STATE OF CALIFORNIA
DEPARTMENT OF FISH AND GAME

FISH BULLETIN No. 113

THE ECOLOGY OF THE SALTON SEA, CALIFORNIA, IN RELATION TO THE SPORTFISHERY

Edited by
BOYD W. WALKER

1961

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FRONTISPIECE. The northwest corner of Salton Sea, 1960.
Photograph by Ward Gillilan.

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INTRODUCTION

The Salton Sea is the largest inland body of water in California. Prior to 1950 the Sea contained only four species of fishes, and two of these never exceed two inches in length. The nearest approach to a sportfishery was a snag-fishery for striped mullet which attracted a considerable number of local residents each year. However, by 1950 even this fishery had started to decline.

Situated near one of the greatest centers of population in the United States and in a region of scarcity of inland water resources, the Salton Sea provided a constant challenge to those men interested in the full utilization of resources for the sportsman. Several attempts to introduce game fishes met with failure. The problem was a difficult one, for the waters of the Sea were salty, but the relative amounts of constituent salts were different from those found in the oceans. In addition, the temperature fluctuated greatly. The little that was known about the environmental variables did not provide much hope for establishing a sportfishery.

In spite of the difficulties and poor prospects, the California Department of Fish and Game, with encouragement from Harvey A. Hastain (then Fish and Game Commissioner from Brawley) renewed its attempts to establish new species of fishes in 1948. Philip A. Douglas, Willis A. Evans (both in 1948), and John E. Fitch (in 1950) were assigned the tasks of locating, capturing, and transplanting desirable species. Attempts were made to secure anchovies and anchovetas through commercial channels but mortalities were high and there seemed little likelihood for success. Consequently, other sources of stock were investigated. The greatest chance for success seemed to lie in the Gulf of California at San Felipe, Baja California. In May 1950, several thousand fishes of a dozen species were transported to the Salton Sea from San Felipe. Because knowledge was inadequate for making selected plantings, these and subsequent operations were on a "shotgun" basis: all species not undesirable were taken with the hope that one or more might adapt to Salton Sea. By the end of 1951, some 7,000 fishes from San Felipe had been introduced into the Salton Sea by the California Department of Fish and Game. The success of the 1950 and 1951 plants is now history. In July 1952, Jack Bechtel of the California Department of Fish and Game, took the first bairdiella, a 1¾-inch fish, from the Salton Sea (Douglas, 1953). Douglas also reported additional collections of young-of-the-year bairdiella, and the capture of an adult corvina. Indications of the success of the introduced species gave hope that a fishery might become established.

Shortly after these discoveries and after it was certain that bairdiella were reproducing at a remarkable rate, the University of California, Los Angeles, contracted with the California Department of Fish and Game to do research basic to developing a sportfishery in the Sea. Funds were supplied by the Wildlife Conservation Board, and in March 1954, work commenced under the contract W. C. B. 126. This project was continued, on an annual basis, through 1955 and 1956, and research activities were discontinued in the fall of 1957.

A laboratory was set up in a rented motel cabin at Fish Springs. Later, as operations expanded, a second cabin was added. Construction and maintenance of research facilities were on a strictly "do-it-yourself" basis. The researchers thus had to double as handymen, and a significant portion of each man's time was occupied by such duties. Help was difficult to get, and more difficult to keep, because of the rigorous conditions for work.

From the outset it was obvious that the kinds of information gathered and analyzed by the project would need to be highly restricted. A complete job on a lake of 340 square miles could never be done in a few years' time by a staff of only three full-time researchers. We chose to do those things which we thought would produce information most apt to be useful in future management. In making these decisions, we were ably advised by a committee representing the California Department of Fish and Game and the Wildlife Conservation Board.

There were many phases of work which we wished to do but could not because of practical considerations. Sometimes seemingly essential information could be sought only in an indirect or incomplete manner, or not at all, because we lacked manpower. The researchers were forced to cover exceedingly wide areas of investigation, and therefore many of the results are incomplete. We did try, however, to carry the most essential phases to a reasonable conclusion.

PROJECT PERSONNEL

I would here like to express my sincere appreciation to the men who served on the project. Their devotion to their studies, and their willing cooperation under extremely severe conditions, earned my greatest admiration. Lars H. Carpelan, the first man on the project, worked continuously until September 1956. He was in charge of all research on the physical and chemical characteristics of the Sea and the investigations on invertebrates and plants. He was aided by Richard H. Linsley, who worked on the pile worm and the barnacle from July 1954 to July 1957. Richard R. Whitney was in charge of the investigation on fishes. He joined the project in April 1954 and was the last man to leave in the fall of 1957. His research was largely confined to the bairdiella and orangemouth corvina. Joseph Hendricks was available for only a short period in 1955 and 1956, but during this time he completed studies on the striped mullet and the threadfin shad, and made preliminary studies on the orangemouth corvina. George W. Barlow, William N. McFarland, and Jay C. Quast worked as part-time researchers on various fish problems. Hisao Arai served ably as research assistant for one summer. Special thanks are due Clarence L. Keller and Frank J. Lucia who served as technicians during various phases of the project. They were unfailingly cheerful and faithful.

The project personnel cooperated fully on all sampling programs, and almost all aided in some way on each of the phases reported in the following papers.

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ACKNOWLEDGMENTS

I am joined by all members of the project in thanking the representatives of the California Department of Fish and Game and the Wildlife Conservation Board who served on the Advisory Committee. They were: Richard D. Beland, Frances N. Clark, Philip A. Douglas, John E. Fitch, John Radovich, and Scott M. Soule. They gave freely of their time and advice and offered many suggestions of great value. The members of the project staff were greatly impressed by the value of the advisory committee, and grateful for the opportunity to work with its members. John F. Janssen, Jr., Regional Manager, Region 5, California Department of Fish and Game, kept in close touch with the progress of the work and provided valuable advice. Everett E. Horn, then Coordinator of the Wildlife Conservation Board, also followed the work with great interest and was a source of much information and encouragement.

We are especially grateful to the following people who generously provided information on special phases of the project. Trygve Braarud, Robert W. Holmes, and Rufus H. Thompson identified phytoplankters. E. Yale Dawson collected and identified the various algaes. Elbert H. Ahlstrom, Richard A. Boolootian, Olga Hartman, and Martin W. Johnson provided taxonomic help on invertebrates. Kenneth D. Carlander and Richard C. Hennemuth read early copies of the bairdiella manuscript, and offered many helpful suggestions. Frances N. Clark provided valuable information on reading orangemouth corvina scales. Specimens of, and information on, the corvinas from the lower Colorado River were made available by J. B. Kimsey.

In the final preparation of the manuscript several persons have been especially helpful. Mary E. Walker labored long hours in general assistance. Wayne J. Baldwin has provided invaluable help in collating the manuscripts, as well as never-failing patient aid on many earlier phases of the project. In particular, John E. Fitch has proven a most able and patient editor. He was especially generous of his time during this entire project, and provided many ideas and much valuable help to the entire staff.—*Boyd W. Walker, Director of the Salton Sea Research Project, Department of Zoology, University of California, Los Angeles, April 1961.*

HISTORY OF THE SALTON SEA

LARS H. CARPELAN

INTRODUCTION

The Salton Sea of southeastern California occupies a basin or sink whose southern boundary is the delta of the Colorado River. The crest of the delta, which is 15 to 20 miles south of the California-Mexico border, separates the desert basin from the head of the Gulf of California. The normal flow of the Colorado is into the head of the Gulf, which lies about 50 miles south of the crest of the delta. However, since the lowest point on the delta crest is only 35 feet above present mean sea level, and since the Salton Sink (also called the Cahuilla Basin) is well below mean sea level (the lowest point is —273.5 feet), the flow of the Colorado may be either northward into the Salton Sink or southward into the Gulf of California.

The Sea is a large body of shallow water surrounded by desert. There is sparse vegetation along the shores except where cattail sedges, tamarisk, and bamboo are present in freshwater drainages. Along the rest of the shore the vegetation is typical of an "alkaline flat," where various species of salt-bushes are dominant. Among the perennials submerged by rising water are cottonwood and mesquite.

The beaches bordering the Sea are sandy in certain areas, but most of the shore is silt or mud with a mixture of snail and barnacle shells. The bottom has an organic mat above the sand or silt, the mat consisting of settled plankton organisms and, near shore, blue-green algae. There are a few areas of rocks at the south shore where volcanic buttes form islands in the Sea.

EXPLORATIONS

Historical knowledge of the region dates from Spanish explorations, beginning in 1539 and ending in 1776, which were reviewed by Sykes (1914 and 1937) and LaRue (1916). In 1826, a British naval officer, Lt. R. W. H. Hardy, reached the mouth of the Colorado. He reported on the great range of tides there, and prepared a map of the estuary (see Sykes, 1937). American explorations of the delta region began with a journey of a trapper, James O. Pattie, down the Colorado to tidewater in 1827 (Pattie, 1833). In 1848, a military reconnaissance, led by Lt. W. H. Emory, crossed the Salton Sink en route from Ft. Leavenworth, Missouri to San Diego, California (Emory, 1848). In 1849 and 1850, emigrants were following Emory's trail to California, crossing the Colorado River at Yuma.

Trouble with Indians led to establishment of a military post at Yuma with Major S. P. Heintzelman in command. In October 1850, Heintzelman and John L. LeConte journeyed to the delta to verify reports of volcanic activity. LeConte (1855) reported discovering mud volcanoes near what came to be called Volcano Lake, a transient sheet of water at the foot of Cerro Prieto on the west side of the delta crest. In the winter of 1850-51, Heintzelman led a supply party down the Colorado

River from Yuma to meet Lt. G. H. Derby of the U. S. Topographical Engineers who came up the river from its mouth. Derby had been assigned the task of mapping the main channel of the river in the hope that supplies might be brought to the military post by water. The channel was navigable, and the chart of Derby (1852) proved useful to the river-boat men who, from the early 1850's to the late 1870's, supplied the military garrison, the ferrymen, and the emigrants at Yuma. The arrival of the railroad at Yuma in 1877 ended the river traffic.

THE DRAINAGE OF THE COLORADO RIVER THROUGH THE DELTA

The key to understanding the formation of the present Salton Sea is the delta of the Colorado, which in its own way is as impressive as the Grand Canyon from which its sediments originated. The delta has been described by Sykes (1926 and 1937) as a "T" with arms extending 200 miles from north (Salton Sea) to south (Pt. San Felipe), and with a stem 70 miles long extending from Pilot Knob, eight miles west of Yuma, to Cerro Prieto, an outlier of the Cocopah Mountains in Baja California (Figure 1). Dowd (1952), in refuting rumors of seepage to the Salton Sea from the Gulf, likened the delta to a dam 300 feet high, 140 miles thick at the base, and 8 to 10 miles wide at the top.

The channel of the Colorado may wander through the many miles of relatively flat delta which has a fall of less than two feet per mile. During the last half of the ninteenth century, the river meandered down the east side of the delta into the Gulf, maintaining a navigable channel, but occasionally flowing into the Salton Sink. According to Sykes (1937), water from the Colorado entered the Sink five times during the middle of the last century: 1840 (probably when the New River was formed), 1842, 1852 (forming a sea discovered by Blake in 1853), 1859, and 1867. In June 1891, a flow of water formed a lake of some 100,000 acres. Investigating this flow into the Salton Sink, Sykes found the mouth of the Alamo River (not known until then) and made his way to the Sea via Beltran's Slough, thus showing the connection to the Colorado River for the first time. Another expedition seeking the source of the 1891 flooding was reported by Cecil-Stephens (1891). The water of the 1891 flooding evaporated, leaving a salt marsh, centered west of the railroad station at Salton, and a salt deposit which was mined by the New Liverpool Salt Company. A boring made by the salt company in 1892 showed a seven-inch crust of sodium and magnesium chlorides above a 22-foot stratum of black ooze (Blake, 1914). The presence of this ooze may have started the rumor of a continuous stratum to the Gulf through which water could enter the Salton Sea.

GEOLOGY OF THE SALTON SINK AND RECORDS OF LAKE CAHUILLA

The first geological survey of the Salton Sink was made in 1853 by a party led by Lt. R. S. Williamson, exploring for railroad routes south of the Sierra Nevada. W. P. Blake, the geologist of the party, reported discovering San Gorgonio Pass (which became the route of the Southern Pacific Railroad) and was the first to recognize that the Salton Sink was below sea level (Blake, 1858). Blake revisited the region after the

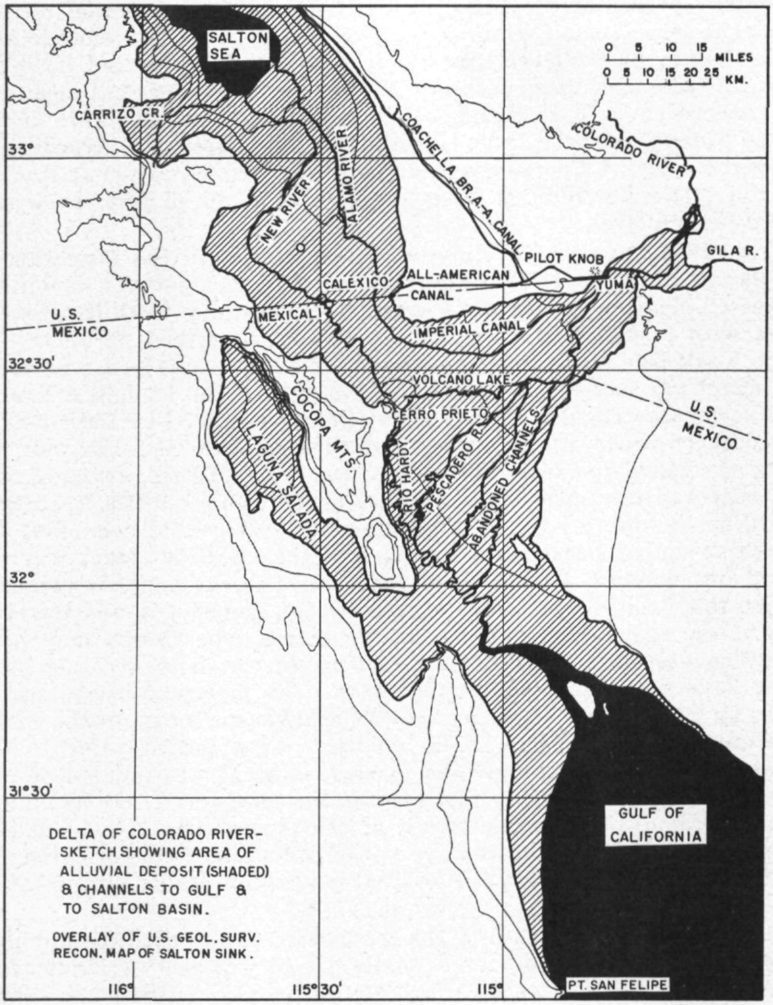


Figure 1. Delta of the Colorado River. Based on U. S. Geol. Surv. Map of Salton Sink, 1908.

present body of water was formed in 1907, and agreed that the name "Salton Sea" was appropriate (Blake, 1907). He suggested that it was the residual of a more extensive ancient lake which he called Lake Cahuilla, just as the Great Salt Lake is the residual of Lake Bonneville. Blake (1914) interpreted what he named the Cahuilla Basin (after the local Indian tribe) as a cut-off arm of the ocean; that is, he suggested it had been a continuation of the Gulf of California prior to the formation of the delta of the Colorado River. Sykes (1914) agreed with Blake that the approximately 2,200 square miles of the Cahuilla Basin represented the former upper extremity of the Gulf of California. According to this view, the ocean extension had been present during the middle Tertiary and was cut off by continental elevation and delta formation during a "pluvial" period of the Pleistocene. There followed a period during which the lake (Lake Cahuilla) received water from the Colorado and drained into the Gulf. The former lake, 100 miles long and 35 miles wide, left a conspicuous beachline 22 to 58 feet above present mean sea level according to U. S. Geological Survey Reconnaissance Map of the Salton Sink, California, 1908, reprinted in 1947. However, according to a recent survey by George Stanley (personal communication from Carl L. Hubbs) the beachline is fairly constant at about 45 feet above current mean sea level.

Free (1914) presented a different interpretation of the formation of the Salton Sink. To Free, it represented a trough between mountain ranges of Mesozoic (Jurassic?) origin with Tertiary foothills above a playa with a small salt body, similar to that described by Emory in 1848: a salt lake about three-fourths of a mile long, one-half mile wide, and about one-foot deep. Paralleling the axis of the trough, a line of mud volcanoes extended from Volcano Lake (described by LeConte) to the southern shore of the present Sea. The ancient shoreline and the series of strands visible below it were, according to Free, evidence of a lake that had disappeared by gradual evaporation—"little by little" according to Indian legends. Free discussed two possibilities: first the interpretation of Blake, and others, that the Cahuilla Basin was the cut-off former head of the Gulf of California; and second, his own suggestion that Lake Cahuilla was of fresh water, and that it, and the mud hills of the region, were of continental origin. The trough may have been above sea level until after formation of the delta and may thus never have been occupied by the ocean. The marine Miocene fossils found by Blake in the Carrizo area (the southwestern part of the Sink) were interpreted by Free to be remnants of a period prior to the Pleistocene when the trough was formed. Later it was pointed out by Brown (1923), that during the Miocene the land was 1,000 feet lower than at present: the marine fossils of the Carrizo are now 1,000 feet above sea level. According to Free's interpretation, delta formation by the Colorado kept pace with a gradual depression of the Sink relative to sea level.

In support of Free's theory, the freshwater nature of Lake Cahuilla is evidenced by shells of small snails (*Hydrobia protea* Frauenfeld and *Physa humerosa* Gould) which were discussed by Stearns (1902) with the comment, "there is probably no area of equal extent on the face of the earth with such an immense number of shells of the genera above named." Further evidence of a lengthy freshwater period is the deposit of calcium carbonate (travertine or calcareous tufa) which is 30 inches thick on Travertine Rock, then near the shore of Lake Cahuilla but now an outcropping a mile west of the present shoreline of the Salton Sea. Jones (1914) pointed out that such deposits were left by all Quarternary lakes of the Great Basin.

Other interpretations of the Cahuilla Basin and of the freshwater lake that left the ancient shoreline are those of Brown (1922 and 1923), Kniffen (1932), Buwalda and Stanton (1939), Cockerell (1946), and Hubbs and Miller (1948). Both Brown and Kniffen considered the Salton Sink to be a dropped fault-block or graben, and discussed the San Andreas, Indio, and San Jacinto faults in reference to the Sink. The San Jacinto fault, which runs through the Sink, through Mexicali and on into the Gulf, is a "line of structural weakness" (Sykes, 1937) along which volcanic activity has created cones which now form buttes or, occasionally, islands at the southern shore of the present Salton Sea. Volcanic activity is currently limited to the mud volcanoes and hot springs which extend from the southern part of the Sea southward through the delta.

In the most recent account of the geologic history of the Salton Sink, Hubbs and Miller (1947) concluded that the main stage of Lake Cahuilla (which they call Lake LeConte, after the naturalist reporting the region in the 1850's) occurred in the Pleistocene, and that it lasted for centuries. Indian artifacts and legends provide evidence for another, more recent, high stage. Hubbs and Miller cited estimates, made by Mendenhall (1909) and by Rogers (1939), that a lake filling the basin to the ancient beachline existed between 1,000 and perhaps as recently as 300 years ago. Between the time of the main stage (Pleistocene) and the recent high stage, Hubbs and Miller postulated an inflow of water from the Gulf, and reported having found marine molluscs left by it. They postulated that at the end of the Pleistocene the ocean may have been 30 feet higher than at present, as evidenced by the alluvial apron that skirts the mountains at the head of the Gulf. The apron is apparent at the foot of the Cocopah Mountains and continues around another basin, called the Pattie or Macuatá Basin, in which at times there is a lake, Laguna Salada, comparable to the Salton Sea. As the ocean level fell, it left the 30-foot apron, which Kniffen (1932) interpreted as a continuation of the Lake Cahuilla shoreline. However, the truncated margins of the apron were regarded by Hubbs and Miller as evidence of erosion by a recent higher-than-present level of water in the Gulf during a time when a 30-foot tide might have topped the crest of the delta at Volcano Lake. This, they pointed out, could have created the trough which later provided drainage for the Colorado River either south via the Rio Hardy to the Gulf, or north via the New River into the Salton Sea. A 30-foot tide would not be unusual because from seven feet at the ocean end of the Gulf, the tidal range increases to 20 feet at Pt. San Felipe, and to over 30 at the mouth of the Colorado River (Kniffen, 1932; Lawson, 1950). The "bore" produced by the incoming tide is pictured by Sykes (1937).

In any event, if a recent saltwater inflow did occur it must have been of short duration, admitting only a minor quantity of ocean water because, as pointed out by Ross (1914) and by Buwalda and Stanton (1939), analyses of the water in Salton Sea showed the salts were in the proportions expected from evaporation of Colorado River water, rather than of the ocean.

PAST AND PROBABLE FUTURE STAGES OF THE SEA

Blake's report in 1857 that the Salton Sink was below sea level led to several non-consummated plans, prior to 1900, to bring water from the Colorado River to the southern end of the Sink (the Imperial Valley) in order to reclaim the land for agricultural use. It was not until 1901 that water was first brought into the region via the Alamo channel. According to Sykes (1937), the 150,000 acres under cultivation by 1904 were being served by 600 miles of canals from a head near Yuma. In the winter of 1904-05, a flood of the Colorado and the Gila River, which enters the Colorado near Yuma, cut through the headworks and enlarged the irrigation channel. A summer flood in 1905 poured into the Salton Sink through this channel. An expedition from the New York Botanical Garden, led by D. T. MacDougal, was collecting on the delta and witnessed the 1905 flooding. Several members of this expedition, under the sponsorship of the Carnegie Institution of Washington, reported on various aspects of the newly-formed Sea in a combined publication edited by MacDougal (1914). Among the collaborators was Sykes (1914), who in a later paper (Sykes, 1937) reported that in 1906 he had observed the Sea rising at the rate of four inches per day with a rapid advance of the water across the nearly level floor of the basin. In May 1906, the surface elevation was —240 feet, and the Sea was 50 feet deep. The break in the irrigation headworks was repaired in February 1907, and the flow of the Colorado was redirected into the Gulf. The Sea formed by the two-year inflow was described by Blake (1914) as having "a length of 45 miles, a maximum breadth of 17 miles, and a total area of 410 square miles with a maximum depth of 83 feet." The maximum surface elevation (—195 feet) was reached in 1907.

Since 1907, water entering the Salton Sea has been controlled by irrigation practice. For many years after the maximum surface elevation was reached, little water entered the Sea and the level fell due to evaporation. Studies have shown the annual evaporation is about six feet (Young and Blaney, 1947; Blaney, 1954). Records of the U. S. Department of the Interior, Geological Survey, show that the surface elevation fell from —195 feet in 1907 to —250 feet in 1925. During the first quarter of the 20th century, there was difficulty maintaining the flow of the Colorado southward, and various levees were built in efforts to keep it moving into the Gulf. Sykes (1937) discussed the changes in the drainage of the Colorado River through the delta. The 1905-1907 breakthrough into the Salton Sink resulted in a westerly shift of the main channel, making the channel on the eastern side of the delta non-navigable after 1909, and sending the main flow down the Rio Hardy.

From 1925 to 1935, the level of the Sea fluctuated between —250 and —243 feet. There had been a desire to stabilize the level since 1907, and the 1927 Holbrook report predicted stabilization at between —223 and —226 feet. In 1928, lands lying below —220 feet were withdrawn from public entry.

After completion of Hoover Dam in the late 1930's, extra water was available, so additional land was put under irrigation and more water was "wasted" into the Sea, which acts as a sump for irrigation drainage. The Alamo channel was replaced by the All-American Canal, and the Coachella Branch of this canal brought Colorado River water into the Coachella Valley, which is the northern part of the Salton Sink. The additional water entering the Sea raised the level to —240 feet in 1948 and to —234.5 feet in 1956. The rise in surface elevation subsequent to World War II revived interest in probable future stages and possible stabilization. Estimates of the future stages of surface elevation were made by Bradshaw, Donnan and Blaney (1951) who predicted —230 feet as the probable stabilization level (that is, the level at which inflow and evaporation of water would be equal). In a more recent prediction, Blaney (1954) estimated that the level would stabilize at —220 feet sometime between 1970 and 1985. However, the rise of the Sea, which was most rapid in 1950-1951, has slowed since then. Irrigation district engineers now believe, on the basis of known rates of water inflow and evaporation, that it may be possible to stabilize the Salton Sea at about the current surface elevation of —235 feet.

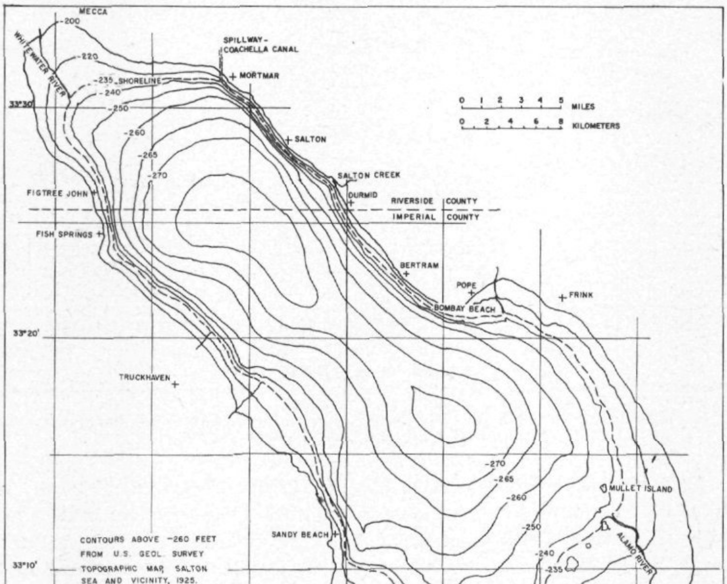
PHYSICAL AND CHEMICAL CHARACTERISTICS

LARS H. CARPELAN

SURFACE ELEVATION

When Hoover Dam was completed in the late 1930's more water became available for irrigation in the Imperial Valley, and the Salton Sea rose from about —243 feet to —240 in 1948 and —234.5 in 1956. In 1956, the maximum depth of the Sea was approximately 40 feet, and it covered about 340 square miles (Figure 2).

The increase in surface elevation from 1953 to 1956 and the annual fluctuations in height are shown in Figure 3. These figures are based on records from the Figtree John's gauging station maintained by the Coachella Valley County Water District. Other agencies concerned with the Salton Sea use different datum levels for elevations in the Salton Sink. Highest elevations have occurred in the spring, and lowest in autumn. There was a net rise of one foot from November 1953 to October 1954, and a rise of 0.4 foot from the fall of 1954 to the fall of 1955.



CONTOURS ABOVE -260 FEET FROM U.S. GEOL. SURVEY TOPOGRAPHIC MAP, SALTON SEA AND VICINITY, 1925.

CONTOURS BELOW -260 FEET APPROXIMATE ONLY, BASED ON SOUNDINGS, 1954 TO 1956, BY U.C.L.A. SALTON SEA RESEARCH PROGRAM

FIGURE 2. Depth contours of Salton Sea. Contours above —260 feet from U. S. Geological Survey, 1925. Contours below —260 feet are approximate only, based on soundings by U.C.L.A. Salton Sea Laboratory, 1954-1956.

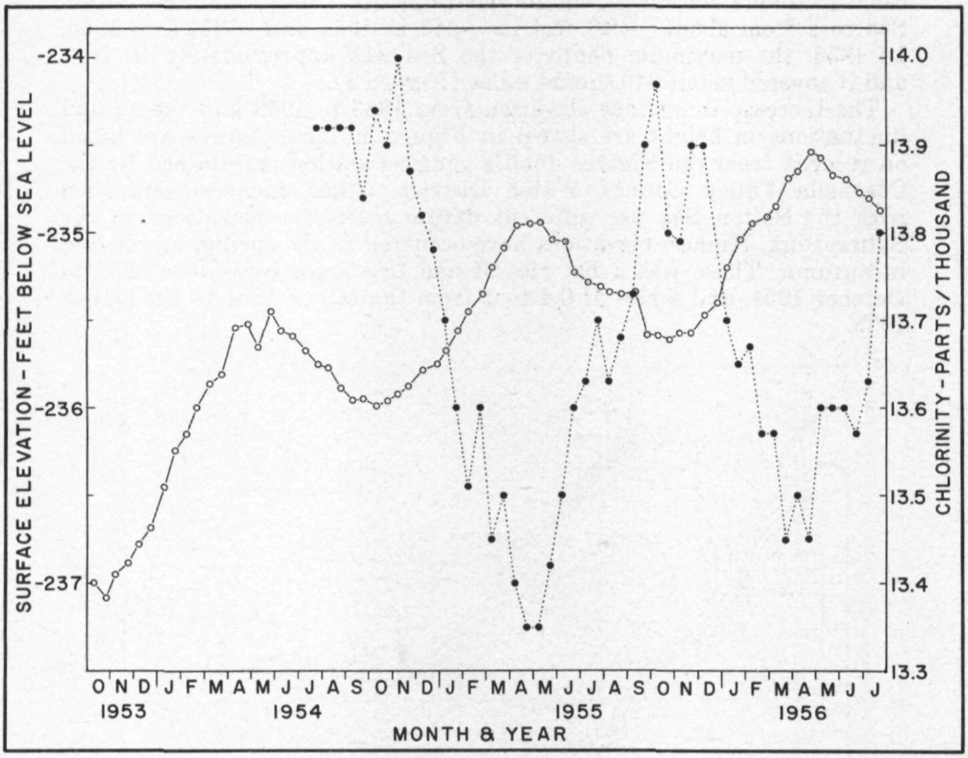


FIGURE 3. Surface elevation (solid line) at Figtree John and chlorinity (dotted line) off Fish Springs, Salton Sea.

The rise has been due to an excess of inflow over evaporation, which has resulted in a net increase in quantity of water in the Sea. Calculations by Holbrook (1927) showed that as the surface elevation rose, relatively more evaporation was possible because the surface area of the shallow Sea increased more rapidly than its capacity. At the 1956 elevation (—235 feet), the capacity of the Sea was 5.5 million acre feet with an area of 220,000 acres. The recent annual increases in elevation (Figure 3) were smaller than the rises that occurred from 1951 to 1952, for example.

Systematic gathering of physical and chemical data for the Salton Sea Research Program ended in July 1956. During the period 1956 to 1959, the surface elevation continued its usual fluctuation of about one foot each year, but the highest elevation attained in 1957 was only 0.1 foot higher than in 1956 (Table 1). In 1958 the springtime maximum was 0.07 foot lower than in 1956, and in 1959 the highest elevation was 0.07 foot higher than in 1956. Thus there was a difference of only an inch or so in surface elevation during this period, indicating near stabilization at this time.

IONIC COMPOSITION

When the present Salton Sea was formed, it was due, as in previous fillings, to inflow of the Colorado River into the Salton Sink. The salinity of the Colorado at the head of the irrigation canal (whose destruction by flood led to the 1905-1907 inflow via the Alamo channel) was reported by Ross (1914) to have been 0.7 o/oo (parts per thousand). Analyses by Ross showed the water of the newly-formed Sea to have had a salinity of 3.6 o/oo in 1907. The greater salinity of the Sea, relative to that of the river, was due to salts leached from the bottom deposit left by evaporation on previous occasions.

The proportions of ions in the Salton Sea had changed since 1907 (Table 2). Calcium had decreased slightly while the proportions of

TABLE 1

Salton Sea Surface Elevations, 1956 to 1959

	Highest		Lowest	
	Elevation	Date	Elevation	Date
1956	—234.54	23 April	—235.55	8 October
1957	—234.64	22 April	—235.78	21 October
1958	—234.47	23 June	—235.59	24 November
1959	—234.61	27 April	--------	------------

TABLE 2

Ionic Composition of Salton Sea Water, 1907 to 1955, and of River Waters Entering the Sea

Date	Ca o/oo	Mg o/oo	Na o/oo	K o/oo	CO_3 o/oo	HCO_3 o/oo	SO_4 o/oo	Cl o/oo	Analyzed o/oo	Total o/oo
1907[1]	0.099	0.064	1.110	0.023	0.066	--	0.476	1.697	3.55	3.65
1910[1]	0.137	0.098	1.893	0.035	0.064	--	0.764	2.809	5.6	6.04
1913[2]	0.197	0.161	3.231	0.035	0.113	--	1.246	4.739	9.72	10.025
1916[2]	0.298	0.272	5.289	0.057	0.114	--	2.079	7.876	15.98	16.47
1929[3]	0.196	0.588	3.921	as Na	0.102	--	1.37	6.39	12.47	14.43
1945[4]	0.850	0.920	11.345	--	0.207	--	6.924	16.241	36.48	37.37
1948[5]	0.804	0.992	11.824	0.192	0.021	0.171	7.55	16.99	38.55	40.425
1955[5]	0.764	0.951	9.938	0.224	0.021	0.159	6.806	14.422	33.29	33.68
Colo. River (1907)[1]	0.072	0.022	0.138	0.015	0.091	--	0.20	0.138	0.68	0.696
Alamo River (1951)[6]	0.157	0.113	0.410	0.011	--	0.199	0.529	0.66	2.08	2.256
New River (1951)[6]	0.141	0.066	0.435	0.01	--	0.209	0.444	0.605	1.91	1.93
Ocean[7]	0.413	1.27	10.55	0.38	--	0.014	2.649	*19.15	34.22	34.48

[1] Analyses from Ross (1914); [2] Analyses from Sykes (1937); [3] Analysis from Coleman (1929); [4] Analysis by Imperial Irrigation District Laboratory; [5] Analyses by USDA Salinity Laboratory, Riverside, California; [6] Analysis from California Division of Water Resources Survey (1953); [7] From Table 35, Sverdrup, et al (1952).

* Chloride plus Bromide.

magnesium and sulphate ions increased. Sodium and potassium were still present in about the same proportions as in 1907; chloride ion had decreased slightly in proportion to total, and bicarbonate had decreased from 1.9 percent in the original Sea to about 0.5. The proportions of salts in 1956 bore out the 1907 observation of Ross that they were due to concentration of Colorado River salts. Comparison of the analyses of Colorado River water in 1907 with analyses of New and Alamo River waters in 1951 showed that greater quantities of salts were now entering. The New and Alamo Rivers contain more salts than the Colorado because they carry water that has been used for irrigation.

In 1956, the salinity of the Salton Sea (about 33 o/oo) was only slightly below the total salt content of the oceans, but its waters contained relatively less magnesium, potassium, and chloride ion; about the same proportion of sodium; and more sulphate, calcium, bicarbonate and carbonate ions than are present in ocean water (Table 2).

The total salt content of the Salton Sea increased gradually from 1907 to 1948 (when the salinity was 11 times greater than the original value), and then decreased from 1948 to 1956 as a result of dilution (Table 2). That is, prior to 1948 less water entered the Sea than evaporated, so the surface elevation fell and the salinity increased. Subsequent to 1948 evaporation did not equal inflow, so the surface elevation rose and the salinity decreased.

CHLORINITY

The ratio of chloride to total salts in the Salton Sea is not the same as in the oceans (Table 2). Similar to the use of the term "chlorinity" in chemical oceanography, it is used in this discussion for total halides, expressed in parts per thousand (o/oo), determined by titration with silver nitrate. The ratio of chlorinity to total salts (salinity) has averaged 2.36 (within a range of 2.42 to 2.31), in analyses made since 1949. Salinity was thus, roughly, 2.36 × chlorinity, compared to the Cl o/oo S o/oo ratio of roughly 1.805 in the ocean (Sverdrup *et al*, 1942). During the years of this study, 1954-1956, chlorinity in the main body of the Sea ranged from 13.3 to 14 o/oo, corresponding to a salinity of 31.4 to 33 o/oo.

The main body of the Sea had a relatively uniform salinity. For example, at the end of November 1954, the chlorinity near shore was 13.6 o/oo at the northern end (off the mouth of the Whitewater), 13.9 on the western side (off Fish Springs and Truckhaven); and 13.7 on the eastern side (off Bombay Beach). Samples from the center of the Sea had values of 13.8 and 13.9.

The slightly lower chlorinity at the north shore was due to drainage from the Whitewater River and the Coachella spillway. The southwestern part of the Sea had a chlorinity only slightly below that of the northern portion. The mean annual chlorinity at the southwest shore was 12.9 o/oo (with a range of 12.3 to 13.5) during a one-year period from May 1955 to May 1956. During this period, the chlorinity in the northern part of the Sea ranged from 13.3 to 14 o/oo. The greatest dilution occurred in the southeastern corner of the Sea, where most of the entering water came in via the New and Alamo Rivers. In contrast to the relative uniformity and the small annual range of chlorinity in most of the Sea, there were wide variations in the southeastern part.

The discharge of the Alamo River was eastward toward Mullet Island during the time of this study. Data obtained on November 8 and 10, 1954 illustrated the effect of fresh water flowing eastward from the mouth of the Alamo. A mile west of the Alamo mouth the chlorinity was 13.9 o/oo at the bottom and 13.5 o/oo at the surface. A quarter of a mile east, however, it was 4.1 o/oo, and at the west shore of Mullet Island it was 9.6. Two and one-half miles north of the island, along the east shore of the Sea, surface chlorinity was 10.2 o/oo, and two miles further north (about four miles from the mouth of the river) the surface value was 12.5 at shore, 12.9 a mile offshore, and 13.3 at the bottom (four meters).

At Mullet Island the average annual chlorinity was 10.8 o/oo, with a range of 1.5 to 13.6 o/oo. Chlorinity of 1.5 o/oo was only about twice that of Alamo River water prior to entry into the Sea. The influence of fresh water was noted as far north as Bombay Beach, approximately 10 miles from the river mouth. In general, the lower salinity was noticeable only along the southeast shore, and there seemed to be considerable delay before the effect of dilution became apparent in the northern part of the Sea. The evaporation of fresher water, which tended to float on the surface, seemed to modify the dilution which spread slowly throughout the Sea by diffusion and a generally counterclockwise current.

An annual cycle of variation in chlorinity in the main body of the Sea, was related inversely to the highest and lowest surface elevations during the year. During 1954-1956, highest chlorinity occurred in autumn and early winter, after high summer evaporation had lowered the surface elevation to the yearly low. The lowest chlorinity occurred in spring following the period with least evaporation (Figure 3).

Lowest chlorinity in the main body of the Sea during 1955 was only slightly below the lowest observed in 1956. It would appear that the decrease in chlorinity which occurred from 1948 to 1956 ended as the result of a new balance between evaporation and rate of inflow. The records of Blaney (1954) show that during the early 1950's the annual inflow was about 1.5 million acre feet. All but about 220,000 acre feet evaporated, but so long as there was a net increment in volume, the Sea was diluted and salinity fell. There was a decrease from nearly 40 o/oo in 1948 to 33 o/oo in 1956. When the elevation of the Sea becomes stabilized, salinity will increase again. If stabilization occurs at —235 feet, the increase in salinity can be calculated from the capacity at that elevation (which is 5.5 million acre feet or 67.8×10^9 cubic meters according to Holbrook, 1927), and from the known annual inflow of salt (3.0 million tons [2.7×10^9 kg.] according to Dowd, 1952). The salinity would increase at the rate of 0.4 parts per thousand per year. In a little less than 20 years (in the mid 1970's) it would be 40 o/oo which might be considered the upper limit of the Sea as a favorable environment for marine organisms.

However, if the estimate made by Blaney should prove true (that the Sea will stabilize at —220 feet when it has a capacity of 9.1 million acre feet) the salinity would decrease to about 25 o/oo at the time of stabilization in 1970-1980, and then it would increase and reach about 40 o/oo 15 to 20 years later. The Sea might thus have a salinity range (from 25 to 40 o/oo) tolerable to marine organisms for the next 30 to

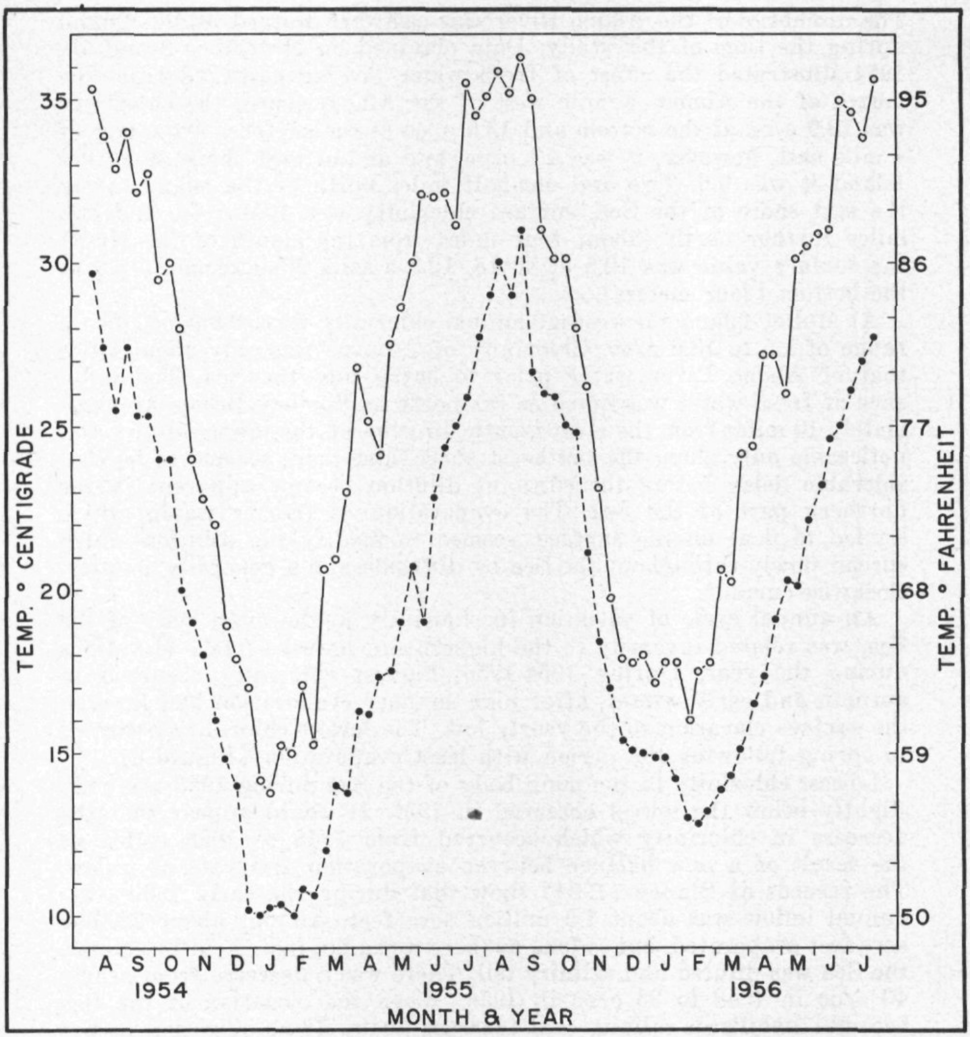


FIGURE 4. Water temperatures at Sandy Beach, Salton Sea, for the period August 1954 to July 1956. The surface maximum temperature is indicated by the continuous line, the bottom (at three meters) minimum temperature by the hatched line.

50 years. Although it seems that the best estimate is based on stabilization at the —235 foot level, accurate prediction is impossible because the amount of Colorado River water available to the Salton Sink in the future is uncertain.

The chlorinity was not determined at regular intervals after July 1956. However, water samples taken from mid-Sea two years later, on August 13, 1958, ranged from 14.0 to 14.15 for an average of 14.1 o/oo (salinity 33.27 o/oo). In July 1956 the chlorinity was 13.8 o/oo (salinity 32.57 o/oo).

The increase in salinity from 1956 to 1958 of 0.7 parts per thousand, is 0.35 o/oo/year. During this period, when stabilization had just begun, the slight increase in salinity was within the range of variation due to the annual cycle of elevation. However, it seems to bear out the estimate, based on calculations given previously, that salinity will increase at about 0.4 parts per thousand per year, so long as the surface remains constant at the present level.

WATER TEMPERATURE

Temperatures were taken by a dual recording thermometer located on a dock at Sandy Beach where the maximum depth was three meters (Figure 4). The extreme range during the two-year period was from 10 to 36 degrees C (50-97 degrees F). Readings obtained by the California Department of Fish and Game with a recording thermometer at Date Palm Beach during 1936, and by the U. S. Geological Survey at Sandy Beach during 1953 were not significantly different from our data. Mean water temperatures were highest in August, but maximum temperatures may be reached during June, July, and September. Coldest water of the year may occur in December, but more often in January or February.

Beginning in April and May air temperatures equal or exceed water temperatures (Figure 5). In June, the increased solar radiation may warm the water surface so rapidly that, although the maximum depth of the Sea is only 40 feet (12 meters), there may be a significant difference between temperatures at surface and bottom (Table 3). At the end of May, there was a difference of only 0.7 degrees C between surface and bottom. On June 8, however, the difference was 5.3 degrees C (9.5 degrees F), but this was temporary and decreased to 2.2 degrees C by June 14, to 1 degree C on June 30 (not shown) and 1.4 degrees C on July 7. The difference in surface and bottom temperature remained slight until July 18 when at mid-day the surface was 3.9 degrees C warmer than the bottom; the next day (July 19) the surface was 3.2 degrees warmer than the bottom at 6 AM, and by 6 PM the difference had increased to 3.9 degrees C (Table 6). By the end of July, the bottom had warmed to nearly 30 degrees C, and its temperature was only 1.1 degrees C below that of the surface. During August, the maximum observed difference was 0.8 degrees C, and at times surface and bottom temperatures were equal (as on August 24). From September until May, the usual difference between surface and bottom was 1 degree C or less.

TABLE 3

Vertical Distribution of Water Temperatures in the Salton Sea, in Degrees C, 1955 *

Depth in Meters	May 27	June 8	June 14	July 7	July 18	July 27	Aug. 24	Sept. 15	Sept. 20	Oct. 19	Nov. 15
0	23.0	28.2	26.2	28.0	30.9	30.9	31.2	32.7	29.0	25.8	20.0
1	--	28.0	--	27.6	--	--	--	--	--	--	--
2	--	27.5	--	27.0	--	--	--	--	--	--	--
3	--	24.8	25.5	26.8	30.4	--	--	--	--	--	--
5	22.4	24.0	25.0	26.6	30.0	30.2	31.3	31.8	28.2	25.5	19.8
7	--	--	--	--	29.7	--	--	--	--	--	--
9	--	23.5	--	--	27.9	--	--	--	--	--	--
11	22.3	22.9	24.2	26.6	27.0	29.8	31.2	31.6	28.2	25.6	19.9

* Measurements made with a reversing thermometer.

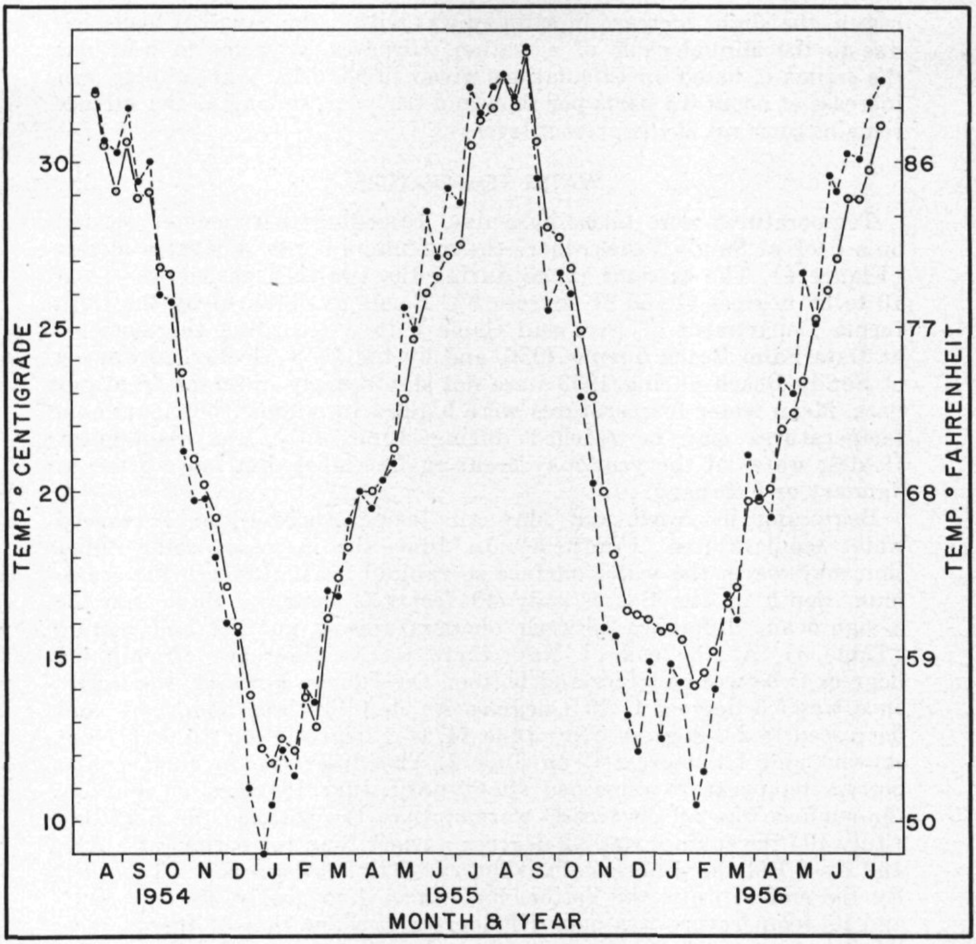


FIGURE 5. Mean water (solid line) and mean air (dotted line) temperature, Fish Springs, Salton Sea.

The temperature gradients that appeared during June and July correlated with changes in the weather. Air temperatures are indicative of the intensity of solar radiation and the warming of the surface on June 8 followed the first protracted period with air temperatures above 38 degrees C (100 degrees F). The rapid rise of water temperature on July 18 and 19 followed four days with a mean maximum air temperature of 40 degrees C (104 degrees F). In August, air temperatures were consistently high—the mean maximum for the entire month was 37.5 degrees C (99.4 degrees F)—and for the first 10 days of September it was 40 degrees C (104 degrees F). During the period of relatively constant air temperatures, the vertical distribution of water temperatures remained quite constant.

The bottom temperature did not fall below 30 degrees C until after mid-September. It fell to 25 degrees C in mid-October and to 20 degrees C by mid-November. Differences between temperatures at the surface and at the bottom during autumn were not great compared to those in June and July. The entire water column seemed to cool uniformly, as would be expected since mixing of cooler surface waters (which tend to sink) is less dependent on chance wind action than is mixing of warmer (and therefore, less dense) surface water in early summer. The appearance of a marked gradient seemed to be dependent on both rapid increase in solar radiation and lack of wind, so that the warmed surface water would not be mixed with the lower layers. Wind action mixes the shallow waters of the Sea thoroughly, as will be brought out in the section dealing with concentrations of dissolved oxygen.

There was no permanent thermocline in the Sea (Table 3). Sometimes, during the brief periods when surface and bottom temperatures were markedly different, a sharp thermocline developed. It could occur near the surface (between two and three meters on June 8) or at greater depth (between seven and nine meters on July 18). Sometimes there was a gradual uniform decrease in temperature with depth, with no thermocline. In any event, there was no permanent layering, but only temporary stratification following short windless periods, when a rapid increase in surface temperature was not dissipated by mixing with cooler sub-surface water.

DISSOLVED OXYGEN

Concentrations of dissolved oxygen were determined by the unmodified Winkler method (American Public Health Assoc., 1955). The unit of concentration used in this report is milliliter of gaseous oxygen per liter of water (abbreviated to ml/L). For conversion to milligram per liter, the factor is $32/22.4 = 1.42$; for conversion to milligram-atom per liter, the factor is $1.42/16 = 0.089$. Saturation values for oxygen in Salton Sea water were approximately six ml/L at 10 degrees C, five ml/L at 20 degrees C, and four ml/L at 30 degrees C.

