	8.3
Fishes				
Unidentified fishes	--	--	13.3	24.9
Fish eggs	0.6	--	--	--
Mammals				
Unidentified mammal	--	--	6.7	10.4
Miscellaneous				
Seeds	0.6	0.4	--	--
Garbage	--	--	6.7	--
Stomachs examined	203		23	
Stomachs containing food	181		15	

The stomachs of 23 channel catfish over 20 cm contained a variety of benthic organisms. Small amounts of *Corophium* were in 12 of the 15 stomachs that contained food. Larger organisms such as crayfish, *Pacifastacus leniusculus;* forage fishes; and adult clams, *Corbicula fluminea* occurred in seven stomachs and formed 88 percent of the diet bulk. One catfish had consumed a small unidentified mammal.

YOUNG-OF-THE-YEAR WHITE CATFISH

More than 25,000 white catfish were caught during the year of sampling. The 1963 and 1964 year-classes were identified by a length-frequency analysis of the catch (Figure 3). The 1963 year-class grew from a range of 4 to 12 cm in September 1963 to a range of 10 to 16 cm in August 1964. The 1964 year-class grew from 2 to 5 cm long in July to 4 to 8 cm long in August.

Distribution

The major concentrations of the 1963 year class of white catfish in the fall of 1963 were in the San Joaquin River below Stockton and in Old River at Victoria Island (Figure 4). Very low numbers were

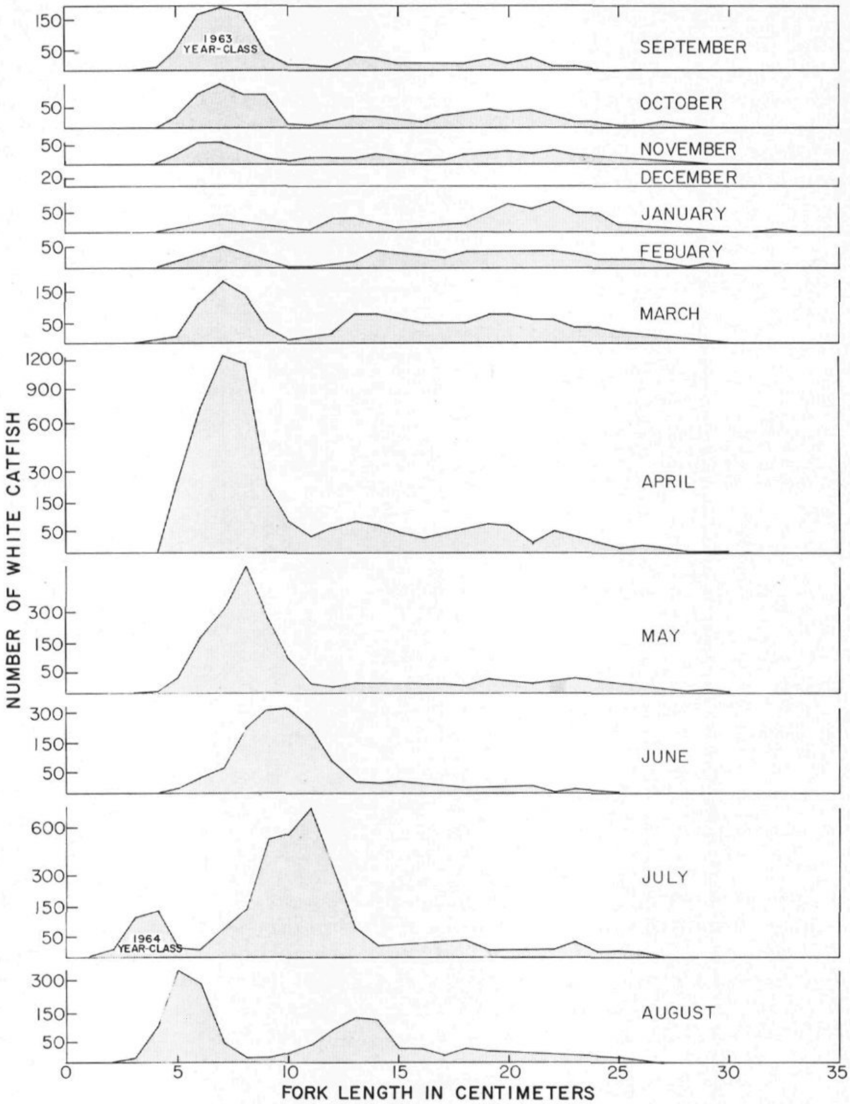

FIGURE 3. Length frequency of catch of white catfish taken by otter trawl.

caught in the western Delta and very few were taken in the northern Delta. Our catches in the winter were low at every station. The catches from March through August were very similar to the fall period. No young-of-the-year white catfish were caught in the Sacramento River at Isleton.

The 1964 year-class of young white catfish were caught in our nets only in July and August 1964. Their distribution pattern was very similar to that of the 1963 young-of-the-year in September-November

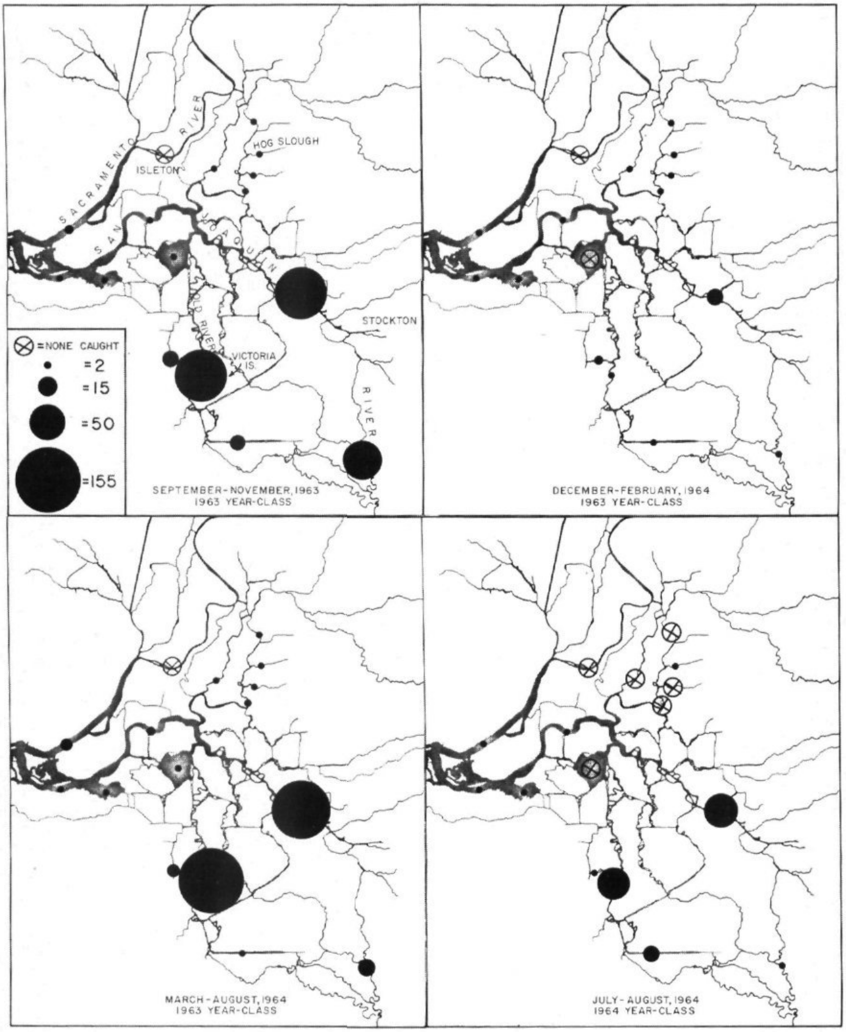

FIGURE 4. Distribution of the 1963 and 1964 year-classes of young white catfish. The area of each circle is proportional to the mean seasonal catch at each sampling station.

1963 (Figure 4). Many were taken in the south Delta, few in the western Delta, and except for one fish taken in Hog Slough, none were taken in the northern Delta. The greatest concentrations were again taken in the San Joaquin River below Stockton and in Old River at Victoria Island.

Food Habits

Our analysis of the stomachs of 967 young-of-the-year catfish disclosed that they fed almost entirely on *Corophium, Neomysis awatschensis,* and tendipedids (Table 4). *Corophium* was the most important food. It was found in 94 percent of the stomachs, and it made up 80 percent of the volume of food. *N. awatschensis* occurred in at least 10 percent of the stomachs throughout all seasons and was especially common in the diet during the summer. Tendipedids also were eaten most frequently in the summer. Four young catfish in their second summer had eaten small fish.

TABLE 4

Stomach Contents of Young White Catfish

Food item	Percent frequency of occurrence					Percent volume
	Fall	Winter	Spring	Summer	Average	All seasons
Mysid shrimp (*Neomysis awatschensis*)	13.4	10.7	17.6	31.5	21.3	12.8
Amphipod (*Corophium*)	92.0	96.0	95.9	92.9	93.9	79.3
Tendipedids	13.9	1.3	8.6	22.1	14.3	5.8
Fishes	--	--	--	1.3	0.5	2.0
Stomachs examined	227	110	283	347	967	--
Stomachs containing food	187	75	244	308	814	--

The diet of young white catfish was not the same throughout the Delta (Figure 5). *Corophium* was consumed in large numbers at every station throughout the year. *N. awatschensis* was an important food in the fall and summer at Isleton and Sherman Island on the Sacramento River and at Santa Clara Shoal and West Island on the lower San Joaquin River. Tendipedid larvae and pupae were common in the diet of the young catfish in Old River at Victoria Island and at Fabian Canal, especially during the summer and fall. They formed a significant part of the diet in the San Joaquin River at Mossdale in the fall, spring, and summer. Our knowledge of the winter diet in the San Joaquin River at Mossdale is limited. We analyzed only six stomachs that contained food; *Corophium* was the only food that had been consumed.

JUVENILE AND ADULT WHITE CATFISH

Large numbers of juvenile and adult white catfish were taken by both the gill net and otter trawl. The monthly catch with the two gears varied considerably. The monthly otter trawl catch was high in the fall and low in the summer (Figure 6). The gill net catch was less variable with increased catches from February through June.

White catfish caught in the Delta were quite small. Over 85 percent of our gill net catch was 25 cm or less FL (Figure 7). The largest fish caught was 57 cm.

Distribution

White catfish were taken at almost every sampling station with both otter and midwater trawls and gill nets (Figure 8). Catches were highest in the quiet water areas of Hog and Sycamore Slough, Franks Tract, and in the San Joaquin River below Stockton. Few catfish were taken in the fast flowing areas of the Sacramento and Mokelumne rivers. Only three white catfish were taken in over a year's sampling with all three gears in the Sacramento River at Isleton.

