THE STRIPED MULLET, *Mugil cephalus* Linnaeus

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Striped mullet have varied in abundance in the Salton Sea over the years, at times forming the basis for a commercial fishery. In recent years, their numbers have undergone a continuous decline until at present they are relatively scarce. They were studied principally to determine the facts concerning their recruitment in the Sea. The California Department of Fish and Game made their catch records available for 1943 to 1953 when a commercial mullet fishery was operating in the Salton Sea.

INTRODUCTION INTO THE SALTON SEA

Since mullet are common in the Colorado River as far upstream as the point where the floodwaters diverged in 1905-1907, it is assumed that they first entered at that time (Dill, 1944). There are no records of mullet having been planted in the Sea until 1950-51 when 15 *Mugil cephalus* and 90 *M. curema* were brought in with other fish from the Gulf of California. Over the years, they probably continued to enter by means of canals that lead from the Colorado River to the irrigated land surrounding the south end of the Salton Sea.

Commercial fishing for mullet began in 1915, reached a peak of 91,000 pounds in 1918, and was voluntarily abandoned in 1921 because of poor catches (Janssen, 1937). In 1931, commercial mullet netting was prohibited by legislation as a protective measure for the game-fish stocks then being introduced. In 1942, a large mullet population, combined with the food shortages of World War II, revived interest in commercial fishing. Full-scale fishing was resumed in 1943 and continued until 1953, when poor market demand and dwindling supplies caused voluntary abandonment. Commercial mullet fishing in the Salton Sea was banned by law in mid-1953 to protect new stocks of game fishes.

GENERAL ECOLOGY

Distribution and Migrations

Mullet have been found in all parts of the Salton Sea. However, in 1955 and 1956 their sparse population made them difficult to locate in areas other than those adjacent to freshwater inlets. They have a schooling habit and, in the days of their abundance, large schools were common in all parts of the Sea. They tended to concentrate around freshwater inlets, but during the fall and winter this tendency was much more strongly pronounced. The fall runs into the freshwater inlets started in early October and continued to late November or early December. These were so definite and pronounced that they were considered by the public as spawning runs into freshwater. The chief evidence supporting this conclusion was their high degree of reproductive development.

Food Habits

Mullet food habits have been studied in a number of areas in the world where they are commercially important. Adults generally feed upon diatoms, blue-green algae, green filamentous algae, plant fibers, detritus, mud, and occasionally a copepod or other small animal (Egusa, 1950; Ghazzawi, 1933; Hiatt, 1944; and Thomson, 1954). Hiatt (1944) stated that a unique pharyngeal filtering device prohibits them from swallowing larger forms.

The food habits of the Salton Sea mullet were studied by Woodhull (Dill, 1944). Those from the Sea proper all had empty stomachs but those from the tributaries of the Sea contained the food items previously mentioned plus a few rotifers and cladocerans. It has been suggested by Thomson (1954) that animal materials such as copepods are ingested incidentally with other food.

The gastrointestinal tracts of 25 mullet taken in the Salton Sea in October 1955 were examined during the present study. The contents of the nine containing food agreed in all essentials with the findings of other observers. Diatoms (Order Pennales) were the chief identifiable item. One or more copepods, or parts thereof, were found in all nine stomachs.

Sportfishing Methods

As a result of their dietary preference, mullet are not readily taken on a baited hook. However, by using specialized methods, (Dill, 1944; and Thomson, 1954) they can be taken. The 8- to 12-inch mullet found in the canals and backwaters near Yuma supposedly can be caught by placing a piece of earthworm no longer than $\frac{1}{8}$ inch on a size 12 to 16 hook and suspending this about 12 inches below a very light float. Fishing should be conducted in an area where mullet are leaping and splashing.

The usual non-commercial method for taking mullet in the Salton Sea consists of snagging them with a weighted treble-hook attached by heavy line to a stout surf-type casting rod. Spearing, clubbing, or dip-netting are also employed. Fishing is usually confined to the fall and early winter when they are concentrated in and around the freshwater inlets.

Forage Value

The mullet, because of their large sizes, do not contribute directly to the food chain of the recently-introduced game fishes. The smallest one taken in the present study was 19.3 inches long (490 mm) and weighed 3 pounds and 3 ounces (1,446 grams). Seining and netting failed to locate any smaller fish. Dill (1944) reported that none of the mullet taken by experimental gill-netting in the Salton Sea was shorter than 9.4 inches.