Near shore there were great diurnal changes in oxygen concentration. An example of this, at a time when water temperatures were at their yearly maxima, is shown in Table 4. The data are from water about three meters deep approximately 100 meters offshore on September 11, 1954. The water temperatures ranged from 29 to 32.4 degrees C. The evening concentration of 6 ml/L was well above the saturation value for the high temperature concerned.

During the colder part of the year, surface water also became supersaturated, with still higher concentrations of oxygen. The evolution of oxygen by an early bloom of phytoplankton on February 17, 1955 is

TABLE 4

Dissolved Oxygen, September 11, 1954, Salton Sea

	Concentration in ml/L			
Depth	6:40 AM	8:30 AM	1:00 PM	6:20 PM
Surface	2.8	3.6	5.9	6.1
Bottom (3 meters)	2.3	3.4	5.7	5.6

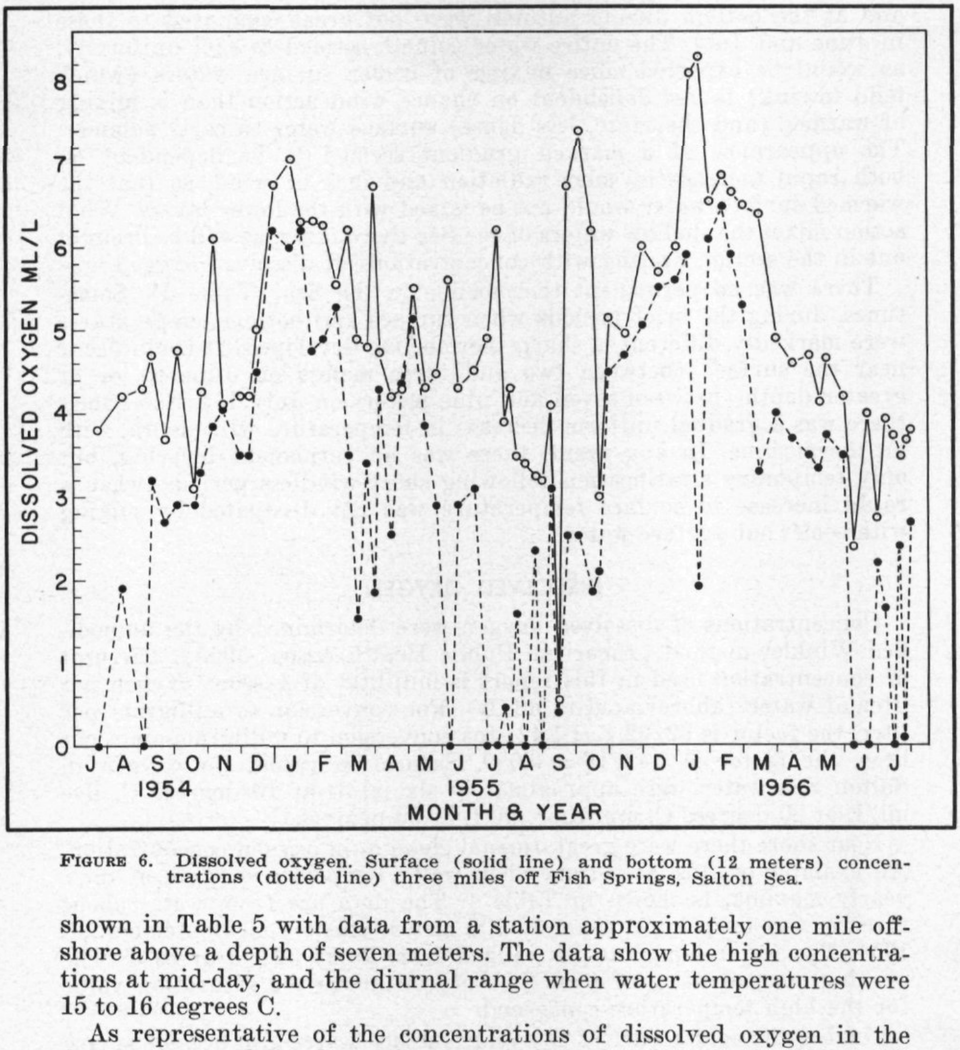


FIGURE 6. Dissolved oxygen. Surface (solid line) and bottom (12 meters) concentrations (dotted line) three miles off Fish Springs, Salton Sea.

shown in Table 5 with data from a station approximately one mile offshore above a depth of seven meters. The data show the high concentrations at mid-day, and the diurnal range when water temperatures were 15 to 16 degrees C.

As representative of the concentrations of dissolved oxygen in the deeper water of the Sea, Figure 6 shows values obtained at approximately weekly intervals during 1955, and bi-monthly during 1956 about

TABLE 5

Dissolved Oxygen, February 17, 1955, Salton Sea

Depth	Concentration in ml/L		
	6:45 AM	12 Midnight	5:30 PM
Surface	6.2	8.1	6.2
Bottom (7 meters)	3.7	3.6	4.0

three miles east of Fish Springs in the deepest part of the Sea (about 12 meters). Surface concentrations ranged from 8.3 ml/L at mid-day (on January 16, 1956) to 0.55 (at dawn on September 16, 1955). Bottom values ranged from winter highs of 6.2 (January 4, 1955) and 6.5 ml/L (February 14, 1956) to the zero recorded on several occasions in summer.

In general, during winter there were high concentrations of oxygen throughout the water column. However, as early as January 1956 and during March and April 1955 there were times when concentrations were low at the bottom. In early June of both 1955 and 1956 the bottom became anoxic, but the condition did not last long (Figure 6). In July 1955, however, only one of six determinations showed any oxygen present, and that one (on July 27) showed only 0.46 ml/L. When oxygen was absent at the bottom there was no wind and the surface of the Sea became so smooth it mirrored the surrounding hills. One such windless period occurred in mid-July of 1955. Samples taken at 9:30 AM on July 12, at noon on July 18, and at 6 AM and 6 PM on July 19 contained no oxygen at depths below nine meters (Table 6).

In contrast, records for mid-September and mid-October illustrate the effect of mixing by wind during the 12-hour period between samplings (Table 7). Surface to bottom differences in concentrations of dissolved oxygen, pH, and temperature disappeared during the mixing.

TABLE 6

Morning and Evening Concentrations of Dissolved Oxygen, Temperature, and pH, July 19, 1955, Salton Sea

Depth in Meters	6 AM			6 PM		
	Dissolved O_2 in mg/L	Temp. in Degrees C	pH	Dissolved O_2 in mg/L	Temp. in Degrees C	pH
0	7.4	30.6	8.69	9.3	31.4	8.73
7	6.4	29.4	8.55	5.6	30.3	8.58
9	0	28.0	8.34	0	----	8.37
11	0	27.4	8.34	0	27.5	8.26

TABLE 7

Morning and Evening Concentration of Dissolved Oxygen, Temperature, and pH, Mid-September and Mid-October 1955, Salton Sea

Depth in Meters	Dissolved O_2 in mg/L	Temp. in Degrees C	pH	Dissolved O_2 in mg/L	Temp. in Degrees C	pH
	September 15, 5 PM			September 16, 5:45 AM		
0	10.1	32.7	8.74	0.8	30.4	8.28
5	3.4	31.8	8.56	0.7	30.4	8.26
11	0.5	31.6	8.52	0.6	30.6	8.3
	October 18, 4 PM			October 19, 6 AM		
0	8.9	25.5	8.7	3.1	25.0	8.48
5	3.7	25.6	8.52	3.1	25.2	8.48
11	2.6	25.6	8.48	3.1	25.3	8.44

During 1956, the bottom anoxia again appeared in June, and was absent in early July. Then by July 16, after a windless period, oxygen was absent below 8 meters, and there was a three-degree difference in temperature between surface and bottom (Table 8). On July 18, two days later and after a day with strong south wind, thorough mixing was indicated by the similarity of surface and bottom temperatures, the presence of oxygen at the bottom again, the small difference in pH, etc. (Table 9).

During the mixing that followed a period of oxygen depletion at the bottom, oxygen concentrations at the surface sometimes would be lowered temporarily below the minimum needed to maintain many forms of life in the Sea. At such times, there sometimes would be a fish "kill," evidenced by dead fish floating on the surface and washed ashore on the beaches. The depletion of oxygen was reflected by the disappearance of a bottom-dwelling worm (*Neanthes*) from the mud at depths below about nine meters during summer. It seems that only the water below nine meters became anoxic; primarily in the central (deepest) part of the Sea, which is approximately the area below the –260-foot contour in Figure 2. Regions near shore that were shallower than nine meters, seemed to be affected only for brief periods in the early morning, when the situation was comparable to that in the surface waters above the deeper parts of the Sea, as shown in Table 7.

TABLE 8

Temperature, pH, and Concentration of Dissolved Oxygen, Ammonia, and Sulfide, July 16, 1956, Salton Sea

Depth in Meters	Temp. in Degrees C	pH	Dissolved O_2 in mg/L	NH_3-N (μg-at/L)	Sulfide-S (μg-at/L)
0	30.0	8.51	5.4	10	0.35
6	29.0	8.42	4.3	11	0.7
8	28.4	8.35	0.5	22	1
9	--	8.19	0	35	15
10	27.2	8.16	0	40	38
11	--	8.08	0	48	64
12	27.0	8.02	0	36	85

TABLE 9

Temperature, pH, and Concentration of Dissolved Oxygen, Ammonia, and Sulfide, July 18, 1956, Salton Sea

Depth in Meters	Temp. in Degrees C	pH	Dissolved O_2 in mg/L	NH_3-N (μg-at/L)	Sulfide-S (μg-at/L)
0	29.5	8.50	5.0	17	0.1
6	29	8.49	4.5	15	0.1
8	29	8.47	4.4	12	0.1
10	29	8.42	3.7	14	0.1
12	29	8.40	3.4	17	0.1

HYDROGEN ION CONCENTRATION

Field determinations, made with a Beckman Model G portable pH meter, showed the pH ranged from 8.3 to 8.6 in winter and from 8.5 to 8.8 in summer. The Salton Sea contains a different ratio of carbonate to bicarbonate than the oceans, and the pH is higher. As in the oceans, photosynthetic uptake of carbon from the buffer system causes a diurnal cycle of pH. An example (Table 10) of the diurnal range of pH near shore and one mile offshore on April 12, 1955 illustrates the daily trend during the time of year when water temperatures were below 20 degrees C (18.6-19.4 degrees C).

Data from the same locations on July 19, 1955 (Table 11) illustrate the pH values during the hottest part of the year, on a day when surface temperatures were 31.4 degrees C. at dawn and 31.6 at sunset. Data for vertical distribution of pH and the diurnal range observed in the deeper part of the Sea on the same date (July 19, 1955) appear in Table 6. Tables 7 and 8 also include data for pH values in deeper water.

OXIDATION AND REDUCTION POTENTIAL OF BOTTOM MUD

The redox potential of the bottom, taken with a platinum electrode in a Beckman Model G portable pH meter, was —560 mV at 12 meters three miles offshore on August 11, 1955, a day without oxygen in the bottom water. The pH was 7.5. During anoxic periods in 1956, the redox potentials of the mud were —474 mV on June 6, —480 mV on June 22, and —450 mV on July 16. The pH of the mud on these occasions was 7.4 to 7.5.

SULFIDE

A thick layer of settled plankton accumulated on the bottom in summer. On the surface of this bottom layer, the sulfur bacterium (or blue-

TABLE 10

Diurnal pH, April 12, 1955, Salton Sea

Time	pH Near Shore		pH One Mile Offshore	
	Surface	3 Meters	Surface	7 Meters
6 A.M.	8.32	8.39	8.41	8.39
12 Midnight	8.5	8.4	8.56	8.51
6 P.M.	8.62	8.6	8.58	8.51
12 Midnight	8.47	8.47	8.46	8.4

TABLE 11

Diurnal pH, July 19, 1955, Salton Sea

Time	pH Near Shore		pH One Mile Offshore	
	Surface	3 Meters	Surface	7 Meters
5 A.M.	8.67	8.63	8.62	8.52
11 A.M.	8.74	8.72	8.7	8.62
6 P.M.	8.81	8.81	8.75	8.63

green alga) *Beggiatoa* was noted in September and October 1955. The combination of sulfur bacteria and periods of bottom anoxia during the summer and fall led to the belief that high concentrations of sulfide might occur when oxygen was absent. A method of determining sulfide in sea water was obtained from Dr. N. W. Rakestraw, Scripps Institution of Oceanography. It was a modification of the colorimetric technique (American Public Health Assoc., 1955) which utilizes para-aminodimethyl-analin and ferric chloride to produce methylene blue in the presence of sulfide ion.

Beginning in January 1956 and continuing through June, determinations were made on a by-monthly basis. Six samples were analyzed during July. The average value of 12 bottom samples (from a depth of 12 meters), taken from January through May, was 0.25 µg-at/L (microgram-atoms per liter), with a range from 0.0 to 0.5. On June 6, the first day of oxygen depletion at the bottom, the concentrations of sulfide rose to 1.5 µg-at/L at the bottom, and on June 22 it was 50 µg-at/L. On both July 2 and 9, concentrations were low: 0.5 µg-at/L. On July 16, the bottom concentration of sulfide rose to 85 µg-at/L. The values for the last three determinations, made on July 18, 24, and 30, respectively, were 0.1, 1.0, and 0.6 µg-at/L. In contrast to high values and great variation at the bottom, the average sulfide concentration in surface samples during January through July 1956 was 0.3 µg-at/L, with a range from 0.0 to 0.6 µg-at/L. Data on vertical distribution of sulfide on July 16 and 18 have been included in Tables 8 and 9.

AMMONIA, NITRATE, AND PHOSPHATE

Ammonia was determined by direct Nesslerization after precipitating interfering ions by the Witting-Buch technique (Wirth and Robinson, 1933); nitrate by the diphenylbenzidine method (Atkins, 1932); and

TABLE 12

Concentration of Ammonia, Nitrate, and Phosphate at Four Locations, Salton Sea

Station Number	Depth in Meters		Concentration in µg-at/L		
			Ammonia	Nitrate	Phosphate
1	0	Average	5.35	0.85	0.47
		Range	0.2-13.5	0.2-1.9	0.33-1.0
	6	Average	5.9	0.8	0.61
		Range	0.2-18.3	0.2-1.7	0.32-1.95
	12	Average	9.5	0.78	0.45
		Range	0.4-40.0	0.2-1.85	0.3-0.85
2	0	Average	5.5	0.91	0.47
		Range	0.1-12.3	0.4-2.0	0.3-0.6
	3	Average	5.9	0.99	0.51
		Range	0.2-13.8	0.4-2.2	0.2-0.85
3	0	Average	4.8	0.93	0.71
		Range	0.1-10.0	0.4-1.4	0.45-1.1
4	0	Average	12.3	7.63	1.1
		Range	0.2-30.0	0.8-30.0	0.55-4.2

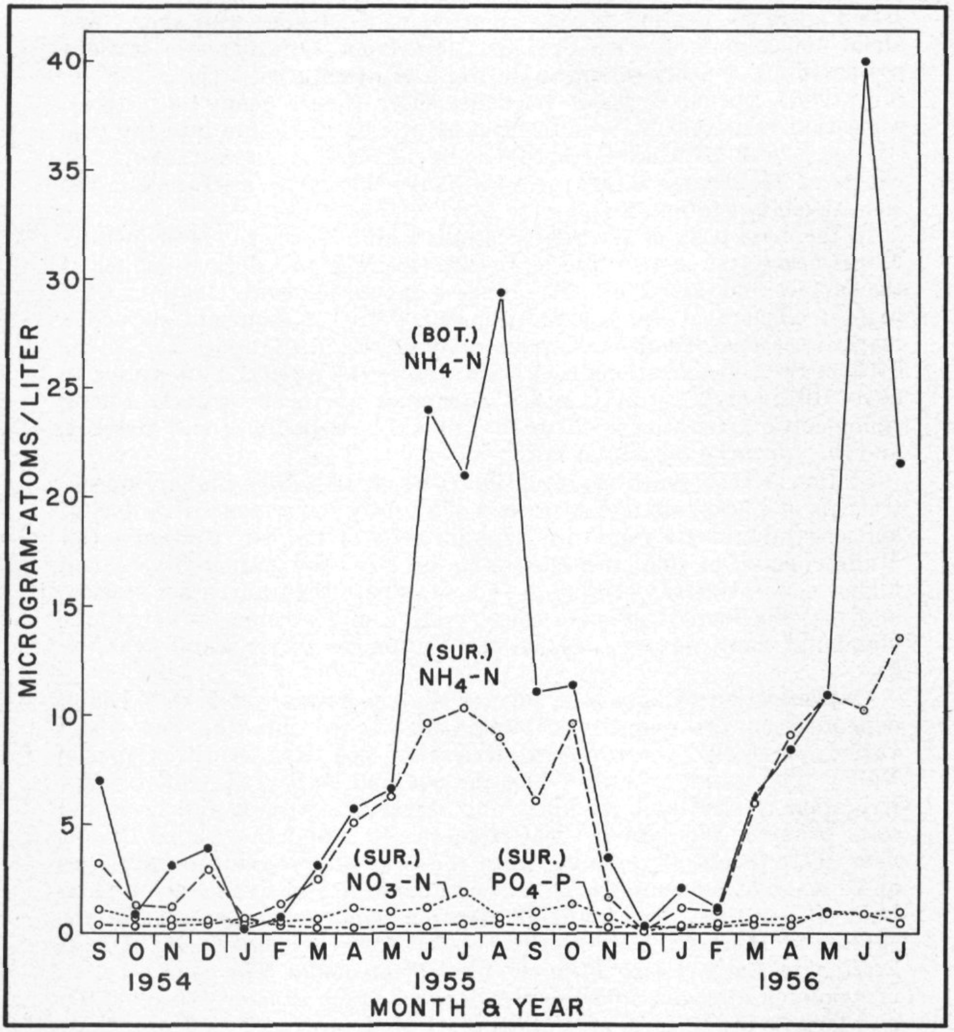


FIGURE 7. **Ammonia-N, Nitrate-N, and Phosphate-P three miles off Fish Springs, Salton Sea.**

phosphate by the molybdate-stannous chloride method (Wooster and Rakestraw, 1951). Only ammonia was in sufficient quantity to show significant seasonal trends. Concentrations of nitrate and phosphate, although high in the water entering the Sea, were so low in the main body of the Sea that not much reliance can be placed on the absolute values obtained with the colorimetric methods used for analysis. Results of the nitrate test, especially, are of doubtful value.

Table 12 summarizes data obtained at four stations. Those from Stations 1 and 2 are based on weekly samplings during a two-year period (September 1954 to July 1956). Station 1, representative of the deepest water in the Sea (12 meters), was about three miles off Fish Springs (see Figure 2). Station 2, representative of conditions near shore, was about 100 meters off Fish Springs. Data from the other two stations are based on monthly sampling during a one-year period (May 1955 to May 1956). Station 3 was on the south shore (depth about 1.5 meters), a location relatively little influenced by stream discharge into the Sea. Station 4 was off Mullet Island (depth about 1.5 meters), where the effects of freshwater discharge were noticeable. Only surface samples were taken at Stations 2 and 3.

In the main body of the Sea (Stations 1 and 2), the range of nitrate-N was nearly the same at all depths: the average was slightly higher at the surface and near shore. The range and average concentrations were highest offshore at the bottom. Concentrations of ammonia showed a marked seasonal trend in the main body of the Sea (Figure 7). At the bottom, the concentrations rose from a low (0.4 µg-at/L) in winter to about 10 µg-at/L by May and a maximum above 20 µg-at/L during summer. Concentrations fell to 10 µg-at/L in September and October, and then down to the winter low.

Station 3 (the south shore of the Sea) had slightly higher concentrations of phosphate and nitrate, and slightly lower concentrations of ammonia, than were found in the main body of the Sea. Station 4 (off Mullet Island, in line with the discharge from the Alamo River) had higher concentrations of nitrate and phosphate than any other station, and had the highest average concentration of ammonia, although the maximum there was exceeded at the bottom in deeper water (Station 1).

Concentration of ammonia, nitrate, and phosphate off Mullet Island depended on the quantity of water discharged into the Sea which varied seasonally according to irrigation practices in the Imperial Valley. The water "wasted" into the Sea had been used primarily for irrigation or for land leaching, and it carried with it fertilizer and salts from the land. In the waters of the New and the Alamo Rivers, near their points of discharge into the Sea, there have been averages of 10 µg-at of ammonia-N, 25 µ-at of nitrate-N and five µg-at of phosphate-P per liter. The available nitrogen momentarily present at the surface of the main body of the Sea was low (average six µg-at/L at Station 1) and was largely in the form of ammonia. The concentration of available nitrogen entering the Sea was much greater (35 µg-at/L) and largely in the form of nitrate. Most of the nitrogen and phosphate were not, of course, in the dissolved inorganic form, but were tied up in the organisms and in the organic mud of the bottom.

PHYTOPLANKTON AND PLANT PRODUCTIVITY

LARS H. CARPELAN

The plant life of the Salton Sea was predominantly single-celled algae living suspended in the water. The organisms were so small (microscopic) that the individually-floating plant cells (phytoplankton) were visible only when their numbers were so great that they colored the water. The only plants large enough to see (macroscopic) were blue-green algae whose massed growth was visible near the shore. There were no brown algae nor any macroscopic red algae (the only red alga identified from the Sea is a small freshwater or brackish-water species, *Asterocystis ornata,* which grows epiphytically on filamentous green algae near freshwater inlets). Although species of *Enteromorpha* and *Cladophora* were in the freshwater drainages into the Sea, neither these, nor other species of macroscopic green algae lived in the main body of water. The only visible plants of the Sea were, thus, the blue-green algae which grew on the bottom in shallow water, and on buoys and pilings. The mixed growth of blue-green algae was determined by Dr. E. Yale Dawson to consist of nine species: *Phormidium tenue* (common), *Plectonema calotrichoides, Spirulina major, Spirulina subtilissima, Calothrix aeruginea, Hydrocoleum sp., Pleurococcus turgidus, Pleurocapsa crepidinum, Oscillatoria sp.,* (near *O. laetevirens*).

Associated with the massed blue-green algae and their gelatinous matrix were littoral diatoms, among which *Nitzschia sigmoides* and a species of *Pleurosigma* were the most abundant. The layer of blue-green algae and associated diatoms plus detritus occasionally would break free from the bottom to float at the surface. The floating mat appeared sporadically during the warmer part of the year, beginning as early as May. On one occasion (May 6, 1955), the dry weight of the mat floating in the Fish Spring boat channel was 1,630 grams (about 3½ lbs.) per square meter.

Although the bottom growth was considerable, and would occasionally be conspicuous when it floated near shore, the principal plants of the Sea, both near shore and in open water, consisted of the individually floating cells of the phytoplankton. In an attempt to learn the prevalence of the commonest species, phytoplankton was sampled routinely at two stations off Fish Springs. One station was about three miles offshore above the deepest water of the Sea (12 meters); the other was about 100 meters from shore where the water was about three meters deep. The phytoplankton cells in one liter surface samples were killed with formalin and allowed to settle for a week. The supernatant was then siphoned off, and the number of cells in the concentrate was estimated by counting them in a haemocytometer chamber. Because the phytoplankton was subject to local blooms, the method was subject to error from variations due to time and location of collection. Another, perhaps more serious source of error, was the possibility of incomplete mixing of the concentrate, of which only a small quantity was actually counted. The estimated numbers given below are based on the average

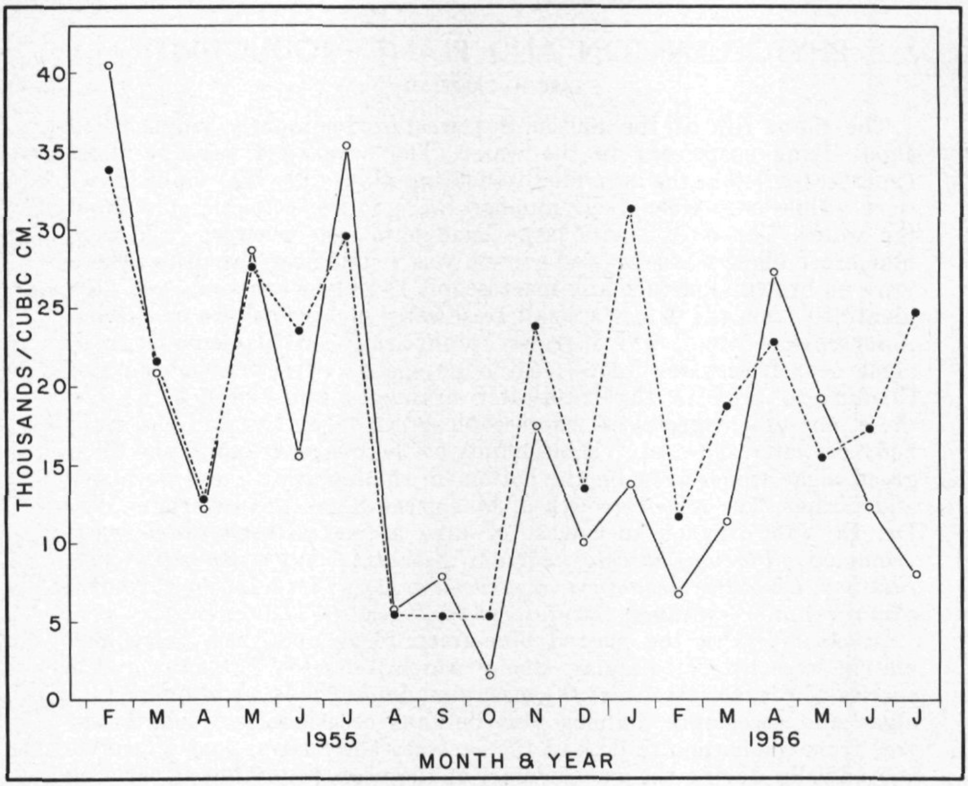


FIGURE 8. Total phytoplankton, Salton Sea. Average monthly number per cm³. Solid line = three miles offshore; dashed line = near shore.

number found in four squares, each with a volume of 0.1 mm³. The average number per 0.1 mm³ was multiplied by 10 (to convert to mm³), then by a concentration factor (volume of concentrate/1,000), and finally by 1,000 to get the number per cm³ (cc) which is the unit used in the discussion.

The smallest numbers were found during the warmest part of the year (August to October) when there were about 5,000 per cm³ (Figure 8). Maximum populations occurred in winter (February 1955 and January 1956), and in early summer (July 1955) when the average exceeded 30,000 cells per cm³. Different species were concerned in the maxima at different seasons.

The totals in Figure 8 comprised three groups of algae: **diatoms** (Class Bacillareiae of the Division Chrysophyta, according to the classification of Smith, 1950), **green algae** (Class Chlorophyceae of the Division of Chlorophyta), and **dinoflagellates** (Classes Desmokontae and Dinophyceae of the Division Pyrrophyta). Several species of diatoms and dinoflagellates were concerned, but only one green alga, in the order Chlorococcales, was abundant enough to warrant inclusion in this treatment which deals with only the most prevalent species.

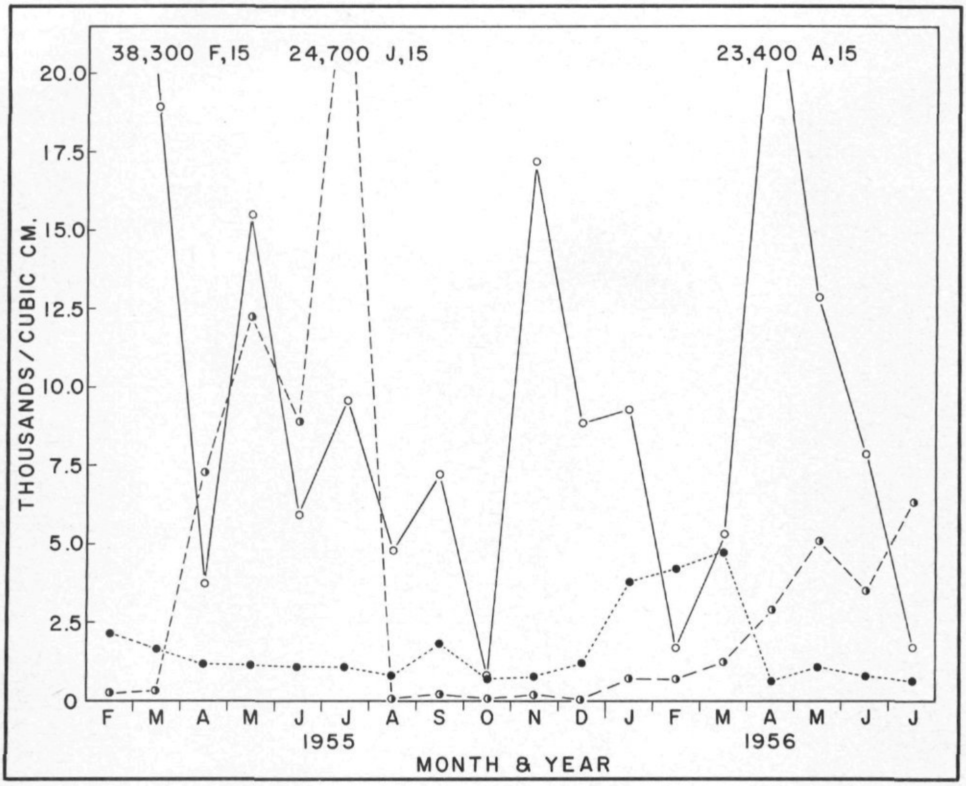


FIGURE 9. Average total numbers of diatoms, dinoflagellates, and green algae per month three miles offshore, Salton Sea. Solid line = diatoms; dashed line = green algae; dotted line = dinoflagellates.

Occasionally present, but not included in the totals were: planktonic Myxophyceae (including *Lyngbya* spp. and *Gomphosphaeria lacustris*); Chrysophyceae (unidentified species of Coccolithophoridae and a silicoflagellate, possibly a *Dictyocha*); Crytophyceae (*Crytomonas* sp.); Chlorophyceae (among which *Crucigenia rectangularis* and *Oocystis* spp. were the most common); and a euglenoid (*Eutreptia lanowii*). These organisms were present in small numbers with two exceptions. The silicoflagellate (Figure 10,I) was present from June to November 1955, and numbered 450/cm^3 in June 1955; and the euglenoid (Figure 10,J), was found sporadically but apparently was most prevalent in autumn: on October 4, 1955 there were 1,300/cm^3 in a sample collected near shore.

The dinoflagellates averaged about 1,000 cells per cm^3 during most of the year, but during January, February, and March (1956) they averaged between 4,000 and 5,000 in the offshore collections (Figure 9). The maximum number of diatoms appeared in late winter and spring (February, March, and May 1955), and during another peak of population in the fall (November) the average number exceeded 15,000 per cm^3. Only small numbers of the green alga were present during the

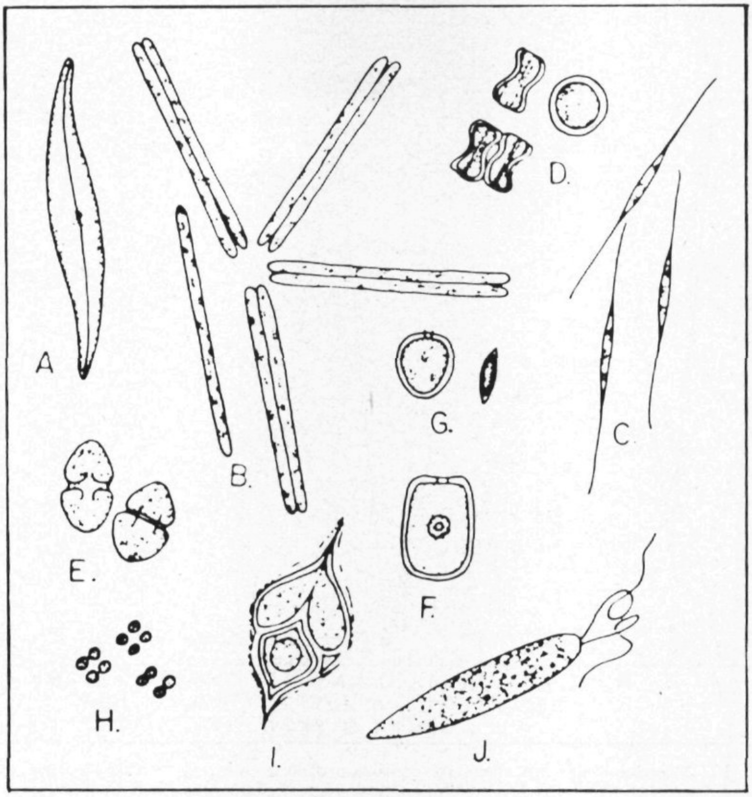


FIGURE 10. Representative phytoplankton organisms of the Salton Sea. A. *Pleurosigma* sp., B. *Thalassionema nitzschoides*, C. *Nitzschia longissima*, D. *Cyclotella caspia*, E. *Glenodinium* sp. F. *Exuviella marina*, G. *Exuviella compressa*, H. *Westella botryoides* (?), I. *Dictyocha* sp. (?), J. *Eutreptia lanowii*. Drawing by W. J. Baldwin.

winter of 1954-55, but the population increased beginning in April 1955 and reached its peak in July when the average was 25,000 per cm^3. Few were present from August 1955 through March 1956, and there were collections in which it was absent. Then, in 1956 as in 1955, the population increased again in April and May.

DIATOMS

Most of the diatoms in the Salton Sea belong to the group of bilaterally symmetrical diatoms (usually elongated forms) known as the Order Pennales, which includes both freshwater and marine species. The marine species are more characteristic of the shore than of the open ocean. Among the pennate diatoms of the Salton Sea were *Nitzschia sigmoides* and *Pleurosigma* sp., which were mentioned previously as having been identified in the growth of blue-green algae near shore. In plankton samples, small numbers of *Synedra* spp., *Navicula* sp., and *Gyrosigma* spp. were present. A species of *Pleurosigma* (Figure 10,A), about 10 by 70 μ in size, was consistently present in plankton samples taken offshore as well as at shore. It was scarce at times, especially in

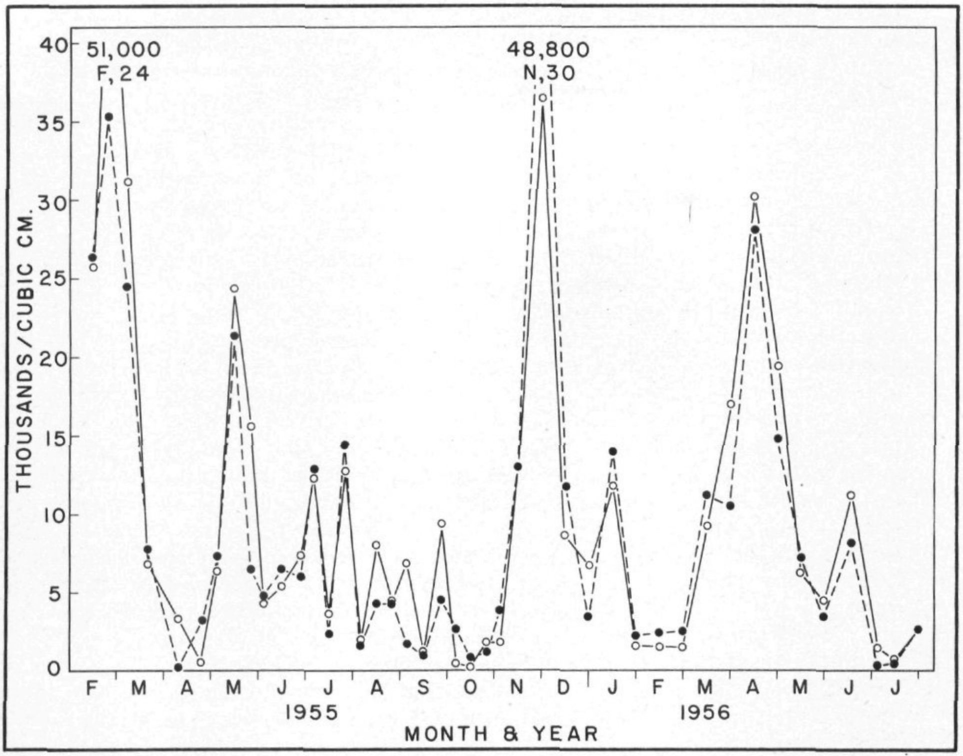


Figure 11. Total numbers of diatoms in individual collections, Salton Sea. Solid line = 3 miles offshore; dashed line = near shore.

summer, but as many as 375 per cm³ (May 17, 1955) were present at the surface offshore.

Another pennate diatom of numerical significance was *Thalassionema nitzschoides* (Figure 10,B), which is also of fair size (2.5 x 55 µ). It was usually present in greater numbers in the offshore collections. The species is free-floating, and generally the cells are solitary, but occasionally they are joined at the ends. *Thalassionema* was scarce during early summer of 1955 but became prevalent beginning in late July. On August 17, there were 5,000 per cm³ offshore, and the number increased to 6,600 on September 2, and to 9,000 on September 27. They declined to fewer than 300 per cm³ during October and November, and very few were found during winter. There was a spring bloom—7,000 per cm³ on April 30—after which *Thalassionema* became scarce during May, June, and July 1956. This species thus seems to have population peaks in spring and in autumn.

The numbers mentioned above are small compared to the two most prevalent diatoms of the Sea. *Nitzschia longissima* (Figure 10,C) and *Cyclotella* sp. (Figure 10,D) accounted for the great numbers of diatoms indicated in Figures 9 and 11. The length of this species of *Nitzschia*, about 60-70 µ, is short for *longissima*, but otherwise it fits the description. It could be a variety of *N. closterium*. This *Nitzschia* occurred in great numbers during most of the year, and was either absent or nearly so only during summer (August, September, and October). In the routine collections, the maximum numbers estimated were 44,000 per cm^3 at the three-mile station, and there was a comparable population (46,000 per cm^3), near shore on November 28, 1955. Even greater numbers were found in non-routine collections; the greatest, 56,000 per cm^3, was found during a bloom on February 1, 1955 about one mile offshore in a sample taken just above bottom at a depth of 8 meters.

In addition to *N. longissima,* the other diatom that became really numerous was a species of *Cyclotella* (Figure 10, D) identified by T. Braarud as close to *C. caspia. Cyclotella* is one of the Order Centrales which are radially symmetrical and includes most pelagic marine diatoms. In place of the elongate structure of the pennate species discussed above, *Cyclotella* is a flattened disk about 6 µ thick and 10 to 16 µ in diameter. In side view it has an offset near the middle. It is usually solitary, but there is a tendency for chain-formation. *Cyclotella* was less numerous in summer than at other seasons, but was in all collections made in the Sea. In the routine collections, the maximum numbers were in the range from 7,000 per cm^3 (offshore, February 23, 1955) to 8,500 (near shore, April 17, 1956). Greater numbers were found in collections from the southern end of the Sea. For example, on May 5, 1955 there were 10,000 per cm^3 off Mullet Island. And on October 7, 1955 during a bloom in the southeastern corner of the Sea, there were 40,000 per cm^3 off the western shore of Mullet Island and 53,000 per cm^3 about a mile north of the Island along the eastern shore of the Sea.

Cyclotella and *N. longissima* were thus the most numerous of the diatoms in the Sea. Their great numbers rivaled those of the equally numerous dinoflagellates.

DINOFLAGELLATES

The name dinoflagellate is used here in the broad sense to include all members of the Pyrrophyta, and not, in the restricted sense, to designate only the Class Dinophyceae. Since the dinoflagellates of the Salton Sea seemed subject to local blooms, it is difficult to generalize about seasonal prevalence from data obtained routinely at only a pair of stations. At these stations, population peaks occurred in winter and fall (Figure 12). In the routine collections, there were usually more dinoflagellates near shore where the maxima occurred on March 8 and October 4, 1955. On both dates, there were approximately 6,400 per cm^3. During 1956, greater numbers were present; near shore there were 41,000 per cm^3 on January 16, and 14,000 per cm^3 on February 14 and 29. The most ever taken offshore was 8,100 per cm^3 on February 29, 1956. As with the diatoms, the largest numbers of dinoflagellates were observed in nonroutine collections during local blooms.

Among the dinoflagellates found in the Sea, *Amphidinium kofoidii* was present occasionally; and *Peridinium trochoideum* was abundant at times as was the species of *Gonyaulax* which Dr. R. H. Thompson thought might be undescribed. Although these three organisms have been included in the dinoflagellate totals, only the two most prevalent dinoflagellates have been considered below. These two were an undetermined species of *Glenodinium* and *Exuviella compressa.* Both were present the year around.

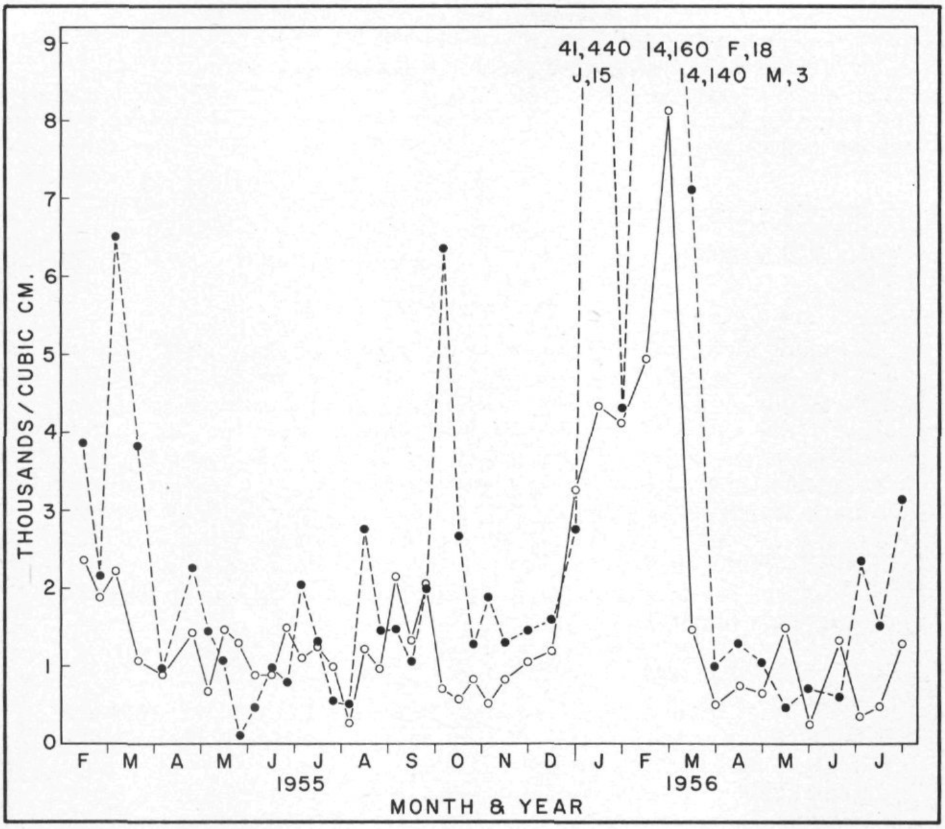


FIGURE 12. Total numbers of dinoflagellates in individual collections, Salton Sea. Solid line = 3 miles offshore; dashed line = near shore.

Glenodinium sp. (Figure 10,E) is dumb-bell shaped, 10-16 μ in diameter and 20-25 μ long. Although fewer than 100 per cm^3 were taken in some collections, it was present every month that collections were made. In the routine collections, the greater numbers usually occurred near shore; for example, there were 6,100 per cm^3 near shore on March 8, 1955, compared to 2,200 three miles offshore. Occasionally many were present offshore, as on September 13, 1955 when there were 6,500 per cm^3 in a mid-Sea collection made half-way between Fish Springs and Bombay Beach. The greatest number taken in routine collections was 41,000 per cm^3, at the shore station on January 16, 1956, and the greatest number in any collection, an estimated 100,000 per cm^3, came from a cove near Fish Springs on March 30, 1955.

Two species of *Exuviella* were found; one, *E. marina* (Figure 10,F), was taken occasionally, the other, *E. compressa* (Figure 10,G), was one of the two prevalent dinoflagellates in the Salton Sea. Because its cell wall is divided into two halves which are not further subdivided into plates, *Exuviella* is placed in a different Class (Desmokontae) from the other Pyrrophyta of the Sea. *Exuviella* is a flattened, heartshaped structure, and is about 15 x 10 μ in size. It is motile, having two flagella coming out from the apical notch.

Exuviella was present all through the year in the routine collections. The numbers ranged from fewer than 100 to the 1,800 per cm^3, found at shore on April 22, 1955. In non-routine collections, *Exuviella* was much more numerous during sporadic blooms, especially at the southern end of the Sea. There were collections in which the numbers of *Exuviella* rivalled those of the most numerous diatoms. For example, there were 32,000 per cm^3 on the west side of Mullet Island on May 5, 1955, and 63,000 per cm^3 in a cove on the southern shore on April 20, 1956.

CHLOROPHYTA

A small alga, usually appearing in groups of four cells (Figure 10, H), became conspicuous in the phytoplankton in April 1955. The organism is possibly *Westella botryoides* Wildem, one of the green algae of the Order Chlorococcales. The number of colonies in the routine collections averaged 13,000 per cm^3 during July, and exceeded the number of all other phytoplankton cells. Few were present during fall and winter, but by May 1956 there were again over 10,000 per cm^3. *Westella* is small, each cell is about 2 μ in diameter, but the great number—up to 40,000 colonies (160,000 individual cells) per cm^3—made it the most numerous plant of the Salton Sea phytoplankton during early summer.

SIZE AND VOLUME OF PHYTOPLANKTON CELLS

Cell size is of interest because, although the small green alga contributed the greatest number of cells in the plankton collections, the volume of material was very small.

The number of cells, the unit used in the discussion, thus might give a false impression of the mass of material present. For example, the large size of *Eutreptia* and *Dictyocha* made them of greater significance than indicated by their relatively small number (Table 13). On the other hand, the tremendous numbers of *Westella* become less impressive when their mass is considered. When both size and numbers are considered it becomes apparent that the four most important were *Nitzschia longissima, Cyclotella caspia, Glenodinium sp.*, and *Exuviella*

TABLE 13

Volume of Various Phytoplankton Organisms Taken in the Salton Sea

Species	Volume Per Cell (μ^3)	Maximum Number/cm^3 in Collections	Volume of Maximum Number (μ^3 x 10^6)
Pleurosigma sp.	800	375	0.3
Thallasionema nitzschoides	175	9,000	1.57
Nitzschia longissima	200	56,000	11.2
Cyclotella caspia	400	53,000	21.2
Glenodinium sp.	3,000	41,000	123.0
Exuviella compressa	400	63,000	25.0
Westella sp. (?)	5	160,000	0.8
Dictyocha sp. (?)	7,000	450	3.1
Eutreptia lanowii	4,000	1,300	5.2

compressa because they made up the great bulk of plant material produced in the Sea.

PLANT PRODUCTIVITY

Plant cells of the types described above were the food producers of the Sea. In the process of photosynthesis, the diatoms, dinoflagellates, and other algae absorb the energy of sunlight, and use it to produce carbohydrates, proteins, fats, etc. from such raw materials as the carbon dioxide, bicarbonate, nitrate, ammonia and phosphate that are dissolved in the Sea.

The amount of plant material produced in the Sea might have been estimated in various ways, but the simplest, technically, was to measure the oxygen evolved during photosynthesis. From the amount of oxygen evolved, one can calculate the amount of carbon assimilated. This method of estimation is possible because in the overall photosynthesis reaction, which amounts to the reduction of carbon dioxide with hydrogen split from water, oxygen is an end product: $CO_2 + H_2O \rightarrow (CH_2O) + O_2$. The amount of carbon fixed can be calculated by assuming, as in the reaction above, that for each mol of oxygen given off, one mol of carbon dioxide is reduced, and that the amount of carbon assimilated would thus be $12/22.4 = 0.536$ mg. per milliliter (ml) of oxygen evolved.

The amount of oxygen produced by the phytoplankton at the surface was measured in one-liter glass-stoppered bottles submerged for four hours just beneath the surface in a floating raft. The difference between the concentrations of dissolved oxygen (determined by the Winkler method) in two bottles, one covered with black cloth and one exposed to light, was the measure of the oxygen produced. The dark bottle showed the oxygen content at the start of the test, minus the oxygen used in respiration by the organisms present. The bottles were placed in the raft early in the morning (between 8 and 9 AM) and removed at noon or at 1 PM. The tests were made at monthly intervals from December 1954 to November 1955, at a location about one-quarter mile off Fish Springs.

Field estimates of productivity, based on the dark- and light-bottle technique, are open to criticism (see Steeman-Nielsen, 1954), and the absolute values are questionable. The results are offered mainly for comparison with results obtained by the same technique in other waters. During most of the year, the amount of oxygen produced in the bottles was well above the limits of sensitivity of the method, which is 0.05 ml/l according to Ryther and Vaccaro (1954). The quantities of oxygen produced during the four-hour exposure, and calculated hourly rates and average daily production of oxygen each month, were determined (Table 14). In the latter calculation, the duration of daylight was arbitrarily chosen as eight hours during winter, nine hours during spring and fall, and 10 hours during summer. The average daily production during the year was 1.4 ml of oxygen per liter.

From the average daily production of 1.4 ml of oxygen per liter, it can be calculated (1.4×0.536) that the average carbon fixation was 0.75 mg per liter per day; the minimum was 0.11 mg of carbon

TABLE 14

Oxygen Production in Dark and Light Bottle Tests in the Salton Sea, 1954-1955

Date	Oxygen		
	ml/L per 4 Hours	ml/L per Hour	ml/L per Day
December 7	0.2	0.05	0.4
January 12	0.7	0.175	1.4
February 1	1.2	0.3	2.4
March 16	0.35	0.09	0.8
April 12	0.5	0.125	1.1
May 24	0.45	0.11	1.1
June 15	0.4	0.1	1.0
July 8	0.4	0.1	1.0
August 15	1.3	0.32	3.2
September 16	1.6	0.4	3.6
October 27	0.2	0.05	0.45
November 15	0.4	0.1	0.8

per liter per day (December and October); the maximum (September) was 1.9.

The average daily carbon fixation of 0.75 grams per cubic meter (M^3) can be compared with the estimate made by Riley (1941) for coastal sea water. Riley, using a similar technique, reported the average amount of carbon assimilated by pytoplankton at the surface of Long Island Sound was 0.175 gm/M^3 per day. Thus, the productivity at the surface of the Salton Sea would seem to be about four times greater than that of fertile coastal sea water. On the other hand, the productivity of the Salton Sea is less than reported for still shallower sea water: for example, Carpelan (1957) reported the average daily surface productivity of salt-producing ponds fixed as much as 3.9 grams of carbon per M^3 per day.

The plant production of the entire Salton Sea can be estimated from its area. Although tests were not made to determine the compensation point, a 20 cm Secchi Disk always became invisible at less than a meter, even under conditions of greatest water clarity. It is doubtful therefore, whether more than the surface meter received enough light to be productive. The estimate of productivity is based only on surface measurements, and thus tends to err on the high side. It should also be remembered that the estimates are based on a method with serious inherent errors, so the following figures are only a rough approximation. Considering that only the top meter of water was productive, the carbon fixation would be 0.75 (the average daily carbon assimilation in grams/M^3) × 4,047 (the number of square meters per acre); which is 3,000 grams per acre or about 6.8 lbs. of carbon per acre per day. The surface of the Sea covered approximately 220,000 acres, so the daily carbon fixation would be about 1,500,000 lbs. (750 tons). During a year, nearly 275,000 tons of carbon would be fixed (365 × 750). Since the dry weight of algae is about one-half carbon (Ketchum and Redfield, 1949), the daily production of plant material would be about double the weight of carbon fixed; nearly 1,500 tons in the entire Sea (220,000 acres). The yearly production of the Sea would be nearly 550,000 tons—about 2.7 tons of plant material (dry weight) per acre per year.