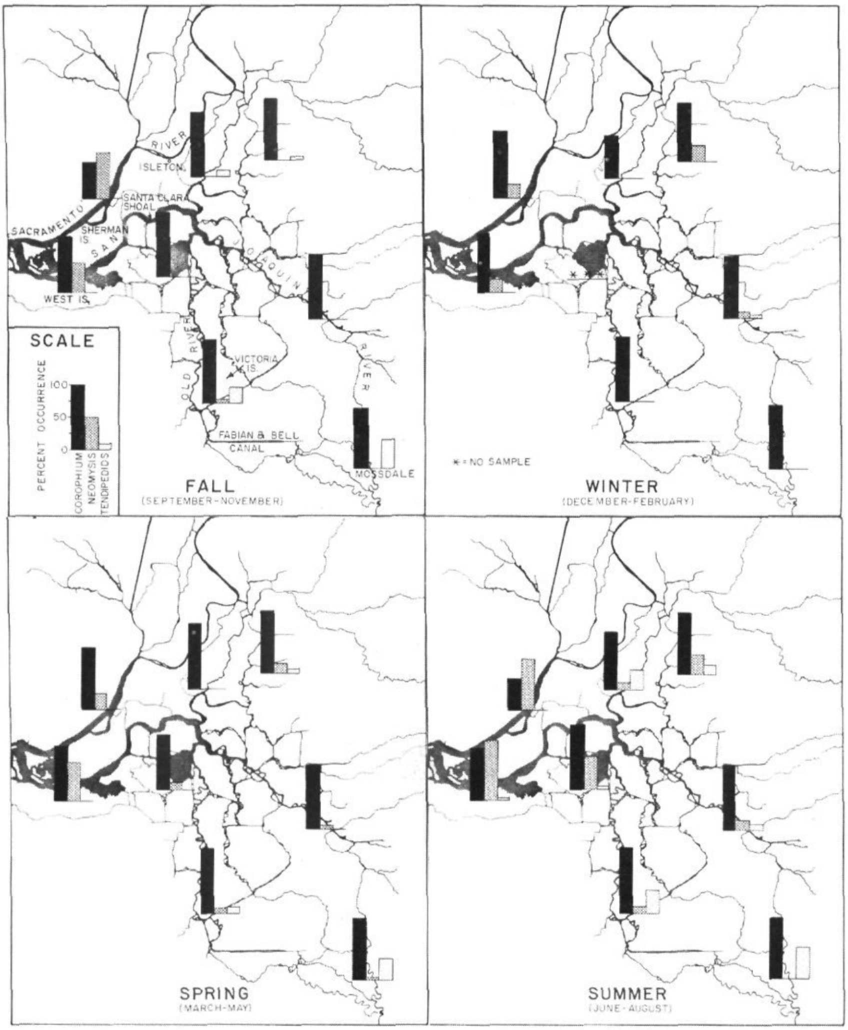

FIGURE 5. Comparison of the percent frequency of occurrence of major food items in the stomachs of young white catfish at various sampling stations in the Delta.

Time of Spawning

The first spent female that we caught was taken on June 10, 1964 at Sycamore Slough when the water temperature was 18.9° C. Most spent females were taken during July and August (Table 5). Very few white catfish were classified as sexually ripe (free-flowing eggs when the abdomen is squeezed). McCammon (1957) found that white catfish spawn in the Delta in June and July when water temperatures reach 21.1° C.

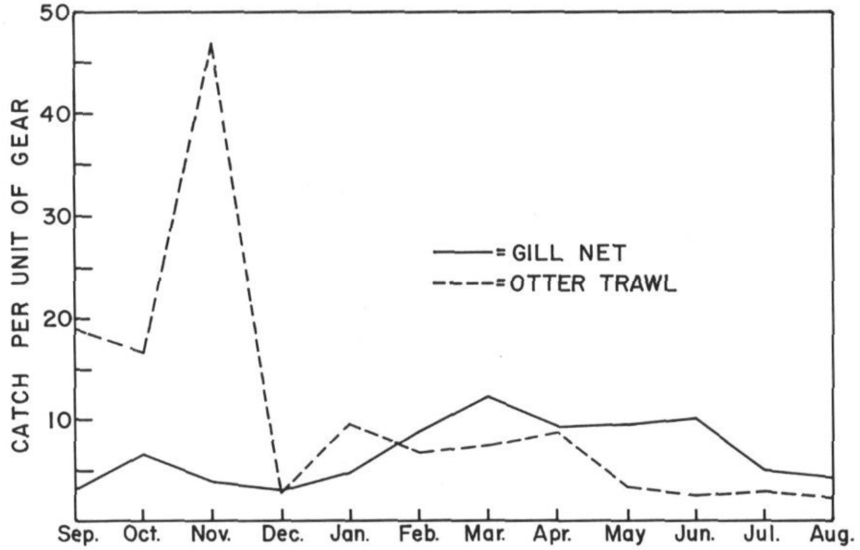

FIGURE 6. Mean monthly catch of juvenile and adult white catfish taken with otter trawl and gill net.

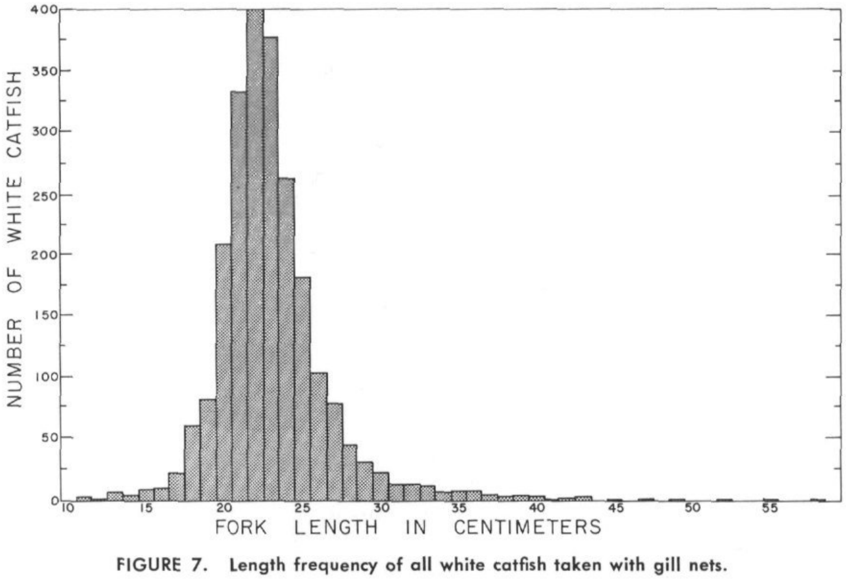

FIGURE 7. Length frequency of all white catfish taken with gill nets.

Food Habits

Our analysis of the stomachs of 3,467 juvenile and adult white catfish shows their food habits to be much more diversified than those of the young white catfish, but the same two invertebrates most common in the diet of the young (*Corophium* and *Neomysis awatschensis*)

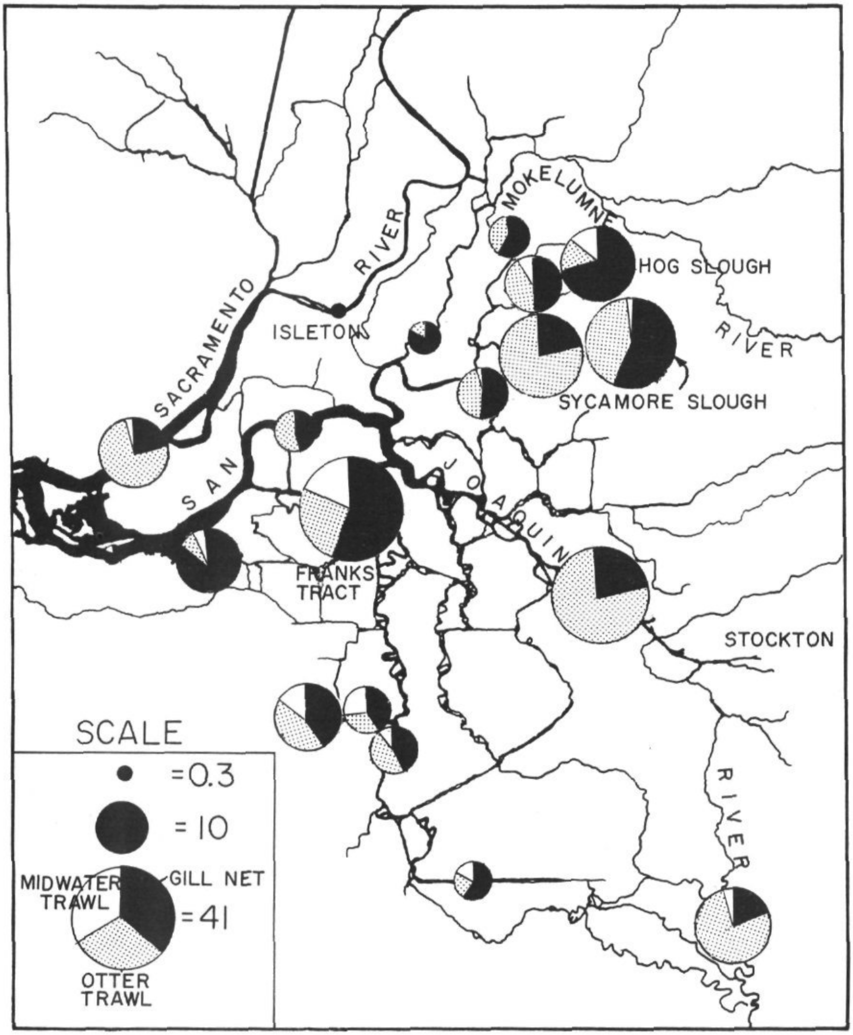

FIGURE 8. Distribution of juvenile and adult white catfish. The area of each circle is proportional to the sum of the mean catch of fish taken by otter trawl, midwater trawl, and gill net.

were the most common food of the older fish (Table 6). *Corophium* were found in more than 80 percent of all stomachs during all seasons and comprised 17.3 percent of the volume of food taken. *N. awatschensis* were found in 21 to 44 percent of the stomachs depending on the season. They were the only food items that appeared in more than 10 percent of the stomachs examined.

TABLE 5

Sexual Maturity of Female White Catfish [1]

Month	Stage of Maturity				Sample Size
	Immature	Developing	Ripe	Spent	
September	85	15	--	--	39
October	42	58	--	--	59
November	4	96	--	--	27
December	--	100	--	--	51
January	--	100	--	--	55
February	--	100	--	--	86
March	--	100	--	--	124
April	--	100	--	--	98
May	--	100	--	--	51
June	1	84	5	10	62
July	2	28	--	70	40
August	18	--	4	78	50

[1] Figures describe percent of the total Delta sample in each stage of gonad development.

TABLE 6

Stomach Contents of Juvenile and Adult White Catfish

Food Item	Percent Frequency of Occurrence					Percent Volume
	Fall	Winter	Spring	Summer	Average	All Seasons
Bryozoans						
Pectinatella	4.2	0.2	--	0.3	1.1	2.0
Annelids						
Earthworm (*Lumbricus terrestris*)	--	0.3	--	--	0.1	.1
Polychaetes	--	--	--	0.5	0.1	--
Unidentified leech	--	1.0	0.1	0.5	0.4	.1
Unidentified Annelids	--	0.3	--	--	0.1	--
Crustaceans						
Copepoda	--	--	--	0.3	--	--
Mysid shrimp (*Neomysis awatschensis*)	21.3	43.8	30.8	33.2	32.3	4.8
Isopod (*Exosphaeroma oregonensis*)	0.9	1.0	1.2	1.3	1.1	.4
Amphipod (*Corophium*)	82.3	85.4	94.5	84.0	87.6	17.3
Amphipod (*Gammarus*)	--	--	0.1	--	--	--
Crayfish (*Pacifastacus leniusculus*)	2.7	1.5	0.7	2.1	1.6	10.5
Crab (*Rhithropanopeus*)	0.5	--	--	--	0.1	.5
Unidentified shrimp	--	0.2	--	0.3	0.1	.1
Insects						
Tendipedids	5.6	8.0	6.3	7.3	6.7	.9
Other Insects	2.0	1.6	1.0	2.1	1.6	.6
Molluscs						
Asiatic clam (*Corbicula fluminea*)	3.4	3.8	4.4	8.4	4.7	6.1
Unidentified slugs	0.4	--	--	--	0.1	.8
Unidentified snails	0.5	0.2	0.1	--	0.2	.1
Vertebrates						
Sardine bait	0.5	2.6	1.0	--	1.1	6.8
Fishes	2.3	3.8	2.0	5.8	3.1	40.8
Fish eggs	--	--	0.4	0.3	0.2	.4
Unidentified lizard	--	0.2	--	--	--	.4
Bird remains	--	0.3	0.1	0.3	0.2	2.9
Mammal remains	0.2	0.5	0.5	--	0.3	3.0
Miscellaneous						
Seeds and berries	1.6	0.2	--	1.6	0.7	1.1
Bone	--	--	0.2	--	0.1	.4
Paper	0.2	--	--	--	--	--
Peat (Percent of total stomachs examined)	13.5	10.7	11.6	8.5	11.4	--
Stomachs examined	936	826	1,060	645	3,467	--
Stomachs containing food	554	610	815	382	2,361	--

Fishes did not occur in more than 5.8 percent of the stomachs during any season and appeared in only 3.1 percent of all the stomachs we examined. However, 41 percent of the total volume of the stomach contents were fish. Most of the fishes were consumed by white catfish larger than 20 cm. They included *Dorosoma petenense, Alosa sapidissima, Roccus saxatilis, Hypomesus olidus, Lampetra ayresi, Clupea pallasi,* and *Lepomis macrochirus.*

Crayfish occurred in relatively few stomachs but formed a large portion of the diet bulk. Often, only chelipeds or walking legs were found in the stomachs.