RECRUITMENT

Spawning

At the time this work was being undertaken, no definite information existed on mullet spawning habits. The generally accepted view was that they spawn in the ocean (Arne, 1938; Breder, 1940; Broadhead

1951). Breder (1940) thought he had observed spawning in the shallow water of a tidal flow near an island on the Florida west coast. He was not able to recover eggs and his view has not been accepted by other workers. Kesteven (1942) observed that freshly-spent fish were found only along the coast and later (1953) stated that he believed mullet spawn in the surf zone. Faouzi (1936) reported that *M. cephalus* was not able to spawn in Lake Qaroun in Egypt (a lake that has a considerable physical similarity to the Salton Sea), but that *M. capito* had spawned successfully in 1934, and later, after the water had reached a salt concentration about two-thirds that of normal sea water.

Arnold and Thompson (1958) reported seeing *M. cephalus* spawning offshore in 755 fathoms in the Gulf of Mexico. They collected eggs and larvae, presumably *M. cephalus*, and post-larvae that were definitely *M. cephalus*. These observations and those of Anderson (1958) established rather definitely that mullet spawn offshore in relatively deep water.

All the authorities cited above agreed that mullet migrate to salt water for spawning. The time of migration varied with the latitude. In the northern hemisphere, the initial assembly for the spawning run occurs as early as May but usually reaches it peak in September. Spawning along the South Atlantic Coast of the United States occurs from October into February with the peak in December (Anderson, 1958).

The Salton Sea mullet were believed by Dill (1944) to be spawning in the shallow waters adjacent to the mouths of the freshwater tributaries. Another commonly held view is that spawning takes place in the tributaries at the time of the fall run. If this last view is correct, it should be possible to recover either eggs or fry in some numbers as they are carried downstream by the current. It should also be possible to recover eggs or fry near the mouths of the streams if Dill was correct. Neither fry nor eggs have ever been recovered in these waters although many efforts to do so have been made. Further, it does not seem likely that a fish could successfully maintain an abundant adult population by spawning in a landlocked body of water without its young being detected.

As a supplement to the observations on spawning activity, gonad condition was studied throughout the year. Fairly definite changes were apparent for both males and females (Figure 35). The male cycle reached a peak and remained there during November, December, and January. Males frequently flowed milt when handled during these months. A rapid decline in development began in late January and the low point apparently was reached in midsummer. The female gonad cycle peaked in December and January and reached a low in June and July. No females had completely developed eggs that were free in the ovary. Resorption of eggs began in February and one mullet taken in May was still in the process. Although egg resorption was observed, none of the fish examined appeared to be spent. It was concluded that spawning was not accomplished, and that the eggs were eventually resorbed.

Since repeated sampling has failed to show any signs of mullet eggs, larvae, or juveniles in the Salton Sea, and since no spent mature fish have been found, it seems certain that mullet have not spawned there.