INVERTEBRATE FAUNA

RICHARD H. LINSLEY and LARS H. CARPELAN

INTRODUCTION

The varieties of invertebrate animals which can live in the Salton Sea are limited because the Sea provides a difficult environment. The annual temperature range is extremely wide for a saltwater environment, from 10 to 36 degrees C (50-97 degrees F). Furthermore, the amount of dissolved oxygen is low in summer, and the deeper water becomes anoxic. In addition, the Sea is an odd environment because, although it is a "marine-like" body of water, it is not of marine origin. Its water was virtually fresh as recently as 1916. Although the salinity is nearly the same as in the oceans, the chemical composition is different.

The number of species is further limited by the limited variety of habitats. The beaches, especially those on the west shore, are of fine sand; the only rocky area is around Mullet Island. Most of the bottom is soft sand or silt. There are no visible plants except blue-green algae which form a mat on the bottom in shallow areas. Inundated brush along the shore provides the only place of attachment for larger sessile organisms.

ORGANISMS PRESENT

In the discussion below the invertebrate animals are considered relative to their role in the food cycle of the Sea. Six phyla of invertebrate animals are represented.

Protozoa

Numerous species of the Class Ciliata were common in the decaying organic matter (detritus) and among the blue-green algae which cover much of the bottom. Of the Class Rhizopoda, amoebas and radiolarians have been observed in the algal mat, and about 30 species of foraminifera have been reported by Chirch (Rogers, 1949) and by Arnal (1957). Bottom-dwelling protozoans are available to those organisms which feed on the bottom; however, the mass represented by protozoans was small, relative to total algae and detritus.

Rotifera

One rotifer, *Brachionus plicatilis*, was an important part of the zooplankton in summer and was available to organisms which get their food by filtering plankton from the water. However, in the observed food chain there was no large filter-feeding animal so the rotifers were not utilized directly; the majority of them would die, settle, and add to the bottom detritus.

Bryozoa

Two species of Bryozoa identified by Soule (1957) were *Nolella blakei* and *Victoriella pavida*. These colonial animals form a moss-like growth on solid objects. They were not sufficiently numerous to be significant in the food cycle, and are mentioned only because the Salton Sea specimens were the first of these species reported on the west coast.

Nematoda

Nematodes occurred in the mat of algae and detritus on the bottom. They have been identified to the genus *Spilophorella.* Although present in fairly large numbers, they are so small, and were so intermeshed in the bottom material that their small mass can be considered a part of the detritus available to bottom-feeding organisms.

Annelida

The one species present, *Neanthes succinea,* was probably introduced in 1930 when a few "pile worms" were included in material planted by the California Department of Fish and Game. *Neanthes* was the most important food for fish in the Sea. It is a detritus-feeding worm which spends most of its life in burrows at the bottom and among masses of barnacles. The sexual stage, one to three inches long, swims to the surface to spawn, and is easy prey for carnivorous fish.

Arthropoda——Class Crustacea.

Ostracoda

Bottom samples contained some unidentified ostracods whose small number made them insignificant in the food cycle except as part of the material available to bottom-feeding organisms.

Copepoda

An unidentified harpacticoid copepod was present in small numbers near short. The only numerically important copepod was *Cyclops dimorphus,* which was in the plankton in summer and fall. It was so numerous in summer that it could support a sizable population of filter-feeding organisms, but, it seemed to be eaten only by the young bairdiella and by the threadfin shad.

Cirripedia

Barnacles, *Balanus amphitrite* Darwin, were first observed in the Sea about 1944 (Cockerell, 1945). The variety there was classed as a subspecies, *B. a. saltonensis,* by Rogers (1949). *Balanus* was probably introduced from the California coast or from the Gulf of California because it most closely resembles *B. a. inexpectus* (Pilsbry, 1916) found in these two areas. Since its introduction, it has reproduced rapidly and spread to all parts of the Sea. It seems to have become smaller and to have undergone change in shell structure so that compared to the parent species, the sides are more nearly parallel and the aperture is about the same size as the base. It may be that this characteristic is due to crowding, because when reared in the laboratory, the shape is conical, similar to the form of *B. a. inexpectus.* The shell of the *B. a. saltonensis* is lighter (thinner), but this may be due to its rapid growth under the high temperatures of the Sea. The numbers in the plankton were greatest in spring and fall. There were usually more near shore than offshore. There were so few places for adults to attach that it was surprising to find as many as 87 nauplii per liter in plankton samples taken three miles from shore (April 22, 1955). Near shore the maximum observed was 644 per liter (April 30, 1956).

The cyprids settled on any submerged hard surface, including each other; they formed large clumps around even small objects. Since surfaces for attachment were limited (because most of the bottom was soft mud), the barnacle was restricted to a few rocky areas, to areas of submerged brush and debris near shore, and to the few pilings and docks in the Sea.

Since any solid object in the water seemed to become completely covered with barnacles within a few days, an attempt was made to determine the rate of settlement. Glass microscope slides were suspended for 10-, 30-, and 90-day periods at various locations. Few settled from November through February. They began to settle in large numbers in March 1955 and continued through October.

There was a rapid increase in the number that settled during March (Table 15). The data for April would seem to indicate a decrease in the number settling; however, since all available space was occupied in fewer than 10 days, the decrease in number per unit area was probably due to lack of surface area brought about by increased rate of growth. On a few occasions, slides were exposed for a 24-hour period. The highest rate of settlement on these was on August 20, 1955 (which was not the period of maximum settlement) when 200 barnacles settled per square inch (410,000/sq. meter/day).

The rate of growth was estimated from the average size of the 10 largest barnacles on the glass slides submerged for 30 days (Table 16). The maximum rate of growth was in summer when, during July, Au-

TABLE 15

Settling Rates and Maximum Growth for Barnacles in the Salton Sea During March and April, 1955

Date	Total Days	Number Settling per m²/Day	Average Diameter in mm of 10 Largest
February 28 to March 13	13	0.246	0.59
March 13 to March 23	10	15.4	0.88
March 23 to April 1	9	139.+	1.07
April 1 to April 13	12	121.+	1.63
April 13 to April 27	14	68.5+	2.07
April 23 to May 4	12	89.6+	2.18

TABLE 16

Average Size of the 10 Largest Barnacles on Glass Slides Submerged in the Salton Sea for 30 Days, 1955-1956

Month	Maximum Basal Diameter in mm	Month	Maximum Basal Diameter in mm
March	2.0	September	8.5
April	5.0	October	5.0
May	5.5	November	less than 1.0
June	6.25	December	less than 1.0
July	8.5	January	less than 1.0
August	9.0	February	1.0

gust, and September, the basal diameter attained in 30 days was about 9 mm ($\frac{3}{8}$ inch). During the coldest part of the year, the growth rate was less than one-tenth that of summer.

The larger barnacles on slides exposed for 30 days during August and September contained well-developed larvae, indicating that growth to sexual maturity took place in less than a month.

The great numbers and the rapid growth of *Balanus* made them significant in the economy of the Sea. The shells were washed up and deposited on some of the beaches where they were crushed by wave action into a coarse "sand." In some regions, this layer was several feet thick and the "sand" beaches were suitable for recreational use in areas that were formerly muddy.

The adult barnacles, although thin-shelled, were only occasionally eaten by any of the fishes in the Sea. Barlow (unpublished data) found that barnacles made up about five percent of the diet of the mudsucker.

TABLE 17

List of Known Introductions of Invertebrates Into the Salton Sea *

Date	Number	Species	Group Name	Where Acquired
13 Nov. 1930	"a few"	*Neanthes succinea*	polychaete worm	San Diego Bay
	15,000	*Calianassa* sp.	ghost shrimp	San Diego Bay
12 May 1950	25?	*Callinectes bellicosus*	crab	San Felipe
	10?	*Loligo* sp.	squid	San Felipe
14 Dec. 1950	6	*Callinectes bellicosus*	crab	San Felipe
15 Dec. 1950	12	*Callinectes bellicosus*	crab	San Felipe
28 Mar. 1951	75	*Callinectes bellicosus*	crab	San Felipe
	15	*Loligo* sp.	squid	San Felipe
	5	*Penaeus stylirostris*	shrimp	San Felipe
31 Mar. 1951	10	*Penaeus stylirostris*	shrimp	San Felipe
	5	*Loligo* sp.	squid	San Felipe
4 May 1953	10,000	Kumamoto oysters	oyster	Japan
	100	*Ostrea lurida*	oyster	Anaheim Slough
	1,000	*Protothaca staminea*	clam	Anaheim Slough
	5,000	*Mytilus edulis*	mussel	Anaheim Slough
	250	*Chione fluctifraga*	clam	Anaheim Slough
16 May 1953	3,500	*Tapes semidecussata*	clam	San Francisco Bay
	500	*Protothaca grata*	clam	San Felipe
	12	*Mytella guyanensis*	mussel	San Felipe
Aug. 1953	10-gal	*Mytilus edulis* (95%)	mussel	Anaheim Slough
		Mytilus californianus (5%)	mussel	Anaheim Slough
10 Apr. 1955	450	*Archaeomysis maculata*	mysid	San Felipe
		Mysidopsis californica	mysid	San Felipe
18 Nov. 1955	3,000	*Archaeomysis maculata*	mysid	San Felipe
		Mysidopsis californica	mysid	San Felipe
9 Aug. 1956	194	*Capitella capitata*	polychaete worm	Culture from Dr. D. Reish
10 Aug. 1956	15,000	*Capitella capitata*	polychaete worm	Culture from Dr. D. Reish
13 Aug. 1956	155	*Capitella capitata*	polychaete worm	Culture from Dr. D. Reish
5 Feb. 1957	?	*Capitella capitata*	polychaete worm	Texas
	?	*Capitella* sp.	polychaete worm	Texas
	?	*Eteone alba*	polychaete worm	Texas
	?	*Marphysa sanguinea*	eunicid tube-worm	Tezas
	?	*Melinna maculata*	polychaete worm	Texas
	?	*Anomalocardia cunemeris*	clam	Texas
	?	*Cerithidea aguayoi*	snail	Texas
	?	*Modiolus aborescens*	mussel	Texas
	?	*Mulinia lateralis*	clam	Texas
	?	*Tellina tampansis*	clam	Texas
	?	*Crepidula* sp.	limpet	Texas
	?	*Mytilus* sp.	mussel	Texas
	?	*Spisula* sp.	clam	Texas

* The list of introductions prior to 1955 was prepared by John E. Fitch. Records of subsequent introductions are from project records.

The larvae would be available to filter-feeding organisms, but it is doubtful that they are a significant source of fish food. Small quantities were eaten by the fry of bairdiella. The Salton Sea barnacle is probably detrimental to the food cycle leading to the corvina, because *Balanus* expends nutriment which might otherwise be available to *Neanthes,* an important fish food.

INTRODUCTIONS

Various invertebrate animals have been introduced into the Sea to provide food for fish populations, or to provide food directly for man (Table 17). The bivalves (mussels, oysters, and clams) were planted with the hope of providing a recreational fishery for these desirable food items. The other species were introduced as fish food, or accidently with other organisms. The plants prior to 1955 were made by the California Department of Fish and Game. The introductions of mysids and polychaete worm *Capitella* in 1955 and 1956 were made by the project personnel. On February 5, 1957, an unknown number of many species of invertebrates was introduced unintentionally with plants of shoal grass, *Diplanthera wighti,* from Texas. The shoal grass was planted by the California Department of Fish and Game to provide food for wildfowl. Other invertebrates undoubtedly were introduced unintentionally during fish transplants, or by boats and other equipment transferred from the coasts of California or from the Gulf of California.

ZOOPLANKTON

LARS H. CARPELAN

INTRODUCTION

Quantitative study of the zooplankton began in August 1954 with sampling at the two stations off Fish Springs. At the deep station, samples were taken routinely at surface, mid-depth (six meters) and

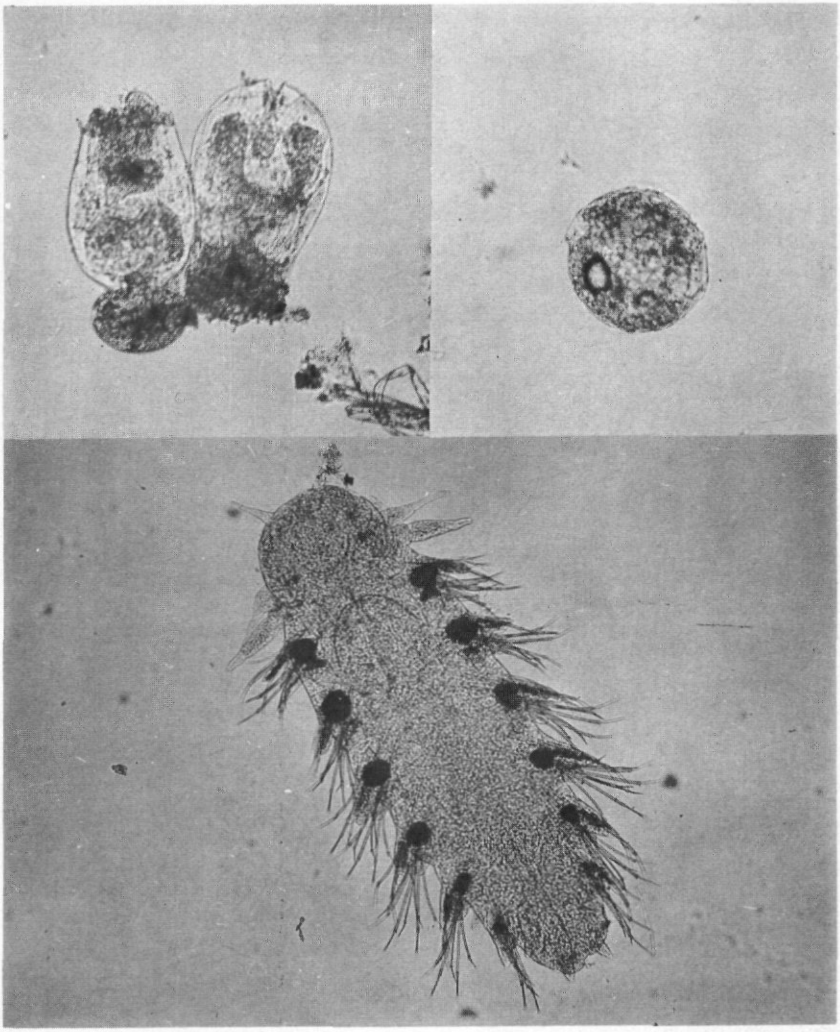


FIGURE 13. *Brachionus plicatilis*, adults, upper left. *Neanthes succinea*, egg, upper right; 6-segmented larva, below. Photos by Lars H. Carpelan.

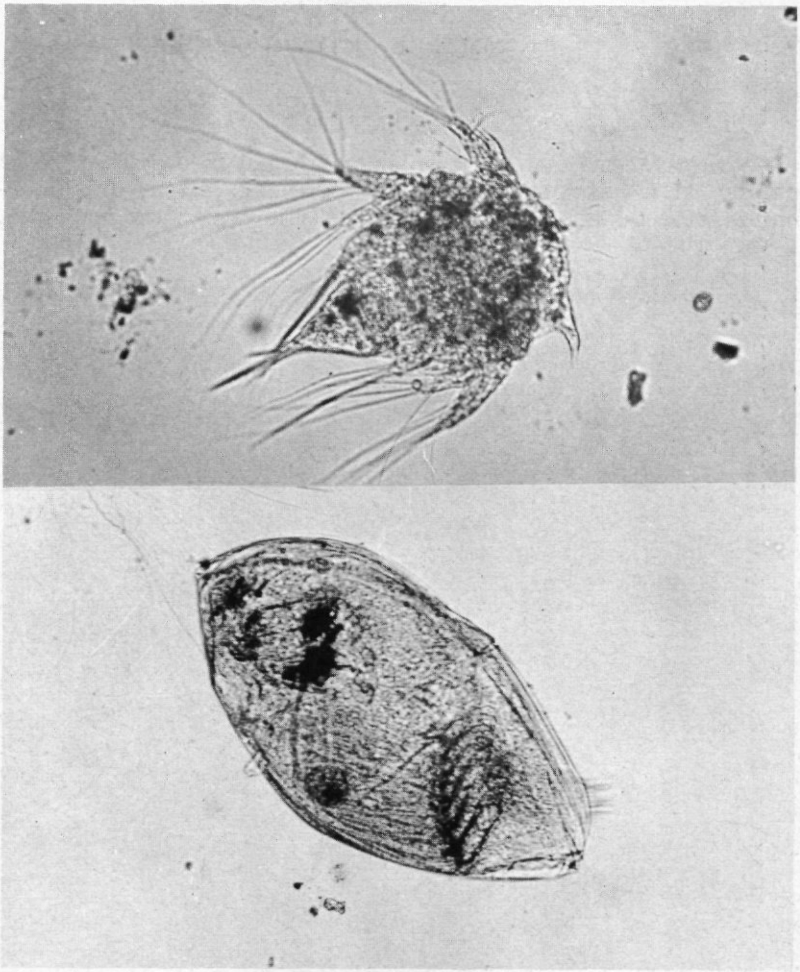


FIGURE 14. *Balanus amphitrite,* nauplius, above; cypris, below. Photos by Lars H. Carpelan.

above bottom (12 meters). In the shallower water, samples were taken only at the surface and bottom (three meters). Three-liter samples collected with a Kemmerer-type water sampler, were strained through a six-inch (15 cm) net of No. 20 bolting cloth (173 meshes per inch). The four principal invertebrates in the concentrate were counted. The sampling method had inherent errors, perhaps the greatest of which were the apparently great local differences in the distribution of organisms in the Salton Sea. However, it did provide a measure at the two particular stations, and the data are offered as indicative of the seasonal changes in the plankton, and the order of magnitude of the numbers present.

Although other animals appeared in the plankton, only four were numerically significant: a rotifer, (Figure 13); an annelid worm,

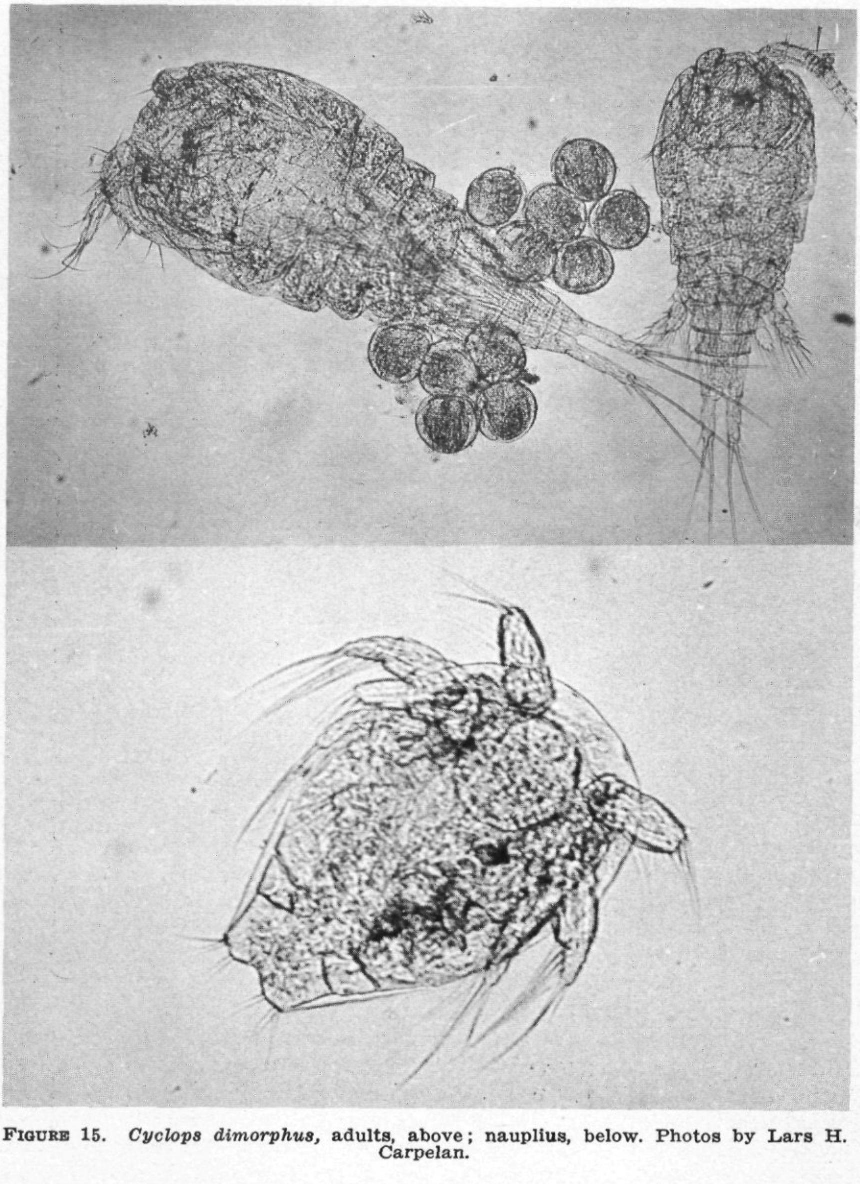


FIGURE 15. *Cyclops dimorphus,* adults, above; nauplius, below. Photos by Lars H. Carpelan.

(Figure 13); a barnacle, (Figure 14); and a copepod, (Figure 15). The worm and the barnacle were not planktonic during their entire life cycles; only the egg and larval stages of the worm, and the naupliar and cypris stages of the barnacle are considered in the following discussion.

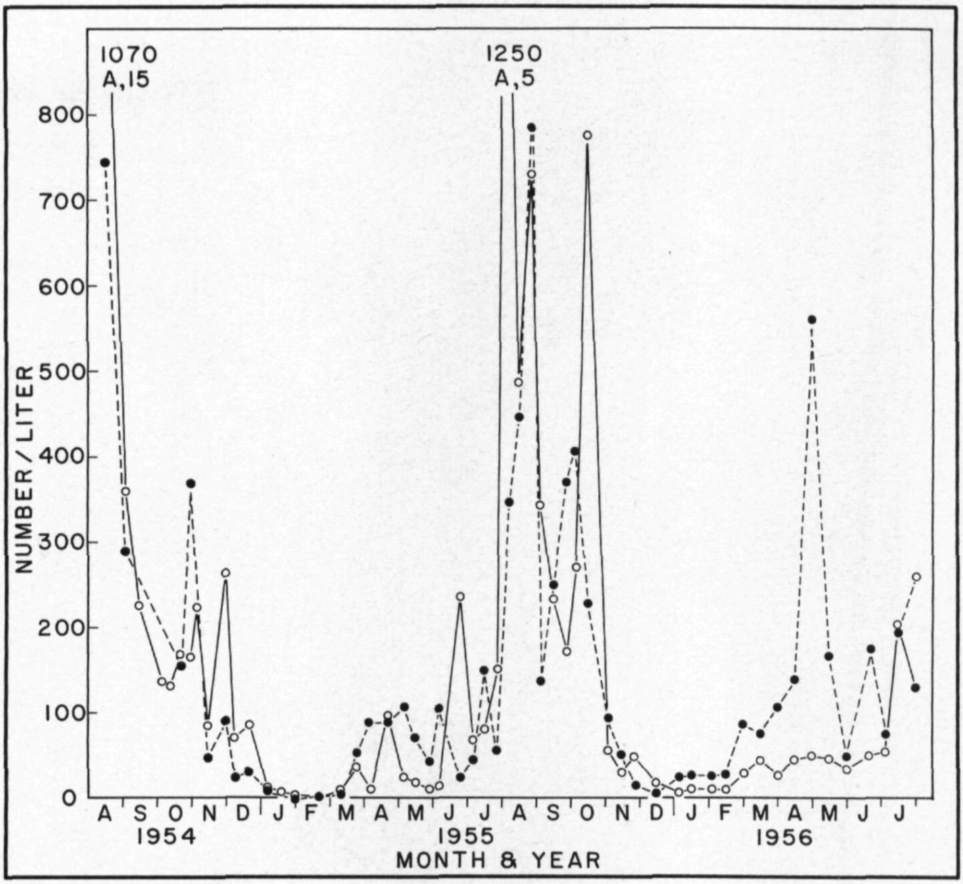


FIGURE 16. Total zooplankton in the Salton Sea, 1954-1956. Three miles offshore (solid line) and 100 yards from shore (dotted line). Offshore collections show average numbers for surface, mid-depth (six meters) and near bottom (12 meters). The near-shore stations show average numbers for surface and three meters.

TOTAL ZOOPLANKTON

Greatest numbers of total plankton occurred in late summer when large populations of the copepod and rotifer predominated (Figure 16). The maximum number in the 1954 collections was 1,717 per liter at the surface offshore on August 18. A year later (August 9, 1955) a total nearly as large (1,590 per liter) was present at the same location.

In contrast to the high number present in summer, winter zooplankton was sparse. On January 12, 1955 there were only 15 animals per liter offshore (eight copepods, three barnacles, and four *Neanthes* larvae). Near shore there were 14 per liter, almost all *Neanthes*. On February 23, 1955 the entire zooplankton offshore consisted of one *Neanthes* larva per liter, while near shore there were two animals per liter: one *Neanthes* and one barnacle. Similarly during the winter of 1955-56 the number of animals fell to a low: there were only 10 per liter (five barnacles and five worm larvae) in February 14 offshore samples.

In spring there was an increase. Beginning in March 1955 the increased reproduction of the barnacle and *Neanthes* raised the total to 38 per liter offshore (5 barnacles, 33 *Neanthes*), and to 54 per liter near shore (50 barnacles and 4 *Neanthes*). During April, May, and June there were collections with as many as 100 barnacle nauplii per liter. As in 1955, the numbers of plankton animals increased in the spring of 1956 until, on April 30, there were 560 per liter (526 barnacles and 34 *Neanthes*). After reaching peak populations in April, May, and June, the numbers of *Neanthes* and barnacles decreased to a low level in summer. During autumn there was a second period of reproduction by *Neanthes* and the barnacle. Their numbers increased to 42 barnacles and 13 *Neanthes* larvae per liter near shore on November 2, 1955.

In contrast to *Neanthes* and the barnacle, which were most prevalent in spring and fall, the rotifer and copepod were present only in summer. Although the spring peaks of reproduction of the worm and barnacle made the spring plankton fairly rich, their numbers in the spring plankton were dwarfed by the copepods and rotifers that appeared in summer.

In 1955, copepods first appeared on June 27 when they averaged 200 per liter offshore; they reached a maximum population during August to October. On August 17, for example, there were 535 per liter at the surface offshore. In 1956, they first appeared in collections made July 9 (none on June 22). By July 16, there were 103 per liter near shore. The copepod disappeared in winter; by November 2, 1955 the number had been reduced to 40 per liter, and they were gone from the plankton by mid-December. The end of the season for the copepod the previous winter (1954-55) had been mid-January 1955.

The rotifer did not appear in quantity until August 9, 1955 when 1,283 per liter were present at the surface offshore. At that station, there were still 292 per liter on October 17, 1955. In 1956, the rotifer appeared in small numbers at the end of May, and by July 16 there were 96 per liter near shore. The two previous years they had disappeared from the plankton by mid-December (1954) and in early November (1955).

THE ROTIFER, *Brachionus plicatilis* (Müller)

(Figure 13)

This rotifer was the most numerous animal in the summer plankton of the Salton Sea. The means of entry into the Sea is not known but the spread of rotifiers is usually by wind or bird transport of the dormant egg. Most species, including *B. plicatilis*, are cosmopolitan (although with discontinuous distribution) and each species is characteristically present under similar conditions throughout the world. Since it has been estimated (by Myers, 1936) that 88 percent of the 1,500 known species are freshwater forms, rotifers may well be considered more typical of freshwater, but there are marine and brackishwater rotifers which, according to Hyman (1951), are similar to freshwater forms and may belong to the same genera and species. The genus *Brachionus* has been monographed by Ahlstrom (1940) who described *B. plicatilis* as

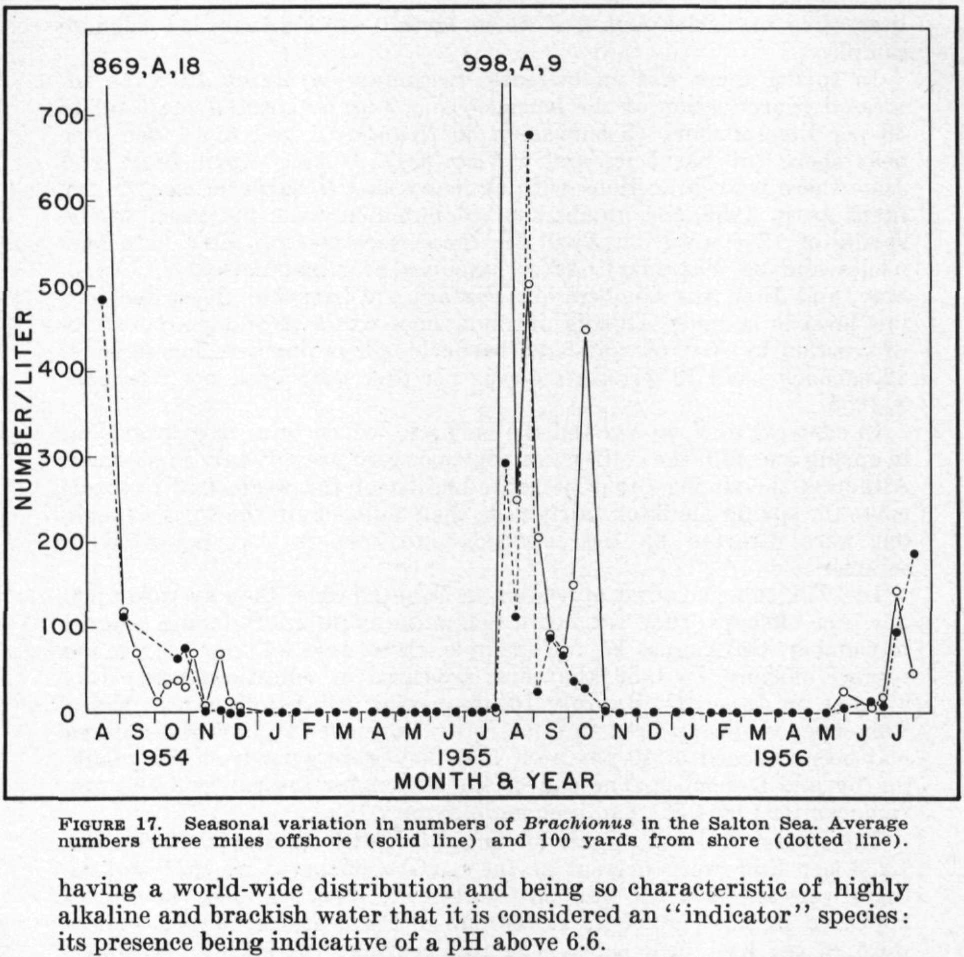


Figure 17. Seasonal variation in numbers of *Brachionus* in the Salton Sea. Average numbers three miles offshore (solid line) and 100 yards from shore (dotted line).

having a world-wide distribution and being so characteristic of highly alkaline and brackish water that it is considered an "indicator" species: its presence being indicative of a pH above 6.6.

Brachionus was very numerous in the first quantitative plankton collection made, which was on August 18, 1954 (Figure 17). The population declined during autumn and the rotifer disappeared from the water near shore in November and from offshore in December 1954. After an absence during winter and spring, *Brachionus* reappeared in the near-short plankton on July 27, 1955 when there were four per liter at the surface. On August 9, 1955, at the surface three miles from shore there were 1,283 per liter, the greatest number found in any sample during 1954-56. A sample from mid-depth (six meters) had a similar number (1,277 per liter), and a sample from just above the bottom (12 meters) had 435 per liter. The average number in the vertical water column was, thus, 998 per liter. The number near shore on August 9 was not as great: there were 200 per liter at the surface and 387 at the bottom, for an average of 293. Adults were prevalent in August, September, and October of 1955. There were smaller numbers in November: the average per liter offshore was three on November 2, and one each on November 15 and 28. None was found in December. In 1956, *Brachionus* reappeared on May 31 (there was none in the previous sampling on May 15), and the population had reached 289 per liter at the surface near shore on July 31, when sampling ceased.

Although the summer form disappeared during winter, another morphological form was present from late November 1955 to mid-March 1956. It is not uncommon for rotifers to show cyclic changes in form which are usually attributed to differences in growth at different temperatures. There are also differences in size under different conditions. Ahlstrom (1940) gave the size range of *B. plicatilis* as from 125 x 105 μ (in North Carolina) to 315 x 260 μ (in northern India). The average size of the *Brachionus* female found in the Salton Sea in summer was 200 x 120 μ. A large egg, about 100 μ in greatest diameter, was often attached to the female. The winter form, which appeared to be inactive, was either oval in shape and approximately 90 x 160 μ, or of more spherical form with dimensions of 120 x 140 μ. In addition to these stages, there was a heavy-walled, dormant egg, about 70 μ in diameter, that was found only in winter.

The life cycle of *Brachionus* in the Salton Sea is not fully known. The species has separate sexes, but no males were recognized in the collections. The male is reported to be much smaller than the female, and to lack spines and a digestive system. In the absence of males, the outline of the life history of *Brachionus* in the Salton Sea has been based on inference from what is known of it and of related species elsewhere. Winter was passed either as dormant eggs or in the cyst-like winter form, described above. The eggs hatched in May or June producing the great numbers of females found in early summer. The females presumably reproduce parthenogenetically by laying "amictic" eggs, which are diploid since they do not undergo meiotic division. In fall, haploid "mictic" eggs are produced, which if unfertilized give rise to males: if fertilized they form the thick-walled, dormant eggs. The females are reported to live only one to two weeks, and in that period they lay four to six eggs. The amictic (summer) eggs hatch immediately, and the females produced are said to reach sexual maturity in a few days.

Brachionus was prevalent in 25 collections made offshore during 1954-56. In 18 of these collections, all made at mid-day (10 AM to 1 PM), the smallest numbers were at the bottom. Lowest numbers occurred at the surface only five times: four at the end of the season (November) and one at the beginning (July). Maximum numbers occurred at the surface in 12 of the 25 collections, and at mid-depth in 10. In general, therefore, at mid-day in the deepest part of the Sea the fewest were at the bottom, but there were as many at mid-depth as at the surface. Near shore approximately the same numbers were at the bottom (three meters) as at the surface: in 11 of 19 collections the majority was at the bottom. Greater numbers may have been present offshore during the peak of the season, but *Brachionus* were more prevalent near shore at the beginning and at the end (Figure 17).

Although the numbers of *Brachionus* in the Salton Sea were large, greater numbers are on record. For example, Ahlstrom (1933) reported 2,000 *Synchaeta* sp. per liter in a freshwater pond which had 5,000 rotifers (of mixed species) per liter. In the Salton Sea *Brachionus* competed, at least for space, with the copepod, *Cyclops,* which also occurred only in the summer plankton. These two animals made up most of the zooplankton during summer which was the period when the worms and barnacles were at their annual low. *Brachionus* did not seem to be the direct source of food of any animal in the Salton Sea. After death the rotifers settled and added to the organic content of the bottom where they served as food for bacteria and for *Neanthes,* the principal bottom-feeding animal of the Sea.

THE PILE WORM, *Neanthes succinea* (Frey and Leuckart)

(Figure 13)

All stages, from egg to the two- to nine-segmented larvae, were numerous in most of the routine plankton collections, both near shore and offshore. The maximum number of larvae, 87 per liter, was collected offshore at the surface on June 27, 1955. The maximum number of eggs in any collection was 28 per liter, found at the surface near shore on April 30, 1956.

During 1955, the eggs and larvae in the plankton indicated two annual peaks of spawning: one in spring (March to June), the other in fall (October-November) (Figure 18). Spawning continued throughout

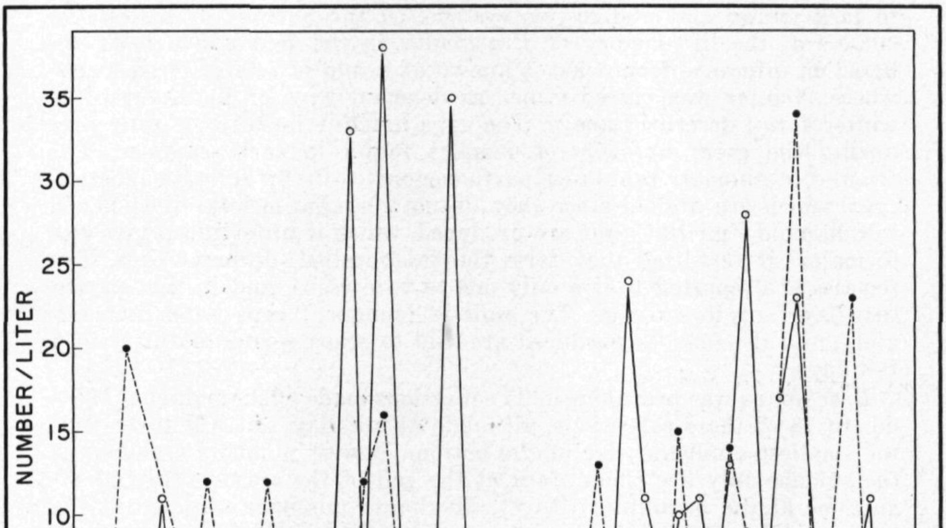


FIGURE 18. Seasonal variation in numbers of eggs and larvae of *Neanthes* in the Salton Sea. Three miles offshore (solid line) and 100 yards from shore (dotted line). Numbers are the averages of samples from surface, mid-depth (six meters) and bottom (12 meters) offshore, and from surface and bottom (three meters) near shore.

winter, although at a low rate in January and February. There was a great reduction in number of planktonic worms in summer, especially offshore. There were times in August and September 1955, and in July 1956, when there were no worms in plankton samples. However, there was evidence that spawning occurred in every month of the year; that is, eggs were found near shore in at least one collection during every month in 1954 from August through December, in every month of 1955 except January and February, and in every month of 1956 from January through July. Thus, considering the records for all three years, eggs were present near shore during every month. Offshore, however, eggs were absent each summer: September and October of 1954; from July to September 1955; and during June and July 1956. *Neanthes* seemed to live and spawn throughout the year near shore, but to disappear from deeper water in summer.

The absence of worms offshore in summer did not seem to be related to seasonal lack of food, especially in summer when the organic matter had been replenished by the spring bloom of phytoplankton that had settled to the bottom. It seems most probable that the adults were killed by lack of oxygen at times during summer at depths below nine meters, or by the simultaneous development of high concentrations of sulfide that sometimes occurred from June through September. Experiments in stoppered bottles indicated that the maximum period *Neanthes* can live in water without oxygen is about 24 hours. *Neanthes,* therefore seems able to survive short periods without oxygen such as occurred for a few hours every night during summer, but is unable to withstand periods of anoxia lasting more than one day.

There was, thus, an annual loss of *Neanthes* from the estimated 56 percent of the total bottom area of the Sea which lay below about nine meters. Only after oxygen became available again in the fall (October or November) did the bottom in the deeper part of the Sea become repopulated with worms.

THE BARNACLE, *Balanus amphitrite* (Darwin)

(Figure 14)

The barnacle was apparently introduced into the Salton Sea (by boats or seaplanes?) during the early 1940's. It was described as a new subspecies, *Balanus amphitrite saltonensis* by Rogers in 1949.

There were two peaks of abundance in the plankton (Figure 19). Maximum numbers occurred from March to June. After a summer low, a secondary peak began in late October of 1954 and in early September of 1955. The autumn increase was practically absent offshore in 1954, but during September and October 1955 there were nearly equal numbers in the near shore and offshore collections. The planktonic population fell to a low in winter (December to February).

A greater number of planktonic barnacles was usually near shore (Figure 19), where there was far more surface area for attachment, and where, therefore, most adults were found. The greatest numbers of barnacles in planktonic samples were collected near shore on April 30, 1956. A greater number of nauplii was found below the surface near shore (Table 18) but this did not seem to represent a constant difference in the vertical distribution. Relative numbers at and below the surface

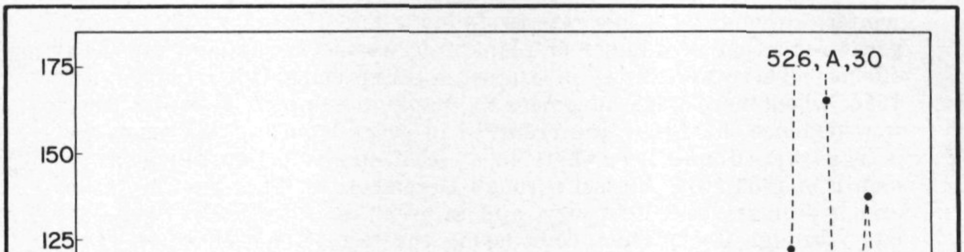


FIGURE 19. Seasonal variation in numbers of the nauplii and cypris of *Balanus* in the Salton Sea. Three miles offshore (solid line) and 100 yards from shore (dotted line). Numbers are the averages of samples from surface, mid-depth (six meters) and bottom (12 meters) offshore, and from surface and bottom (three meters) near shore.

varied with samples and, although half the bottom samples had more planktonic barnacles than were found at the surface, a quarter of the samples had equal numbers at surface and bottom, and the other quarter had more at the surface. Relative numbers of naupliar and cypris stages also varied, and in some collections seemed indicative of syn-

TABLE 18

Number of Barnacle Nauplii and Cypris Stages Taken at Two Locations in the Salton Sea on April 30, 1956

Location	Depth	Number per Liter	
		Nauplii	Cypris
3 Miles offshore	Surface	5	19
	6 Meters	21	15
	12 Meters	9	21
Near Shore	Surface	383	25
	3 Meters	633	11

chronous spawning. Thus, during the spring of 1955, the surface sample near shore on May 4 contained 150 nauplii and only three cypris per liter, while on June 8 at the same place there were 23 nauplii and 110 cypris per liter.

Some collections in January and February, and some in July and August contained no barnacles indicating either that spawning did not occur, or that it went on at a very low rate in mid-winter and mid-summer. The increased numbers of planktonic barnacles in the autumn of 1954 and in the spring of 1955 seemed to indicate a possible correlation between spawning and temperature. Spawning began in October 1954 when water temperatures had fallen to 27 degrees C. (81 degrees F.), and continued until they reached 17 degrees C. (63 degrees F.). Spawning did not increase until water temperatures again reached a mean of 17 degrees C. in March 1955. Thus, the range from 17 to 27 degrees C. might be inferred as the optimum for spawning. However, when the autumn increase began in 1955 (August and September), water temperatures were at their peak for the year (the mean was 33 degrees C.); after the winter low of spawning, the first marked increase in the number of planktonic stages occurred in February 1956 when water temperatures were at their minimum for the year (mean of 15 degrees C.). It would seem therefore that barnacle spawning may occur at both the maximum and the minimum temperature found in the Salton Sea.

While there seemed to be no predator on the adult barnacles, naupliar and cypris stages were eaten, to a limited extent, by young bairdiella.

THE COPEPOD, *Cyclops dimorphus* (Kiefer)

(Figure 15)

The time or means of introduction of *Cyclops dimorphus* is unkown. It was described as a new species by Kiefer (1934) and redescribed by Johnson (1953) who postulated the lower Colorado River as the possible source of entry. As described by Johnson, the female, approximately 1 mm long, is larger than the male which has an average length of 0.75 mm. The mature female carries two posterior egg sacs, each containing 12-16 eggs. Eggs hatch within the ovisac and give rise to typical arthropod nauplii which are free-swimming. The nauplius grows through a series of larval stages (nauplius, metanauplius, cyclops) before it attains adult form. All the larval stages have been combined in this discussion as "immature." Eggs were not counted nor included in the totals.

Cyclops was in the plankton only during the warmest part of the year (Figure 20). It gradually disappeared in winter (as early as December or as late as January). In the fall of 1954, the population decreased from 316 per liter on November 29 to 74 on December 13. In these end-of-the-season samples, immature stages predominated: 263 immature and 53 adults on November 29, and 57 immature and 17 adults on December 13. By January 12, 1955 there was only one adult per liter, and none was found in the collections from February to May. In the autumn of 1955, the last date *Cyclops* was prevalent was October 17, when there were 284 per liter at the surface offshore. By November 12, the total had decreased to 33, and by November 28 to

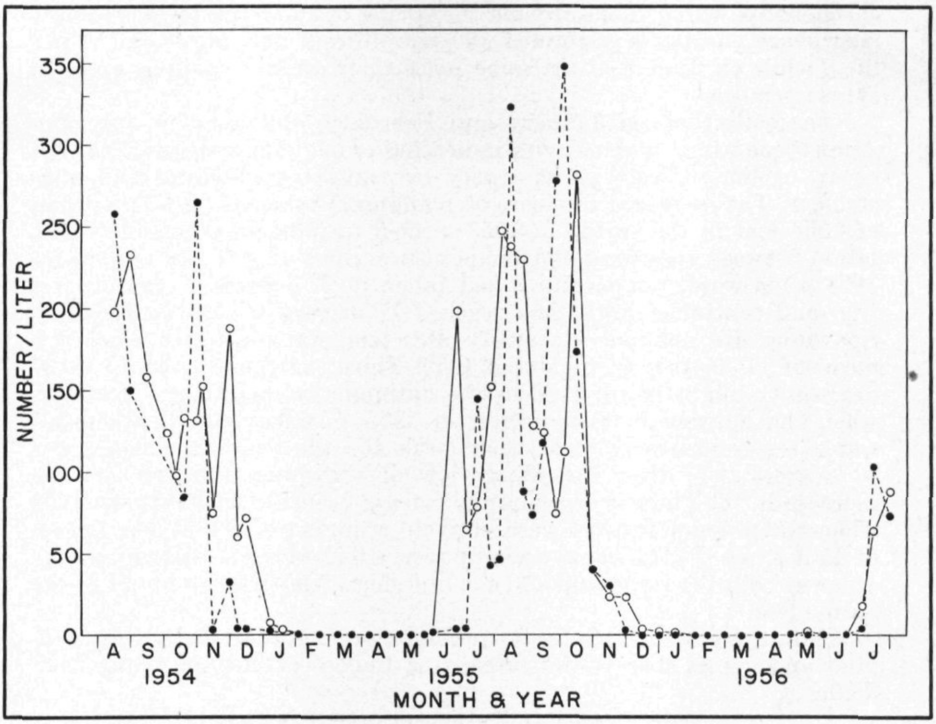


Figure 20. Seasonal variation in numbers of *Cyclops* in the Salton Sea. Three miles offshore (solid line) and 100 yards from shore (dotted line). Numbers are the averages of samples from surface, mid-depth (six meters) and bottom (12 meters) offshore, and from surface and bottom (three meters) near shore.

10 per liter. On December 13, 1955 and on January 4, 1956 there was only one adult in each three-liter sample, and none was present on January 16.

After an absence in winter and spring, *Cyclops* reappeared in June and July. In early summer the population increased very rapidly: on June 8, 1955 only one adult was noted in offshore collections; on June 27 there were 2 adults and 266 immature stages per liter at the surface. Maximum numbers offshore were 535 per liter (503 adults and 32 immature) at the surface (August 17, 1955); the greatest number taken near shore was 454 (397 adults and 57 immature), at the surface on October 4, 1955. In 1956, they first appeared in early July; none was present in collections made on June 22, but on July 9 there were 7 adults and 10 immature stages per liter at the surface offshore, and by July 16 the population had increased to 56 adults and 53 immatures per liter. Although there are species of copepods that have spring and fall peaks of population, and others that occur only in winter, many, like *Cyclops dimorphus*, appear only during the warmest season.

During this study, no records were obtained for possible diurnal migrations, such as have been reported for other copepods (e.g., Nicholls, 1933), because all plankton collections were made at mid-day (10 AM to 1 PM). In 24 of 35 offshore collections, the smallest numbers were at the bottom; samples from mid-depth had the intermediate number in 21 cases (of 35). Greatest numbers of *Cyclops* were found at the bottom in only seven of the 35 collections and all of these were at the end of the season when *Cyclops* was disappearing from the plankton. The usual offshore distribution was a decrease in number from the surface to the bottom. Near shore, seven of 27 collections had the greater number at the bottom, while they occurred at the surface in 16 (in four samples there were equal numbers at surface and bottom). Thus at mid-day, in shallow as well as in deeper water, more *Cyclops* were at the surface than at the bottom, but they were generally well-distributed throughout the water column.

The overlapping of generations made it difficult to estimate the life span of *Cyclaps* in the Salton Sea. Development from egg to sexual maturity was on the order of two weeks, and may have been as short as 10 days during August and September. Each year, during the five months from July through November when *Cyclops* was in the plankton, there was time for at least 10 and perhaps as many as 15 generations.

As in the oceans, they were a very important link in the food chain of the Salton Sea. They fed on the floating plant cells (phytoplankton) and in turn served as food for the young stages of the bairdiella which was the most prevalent fish of the Sea. The copepod provided a considerable portion of the diet of fish smaller than 70 mm (two and three-quarters inches). However, much of the great mass of copepods produced each year sank to the bottom, where they, like the rotifers, became food for bacteria and for the bottom-feeding worm, *Neanthes*.

THE PILE WORM, *Neanthes succinea* (Frey and Leukart)

LARS H. CARPELAN and RICHARD H. LINSLEY

The nereid polychaete, *Neanthes succinea,* was first reported in the Salton Sea by Hartman (1936) from a collection made by S. F. Light in June 1935. Just how or when it was introduced is uncertain, but it may have been in 1930 when, according to records of the California Department of Fish and Game, "a few pile worms" were brought in from San Diego Bay. *Neanthes* is now abundant in the Sea, and the present fish fauna is largely dependent on its presence. Zenkevich (1951) discussed the value of *Neanthes* as a fish food.

It spends most of its life in burrows in the mud and among the masses of barnacles. Mature *Neanthes* leave their protective burrows at night and swim to the surface to spawn. The swimming, or epitokol, stage lasts only a few days and then the worm dies.

SPAWNING

Spawning or swarming of *Neanthes* can be observed at night because they are attracted to light. In the Salton Sea swarming follows the pattern recorded on March 20, 1955 in the boat channel at Fish Springs (Table 19). Observations began at 6:15 PM, Pacific Standard Time and ended at 11:15 PM. All of the worms attracted to a suspended light were collected, and collections per 15-minute period were kept separate.

When a female appeared she was soon surrounded by several males; spawning then occurred almost immediately and lasted only a few seconds. The eggs and sperm appeared as milky patches in the water. Immediately after shedding her eggs the female would sink out of sight, apparently completely spent. The male epitokes continued to swim. The duration of the male epitoke after spawning was observed in the laboratory where 9 of 17 were active 24 hours after collection; 7, after 48 hours; and 2, after 96 hours. Twelve of the 17 were dead

TABLE 19

Numbers of Neanthes Epitokes Collected at Fish Springs, Salton Sea on March 20, 1955

Time (PM)	Number of Epitokes Collected
6:15- 6:30	None (sunset)
6:30- 6:45	None
6:45	1
6:45- 7:00	24: 16 males, 8 females
7:00- 7:15	115: 101 males, 14 females
7:15- 7:30	215: 189 males, 26 females (maximum activity)
8:00- 8:15	87: 69 males, 18 females
9:00- 9:15	4: 3 males, 1 female
10:00-10:15	None
11:00-11:15	None

96 hours after collection, but one was still alive after 11 days. Half of the male epitokes lived for only 24 to 48 hours after collection, and, presumably, after spawning.

FERTILIZATION AND LARVAL DEVELOPMENT

The development of eggs, obtained from mature worms collected on the nights of February 15 and May 8, 1955, was observed in the laboratory where the temperatures ranged from 20 to 25 degrees C. The spherical eggs were 150-200 micra in diameter. Immediately following fertilization a gelatinous sheath surrounded the egg; this sheath began to swell and many sperm seemed to become entangled in it. After 80 minutes, the fertilization membrane was visible, and after an hour and a half the first polar bodies appeared. Twenty minutes later the first division occurred, and in another 30 minutes the second division. Within 13 hours the eggs had become ciliated, lost their gelatinous covering, and were free-swimming. The egg had developed into a trochophore larva after 24 hours, and in 36 hours had two larval segments with setae. In 54 hours, they possessed three seta-bearing segments.