During the fall, white catfish in dead-end sloughs ate the bryozoan, *Pectinatella* sp. Sometimes only the statoblasts were present in stomachs. *Pectinatella* was not eaten in other environments.

Other items consumed include the clam, *Corbicula fluminea;* sardine bait; the crab, *Rithropanopeus* sp.; aquatic snails; terrestrial slugs; insects; seeds and berries; and annelids including leeches and the earthworm, *Lumbricus terrestris.* Some of the larger catfish had eaten small mammals and birds. One stomach contained a pair of coot, *Fulica americana,* feet. Another catfish consumed an unidentified lizard. Approximately 3 cc of sturgeon (*Acipenser* sp.) roe was in the stomach of a catfish taken during April in the lower San Joaquin River. Quantities of peat and other vegetable matter were often in stomachs. It is not known if this material was ingested intentionally, or if it was eaten accidentally while the catfish were foraging on benthic items.

As with young white catfish, the diet of older white catfish varies throughout the Delta. *Corophium,* the most important food, was eaten frequently at every sampling station (Figure 9). *Neomysis awatschensis* was common in their diet in the western Delta throughout the year particularly at Sherman Island on the Sacramento River and at West Island on the San Joaquin River. It was never a common item in the diet of catfish taken at Mossdale on the San Joaquin River. Fishes were never a common item in the diet of older white catfish. They did appear most frequently in the stomachs of white catfish in dead-end sloughs and in the San Joaquin River below Stockton. They occurred least frequently in the diet of catfish in the Mokelumne River.

DISCUSSION

The four species of Ictalurids occupy somewhat different environments in the Delta. The channel catfish were found in swift water situations where few bullheads or white catfish were caught. The bullheads, both brown and black, were most common in dead-end sloughs. Their distribution in the Delta was very similar to the distribution of Centrarchids (see Turner, p. 145). White catfish were also common in dead-end sloughs as well as flooded islands and the San Joaquin River below Stockton. No bullheads or channel catfish were caught in flooded islands and very low numbers were taken in the San Joaquin River below Stockton.

Both channel catfish and bullheads appear to avoid the western Delta. Ganssle (1966) reported that he caught no channel catfish and only two bullheads in over 18 months of sampling in the estuary below the Delta. McCammon and LaFaunce (1961), following an extensive

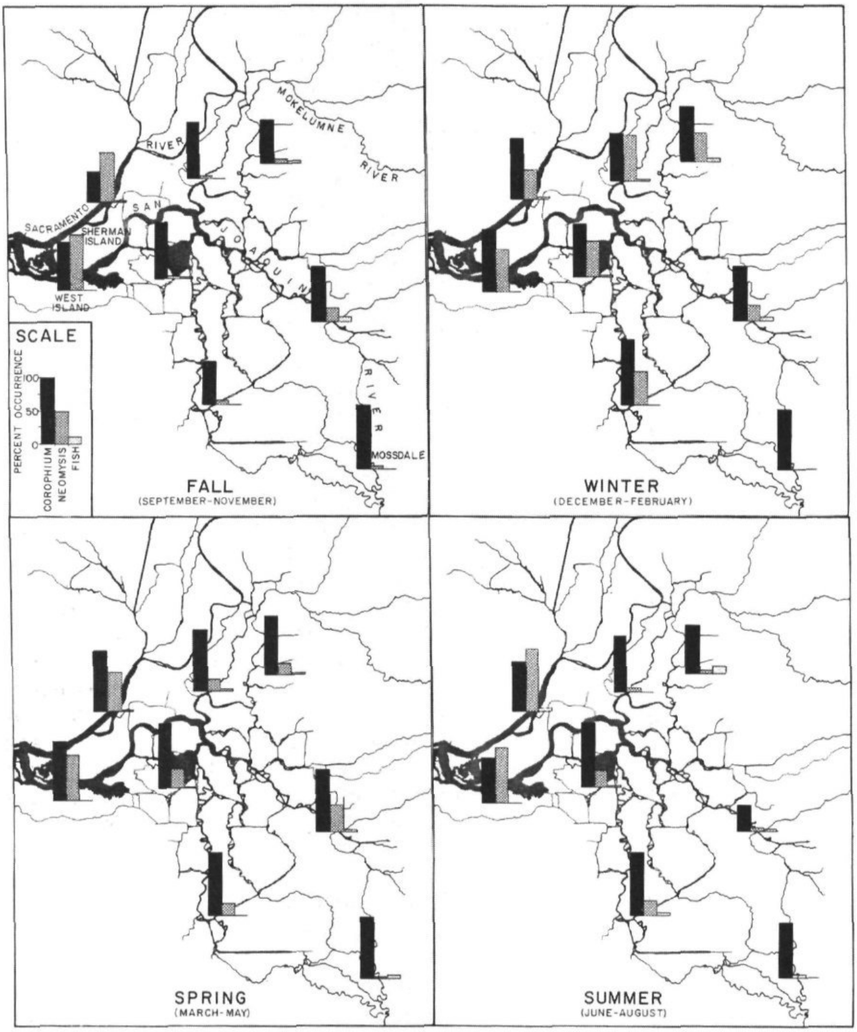

FIGURE 9. Comparison of the percent frequency of occurrence of major food items in the stomachs of juvenile and adult white catfish at various sampling stations in the Delta.

tagging study in the Sacramento River, felt that channel catfish avoided the western Delta due to brackish water intrusion.

Most of the channel catfish taken were small and were caught near the edge of the Delta. These fish may have moved down from the rivers above the Delta. McCammon and LaFaunce (1961) reported that a sizable fishery for channel catfish exists in the Sacramento River some 50 miles above the Delta.

White catfish exhibit a much greater tolerance for brackish water than the other catfish. Ganssle (1966) reported limited catches of white catfish in the estuary downstream from our sampling area. In the eastern United States the white catfish are common in the coastal streams.

McCammon (1957) found that the growth rate of white catfish in the Delta was steady but very slow. This might be due to a limited or unavailable food supply, particularly of a suitable size for the larger catfish. Comparison of the total lengths of various age-groups of white catfish from the Santee-Cooper Reservoir in South Carolina (Stevens, 1959) with the fork lengths of various age groups in the Sacramento-San Joaquin Delta (McCammon, 1957) indicates that the growth rate for the first two years of life in both areas is similar but the older fish grow much faster in Santee-Cooper Reservoir. A 4-year old fish was 10.7 inches long in Santee-Cooper Reservoir compared to 8.5 inches in the Delta; a 9-year old fish was 18.5 inches long compared to 14 inches. Stevens also found that fish were consumed by 64.4 percent of *all* the white catfish taken in the Santee-Cooper Reservoir. We found fish in the stomachs of only 5.8 percent of the *older* white catfish taken in the Delta during the season when they fed most heavily on fish.

We found very little change in frequency of occurrence of certain food items in the diet with increased size of the white catfish; the same two invertebrates most frequent in the stomachs of young-of-the-year white catfish were also most frequent in the diet of the older fish. Ivlev (1961) reported that predatory fish prefer to devour victims of the largest possible size so that they obtain optimum growth for the energy expended. Prey of smaller sizes also serve as food but as the prey gets smaller and are thus further from the optimum size, they are pursued with less intensity. Nikolsky (1963) found that young pike feed on planktonic crustaceans but very soon the amount of energy expended on the capture of the crustaceans starts to exceed their caloric value, and the pike begins to feed on fish. If the pike is retained on planktonic crustaceans, it gradually ceases to grow.

Why the larger white catfish in the Delta do not feed more on fish is unknown. Perhaps forage fish are unavailable. The Delta is very turbid, with Secchi disk readings, varying from 5.1 to 35.4 inches during our study. Although catfish are not generally considered "sight feeders", the poor visibility in the Delta could affect their ability to capture fish, thereby restricting their diet to the more easily captured invertebrates. This could result in poorer growth.

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DISTRIBUTION AND FOOD HABITS OF CENTRARCHID FISHES IN THE SACRAMENTO-SAN JOAQUIN DELTA

JERRY L. TURNER

Members of the centrarchid or sunfish family taken in the Sacramento-San Joaquin Delta were black crappie, *Pomoxis nigromaculatus,* white crappie, *Pomoxis annularis,* bluegill, *Lepomis macrochirus,* warmouth, *Chaenobryttus gulosus,* largemouth bass, *Micropterus salmoides,* green sunfish, *Lepomis cyanellus,* and Sacramento perch, *Archoplites interruptus.* The only native representative is the Sacramento perch; all the others were introduced years ago.

The major concentrations of centrarchids were found in the quiet sloughs off the main channels. Black crappie, bluegill, and warmouth were the most abundant species caught. Only a few green sunfish and largemouth bass were taken. The Sacramento perch and white crappie were extremely rare. Most of these centrarchids were unusually small, a condition that could be a result of the turbid water in the Delta. Their food habits are similar to that reported by workers in other areas except that a mysid shrimp and amphipods are the major invertebrates eaten rather than aquatic insects.

DISTRIBUTION AND CATCH

Centrarchids were sampled with the otter and midwater trawls and gill nets but most were taken with the trawls (Table 1). Very few centrarchids were collected with gill nets.

TABLE 1

Total Number of Black Crappie, Bluegill and Warmouth Taken With Gill Net, Otter Trawl and Midwater Trawl

Species	Gill Net	Otter Trawl	Midwater Trawl	Total Number
Black Crappie	428	4,860	3,096	8,384
Bluegill	87	2,700	288	3,075
Warmouth Bass	17	216	7	240

The seasonal catch with all three sampling gears fluctuated considerably (Figure 1). Otter trawl catches were highest from September through January and midwater trawl catches were highest from February through June. The gill net catches were consistently low throughout the year.

The centrarchids collected in the Delta were unusually small (Figure 2). Only a third of the black crappie and very few warmouth and bluegill were over 20 cm (8 inches) FL.

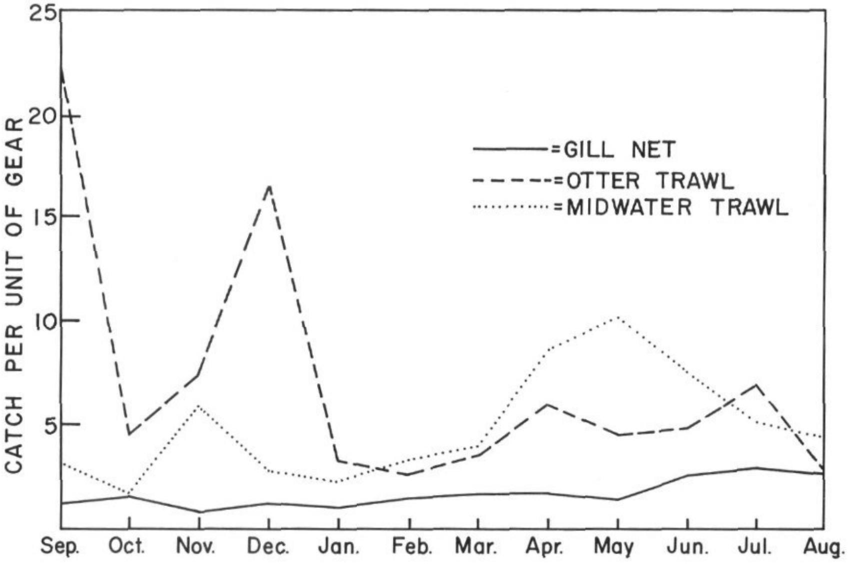

FIGURE 1. Average monthly catch of centrarchids taken with otter trawl, midwater trawl, and gill net.

A total of 10,670 out of 11,699 black crappie, bluegill and warmouth bass caught in the Delta were taken in the dead-end Hog, Sycamore and Indian sloughs (Figure 3). Two-thirds of these were caught at the upper-most sampling station in these sloughs. Very few were taken from any other area in the Delta.