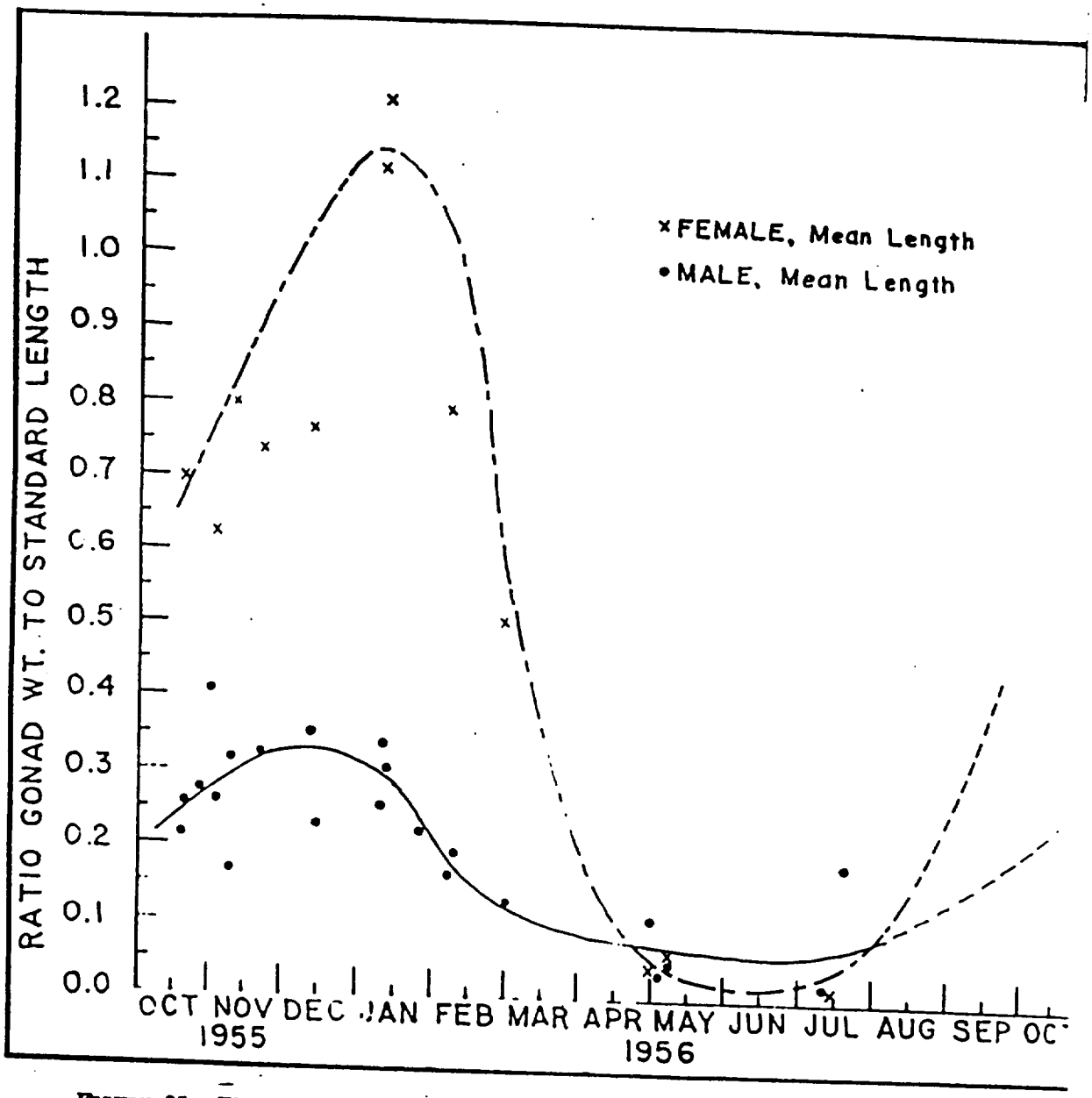


FIGURE 35. The ratio of gonad weight in grams to standard length in millimeters for 405 male and 23 female mullet from the Salton Sea, taken October 19, 1955 to July 18, 1956.

Source of the Mullet in the Salton Sea

Water from the Colorado River is used to irrigate the agricultural land in the Salton Sink and the surplus is drained off through a series of ditches, some of which form the Alamo and New Rivers, which empty into the Sea. During the present study, mullet were found in the Colorado River from its mouth at the Gulf of California to the base of the Imperial Dam. Juveniles shorter than two inches are abundant in the tidal portion of the Colorado River. As one goes upstream only larger mullet are seen. Those seined in the vicinity of Yuma in January 1956, were 7 to 10 inches long. Dill (1944) reported the smallest mullet taken in the river north of the International Boundary from January to May 1942 were four inches long. These observations support the con-