The duration of the free-swimming planktonic period was difficult to determine because the change from the three- to the four-segmented stage seemed to be critical in their development. In laboratory rearing experiments, *Neanthes*, after reaching the three-segmented stage in two and one-half to three days, have lived for as long as 10 days without developing further. In nature it would seem that three to six additional segments were added in 10 to 14 days.

The eggs and larvae were planktonic. When they had six to nine adult segments they began to settle. By the time they reached the nine-segmented stage virtually all had settled to begin their bottom-dwelling period. Plankton and worms that had recently settled were studied to provide data showing time of spawning, changes in seasonal prevalence, and rate of growth.

PLANKTON

The number of eggs and planktonic larvae in a three-liter sample were ascertained during a two-year period at two stations off Fish Springs. At the station three miles offshore, samples were taken above the bottom (12 meters), at mid-depth (six meters) and at the surface. Near-shore samples were collected above the bottom (three meters) and at the surface (Figure 21).

This sampling revealed a spring peak of spawning (which occurred from March to June 1955) followed by reduced activity during summer, as indicated by fewer worms in the plankton. Spawning increased again in the fall (starting in September 1955), continued during winter, and culminated in another spring peak in April and May of 1956.

The spawning of *Neanthes* has been reported to follow a monthly cycle, always, according to Lillie and Just (1913), between full and new moon. This did not seem to be the case in the Salton Sea where eggs were found in samples taken at all phases of the moon. Eggs in the plankton can be assumed as evidence of spawning within the previous 24 hours; spawning thus occurred irregularly or continuously. The seemingly continuous spawning made it difficult to estimate the time

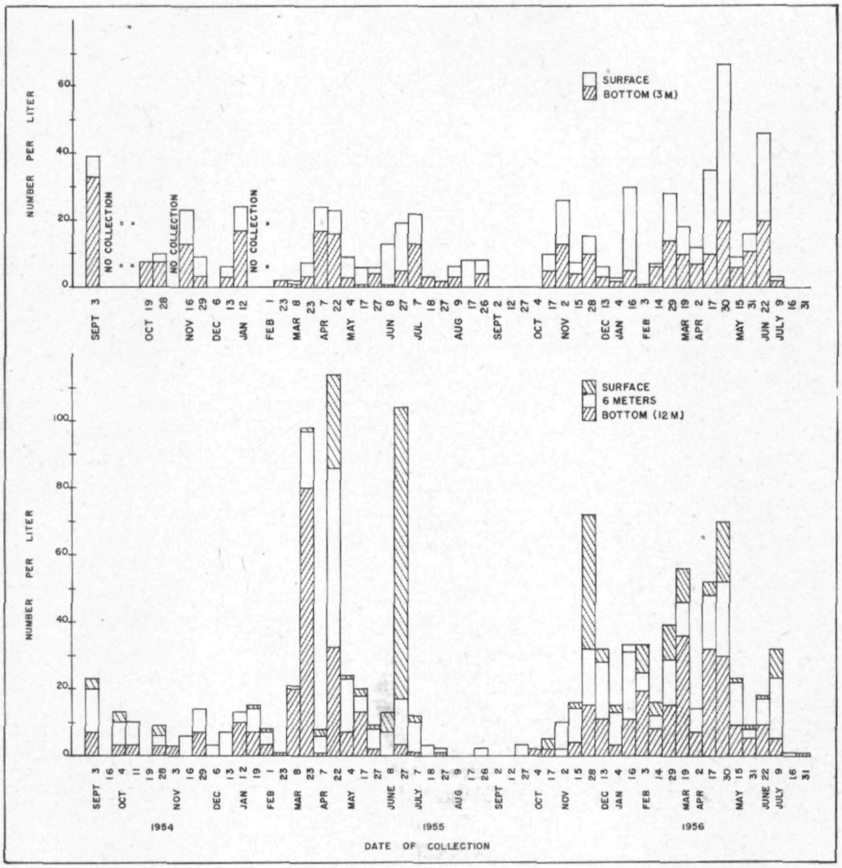


FIGURE 21. The number of eggs and planktonic larvae taken in a three-liter sample during a two-year period at two stations off Fish Springs, Salton Sea. At the station three miles offshore, samples were taken above the bottom (12 meters), at mid-depth (six meters) and at the surface. At the station near shore, samples were collected above the bottom (three meters) and at the surface.

Neanthes spent in the plankton, but the planktonic stage ended when, with attainment of six to nine segments, the worms settled to the bottom.

SETTLEMENT

Their settlement was studied by using one-gallon glass jars suspended beneath the surface at nine different locations in the Sea. The mouth of each jar had a diameter of 10.5 cm; the area through which the worms settled thus represented 83.5 cm ^{2}, which is, roughly, 0.01 square meter. A few of the samples were collected at 10- and 90-day intervals, but most at 30-day intervals. That is the jars were usually removed and replaced monthly. The worms in the jars were counted, and as an estimate of their rate of growth, the number of segments per worm in representative portions of the sample was also determined.

Ten-Day Collections

Settling jars removed at 10-day intervals indicated irregular periods of maximum spawning each month. For example, 90 percent of the worms settling during March 1955 at the station 100 yards off Fish Springs did so during the last 10 days. On the other hand, at a station two miles south of Fish Springs only 22 percent of the number that settled during March did so during this same 10-day period (the last 10 days of the month). At this second station, maximum spawning was during the first 10 days, when 70 percent of the month's total accumulated. There may have been, as in the preceding examples, one period of maximum spawning in a month, or there may have been more than one, as in May, when, at the station 100 yards off Fish Springs, 10 percent of the month's total settled in the first 10 days, 45 percent during the second 10 days, and 45 percent during the last 10.

The 10-day collections thus showed no regularity in peaks of monthly spawning nor correlation with phases of the moon. The 10-day samples proved helpful in estimating rates of growth for the 30-day samples (see below); for example, if most of the worms had settled during the last 10 days of a 30-day period, the majority would have been smaller than if most had settled early in the month.

Thirty-Day Collections

The average numbers of worms in the 30-day settling jars (Table 20) verified the annual spawning cycle indicated by the plankton collections: a spring period of maximum spawning (reaching its peak in April and May) was followed by a summer period with reduced activity. In late fall, another peak of spawning occurred (in November 1955) which preceded a winter period of reduced activity. About 60 percent of the worms that settled in the jars during the year were spawned during the months March through June, 15 percent during July through October, and 25 percent during November through February.

Figure 22 shows the sizes of worms that settled in 30 days during the spring spawning three miles east of Fish Springs, above the deepest water of the Sea. The numbers of worms in the jars, the mean number of segments, and the maximum number of segments have been listed in Table 21. The increase from March to April and May, and the decrease at the beginning of summer were comparable to the trend shown by the plankton and by the average numbers settling each month for all stations.

TABLE 20

Average number of Neanthes in 30-Day Settling Jars in Salton Sea, 1955-1956

Month	Average Number of *Neanthes* per 30 Days	Month	Average Number of *Neanthes* per 30 Days
March	1,688	September	434
April	2,720	October	258
May	1,903	November	1,475
June	1,304	December	704
July	959	January	605
August	180	February	1,000

The increase in the mean number of segments from March to the maximum in June and July may be indicative of a faster growth rate, correlated with warming of the water. The increased prevalence of worms having more than 30 segments in May and June (Figure 22) may also have been due to a more rapid rate of growth. However, since the larger worms may have crawled in from surroundings it would seem

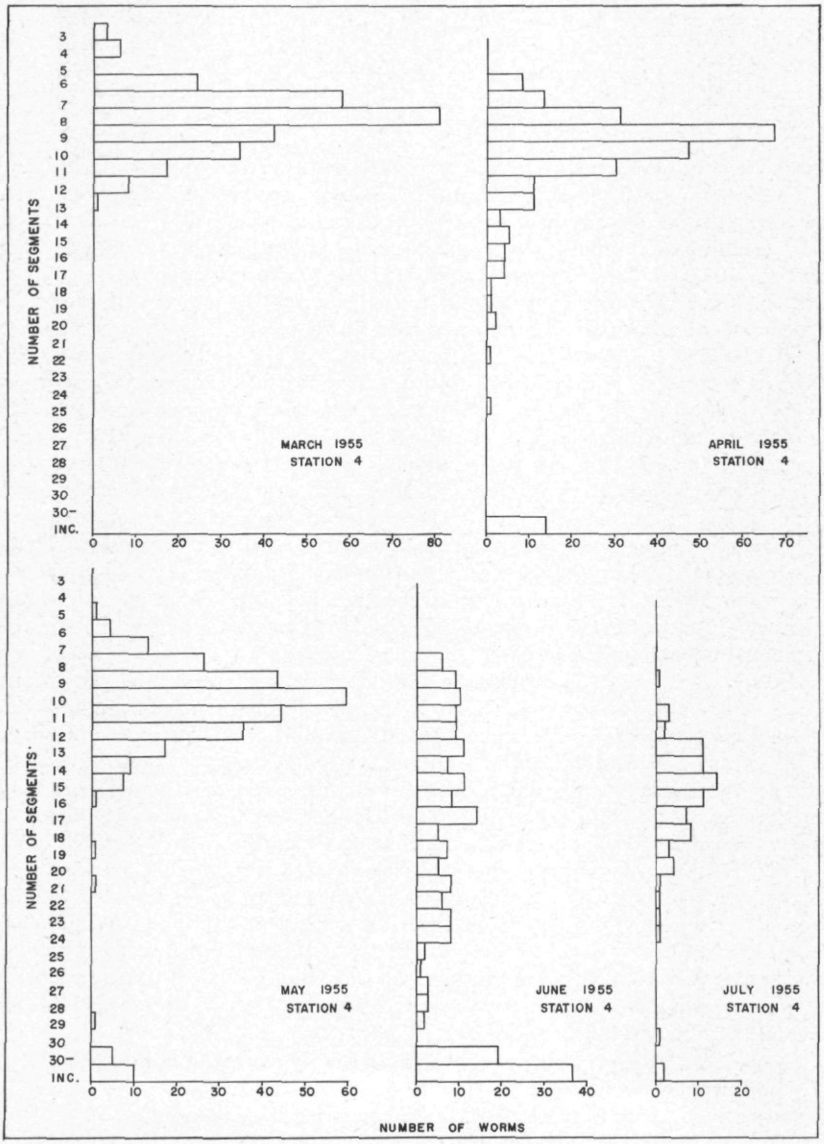


FIGURE 22. Size distribution of *Neanthes* settling in jars in a 30-day period during March to July, 1955. All collections made at a station three miles east of Fish Springs, above the deepest water of the Salton Sea.

TABLE 21

Number of Neanthes, Mean Segment Number, and Maximum Segment Number, in 30-day Settling Jars from 3 Miles East of Fish Springs, Salton Sea During Spring, 1955

Month	Number	Mean Segment Number	Maximum Segment Number*
March	1,040	8	13
April	3,119	9	18-22
May	3,372	10	16-21
June	991	16	25-29
July	344	15	20-24

* Only worms in lower size modal group included.

more justifiable to estimate the "usual" rate of growth from the start of the "tail" of the distribution, shown in Figure 22, rather than from the individuals having more than 30 segments.

If estimates are made in this way, the maximum of 13 segments in March indicates that the worms entering as six-to-nine-segmented larvae added four to seven segments during the month. In April and May, the maximum of about 20 segments would indicate that the settled larvae grew 11 to 14 segments during the month. In June, the segmental distribution tapered out between 25-29 which would indicate addition of 17-23 segments per month, which was the maximum observed in the deepest parts of the Sea. At the three-mile station in July, the number of worms decreased and their rate of growth seemed to decrease to about that observed for April and May. By August, *Neanthes* had disappeared from the bottom below depths of about 25 feet.

During spring and early summer, worms in the collections from shallow water near shore (e.g., Station 1, upper part of Figure 23) contained the same mean number of segments and the same maximum number as those found in the deeper water, indicating growth rate was uniform in various parts of the Sea.

Data for all the shallow-water stations during summer, fall, and winter were similar to those in the lower part of Figure 23, which shows the size distributions of worms collected in 30-day settling jars one-half mile north of Mullet Island. At this station in August, there were relatively few worms (336 total), and relatively few were small: half the worms had more than 30 segments. Although the distribution shows no real peak, if rate of growth is estimated from the "tail" of the size-distribution curve, it would be 25-30 segments per month. However, if rate of growth is judged from the size attained by 171 of 336 worms in the collection, it would be more than 30 segments per month. It is conceivable that those with more than 30 segments settled during a period of intensive spawning early in the month, and that the smaller worms were spawned later in the month (an interpretation is suggested in the discussion of the 10-day collections).

There may be a correlation between growth rate and temperature. It was not until November that the mean water temperature decreased to 20 degrees C., approximating those of the spring (Table 22).

By November, the size distribution (Figure 23) was about as it had been in March: there were many small worms, with a mean segment number of 7 and a maximum of 12. The growth rate was three to six

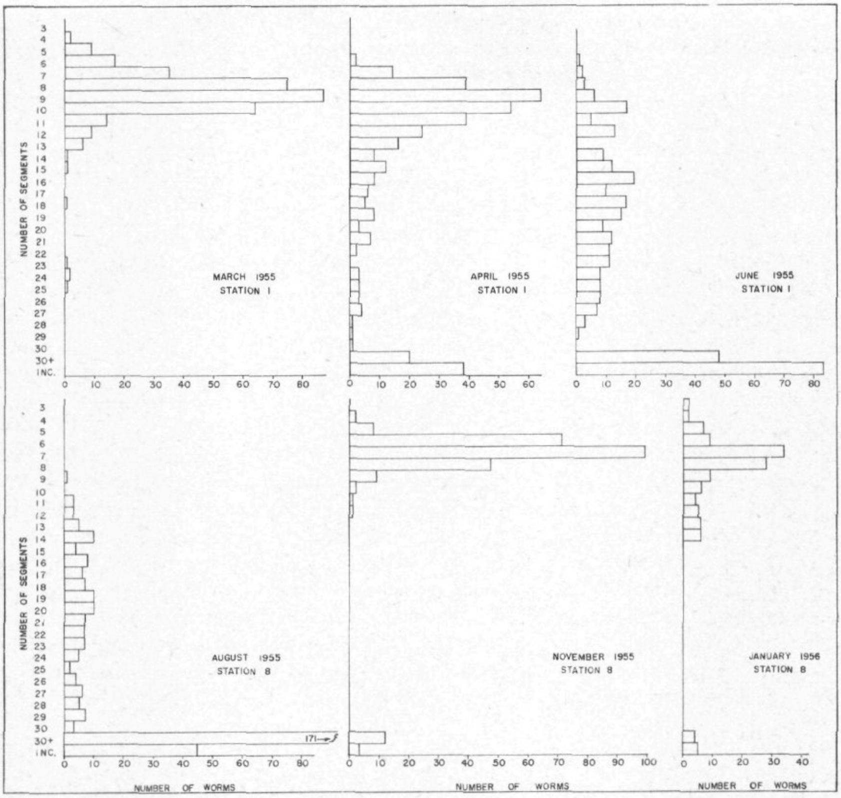


FIGURE 23. Size distributions of *Neanthes* settling in jars in a 30-day period during six different months in 1955 and 1956. All collections were made at a station one-half mile north of Mullet Island, Salton Sea.

segments per month. In November, worms having more than 30 segments were no longer numerous, as they had been in August, and, at some stations in September and October. In December and January, the growth rate was about as in November but there were far fewer worms: 387 compared to 1,099. These figures for fall and winter are in contrast to the greater number that settled during the spring spawning—in April 1955, 2,774 worms settled in the jar at Station 8.

TABLE 22

Mean Monthly Surface Temperatures in Salton Sea, 1955

Month	Temperature in Degrees C	Month	Temperature in Degrees C
January	13	July	30
February	14	August	32
March	18	September	31
April	21	October	27
May	23	November	20
June	27	December	16

The data from the 30-day settling jars showed the rate of growth was slow (three to seven segments per month) in early spring and during fall, but during the summer it was 25-30 segments per month, or even more.

Ninety-Day Collections

There were no sexually mature worms in any of the jars left for 30-day periods. Collections for 90-day periods contained a few epitokes showing that some *Neanthes* reach maturity within 90 days.

In judging maturity of *Neanthes* it should be mentioned that, based upon 114 epitokes (21 female, 93 male), the normal number of segments of mature males was 88 to 98 and for females, 103 to 125. For the males, 14, 34, and 40 to 50 segments were pre-natatory, natatory, and post-natatory; while for females there were 17, 26, and 60 to 82, respectively.

Although the number of pre-natatory and natatory segments was nearly constant, the number of post-natatory segments was more variable. Although most complete males had 40-50, individuals with 58, 64, and 85 were found. Among the females, although most had more than 60, one complete female had only 44. The counts of post-natatory segments were based on complete worms; the actual number varied, however, because terminal segments were often missing. Sexually functional worms may lack all the post-natatory and even some of the natatory segments. It was observed in an aquarium that the tails of *Neanthes* may protrude from their burrows. Loss of terminal segments may be due to "grazing" on the protruded tails by other *Neanthes* or by fish. The epitoke of *Neanthes* thus has at least 50 segments, and if complete, 90 to 100 or more.

The sizes of the worms that settled in a jar in three months, (March 3 to June 1, 1955) one-half mile north of Mullet Island are shown in Figure 24. The continuous distribution (up to a length of 80 segments), and the presence of three epitokes, of which two were males (one with 56 segments, the other with 62) and one female (with 79 segments) is evidence that during spring at least a few *Neanthes* reached maturity within 90 days.

The rate of growth can be estimated if it is assumed that the largest one-third of the worms had settled during the first 30 days of the 90-day period and that their growth was constant. The presence of 50 to 80 segments indicates a growth of 17 to 27 per month. Since this took place during March, April, and May when mean water temperatures were between 20 and 30 degrees C., it is conceivable that during July, August, and September, when mean water temperatures ranged from 30 to 35 degrees C., the growth rate may, indeed, have been greater than 30 segments per month, as was indicated by numerous individuals somewhat longer than 30 segments in 30-day collections—i.e., that made in August at Station 8, shown in the lower left of Figure 23.

Number Per Unit Area in Settling Jars

The settling jars showed that tremendous numbers of worms settled to the bottom. The minimum number in a 30-day collection near shore was 99 (Station 7, October); the maximum during the peak of spring spawning was 5,423 (Station 10, April). Since the area through which they settled was approximately 0.01 square meter, these figures repre-

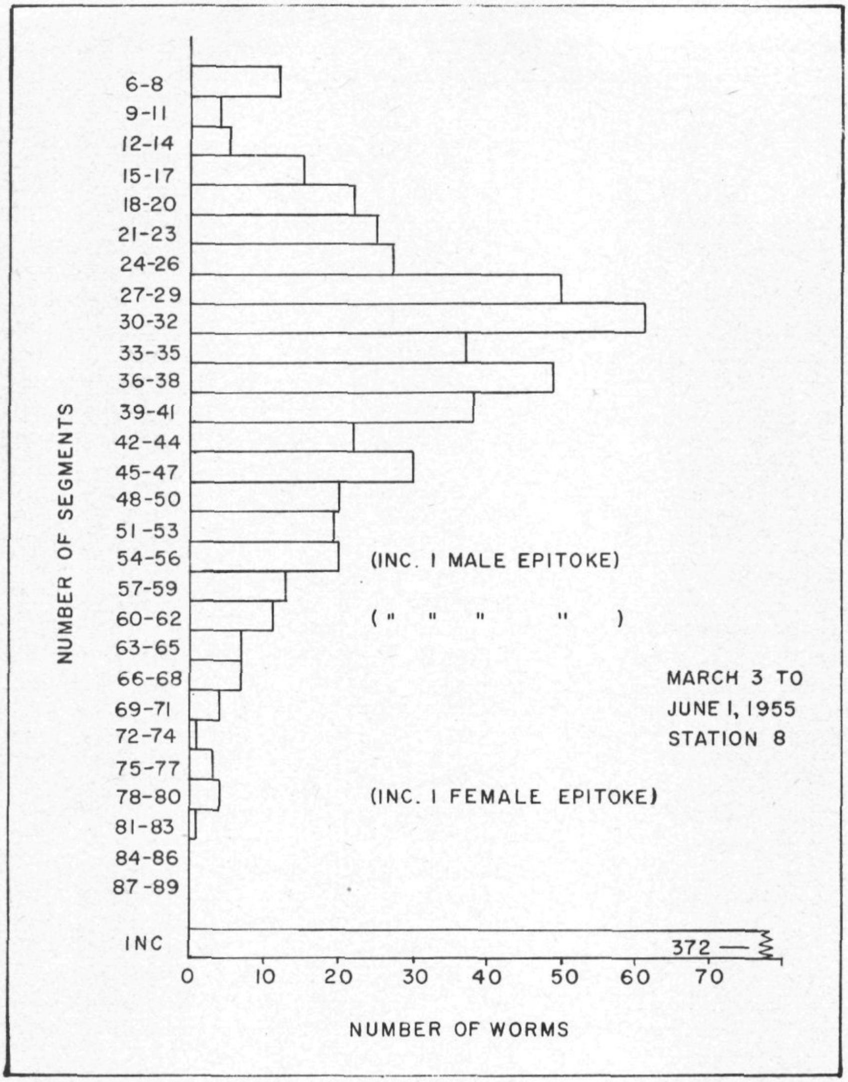


Figure 24. The size distribution of *Neanthes* settling in jars in the 90-day period, March 3 to June 1, 1955, at a station one-half mile north of Mullet Island, Salton Sea.

sent 10,000 to 540,000 worms per square meter of bottom, or 1 to 54 worms per square cm. The maximum number collected represented one worm per two square mm.

Measurements of small *Neanthes* showed immature worms, up to about 30 segments, were about 0.1 mm long per segment. That is, a 10-segmented worm was about 1.0 mm long; a 30-segmented one about 3.0 mm. So, because of their small size, great numbers can settle, and for about the first month of bottom-dwelling there was room for the maximum found in 30-day collections. However, mature *Neanthes* epitokes of 70-90 segments were four to five cm long (1¾ to 2¼ inches). Obviously there was insufficient area for all that settle to reach maturity. Samples of the bottom mud, screened to determine the number actually present, averaged about 6,500 per square meter, while the maximum was about 19,000.

BOTTOM SAMPLES

From bottom samples taken to study the sedimentation and Foraminifera of the Sea, Arnal (1957) concluded that "*Neanthes* lives only in littoral sediments, and is restricted to fine sand and silt material. None were found [*sic*] in coarse sand or in fine mud in the center of the Sea." Through the courtesy of Mr. Arnal, the samples he had taken were made available to us. *Neanthes* were in 58 of 78 of these taken at depths of 1 to 29 feet; none was in 21 collections from depths greater than 30 feet. However, none of Arnal's samples from greater than 30 feet had been taken in winter or spring. His collections thus showed only that *Neanthes* was absent from the bottom at greatest depths in summer and early fall.

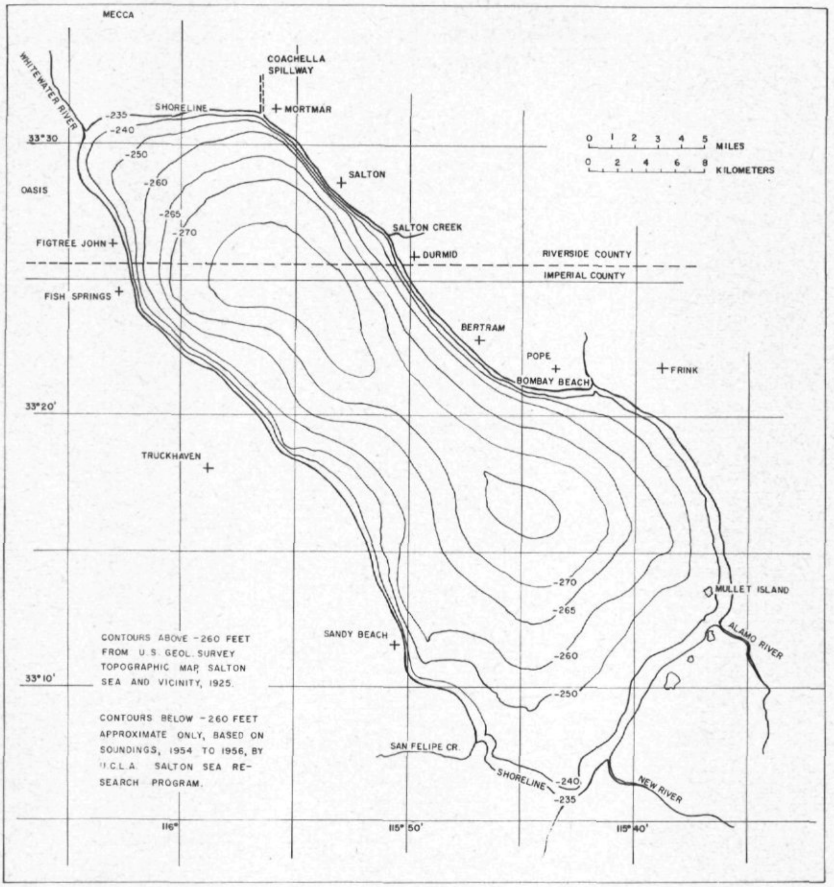
Neanthes have been found in winter and late fall in the deepest part of the Sea. For example, three miles off Fish Springs (depth 40 feet) *Neanthes* were present in samples taken with an Ekman-type dredge on February 22, 1955, when there were 39 per 36 square inches, and, after being absent in summer, on October 25, 1955 when there were 17 per 36 square inches.

During the summer of 1955, routine dissolved oxygen determinations at the station three miles east of Fish Springs showed that the waters below about 20 feet became anoxic at times in June, July, August, and September. The periods of anoxia were usually short (especially in June) but were occasionally of sufficient duration to suggest that lack of oxygen might account for the worm's disappearance from the plankton and from the bottom in the deepest part of the Sea in July, August, and September.

In order to verify the apparent summer disappearance of *Neanthes* from the plankton and from the bottom at depths below about 25 feet, and to obtain an estimate of the actual mass of *Neanthes* in the bottom of the Sea, two series of bottom samplings were made during September and November of 1956. One series of samples was collected at the end of summer when anoxic conditions should have eliminated *Neanthes;* the second was taken during the fall peak of spawning after return of oxygen at the bottom.

An Ekman-type dredge, which samples a bottom area of 36 square inches, was used. The samples were preserved with formalin, sorted through a U. S. Standard Sieve series and stored in 70 percent isopropyl alcohol. The weight and the number of worms were determined. The weight was that of the preserved animals after excess moisture had been removed by placing them on filter paper for a short time.

Bottom samples were collected along transects from Fish Springs to Mortmar and from Durmid to Truckhaven on September 18, 1956 (Figure 25). *Neanthes* were absent in all five samples from depths below 30 feet, but were present in the five collected at less than 16 feet (Table 23). On September 21, 1956, samples were collected along a transect due south from Bombay Beach toward the southern shore of the Sea.



CONTOURS ABOVE -260 FEET FROM U.S. GEOL. SURVEY TOPOGRAPHIC MAP, SALTON SEA AND VICINITY, 1925.

CONTOURS BELOW -260 FEET APPROXIMATE ONLY, BASED ON SOUNDINGS, 1954 TO 1956, BY U.C.L.A. SALTON SEA RESEARCH PROGRAM.

Figure 25. Bottom contours and local reference points, Salton Sea.

A few small *Neanthes* (ranging from one to five per 36 square inches) were present in the four bottom samples from deeper than 25 feet, but were numerous in two samples taken in 7 to 10 feet of water.

In a series of samples taken November 29, 1956 at approximately five-foot depth-intervals along a line from Fish Springs toward Mortmar, *Neanthes* were present in all collections made in from 5 to 36 feet (Table 24). It would thus seem that *Neanthes* was absent at these depths in September, but had returned by November.

Another series of samples was taken on December 3, 1956 along a transect from the spillway north of Mortmar to Oasis. *Neanthes* were in all of these samples which were taken at depths from 10 to 23 feet (Table 24).

Depth Distribution of *Neanthes*

It would seem from the data of Table 24 that the zone at the upper boundary of the depth that becomes anoxic in summer is the zone that, in fall at least, is the most productive of *Neanthes*. At nine stations in

TABLE 23

Numbers and Weight of Neanthes per Unit Area of Bottom in Collections Made in September 1956, Salton Sea

Location	Depth in Feet	*Neanthes*		
		Number per 36 in^2	Weight	
			g/36 in^2	g/m^2
September 18, 1956				
100 yd off Fish Springs	11	51	0.313	13.2
2 mi NE of Fish Springs	36	0	0	0
4 mi NE of Fish Springs	37	0	0	0
6 mi NE of Fish Springs	38	0	0	0
150 yd off Mortmar	13	441	1.587	67.2
150 yd off Mortmar	13	423	1.71	72.0
500 yd off Durmid	14	69	0.278	11.7
2 mi SW of Durmid	39	0	0	0
4 mi SW of Durmid	42	0	0	0
300 yd off Truckhaven	10	124	1.070	45.0
September 21, 1956				
200 yd off Bombay Beach	9	91	0.683	28.8
2½ mi S of Bombay Beach	37	9	----	----
5 mi S of Bombay Beach	39	1	----	----
7½ mi S of Bombay Beach	35	5	----	----
10 mi S of Bombay Beach	26	3	----	----
Southern Shore	7	69	0.184	7.75
Second Sample, No. 6	7	62	0.296	12.5

TABLE 24

Numbers and Weight of Neanthes per Unit Area in Collections Made in November and December 1956, Salton Sea

Location	Depth in Feet	*Neanthes*		
		Number per 36 in^2	Weight	
			g/36 in^2	g/m^2
November 29, 1956				
Fish Springs Jetty	5	109	.2495	10.5
150 yd NE of Fish Springs	10	174	.6712	28.2
300 yd NE of Fish Springs	16	215	.3361	14.1
500 yd NE of Fish Springs	20	231	1.8060	75.9
1 mi NE of Fish Springs	30	77	.2825	12.0
4.5 mi NE of Fish Springs	36	39	.1067	4.5
S of Mortmar	10	261	.2838	12.1
1½ mi NW of Mortmar	10	189	.4095	17.2
1½ mi NW of Mortmar	10	166	.4081	17.1
December 3, 1956				
400 yd true S of spillway	10	189	.3307	14.0
200 yd from spillway	20	222	.8187	34.4
3 mi SW of spillway	23	118	.7115	30.0
6 mi SW of spillway	20	115	.9155	38.5
200 yd offshore E of Oasis	10	98	.3770	15.8
200 yd offshore 3 mi N of Fish Springs	10	167	.3177	13.3

water shallower than 16 feet, the weights of worms in 36 square inches of bottom ranged from 0.2495 to 0.6712 grams, and averaged 0.376. At depths of about 20 feet, the weights ranged from 0.5903 to 1.8060 grams for an average of 0.968. At greater depths (exceeding 30 feet) the range was 0.1067 to 0.2825 for an average of .1946 (three samples).

The bottom that becomes anoxic and unsuitable for the worm in summer is black organic mud, covered with a mat of bacteria and detritus. The bottom at about 20 feet is a brownish sand with an admixture of barnacle shells. The shallowest areas near shore are silt or clay or sand, black or brown in color, and covered with a mat of blue-green algae and diatoms. This mat may become detached, and eventually settles in deeper water or is thrown on the shore by wave action. Arnal (1957) found that the shallower zone near shore had the least organic matter (one to two percent) but with depth it increased in the bottom mud to a maximum of five to six percent. The bottom below a depth of 25 feet evidently became anoxic during the time of degradation of the great amount of phytoplankton and zooplankton produced in the spring due to the bacterial decomposition of the increased amounts of settled organic matter. *Neanthes,* therefore did better in the intermediate depths, where the amount of organic matter was two to four percent, than in the zone near shore, where there was less food (organic matter one to two percent), or at greater depths where, although there was a rich food supply, the amount of organic matter (five to six percent) was so great that oxygen was not available for prolonged periods in summer.

The lengths of the anoxic periods were important. In shallower water, oxygen frequently was depleted at dawn during summer. But the anoxic condition lasted only a few hours each day. In laboratory experiments conducted July 21-26, 1955, some *Neanthes* survived 24 to 27 hours in oxygen-depleted water. It would thus seem that *Neanthes* can tolerate absence of oxygen for about one day, but cannot endure anoxia for longer periods.

Neanthes, therefore, were absent from the bottom below about 25 feet during July, August, and September. From October to June, after the organic matter had been degraded, the deepest zone again had sufficient oxygen to support them. During this period, they could make use of the richest food supply in the Sea.

Standing Crop of *Neanthes*

It can be calculated from the bottom contours (Figure 25) that 30 percent of the Sea lies above —250 feet, 14 percent lies between —240 and —260 feet, and 56 percent lies below —260 feet. This means that with the surface elevation at —235 feet, 30 percent of the 220,000 surface acres is shallower than 15 feet, 14 percent lies at depths between 15 and 25 feet, and 56 percent is deeper than 25.

These depths delimit, approximately, the three distributional zones of *Neanthes:* that of greatest productivity between 15 and 25 feet, the less productive shore area, and the deep zone from which *Neanthes* is excluded in summer and early fall.

The surface area of the Sea at —235 feet is 220,000 acres, or 890×10^6 m^2. The three zones (shore, intermediate, and deep) contain respectively 265×10^6, 125×10^6, and 500×10^6 m^2.

The weight of worms found in bottom samples (Table 24) in late fall can be used to indicate the standing crop of *Neanthes* at that season. In the deepest part of the Sea (depths greater than 30 feet), this was about 8 grams/m^2. The 500×10^6 m^2 of this zone would contain 4×10^6 kilograms of *Neanthes*. In the most productive zone (between 15-25 feet) the average weight of *Neanthes* was about 40 grams per m^2, so this zone would contain 5×10^6 kilograms of worms. The shallower shore area (less than 15 feet deep) contained an average of about 16 grams per m^2, or about 4.2×10^6 kilograms of worms.

The entire Sea, on this rough estimate, would contain 13.2×10^6 kilograms of *Neanthes*. Since there are 907 kilograms per ton, there would be 14,500 tons of *Neanthes* in the bottom of the Sea in fall. This represents about 125 pounds per acre. Previously it was estimated, on the basis of numbers in settling jars, that about 25 percent of the annual spawning took place in fall and winter, 60 percent in spring, and 15 percent in summer. If this proportion applied to the numbers on the bottom, it may be that the standing crop in spring averages about 300 pounds per acre, and in summer about 75.

THE FISHES OF THE SALTON SEA

BOYD W. WALKER, RICHARD R. WHITNEY, and GEORGE W. BARLOW

The original fish fauna of the present Salton Sea came from the Colorado River. Undoubtedly most of the species in the lower Colorado were carried into the Salton Sink when the Sea was formed in 1905 and 1906. Unfortunately no records exist of the early fauna, but fishes were said to be very abundant (Evermann, 1916). As the waters became more saline, because there was no outflow, there was a depletion of the original freshwater fish stock. Evermann (1916) reported that, as late as May 1916, there was still a sizeable population of freshwater forms, despite the fact that the water was "quite brackish, strongly alkaline, and very warm." He listed the following:

1. Carp, *Cyprinus carpio* Linnaeus—the most abundant species.
2. Bonytail, *Gila robusta* Baird and Girard—not uncommon, though Evermann saw no specimens.
3. Humpback sucker, *Xyrauchen texanus* (Abbott)—rather common, but the several seen by Evermann had a starved appearance.
4. Rainbow trout, *Salmo gairdneri* Richardson—listed by Evermann as *Salmo pleuriticus* Cope. Miller (1950) interpreted all Salton Sea records of *Salmo clarki pleuriticus* as having been based upon rainbow trout washed into the Sea from Arizona. Everman reported, "It is said to be fairly common. I saw one fine example about 16 inches long. It was in excellent condition, albeit somewhat bleached in color."
5. Striped mullet, *Mugil cephalus* Linnaeus—the second most common species.
6. Desert pupfish, *Cyprinodon macularius* Baird and Girard—found in Figtree John Spring.

Although salinities had increased greatly, two freshwater fishes were still present in 1929 (Coleman, 1929). The carp and bonytail had disappeared, but the "Colorado River trout" was occasionally seen near the east end of the Sea, and the humpback sucker was reported as rather common. The mullet had become scarce. The desert pupfish was common along the north shores of the Sea. The mosquitofish, *Gambusia affinis* Baird and Girard, was found for the first time, and was abundant at several points along the shore.

In 1929 and 1930, large plants of striped bass, *Roccus saxatilis* (Walbaum) were made, but there is no record that any of these survived. On November 13, 1930, 500 longjaw mudsuckers, *Gillichthys mirabilis* Cooper, from San Diego Bay evidently were the start of the present population in the Salton Sea. During 1934, a load of 15,000 silver salmon, *Oncorhynchus kisutch* (Walbaum), presumably fingerlings, was dumped into the Sea, never to be seen again.

TABLE 25

Known Fish Introductions Into the Salton Sea *

Date	Number	Species	Common Name**	Where Acquired
20 Oct 1929	900	*Roccus saxatilis*	striped bass	Tracy, California
24 Oct 1929	1,500	*Roccus saxatilis*	striped bass	Tracy, California
21 Oct 1930	1,800	*Roccus saxatilis*	striped bass	San Francisco Bay
13 Nov 1930	500	*Gillichthys mirabilis*	longjaw mudsucker	San Diego Bay
1934	15,000	*Oncorhynchus kisutch*	silver salmon	Forest Home Hatchery
2 Oct 1948	43	*Anchoa mundeoloides*	anchovy	Guaymas
23 Dec 1948	1,000	*Cetengraulis mysticetus*	anchoveta	San Diego (tuna boat)
	12	*Caranx caballus*	green jack	San Diego (tuna boat)
10 May 1950	5,000	*Cetengraulis mysticetus*	anchoveta	San Felipe
12 May 1950	29	*Albula vulpes*	bonefish	San Felipe
	2	*Cetengraulis mysticetus*	anchoveta	San Felipe
	1	*Paralichthys aestuarius*	halibut	San Felipe
	40	*Colpichthys regis*	silverside	San Felipe
	1	*Eucinostomus argenteus*	spotfin mojarra	San Felipe
	2	*Trachinotus paitensis*	paloma pompano	San Felipe
	27	*Cynoscion xanthulus*	orangemouth corvina	San Felipe
	14	*Cynoscion parvipinnis*	shortfin corvina	San Felipe
	1	*Cynoscion macdonaldi*	totuava	San Felipe
	7	*Menticirrhus undulatus*	California corbina	San Felipe
	1	*Menticirrhus nasus*	corbina	San Felipe
	15	*Micropogon megalops*	croaker	San Felipe
	57	*Bairdiella icistius*	bairdiella	San Felipe
14 Dec 1950	25	*Mugil curema*	white mullet	San Felipe
	600	*Colpichthys regis*	silverside	San Felipe
	1	*Paralichthys woolmani*	halibut	San Felipe
	1	*Scomberomorus concolor*	Monterey spanish mackerel	San Felipe
	1	*Menticirrhus undulatus*	California corbina	San Felipe
	12	*Eucinostomus argenteus*	spotfin mojarra	San Felipe
		Eucinostomus gracilis	mojarra	San Felipe
15 Dec 1950	15	*Mugil cephalus*	striped mullet	San Felipe
	60	*Mugil curema*	white mullet	San Felipe
	70	*Colpichthys regis*	silverside	San Felipe
	1	*Nematistius pectoralis*	roosterfish	San Felipe
	1	*Menticirrhus undulatus*	California corbina	San Felipe
	75	*Eucinostomus argenteus*	spotfin mojarra	San Felipe
		Eucinostomus gracilis	mojarra	San Felipe
28 Mar 1951	30	*Cetengraulis mysticetus*	anchoveta	San Felipe
	300	*Leuresthes sardina*	grunion	San Felipe
	3	*Cynoscion xanthulus*	orangemouth corvina	San Felipe
	2	*Cynoscion parvipinnis*	shortfin corvina	San Felipe
31 Mar 1951	48	*Albula vulpes*	bonefish	San Felipe
	6	*Anchoa mundeoloides*	anchovy	San Felipe
	8	*Cetengraulis mysticetus*	anchoveta	San Felipe
	5	*Mugil curema*	white mullet	San Felipe
	3	*Colpichthys regis*	silverside	San Felipe
	4	*Paralichthys aestuarius*	halibut	San Felipe
	140	*Hypsopsetta guttulata*	diamond turbot	San Felipe
		Etropus crossotus	flounder	San Felipe
	65	*Anisotremus davidsoni*	sargo	San Felipe
	12	*Paralabrax maculatofasciatus*	spotted bass	San Felipe
	7	*Girella simplicidens*	opaleye	San Felipe
	2	*Halichoeres*(?)	wrasse	San Felipe
	200	*Cynoscion xanthulus*	orangemouth corvina	San Felipe
		Cynoscion othonopterus	scalyfin corvina	San Felipe
		Cynoscion parvipinnis	shortfin corvina	San Felipe
		Cynoscion macdonaldi	totuava	San Felipe
	10	*Bairdiella icistius*	bairdiella	San Felipe
	2	*Menticirrhus nasus*	corbina	San Felipe
	1	*Eucinostomus argenteus*	spotfin mojarra	San Felipe
	63	*Gillichthys seta*	mudsucker	San Felipe
14 Dec 1951	72	*Colpichthys regis*	silverside	San Felipe
11 May 1953	6,000	*Engraulis mordax*	northern anchovy	Los Angeles Harbor
13 May 1953	44	*Cynoscion parvipinnis*	shortfin corvina	San Felipe
	35	*Micropogon megalops*	croaker	San Felipe
	4	*Menticirrhus undulatus*	California corbina	San Felipe
	1	*Trachinotus paitensis*	paloma pompano	San Felipe

TABLE 25—Continued

Known Fish Introductions Into the Salton Sea *

Date	Number	Species	Common Name**	Where Acquired
	26	*Opisthonema libertate*	Pacific thread herring	San Felipe
15 May 1953	50	*Cynoscion parvipinnis*	shortfin corvina	San Felipe
	38	*Cynoscion xanthulus*	orangemouth corvina	San Felipe
	4	*Menticirrhus undulatus*	California corbina	San Felipe
10 Mar 1955	3,000	*Cetengraulis mysticetus*	anchoveta	Gulf of California
10-11 May 1955	114	*Cynoscion parvipinnis*	shortfin corvina	San Felipe
	4	*Cynoscion xanthulus*	orangemouth corvina	San Felipe
Apr-May 1956	8	*Cynoscion macdonaldi*	totuava	San Felipe
	1	*Cynoscion othonopterus*	scalyfin corvina	San Felipe
	1,545	*Cynoscion parvipinnis*	shortfin corvina	San Felipe
	59	*Cynoscion xanthulus*	orangemouth corvina	San Felipe

* Prepared by John E. Fitch.

** Common family name used when no specific common name is available.

Dill and Woodhull (1942) reported numerous machete or tenpounders, *Elops affinis* Regan, at various localities in the Sea, but there have been no subsequent records. Presumably there was not sufficient suitable food to support a carnivorous fish at that time.

In 1948 the California Department of Fish and Game resumed efforts to establish additional fish species in the Sea. In 1950 and 1951, they made large plants of many species secured from the Gulf of California at San Felipe, Baja California. The present populations of bairdiella, orangemouth corvina, and sargo resulted from these plantings. Subsequent introductions were also made in 1953, 1955, and 1956, but they probably had no significant effect.

Many of the plants made during and after 1950 were of the "shotgun" type. Since there was no way to predict what fishes might be successful, many species were introduced. All fishes known to have been introduced into the Salton Sea are listed in Table 25.

The fish fauna of the Salton Sea now consists of the nine species listed below.

THREADFIN SHAD, *Dorosoma petenense* (Günther)

(Figure 26)

The threadfin shad, family Clupeidae, was brought into California in 1953 from its native waters in the southeastern United States. In 1954 and 1955, it was introduced into the Colorado River, and it quickly spread throughout the lower river system. It was first taken in the Salton Sea, which it had entered via irrigation laterals, in September 1955. There has been no sign that this species spawns in the Sea, but there is a continuing recruitment from the Colorado River system. At times they are present in large numbers.

Recognition Characters

Threadfin shad reach lengths of nearly nine inches in the Salton Sea. They may be recognized by their single dorsal fin with an elongated posterior ray, much compressed body, extremely elongate anal fin, and bright silvery color.

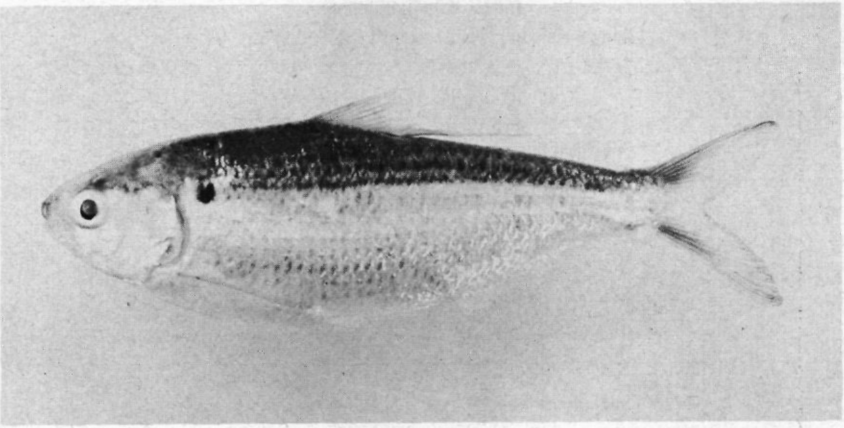


FIGURE 26. The threadfin shad, *Dorosoma petenense* (Günther). Photo by W. J. Baldwin.

Importance

They form an important item in the diet of the corvina. They are a desirable addition to the food chain, because they feed directly on the tiny animals in the plankton.

DESERT PUPFISH, *Cyprinodon macularius* Baird and Girard
(Figure 27)

The desert pupfish, family Cyprinodontidae, is the only native species in the Salton Sea. Its range includes the basin of the lower Colorado and Gila Rivers, from southern Arizona to southeastern California and eastern Baja California, and the Sonoyta River of northern Sonora, Mexico (Miller, 1943). Pupfish are everywhere about the shores of the Salton Sea where there is quiet water, and penetrate a few of the streams that enter the Sea. They are especially abundant in the hypersaline shore pools behind the wave built sand bars. In these pools, they tolerate extreme environmental conditions. Temperatures often exceed 99 degrees F. in summer, and sink as low as 35 or 36 degrees F. in winter. They have been known to survive and spawn in these pools when the salinity has exceeded twice that of sea water.

The food habits of the pupfish were not studied in detail, but a few observations indicated that they were similar to those of the bairdiella. The pupfish are not considered serious competitors, however, because of their small population size. They are preyed upon by the large wading birds and by the longjaw mudsuckers and bairdiella, but they are not important in the diets of any of these.

The population density fluctuates through a wide range even in areas where no predators are found. Growth is very rapid, and fish hatched in the early summer mature and spawn in the same summer. The maximum size attained is about 45mm standard length. Scale readings indicate that they attain this in one year or less.

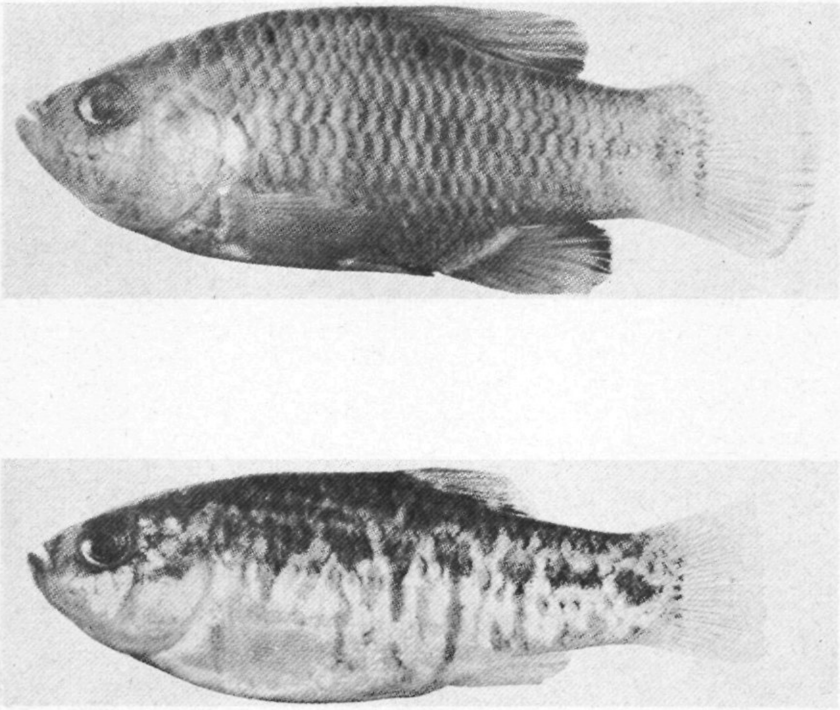


FIGURE 27. The desert pupfish, *Cyprinodon macularius* Baird and Girard. Male above, female below. Photo after R. R. Miller (1943).

Recognition Characters

Pupfish are small chubby fish, usually not over two inches long. The males are brightly colored during the summer, with blue backs and golden bellies. In the winter the colors are duller, often fading to brown or olive on the back and white on the under surface. The females are marked with definite brownish blotches on a pale background. The thick body, small size, color, and single dorsal fin distinguish them from all other fishes in the Sea. The only species with which they might be confused is the mosquitofish. Mosquitofish differ markedly in color, being uniformly tan with tiny black spots, and with a black blotch under the eye. The anal fin of the male mosquitofish is elongate and slender, and is modified into a special reproductive organ.

Importance

There is no evidence the pupfish have any appreciable effect on other fishes in the Sea. They are interesting aquarium fish, and small numbers are collected for this purpose.

MOSQUITOFISH, *Gambusia affinis affinis* (Baird and Girard)
(Figure 28)

The mosquitofish, family Poeciliidae, was introduced into the Salton Sea sometime prior to 1929. It is native to the eastern United States, but was distributed widely during the early part of this century to aid in mosquito control. It is common in the fresh waters surrounding the Sea, and is often found in the shallow areas, particularly near freshwater inlets.

Recognition Characters

Mosquitofish rarely exceed $1\frac{3}{4}$ inches in length. The small size rather uniform tan coloration on back and sides, with tiny black spots, the black blotch under the eyes, and the single dorsal fin composed of soft rays, set them apart from all other fish in the Sea. The only species with which they might be confused is the desert pupfish, from which they differ markedly in coloration.

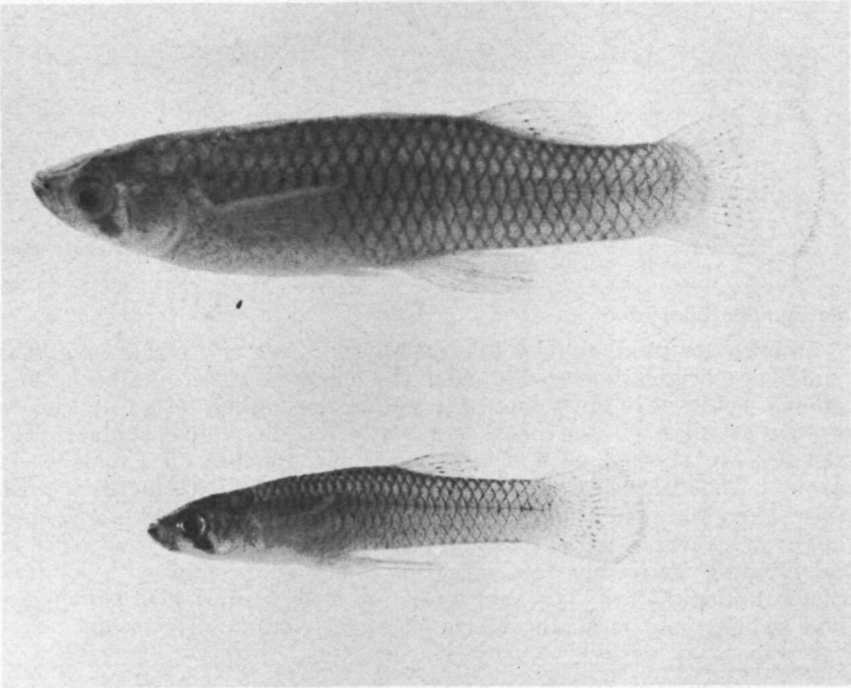


FIGURE 28. The mosquitofish, *Gambusia affinis affinis* (Baird and Girard). Photo by W. J. Baldwin.