Largemouth bass were commonly caught by anglers in limited areas in the Delta but we caught only 34 in our sampling. One was taken with the otter trawl and one with the midwater trawl in 12 months of sampling. Thirty-two largemouth bass were taken with gill nets. Twenty-four of these were caught in Hog, Sycamore, and Indian slough (all dead-end sloughs).

Only 15 green sunfish were caught in the Delta of which 12 were taken in Hog, Sycamore, and Indian sloughs.

One white crappie and one Sacramento perch were taken during our sampling. The white crappie was caught in April at Mossdale on the San Joaquin River and the Sacramento perch was caught in May in Sycamore Slough. The Sacramento perch, the only native centrarchid, was considered very numerous in the sloughs and slow moving channels of the Delta in the early days. Rutter (1907) reported that they were becoming rare.

FOOD HABITS

Food Habits of Black Crappie

The food habits of black crappie were described by examining the stomachs of 1,476 fish. So that diet could be related to fish size, each fish was classed as belonging to one of three size groups: "small" (5 to 10 cm), "medium" (11 to 20 cm) and "large" (> 21 cm).

The mysid shrimp, *Neomysis awatschensis,* and amphipods, *Corophium,* were the most common food items of all sizes of black crappie.

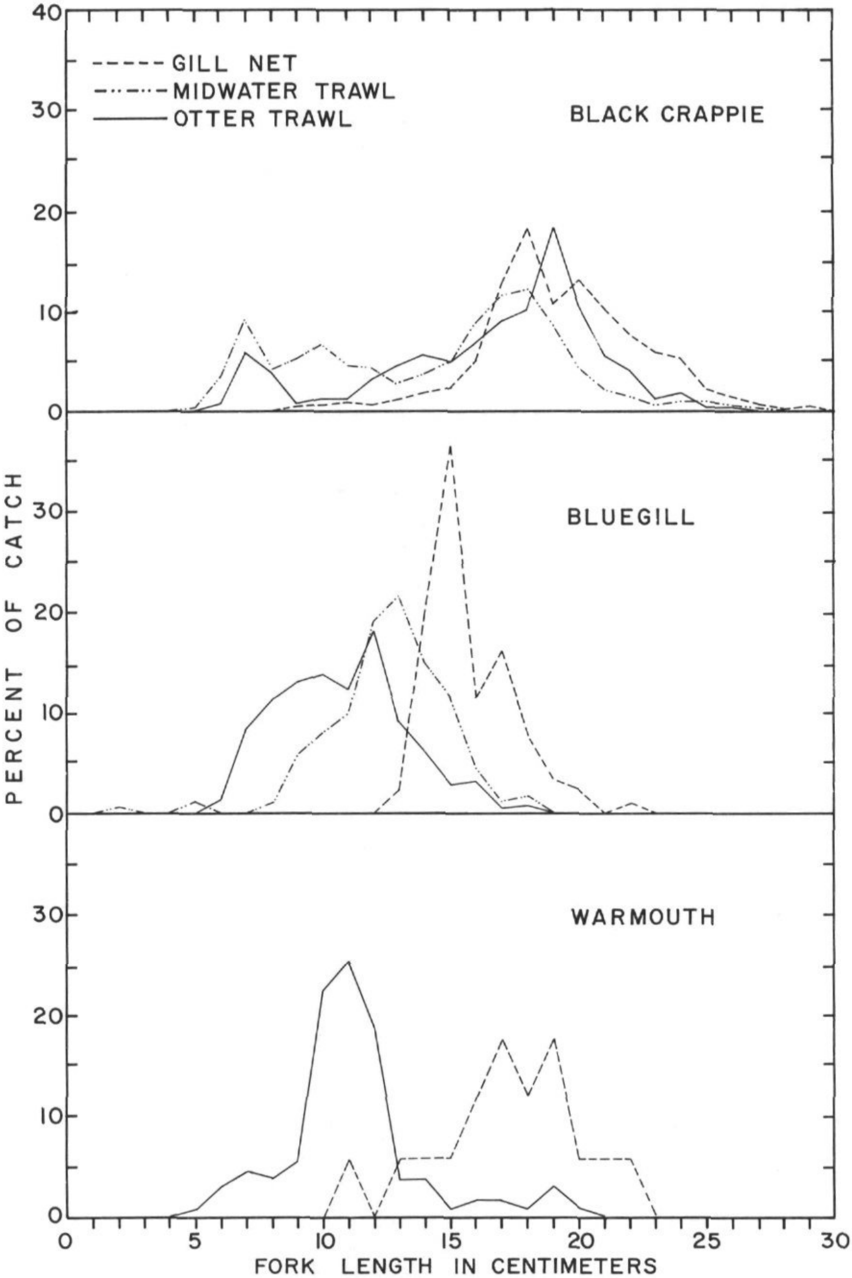

FIGURE 2. Length frequency of black crappie, bluegill, and warmouth taken with midwater trawl, otter trawl, and gill nets.

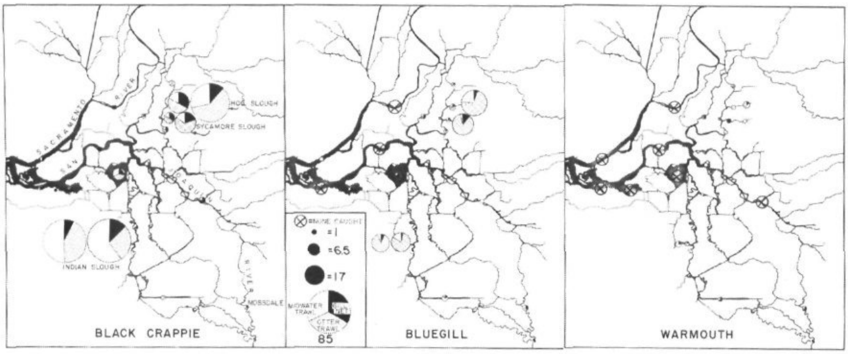

FIGURE 3. Distribution of black crappie, bluegill, and warmouth in the Sacramento-San Joaquin Delta. The area of each circle is proportional to the sum of the mean catches of the otter trawl, midwater trawl, and gill net.

N. awatschensis was present in the stomachs of most crappie of all sizes. They made up 44, 24, and 7 percent of the volume of food of the "small", "medium", and "large" crappie (Tables 2, 3, 4). *Corophium* occurred in at least 50 percent of the stomachs of all sizes of black crappie and formed 16, 10, and 4 percent of the volume of food.

TABLE 2

Stomach Contents of 5 to 10 cm Black Crappie

Food item	Percent frequency of occurrence					Percent of total volume
	Fall	Winter	Spring	Summer	Average	
Crustaceans						
Copepod and Cladocera	--	--	39.1	16.7	28.0	27.9
Mysid shrimp (*Neomysis awatschensis*)	100.0	100.0	78.3	38.9	72.0	43.5
Amphipod (*Corophium*)	100.0	40.0	60.9	27.8	50.7	16.0
Insects						
Tendipedids	--	10.0	17.4	44.4	22.7	8.4
Unidentified insects	--	--	--	5.6	1.3	2.9
Fishes						
Unidentified fishes	--	--	2.2	--	1.3	1.4
Stomachs examined	1	10	47	18	76	
Stomachs containing food	1	10	46	18	75	

Cladocerans and copepods occurred in 28 percent of the stomachs of small crappie and comprised 28 percent of their volume of food. Tendipedid larvae and pupae were also of some importance to the small crappie.

The isopod, *Exosphaeroma oregonensis;* the crayfish, *Pacifastacus leniusculus;* the amphipod, *Gammarus;* and adult insects were consumed but were of minor value to the crappie.

Forage fish became important as crappie increased in size. They occurred in 1, 17, and 33 percent of the stomachs, and formed 1, 60, and 88 percent of the volume of food for the small, medium, and large black crappie. Threadfin shad, *Dorosoma petenense,* and young-of-the-

TABLE 3

Stomach Contents of 11 to 20 cm Black Crappie

Food item	Percent frequency of occurrence					Percent of total volume
	Fall	Winter	Spring	Summer	Average	
Bryozoans						
Pectinatella sp.	2.6	--	--	--	0.2	0.2
Annelids						
Unidentified leech	--	0.7	--	0.5	0.3	0.1
Crustaceans						
Copepoda and Cladocera	1.3	0.7	14.0	2.8	5.8	1.8
Mysid shrimp (*Neomysis awatschensis*)	51.9	91.0	87.1	72.1	78.0	23.7
Isopod (*Exosphaeroma oregonensis*)	--	2.1	2.2	2.5	2.1	3.4
Amphipod (*Corophium*)	44.2	47.9	75.9	69.6	65.9	9.2
Amphipod (*Gammarus*)	--	--	0.4	0.8	0.4	--
Crayfish (*Pacifastacus leniusculus*)	1.3	--	0.7	--	0.3	0.6
Insects						
Tendipedids	1.3	6.9	16.9	--	6.5	0.1
Other insects	--	1.4	3.2	3.8	2.9	0.9
Fishes						
Threadfin shad (*Dorosoma petenense*)	7.8	2.1	--	7.0	4.1	19.7
American shad (*Alosa sapidissima*)	--	--	--	1.5	0.7	1.0
Unidentified Clupeids	--	0.7	--	0.5	0.3	1.3
King salmon (*Oncorhynchus tshawytscha*)	--	--	0.4	--	0.1	1.2
Pond smelt (*Hypomesus transpacificus*)	--	--	--	0.5	0.2	1.3
White catfish (*Ictalurus catus*)	--	--	--	1.3	0.6	0.3
Striped bass (*Roccus saxatilis*)	--	0.7	0.4	10.6	4.9	15.0
Unidentified fishes	19.5	2.8	1.1	5.8	6.1	19.8
Stomachs examined	100	147	283	425	955	
Stomachs containing food	77	118	278	398	871	

TABLE 4

Stomach Contents of Black Crappie Longer Than 20 cm

Food item	Percent frequency of occurrence					Percent of total volume
	Fall	Winter	Spring	Summer	Average	
Annelids						
Unidentified leech	--	1.1	0.8	--	0.5	--
Crustaceans						
Copepoda and Cladocera	--	1.1	0.8	--	0.5	--
Mysid shrimp (*Neomysis awatschensis*)	26.0	80.0	72.8	61.4	64.8	6.7
Isopod (*Exosphaeroma oregonensis*)	2.0	--	0.8	2.1	1.2	0.2
Amphipod (*Corophium*)	50.0	46.2	69.6	73.6	63.3	4.0
Amphipod (*Gammarus*)	--	--	0.8	--	0.2	--
Crayfish (*Pacifastacus leniusculus*)	2.0	--	0.8	0.7	0.7	1.4
Insects						
Tendipedids	4.0	5.5	9.6	15.7	10.1	--
Other insects	4.0	1.1	2.4	1.4	2.0	0.2
Fishes						
Threadfin shad (*Dorosoma petenense*)	12.0	22.0	7.2	5.7	10.6	50.0
American shad (*Alosa sapidissima*)	--	--	0.8	0.7	0.5	1.2
Unidentified Clupeids	8.0	--	--	1.4	1.5	3.0
King salmon (*Oncorhynchus tshawytscha*)	--	--	2.4	--	0.7	1.0
Pond smelt (*Hypomesus transpacificus*)	2.0	--	--	--	0.2	0.7
Goldfish (*Carassius auratus*)	--	1.1	--	--	0.2	0.5
Striped bass (*Roccus saxatilis*)	14.0	--	--	27.1	11.1	21.7
Bluegill (*Lepomis macrochirus*)	2.0	--	--	--	0.2	0.1
Unidentified fishes	14.0	3.3	7.2	8.6	7.6	9.1
Stomachs examined	65	93	132	155	445	
Stomachs containing food	50	91	124	140	405	

year striped bass, *Roccus saxatilis,* were the major fish eaten. Small numbers of king salmon, *Oncorhynchus tshawytscha;* pond smelt, *Hypomesus transpacificus;* American shad, *Alosa sapidissima;* goldfish, *Carassius auratus;* bluegill, *Lepomis macrochirus;* and white catfish, *Ictalurus catus* were also consumed.