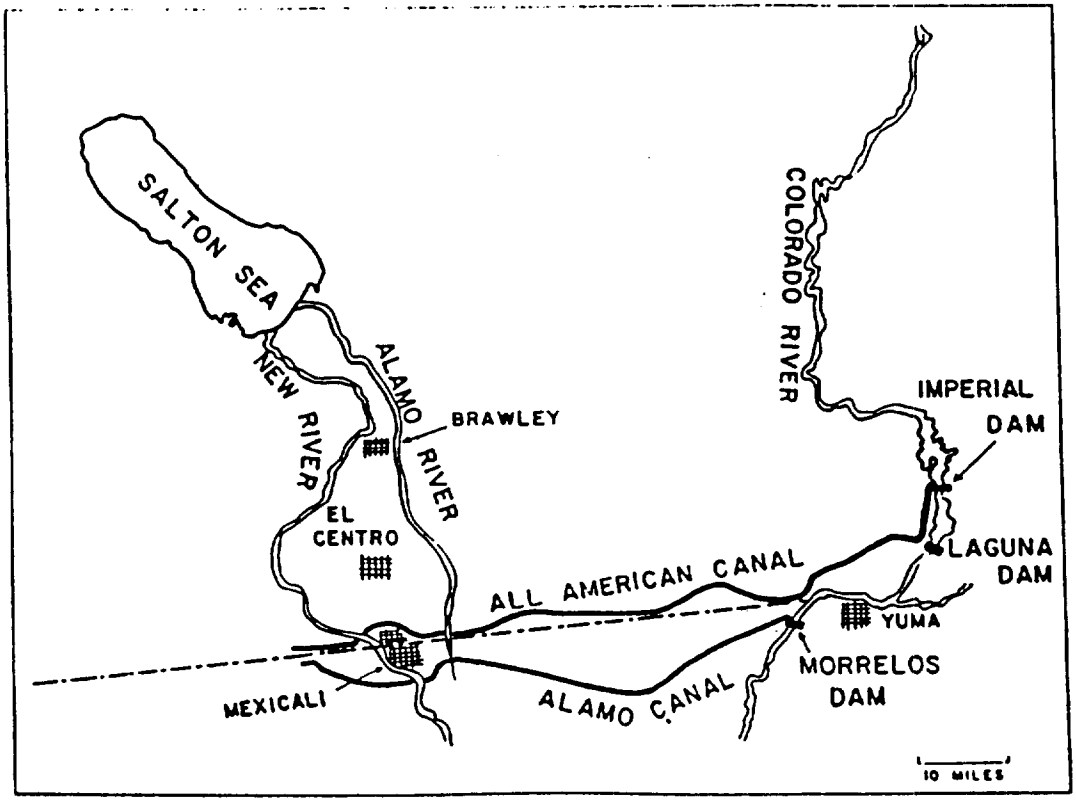
clusions of other investigators, that mullet spawn in offshore waters and the fry make their way back to the rivers.

Thus the Salton Sea mullet were derived from spawnings in the Gulf of California, and have reached the Sea by way of the Colorado River and the canals and drainage ditches of the Imperial Valley Irrigation System.

What, then, has caused the recent marked decline in the number of mullet in the Salton Sea? To answer this question the canal system was investigated in detail and a plausible answer was found.

Mullet were in the Colorado River as far upstream as the base of the Imperial Dam (see Figure 36). They were also in the canals on the Mexican side of the International Boundary but not in those on the California side. Investigation revealed that the canals of the Mexican system are separate from those on the American side, and their water is taken from the Colorado River near the International Boundary at Morrales Dam. Mullet were in the river above and below this dam and were quite abundant in the main canal feeding the Mexican system.

The water used on the California side of the boundary is taken from the Colorado River above the Imperial Dam. No mullet were found above this dam although they were in the river a short distance below. The Imperial Dam, which raises the water surface of the Colorado River 22 feet (Imperial Irrigation District, 1956), acts as a barrier to the upstream movement of these fish, and since the All-American Canal, the water supplyline for Imperial Valley, heads above the dam, mullet cannot get into the distribution system. Careful questioning of personnel of the irrigation district, seining and netting, and inspection of trash screens, failed to reveal mullet in the All-American canal system.



The possibility of a water connection between the Mexican area and the California area was investigated, since this seemed to be the only remaining route to the Salton Sea. Since mullet were present in the Mexican canals it is conceivable that they could reach the Sea through canals and drains to the New and Alamo Rivers. An examination of the Mexican drainage system failed to reveal any channels crossing the international border except the New and Alamo Rivers.

The New River, which originates south of Mexicali, was definitely eliminated as a possible route under present conditions. It is grossly polluted for at least five miles downstream from Mexicali, an area through which fish coud not pass alive. However, the only barrier on this river to downstream or upstream movement was this heavily polluted area.

The Alamo River, on the other hand, did not have any polluted areas that would have prevented the passage of fish. However, its length in Mexico does not exceed one mile and the flow crossing the border is usually less than one cubic foot per second. The water in the river is derived from drainage of irrigated lands and has no direct connection with the canals. There is a fallout (an overflow structure) on the old Imperial (Alamo) Canal for spilling excess water at the head of the river but there was no indication it was being used. Flooding, as a result of heavy rain, does not appear to be a factor in this desert area. The maximum recorded flow in the Alamo River at the border was only 30 cubic feet per second (Imperial Irrigation District Records). It seems unlikely that mullet, other than an occasional straggler, could reach the Salton Sea via the Alamo River.