Importance

Mosquitofish are never present in sufficient numbers to be important as forage or as competitors. They may be of some value in mosquito control.

STRIPED MULLET, *Mugil cephalus* Linnaeus

(Figure 29)

The striped mullet, family Mugilidae, was at one time abundant in the Salton Sea, and provided both a commercial and a sport fishery. The entire population consisted of mullet which had been spawned in the Gulf of California, and which had reached the Sea via the Colorado River and irrigation laterals. Due to changes in the irrigation laterals in the Imperial Valley, mullet can no longer enter the Salton Sea, and they are now virtually extinct. There is no evidence that they ever spawned in the Sea.

Recognition Characters

Striped mullet reached a large size in the Sea, and fish of 10 to 12 pounds were not uncommon. They are easily recognized by their broad heads; bluegreen backs and silvery sides and bellies, with narrow black stripes along the upper scale rows; and the small first dorsal fin, composed of spines, placed well forward of the second dorsal, composed of soft rays.

Importance

Now virtually extinct and of no importance.

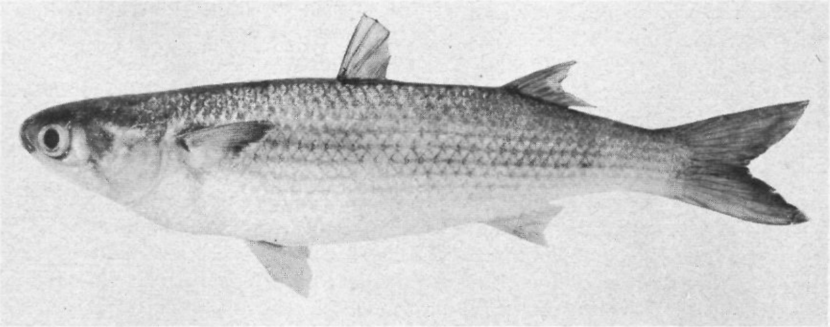


FIGURE 29. The striped mullet, *Mugil cephalus* Linnaeus. California Department of Fish and Game photo.

SARGO, *Anisotremus davidsoni* (Steindachner)

(Figure 30)

The sargo, family Pomadasyidae, has a normal range from Point Conception, California to southern Baja California, and in the upper Gulf of California. In California it may reach 20 inches, but fish longer than 14 inches are rarely taken in the Gulf of California. The large population of sargo now in the Salton Sea was derived from a single

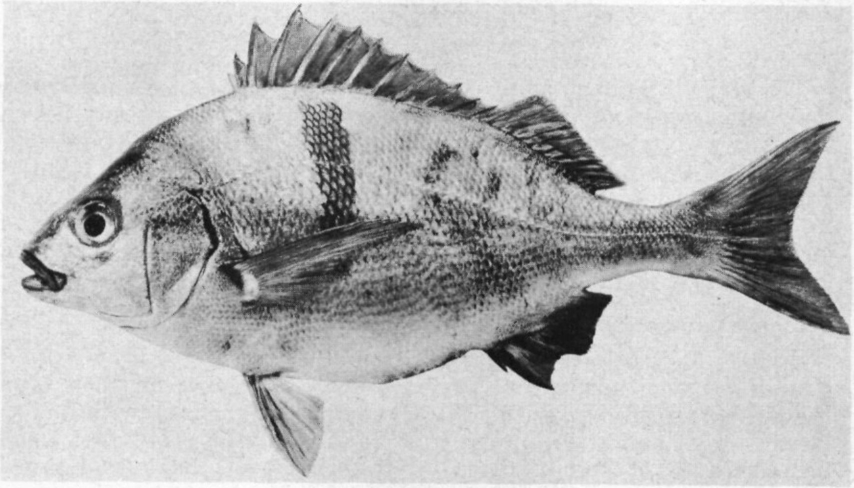


FIGURE 30. The sargo, *Anisotremus davidsoni* (Steindachner). California Department of Fish and Game photo.

plant of 65 fish, made on March 31, 1951 by the California Department of Fish and Game. Unlike the bairdiella, the sargo did not show an explosive early increase in numbers. Only three specimens were taken during the period of study by the Salton Sea Project. The first was taken October 29, 1956, in a gill net set at a depth of 30 feet, one mile off Fish Springs. It was 199 mm standard length, and obviously represented a year-class spawned in the Salton Sea. A second specimen, 91 mm standard length, was taken on November 26, 1956, on the opposite side of the Sea. The only other specimen was a young-of-the-year, 26 mm standard length, taken May 22, 1957, by seining at Fish Springs. These catches indicated the establishment and spawning success of the sargo, but there was no indication of a sizable population. They have increased remarkably in numbers since 1957, and by 1960 had produced an extremely large population supporting a considerable sport fishery. Unfortunately, since the sargo did not show its abundance until after the field study on the Salton Sea was terminated, we have no information on its life history.

Recognition Characters

The size that the sargo will reach in the Salton Sea is not known, but it may be expected to exceed 14 inches. It is easily recognized by its deep body; the strong, spinous first dorsal which is connected to the second dorsal; the three strong spines in the anal fin; and the black bar extending below the fifth to seventh dorsal spines. Very small sargo have two black stripes running laterally along the body, and they do not show the black bar.

Importance

With their great increase in population, the sargo has become an important game and forage fish in the Salton Sea. It well may replace the bairdiella in importance as forage for the orangemouth corvina. It is a good game fish in its own right, and is an excellent food fish.

Fishing Methods

Sargo readily take almost any kind of bait on moderate-sized hooks. They may be fished from shore or from a boat.

BAIRDIELLA, *Bairdiella icistius* (Jordan and Gilbert)

(Figure 31)

The bairdiella, family Sciaenidae, is native to the Gulf of California, where its is common in shallow and moderate depths. Sixty-seven specimens, taken at San Felipe, Baja California, Mexico, were planted in the Salton Sea in 1950 and 1951. From this modest introduction, their numbers in the Sea increased until millions were present in 1953.

Recognition Characters

The bairdiella is a small, silvery fish, usually less than 10 inches long, and never exceeding 12. It, as well as the two corvinas, has only two spines in the anal fin. The second spine provides the best recognition character, for it is much longer than the anal spine of any other fish in the Sea. When pushed flat against the ventral surface of the body it extends well past the end of the anal fin. In all other species in the Sea, the anal spine is shorter than the anal fin. Rarely, bairdiellas are taken in the Salton Sea with more than two spines. These fish may still be distinguished by the length of the anal spines, however.

Importance

It is chiefly valuable as forage for the corvinas. Because of its small size it is not of much value as a game or food fish, but many are caught incidentally.

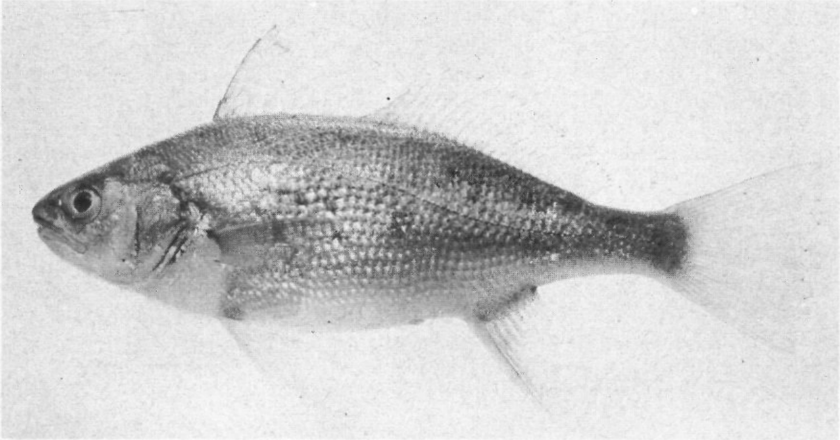


FIGURE 31. The bairdiella, *Bairdiella icistius* (Jordan and Gilbert). Photo by Jack W. Schott.

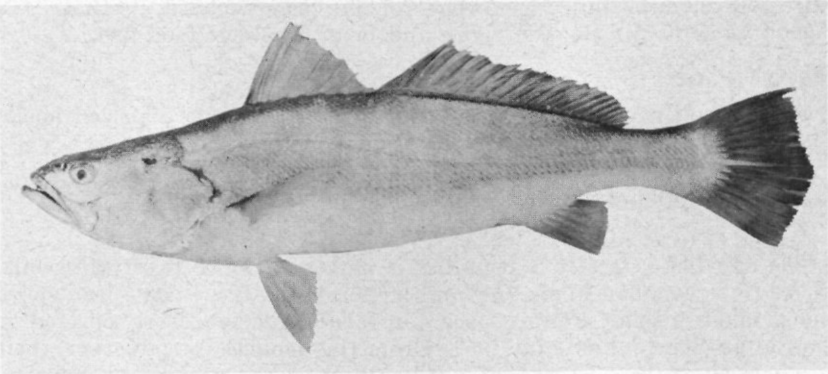


FIGURE 32. The orangemouth corvina, *Cynoscion xanthulus* Jordan and Gilbert. California Department of Fish and Game photo.

ORANGEMOUTH CORVINA, *Cynoscion xanthulus* Jordan and Gilbert

(Figure 32)

The orangemouth corvina, family Sciaenidae, has a normal range within the Gulf of California, where it is a well-known and much sought-after game fish. This species was planted in the Salton Sea at various times between 1950 and 1955. It is not known exactly how many were introduced, but the number did not exceed 272. From this small stock, the population has increased to the point where a substantial sport fishery flourishes today. Certainly millions of corvina are present in Salton Sea at this time.

Recognition Characters

The orangemouth corvina is a long, racy fish, with a tan back and silvery flanks. From most fish in the Salton Sea, it can be distinguished by its two anal spines; its large mouth which reaches nearly to a vertical from the back of the eye; its undershot jaw; and its two, almost separated, dorsal fins. It most closely resembles the shortfin corvina, from which it can be distinguished by the shape of the caudal fin and the number of rays in the anal fin. In the orangemouth corvina the middle caudal rays are long, so that the posterior edge of the tail is > shaped. In the shortfin corvina the posterior border of the caudal is straight or forms a weak ʃ shape. In the orangemouth corvina there are 7 to 9 anal rays, while in the shortfin corvina there are 10 or 11.

Importance

The chief game fish in the Salton Sea. Orangemouth corvina reach a large size, a 32-pounder being the largest taken in the Sea. Fall and spring are the best angling seasons, and many anglers take their limits (6 fish) during these times.

Fishing Methods

May be taken with live bait, or with large spoons and plugs, either fishing from shore or from a boat.

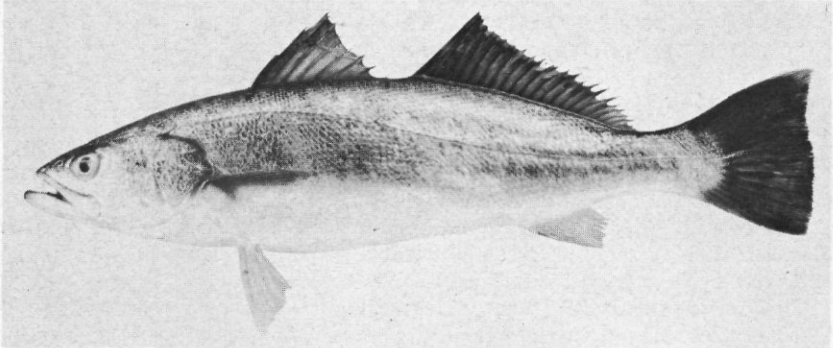


FIGURE 33. The shortfin corvina, *Cynoscion parvipinnis* Ayres. California Department of Fish and Game photo.

SHORTFIN CORVINA, *Cynoscion parvipinnis* Ayres

(Figure 33)

The shortfin corvina, family Sciaenidae, has a normal range from central Baja California to and including the Gulf of California. It was introduced into the Salton Sea by members of the Department of Fish and Game at the same time as the orangemouth corvina in 1950, 1951, and 1953. The fish were brought from San Felipe, Mexico. The number planted was no less than 110, nor more than 310, depending on the corvina planted on March 31, 1951, which were not identified as to species. In addition, plants were made in 1955 and 1956 in a cooperative venture of the University of California and the Department of Fish and Game. A total of 114 was planted in 1955, and 1,545 in 1956. All of these fish were marked.

The shortfin corvina has demonstrated an ability to survive in the Salton Sea, but has never clearly shown any evidence of having spawned there. Eleven fin-clipped individuals have been recovered from the 1955 and 1956 plants. Four of these were caught at least one year after having been planted. Some regeneration of the pelvic fins was observed in five of the fish, though it was very slight in two, consisting of a few twisted rays projecting from the stump. One fish, however, showed almost complete regeneration of the fins, though the rays were twisted and recognizable as having regenerated. Five of the fin-clipped fish also showed injuries to lower or upper rays of the caudal fin, these being bent at the edge or coalesced. Undoubtedly, these injuries were accidentally inflicted either during the netting operations in Mexico or the handling for fin-clipping, or during transportation in tank trucks to the Salton Sea.

Two shortfin corvina which were not fin-clipped were taken in the Salton Sea; one in June 1954 and the other in May 1956. Both might have come from plants made previously.

Recognition Characters

See discussion under orangemouth corvina.

Importance

Probably none, since there is no indication of successful spawning. If spawning should be successful in the future, they would play the same role as the orangemouth corvina.

LONGJAW MUDSUCKER, *Gillichthys mirabilis* Cooper

(Figure 34)

The longjaw mudsucker, family Gobiidae, has a normal range from central California to Magdalena Bay, Baja California, and in the Gulf of California. The Salton Sea population evidently stems from 500 fish planted on November 13, 1930 by the California Department of Fish and Game. They had been secured in San Diego Bay.

The major objective of the research on *Gillichthys* was to evaluate the role they played in the over-all economy of the Salton Sea. Factors that determined distribution and abundance, as well as relationships with other fish were considered. An additional goal, was to ascertain the possibilities of maintaining a mudsucker bait fishery. The location of the Salton Sea between population centers of southern California and the Colorado River fishing areas makes it an ideal site for obtaining mudsuckers.

In order to determine their reproductive potential, samples were collected approximately a month apart beginning in October 1954 at two stations. One was the boat channel at Fish Springs, which was typical habitat for fish in shallow water about the perimeter of the Sea. The second station was a series of shore pools at Salton Sea Beach. These shore pools were extremely variable in such physical factors as salinity, oxygen tension, and temperature.

In the boat channel at Fish Springs, ovary development started in September, but it did not begin until a month later (in October) in the shore pools. Gonadal development reached a peak in the Fish Springs population in late December and spawning started in January. The peak for the shore pool populations occurred in late January and early February. The first spawning in the shore pools occurred in February.

Apparently the January and February spawnings were not highly successful. No larval *Gillichthys* were recovered during this period from either day or night samples taken along the shore at several points, as well as in the shore pools. Some young fish did survive

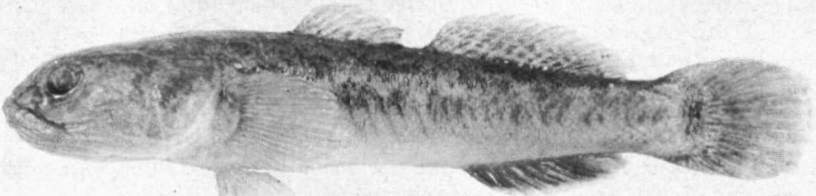


FIGURE 34. The longjaw mudsucker, *Gillichthys mirabilis* Cooper. California Department of Fish and Game photo.

however, because during subsequent months they were found as juveniles in shallow water.

The small number of mudsuckers produced in January and February probably was not attributable to fewer spawning females, because the conditions of the ovaries indicated that many fish spawned during these months. It seems more probable that the level of zooplankton at that time was too low to support the majority of the larvae. Such zooplankton organisms as rotifers, copepods, and barnacle nauplii were scarce in winter, becoming more abundant in the months that followed. However, the food habits of the early larvae were not studied because of a lack of material previous to April. We may postulate that since zooplankton must play an important role in their diet, a low level of zooplankton may limit the abundance of the larval mudsuckers.

Spawning in the Fish Springs population again reached a peak during late March and early April. The intensity of spawning, as determined by examining the ovaries of the females, was confirmed by a corresponding increase in abundance of larval *Gillichthys.*

By the middle of May, most of the females had spawned and the ovaries of many were again starting to develop. Many of the gonads were, at this time, slightly abormal in appearance. Often large, unspawned eggs had been retained and were being resorbed. Apparently, some females did not release all of their eggs during spawning.

Each female spawned at least twice and perhaps three times per season. A fair idea of the rate of development of the ovaries was determined by following the frequency of a particular stage in succeeding samples after the January spawning. These samples indicated that the interval between spawnings was probably not more than two to three months.

It was found convenient to separate the Salton Sea *Gillichthys* into five different size categories for study: prolarvae; prolarvae to 15 mm; 15 to 25 mm; 25 mm to young adults (about 60 to 70 mm); and adults. The food habits and mode of life together with certain morphological changes constitute the criteria for these divisions.

The prolarvae were seldom taken. They are less than 3.5 mm long and retain the yolk sac. The earliest developmental stage commonly taken was fish larger than prolarvae and shorter than 15 mm. These heavily-pigmented little fish were still pelagic though they lived in quiet, shallow waters along the shore.

At about 15 mm the young mudsuckers descended to the bottom in shallow water, and assumed a mottled coloration. Between 15 and 25 mm, the diet was quite different from that of the slightly larger juveniles. Harpacticoids and punky fly (Heleidae) larvae formed nearly 100 percent of the diet of the 15 mm fish. The relative abundance of this food fell off sharply as the fish approached 25 mm in length. Punky fly larvae were seldom found in fish as large as 30 mm. Free-living nematodes, at times, comprised up to 10 percent of the bulk of the food in a *Gillichthys* 15 to 25 mm long. They were eaten only incidently in fish larger than this. Rarely, fish as large as 80 mm had a few nematodes in their stomachs. These definitely were not parasitic.

In *Gillichthys* as small as 15 mm, *Neanthes* were occasionally found. They became increasingly important in the 23 to 25 mm fish and often comprised 100 percent of the food in fish as large or larger than 30 mm. In the 30 mm and larger fish, young pupfish were sometimes found.

Juvenile fish from 25 mm to young adults were captured only in very shallow water along the shore and in the lagoons. They are usually heavily barred and the first dorsal fin has a large, black blotch. A large part of their diet was made up of *Ephydra* (brine fly) larvae, and *Trichocorixa*, an aquatic Hemiptera. These insects were especially abundant along the shore and in the lagoons. *Neanthes,* however, was the most important food organism.

The only important food of the adult *Gillichthys* was the pile worm, *Neanthes*. Barnacles were sometimes eaten shell and all. Although a single mudsucker may have made a complete meal of barnacles, they seldom provided more than 5 to 10 percent of the over-all diet of the population.

Ephydra and *Trichocorixa* larvae were often eaten by mudsuckers living near the shore. Due to the small sizes of these insect larvae as compared to the adult *Gillichthys*, they comprised very little of the bulk of the ingested food organisms. They were not important to the adult mudsucker. Desert pupfish and young mudsuckers were the only fish eaten by the mature *Gillichthys*. Their low frequency of occurrence in the stomachs suggested they were not an important food source.

Trapping and netting was done at regular intervals over 24-hour periods. No pattern could be discerned in which *Gillichthys* fed significantly heavier than at any other time. Daylight feeding seemed to be slightly heavier than night feeding.

The *Gillichthys* in the Salton Sea were exceptionally free of parasites. In over 300 preserved fish, only one had an embedded nematode in the lower intestine. In 25 fresh fish, only two parasites were found. These were small monogenetic flukes found on the gills. San Francisco Bay mudsuckers are commonly infested with nematodes in the gut and with monogenetic flukes on the gills. A few Newport Bay mudsuckers were found with ectoparasitic leeches on their heads.

Growth of young *Gillichthys* was rapid. It was fastest during May to August, the hot summer months. By August, the modal size usually had reached about 60 to 80 mm standard length, when they may be considered young adults. Sex is clearly distinguishable by examining the genital papilla. The males grew slightly faster than the females.

Growth tapered off during the winter. In December, the yearlings ranged from about 80 to 115 mm, but growth was very slow after that. A few of the larger fish reached 120 mm by May and all fish spawned at the end of their first year.

The life span was at least two years, maximum size being about 135 to 140 mm standard length (about 5½ inches total length). A preliminary examination of the otoliths, opercles, vertebrae, and hypural plates, failed to reveal more than one annual mark. More sensitive procedures may reveal at least a second annulus. Since growth after the first year was very slow, one would not expect to find a well-separated second annulus.

In only a few places, were mudsuckers abundant in the Salton Sea. They have been taken along all the shores and a few have been trapped in water as deep as 35 feet, two miles offshore. All those taken in deeper water were males.

Cover and quiet water appear to be the most important factors determining their distribution in the Salton Sea. Wave action will drive them from cover. They have been found in areas of low salinity, such as in Salton Creek and around Mullet Island. Areas in which the salinity was almost twice that of ocean water also harbored a few. They have been found in lagoons in which the minimum temperature was 35 degrees C. In locations such as the boat channel at Fish Springs in which the oxygen tension drops to less than 2 ml per liter at night, they were able to survive by a combination of behavioral and physiological mechanisms. The fins became engorged with blood, evidently enabling them to undergo cutaneous respiration when in the low oxygen water. At night, many moved up onto the bank into water about six inches deep where the oxygen tension was higher than in the deeper water. This same behavior has been observed in the *Gillichthys* in the lagoons during the hot months.

In the habitats in which *Gillichthys* occurs, there appears to be little competitive overlap with the other fishes. They are not known to eat mosquitofish and bairdiella but desert pupfish are occasionally taken. In areas where *Cyprinodon, Gambusia,* and *Gillichthys* were found together, the abundance of the former appeared not to have been affected.

Recognition Characters

The longjaw mudsucker may reach 5½ inches in length in the Salton Sea. The extremely long upper jaw, reaching to the posterior part of the head in adults; the muddy brown color; the small embedded scales; and pelvic fins joined to form a disc, all separate them from any other species in the Sea.

Importance

They are probably not numerous enough in the Salton Sea to be seriously considered predators on, or competitors with, other fishes. They have value as bait fish, and perhaps the population is large enough to support a small bait fishery. Mudsuckers are one of the best baits for corvina. At certain seasons they were important in the diet of the corvina.

Fishing Methods

May be taken with baited traps.

THE THREADFIN SHAD, *Dorosoma petenense* (Gunther)

L. JOSEPH HENDRICKS

INTRODUCTION

Threadfin shad were first taken in the Salton Sea on September 13, 1955 at several stations widely scattered along the eastern shore. On September 14, one was recovered at the southwest corner of the Sea. Other specimens were taken in small numbers during the fall and winter of 1955 in netting and seining operations all around the Sea, but principally along the east side. They were taken less frequently in shore seining as winter progressed. This was also true of bairdiella, apparently because the fish moved into deeper waters during the colder part of the year. As spring progressed, increasing numbers of shad were taken along shore.

The threadfin shad was introduced to California from Tennessee by the California Department of Fish and Game in November 1953 (Kimsey, 1954). They were first held and bred in ponds near San Diego, but in November 1954 and in March 1955, 600 and 550 respectively were planted in the Colorado River at Lake Havasu (the lake behind Parker Dam) about 20 miles below Topock, Arizona (personal communication, Richard Beland, 1955). The fish reproduced successfully and spread throughout the river system. By late summer of 1955, small schools of them were in the canal system of the Imperial Valley, a minimum of 200 miles via the All-American Canal and the Colorado River from the planting site. In early October 1955, I collected 19 with a dip net from a school of at least 100 in a pool behind a headgate on the Vail Canal, about 4 miles north of Westmoreland, California, and about 10 miles from the south end of the Salton Sea.

The presence of this freshwater fish in the Salton Sea is not too surprising since it is taken fairly commonly in trawling operations along the Louisiana coast (Gunter, 1938).

The shad seemed to do well in the Salton Sea as all fish captured appeared in good health and in good condition. No abnormalities were observed, such as occurred in bairdiella following its introduction and subsequent explosive increase. Perhaps the two cases aren't strictly comparable since the shad have not been nearly as abundant as the bairdiella. Further, it is not likely that the shad is as free from predation as was bairdiella, since the shad occurring in the Sea were spawned in fresh water where they would have been subjected to predation from various freshwater fishes and other predators in that environment.

The mean size of the shad captured in the Salton Sea increased during the seven months they were under observation (Table 26). The largest of several taken in an experimental gill net on January 6, 1960, had a total length of 22.3 cm (8.78 in.) and a standard length of 17.3 cm.

No spawning was observed, nor is any expected, in the Salton Sea. Since they are freshwater spawners it is unlikely that their delicatelyadjusted demersal eggs and fry could tolerate salinities as great as those in the Salton Sea. Their recruitment would appear to depend on fish spawned in freshwater.

In April 1956, a large concentration of shad was in the mouth of the Coachella spillway, a freshwater inlet, attempting to move upstream. Due to the strong current they were unsuccessful. It was thought that this may have been an attempt on the part of the fish to return to freshwater in response to a spawning urge. However, the gonads of several varied from poorly- to well-developed and a few were interpreted as being spent. These latter fish, if truly spent, probably had spawned in the canal system or in the quiet water at the lower end of the Coachella spillway.

The diet of the threadfin shad consists largely of planktonic species. Haskell (1959), reporting on their diet in an Arizona lake, noted that diatoms and unicellular green algae were the principal constituents during the winter months. In spring and summer, the algal species were still important but the planktonic animals, principally rotifers and crustaceans, formed the bulk of their diet.

No detailed food studies were made during this investigation. Cursory examinations revealed a variety of algae (diatoms and dinoflagellates were chiefly recognizable), and portions of copepods, rotifers, and barnacle nauplii in the digestive tract.

Shad occurred commonly in the corvina stomachs. Considering the relative numbers of shad to bairdiella, based on seine and gill-net sampling, it would appear that shad were a favored food item. On several occasions, shad were eaten to the exclusion of bairdiella, by grebes and corvinas, in areas where gill nets captured many bairdiella but no shad.

No estimate was made of their abundance or numbers. They were distributed over the entire Sea but the greatest numbers occurred along the eastern shore. They were most abundant in the vicinities of freshwater inlets.

This species promises to be a valuable forage fish if recruitment remains at a satisfactory level.

TABLE 26

Lengths of 336 Threadfin Shad Captured in the Salton Sea From September 13, 1955 to April 17, 1956

Date	Number of Fish	Mean Length in mm	Range of Length in mm
13 Sept. 1955	38	34.7	25.5- 45.1
18 Oct. 1955	77	59.5	32.8- 91.4
17 Apr. 1956	221	106.0	55.2-125.5

THE STRIPED MULLET, *Mugil cephalus* Linnaeus

L. JOSEPH HENDRICKS

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 dipnetting 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, 1953; Faouzi, 1936 and 1938; Kesteven, 1942 and 1953; and Thomson, 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.

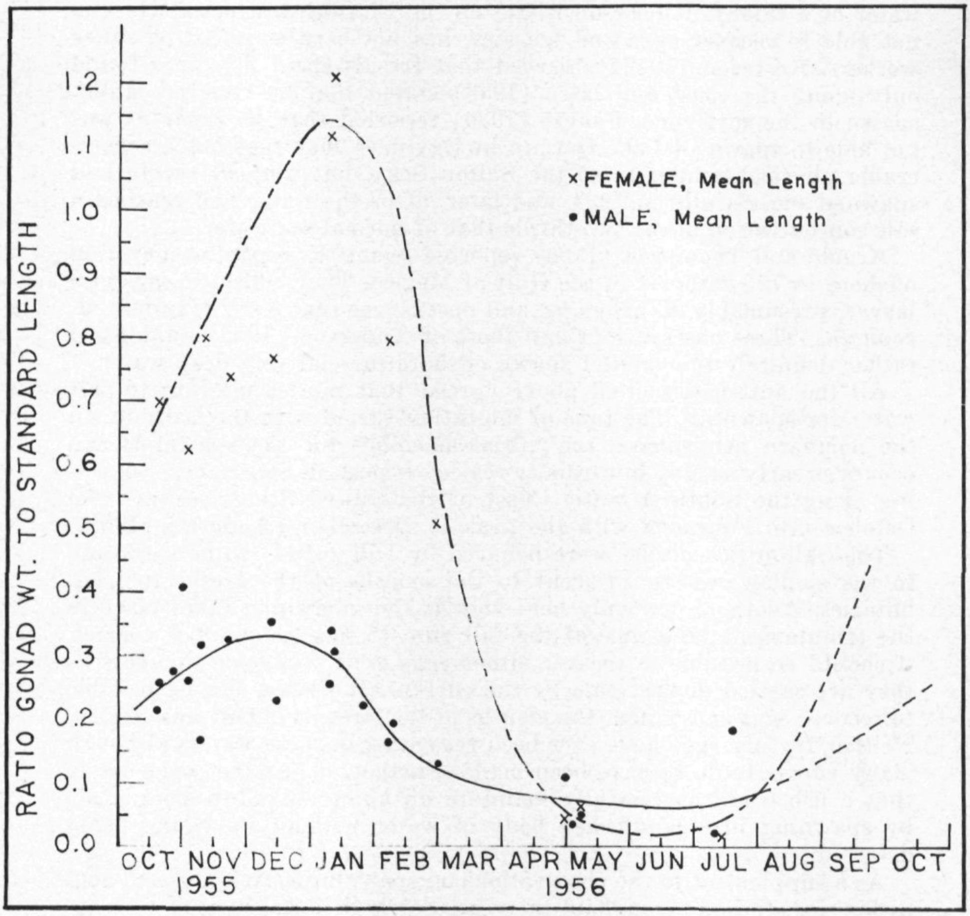


Figure 35. The ratio of gonad weight in grams to standard length in millimeters for 405 male and 23 female mullet from the Salton Sea, taken October 19, 1955 to July 18, 1956.

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 conclusions 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.

FIGURE 36. The principal canal connections between the Colorado River and southern Salton Sea drainages, 1956.

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 divisions formed by the annuli were proportional to the length of the fish at the corresponding time.

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 indicates several possibilities: that the 1941 year-class was large; that 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.

THE BAIRDIELLA, *Bairdiella icistius* (Jordan and Gilbert)

RICHARD R. WHITNEY

INTRODUCTION

The bairdiella is a small, silvery sciaenid, native to the Gulf of California. It rarely exceeds 11 inches and is of only minor importance as a food fish in its native waters (Berdegue, 1956).

Douglas (1953) described the successful introduction of bairdiella into the Salton Sea. Only 67 fish made up the entire plant of this species: 57 in 1950 and 10 in 1951. The first known successful spawning in the Salton Sea occurred in 1952 (Douglas, 1953). Sampling indicated that a sizeable year-class had been produced, and that many abnormal individuals were present in the population.

Subsequent sampling by personnel of the Salton Sea Research Project of the University of California indicated that bairdiella spawned every year up to and including 1957, when the project terminated. No doubt the species is sufficiently well established that it will continue to spawn until conditions in the Salton Sea are no longer favorable.

Clearly, bairdiella was well-adapted to the conditions in the Salton Sea. Other species which were introduced in larger numbers failed to maintain themselves. While only small numbers of bairdiella were planted, they found themselves in a large body of water with an abundant food supply and virtually no competitors or predators. The polychaete worm was well-established and abundant, but was fed upon only in the shallow water near shore by the mosquitofish, pupfish, and goby which were largely restricted to that habitat. The open water was occupied only by schools of striped mullet which fed on detritus and plant material. The croaker was further favored by a high reproductive potential, and within two years the offspring of the original 67 fish undoubtedly numbered in the millions.

REPRODUCTION

Spawning and Development

The spawning of the bairdiella and the development of its eggs are very similar to what has been described for *Bairdiella chrysura* of the Atlantic by Kuntz (1914) and Welsh and Breder (1923).

The eggs and fry of bairdiella were taken throughout the Salton Sea during the spawning season. There was no indication of any localization of spawning grounds. The eggs are small, 0.7 to 0.75 mm in diameter, and are pelagic. They tend to float just under the surface in quiet water, but rough water or disturbances may stir them to considerable depths.

Both *B. icistius* and *B. chrysura* spawn in the evening and apparently over a short period of time. Eggs taken in plankton tows were in uniform stages of development. In our samples, most eggs in the early blastula stage were encountered between 6 and 10 PM (Pacific

Standard Time). The fish normally showed increased activity at this time of the day, regardless of the season. Kuntz felt that *B. chrysura* probably spawns in the evening before 8 PM.

Kuntz mentioned that efforts to artificially fertilize eggs from ripe females of *B. chrysura* did not meet with success. Our efforts with *B. icistius* were also unsuccessful, though several attempts were made when ripe males and females were taken together in gill nets. The time of day probably is a factor in the ripening of the sexual products. Since spawning evidently occurs in the evening, it is possible that fertilization can only be accomplished at that time. All of our attempts at artificial fertilization were made earlier in the day.

Eggs were easily collected from the Salton Sea with Number 0 plankton nets (38 meshes per inch). Large numbers could be collected in a short period during most of the spawning season. This plankton net provided an almost pure sample of eggs and fry, since the mesh was large enough to allow phytoplankton and much of the zooplankton to pass through. Some copepods, *Neanthes* larvae, and barnacle nauplii and cyprids were taken, but not in proportion to their abundance.

The eggs hatched in 24 hours at the water temperatures present during the peak of the spawning season. At 6:30 PM (Pacific Standard Time) on May 9, 1956, numerous eggs in early stages of development were brought into the laboratory and placed in aquariums where mild aeration kept them circulating to the full depths (10 inches) of the aquariums. The eggs hatched during the evening of May 10, apparently about 24 hours after being spawned.

Hatching occurs over a rather short period. A large number of eggs collected at 9 AM on May 9, 1956, and placed in aquariums, hatched during the evening of that day. Newly-hatched fry first appeared at 6 PM; the greatest percentage (73 percent) hatched from 8 to 10 PM with the peak between 8 and 9 (Figure 37). By 10 PM, 95 percent of the eggs had hatched, and by 11, 98 percent. Obviously, these eggs had been spawned at very nearly the same time, and had developed at the same rate. The water temperature in the aquariums was between 72 and 74 degrees F. during the period of development. The peak of spawning activity in the Salton Sea took place when the average water temperature was 73 degrees. Kuntz (1914) stated that the egg of *B. chrysura* requires about 18 hours to hatch at a temperature of 82 degrees.

Eggs of *Bairdiella icistius* taken in plankton tows during the day appeared clear and spherical and each had a yellowish-white embryo stretching across it. A clear, transparent perivitelline-space was always present in normally developing eggs. At mid-day the embryo reached a little more than half way around the egg, with the tail-bud near the oil globule. By 3 PM, a pointed, movable tail was present and the embryo reached two-thirds of the way around the egg. The embryo is dotted with chromatophores which are dense just back of the head and sparse toward the tail. The oil globule is also dotted with chromatophores.

Newly-hatched larvae float upside down, just beneath the surface film in quiet water, The chromatophores are inconspicuous except on the oil globule, and they appear to migrate to the dorsal and ventral portions of the body at this time. By 2 PM of the first day after hatch-

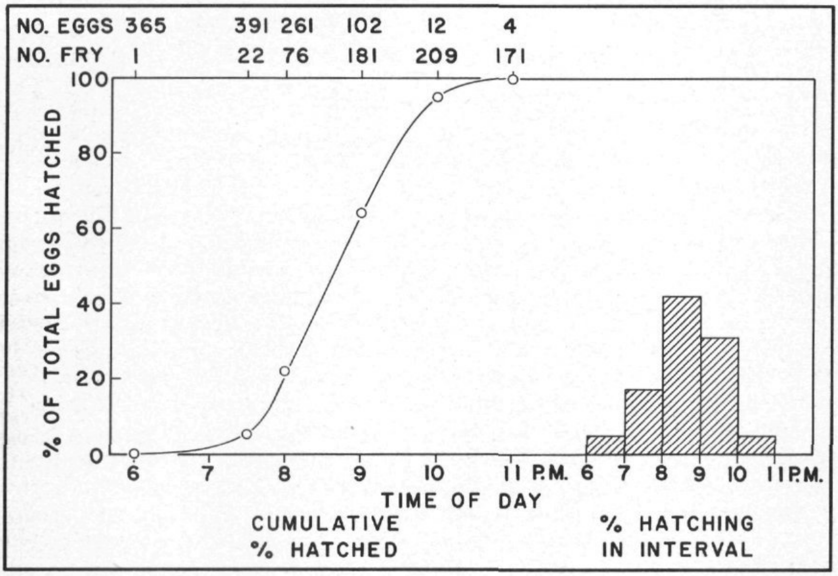


FIGURE 37. Time (Pacific Standard) of day that bairdiella eggs hatched in the Salton Sea.

ing, the chromatophores were clustered in regions along the dorsal and ventral lines of the body and gave an impression of banding. The mouth began to form around noon of the first day after hatching, and by 2 PM, there was a large opening with a well-formed lower jaw.

The larvae died during the second day after hatching. At the time of death, the chromatophores had become more conspicuous and enlarged. They were arranged in a continuous dark line along the dorsal and ventral portions of the body, and there was a cluster just back of the head. The body cavity was also sprinkled with melanophores and there was a cluster along its dorsal wall.

Larval fish up to 5 mm long were taken in plankton tows. Schools of somewhat larger fish were observed near shore. These were sampled with dip nets and individuals measuring 7 to 25 mm standard length were taken.

Number of Eggs

The number of eggs in the ovaries was estimated for three ripe female bairdiella taken in May 1953. The volume of each was determined by the amount of water it displaced, then the volume of a small portion was measured, and the eggs in this portion counted. This count was multiplied by the ratio of the total volume of the ovary to the sample volume. Counting only the enlarged ripe eggs, the estimated number was 38,000 for a 125 mm fish, 35,000 for a 123 mm fish, and 72,000 for one 127 mm long. These estimates are in the order of their reliability. Three subsamples, each about one-tenth the volume of the ovary, were counted and averaged in the first estimate, two in the second, and only one in the third. If these are weighted accordingly, and averaged, the estimate is about 43,000 eggs per female *bairdiella*. It is to be expected that egg production will vary rather widely, and vary also with size of females.

Spawning Season and Distribution of Eggs and Fry

The duration of the spawning season and the distribution of eggs and fry were ascertained by sampling with "standard" five-minute plankton tows. Number 0 plankton nets were used. The net was towed at a speed which put the top of it just under the surface of the water without splashing. A four-ounce jar at the end of the net collected the eggs and fry and a small quantity of formalin was added as a preservative. The number of eggs and fry was then determined in the laboratory, by direct count in most cases. Samples containing unusually large numbers were estimated with counting-blocks. Each counting-block was 50 by 100 mm, and was marked off into 50 squares. The total was estimated by pouring a reasonable number into a block, and counting a random sample of 5 or 10 squares (depending on the apparent total number of blocks which would be required to contain the sample). This procedure was repeated until the entire sample had been treated, and an estimate for the total sample could be made by summing the series.

To check the variability in the number of eggs and fry which might be expected at the same location, buoys were dropped at the beginning and end of various five-minute tows, and duplicate tows were made over the same course. The numbers of eggs and fry taken in these duplicate tows were in the same order of magnitude (Table 28). Tows made at different locations however, varied considerably.

TABLE 28

Numbers of Bairdiella Eggs and Fry in Duplicate Plankton Tows at 13 Locations in the Salton Sea

Eggs	Fry	Eggs	Fry
15 July 1955		**5 June 1956**	
1504	0	230	0
2001	0	241	65
1015	0	86	7
819	1	51	20
5	0	532	2
1	0	878	3
1	1	350	1368
2	0	166	2802
1	0		
0	0		
1 August 1955		**7 June 1957**	
0	1	1028	5
0	1	1386	13
		1596	53
26	0		
1	1		
1	0		
1	0		

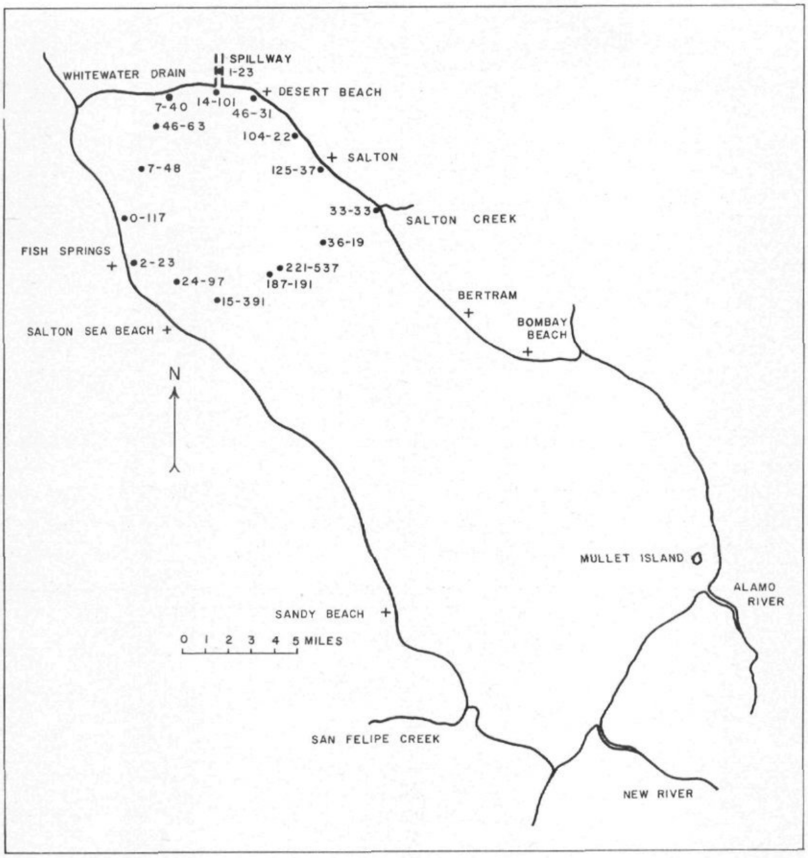


Figure 38. Locations of plankton tows and numbers of eggs and fry taken on April 28, 1955, Salton Sea. The eggs are indicated by the first number, and the fry by the second.

The numbers of eggs and fry taken at different localities varied from day to day. For example, on April 28, 1955 all of the tows made on the west side of the Sea contained more fry than eggs, while those on the east side contained more eggs than fry (Figure 38). The differences might have been caused by wind transporting the eggs to the east side. A series of tows made at some of the west shore stations on April 27, 1955, the evening before the above series was taken, contained more eggs than fry (Table 29). The vast majority of the eggs taken in this evening series were in late stages of development. Very few were in early stages, though spawning should have been taking place during the sampling. Possibly, cooler water temperatures inhibited spawning that particular evening. A longer period of development would be expected at the temperatures normally present during this early part of the spawning season, and would allow more time for transport. The sampling stations were visited in a clockwise direction beginning at Fish Springs (Figure 38), so the differences were not due to changes

TABLE 29

Number of Bairdiella Eggs and Fry Taken per Five-minute Tow With a 12-inch Plankton Net * on April 27, 1955, Salton Sea

Pacific Standard Time	Number of Eggs	Number of Newly Hatched Fry	Number of Advanced Fry	Location
6:30 PM	432	2	26	First Canal N. of Fish Springs
7:00 PM	295	0	28	First Canal
7:30 PM	198	52	48	1 mi off First Canal
8:00 PM	165	9	34	North of First Canal
8:30 PM	608	13	6	1 mi offshore
9:00 PM	244	27	6	2-3 mi offshore
9:30 PM	150	1	338	3 mi off Fish Springs

* Number 0 mesh.

in wind or water conditions which might have taken place during the sampling.

Peak spawning activity was in mid-May (Figure 39). The fry were available to plankton nets much longer than the eggs so the curve for fry reflects a cumulative effect of adding hatching fry.

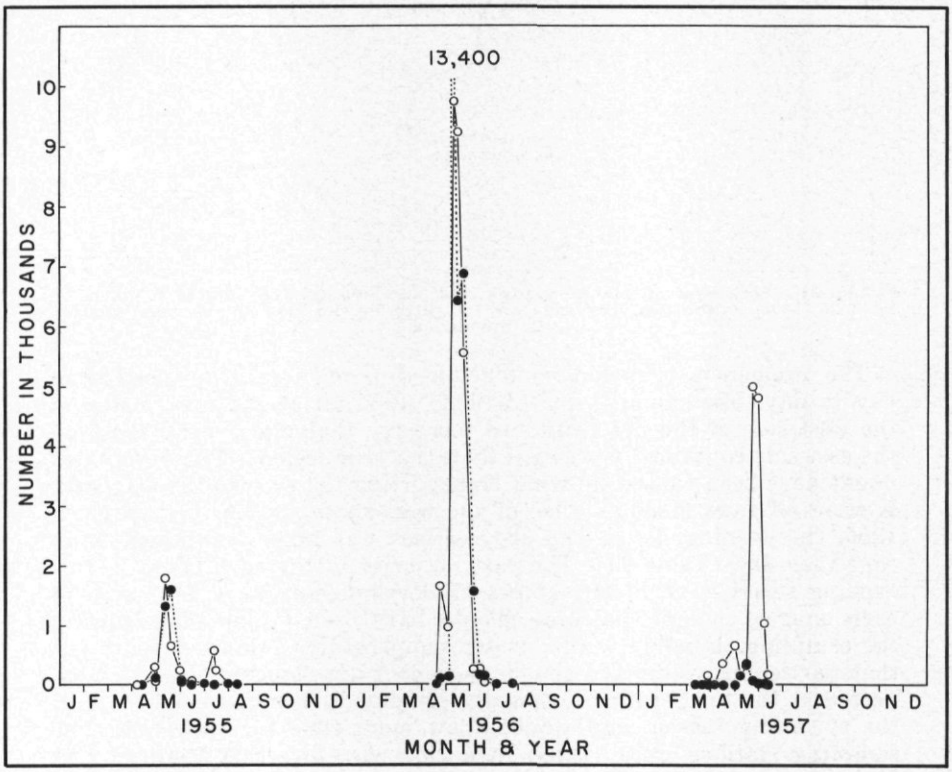


FIGURE 39. Number of eggs and fry of bairdiella in the plankton in 1955, 1956, and 1957, Salton Sea. Data based on 106 tows made in 1955, 54 tows in 1956, and 56 in 1957. ○ = Eggs; ● = Fry.

The increase in egg production in July 1955, occurred in local areas and was not followed by any increase in the number of fry. Eggs were found in the plankton from April 13 to August 1, 1955; the greatest number being taken on May 12, 1955. Very few fry appear to have been produced after about June 19. Surface water temperatures varied from 65 degrees F. on April 15 to 96 degrees F. on August 1, 1955 and during the peak period, May 11 to 20, 1955, averaged 73 degrees F. Prior to June 19, 1955 the maximum surface water temperature was 90 degrees F., while night surface water temperatures remained cool, reaching 75 degrees F. or lower.

Welsh and Breder (1923) found the peak of spawning for *B. chrysura* was May in North Carolina waters, and June in New Jersey waters. Kuntz (1914) found the peak was in June in North Carolina waters, perhaps because of unusual water temperatures that year.

It is apparent that there were many more eggs and fry in the plankton in 1956 than in 1955. Tows made during May 1956 caught consistently high numbers. The average catch-per-tow in 1956 during peak activity was over 9,000 eggs and 12,000 fry; whereas, in 1955 during the same period, the average catch was under 2,000 eggs and 2,000 fry. In order to smooth somewhat the variation between tows, the 1956 counts were grouped by weekly intervals and averaged.

Spawning appears to have occurred slightly later and on a somewhat more limited scale in 1957 than in 1956, but probably exceeded that of 1955. Of particular interest, was the surprising failure in fry production in 1957. The largest number taken in a tow was 1,184 on May 17, 1957, while in both previous years there had been over 40,000 in a tow.

Each year an apparent false spawning start was made in April. Part of this false peak might have been due to eggs remaining unhatched for more than 24 hours during the early part of the season. Water temperatures reached about 70 degrees F. by the first of May in 1955 and 1956 so that the eggs would be in the plankton for only 24 hours after that time.

Relative Abundance of Year-Classes

Beach seines 50 feet long with ⅝-inch stretched mesh were used to sample the fish populations at monthly intervals from May 1953 to the end of 1956. This same type of seine was used by Douglas in 1952. A general idea of the relative abundance of the year-classes was obtained from the catch with this seine. Identification of the year-classes was generally simple because of differences in their rates of growth. The 1952 and 1953 year-classes could be separated by the Petersen size-frequency method until 1955. The same method provided separation of subsequent year-classes from the 1953 year-class until late in their first summer when they approached the size of the 1953 year-class. By this time, the numbers of fish in these later year-classes were so reduced they were inconsequential. Scale samples were read to verify these conclusions.

The 1952 year-class was produced by the first known successful spawning of bairdiella in the Salton Sea. These fish matured at the end of their first year, and produced a huge 1953 year-class. As an example of their unusual abundance, two hauls made in July 1953 with a 50-foot seine brought in 5,162 fish. The 1953 year-class quickly assumed

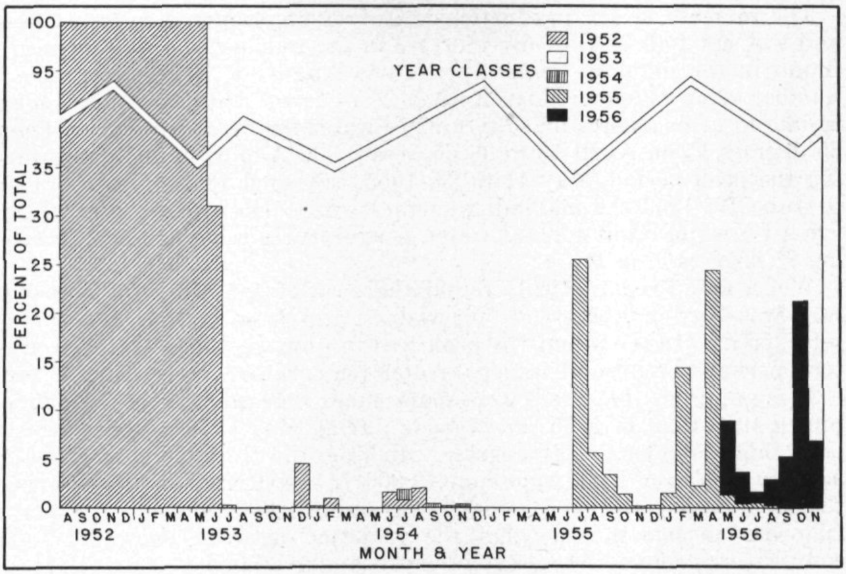


FIGURE 40. Relative abundance of bairdiella year-classes in the Salton Sea as indicated by their percentage in the seine catch.

dominance and maintained it throughout the period of study (Figure 40). The importance of the year-classes after 1953 probably has been overemphasized in Figure 40, because young-of-the-year bairdiella were attracted to shallow water where they were more susceptable to capture in seines than older fish. Furthermore, the older fish moved inshore and offshore seasonally, so that their susceptability to capture in beach seines would vary with the season. In spite of these differences in habits, fish of the 1953 year-class always made up at least 75 percent of the catch by numbers after June 1953.

The 1953 year-class first appeared June 1953. Beginning in July 1953, the 1953 year-class took the role of a typical dominant group. The 1954 year-class did very poorly and it seems obvious that it was suppressed by the 1953 year-class. It is doubtful that any of its members survived more than a few months.