Small crappie feed principally on small invertebrates and change to a fish diet as they grow larger (Figure 4). Sasaki (see p. 48) and Turner (see p. 160) have shown that young striped bass and threadfin shad, the most important prey species, are at peak abundance during the summer and fall. Predation on forage fishes was also most intense during these seasons. Many large crappie that fed on forage fishes had not eaten invertebrates. Selection for forage fishes rather than a decrease in numbers of invertebrates in the environment is probably the reason for the decline in consumption of invertebrates during the fall.

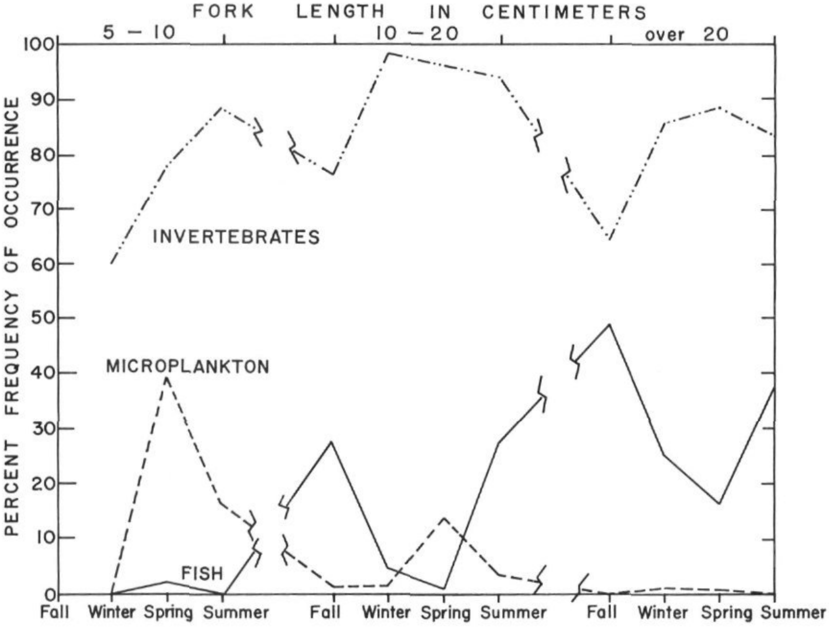

FIGURE 4. Percent frequency of occurrence of food items in the diet of black crappie from fall, 1963 through summer, 1964.

Food Habits of Warmouth

Our analysis of the stomach contents of 105 warmouth indicates that *Corophium* and *Neomysis awatschensis* were the most common food (Table 5). Crayfish, bluegill, white catfish and unidentifiable fish formed a large part of the diet volume, but only occurred in a relatively small percent of the stomachs. The isopod, *Exosphaeroma oregonensis,* and the clam, *Corbicula fluminea,* were also found. Only the larger (over 14 cm) warmouth had eaten crayfish.

TABLE 5

Stomach Contents of Warmouth

Food item	Percent frequency of occurrence					Percent of total volume
	Fall	Winter	Spring	Summer	Average	
Crustaceans						
Mysid shrimp (*Neomysis awatschensis*)	--	72.7	59.5	29.7	46.1	3.7
Isopod (*Exosphaeroma oregonensis*)	--	9.1	2.7	8.1	5.6	5.4
Amphipod (*Corophium*)	--	18.2	89.2	67.6	67.4	3.7
Crayfish (*Pacifastacus leniusculus*)	100.0	18.2	8.1	18.9	18.0	55.5
Molluscs						
Asiatic clam (*Corbicula fluminea*)	--	--	--	2.7	1.1	--
Fishes						
White catfish (*Ictalurus catus*)	--	--	--	10.8	4.5	11.7
Bluegill (*Lepomis macrochirus*)	25.0	--	--	--	1.1	10.5
Unidentified fishes	--	9.1	--	--	1.1	9.6
Miscellaneous						
Peat (percent of total stomachs)	--	--	--	10.6	4.8	--
Stomachs examined	5	12	41	47	105	
Stomachs containing food	4	11	37	37	89	

Food Habits of Bluegill

The stomach contents of 436 bluegill were examined. The amphipod, *Corophium*, was the major food item. It was found in 87 percent of the stomachs and it comprised 31 percent of the volume of food (Table 6). Tendipedid larvae and pupae were found in 45 percent of the stomachs but they provided only 7 percent of the volume of the stomach

TABLE 6

Stomach Contents of Bluegill

Food item	Percent frequency of occurrence					Percent of total volume
	Fall	Winter	Spring	Summer	Average	
Annelids						
Earthworm (*Lumbricus terrestris*)	--	1.1	--	--	0.3	1.3
Polychaeta	5.6	1.1	0.7	0.8	1.0	0.9
Unidentified Annelids	--	--	--	0.8	0.3	0.4
Crustaceans						
Copepoda	--	--	0.7	--	0.3	0.2
Mysid shrimp (*Neomysis awatschensis*)	--	8.6	--	1.6	2.6	0.4
Isopod (*Exosphaeroma oregonensis*)	--	5.4	7.4	9.7	7.3	44.6
Amphipod (*Corophium*)	88.9	82.8	93.9	80.6	86.7	34.7
Amphipod (*Gammarus*)	--	--	0.7	--	0.3	--
Crayfish (*Pacifastacus leniusculus*)	--	--	0.7	--	0.3	0.5
Insects						
Tendipedids	61.1	24.7	52.7	47.6	44.6	7.3
Other insects	27.8	--	4.7	8.9	6.0	2.0
Miscellaneous						
Terrestrial Arachnids	--	--	0.7	--	0.3	0.1
Asiatic clam (*Corbicula fluminea*)	--	--	0.7	4.0	1.6	2.8
Unidentified aquatic snail	--	1.1	--	--	0.3	0.2
Unidentified fishes	--	1.1	--	0.8	0.5	3.7
Seeds	5.6	--	--	0.8	0.5	1.1
Stomachs examined	25	109	159	143	436	
Stomachs containing food	18	93	148	124	383	

contents. The isopod, *Exosphaeroma oregonensis,* formed 40 percent of the diet bulk but occurred in only 7 percent of the stomachs examined.

Food Habits of Largemouth Bass

The food habits of largemouth bass were based on the examination of 55 stomachs. Five small bass (6–8 cm long) were collected in Sycamore Slough during April. Their stomachs contained from one to seven unidentified damsel fly nymphs. Two of these bass also had consumed an insect we could not recognize.

Largemouth bass, 16 to 49 cm long, preyed primarily on fish and crayfish (Table 7). One bass ate a king salmon, *Oncorhynchus tshawytscha,* 6 cm FL; all other recognizable fishes in the bass stomachs were either centrarchids or threadfin shad, *Dorosoma petenense.* Crayfish, *Pacifastacus leniusculus,* were present in 9 of 27 stomachs. An American bullfrog, *Rana catesbeiana,* 22 cm TL was eaten by a bass 44 cm long collected in Hog Slough. Small quantities of *Neomysis, Corophium,* tendipedid larvae and pupae, and unidentified insect larvae were also consumed.

TABLE 7

Stomach Contents of 16 to 49 cm Largemouth Bass

Food Item	Percent Frequency of Occurrence	Percent of Total Volume
Crustaceans		
Mysid shrimp (*Neomysis awatschensis*)	3.7	—
Amphipod (*Corophium*)	3.7	—
Crayfish (*Pacifastacus leniusculus*)	33.3	15.5
Insects		
Tendipedids	3.7	—
Other insects	3.7	—
Amphibian		
Bullfrog (*Rana catesbeiana*)	3.7	51.4
Fishes		
Threadfin shad (*Dorosoma petenense*)	14.8	3.3
King salmon (*Oncorhynchus tshawytscha*)	3.7	0.4
Bluegill (*Lepomis macrochirus*)	18.5	19.4
Black crappie (*Pomoxis nigromaculatus*)	7.4	4.6
Unidentified fishes	18.5	5.3
Stomachs examined	50	—
Stomachs containing food	27	—

DISCUSSION

The native habitat of most members of the centrarchid family is the quiet waters of lakes and backwaters of large rivers. We found the largest concentrations of centrarchids in the Delta in the quiet waters of dead-end sloughs off the main channels. Very few were taken in any other type of habitat.

The higher catches in the upper end of the sloughs may be due to more available food there. Turner (1966) found higher concentrations of zooplankton toward the upper end of Sycamore Slough.

Few fish were caught that were 20 cm (8 inches) or more in length. This is unusual as in most places centrarchids grow much larger. Murphy (1951) reported that the mean length of black crappie caught by anglers over a 4-year period in Clear Lake, California, was 11.5 inches. Beland and Sasaki (1962) found the mean length of black crappie caught by anglers in San Vicente Reservoir, California, was 11.3 inches. Hall, Jenkins, and Finnell (1954) reported that crappie should reach 10 inches in their fourth year of life to provide adequate fishing for the angler. We did not age the crappie but very few were 10 inches in length in the Delta (1.3 percent of gill net catch).

Murphy (1951) reported that the mean length of bluegill caught by the angler in Clear Lake was 8.1 inches. Few bluegill were 20 cm (8 inches) or longer with the largest being only 22 cm.

One factor that may affect the growth of centrarchids in the Delta is turbidity. Secchi disk readings in the Delta ranged from 13 to 90 cm (5.1 to 35.4 inches) and averaging 43 cm (17 inches). Hall, Jenkins, and Finnell (1954) found from a study of numerous reservoirs in Oklahoma that the majority of poor-growing crappie populations (both black and white crappie) were found in turbid waters. Information on actual measured turbidities was not available. Buck (1956) reported from further studies in Oklahoma reservoirs that the growth of both largemouth bass and bluegill was considerably less in bodies of water with high turbidities.

The results of our food habit studies of centrarchids in the Delta differ somewhat from that reported by workers in other areas. We found that an amphipod, *Corophium*, and mysid shrimp, *Neomysis awatschensis*, rather than aquatic insects, were the primary invertebrates in their diet. Larimore (1957) reported the dominant food of adult warmouth to be crayfish, fish, and aquatic insects. McCormick (1940), Ball (1948), and Seaburg and Moyle (1964) have indicated that invertebrates (particularly aquatic insects) form the greatest portion of the diet of bluegill. Reid (1950) found the chief food of young black crappie to be microplankton. Dendy (1946), Reid (1950), and Lux and Smith (1960) determined that the food of adult crappie consists largely of aquatic insects, crustaceans, and fishes. Dendy (1946), Schedermeyer and Lewis (1946), and McCammon, LaFaunce and Seeley (1964) indicated that small fishes and crayfish are common foods of largemouth bass.

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DISTRIBUTION OF CYPRINID FISHES IN THE SACRAMENTO-SAN JOAQUIN DELTA

JERRY L. TURNER

Members of the cyprinid family in the Sacramento-San Joaquin Delta include the native Sacramento blackfish, *Orthodon microlepidotus,* Sacramento hitch, *Lavinia exilicauda,* splittail, *Pogonichthys macrolepidotus,* Sacramento squawfish, *Ptychocheilus grandis,* and the introduced carp, *Cyprinus carpio,* goldfish, *Carassius auratus,* and golden shiner, *Notemigonus crysoleucas.*

Carp were the most abundant of the cyprinids. Some evidence was found suggesting a migration of carp into the flooded islands of the Delta in early summer from the San Joaquin River above Stockton. No evidence was found of carp spawning in the Delta.

Highest densities of carp, Sacramento blackfish, Sacramento hitch and goldfish were in the San Joaquin River at Mossdale. The high concentrations of dissolved solids in this area may favor these members of the cyprinid family. Conversely, these same conditions may exclude the Sacramento squawfish which were never taken in that area of the San Joaquin River.

RESULTS

Cyprinids were taken with otter and midwater trawls and set gill nets. Greatest catches of the larger cyprinids, except for carp, were taken with gill nets (Table 1). Most of the goldfish were taken with the otter trawl and most of the golden shiners with the midwater trawl. Only carp catches were large enough for an analysis of catch by different seasons. A total of 10,452 carp was taken with all three sampling gears.