The canal system as it exists today does not present an easy avenue of access to the Salton Sea. Since mullet were once abundant in the Sea, they must have had a means of entry, but what has changed?

Prior to February 13, 1942, a common main feeder-canal from the Colorado River, the Alamo Canal, was shared by users on the Mexican and American sides of the International Boundary. The water in this canal came from the Rockwood heading near Yuma. In February 1942, the last of the connections with the canal on the Mexican side of the border was broken, and since then all the water used in California has come from above Imperial Dam. Mullet were abundant in the California canals prior to the operation of the All-American Canal, but during the present study not a single mullet could be found in the California canals although they were in those on the Mexican side of the border.

If the movement of mullet into the Salton Sea has been restricted since 1942, the majority of the fish there in 1956 would have to be at least 14 years old. This was essentially true.

AGE

Of the structures examined in an effort to assess the ages of the mullet, scales seemed the most feasible. Tagging studies and observations in other areas have shown that annuli are laid down in the spring following the winter cessation of growth (Devasunnadaran, 1952; Kesteven, 1953; Paget, 1923; Thomson, 1951; and Wimpenny, 1932). Through tagging studies, Kesteven (1953) determined that the divi-

Scales from 844 Salton Sea mullet were studied during the present investigation. Included were those from 236 fish collected between 1948 and 1952 by biologists of the California Department of Fish and Game. Age determination from the scales was difficult due to the large number and crowded character of the markings. In general, there were two to four distinct annuli near the center of each scale. However, as one approached the periphery, there was a crowded sequence of markings whose exact enumeration usually was not possible.

On a few scales the marginal markings were fairly distinct, and total annuli could be enumerated with some confidence. For the scales collected in 1955, usually 14 to 16 annuli could be distinguished. Readable scales from fish captured in 1948, had 7 to 10 annuli; those taken in 1949, 8 to 11; in 1951, 11 or 12; and 1954, 13 to 15. A higher percentage of the scales collected in 1948 and 1949 was readable than those taken in later years. The earlier scales had fewer annuli, were less crowded at the periphery, and showed much less resorption than those collected later.

In counting the annuli, it was necessary to add one for the center of the scale, since the first winter mark could only rarely be distinguished. Scales from small mullet from the Colorado River below Yuma demonstrated that the first winter's growth usually consisted of no more than a few circuli laid down around the nucleus. For mullet up to three years old, from the Colorado River, the nucleus was usually still visible, but in older fish from the Salton Sea it was usually eroded away. Paget (1923) and Wimpenny (1932) found that the first winter check on scales of Egyptian mullet could only rarely be ascertained, and the first reliable winter ring was the one formed during the second winter.

It was not possible to determine the time of annulus formation in the Salton Sea. Mullet taken from the Colorado River resumed growth in late March or early April, as annuli were visible on their scales by late April or early May.

All fish whose scales were readable, except three, were old enough to have reached the Salton Sea prior to the change in the canal system in 1942. Scales whose annuli could not be accurately enumerated were also from old fish, since crowding and resorption were the factors preventing enumeration. The three younger fish were captured in a two-day period in July 1956, near the mouth of the Alamo River. They were II, III, and IV years old. These were also the smallest fish taken in the study.

The capture of three fish, too young to have entered before the change in the canal system, demonstrated that some recruitment was being accomplished. Whether this was due to limited spawning or to migration from the Colorado River is not known, but the latter seems more likely. Of the 844 fish examined, only these three could have entered the Sea after the change in the canal system. If these limited data can be taken as an index of recruitment, the population should decrease to a small fraction of that existing at present, and it is noteworthy that the present population (1956) is only a small fraction of that existing in 1942.

While the evidence from the scales was not conclusive, a majority of the readable scales could be counted back to the 1941 year-class. This

ingress from the Gulf into the Sea was easier in 1941; or that since the mullet were nearing the end of their life span the youngest (that is, the 1941 year-class) would be present in largest numbers.

Flow records for the Colorado River for 1941 and 1942 (U. S. Geological Survey, 1954) show a greater than normal runoff. The larger flows may have induced heavier migrations than normal.

