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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 pre-spawning season level after June.

TABLE 2

Stomach Contents of Adult American Shad

Food Item	Percent Frequency of Occurrence					Percent of Total Volume
	Fall	Winter	Spring	Summer	Average	
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 zooplankton 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.

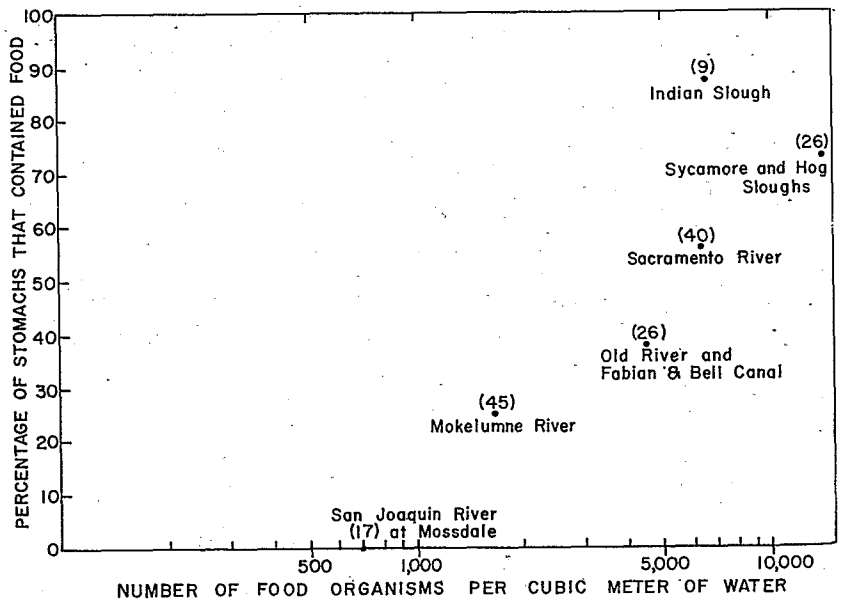

FIGURE 2. Concentrations of food in the environment compared with percentages of stomachs of adult American shad that contained food during April and May 1964. Comparisons are only for areas where more than five stomachs were examined. Numbers of stomachs examined are in parentheses.

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.

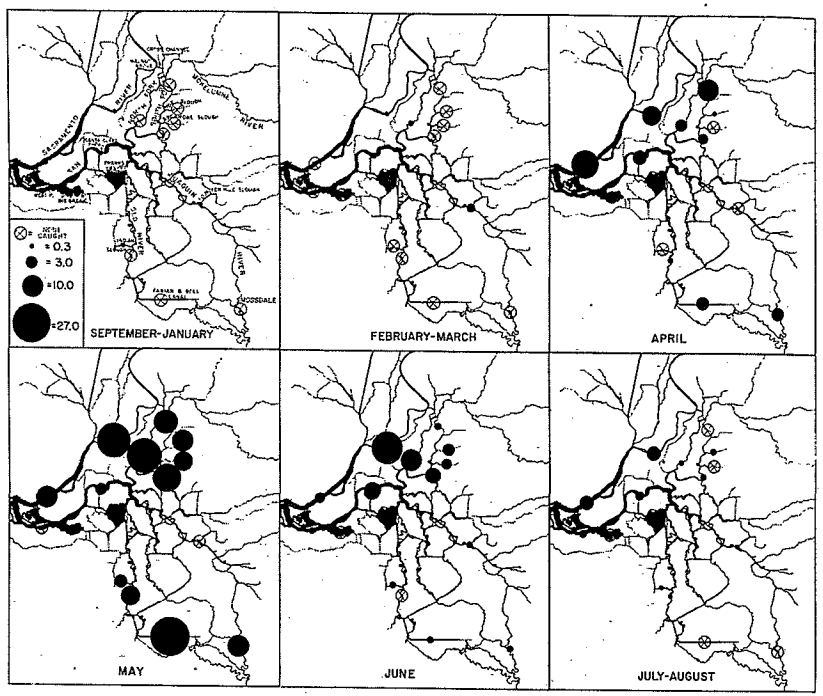

FIGURE 1. Concentrations of adult American shad in the Sacramento-San Joaquin Delta from September 1963 to August 1964. The area of each circle represents the mean number of shad caught in an overnight gill net set.

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 Joaquin River 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.