TABLE 1

Total Number of Various Cyprinids Taken with Gill Net, Otter Trawl, and Midwater Trawl

Species	Gill Net	Otter Trawl	Midwater Trawl	Total Number
Carp	3,396	5,616	1,440	10,452
Sacramento blackfish	236	22	136	394
Sacramento hitch	160	33	58	251
Splittail	244	184	108	536
Sacramento squawfish	124	11	7	142
Goldfish	14	320	86	420
Golden shiner	—	76	136	212

CARP

Distribution

Catches of carp were low when we began sampling in the fall of 1963; two exceptions were slightly higher catches made in Franks Tract and Big Break, both flooded islands (Figure 1). All catches were low during the winter. In March and April the catches continued to be low at most stations but increased greatly at Mossdale on the San Joaquin River above Stockton. In May the catches at most stations still remained much the same but the catch at Mossdale was five times greater than at the next highest station.

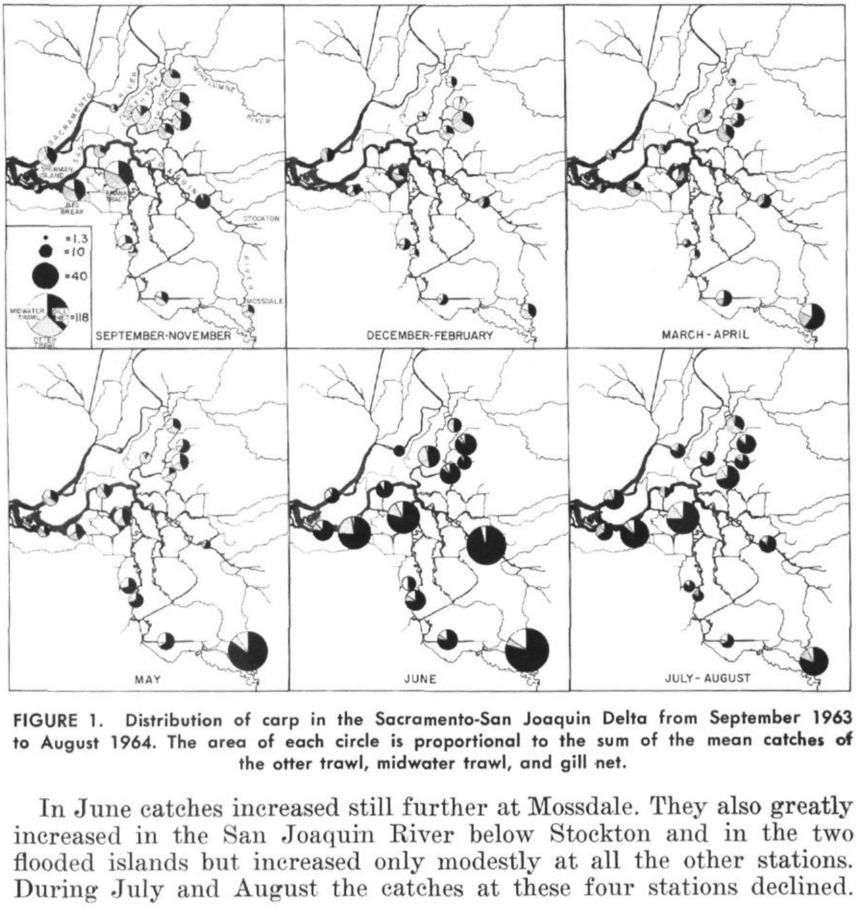

FIGURE 1. Distribution of carp in the Sacramento-San Joaquin Delta from September 1963 to August 1964. The area of each circle is proportional to the sum of the mean catches of the otter trawl, midwater trawl, and gill net.

In June catches increased still further at Mossdale. They also greatly increased in the San Joaquin River below Stockton and in the two flooded islands but increased only modestly at all the other stations. During July and August the catches at these four stations declined.

Sexual Maturity

Our analysis of the gonad condition of female carp reveals no clear-cut spawning season. The first spent carp was examined on May 18; however, only about one-third of the fish examined in June, July, and August were spent (Table 2).

Length Frequency of Catch

A comparison of the monthly length frequency of catch of carp by both gill net and otter trawl shows almost no change in the size range of fish over the entire 12 months of sampling (Figure 2). There was almost no recruitment of smaller fish into the catch of either net during the year and no change in the average length of fish caught from month to month.

TABLE 2

Sexual Maturity of Female Carp. Figure Describes Percent of Total Sample in Each Stage of Gonad Development

Month	Stage of Maturity				Sample Size
	Immature	Maturing	Ripe	Spent	
April	0	100	—	—	49
May	4	89	—	7	45
June	2	52	17	29	161
July	12	50	7	31	232
August	18	28	19	35	246
September	1	99	—	—	76

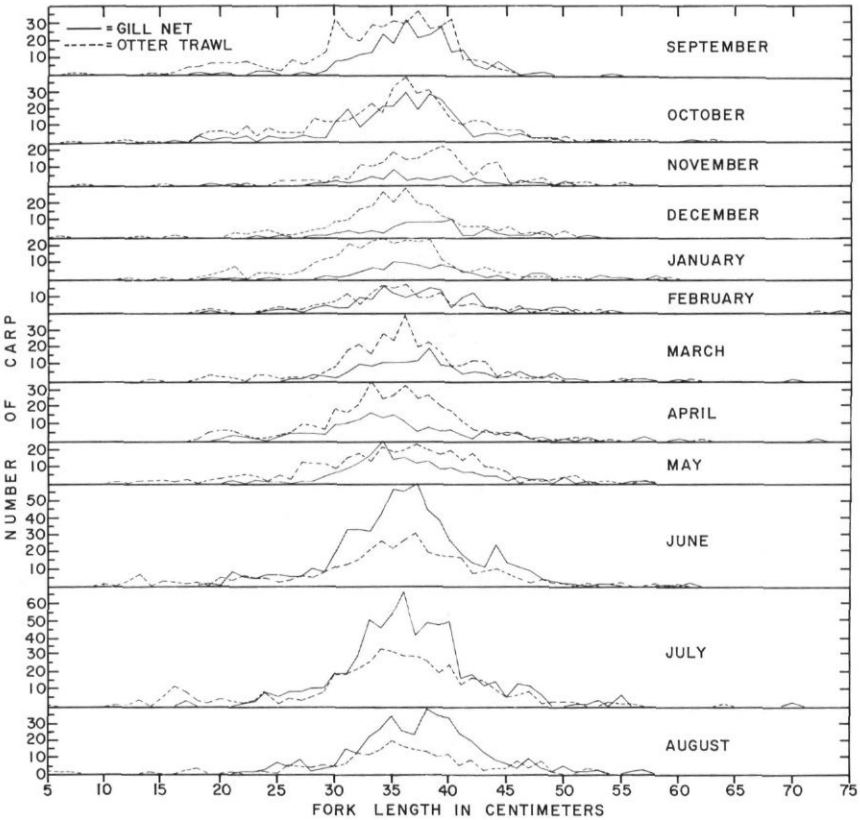

FIGURE 2. Length frequency of carp taken by otter trawl and gill net in the Sacramento-San Joaquin Delta.

Young-of-the-Year

Although adult carp were taken in greatest numbers in the San Joaquin River and flooded islands, there were no young-of-the-year carp taken in these areas with either midwater or otter trawls. Only 38 young-of-the-year carp were caught from September-December 1963 and from June-August 1964. All these were taken at stations in the North or South Fork of the Mokelumne River or at Sherman Island on the Sacramento River; none in the San Joaquin River system. Carp were classified as young-of-the-year if they were less than 15 cm before January 1. Other studies (Carlander, 1950) have reported that most young-of-the-year carp were less than 15 cm by January 1 after they were spawned.

SACRAMENTO BLACKFISH

Three hundred and ninety-four Sacramento blackfish were caught, of which 286 or 73 percent were taken in the San Joaquin River at Mossdale (Figure 3). A few were taken in the dead-end sloughs. Very few were caught in the western Delta. Blackfish in our catches ranged from 25 to 46 cm FL with an average length of 36.7 cm. One ripe fish was examined at Mossdale in July.

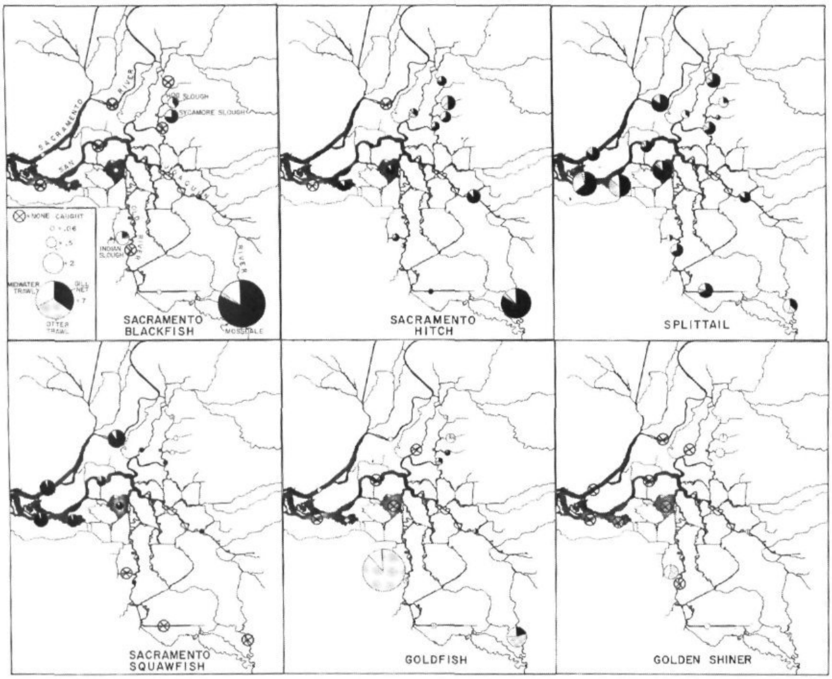

FIGURE 3. Distribution of various cyprinids in the Sacramento-San Joaquin Delta from September 1963 to August 1964. The area of each circle is proportional to the sum of the mean catches of the otter trawl, midwater trawl, and gill net.

SACRAMENTO HITCH

Like the Sacramento blackfish, the greatest numbers of Sacramento hitch were caught at Mossdale on the San Joaquin River (Figure 3). A total of 251 hitch was caught in the Delta of which 116 were taken at Mossdale. Only a few were taken in the western Delta. They ranged in length from 13 to 32 cm FL with an average length of 25.8 cm. A total of 8 out of 10 females examined in June and July were spent.

SPLITTAIL

Splittails were taken at every station in the Delta and were the most evenly distributed of the cyprinids (Figure 3). They ranged in length from 4 to 37 cm FL and average 20.3 cm. All of the females examined in July (nine fish) were spent.

SACRAMENTO SQUAWFISH

Unlike the Sacramento hitch and Sacramento blackfish, almost all of the Sacramento squawfish were caught at stations in the Sacramento River drainage (Figure 3). None were taken in dead-end sloughs and only one caught in the south Delta at Victoria Island on Old River. The length of squawfish varied from 22 to 60 cm FL and averaged 44.1 cm. A total of 12 of 22 females examined from June through August were spent.

GOLDFISH

The greatest numbers of goldfish were taken in Indian Slough and at Mossdale on the San Joaquin River (Figure 3). Very few goldfish were caught at any other station. They ranged in length from 6 to 27 cm FL with an average of 14.6 cm.

GOLDEN SHINER

A total of 212 golden shiners were taken in the Delta. Most of these were caught in the dead-end Hog, Sycamore and Indian sloughs (Figure 3). They varied in length from 7 to 17 cm FL and averaged 10.7 cm.

DISCUSSION

Most of the increased catches of carp from April through August were made with the gill net. Very little change was evident in the average catch of otter trawl and midwater trawls. Gill nets are passive fishing gear and the fish must catch themselves. Our gill net catches of carp were lowest during the winter months which was expected due to the cold water and reduced activity of the fish. From March through May, however, our catches increased greatly at Mossdale on the San Joaquin River but rose only slightly at other stations. In June our catches were high at Mossdale and below Stockton and in the two flooded islands.

The pattern of increase in carp catches, the relatively high percent of spent carp, and lack of any large catches of ripe carp, and the lack of young-of-the-year carp suggest that: (i) carp did not spawn in the Delta, and (ii) there was a movement of carp down the San Joaquin River into the Delta probably after spawning.