Probably the typical pattern of a new year-class competing with the dominant 1953 group was shown by the 1955 hatch. Initial high catches in July 1955 were followed by sharp declines through the rest of the year. The increase in the percentage of fish from the 1955 year-class, in February 1956, was primarily due to a decrease in the catch of 1953 fish, which had moved to deeper water.

A slight increase in the catch of 1955 fish took place in April 1956, indicating that perhaps some offshore movement had occurred previously and that the fish were then moving back into the sampling range of the seines. The total catch of 1953 fish increased only slightly at the same time, so the 1955 year-class showed a false increase in relative abundance (Figure 41). The total catch of the 1953 year-class then increased while the 1955's decreased during the rest of 1956. The per-

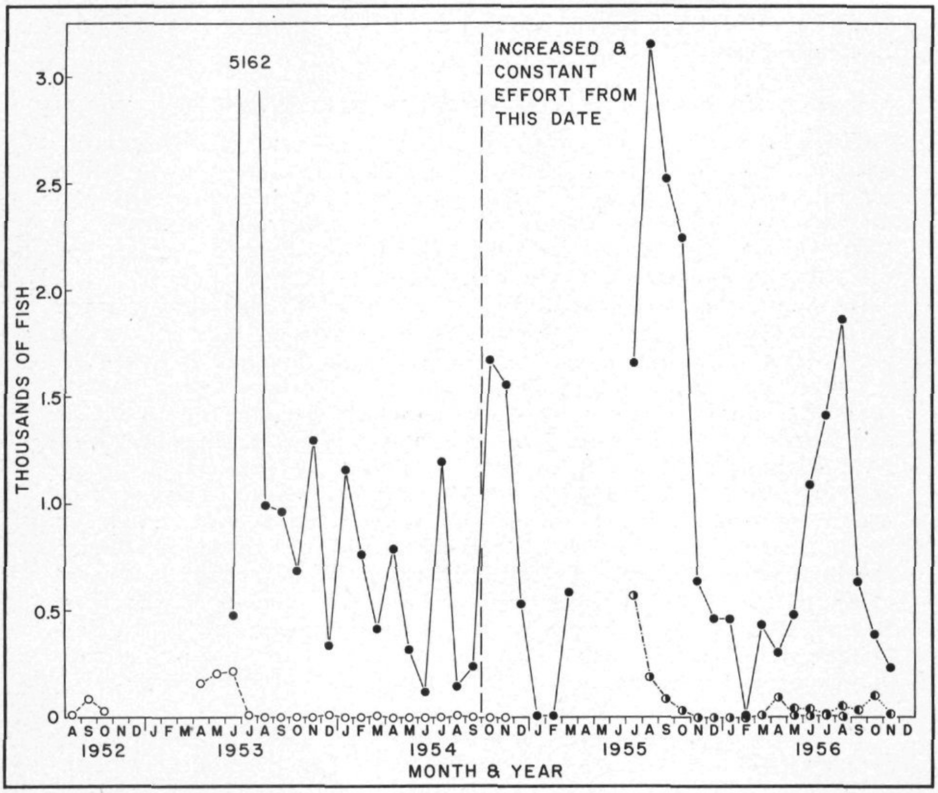


FIGURE 41. Total catch of each year-class of bairdiella taken in beach seines, 1952-1956, in the Salton Sea. The 1954 year-class was not taken in large enough numbers to show in the figure. ○ = 1952 year-class; ● = 1953 year-class; ◑ = 1955 year-class; ◐ = 1956 year-class.

centages shown in Figure 40 are probably correct in implying virtual elimination of the 1955 year-class.

The catch of fish of the 1956 year-class was almost constant from May to September 1956. As a result, when the 1953 fish moved into deeper water in the fall, a false increase in the 1956 year-class is indicated in Figure 40. Probably the August value of 2.7 percent could be considered a maximum estimate for the contribution of this year-class to the population of the Salton Sea.

Each year-class produced after 1954 was slightly more successful than its predecessor. However, none can be said to have contributed important numbers to the population.

The complete dominance of the 1953 year-class is most strikingly illustrated in Figure 41, showing the total catch made by seines. Their excessive abundance evidently drove the fish of the 1952 year-class into water deeper than was sampled by the seines, for very few of them were taken with this gear after June 1953. They apparently never returned to the shore areas. However, when gill nets were used in deeper water, large numbers of the older fish were taken. In April 1954, for example, one set of 200 feet of one-inch-mesh net caught 1,769 fish of the 1952 year-class in 24 hours.

SEASONAL MOVEMENTS INSHORE AND OFFSHORE

The total seine catch from October 1954 to the end of 1956 was indicative of the inshore availability of bairdiella. During that period, a constant number of hauls was made each month at 16 locations around the Salton Sea. The catch after May 1953 consisted almost entirely of 1953 year-class fish, except for a brief period in July and August 1955 when the 1955 year-class first appeared (Figure 41).

Considering only the 1953 year-class after October 1954 a clear pattern of availability was shown by the catches. A maximum catch occurred in August each year and a minimum in January or February. Apparently, they moved to deeper water in the late winter, and to shallower water in late summer. Inshore movement began in March and April, as shown by the increased catches in the beach seines. Perhaps this movement was heightened in late summer by lack of oxygen and the resulting failure of the food supply in certain areas of deep water. In areas near shore the pile worm spawned the year round, but in water over 25 to 30 feet deep it was eliminated from the bottom during the summer due to lack of sufficient oxygen. However, the movement of the bairdiella toward shore was probably not entirely due to these factors, since it began before any oxygen shortages occurred. In September, the croakers began to move away from shore, and by January or February they could not be reached in appreciable numbers by beach seines.

There was great variability in the catch from month to month before October 1954 making interpretation difficult. This variability was undoubtedly caused by the limited sampling during this period. It would seem, however, that no general movement of the 1953 year-class to deeper water took place in the winter of 1953-54. The trend of the catches was downward in 1953 and 1954, probably partly a result of high natural mortality associated with the high population level. It is also probable, however, that a movement toward deep water tended to reduce the catch in late 1954. This movement must have started earlier in 1954 than in 1955, since larger catches were made in October 1955 with the same amount of effort.

Gill nets were also used to sample the 1953 year-class beginning in April 1954. Usually, the gill nets were set in water which would not be reached by the seines. The catch-per-effort of bairdiella in gill nets should therefore provide a check on the information of inshore and offshore movements indicated by the seine catches. It was not practical to make standard sets of gill nets. During the course of the study, nets of various mesh sizes, lengths, depths, and materials (linen and nylon) were used. Furthermore, catches were highly variable even when using the same net at different times.

One factor contributing to the variability stems from the tendency of bairdiella to move more (or at least to be netted more readily) at night (Table 30). This was probably related to their feeding behavior, since *Neanthes* spawned at night and was free-swimming and hence more available at that time. Because of this variability, gill-net catches made

TABLE 30

Comparison of Catch-per-Unit-Effort of Day and Night Gill-Net Sets for Bairdiella in the Salton Sea

Time	Catch (Numbers of Fish) per 100-Foot Gill-Net-Hour Numbers in Parentheses Indicate Number of Net Sets				
	September	October	November	January	Unweighted Average
Daylight	0.1 (6)	0.0 (5)	0.1 (4)	0.1 (1)	0.1
Overnight	0.3 (1)	0.8 (8)	1.8 (10)	0.6 (3)	0.9

during daylight hours were omitted. In comparing the gill-net catch-per-effort with the seine catch, only fish of the 1953 year-class were considered. No attempt was made to separate the catches according to mesh size, except that catches from experimental gill nets were not included since they were excessively high compared to the other nets, and since they were not set as consistently. The catch-per-effort data in Figure 42 were therefore derived from nets of 1.0- to 2.5-inch bar mesh of various twine sizes and materials set overnight. Time in the water averaged about 24 hours, but variations contributed to the error along with that incurred from using different nets. The lowest average catch was in late summer; August and September in 1954 and 1956, and September in 1955 (Figure 42). This corresponded with the time when the seine catches were near their maximum. Increased catches in the gill nets in October of each year followed the expected pattern, and

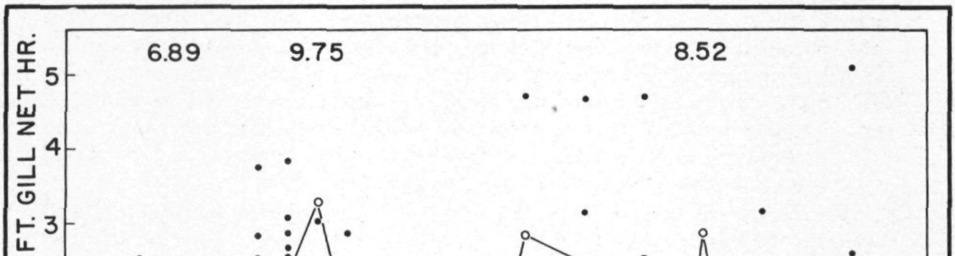


FIGURE 42. Gill net catch of bairdiella per unit-of-effort in the Salton Sea. ● = Catch per 100-foot gill-net-hour in a 24-hour set; ○ = Average catch-per-effort for the month.

implied movement into deeper water. The high October catches might also have been influenced by the increased activity of the croaker feeding on spawning *Neanthes*. The low gill-net catches in the winters of 1954 and 1956 might have been due to reduced activity of the fish in response to cooler water temperatures, though the catch in the winter of 1955 was rather high.

SURVIVAL ESTIMATES FOR THE 1953 YEAR-CLASS

A decline would be expected in the catch-per-effort for the 1953 year-class from year to year, and this is indicated in Figure 41. A rough estimate of survival can be derived from the data. A discussion of the method used can be found in Ricker (1958). Differences in the degree to which the population moved toward shore each year would distort the estimate. It appears that they did not remain near shore as long in 1956 as in 1955, as indicated by the rapid decline in catch in September and October 1956, compared to the same period in 1955. Perhaps some of this distortion can be reduced by considering only the catches for August of each year: 3,122 in 1955, and 1,860 in 1956. This produces a survival estimate of 60 percent from 1955 to 1956. If the catch from July through November of each year is used to estimate survival (the catch for 1955 was 10,270 and for 1956, 4,519) the survival was 44 percent. Thus, the estimates indicate survival was between 44 and 60 percent, though both might still be subject to error due to differences in the degree of inshore movement in the two years.

RATE OF GROWTH

Materials and Methods

All netted fish were placed in 10 percent formalin, allowed to fix, washed in water and then placed in 50 percent isopropyl alcohol in which they were stored until measured and weighed. Preservation affects lengths and weights of fish; Carlander (1953) lists nine studies in which slight shrinkage was noted. Since the fish in this case were all treated alike and interest was not in absolute size but in changes, no correction was felt necessary. In addition to the sampling with seines and gill nets which has already been described, a few small young-of-the-year were collected with dip nets.

The fish were measured with dividers to the nearest millimeter, and weighed to the nearest 0.1 gram. Standard length was used. In samples containing more than 100 fish, only the first 100 were weighed, and the remainder were only measured. Some excessively large samples containing over 500 fish were subsampled. Since the fish had never been arranged according to size, it was thought they were randomly distributed in the jars in which they were preserved, so that they could be subsampled simply by taking them as they came. Some of the fish collected in 1952, 1953, and early 1954 were not weighed at the time they were measured. A sample of about 50 from each of these was measured and weighed subsequently. Carlander (1956) pointed out the necessity for using large samples to determine the average lengths of fish with accuracy. In the present study, 31,098 seine-caught fish of the 1953 year-class were measured: 4,750 in 1953; 7,832 in 1954; 11,296 in 1955; and 7,220 in 1956. An additional 12,398 fish taken in gill nets

TABLE 31

Sample Sizes and Average Lengths and Weights of Bairdiella From the Salton Sea

Date	SEINED				GILL-NETTED			
	Number Measured	Average Length in mm	Average Weight in gr	Number Weighed	Number Measured	Average Length in mm	Average Weight in gr	Number Weighed
1952 YEAR-CLASS								
1952								
Aug.	11	70	6.9	11				
Sept.	81	80	13.2	81				
Oct.	28	90						
1953								
Apr.	117	110	27.7	88				
May	204	109	28.4	20				
June	215	111	37.0	39				
July	11	145	64.8	11				
Oct.	1	135	—	0				
Dec.	16	136	32.4	16				
1954								
Feb.	7	143	42.3	7				
Apr.					549	162	65.5	53
June	2	153	—	0	294	166	63.9	9
July	10	149	46.2	10	118	162	67.4	85
Aug.	3	158	53.1	3	88	160	57.9	53
Sept.					12	166	57.8	11
Oct.	2	141	32.5	2	44	157	58.1	44
Nov.	2	148	38.7	2	28	160	65.3	28
Dec.					4	165	66.6	4
1955								
Jan.					1	156	65.5	1
Feb.					55	156	61.2	55
Mar.					238	157	71.8	185
Apr.					8	156	85.5	6
May					3	160	72.0	3
June					1	141	60.8	1
July					32	158	72.0	29
Aug.					4	171	85.6	4
Sept.					13	165	71.1	13
Nov.					5	151	63.1	5
1956								
Jan.					22	160	76.5	22
Mar.					1	150	72.1	1
Apr.					1	144	54.0	1
May					51	166	—	0
June					11	159	—	0
1953 YEAR-CLASS								
1953								
June	478	20	0.1	54				
July	1,444	46	3.0	51				
Aug.	655	59	4.1	51				
Sept.	452	70	5.9	51				
Oct.	685	71	5.8	51				
Nov.	680	72	6.0	50				
Dec.	356	76	6.7	75				
1954								
Jan.	664	76	6.6	143				
Feb.	348	75	7.2	51				
Mar.	419	75	7.4	51				
Apr.	626	77	8.4	51	14	83	10.6	11
May	318	86	11.1	51				
June	121	87	11.1	51	12	90	11.9	12
July	1,199	86	11.3	835	78	99	16.1	78
Aug.	145	88	10.8	145	192	89	9.9	106
Sept.	237	88	10.3	237	28	88	10.4	28
Oct.	1,674	89	12.6	1,051	506	90	13.9	488
Nov.	1,560	90	13.3	1,040	965	92	14.4	965
Dec.	521	91	13.9	295	121	92	15.2	121

TABLE 31—Continued

Sample Sizes and Average Lengths and Weights of Bairdiella From the Salton Sea

Date	SEINED				GILL-NETTED			
	Number Measured	Average Length in mm	Average Weight in gr	Number Weighed	Number Measured	Average Length in mm	Average Weight in gr	Number Weighed
1955								
Jan.	10	91	12.8	10	33	92	14.1	33
Feb.	8	89	11.0	8	431	96	17.1	431
Mar.	587	93	16.9	201	1,188	98	20.3	734
Apr.					256	103	25.2	178
May					271	104	24.3	178
June	58	105	21.0	58	115	108	28.9	115
July	1,785	102	19.5	1,232	407	106	22.1	302
Aug.	3,122	104	20.9	1,452	622	102	20.1	397
Sept.	2,482	103	20.8	1,470	33	105	22.9	33
Oct.	2,246	105	20.9	1,169	224	103	19.8	189
Nov.	635	105	21.6	519	579	109	23.4	240
Dec.	363	104	20.7	296	160	106	23.7	160
1956								
Jan.	461	105	21.0	401	901	114	30.0	653
Feb.					203	110	26.1	170
Mar.	431	104	20.1	207	675	112	29.0	309
Apr.	301	109	25.1	264	129	119	34.2	129
May	419	112	26.4	417	822	120	34.3	518
June	1,089	113	24.8	710	122	119	31.0	122
July	1,412	115	25.8	819	1,413	118	34.0	1,151
Aug.	1,860	113	24.0	914	54	115	26.8	54
Sept.	631	114	24.0	442	32	119	30.6	32
Oct.	384	114	23.8	342	867	121	34.5	503
Nov.	232	116	24.6	196	769	120	33.3	560
Dec.					176	124	35.6	176
1954 YEAR-CLASS								
1954								
July	78	14	0.2	78				
Sept.	7	46	1.9	7				
Oct.	26	49	3.2	26				
Nov.	31	57	4.2	31				
1955								
July	5	81	14.3	5				
Aug.	1	92	13.8	1				
Sept.	2	95	—	0				
Oct.	1	90	—	0				
1955 YEAR-CLASS								
1955								
May	18	8	—	0				
June	214	11	—	0				
July	571	35	1.3	566				
Aug.	187	48	3.4	163				
Sept.	140	72	8.9	110				
Oct.	33	84	12.7	33				
Nov.	1	76	—	0				
Dec.	2	78	13.4	1				
1956								
April	59	92	—	0				
June	1	89	15.2	1				
July	2	89	15.4	2				
1956 YEAR-CLASS								
1956								
May	40	10	0.1	40				
June	36	25	0.5	36				
July	16	29	0.6	1				
Aug.	52	63	5.7	52				
Sept.	35	58	10.5	35				
Oct.	104	71	7.4	104				
Nov.	17	85	13.3	17				

provided a comparison of the two methods. Also measured were 710 seine-caught fish of the 1952 year-class and 1,598 from the same year-class taken in gill nets. Various numbers of fish of the other year-classes were measured and weighed. These will be discussed in detail below. The samples of 1953 year-class fish were in sufficient numbers that their growth could be followed on a monthly basis. The same was attempted for the other year-classes, though the samples were smaller and as a consequence less reliable. Sample sizes and the average lengths and weights of the fish are shown in Table 31.

When the length-frequencies of fish of particular year-classes taken in the same sample are graphed, the frequencies can not be satisfactorily described using the normal distribution (Figure 43). They differ from the normal distribution in that there appears to be more than one maximum point, and they are flattened and skewed. There is also some indication in Figure 43 that the nature of the distribution changed with time. As the fish grew, their range of sizes narrowed from about 40 mm in July to about 30 in November 1953.

It is not difficult to imagine how this type of distribution could develop. The bairdiella spawns over a period of about three months and variable success of hatches within that period would be expected. In addition, there is a strong schooling tendency, particularly among the young-of-the-year. Differences in length resulting from variable spawning success would tend to be maintained by this schooling behavior.

An illustration of how this might come about can be taken from some samples collected in 1955. On June 7, 1955, four different schools of young-of-the-year bairdiella were observed in the vicinity of the Fish Springs boat channel. Each school was sampled with a dip net and the fish kept separate. Samples of 32, 44, 54 and 84 fish were collected and there was considerable difference between the average lengths of the fish in the schools: 11.5, 8.0, 14.0, 11.0 mm (Figure 44). Assuming the normal distribution is appropriate to describe their lengths, analysis of variance can test the significance of the difference between the lengths of fish in the schools (Table 32). A subsample of 50 fish was randomly selected from the sample of 84 for the analysis. Highly significant differences between the lengths of fish in the schools are indicated. The schools when sampled were clearly separated but were along a shoreline of about 200 yards. It is natural to assume that as these small fish increased in size and mobility, mixing would occur. The result

TABLE 32

Analysis of Variance to Test Differences in Average Lengths of Bairdiella From Four Schools, Salton Sea

Source	Degrees of Freedom	Sums of Squares	Mean Square
Between Schools	3	924	308
Within Schools	176	348	2
Total	179	1,272	

F=154, df 3 and 176, highly significant.

would be as in the combined samples in Figure 44, a distribution with three or more modes, closely resembling the one observed in the older fish.

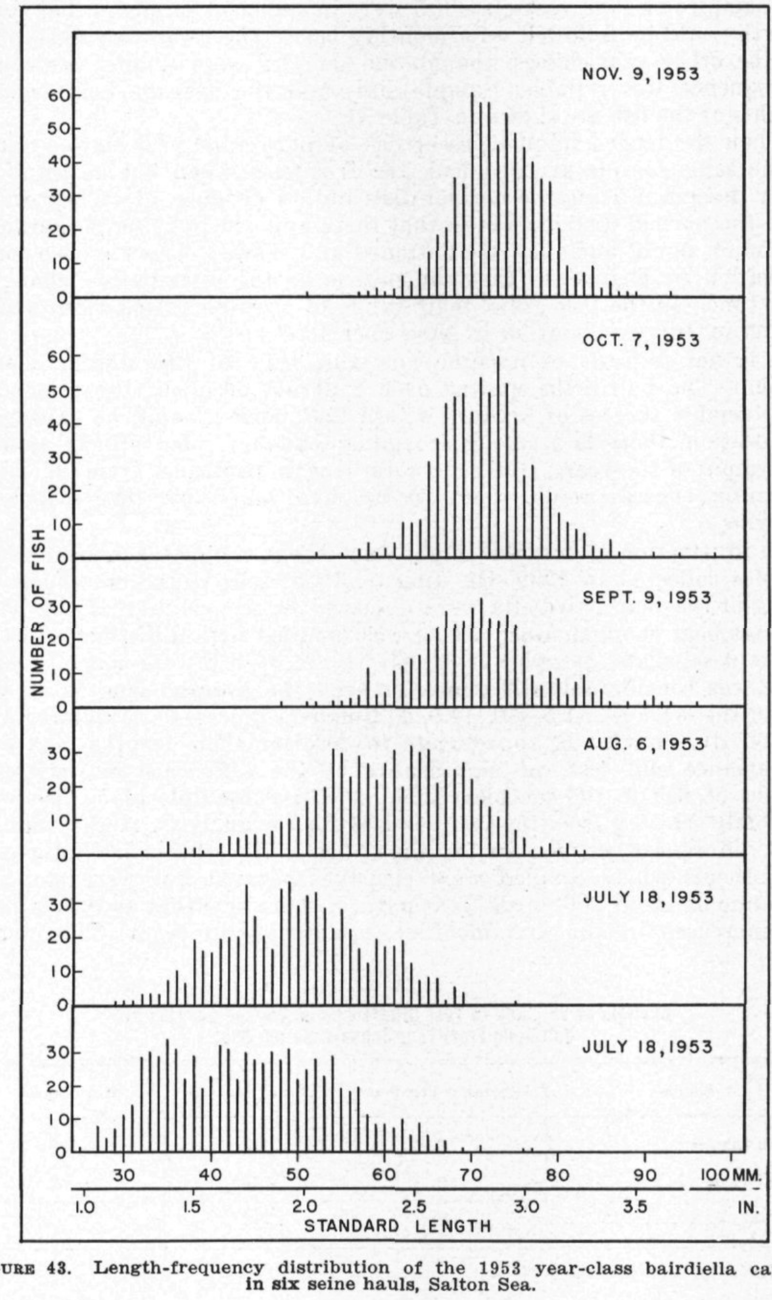


FIGURE 43. Length-frequency distribution of the 1953 year-class bairdiella caught in six seine hauls, Salton Sea.

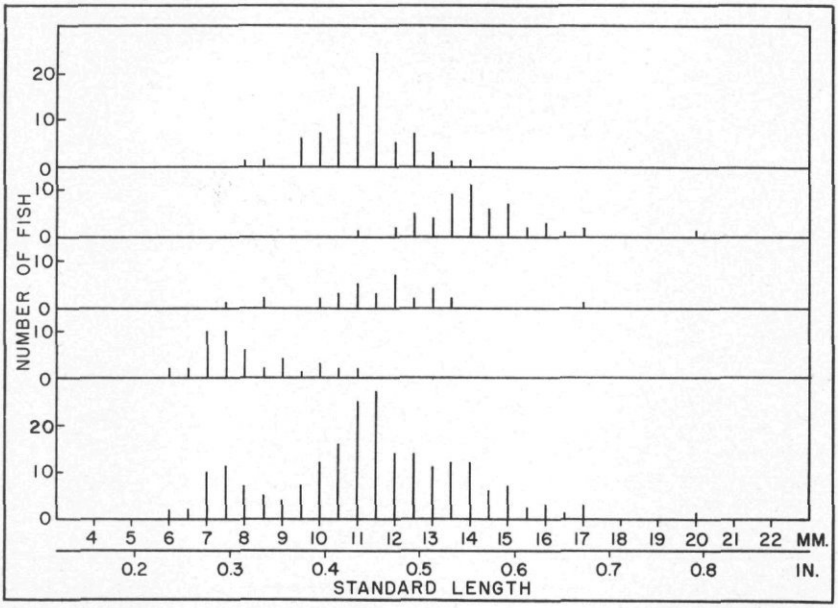


FIGURE 44. Lengths of young-of-the-year bairdiella from four different schools sampled on June 7, 1955, Salton Sea. Schools combined at bottom.

In spite of this complication, it is sufficient for the present to assume that, since interest is in their growth in the Sea as a whole, some complex frequency distribution could be devised to describe the length of the general population of bairdiella in the Salton Sea. No matter what the nature of this frequency distribution, it can be shown that the distribution of the mean approaches a normal distribution as the sample size increases. Since rather large samples have been used, the mean of the samples should be indicative of some population characteristic.

Growth in the Gulf of California

Bairdiella growth has not been studied in their native habitat, the Gulf of California. We had only one sample of 43 specimens from San Felipe, Mexico. These ranged from 117 to 183 mm in standard length (Table 33). They were taken in March and April 1956, when an annulus

TABLE 33

Standard Lengths of Bairdiella Taken at San Felipe, Mexico, March and April 1956

Age*	No. of Specimens	Standard Length in mm	
		Range	Average
I	17	117-137	131
II	18	146-166	154
III	7	165-183	172
IV	1	173	173

* Determined by number of annuli.

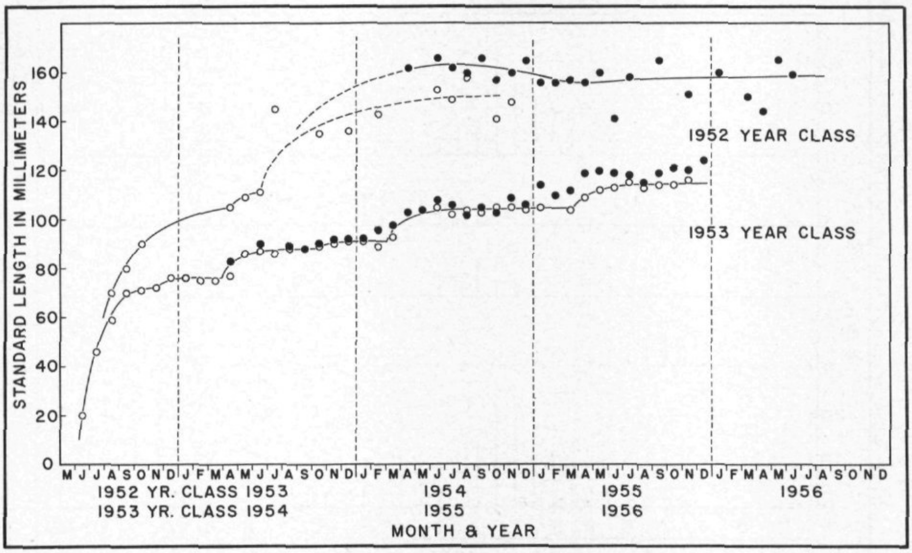


FIGURE 45. Growth of the 1952 and 1953 year-classes of bairdiella in the Salton Sea. The graph was drawn, for ease of comparison, as though the year-classes started growth at the same time (points joined by eye). ○ = Average length in seine samples; ● = Average length in gill-net samples.

was just beginning to form at the edges of their scales. The average lengths of the groups, therefore, probably represented only a slight overestimate of the length achieved at the particular annulus. Accordingly, fish from the Gulf of California reach an average length of 131 mm at the time of the first annulus, 154 mm at the second, and 172 at the third.

Growth of the 1952 Year-Class in the Salton Sea

The 1952 year-class grew rapidly in 1952 and 1953, apparently in response to their low population level and an abundant food supply. After April 1954 however, fish of this year-class showed no increase in length (Figure 45). In fact, 238 fish taken in March 1955 were slightly smaller than fish of the same year-class taken in 1954. This might be partly explained by the fact that the 1952 year-class could no longer be clearly separated from the 1953 year-class at this time. By March 1955, a few of the 1953 fish were 130 to 140 mm long so there was some overlap in the length frequencies of the two year-classes (Figure 46). For the 1955 data, a separation point of 140 mm was arbitrarily used. Even using this point, no growth was indicated for the 1952 year-class between 1954 and 1955. The length-frequencies of the larger fish did not shift, while the smaller fish obviously increased in length.

In general, year-classes could still be distinguished by examining the scales. Even in cases where subsequent annuli were not formed, the 1952 year-class could be recognized by the great distance from the focus of the scale to the first annulus. In dealing with the 1956 samples, it was necessary to examine scales in order to identify members of the 1952 year-class.

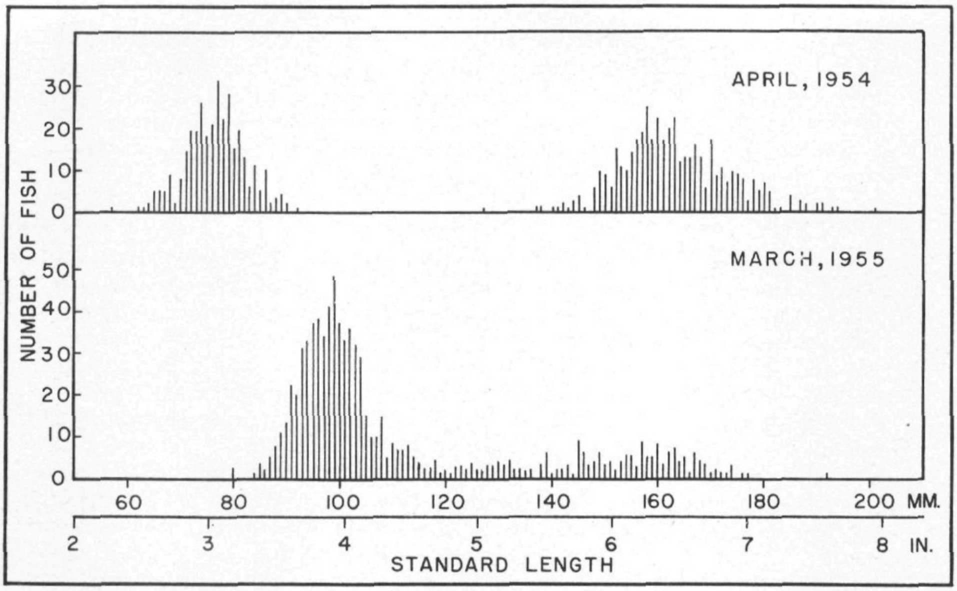


FIGURE 46. Length frequencies of bairdiella from the Salton Sea in a 1954 sample and a 1955 sample, showing separation of the 1952 and 1953 year-classes in 1954, and overlap in 1955.

Only very few 1952 fish were taken in 1956. Of 149 bairdiella collected on May 24, 1956, ranging from 130 to 186 mm in standard length, only 51 were identifiable from the large center area on the scales as 1952 year-class fish. These ranged from 142 to 186 mm and averaged 166. The remaining 98, ranging from 130 to 164 mm, were identified as 1953 year-class fish by the small area between the center of the scale and the first annulus.

Very few larger fish were taken again until October 1956. Scales were removed from all fish over 144 mm long in one sample. Of the 26 fish in this category, only three seemed to be 1952's judging by the scales, but only two annuli were apparent. One fish measured 163 mm and the other two 167. The remaining 23 fish had three, evenly-spaced annuli on their scales, and were probably 1953's since the first annulus was much closer to the center of the scale. In another sample taken in October 1956, every fish about 140 mm or longer was scale sampled. This included 65 fish, of which only eight were identifiable as 1952's. They ranged from 146 to 165 mm standard length and averaged 157. The 57 other fish, probably members of the 1953 year-class, ranged from 138 to 168 mm.

The fact that only small numbers of the 1952 year-class were taken in 1955 and 1956 would seem to indicate that their population was being sharply reduced, probably as a result of competition with the 1953 year-class. No great reliance can be placed on the estimated growth from these small samples, but they all showed cessation of growth in 1955 and 1956.

It has already been mentioned that the fish of the 1952 year-class moved out to deeper water in 1953. Few of them were taken in seines after June 1953, while many were taken in gill nets in deeper water in 1954. Since there is a gap in the samples between June 1953 and April 1954, their growth during that period can not be adequately described. It appears, however, that the fish which moved to deeper water grew longer than did the few stragglers that stayed near shore.

Growth of the 1953 Year-Class in the Salton Sea

It is evident that the 1953 year-class grew more slowly than the 1952's (Figure 45). During the first few months of life growth was quite rapid and probably compared favorably with that inferred for the 1952 year-class. A plateau was reached by the 1953 fish in September, however, when they averaged 70 mm. This was far below the 80 mm reached by the 1952 year-class in a comparable period. Furthermore, the samples indicate that the fish had continued to grow during this period of their lives, and had reached 90 mm in October. Members of the 1953 year-class stopped growing in September of their first year. From that time on, growth was confined almost exclusively to the spring months of April, May, and June. As already mentioned, this corresponded with the time of maximum spawning of *Neanthes,* which was virtually their sole food in the Salton Sea. No growth occurred during the summer of any year after 1953. A slight upward trend in their average lengths took place during the fall of each year. This was also apparently related to the increased availability of *Neanthes* in October and November. Catch-effort data from gill nets implied increased bairdiella activity at those times. No growth took place during the winter.

Also shown in Figure 45 is a series of points representing the average lengths of bairdiella taken with gill nets. The pattern of growth is the same as for the seine samples, though the gill nets consistently took slightly larger fish. It would seem that the fish sampled with gill nets began their spring growth before those sampled with seines near shore.

Weight Increase of the 1953 Year-Class

The preceding discussion emphasized length because of the less variable nature of the measurements, and the greater ease with which they were obtained. However, fish weights might at times be a more sensitive indicator of population condition because losses can occur.

Weight increases took place primarily in the spring months when the fish were also increasing in length (Figure 47). Assuming the gill nets and seines sampled different groups, the gain in weight for either group from 1954 to 1955 was about 10 grams, representing a 50 percent increment to the original weight, and from 1955 to 1956 the gain was five grams or 20 percent of the 1955 weight.

A comparison of the weights of fish taken with gill nets and those taken with seines showed a recurring pattern which cannot be explained by the selectivity of the gill nets, since they would be expected to catch heavier fish at all times. There is a definite indication that the fish caught in deeper water with gill nets were heavier in the spring than fish taken near shore with seines. While the fish near shore maintained their rather low weights throughout the summer months or lost

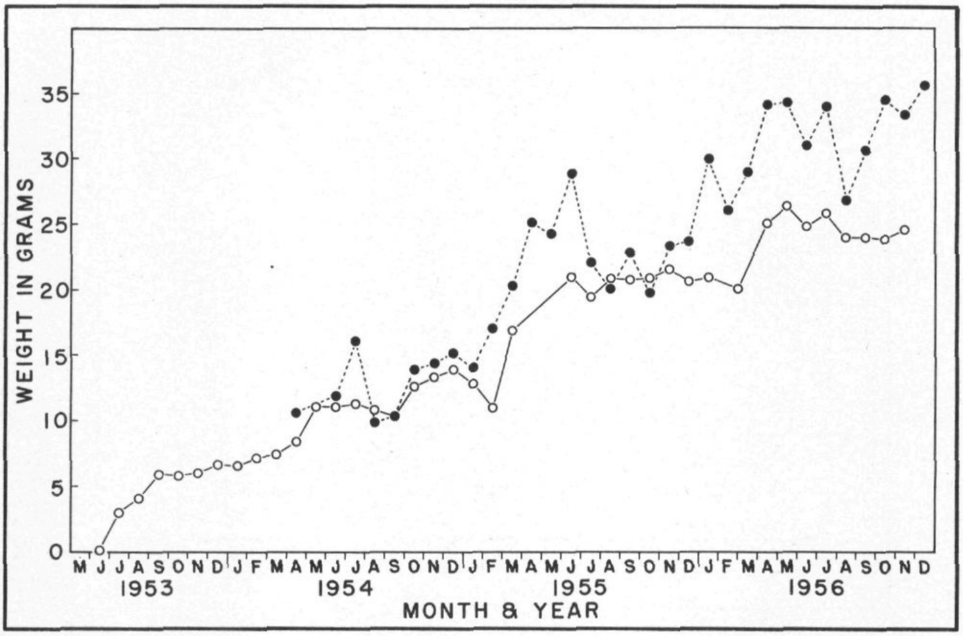


FIGURE 47. Increase in weight of the 1953 year-class bairdiella from the Salton Sea. ○ = Seine sample; ● = Gill-net sample.

only slightly, fish in deeper water showed striking weight losses in August and September, undoubtedly as a result of the failure of the food supply. It has been mentioned previously that the bairdiella moved away from shore more rapidly in the fall of 1956 than in 1955. In this connection, fish taken with gill nets in September and October 1956 had increased considerably in weight, being about 10 grams heavier than fish taken near shore with seines at the same time. In 1955, the fish were slower to gain weight and slower to move away from shore. This suggests that the movements inshore and offshore might have been influenced by the available food supply.

Losses of weight in May 1955 and June 1956 might have been a result of spawning. No such losses occurred in May or June of 1954. It is believed that the majority of the members of the 1953 year-class did not spawn in 1954

Growth of the 1954 Year-Class

Bairdiella spawning in the Salton Sea in 1954 must have been on a limited scale, since the members of both the 1952 and 1953 year-classes were in poor condition throughout the spring months.

Only small samples of 1954 fish were taken. They were not produced in large numbers, and survival appears to have been poor from the beginning. As the season progressed, they became more scarce, probably because as they increased in size they began to depend more on the *Neanthes* for food, which meant severe competition with the dominant 1953 year-class. For the most part, fish were obtained only with special effort, using common-sense seines and throw nets. Few were

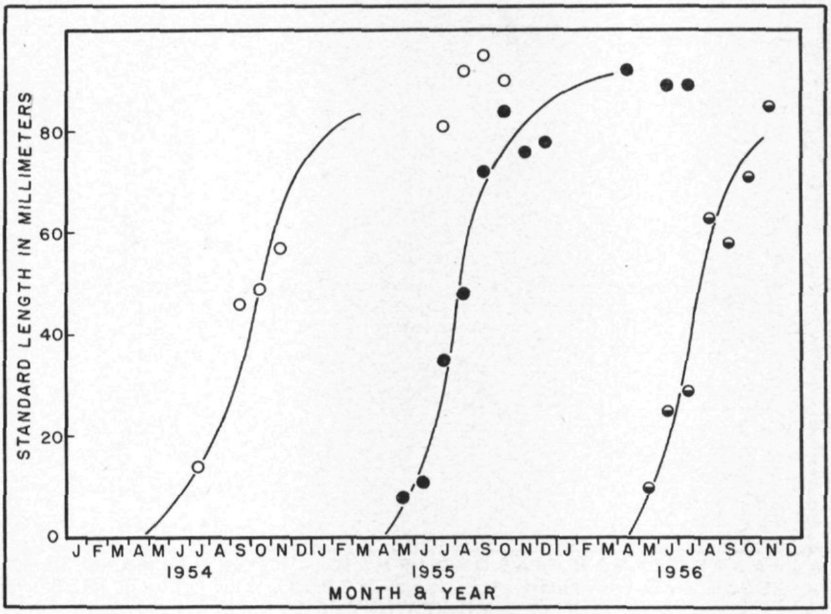


FIGURE 48. Average lengths of the 1954, 1955 and 1956 year-classes of bairdiella from the Salton Sea. Curves drawn by eye. ○ = 1954 year-class; ● = 1955 year-class; ◓ = 1956 year-class.

taken in the standard sampling with beach seines. From these, it appears that growth of the 1954 year-class was quite poor (Figure 48). Fish caught in November 1954 averaged only 57 mm, which was 13 mm less than the length reached by 1953 year-class fish at a comparable period in their lives. Representatives of this year-class in 1955 were identifiable only by reading their scales. Since they may have been included as members of the 1953 year-class in 1955 and 1956, they could have introduced some error in the length estimations of that group. This error would be extremely slight considering the very small numbers which might have been included. In November 1954, for instance, they totaled less than 0.3 percent of the catch in 50-foot seines, and this would probably be an overestimate of their true abundance. It is not realistic to project an estimate of their growth beyond November 1954.

Growth of the 1955 Year-Class

There was large-scale spawning in 1955, due to the maturation of 1953 fish. Large numbers of eggs and fry were produced and the young fish grew rapidly in June, July, and August 1955 (Figure 48). By October 1955, they had reached an average length of about 80 mm. As mentioned previously, their numbers were reduced as they increased in size. They declined from 21 percent of the seine catch in July 1955 to 0.2 percent in December. A few survived the winter and made up a small part of the 1956 catch.

Though their beginning was much more promising, their numbers were reduced as the season progressed until they contributed little more to the population than did the 1954 year-class.

Growth of the 1956 Year-Class

Spawning in 1956 was comparable with that in 1955. Members of the 1956 year-class showed an almost straight-line increase in length from May 1956 to November 1956 (Figure 48). The average length of 71 mm in October 1956 was less than had been achieved by fish of the 1955 year-class at a comparable period, and is about the same as was reached by members of the 1953 year-class. However, growth of the 1956 year-class apparently continued into November. In all the other year-classes except the 1952's, growth had stopped by October. There was also an indication that survival of the 1956 year-class was better than it had been for the 1954's or 1955's.

Discussion on Growth

Growth of the 1952 year-class in the Salton Sea was evidently comparable to that of bairdiella from the Gulf of California during their first two years. However, the fish from the Sea showed no growth after that, while the Gulf bairdiella added 20 mm in their third year. Certainly the 1952 year-class could not have been seriously crowded in the Salton Sea during their first year, since competition was not sufficient to eliminate abnormal individuals, and they reached spawning condition in one year. An oversupply of eggs was undoubtedly produced at that time, as shown by the extreme abundance and poor growth of the resulting fish. They were so abundant they forced the older fish out to deeper water.

The ensuing competition resulted in a cessation of growth among the 1952 fish, and a reduction in their numbers which affected the abnormal fish first. Competition between members of the 1953 year-class resulted in a slow rate of growth for them, and led to the virtual elimination of the 1954, 1955, and 1956 year-classes. Growth of the 1953's, after 1953, took place only in the spring months. This apparently related to increased availability of food at that time, though other factors might have been operating. Brown (1946) found that the growth rate of brown trout was greatest in the spring even when the food supply and temperature were constant.

Growth of the year-classes is compared in Table 34. The poorest first-year growth was shown by the 1954 year-class, which was also the least successful group in terms of survivors. The next poorest growth, however, was shown by the 1953's, which were the most successful survivors. They took three seasons to reach a length which the 1952's had attained in their first season. For the 1953 year-class, the greatest length increment after their first year was 15 mm, while the 1952's grew 40 mm or more in their second year. Considering the evident competition within the 1953 year-class, as demonstrated by their poor growth and condition, it is not surprising that none of the following year-classes was able to survive. The competition was apparently more acute as the fish approached the sizes of the 1953's. For example, in 1954 the fish of the 1953 year-class did not increase in length after May, and they lost weight in August and September, at which time large numbers of dead

TABLE 34

Comparison of the Growth of Year-Classes of Bairdiella in the Salton Sea *

Year-class	Standard Length in January (in mm)				
	in First Year	in Second Year	in Third Year	in Fourth Year	in Fifth Year
1952	>100	140 to 162	157	160?	160?
1953	76	91	105	116	---
1954	ca. 70	---	---	---	---
1955	ca. 84	---	---	---	---
1956	ca. 85	---	---	---	---

* See Table 31 for data.

washed up on shore. This kill occurred when fish of the 1954 year-class were reaching a size where they were beginning to shift their diets from copepods, etc., to *Neanthes*, which were already being heavily utilized by the 1953 year-class.

The failure of 1952 fish to increase in length after 1954 might have been related to their larger size and possible need for a greater volume of food to maintain themselves, since the smaller 1953 year-class fish were able to increase at least slightly each year. Most 1952 year-class fish formed an annulus on their scales in 1955, implying that some growth had taken place. Yet, no increase in their average length was demonstrated (Figures 45 and 46). Perhaps the larger fish of the year-class were eliminated and the smaller members grew slightly. This would explain the slight downward shift in the average length of the year-class between 1954 and 1955.

The difference in growth of the year-classes was associated with a difference in age at maturation. The fast-growing 1952's were mature after one year, while none of the females of the slow-growing 1953 year-class matured until after two years. Few members of either year-class appear to have matured in 1954, when fish of both groups were in poor condition. Alm (1953) found that perch, *Perca fluviatilis* Linnaeus, with exceedingly good growth matured at one year, while stunted populations did not mature at three years. Davidson and Vaughan (1941) suggested that more-abundant populations of pink salmon are slower growing and late in their spawning migrations. Laskar (1940) and Svardson (1943) as reported in Alm (1953) also found that slow-growing fish matured at a later age than fast-growing fish. This might not be a general rule, because the studies of Foerster (1947) and Alm (1952) indicate that slow-growing populations might mature earlier than fast-growing populations in certain situations.

BAIRDIELLA MORTALITIES IN THE SALTON SEA

Mortalities occured in the late summer or early fall of each year from 1953 to 1956. Dead fish were first observed in October and November 1953 by Wayne J. Baldwin and John E. Fitch (unpublished field notes). In November, they made counts of the dead fish washed up on shore. A total of 300 was tallied along an estimated 280 feet of beach. Apparently this kill continued until March 1954, since a few fish were observed on the shore at that time. While it was not so severe as those in later years, the 1953 kill seems to have extended over a longer period of time.

The kill which took place in 1954 was the most severe; it began in August when large numbers of bairdiella washed up on shore. To get an idea of the duration and magnitude of the kill, sections of shoreline were cleared of fish in September 1954, and the fish appearing each day were counted. A 50-foot section of shoreline was chosen, since this seemed to promise a reasonable number of fish in daily counts. Four counting stations were selected. It was not possible to locate them at random from the total shoreline of the Sea, because the majority was not accessible. The four stations, two on the east and two on the west shore, were near roads but away from much-used beaches, so they were relatively undisturbed. The stakes marking one station were lost after one month, and it had to be relocated.

It was not always possible to make daily counts, but usually the interval between them was no more than three or four days. This made it possible to distinguish to some extent between newly dead fish and those washed in from other areas, since fish that had been on the beach for any length of time usually had dried out in the desert heat. Fish which appeared to have dried for periods longer than the interval between counts were not included.

Considerable variation showed up in the daily counts, though there was a general agreement between the areas with time (Table 35). The counts for August are merely the dead fish found when the sections were first cleared. Differences between the east and west shore stations may have been due to real differences in the kill or to the effects of wind. Strongest winds in the area are from the northwest which would tend to deposit more fish on the east shore.

Daily counts in September varied from 0 to 108 dead fish on a 50-foot section of beach; the average for the month was 8.8 fish per day per 50 feet. In October 1954, the counts varied from 1 to 98, and averaged 22.6 fish per day per 50 feet (Table 35).

Total mortality in 1954, estimated from these counts, might be of some interest. The expansion of the counts is not strictly legitimate, because of the nonrandom location of the counting sites. Nevertheless, some idea of the magnitude of the kill may be gained. Certainly not all fish which died were necessarily washed up on shore. However, as pointed out

TABLE 35

Number of Dead Bairdiella Counted on the Shore of Salton Sea, 1954

Location	Station No.	Number of Dead					
		Aug	Sept	Oct	Nov	Dec	Total
West Shore	1	34	240	314	38	2	628
	2	36	260	923	59	25	1,303
East Shore	3	670	273	lost	--	--	--
	4	615	283	868	108	8	1,882
	5	1,219	--	236	110	6	1,571
Average	--	515	264	585	79	10	1,346

previously, shoreward migration of the fish reached a maximum in August, so many were already near shore when the kills began. Receding water at that season might also have aided the deposition of fish on shore. The counting stations were on open stretches of beach, where currents would not deposit unusual numbers of fish. These sections were reasonably typical of the shoreline around the entire Sea. Scattered observations on other parts of the shore revealed dead fish in the same general degree of numerical abundance. The total shoreline was about 90 miles long, or about 9,400 sections 50 feet long. Thus, the total kill in 1954 could be estimated as 9,400 x 1,300, or about 12,000,000 fish. This would amount to 55 fish per surface acre of the Salton Sea, or, using the average weight of 12.5 grams, 1.5 pounds per acre.

After the kill of 1954, the beach was closely watched for dead fish. At times these checks showed no dead fish and counts were made at less-frequent intervals. During the spring and early summer of 1955, only one or two counts were made each month.

Figure 49 shows the average count per station per day for each month from August 1954 to September 1956. Dead fish were only rarely washed up during the spring and summer months. In the fall

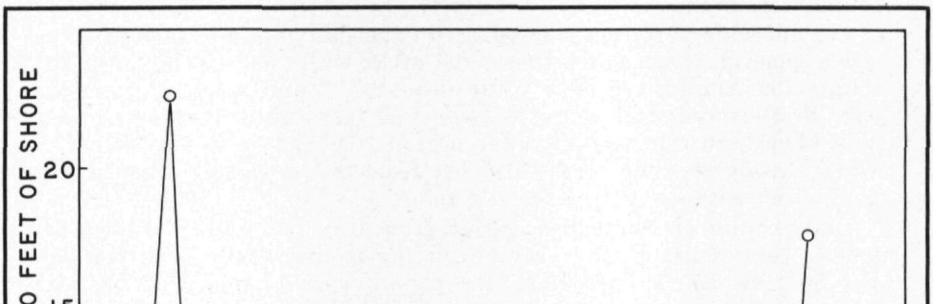


FIGURE 49. Monthly average counts of dead bairdiella washed ashore on the Salton Sea per 50 feet of shoreline per day.

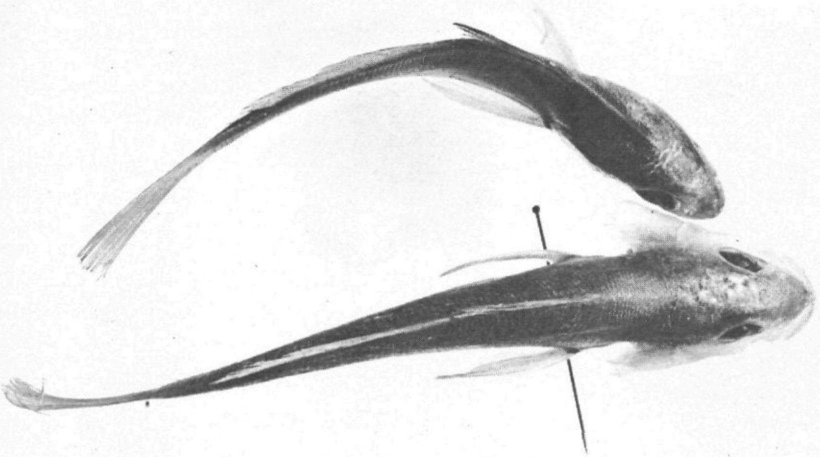


FIGURE 50. Comparison of a thin bairdiella (upper) with a normal bairdiella from the Salton Sea, 1955. Photo by R. H. Linsley.

of 1955, a very minor kill was observed. At that time the 50-foot sections of shoreline were deemed insufficient to provide a count of the dead fish, so a larger section 1,700 feet long was cleared and checked regularly. The counts were then put on a 50-foot basis for comparison with the other data. The kill was of short duration; very few dead fish were observed in October, and none in other counts up to July 1956. In August and September 1956, a severe kill again occurred. Unfortunately, no counts were made in October, but observations indicated the peak of the kill was in September and that fewer dead fish were on the beach during October 1956. Dead fish were uncommon on a two-mile section of shoreline examined in November.

There can be no doubt that the bairdiella were using the available food supply in the Salton Sea to the fullest possible extent. This was indicated by the slow growth of the 1953 year-class, by the long periods of no growth, and by their close reliance on spawning *Neanthes* for growth. The food supply obviously is not constant. The elimination of *Neanthes* from deeper waters in late summer represents a real crisis for bairdiella, especially since it occurs when water temperatures are highest.

In the late summer and fall when the members of the 1953 year-class were showing no growth and were losing weight, noticeably thin fish began to appear in the samples. Extremely thin fish were observed at times (Figure 50). A fish was deemed thin if its dorsal muscles were reduced, leaving a sharp-edged crest in back of the head. Of course, this was present in varying degrees so judgment was subjective to a certain extent.