No record, as such, was found in the literature for the maximum age attained by *M. cephalus;* however, Thomson (1951) indicated in a chart that Australian mullet reached eight years. All the other literature on mullet that was examined suggested that they live to five or six years of age, and no records were mentioned of older specimens. Thus, the Salton Sea mullet appear to be reaching the end of their life span.

SIZE

Fish from the Salton Sea were taken in gill nets having mesh of 0.5 to 4.0 inches, square measure. Although seining was regularly carried out, no mullet were captured by this means. Some fish were caught in throw nets from small schools found in or near the mouths of freshwater inlets. These fish did not differ from those taken in gill nets.

The mullet were all large, and had such a limited size range that a length-frequency analysis is pointless. Their average size approaches the maximum reported for other areas. Table 27 summarizes the important measurements for the 533 fish taken in 1955 and 1956. The females were both longer and heavier than the males. No seasonal change in this relationship was noted.

SEX RATIO

The 1955 and 1956 catch of mullet had a sex ratio of only 6.2 females per 100 males. There is no reason to suspect that this badly skewed ratio resulted from bias in the sampling, since the low catch of females occurred in all locations, at all times of the year, and with both successful types of gear.

In the 1954 sample of 75 fish there were 25 females per 100 males. The sex ratio for 236 fish caught during 1948 to 1951 was 45 females per 100 males.

The change in the ratio between 1948 and 1956 suggests that age was a factor. It seems likely, that the males live longer than the females, and that this caused the badly skewed sex ratio. A differential migra-

TABLE 27

Weights and Lengths for 533 Salton Sea Mullet, 1955 and 1956

Measurements	Male		Female	
	Range	Mean	Range	Mean
Standard Length	437-599 mm (17.25-22.0 in)	508 mm (20.0 in)	409-622 mm (16.12-24.50 in)	559 mm (22.0 in)
Weight	1559-4093 gm (3.43-9.00 lbs)	2766 gm (6.10 lbs)	1446-4310 gm (3.12-9.50 lbs)	3499 gm (7.71 lbs)

tion from the Gulf of California in favor of the males cannot be ruled out with the evidence at hand. The egg-bound condition of all female mullet in the spring and early summer months suggests itself as a factor in achieving a differential mortality.

ABNORMALITIES

In a population where no predators decimate the ranks of the sick, injured, and deformed, it is not unreasonable to expect large numbers of abnormal individuals to survive. If the entire population were composed of old individuals then the frequency of abnormalities should be compounded.

About 75 percent of the Salton Sea mullet had one or more abnormalities, some of a serious nature. For the most part, these were pathological and consisted chiefly of internal and external tumorous growths and ulcers. In one case a normal appearing fish, when opened, was found to have a perforated ulcer clearly penetrating the wall of the gizzard-like stomach. About 25 edematous fish were encountered, with the extreme an enormously bloated specimen weighing 12.9 pounds before, and 6.5 pounds after the excess fluid was drained away. Several extremely obese fish were noted, one being a football-shaped mullet weighing 6.6 pounds, and containing two large fat bodies, weighing together 2.1 pounds.

Probably the most interesting pathological abnormalities were the calculi or "kidney stones" in the mesonephric duct. The largest encountered had a fresh weight of 40.9 grams and a size about equal to a golf ball. Calculi weighing more than 20 grams were occasionally encountered and those in excess of 10 grams were common. Of the 533 fish examined during 1955 and 1956, 46.3 percent had calculi. No mention of these calculi was found in any of the earlier notes on Salton Sea mullet nor were any references found in the worldwide literature on mullet. It is not likely that a stone of 10 grams or more would be overlooked when examining a mullet. Their presence may be another indication of the extreme age of the mullet.

FUTURE OF THE MULLET IN THE SALTON SEA

Finding the three young mullet in July 1956, indicated that a few mullet will probably continue to enter the Sea as long as present conditions exist. It appears that the population will decline rapidly as old age takes its toll. Access will not be made easier unless there is some change in the canal system or its operation, or the pollution is abated on the New River. Floods in the area could carry mullet into the Sea, but so far this has never occurred except for the breakthrough of the Colorado River in 1905. The several large dams built on the Colorado River since then, coupled with the high rate of water use on the Colorado River, make it improbable that floods will occur in the foreseeable future on the lower river. In fact, the demand for water has resulted in a drying-up of the Colorado River to little more than a trickle below the International Boundary. If this policy continues, mullet may become scarce in the Mexican canals and in the Colorado River above Morrales Dam.