The few young-of-the-year carp that were caught were taken in the northern Delta in the Sacramento or Mokelumne River systems in the late summer and fall. Thomas (1967) mentioned the appearance of large numbers of small carp in the diet of striped bass in the upper Sacramento River above our study area. This occurred in the late summer and fall corresponding to drainage of the rice fields along the Feather River. These small carp might have been carried into the northern Delta from the Sacramento River.

Conditions for carp spawning may be poor in the Delta. Wales (1941) and Sigler (1958) reported that carp choose shallow waters of 6 inches to 3 feet deep to spawn. Carp eggs are slightly adhesive and usually stick to debris or plants or sink to the bottom. Any exposure to air will kill the eggs. There is little shallow water less than 3 feet in depth in the Delta, and tidal fluctuations would alternately flood and expose any eggs that were deposited in extremely shallow water. The water level of reservoirs has been dropped to kill carp eggs and reduce their populations in South Dakota (Shields, 1957).

The length frequency of catch with both gill net and otter trawl indicates the population is dominated by a certain size of fish (over 70 percent of the catch by all gears was 30–39 cm in length). This is not uncommon with carp populations, as a uniform size group or perhaps a single year-class has been known to dominate a carp population over a period of time (Mraz and Cooper, 1957).

Carp, Sacramento blackfish, and Sacramento hitch were all extremely abundant at Mossdale, more than at any other station in the Delta. During low flow months, flows in this reach of the San Joaquin River are made up almost entirely of irrigation return waters having high concentrations of dissolved solids (see Radtke, p. 25). These conditions appear to favor the carp, blackfish, and hitch. These same conditions may exclude the Sacramento squawfish which was never taken at Mossdale on the San Joaquin River or in the adjacent sampling stations with high total dissolved solids.

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DISTRIBUTION OF THREADFIN SHAD, *DOROSOMA PETENENSE*; TULE PERCH, *HYSTEROCARPUS TRASKII*; SCULPIN SPP. AND CRAYFISH SPP. IN THE SACRAMENTO-SAN JOAQUIN DELTA

JERRY L. TURNER

THREADFIN SHAD

The threadfin shad, *Dorosoma petenense*, was introduced into southern California from Tennessee by the California Department of Fish and Game in November 1953 (Parsons and Kimsey, 1954). They were later introduced into several reservoirs in the Central Valley of California and have since found their way into the Sacramento-San Joaquin Delta. This paper is a description of their distribution in the Delta from September 1963 to August 1964 and their food habits from September 1963 to May 1964.

Threadfin shad were most abundant in September and were least abundant in January. We found evidence that low water temperatures during the winter caused a heavy mortality of threadfins. Animal matter, particularly crustacean plankton, was the most frequent item in the diet of the threadfin shad, but it and plant material were equally important on a volume basis. Threadfin shad concentrated in areas of high crustacean plankton abundance. It is doubtful that severe competition for food exists between young-of-the-year striped bass and threadfin shad because relatively few young bass inhabit the areas where threadfin shad are most abundant.

Distribution

More than 64,000 threadfin shad were captured during our sampling. Most of these fish were caught with the midwater trawl (Table 1). Very few were captured with the otter trawl except at some of our shallow water stations. Only two threadfin shad were taken with the gill nets. Most were small enough to pass through the meshes.

TABLE 1

Total Number of Threadfin Shad, Tule Perch, and Sculpins Collected in the Gill Net, Otter Trawl, and Midwater Trawl

Species	Gill Net	Otter Trawl	Midwater Trawl	Total Number
Threadfin shad	2	2,268	62,136	64,406
Tule perch	52	820	23	895
Sculpins	—	97	—	97

Threadfin shad were caught at every sampling station in the Delta (Figure 1). The greatest numbers were caught in late summer and fall in Hog and Sycamore Slough (both dead-end sloughs) and in the San Joaquin River at Fourteen Mile Slough. A total of 1,625, 4,385, and 4,279 threadfish shad was taken in three successive 10-minute tows at Fourteen Mile Slough in September 1963. Few threadfin shad were caught at our stations in the western Delta.

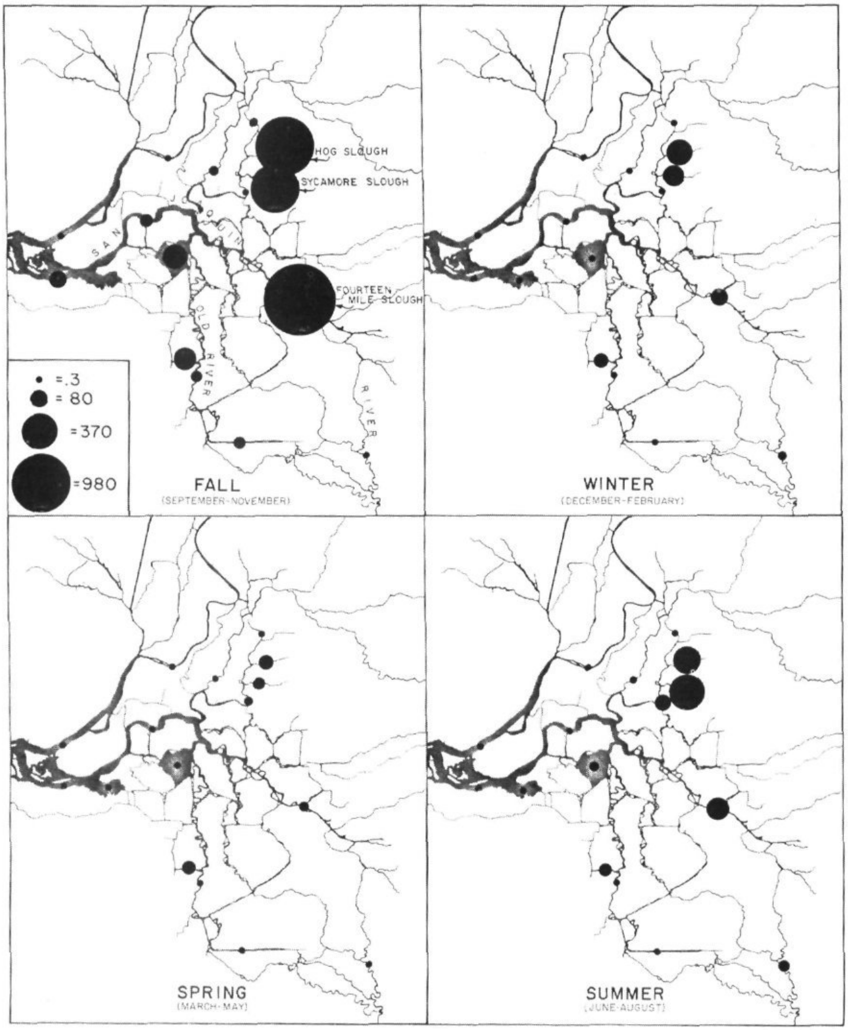

FIGURE 1. Distribution of threadfin shad in the Sacramento-San Joaquin Delta from September 1963 to August 1964. The area of each circle is proportional to the mean number caught in the midwater trawl at each station.

Most of the threadfin shad caught in the fall and winter ranged in length from 5 to 12 cm FL (Figure 2). These were of the 1963 year-class. Their numbers declined rapidly during late fall and winter and increased only slightly the following June. A second and smaller size group (the 1964 year-class) appeared in our catches in July 1964 and completely dominated our August sample.

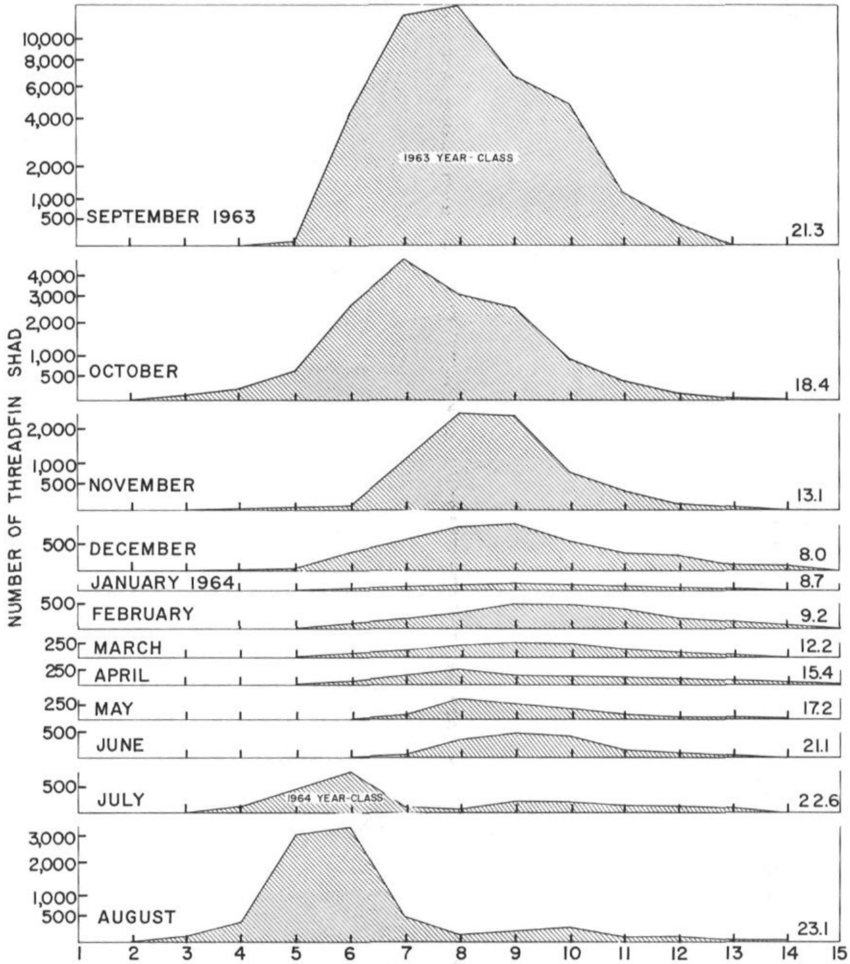

FIGURE 2. Length frequency of catch of all threadfin shad taken by midwater trawl from September 1963 to August 1964. Average monthly temperature in degrees centigrade is noted in the right-hand margin.

Food Habits

Food habits of threadfin shad were determined by analyzing 518 stomachs collected from September 1963 to May 1964. These stomachs came from fish that were preserved in 10 percent formalin soon after they were collected. In the laboratory, the contents of each stomach and esophagus were washed into individual petri dishes and stained with rose bengal dye to facilitate identification and enumeration of food organisms. Cladocerans and copepods were found in most stomachs (Table 2). Desmids, diatoms, and filamentous algae were found in many. A large portion of the contents of many stomachs was so ground up that it could not be recognized. We estimated that 53 percent of the total volume of the stomach contents was plant material. A number of stomachs contained sand. Kimsey, Hagy, and McCammon (1957) and Haskell (1959) also found quantities of sand in threadfin stomachs.

TABLE 2

Stomach Contents of Threadfin Shad in the Sacramento-San Joaquin Delta, 1963–1964

Food Item	Percent Frequency of Occurrence (Average of all Stations)
Animal Matter	
Rotifers	26.5
Annelids	6.1
Cladocerans and Copepods	82.4
Amphipod (*Corophium*)	1.6
Amphipod (*Gammarus*)	0.2
Insect larvae	6.4
Asiatic clam (*Corbicula fluminea*)	4.2
Unidentified animal matter	80.9
Plant Matter	
Algae	46.1
Unidentified plant matter	66.1
Inorganic Matter	
Sand	54.8

Young Asiatic clams, *Corbicula fluminea,* averaging 1 mm greatest shell diameter, were common in the stomachs in the spring. One threadfin shad collected in Old River had eaten 26 clams. Young clams are regularly collected in plankton nets in the spring in the Delta (Hazel and Kelley, 1966).

The numbers of crustacean plankton ingested by individual threadfin shad at each station in the fall were directly related to the concentration of crustacean plankton in the environment (Figure 3). The concentration of crustacean plankton at each station was measured during a plankton survey conducted during the same months the shad were collected (Turner, 1966). Ivlev (1961) observed that the ration of a predator experiencing favorable feeding conditions cannot increase above a certain size. Because the curve in Figure 3 is not asymptotic, it indicates that optimum feeding conditions for threadfin shad may not have existed in the Delta at the time of our comparison.