The samples with the highest percentage of thin fish occurred in the winter of 1953-54. For a period of three months, December, January, and February, over 50 percent of the individuals were thin (Figure 51). In a sample of 1,162 fish taken January 9, 1954, 94 percent were thin.

Each year after 1953 the percentage of thin fish was high in the late summer and early fall, corresponding to times of food shortage, and then decreased in the late fall after the spawning of *Neanthes*. Few thin fish were observed in the spring months. The occurrence of thin fish corresponded roughly with the periods of fish kills (Figures 49 and 51).

Since to record fish as being thin depends on subjective judgment, it might be better, in determining the condition of the population, to use data based on K or condition factor of the fish, where $K = \frac{W}{L^3} \times 10^5$; W being the weight in grams and L the length in millimeters. K factors for fish of the 1952 and 1953 year-classes computed from their average lengths and weights (Table 31) are shown in Figure 52. This provides an index to the average condition of the population at monthly intervals over the period investigated.

LeCren (1951) pointed out that on a mathematical basis, the K factor is not independent of the absolute length of the fish. The value of K would be expected to decrease with increased fish length. On the other hand, in some cases changes in body form of the fish more than counteract this tendency. For example, Sigler (1949) found that the K factor of white bass increased with increasing lengths of fish. Hansen (1951) found the same was true for white crappie.

In the present case, the problem was simplified by the fact that within each year-class the range of lengths was rather narrow. The observed changes in K factor go beyond anything which could be ex-

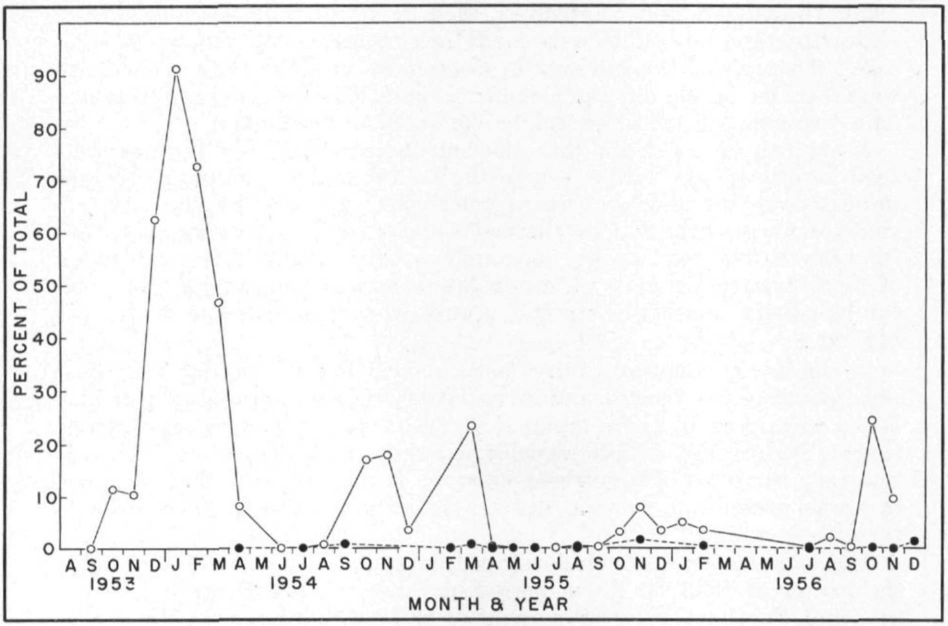


FIGURE 51. Percentage of bairdiella of the 1953 year-class recorded as thin in samples from the Salton Sea. ○ = Seine samples; ● = Gill-net samples.

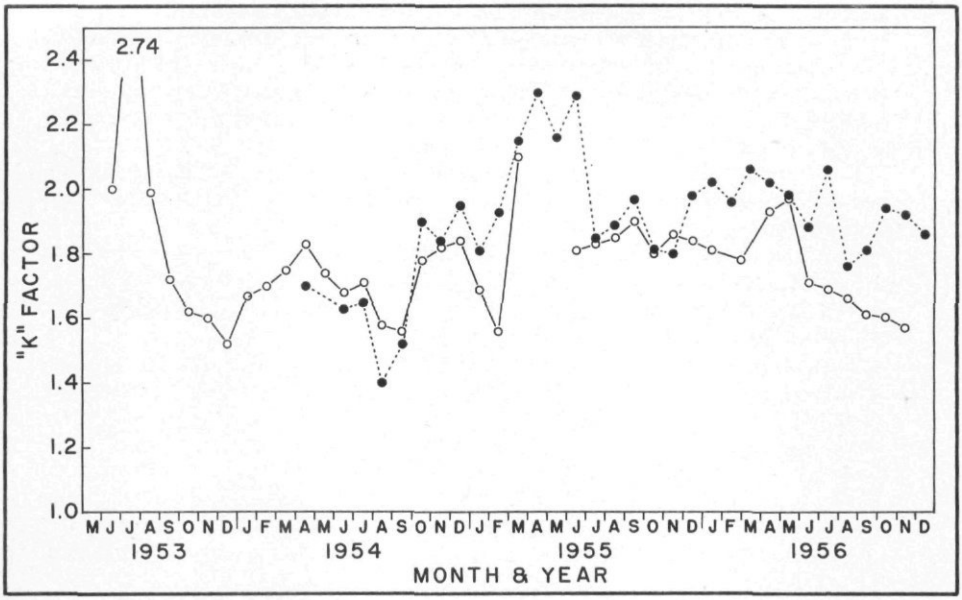


FIGURE 52. *K* or condition factors computed for bairdiella of the 1953 year-class from the Salton Sea. ○ = *caught in seines;* ● = *caught in gill nets.*

plained as having been caused by a relationship with lengths of the fish. This was particularly true of changes during the summer, fall, and winter months in the years when the lengths of the 1953 fish were constant. During such periods, the changes in weight alone were sufficient to indicate changes in their condition. The usefulness of the *K* factor in comparing the condition of fish in different years is shown by the rather good agreement of Figures 51 and 52. At times when fish were described as thin, the *K* factor was also low. Thus, in October, November, and December 1953, and January 1954; September 1954; January and February 1955; and October and November 1955, the *K* factor was low when more than 10 percent of the fish were described as thin.

Starvation was again suggested as a cause of the kills because when the *K* factor of 1953 year-class fish fell to values of 1.6 or lower, dead fish were observed on shore; as in November and December 1953, and January 1954; August and September 1954; February 1955; and September and October 1956. The relationship was not always direct, however. For instance, the *K* factor improved in October 1954, when the observed kill was at a maximum. Though of a minor nature, a kill did occur in 1955, while the *K* factor remained at a fairly high level. Also, in 1956 the *K* factor, as computed from seine samples, declined through November, although observations indicated that the kill reached a maximum in September and was not seriously affecting the fish in November. In the latter case, however, the reduced November catch indicated that offshore movement of the fish may have left only a few weak individuals inshore.

Also in Figure 52 is a series of *K* factors computed from the gill-net samples. The pattern is quite similar to the series computed from the seine samples, though from October 1954 to November 1956 the *K* factor for gill-netted bairdiella exceeded that determined from seine samples in every case but one. LeCren (1951) felt that gill nets might be selective in regard to *K* factor.

During the early phases of growth in 1953, the value of *K* for seined 1953 fish decreased drastically from August through December, although lengths showed little change after September.

Conditions improved in February 1954, a trend that continued into the spring. Declines occurred in the summer of 1954 followed by gains in the fall. The lowest values of *K* occurred in August and September when dead fish were first observed.

The declines in *K* factor in May 1955 and 1956 were due in part to spawning, but continued losses in the summer and fall must be regarded as having been due to shortages of food. In each of the three years, 1954, 1955, and 1956, the fish showed a decline in *K* factor during May even though growth in length and weight seemed to have continued.

The *K* factors for the 1952 year-class show possible effects of the absolute lengths of the fish; values which in 1954 never exceeded 1.6 (Figure 53). Since no increase in average length of 1952 year-class fish

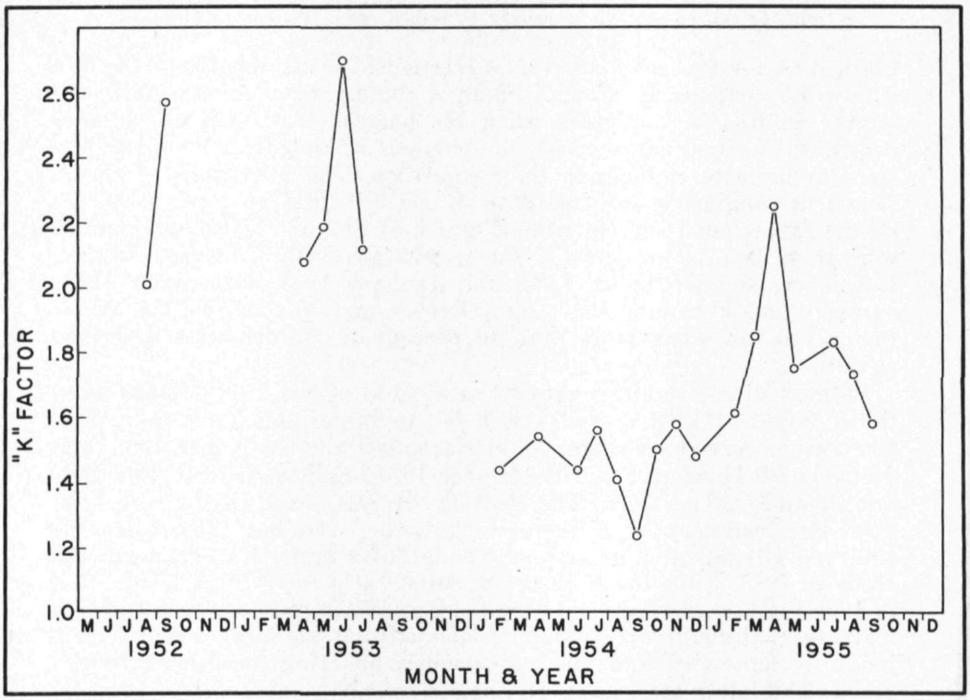


FIGURE 53. *K* or condition factors computed for bairdiella of the 1952 year-class from the Salton Sea.

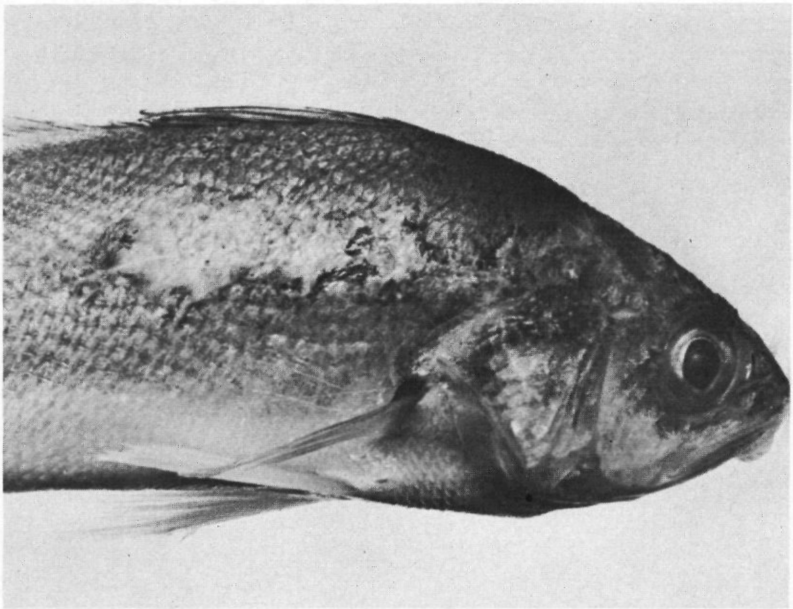


FIGURE 54. Bairdiella from the Salton Sea with injury to head and lateral line, 1956. Photo by R. H. Linsley.

was observed after April 1954, the length may be considered constant from then on. There was real improvement in condition of the 1952 year-class in 1955 as compared to 1954.

Values of *K* for the 1952 year-class in 1952 and 1953 were 2.0 and more. In April and July 1955 the *K* factors for the two year-classes were nearly equal. This indicates that the 1952 year-class fish must have been in very poor condition in 1954 compared to their condition in 1953 and 1955. It is also evident that they were not in as good condition in 1954 as fish of the 1953 year-class. This would be expected, since they showed little or no growth, while 1953 year-class fish increased in length and weight.

The excellent agreement between the loss of weight in the fish and the times of kills leaves little doubt that the two were associated. Furthermore, since the weight losses occurred at times of food shortage it is reasonable to suppose that starvation was a contributing factor to the kills. However, not all of the fish observed on shore were thin. It certainly is possible that factors other than starvation contributed to the kills.

Also observed with the thin fish were some with open sores on the dorsal portion of their heads. In some cases, this condition affected the lateral line and extended for some distance along it (Figure 54). Some fish were observed with the skin and muscle tissue of the head missing and the bone exposed. The wounds generally resembled bacterial infections. Some of these fish showed a general loss of equilibrium, and swam weakly in spirals or circles near shore.

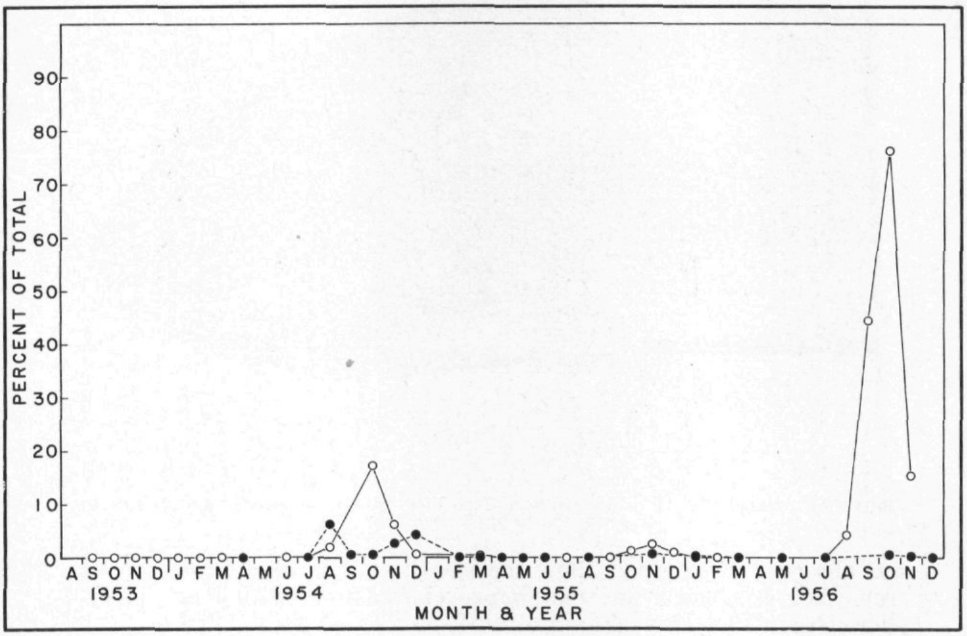


FIGURE 55. Percentage of bairdiella of the 1953 year-class from the Salton Sea with injuries to the head and lateral line. ○ = Seine samples; ● = Gill-net samples.

Fish with this condition were observed only in the fall and winter months (Figure 55). It affected large percentages of the fish in the late fall of 1954 and 1956. In 1955, however, such fish never amounted to more than five percent of any sample. There was not a perfect agreement between the time of maximum occurrence of this disorder and the maximum kill, though the general agreement as to time of year and severity from year to year was good. Not all of the fish washed up on shore showed external evidences of this disorder. It might not be unreasonable to speculate that thin fish, suffering from malnutrition and crowded inshore, would be more subject to disorders or infections of this sort. Fish taken in gill nets rarely showed evidence of this disorder even when, as in the fall of 1956, over 40 percent of the seined fish were affected (Figure 55). As already mentioned, fish in gill-net samples also had higher *K* values than those in seine samples. It is possible to associate both of these differences with the selective action of gill nets, weak fish perhaps being less apt to be caught in gill nets than in seines, but it is more likely that the differences are real.

At least one kill occurred which cannot be ascribed to starving. On July 20, 1955, several thousand fishes washed ashore at Sandia. The most abundant were bairdiella, but striped mullet, desert pupfish, and longjaw mudsuckers were also observed. According to personnel stationed at Sandia, large numbers of bairdiella appeared at the surface on the evening of July 19, about two or three miles southeast of Sandia. Their behavior was typical for fish suffering from lack of oxygen. No dead fish were observed at that time in parts of the Sea other than in this immediate vicinity. Fifty-one bairdiella were collected from the shore, preserved in formalin, and later measured and weighed. All were in excellent condition, with an average K factor of 2.0 and none had external sores or other indication as to the possible cause of the kill. The K factor agrees quite well with the average K of 2.5 observed from gill-net samples at that time. Although no certain explanation for this kill is available, it seems probable that it was caused by a local anoxic condition.

ABNORMALITIES

A great many abnormal individuals were noted in the samples of *Bairdiella* taken in the early stages of the population buildup in the Salton Sea (D. C. Joseph, personal communication). Whether produced genetically or environmentally, such abnormal individuals evidently are eliminated under ordinary conditions by interspecific or intraspecific competition or predation at least when the abnormality is such as to put the individual at a disadvantage in the struggle for survival. The relative frequency of occurrence of different abnormalities in succeeding year-classes would seem, therefore, to give a rough index to the degree of competition and predation taking place during the development of each year-class.

In determining the frequencies of abnormalities, no attempt was made to use the entire sample of bairdiella that had been collected. Effort was concentrated on samples containing large numbers of individuals, so as to reduce somewhat the manipulative labor involved. Thus, the size of the sample jars became a criterion in deciding whether to examine for abnormalities. A total of 1,443 members of the 1952 year-class was inspected for abnormalities, 122 from samples collected in 1952 (the entire collection), 651 from 1953, and 670 from 1954. Samples of the 1952 year-class taken in 1955 and 1956 were too small to provide an estimate of frequencies of abnormalities. Also inspected were 37,324 members of the 1953 year-class, 9,437 from samples collected in 1953, 7,145 from 1954, 10,834 from 1955 and 9,908 from 1956. Anal spine abnormalities were determined from a smaller sample because this feature was not noted until after the work had progressed into 1955.

Blindness

Blindness as considered here refers to external evidences of blindness. Such evidences ranged from eyes of normal size but with no apparent pupil, or with the eye clouded (Figure 56), to eyes reduced to a very small size and even completely missing. In the latter cases, the bone structure around the eye was also affected, being misshapen or absent (Figure 57).

Blindness in the 1952 Year-Class

The year-class of *Bairdiella* produced in 1952 was at first apparently unaffected by predation or competition of any consequence. The sample from 1952 was small, consisting of only 122 individuals, but of these, three were totally blind, and five were blind in one eye (Table 36).

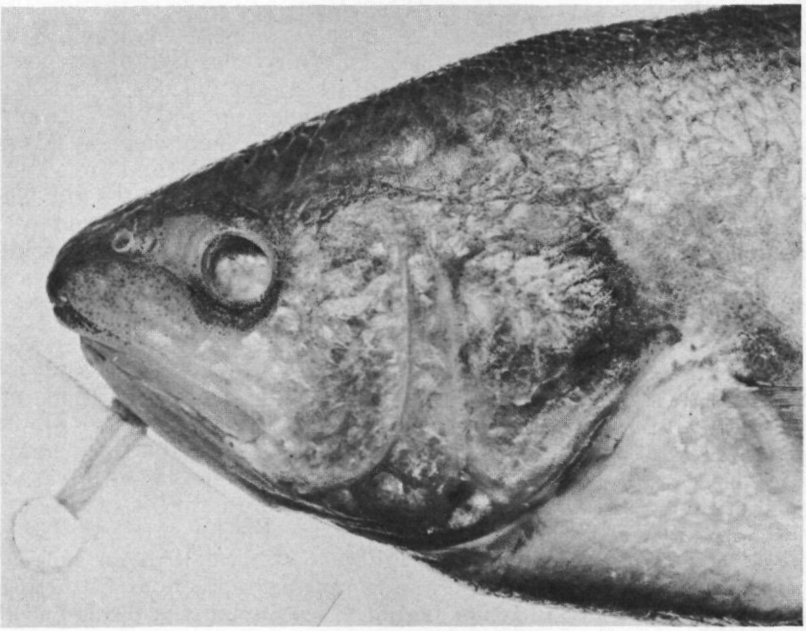


FIGURE 56. Blind bairdiella, with the eye clouded, from the Salton Sea. Photo by R. H. Linsley.

FIGURE 57. Blind bairdiella, with the eye greatly reduced and the surrounding bony structure misshapen, from the Salton Sea. Photo by R. H. Linsley.

If this same year-class is followed into 1953, however, it can be seen that the samples are not uniform in their estimates for blindness in the population (Table 37). One wishes for a larger sample to compare. At any rate, local populations of this year-class of *Bairdiella* showed percentages of blind which differed from those of other local populations (chi-square = 50.9, df 2, highly significant). There is no reason to believe that this was due to any factor other than failure of the fish to mix. The samples were all taken within three months of one another and show no trend in percentage blind with time.

Further information on the lack of agreement of the samples in 1953 comes from comparing the number of fish blind in the right eye with those blind in the left eye (Table 38). Logically, a ratio of 50:50 might be expected. The sample of May 4, 1953, however, had more fish blind in the right eye than in the left. This may have been an unusual sample, since there were no differences in the other samples or in the combined samples (Table 38).

Because of the variability of the early samples in their estimates of blindness in the 1952 year-class, it is not surprising that the totals for 1952 and 1953 differed. An increase in blindness is indicated, but is to be interpreted merely as unusual sampling variation, particularly con-

TABLE 36

Blindness in the 1952 Year-Class of Bairdiella From the Salton Sea in 1952

Date	Locality	Sample Size	Blind One Eye		Blind Both Eyes		Total Percent of Blindness
			Number	Percent	Number	Percent	
5 Aug. 1952	Salton Sea Beach	30	--	--	--	--	0.0
29 Aug. 1952	Sandia	11	1	9.1	--	--	9.1
4 Sept. 1952	Durmid	53	3	5.7	2	3.8	9.5
27 Oct. 1952	Salton Sea	28	1	3.6	1	3.6	7.2
Total		122	5	4.1	3	2.4	6.5

TABLE 37

Blindness in the 1952 Year-Class of Bairdiella From the Salton Sea in 1953

Date	Locality	Sample Size	Blind One Eye		Blind Both Eyes		Total Percent of Blindness
			Number	Percent	Number	Percent	
2 Apr. 1953	Salton	86	4	4.6	--	--	4.6
10 Apr. 1953	Salton Sea Beach	275	24	8.7	--	--	8.7
4 May 1953	Fish Springs	203	59	29.0	--	--	29.0
13 June 1953	Fish Springs	15	4	26.7	1	6.7	33.4
13 June 1953	Salton Sea Beach	145	21	14.5	--	--	14.5
17 June 1953	Salton Sea Beach	50	2	4.0	--	--	4.0
18 July 1953	Salton Sea Beach	5	--	--	--	--	--
Total		779	114	14.6	1	0.14	14.7

sidering the small size of the 1952 sample. The samples indicate that between 6 and 15 percent of the fish were blind in 1952 and 1953.

In contrast to the samples of 1952 and 1953, only two percent of the 1952 fish were blind in 1954 (Table 39). None was blind in both eyes. Blind fish were so uncommon that, although more fish were examined than in either of the two previous years, only two samples produced enough blind fish to be suitable for comparison. They were obviously quite similar in the percentages blind, and did not differ from the grouped samples from the rest of the year. The highest percentage in a single 1954 sample, 3.1 percent, was lower than the lowest of the two previous years, 3.6 percent. In spite of the variability in the earlier samples, it seems clear that a decrease in the percentage blind occurred between 1953 and 1954, including a decline in the number blind in both eyes.

Blindness in the 1953 Year-Class

Blindness in the 1953 year-class was extremely rare, in striking contrast to the common occurrence in the 1952 year-class. Only about 0.1

TABLE 38

Comparison of Number Blind in Right Eye Versus Left Eye in the 1952 Year-Class of Bairdiella, Salton Sea

Date	Number Blind Right Eye	Number Blind Left Eye	Chi-square
1952	4	1	--
2 April 1953	3	1	--
10 April 1953	15	9	1.5
4 May 1953	39	20	6.1 (Significant)
13 June 1953 (a)	1	3	--
13 June 1953	10	11	0.0
14 June 1953	0	2	--
1954	4	5	0.1 Sum 8.1, df 5 (Nonsignificant)
Total (Except 1952)	72	51	Pooled chi-sq. 3.6, df 1 (Significant) Interaction chi-sq. 4.5, df 4 (Nonsignificant)

TABLE 39

Blindness in the 1953 Year-Class of Bairdiella, From the Salton Sea in 1954

Date	Locality	Sample Size	Number of Blind	Percent of Blind	Total Percent of Blindness
23 April 1954	Salton Sea Beach	266	4	1.5	1.5
8 June 1954	Salton	292	9	3.1	3.1
Others	Various	445	7	1.3	1.3
TOTAL		1,003	20	1.99	2.0

percent were blind in one eye (Table 40). The numbers of blind fish in particular samples of the 1953 year-class were too low to permit a test of homogeneity within any of the years. Since samples in 1953 were taken mainly at one location, there is some danger that they might not have been representative of the population in general. No obvious differences occurred, however, in the few samples taken at other places, so that it is probably reasonable to assume they were representative.

There was no difference in the number of fish blind in the right and left eyes. Of the 39, 18 were blind in the right eye and 21 in the left.

Comparison of the 1952 and 1953 Year-Classes With Respect to Blindness

The year 1953 found two year-classes of *Bairdiella* in the Salton Sea differing radically in the percentage blind. There were about 50 to 100 times as many blind among the 1952's as 1953's (6 to 15 percent of the 1952 year-class were blind as compared to 0.16 percent of the 1953's). Apparently the 1953 year-class was produced in such numbers that the effects of competition were almost immediate.

It was undoubtedly during late 1953 that the reduction in percentage blind (from 15 to 2 percent) in the 1952 year-class was taking place. Though a few totally blind fish of the 1952 year-class survived in 1952 and early 1953, none was found in later years and no member of the 1953 year-class was ever found that was blind in both eyes.

The frequency of blindness in 1954 was 2 percent in the 1952 year-class compared to 0.1 percent in the 1953 year-class (chi-square > 12.0, df 1, highly significant). The initial stress of competition was therefore within the 1953 year-class, and its effects on the 1952 year-class came later.

Malformed Mouths

Abnormalities of the mouth included underdeveloped, poorly developed, and twisted lower jaws; and one or both maxillaries missing, vestigial, or reduced. Several fish had the maxillaries and premaxillaries twisted inward so that they lined the inside of the mouth. Various combinations of the abnormalities occurred.

If the fish suffering from missing, vestigial, or slightly reduced maxillaries or premaxillaries, or combinations of these, are considered to-

TABLE 40

Blindness in the 1953 Year-Class of Bairdiella From the Salton Sea, 1953-1956

Year	Sample Size	Blind One Eye		Small Eye or Pupil	
		Number	Percent	Number	Percent
1953	9,437	16	0.17	15	0.16
1954	7,145	7	0.10	3	0.04
1955	10,834	6	0.06	7	0.06
1956	9,908	10	0.10	3	0.03
Total	37,324	39	0.10	28	0.08

To test significance of differences in percent blind in one eye between the years, chi-square = 6.8, df 3, nonsignificant.

To test significance of differences in percent with small eyes or pupils between the years, chi-square = 13.6, df 3, highly significant.

TABLE 41

Occurrence of Abnormal Maxillaries and Premaxillaries in Bairdiella From the Salton Sea

Year	Sample Size	Number With Abnormal Maxillaries and Premaxillaries	Percent Abnormal
1952 Year-class			
1952	122	1	0.82
1953	651	12	1.84
1954	670	2	0.30
Total	1,443	15	1.03
1953 Year-class			
1953	9,437	35	0.37
1954	7,145	37	0.52
1955	10,834	39	0.36
1956	9,908	31	0.31
Total	37,324	142	0.38

gether, it appears that a considerable reduction in frequency occurred (in the 1952 year-class) between 1953 and 1954 (the 1952 sample was too small to be used). A decline from 1.8 to 0.3 percent took place at that time (Table 41). Yearly counts were quite similar for the 1953 year-class and gave a combined estimate that about 0.4 percent of the population possessed abnormal maxillaries or premaxillaries or both. The two year-classes probably were quite similar with respect to the frequency of this characteristic by 1954.

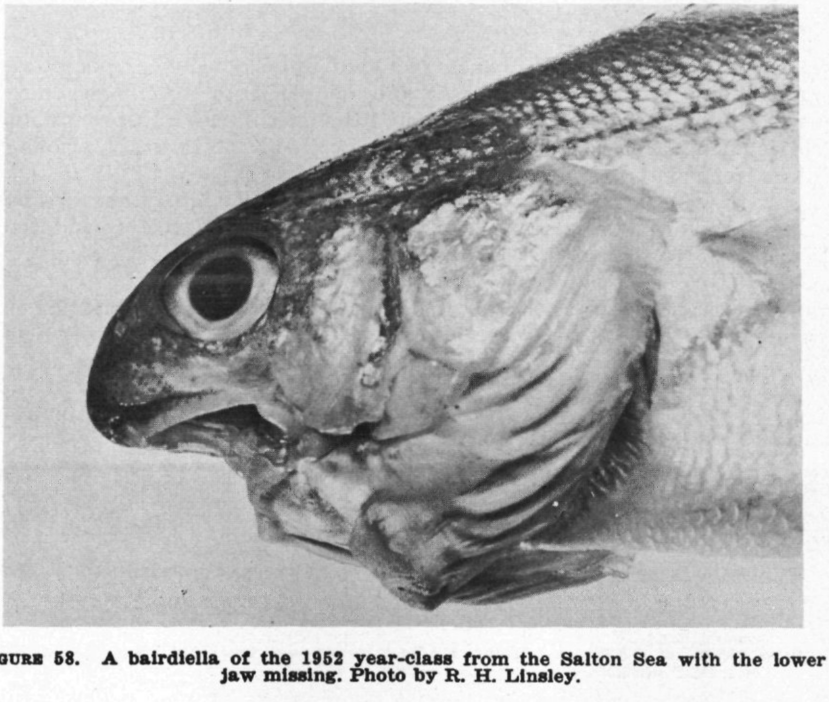


FIGURE 58. A bairdiella of the 1952 year-class from the Salton Sea with the lower jaw missing. Photo by R. H. Linsley.

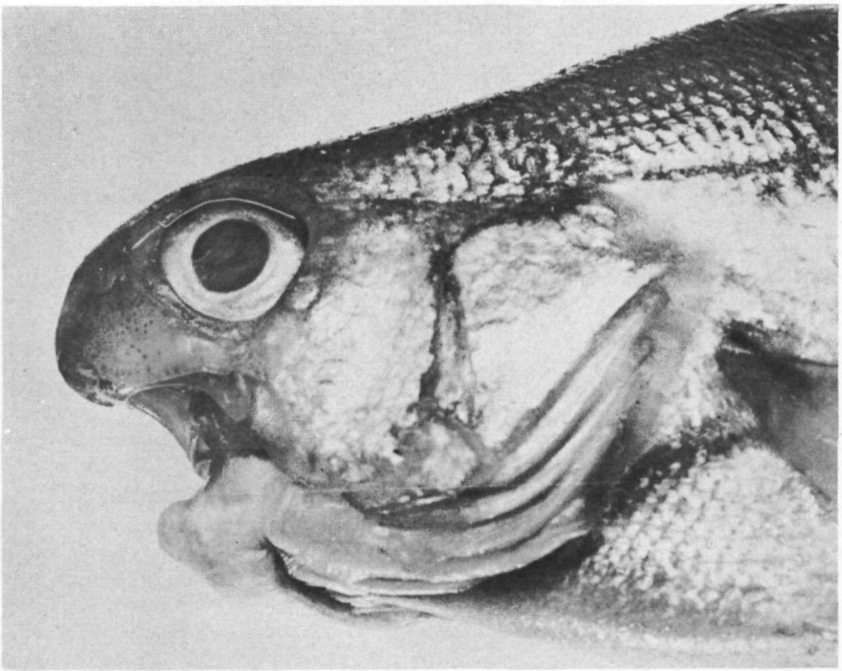


FIGURE 59. A bairdiella of the 1952 year-class from the Salton Sea with a cartilage knob in place of the lower jaw. Photo by R. H. Linsley.

Malformations of the lower jaw were so severe in some fish of the 1952 year-class that it was impossible for them to close their mouths. In fact, four fish completely lacked functional lower jaws, and four others had severely reduced lower jaws, very nearly non-functional (Figure 58). There was an apparent relationship between this type of abnormality and another that affected the cartilage in the lower jaw. All of the fish with missing lower jaws had masses of undifferentiated and twisted cartilage at the isthmus. One with a poorly-developed lower jaw had the cartilage drawn out to a blunt point which extended beyond the end of the jaw (Figure 59). Three fish with normal jaws had a knob of cartilage extending downward at the isthmus. The knob was associated with the ends of the gill arches. In some fish the lower jaws, otherwise normal, were twisted to one side or the other.

There was an apparent difference between the year-classes in the percentage of fish with abnormal jaws; they were more common in the 1952 year-class. Also apparent was a reduction in this type of abnormality among the 1952's between 1953 and 1954 (Table 42).

Malformed Preorbital

This malformation was also associated with abnormalities of the mouth. Often the maxillary or mandible would be twisted to fill the gap left by a reduced or missing preorbital. In severe cases, the maxillary came in direct contact with the lower edge of the eye and caused some distortion in its shape. In one fish, the maxillary was so reduced that the lower jaw closed against the lower edge of the right eye. No apparent injury had been done to the eye. Malformation of the preorbital was quite rare, affecting only 25 fish out of the 37,324 of the 1953 year-class examined (Table 43). No member of the 1952 year-class was observed with this feature.

Deformed Gill Cover

Quite rarely *Bairdiella* were encountered with the branchiostegal rays twisted inward and sometimes involving the subopercle and opercle so that portions of the gill were exposed (Figure 60). Only 9 of the 37,324 fish of the 1953 year-class were thus disfigured. One was observed among the 1,443 of the 1952 year-class.

Snub-nose (Pug-head)

Another rare disorder involved the snout. In some fish the snout bluntly terminated just in front of the eye, leaving the lower jaw protruding beyond the upper, while in others the snout was only mildly reduced. There was a certain variability in the pointedness of the snout among the normal fish, as well as a variability in the position of the

TABLE 42

Frequency of Occurrence of Abnormal Lower Jaws in Bairdiella From the Salton Sea

Year	Sample Size	Number With Twisted Jaws	Number With Missing Jaws	Number With Reduced Jaws (Severe)	Total	Percent Abnormal
1952 Year-class						
1952	122	1	0	0	1	0.82
1953	651	2	5	6	13	1.99
1954	670	0	0	0	0	0.00
Total	1,443	3	5	6	14	0.9
1953 Year-class						
1953	9,437	3	2	5	10	0.10
1954	7,145	6	0	11	17	0.24
1955	10,834	4	0	4	8	0.07
1956	9,908	6	1	7	14	0.41
Total	37,324	19	3	27	49	0.12

TABLE 43

Malformed Preorbitals in the 1953 Year-Class of Bairdiella From the Salton Sea

Year	Sample Size	Number With Malformed Preorbitals	Percent Malformed
1953	9,437	7	0.07
1954	7,145	8	0.10
1955	10,834	7	0.06
1956	9,908	3	0.03
Total	37,324	25	0.06

To test the difference between the years, chi-square = 4.2, df 3, nonsignificant.

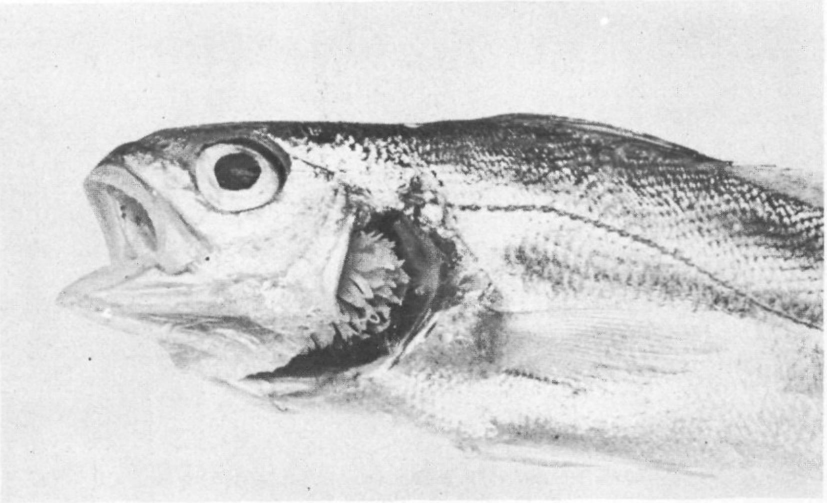


FIGURE 60. A bairdiella of the 1952 year-class from the Salton Sea with a deformed gill cover. Photo by R. H. Linsley.

mouth relative to the snout. In the final analysis, by considering only those fish which were obviously malformed and "dolphin-like", 27 (.06 percent) were snub-nosed. No difference was indicated from year to year in the 1953 year-class, but a decline is indicated between 1953 and 1954 in the 1952 year-class (Table 44).

Deformed Vertebral Column

Variations ranged from fish with a mild horizontal or vertical flexure of the spine to those with badly twisted and distorted bodies. A system of grading was employed in an attempt to separate the degrees of abnor-

TABLE 44

Occurrence of the Snub-nose Conditions in Bairdiella From the Salton Sea

Year	Sample Size	Number With Snub-nose	Percent Snub-nose
1952 Year-class			
1952	122	0	0.0
1953	651	6	0.9
1954	670	0	0.0
Total	1,443	6	0.4
1953 Year-class			
1953	9,437	1	0.01
1954	7,145	3	0.04
1955	10,834	9	0.08
1956	9,908	8	0.08
Total	37,324	21	0.05

To test the difference between the years 1953 and 1954 for the 1952 year-class, chi-square = 4.8, df 1, significant.
To test the difference between the years for the 1953 year-class, chi-square = 6.3, df 3, nonsignificant.

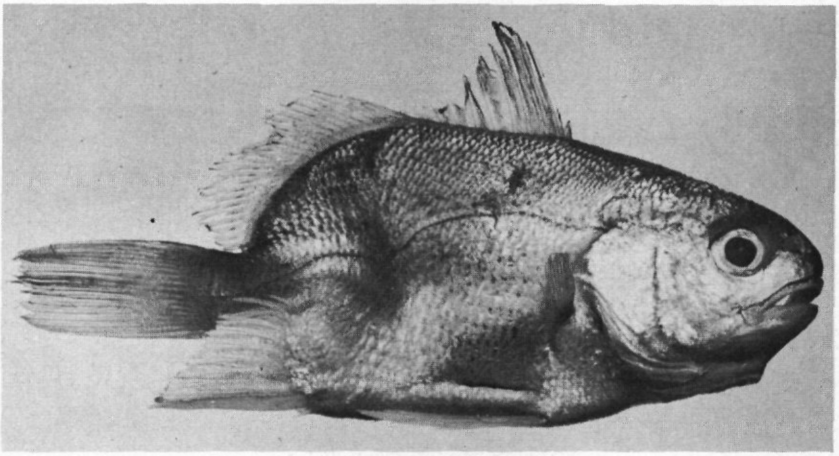


FIGURE 61. A bairdiella of the 1952 year-class from the Salton Sea with a severe distortion of the vertebral column. Photo by R. H. Linsley.

mality Grade 1 fish had serious deformations of the vertebral column (Figure 61). Grade 3 included those with any slight, but fixed, horizontal or vertical flexure. Those placed in Grade 2 were intermediate.

Two distinct trends appeared in the frequency of occurrence. In the 1952 year-class there was a drastic decline from 3.0 percent occurrence in 1953 to 0.14 percent in 1954. Again this corresponded with the initial impact of competition between the year-classes. The frequency was probably about the same in both year-classes in 1954. Unfortunately, later samples of the 1952 year-class were too small to determine the frequency of an abnormality as uncommon as this.

In the 1953 year-class, there was an unexpected increase in the occurrence of vertebral anomalies from year to year (Table 45). If the deformed vertebrae were genetically induced then it must be that the effects were slow to appear, and that the initial action of selection was more severe than its later action, thus allowing an increase in the population. In place of hypothesizing a latent genetic background for de-

TABLE 45

Occurrence of Abnormal Vertebral Column in Bairdiella From the Salton Sea

Year	Sample Size	Degree of Abnormality			Total	Percent Abnormal
		Grade 1	Grade 2	Grade 3		
1952 Year-class						
1952	122	0	0	0	0	0.00
1953	651	1	4	15	20	3.07
1954	670	1	0	0	1	0.15
1953 Year-class						
1953	9,437	0	1	4	5	0.05
1954	7,145	1	1	7	9	0.12
1955	10,834	0	5	24	29	0.26
1956	9,908	1	5	29	35	0.35

formed spines, it might be theorized that they were environmentally induced, perhaps by the effects of prolonged malnutrition in the 1953 year-class. The increase that occurred was mainly in the mild twisting, graded "3" and "2". Perhaps twisted spines are more easily observed in larger fish, so that more were noted as the fish increased in length. Increases in length were not great after 1953, however.

Lateral Line Anomalies

Ordinarily, the lateral line on bairdiella extends in a smooth curve from the head to nearly the end of the caudal fin. A few of the Salton Sea fish were unusual in this respect, and probably others with unusual lateral lines escaped notice. Nine fish in the 1953 year-class had interrupted or branched lateral lines. The most common defect observed was a sudden upturning at the hypural plate, so that the lateral line entered the caudal fin at an approximate 45 degree angle. In other cases, the lateral line ended abruptly and then continued at a level two or three scale rows below. These may have resulted from physical injury, as regenerated scales commonly were associated with them. Four fish had lateral lines ending at the hypural plate, and 24 had the lateral line upturned or downturned at the hypural plate, so that it extended onto the tail at an angle. No 1952 year-class fish were observed with this defect.

Abnormal Anal Spines

An anal spine count of two or less is one of the characteristic features of the family Sciaenidae. Most species in the family, including *Bairdiella icistius*, invariably have two, but some have one or none. No species has more than two spines and there is no previous record of an abnormal increase in anal spine number in any sciaenid. It was particularly surprising, therefore, to find a significant number of bairdiella in the Salton Sea with other than the usual count.

TABLE 46

Occurrence of Three Anal Spines in Bairdiella From the Salton Sea

Year	Sample Size	Number With Three Anal Spines	Percent With Three Anal Spines
1952 Year-class			
1952	122	2	0.80
1953	772	1	0.13
1954	544	0	0.16
1955	59	1	
Total	1,497	4	0.26
1953 Year-class			
1953	1,454	19	1.30
1954	694	9	1.29
1955	9,432	141	1.49
1956	9,908	151	1.52
Total	21,488	320	1.48

As indicated in Table 46, 1,497 specimens of the 1952 year-class were examined for this characteristic. The sample size differed from that used in determining the frequency of some of the other abnormalities because fish possessing three anal spines were not noted until the work had progressed into 1955, and it was not deemed profitable to reexamine the entire early sample. An estimated 0.3 percent of the 1952 year-class had three anal spines. In addition, two fish were found with a double-pointed second anal spine and two with a triple-pointed spine.

An increase in the percentage of fish with three anal spines occurred in the 1953 year-class (Table 46). There was no change in frequency of occurrence within the year-class with time. A total of 320, or 1.5 percent of the sample, had three anal spines, an estimated five times as many percentage-wise as in the parent 1952 year-class. There is no apparent competitive advantage to possessing three anal spines. Probably this was an example of genetic drift resulting from chance retention of a gene or genes normally quite uncommon in *Bairdiella.* To believe that the formation of three anal spines was environmentally induced requires the assumption that there was a difference in the environment between 1952 and 1953. There is no evidence for this. It would have been interesting to observe the occurrence of three anal spines in future generations, but through 1956 it was not possible to study any other year-class in the Salton Sea since they were produced in such small numbers.

Besides those with three anal spines, one bairdiella had only one (the large spine), another had four (Figure 62), and one had five (Figure 63). Such fish must be considered extremely rare (3 out of 21,488 fish examined).

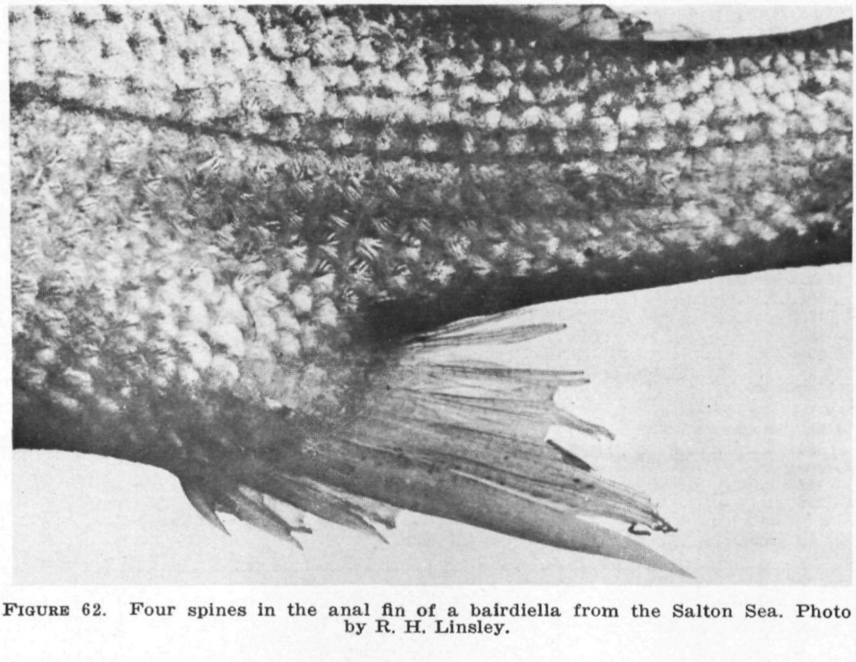


FIGURE 62. Four spines in the anal fin of a bairdiella from the Salton Sea. Photo by R. H. Linsley.

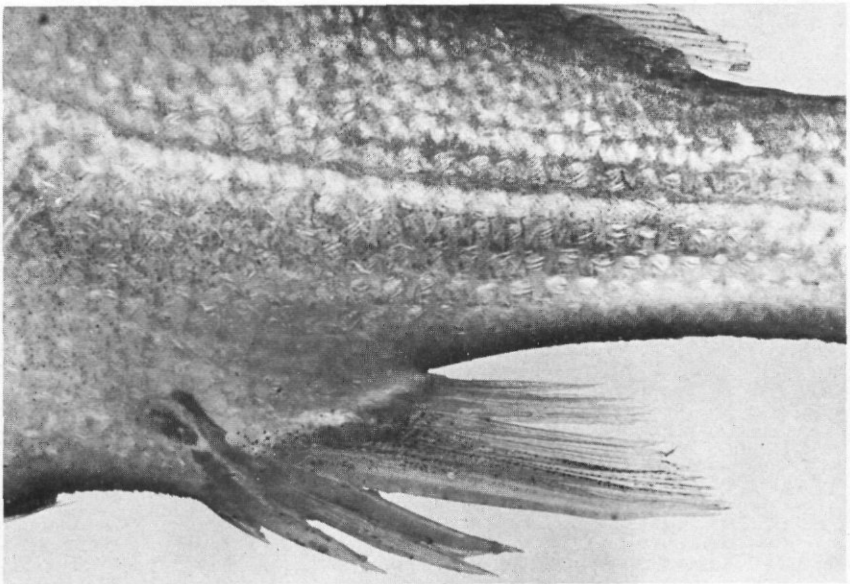


FIGURE 63. Five spines in the anal fin of a bairdiella from the Salton Sea. Photo by R. H. Linsley.

The 1953 year-class sample had three fish, or 0.01 percent of its members, with the second anal spine split at the end into two points, an apparent reduction from the two out of 1,497 or 0.13 percent of the 1952 year-class. No 1953 fish were found with triple-pointed anal spines although two of the 1952's were so adorned.

Anal fin ray counts of 121 bairdiella with three anal spines were compared with 121 having two anal spines. No difference was detected in the number of fin rays (7 to 10) between the groups (Table 47). However the fish with four and five anal spines had the number of rays reduced to five and six respectively. Thus it is not at all clear as to the source of the supernumery anal spines. The data on number of fin-rays occurring with three anal spines indicate the first ray did not develop into a spine (a situation normal in *Mugil, Eucinostomus, Sebastodes*

TABLE 47

Comparison of Anal Fin Ray Counts for Bairdiella With Two and Three Anal Spines From the Salton Sea

	Number of Anal Rays				Sample Size
	7	8	9	10	
Fish With Two Anal Spines	5	73	39	4	121
Fish With Three Anal Spines	3	79	37	2	121

To test the difference in anal fin ray counts chi-square = 0.8, df 1 nonsignificant. (Those with 7 and 10 anal rays not included in test because of small expected number. If grouped 7 and 8 vs. 9 and 10, chi-square = 0.6, df 1.)

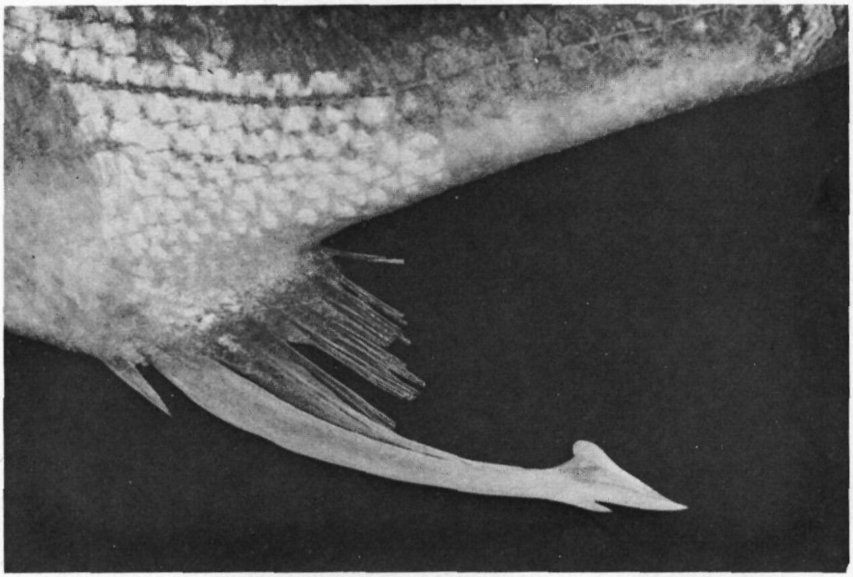


FIGURE 64. Knob on the second anal spine of a bairdiella from the Salton Sea. Photo by R. H. Linsley.

and other fishes). However, the reduction in ray number in the fish with four and five anal spines is strongly suggestive that the number of spines is related to a fixed total number of elements in the anal fin.

Rarely, other peculiarities of the second anal spine were noted in the sample studied. One fish had a flat, thin projection on the left side of the second anal spine. Another had a knob on the end of the spine (Figure 64) while one had a short, blunt second anal spine enlarged at the base. One fish had a thin spine that was stiff-jointed and curved downward.

Discussion

The 1952 year-class of *Bairdiella* which was produced in the Salton Sea obviously experienced little selection pressure during 1952 and 1953. The excellent growth of this year-class in those two years has already been described. Absence of competitors or predators allowed abnormal individuals to survive and these constituted an important percentage of the total population. In 1953, between 6 and 15 percent of the year-class were blind, about two percent had malformed maxillaries or premaxillaries, two percent had abnormal lower jaws, one percent were snub-nosed, and three percent had twisted vertebral columns, making 13 to 23 percent which were abnormal in some way.