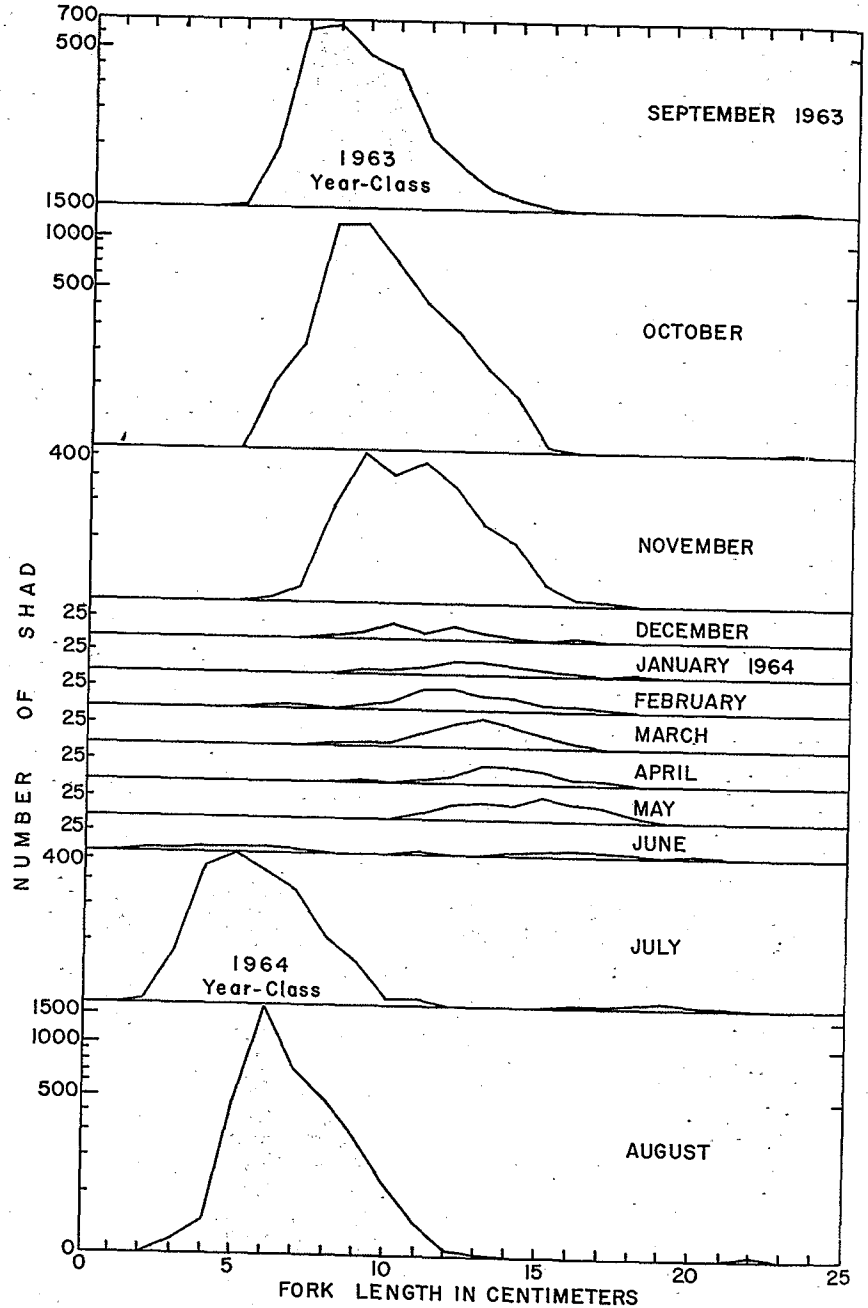

FIGURE 3. Length frequency distribution of American shad caught in the midwater trawl.

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

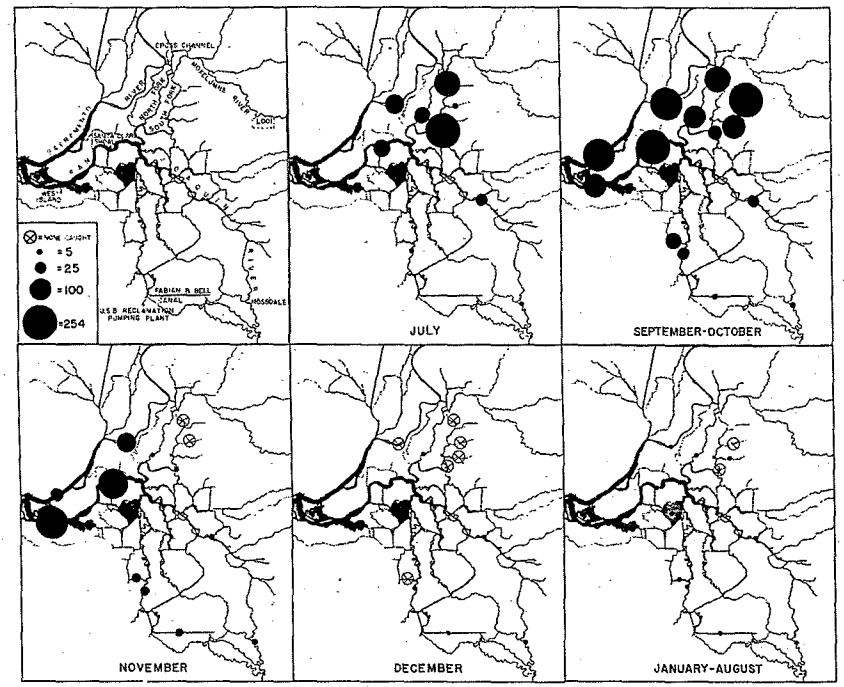

FIGURE 4. Concentrations of American shad of the 1963 year-class in the Sacramento-San Joaquin Delta between July 1963 and August 1964. The area of each circle represents the mean number of shad caught in a 10-minute tow with the midwater trawl.

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

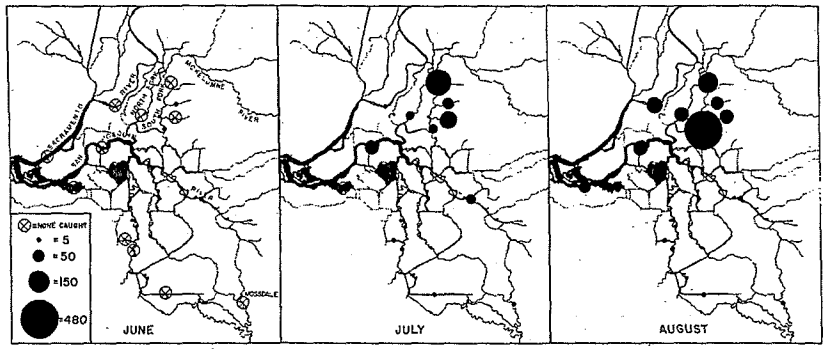

FIGURE 5. Concentrations of American shad of the 1964 year-class in the Sacramento-San Joaquin Delta between June 1964 and August 1964. The area of each circle represents the mean number of shad caught in a 10-minute tow with the midwater trawl.

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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