The concentrations of threadfin shad in the Delta were directly related to the concentrations of crustacean plankton in the Delta (Figure 4). The areas of high plankton concentrations had low net velocities and high concentrations of dissolved solids (Turner, 1966).

DISCUSSION

Few threadfin shad were taken in the western Delta. Ganssle (1966) reported a decreasing catch of threadfin shad with increasing distance into the salinity gradient downstream from our study area. Kimsey (1958) found that threadfin shad live and show excellent growth in the Salton Sea but he did not believe that they spawned there. He

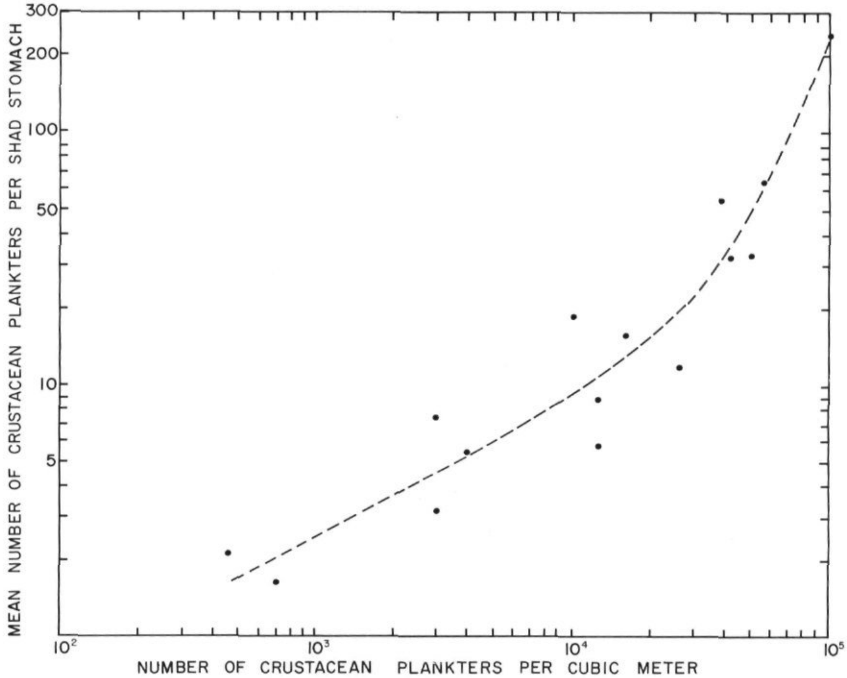

FIGURE 3. Mean number of crustacean plankters per threadfin shad stomach compared with the concentration of crustacean plankters in the environment, September to November 1963. Comparisons were made only if five or more stomachs were examined.

thought they were swept into the sea from adjacent waterways. Shad milt expressed into Salton Sea water, which approaches salt content of sea water, congealed into strings and was incapable of fertilization. Hendricks (1961) found that threadfin shad were most abundant in the Salton Sea near freshwater outlets.

A heavy mortality of threadfin shad must have occurred in the Delta during the winter months. Our catches of the 1963 year-class declined rapidly after September and increased only slightly the following summer. Dryer and Benson (1957) reported that heavy winter mortalities of threadfin shad are common in TVA waters. Parsons and Kimsey (1954) found that the mortality of threadfin shad was high when water temperatures were experimentally decreased from 10°C and 15.6°C to below 7.7°C, and they observed that very few fish survived when water temperatures were below 4.4°C. Water temperatures in the Delta averaged 8.0°C in December. The minimum temperature was 6.7°C.

Before the threadfin shad was introduced into the Central Valley of California, Kimsey (1958) expressed concern over the possibility that threadfin shad and small striped bass would compete for food in the Delta. I do not believe that competition between the two species is severe. Copepods and cladocerans are important foods of threadfin shad throughout their life but are important to striped bass only in their first 3 months of life (Heubach, et al., 1963). Relatively few young bass of this age inhabit the areas in the Delta where threadfin

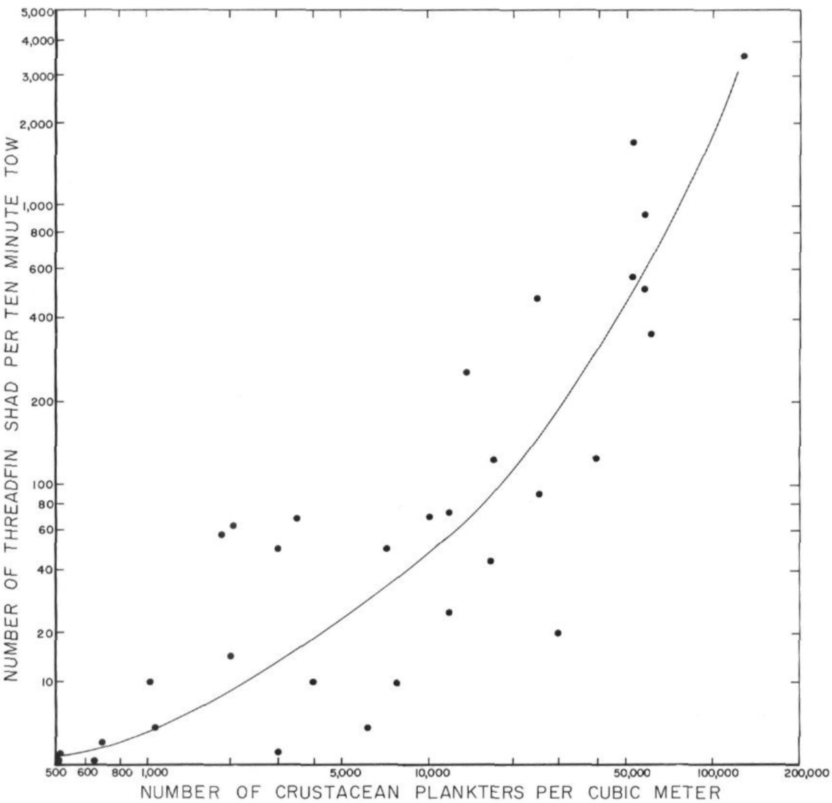

FIGURE 4. Number of threadfin shad taken per 10-minute tow by the midwater trawl compared to number of crustacean plankters per cubic meter of water in the environment, September to November 1963.

shad have become abundant. Chadwick (1964) demonstrated from extensive tow net surveys that in the summer most of the population of young bass (1 inch long) are within a few miles of the confluence of the Sacramento and San Joaquin rivers. Sasaki (see p. 49) found that young bass (2 inches and longer) were concentrated in the fall in the western Delta and were not abundant in other areas of the Delta. Stevens (see p. 72) reported that these young bass were not feeding on copepods or cladocerans but were feeding on larger organisms such as the mysid shrimp, *Neomysis awatschensis,* and the amphipod, *Corophium*. These larger organisms did not occur in the diet of the threadfin shad.

The small size of the threadfin shad makes it a very desirable food source for piscivorous fishes, but its importance as a forage fish in the Delta may be limited because it is abundant only in restricted areas of quiet water.

TULE PERCH

Eight hundred and seventy-five tule perch, *Hysterocarpus, traskii,* were collected with the otter and midwater trawls and with set gill nets (Table 1). Analysis of the tule perch distribution is based on the mean numbers caught in the otter trawl at each station over the entire sampling period.

The tule perch in our catches ranged from 4 to 20 cm FL; the mean was 10.9 cm.

Tule perch were relatively scarce in the Delta. The greatest concentrations were in stations upstream from the central Delta. Highest catches were made in the North and South Fork of the Mokelumne River. No tule perch were taken in the San Joaquin River below Stockton, the Sacramento River below Isleton, and in Old River below Fabian Canal (Figure 5). Limited numbers were taken in Franks Tract and Big Break.

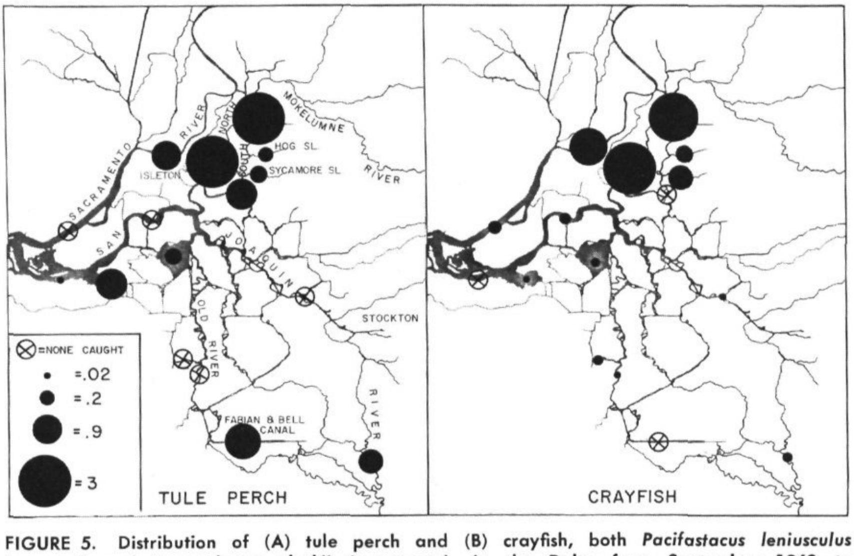

FIGURE 5. Distribution of (A) tule perch and (B) crayfish, both *Pacifastacus leniusculus* (common) and *Procambarus clarkii* (uncommon), in the Delta from September 1963 to August 1964. The area of each circle is proportional to the mean number caught in the otter trawl at each station.

The tule perch was the only viviparous fish that we collected. A total of 14 females containing unborn young were collected in April and May in Sycamore and Hog Slough (dead-end sloughs), Franks Tract and Big Break (flooded island), and in the Mokelumne River. In June and July a total of 16 out of 21 females examined were spent.

The stomachs of 206 tule perch were examined to determine their food habits. They are primarily benthic feeders (Table 3). *Corophium* occurred in the stomachs more frequently than any other organism. These amphipods made up over 91 percent of the diet bulk. Tendipedid larvae were also an important food source, especially for young-of-the-year tule perch. Tendipedids were consumed by 9 of 10 young-of-the-year collected during the summer in the Mokelumne River. Seventyseven small Asiatic clams, *Corbicula fluminea,* were the only food in the stomachs of five tule perch captured during the spring in the Sacramento River at Isleton.

TABLE 3

Stomach Contents of Tule Perch in the Sacramento-San Joaquin Delta, 1963–1964

Food Item	Percent Frequency of Occurrence					Percent of Total Volume
	Fall	Winter	Spring	Summer	Average	
Mysid shrimp (*Neomysis awatschensis*)	—	9.1	—	—	2.4	0.2
Isopod (*Exosphaeroma oregonensis*)	—	3.0	—	—	0.8	0.5
Amphipod (*Corophium*)	100.0	90.0	87.2	77.5	86.3	91.8
Tendipedids	16.7	9.1	12.8	40.0	21.0	3.9
Asiatic clam (*Corbicula fluminea*)	—	—	12.8	—	4.0	3.6
Stomachs examined	22	58	58	68	206	
Stomachs containing food	12	33	39	40	124	

SCULPINS

Very low numbers of Pacific staghorn sculpin, *Leptocottus armatus,* and prickly sculpin, *Cottus asper,* were taken with the otter trawl (Table 1). The staghorn sculpin is a saltwater form that ranges into brackish and fresh water. The prickly sculpin is found in the fresh water of coastal streams. Regrettably, the two forms were not separated and their distribution cannot be described other than that one or the other was caught at every sampling station in the Delta. Large numbers of sculpin larvae, believed to be *Cottus asper,* were taken in plankton nets towed during the spring. Chadwick (1958) reported that large numbers of larvae of *Cottus asper* were taken in the Delta about the first of April.

CRAYFISH

Two species of crayfish, *Pacifastacus leniusculus* and *Procambarus clarkii,* were caught with otter trawls. *Pacifastacus* were much more numerous than *Procambarus* in our catches. The greatest concentrations of crayfish occurred in the northern Delta, particularly at Isleton on the Sacramento River and in the North and South Fork of the Mokelumne River (Figure 5). Very few crayfish were taken in other areas.

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