At the same time, the 1953 year-class was produced in such large numbers that competition within it apparently eliminated abnormal individuals during an early stage in development, so that only about 0.3 percent were blind, 0.4 percent had malformed maxillaries or premaxillaries, 0.1 percent had abnormal lower jaws, 0.05 percent were snub-nosed, and at most 0.35 percent had twisted vertebral columns. In addition, 0.06 percent of the 1953 year-class had malformed preorbitals, making only slightly more than one percent of the members abnormal in some way.

The stress of competition with the younger more abundant 1953 year-class evidently led to a reduction of abnormalities in the 1952 year-class to about 2.5 percent in 1954. These consisted of 2 percent blind, 0.3 percent with malformed maxillaries or premaxillaries, and 0.15 percent with twisted vertebral columns. Thus, abnormal individuals were still slightly more common in the 1952 year-class than in the 1953's, the latter having about 0.7 percent of its members abnormal in some way. The only reduction of abnormalities in the 1953 year-class was in the frequency of blindness.

The sample of 1952 fish taken in 1955 was not large enough to permit comparison of frequencies. This was undoubtedly a reflection of declining abundance, since the fishing effort was about the same in 1955 as in 1954. The failure of the year-class to grow in 1955 and 1956 has already been mentioned. Apparently, competition began to eliminate even the normal individuals of the 1952 year-class when their larger size put them at a disadvantage due to their need for more food per individual than the smaller fish.

THE FOOD OF THE BAIRDIELLA

JAY C. QUAST

INTRODUCTION

Because of the large bairdiella population after their successful hatching in 1952 and the relatively small sizes of the individuals, it was anticipated that they would be important as forage for any larger sport species subsequently established. This assumption was justified upon the later spawning success and multiplication of the orangemouth corvina. As part of the program to obtain information basic to managing a sportfishery, a food study was begun on bairdiella in 1954. The study was conducted on a part-time basis and terminated in the summer of 1956.

METHODS

Gut contents of approximately 1,000 bairdiella were examined over a two-year period. Gill nets and seines were employed for sampling, on a monthly basis during the first year, and bi-monthly thereafter. Each monthly sample consisted of at least four subsamples taken at equal intervals over a 24-hour period.

Intensive sampling with gill nets started in July 1954, following a few earlier trials that spring and the previous year. Variable-mesh nylon nets were usually used; the net dimensions were 8 x 125 feet, and the mesh size ranged from 0.5 to 2.0 inches (squared). Juvenile and adult bairdiella were usually obtained in abundance and it is believed that all ages were adequately represented. Nets were laid on the bottom, and two sets were made simultaneously in which one of two alternative arrangements was followed: either one set was made in the shallows (approximately six feet) and the other in deep water (25-30 feet), or both were made at the same depth at different locations. Normally the fish were obtained at different depths near Fish Springs. However, some samples were taken at Salton Sea Beach, and at some localities on the east shore.

The digestive tract of *B. icistius* is short, with a sac-like stomach, a pylorus with appendages, and an intestine with one forward-directed loop. The jaws and pharyngeal bones have cardiform dentition. The gill-rakers are fairly long and slender and are studded with fine calcareous tubercles which give them a roughened appearance under magnification. When examining for food, both stomach and intestine were removed and each checked separately. The items were listed on a food card along with accessory data such as degree of stomach fullness; stage of digestion; size, sex, and condition of fish; and the time and locality of capture.

Early in the study it was found that *Neanthes* weight could be accurately predicted from the lengths of the paired mandibles of its pharynx. Fortunately, mandibles were not affected by fish digestive juices and furnished a reasonably accurate index to the size and quantity of the food eaten by the fish. Mandible length was a far more accurate method of estimating worm weight than either segment counts or worm length—segment count varied widely in worms of the same weight because of damaged or lost tail portions. Both of the latter methods were rendered highly inaccurate by digestion.

In order to obtain a standard for estimating weight from mandible length, live worms were gathered from under the bark and barnacles of submerged brush around the edge of the Sea, fixed in mild formalin, and weighed. Damp weights were utilized and all excess liquid was blotted off. After weighing, each worm was dissected for its mandibles which were measured by means of an ocular micrometer. It was found that worm weight increased by a factor slightly less than the cube of the mandible length, for the sizes of worms that were eaten by the fish (Figure 65). Two such samples were taken, one at Salton Sea Beach in April 1954, and the other at Fish Springs in August 1955; both agreed substantially and the estimates were pooled for construction of a weight vs. mandible-length table. Weights of *Neanthes* eaten by individual fish were then computed from the mandible size frequencies recorded from the fish.

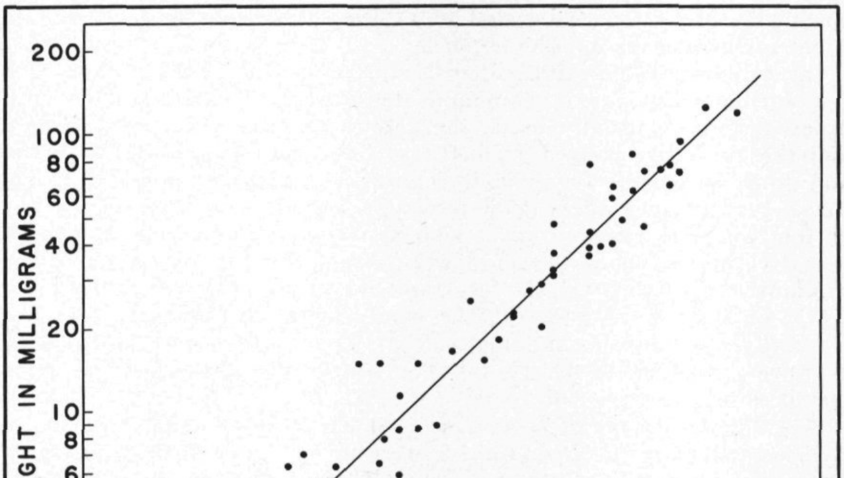


FIGURE 65. Relationship between body weight and mandible length in *Neanthes succinea*. Regression line (log weight = 2.890, log length = 1.844) fitted by least squares. Samples were mainly immature forms, however, some individuals near maturity were included, the sizes of worms nearly duplicating the sizes taken by adult fish.

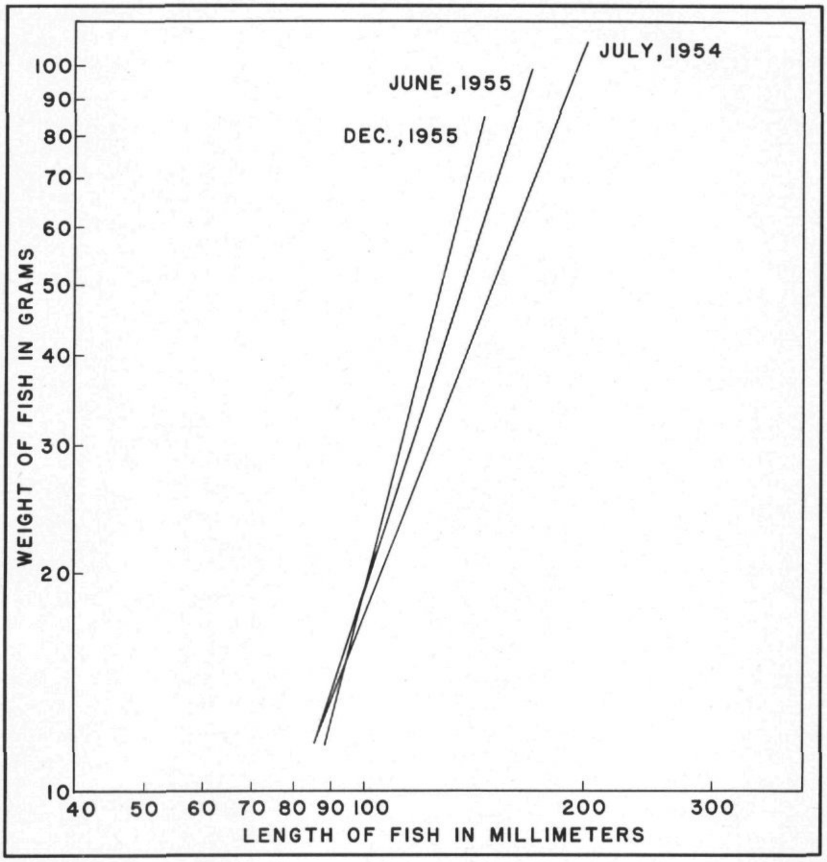


FIGURE 66. Weight-length regressions of bairdiella in three samples from the Salton Sea. Each sample is based on a minimum of 30 specimens. Data fitted by least squares.

A small percentage of the worms in stomach samples collected at night probably had spawned and the calculated weights in these cases would be too high. This may be especially true for the periods in March when the stomach totals seemed unusually high. However, a comparison of these amounts with quantities obtained in feeding experiments showed that the March figures were high but not unreasonably so. For the remainder of the year, the fraction of weight lost to spawning was probably small and reasonably constant.

Individual weighing of all fish was expensive in time and effort, so most fish weights were estimated from a regression based upon their standard lengths. Weight-length relationships were calculated for normal specimens taken at three separate dates (Figure 66). Since the data for each sample seemed distinct from the others (fish were lightest per-unit-length in the first sample and heaviest in the last), weight-length tables were constructed for each of the regressions. In assigning weights to measured fish, the table closest chronologically to the fish sample was used. Individual fish condition was also evaluated and one of three categories (normal, thin, very thin) was noted on the food cards.

RESULTS

Food Items of Bairdiella in the Gulf of California

B. icistius are common in the shallow surf zone of the beaches near San Felipe, Mexico, at the head of the Gulf of California. Two samples of fish (averaging approximately seven inches total length) were taken there in March (1954 and 1955). Small crustacea (shrimp, amphipods, and isopods) were important in their diets and fish remains and small bivalves were also noted.

Food Items of Bairdiella in the Salton Sea

In the Salton Sea, nauplius larvae of copepods and barnacles, barnacle cypris larvae, larval and small adult *Neanthes,* and *Bairdiella* eggs and larvae made up the total food types found in the stomachs of the 0-30 mm fish (Table 48). The percentage of occurrence of these items differed sharply from the food of adult fish over the same period. Although rotifers were abundant in the plankton throughout the summer none was found in the fish stomachs. Nauplii of barnacles and copepods were the first food of the fish but were not utilized after they reached 30 mm. In addition, some of the smaller fish, when captured near solid objects upon which they appeared to be "grazing", contained an abundance of barnacle cypris larvae. Adult patterns of feeding appeared early and the young fish began to feed on the larger bottom-dwelling *Neanthes* during the first month of their existence. Although copepods were consistent in diets of both young and adult fish, they probably were of major importance only to the smaller fish. *Bairdiella* eggs and larvae were extensively preyed upon by larger postlarval fish of the same species during June and July of 1953, 1954, and 1955 (Table 48).

Neanthes was the staple food item for all but the very young fish (Table 49). The worms were probably taken from the mud or silt bottom during the daytime and from near the bottom or free in the water at night. Fish netted during the day commonly had sand mixed with

TABLE 48

Food of Young and Adult Bairdiella From the Salton Sea, 1953-1955

Sample Period Size of Fish in mm	Percent of Fish Showing Food Item						Number of Fish Examined
	Nauplii	Cypris	Copepods	Fish Eggs	*Neanthes*	Fish	
May-July							
0-30	46	22	36	25	4	13	69
>70	--	--	12	1	66	1	220
Aug-Nov							
30-70	--	--	45	--	72	--	29
>70	--	--	8	--	68	--	412

TABLE 49

Food of Adult Bairdiella by Month From the Salton Sea

Month	Percent of Fish (over 70 mm in Standard Length) Showing Food Item							Number of Fish Examined
		Bairdiella						
	Copepods	Eggs	Larvae	Insects	Barnacles	*Neanthes*	Debris	
Jan	--	--	--	--	--	79	--	48
Feb	--	--	--	--	2	81	--	58
Mar	8	--	--	--	--	100	--	12
April	1	--	--	1	1	88	--	64
May	12	3	--	3	--	66	--	74
June	6	3	--	--	--	75	1	72
July	19	--	3	--	--	57	15	73
Aug	7	--	--	2	1	43	11	152
Sept	5	--	--	1	--	85	--	80
Oct	16	--	--	1	2	83	4	90
Nov	3	--	--	2	9	81	1	90
Dec	16	--	--	--	3	77	1	88

Neanthes in their stomachs while samples taken at night rarely contained material other than the worms. Because they were small, it is doubtful that copepods made any significant contribution despite the fact that they occurred in fish digestive tracts during almost all parts of the year. Several adult fish contained copepods in very large numbers (estimates of up to 1,000) but only 13 such individuals were encountered during the entire study. The majority of feeding on copepods involved greatly lessened numbers (5-100) which probably contributed little to the total nutrition of the fish. The occurrence of copepods offered evidence that food had been selected, however. In those fish which had eaten large amounts of copepods, these were usually the only food items while other fish taken at the same time and place had only *Neanthes* in their digestive tracts.

During the months of May and June a small percentage of adult fish contained *Bairdiella* eggs in their stomachs (Table 49). During July, a similar percentage of larval and postlarval fish occurred as a food item in the adult fish. It appeared that the eggs and larvae from the late spring spawnings underwent considerable predation during the summer. After July, however, young *Bairdiella* seemed unavailable to the larger fish. Several desert pupfish were noted in the larger fish. At the time, the pupfish was common in the fresh and brackish ponds near the Sea but was rarely encountered away from shore.

Insects made up a small proportion of the food and were noted only from April through November. Because of their small size and their rarity in the diets, they were probably insignificant as a food. Insect items were usually small dipterans or hymenopterans, but occasionally a larger corixid or yellowjacket was encountered. One group of *Bairdiella* that was land-locked in a shore pond had fed heavily on corixids that abounded in the pools.

Debris (twigs, barks, blue-green algae) appeared most commonly in the stomachs during July and August, and seemed to be a result of the reduction in *Neanthes* availability at that time. A fairly high percentage of fish stomachs contained inedible material in October 1954 during a period of exceptionally low food intake after the peak of a severe "kill." Barnacle shells occurred in a low percentage of fish, especially

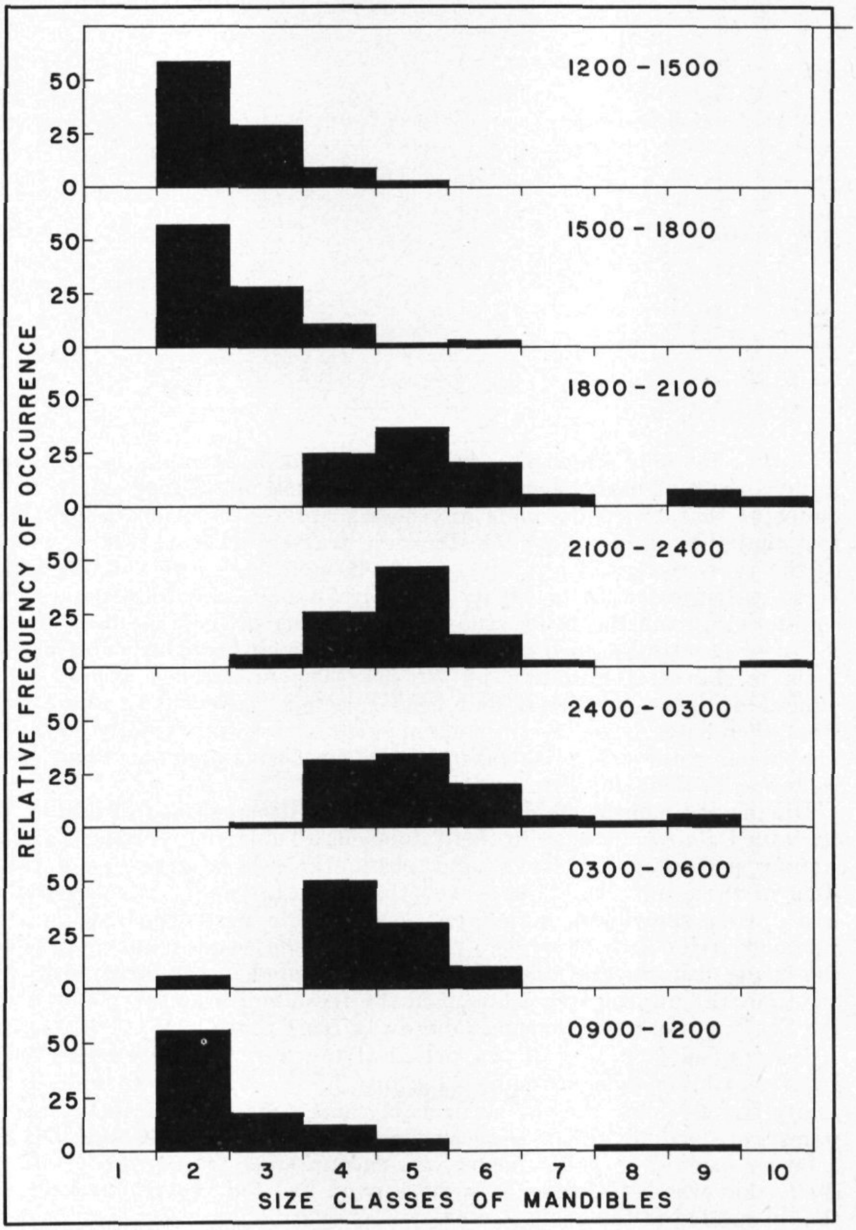


FIGURE 67. Diurnal variation in sizes of worms eaten by bairdiella in the Salton Sea. Frequency of each size-class is presented as a percentage of the total for the sample.

in the fall months. Whether these were entire animals the fish had managed to remove from the substrate, or merely loose plates, is not known.

Diurnal Variation in Food Intake

A comparison of size classes of worms taken by fish at various times of day usually demonstrated that those taken at night were considerably larger (Figure 67). Usually the break between fish feeding on large or small worms coincided with night and day. This was evident for nearly every month and whenever worms of two modal frequencies were noted the larger ones had been taken at night. In general, the greatest differences between the day and night modes corresponded to periods of good feeding (Figure 68); however, the fish fed more heavily at night than during the day even during periods of poorer feeding.

Spring increase in worm size coincided with rising temperatures which were lowest in January and reached a peak during July and August. Modal size of night-swimming worms was lowest during January which was also the month of the lowest total intake during the winter and spring. After January, both the day and night size-frequency peaks of worms moved to larger classes and reached their

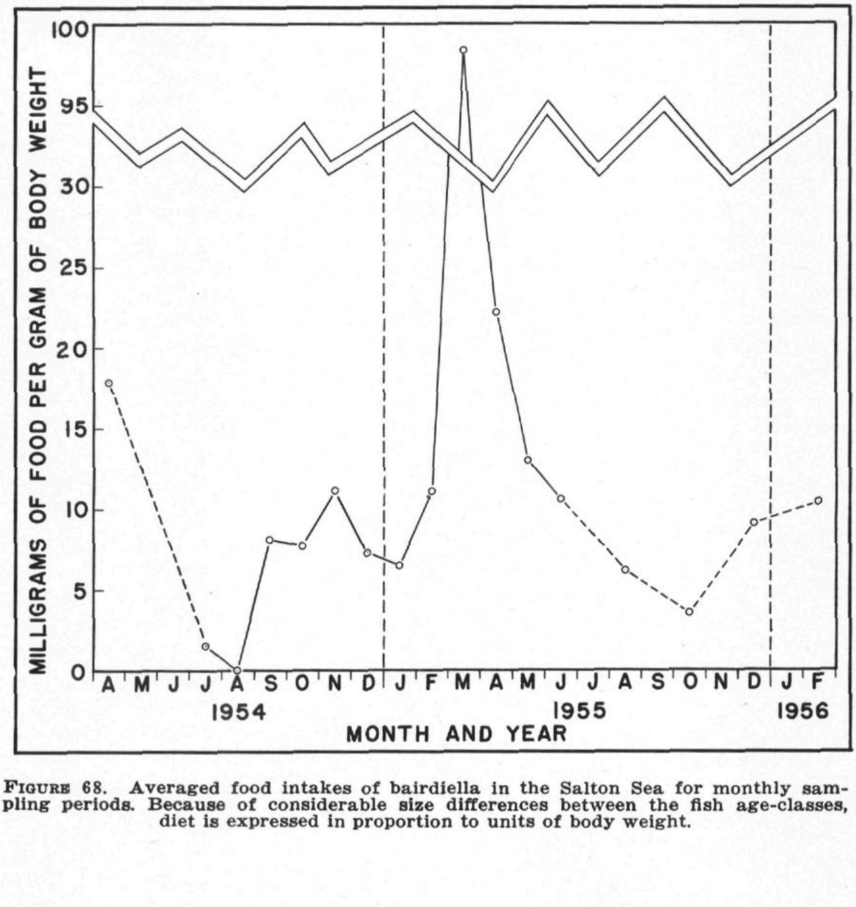


FIGURE 68. Averaged food intakes of bairdiella in the Salton Sea for monthly sampling periods. Because of considerable size differences between the fish age-classes, diet is expressed in proportion to units of body weight.

maxima in March. After March, size peaks of ingested worms declined in both day and night samples.

Seasonal Variation in Food Intake

Food intake varied considerably through the seasons and two peaks of high feeding were noted each year. The spring peak, however, dwarfed that of the fall (Figure 68). During the seasonal peaks all size classes of worms became more available to the fish, indicating a probable overall increase in productivity in the worm population (if maturation of adults was the sole factor governing the increased food intake it would be expected that the large mature or nearly mature worms would be the chief size classes that became more available). Despite severe fluctuations in the worm population, spawning worms were eaten by the fish at all times of year. Peaks in the numbers of spawning worms ingested occurred during the spring and fall, the spring peak being much the larger.

At numerous times, extensive fish mortalities occurred and thousands of *B. icistius* washed ashore. Frequently these were very thin fish, literally made of "skin and bones." These catastrophies were apparently due to several factors, but food shortages during late summer seemed to be a principal cause. The relationship between fish condition and the kills is particularly clear when the incidence of thin and very thin fish in the samples is compared with the relative intensity of the kills (Figure 69). In both 1954 and 1955, thin fish and large numbers of dead fish occurred in the fall, the frequencies of each category rising and falling together.

The evidence is quite conclusive that the autumnal die-offs were due to severe food shortages during the summer. Pooled percentages for the two years show that the lowest percentages of *Neanthes* occurred in the fish stomachs during July and August (Table 49)—an important fact when it is considered that *Bairdiella* was nearly completely dependent upon the worm for food. The high incidence of inedible debris (sticks, mud, sand) in the fish stomachs at this time and the low volumes of food intake during the summer months corroborated these findings (Figure 68). Summer food shortages seemed largely due to the anoxic conditions in the deeper waters during the warmer months.

Despite improved feeding conditions from September through the fall of 1954, large numbers of thin and dead fish continued to appear on and near the beaches. Gill nets set in shallow locations caught some extremely thin individuals and others that were in excellent condition. This paradoxical situation continued into the winter, apparently because very thin fish were too weak to obtain their food, which normally consisted of actively-swimming worms. This was shown by comparing the diets of thin and normal fish over this period (Table 50). Feeding conditions were not as restricted in the fall of 1955 as in the same season of the previous year. Thin fish appeared in samples taken during the fall of the second year but they were not as emaciated, and the associated die-off was less intense. The factors responsible for the improved conditions in the second year are not known. These could have included increased productivity of worms, shorter periods of worm absence in deep water, or a smaller population of fish utilizing this resource.

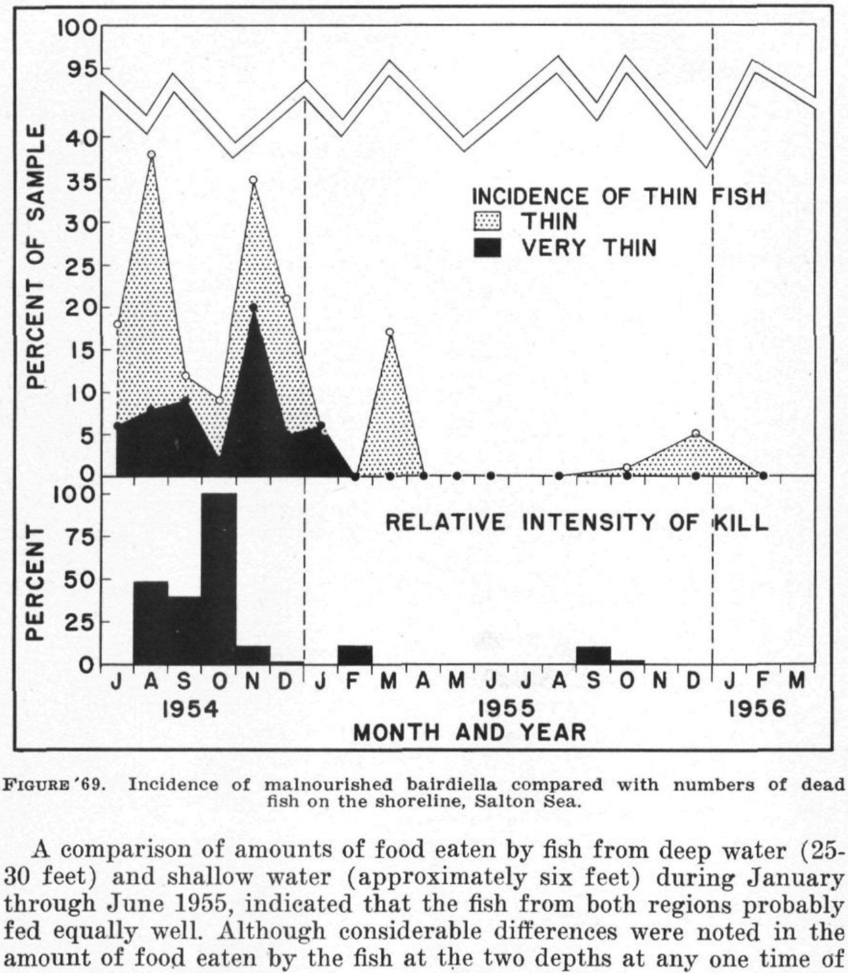


FIGURE 69. Incidence of malnourished bairdiella compared with numbers of dead fish on the shoreline, Salton Sea.

A comparison of amounts of food eaten by fish from deep water (25-30 feet) and shallow water (approximately six feet) during January through June 1955, indicated that the fish from both regions probably fed equally well. Although considerable differences were noted in the amount of food eaten by the fish at the two depths at any one time of day, neither position seemed superior during the spring. Unfortunately,

TABLE 50

Comparison of Amount of Food in Stomachs of Normal and Thin Bairdiella From the Salton Sea After Two Periods of Summer Food Shortage

	Normal Fish		Thin Fish		Very Thin Fish	
Sample Period	No. of Fish	Mg of Food Per gm of Fish	No. of Fish	Mg of Food Per gm of Fish	No. of Fish	Mg of Food Per gm of Fish
August 1954	63	.07	25	.10	6	.00
Sept 1954- January 1955	224	9.00	25	5.59	37	3.75

shallow and deep sets were not run during the periods of severe bottom anoxia. The role of bottom conditions in the economy of the Sea was not sufficiently understood at that time.

Feeding and Digestion Rates

Feeding and digestion rates were sought from two sources: consecutive fish samples taken during 24-hour periods in the same locality, and experiments in which the fish were fed whole worms and then sacrificed at various periods after feeding. Although the results of both approaches were inconclusive, some general information was obtained.

A food ratio of 150 mg of worms per gram of fish is probably near the upper limit for bairdiella gastric capacity. In only three instances was this value exceeded, and these included calculations for the entire digestive tract (excesses of 2 to 56 mg). Far more common were quantities ranging from 60-90 mg/g for the fullest fish of the night-time samples. Average values were much lower (Figures 68 and 70).

Feeding experiments with captive fish in aquaria disclosed tremendous variation in digestive rates, apparently depending upon the quantity of food eaten. Although fish that had eaten small amounts were able to empty their stomachs sooner, fish ingesting 500-2,000 mg of food usually retained it after 16 hours of digestion at 30 degrees C. In the latter group, fish weights varied from 12-28 g and food ratios for their stomachs from 44-78 mg/g.

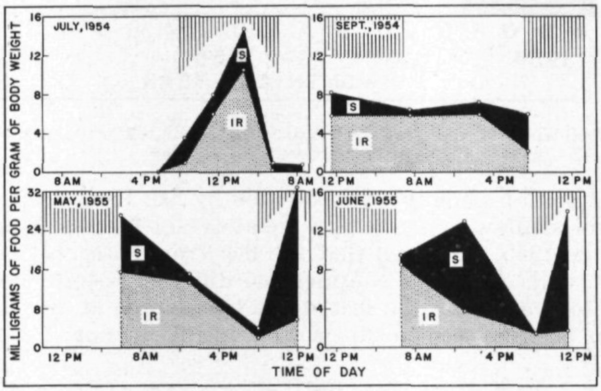


FIGURE 70. Diurnal feeding patterns of bairdiella in the Salton Sea. S = estimated weight of food in stomach; IR = estimated weight of food in lower digestive tract; vertical shading at top indicates hours of darkness. Fish examined per day = 30 to 50.

The variation in diurnal feeding patterns in respect to volume of food was observed by graphing consecutive diurnal samples (Figure 70). On July 13 and 14, 1954, the stomachs were empty during the daytime, contained various quantities of worms during the first half of the night (the stomachs and intestines reached their maximum expansion after midnight), and were nearly empty the following morning. On September 11, 1954, food was found during the entire sampling period, and feeding was apparently quite constant. In May 1955, night feeding was very intense and day feeding relatively low, and the quantities obtained during the previous night apparently were well-digested and removed by the following evening. The June sample showed a daylight peak in feeding, as judged by stomach contents, and also a constant decline in contents of the intestine and rectum during the day. This daylight peak in feeding was exceptional and indicated an abnormally high availability of worms. Such availability, normally seen only after dark, may have been caused by anoxic conditions developing near the Sea bottom.

During the warmer part of the year (April-October), declines were usually discernable in the daily feeding records during the afternoons with peaks occurring at night. This feeding cycle was evidence that the result of the night's feeding normally was digested by the following evening. This was substantiated by the modal sizes of the worms in the digestive tracts: the large mandibles of night-swimming worms normally disappeared completely from the digestive tracts during the 12 to 14 daylight hours that followed a night feeding period.

Reliability of Stomach Fullness Estimates

When fish were opened a visual estimation was made of stomach fullness, in the hope that it might be a rapid yet reasonably accurate method of measuring food intake. Subsequent examination of the data, however, led to the conclusion that such a technique had serious shortcomings as far as bairdiella was concerned. Estimates of weight of food in the stomachs that were made in the summer and fall of 1954 and 1955 were consistently lower than those made in the spring of 1955. The fall estimates for 1954 were also consistently lower than those of the fall of 1955, but the discrepancy was smaller. Although a reasonably reliable regression line, estimating the fullness from actual worm weight, could be drawn within each of the three periods, there was a very great variation in regard to the estimate and the actual weight. The errors among the three periods were probably not due to changing bias on the part of the observer but rather upon actual changes in the stomach dimensions with the seasons. In the poorest feeding period of the study (summer and fall 1954), stomachs one-half or one-quarter full actually contained much less weight of food than those with the same estimated amounts taken in the summer and fall of 1955. The spring of 1955, which was one of glut for the fish, gave the highest actual weights for the estimates of fullness. Evidently during periods of heavy feeding, such as the spring of 1955, the stomach maintained a larger size, which persisted throughout the period of food abundance. This led to higher weights for a given estimated stomach fullness. During the season of heavy feeding, the stomach walls appeared very thin, even when they were not filled to capacity.

DISCUSSION

Reproduction of *Bairdiella icistius* in the Salton Sea resulted in the rather unique situation of having a large population of marine fish dependent upon a single food resource. This food resource effectively limited the size of the fish population by severe fluctuations in standing crop during the year. Although actual data on fish population densities are lacking, a decrease in numbers may be inferred from the large kills that occurred. These periods of starvation and attrition of the fish population occurred during and after summer food scarcities that presumably were caused by anoxia in the deeper waters.

Young-of-the-year bairdiella utilized copepods and their larvae, barnacle larvae, and fertile eggs and smaller larvae of their own species. Many young bairdiella were able to bridge the summer *Neanthes* shortage, and were recruited into the fish population during the fall, when the *Neanthes* again became available in quantity. Survival of the fish population through the annual summer worm shortages was assured because of three factors: the young were able to utilize a different food resource than the adults; they were not completely destroyed by larger fish during the summer food shortage; and large numbers of adults survived despite the shortages. Significant predation on adults did not occur during the period of study because no predator was present in sufficient numbers at that time.

The benefits to fish production as a result of introducing the same or a similar polychaete into the Black and Caspian Seas were described by Zenkevich (1957). In the Sea of Azov, at least, it was the sturgeon that benefited most from the introduction. In both bodies of water, however, elaborate food chains were present before the worm was introduced (Caspers, 1957), in contrast to the limited chains present in the Salton Sea. Establishing a predator in the Sea (successfully accomplished at the time of writing) and introducing other food sources for forage and predator species should smooth out the fluctuations that characterized the relatively simple worm-fish economy.

THE ORANGEMOUTH CORVINA, *Cynoscion xanthulus* Jordan and Gilbert

RICHARD R. WHITNEY

INTRODUCTION

The orangemouth corvina promises to become the gamefish long sought for the Salton Sea by the California Department of Fish and Game. They apparently spawned for the first time in the Salton Sea in 1952, and continued to spawn successfully each year up to and including 1957, when our observations terminated. Each new year-class was more abundant in the samples than its predecessors. Spawning in 1956 and 1957 produced year-classes which seemed abundant enough to support sport fishing. The 1955 year-class, which was not abundant in our samples, yielded at least five hook and line captures to a fishing effort which was understandably slight. The effort was so slight, in fact, that at no time during the study was it practical to survey it quantitatively. A close contact was maintained, however, with operators of access points on the shore of the Sea, with local sportsmens groups, sporting goods stores, and newspapers, in order to obtain authentic records of catches by hook and line. The nature of the five reports received emphasized the slight effort for corvina, only three of the five having been taken by individuals who were fishing specifically for corvina. A fishing contest sponsored by a local resort in the spring of 1957 brought 39 registrants, but no success for corvina.

Very little is known about orangemouth corvina. Their spawning habits and growth rates have apparently not been studied. Skogsberg (1939) mentions that they played a minor role in the Mexican catch of corvina which is brought into California. Berdegue (1956) stated that the major portion of the Mexican catch was exported into California.

The orangemouth corvina has been observed making runs at times up the Colorado River, at least in tidal waters (personal observation, observation of L. J. Hendricks, and verbal communication from J. B. Kimsey). Kimsey also found small orangemouth corvina, 82 to 114 mm long, in tidal waters of the Colorado River in mid-March 1957, giving some indication that spawning might occur in nearby areas. The corvina have not been observed in the rivers or canals emptying into the Salton Sea, but do seem to congregate near the mouths of these freshwater inlets in the spring months.

INCREASE IN POPULATION IN THE SALTON SEA AS INDICATED BY CATCHES IN GILL NETS AND SEINES

Although it was not practical to set standard amounts of gill nets at periodic intervals, as was done with seines, the total gill-net effort in the Salton Sea was in the same order of magnitude each year (Table 51). The catch of corvina increased considerably each year, however, due to increased catches of the later year-classes.

Nylon and linen gill nets of four-inch and five-inch stretch mesh were used primarily. Two-inch mesh nets and experimental gill nets with various mesh sizes were used to a lesser extent. The nets longest employed were of the four- and five-inch mesh sizes, since these reduced somewhat the nuisance catches of bairdiella. Because of the many snags from submerged trees and brush in the Sea, the gill nets used in 1954 and 1955 had to be replaced at the end of 1955. The replacement nets were of about the same mesh sizes as the others but of heavier twine. They were about 340 feet long, 12 feet deep and of No. 288 twine. The usual overnight set consisted of three of these nets and 100 feet of two-inch mesh net set in the same vicinity. Experimental gill nets were usually set for short periods and specifically for bairdiella or threadfin shad. Their small mesh sizes were not efficient for catching corvina.

Figure 71 shows locations where overnight sets of gill net were made in the Salton Sea and the number of corvina captured is shown in Table 52. Certain locations were fished more heavily than others. This might have affected the total catch, especially in 1956 when considerable effort was expended in the vicinity of the mouth of the Alamo River, where the largest catches of corvina were made. In 1957, however, the catch was greater in that area — 144 fish compared to 102 in 1956 — even though there was much less effort than in 1956.

The most successful corvina fishing was in the vicinity of the former mouth of the Alamo River, a straight, dredged channel whose banks had become overgrown with brush and trees and subsequently submerged by rising water. The tops of the dead trees extended from the water and marked this old channel which ran about three miles into the body of the Sea where the water was six to eight feet deep. A very strong current of water, moving from west to east across the end of the old channel, was observed on many occasions, even when winds were light. No freshwater ran through the channel, because the river had been diverted by a dike. Catches of corvina were highest in the spring and fall months in this area.

In other areas, it was our impression that catches near the canals were highest in the spring and fall months. The fish seemed to spread out

TABLE 51

Yearly Gill Net Catches of Orangemouth Corvina of Various Year-Classes in the Salton Sea

Year-Class	Catch in Numbers of Fish by Year				Total Catch
	1954	1955	1956	1957	
1952	3	5	4	---	12
1953	--	--	4	1	5
1954	--	2	44	6	52
Early 1955	--	--	43	17	60
Late 1955	--	--	111	108	219
1956	--	--	---	30	30
1957	--	--	---	2	2
Total Catch	3	7	206	201*	417
Gill Net Effort in Hundred Foot Hours	3,383	2,993	4,668	3,292	

* Includes 37 fish caught in April 1957 which were not identified as to year-class.

somewhat in the summer, July, August, and September, and catches were generally lower. Winter catches were uniformly low, a result, perhaps, of dormancy among the corvina.

The uniform catch of 1952 year-class fish each year except 1957 was a reflection of the roughly uniform fishing effort. The gill-net catch for 1957 did not reflect the real abundance of fish of the 1956 or 1957 year-classes, since they did not become susceptible to capture in our large-mesh nets until just before sampling was curtailed. The first high catches of 1955 year-class fish, for instance, came in the fall of 1956. Certainly, an increase from year to year in availability of corvina is indicated by the gill-net catches, undoubtedly due to increases in abundance of the 1954 and 1955 year-classes. The 1953 year-class did not appear to have been as successful as the others.

An idea of the relative abundance of the 1956 and 1957 year-class of orangemouth corvina can be derived from catches of young-of-the-year in the 50-foot seines used each month from October 1954 to May 1957.

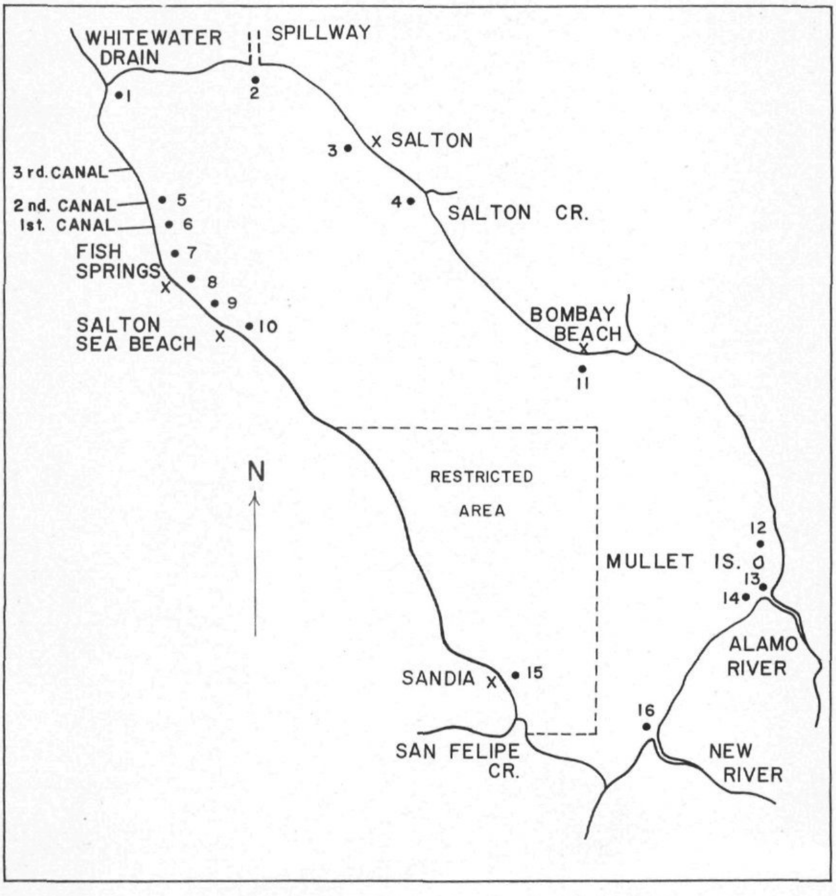


FIGURE 71. Locations of gill-net sets for orangemouth corvina in the Salton Sea, 1954 to 1957.

TABLE 52

Location, Catch, Total Effort and Number of Gill Net Sets for Orangemouth Corvina in the Salton Sea, 1954-1957

Number of Gill Net Sets (Numbers of fish caught shown in parentheses)						Number of Gill Net Sets (Numbers of fish caught shown in parentheses)					
Station Number*	January-March	April-June	July-September	October-December	Effort in 100 Foot-Hours**	Station Number*	January-March	April-June	July-September	October-December	Effort in 100 Foot-Hours**
1954						**1955**					
1	--	--	--	--	--	1	--	--	1	1	150
2	--	2	--	--	150	2	1 (1)	1	--	2	200
3	--	1 (1)	1	--	100	3	1	1 (1)	--	--	150
4	--	1	--	--	100	4	--	--	--	--	--
5	--	--	1	2	400	5	1	1	1	1	400
6	--	3 (2)	1	3	1,000	6	2	--	2	--	550
7	--	--	--	--	--	7	--	--	--	--	--
8	--	2	2	2	800	8	2	--	2 (1)	1	400
9	--	--	--	1	100	9	--	--	--	--	--
10	--	1	1	1	300	10	--	--	--	--	--
11	--	--	--	1	100	11	--	--	1	--	100
12	--	--	2	1	250	12	--	--	--	--	--
13	--	--	--	--	--	13	--	2 (1)	--	3	300
14	--	--	--	1	100	14	1 (2)	--	1	1 (1)	350
15	--	--	--	--	--	15	--	--	--	--	--
16	--	--	--	--	--	16	--	1	--	1	100
1956						**1957**					
1	--	1	--	--	100	1	--	--	--	--	--
2	1	3 (12)	1	2 (14)	850	2	2 (2)	1	--	--	500
3	--	1 (1)	2 (3)	--	300	3	1	1 (10)	1 (25)	--	300
4	--	--	--	--	--	4	--	--	--	--	--
5	--	2 (8)	1 (1)	--	150	5	1 (2)	--	--	--	100
6	--	--	2 (3)	3 (27)	850	6	2	1 (7)	1 (10)	1 (14)	950
7	--	1	--	--	100	7	--	--	--	--	--
8	--	2 (8)	3 (12)	3 (8)	1,100	8	1	--	--	1 (6)	200
9	--	--	--	--	--	9	--	--	--	--	--
10	--	--	1	1	250	10	--	--	--	--	--
11	--	--	--	--	--	11	--	--	--	--	--
12	5	--	2 (1)	--	500	12	1	--	--	--	100
13	3 (3)	1 (1)	2 (3)	1 (2)	500	13	1 (9)	1 (15)	--	--	150
14	1	1 (3)	2 (18)	2 (71)	450	14	2 (6)	3 (114)	--	--	1,100
15	--	--	--	--	--	15	--	--	--	--	--
16	--	1	--	--	150	16	--	--	--	--	--

* See Figure 76 for localities.

** 100 feet of gill net fished for one hour.

No corvina were caught in seines until 1956 when one member of the 1955 year-class was taken in June. Routine seining in 1957 brought 16 corvina of the 1956 year-class and eight of the 1957 year-class, though the monthly sampling had to be discontinued after August while the fish were still available to seines. Catches in 1957 were made at six of the eight locations where 50-foot seines were used around the shore of the Sea.

POPULATION ESTIMATE

Considerable importance was attached to the possibility of estimating the number of corvina in the Salton Sea, because of their potentialities as gamefish. Marking a sufficient number from catches made in the Sea seemed to be impractical because of the apparent small size of the population relative to the area of water. A prohibitive amount of effort would have had to be expended to mark enough to expect recaptures. In view of the demonstrated ability of the orangemouth corvina to survive in the Salton Sea, additional plants were made. Marking the fish brought from the Gulf of California offered the possibility of introducing a large enough number so that recaptures might be expected. A total of 1,263 corvina, marked by removing one or both pelvic fins, was planted in the Salton Sea in April and May 1956.

Unfortunately, only a few orangemouth corvina were captured in the Gulf of California for planting in 1956. Most of the fish were shortfin corvina, *Cynoscion parvipinnis*. Of the 1,263 fish marked, 1,200 were shortfin corvina and only 59 were orangemouth corvina. The total plant in 1956 consisted of 1,604 corvina. This of course raises a question as to the validity of using recaptures predominantly of shortfin corvina to estimate a population of predominantly orangemouth corvina. If it can be assumed that differences in their habits would not lead to a differential rate of capture in gill nets in the Salton Sea, then this difficulty can be overlooked. Unfortunately very little is known about the habits of these species. They were often taken together in seining operations in the Gulf of California, so they must be similar in some habits. The possibility exists that the two species school separately. If it can be assumed that the schools were sampled at random, this difficulty can also be overlooked. It must also be assumed that mortality of the planted fish was the same as the mortality of fish already present.

It is possible that fish newly introduced into the Salton Sea might be more, or less, active than those already present. It seems reasonable to suppose that a predatory fish, such as the corvina, would become more active on being transported to a place where food is more abundant and competition slight, and this would make it more likely to be caught in gill nets. This would result in too many recaptures, and tend to lower the population estimate. If the estimate can be regarded as too low, then it is of more use in the present case than it otherwise might be.

The planted fish apparently became well-distributed in the Sea or at least ranged widely. They were captured in all areas where nets were set. A total of 12 fin-clipped fish, 11 shortfin and one orangemouth, was taken in a catch of 385 (not including 1956 or 1957 year-class fish), from April 1956 to October 1957. This gave an estimated population of 40,000 corvina, with a 95 percent confidence interval of 20,000 to 120,000, in the Salton Sea in 1956. This estimate refers to both species and includes introduced fish and native-spawned fish of the 1952, 1953, 1954 and 1955 year-classes. The wide and asymmetrical confidence interval certainly reflects the crudity of the estimate. It was apparent, nevertheless, that the nearly 2,000 fish planted, amounted to at most 10 percent of the population. Considering the continued success of spawning each year in the Salton Sea, the planting operations were discontinued.

Judging from the catch in seines, the 1956 and 1957 year-classes were more than 20 times as abundant as the 1954 or 1955 year-classes, so an estimate of 800,000 corvina in the Sea in 1957 was probably conservative.

GROWTH

The fish were measured and weighed in the laboratory as soon after netting as possible. This varied from two to six hours after capture, depending on the distance from the laboratory and the number of fish in the catch. If air temperatures were high, the fish were transported in ice. One large sample of 80 fish was subsampled, and only 43 were taken into the laboratory. Scales were removed from an area just below the lateral line and near the end of the pectoral fin when it was flattened against the body. Otoliths were taken from each fish, fin rays were counted, and notes made of any abnormalities. The viscera and gills were then removed from each fish and preserved in 10 percent formalin. These were later examined for gill-raker counts, stomach contents, and gonad condition. No parasites were observed during the examinations.

Lengths, in the discussion which follows, refer to standard length in all cases. Standard length was chosen because the caudal fin is much more pointed and longer in relation to the rest of the body in the small corvina (Figure 72) than the larger ones. Measurements of total length would therefore not give a true picture of increases in body length.

Description of growth of the individual year-classes was complicated by the appearance of a double brood in 1955 and 1957. Though only small samples of young-of-the-year fish were available, it appeared that in those years two groups of fish developed from spawning in the spring, and that each was characterized by its own growth rate. The

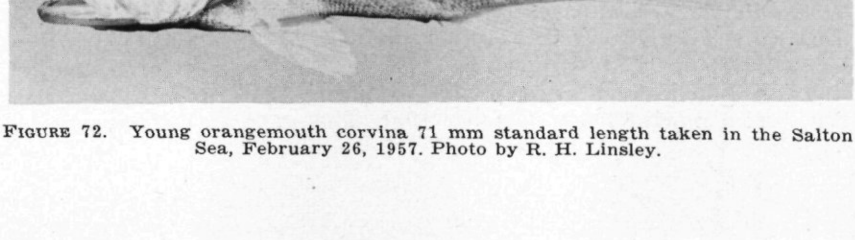


FIGURE 72. Young orangemouth corvina 71 mm standard length taken in the Salton Sea, February 26, 1957. Photo by R. H. Linsley.

young-of-the-year corvina fed on *Neanthes* for a time, and therefore were competing for food with bairdiella. As a result, growth was slow at first. It is possible that corvina which hatched earlier in the spring were able to reach a size by September or October where they could feed on bairdiella, and as a result showed rapid growth. Perhaps corvina that hatched somewhat later found their growth paralleling that of the young bairdiella and were unable to feed on fish, and therefore did not grow rapidly until the following spring, after bairdiella had spawned and produced a new supply of small fish.

The indication of a double brood came from tracing the growth of a group of young-of-the-year corvina which were sampled first in August of 1957. The eight specimens taken in seines at that time had an average length of 43 mm, and ranged from 20 to 77 mm. They were clearly young-of-the-year, since none showed any signs of a mark or annulus on the scales. It appears, however, that differences in growth were already separating them into two groups, their lengths being 20, 21, 27, 30, 38, 64, 71, and 77 mm. Table 53 shows the average lengths of these fish taken through October 1957. The average length of four taken in September 1957 was 58 mm, though again their lengths of 32, 42, 57, and 100 mm suggest two groups with different growth rates. The corvina of this year-class taken in October 1957 were probably all representatives of the faster-growing segment of the population which were large enough to feed on bairdiella and other fish. This would account for the sudden increase in average length between September and October 1957. Possibly, the corvina of the slower-growing segment of the population moved away from shore in the fall so that they were not available to the seines.

The existence of a slower-growing part of the population would explain the small corvina in the seines in February 1957 (Table 53). Ten corvina taken at that time averaged 68 mm and had quite uniform lengths, these being 56, 57, 59, 65, 67, 68, 71, 82, and 90 mm. The

TABLE 53

Average Lengths and Scale Characteristics of Small Orangemouth Corvina Caught in the Salton Sea, 1957

	Fish With a Mark Near the Focus of the Scales				Fish With No Marks or Annuli Anywhere on the Scales			
Month	Average Standard Length in mm	Range in mm	No. of Fish	Method of Capture	Average Standard Length in mm	Range in mm	No. of Fish	Method of Capture
Feb. & March	68	56–90	10	50′ seine				
April & May	88	67–111	6	50′ seine				
June	257	–	1	gill net				
July	290	–	1	gill net				
August					43	20–77	8	50′ seine
Sept.	363	338–392	11	gill net	58	32–100	4	50′ seine
Oct. 4	337	325–358	6	gill net				
Oct. 11					179	–	1	hook and line
Oct. 23	364	310–436	11	gill net	266	241–291	2	gill net

scales of these fish showed signs of an annulus or mark developing near their edges. All of the members of this group taken several months later, in April and May, showed this mark near the edge of their scales. They apparently were members of the 1956 year-class, all of which were slow-growing during their first year.

Also bearing on this problem was the growth of two groups of fish sampled in 1956. Two fish taken in January and one in May were 282, 308, and 300 mm long, respectively, and showed no marks or annuli on the scales, except the one taken in May. It had an annulus very near the margin of each scale. These fish clearly represented the 1955 year-class, and had obviously shown no retardation of growth; probably they grew as did the group sampled late in 1957, with length increases in the fall of their first year. A group of fish then appeared in the June 1956 samples which showed an annulus-like mark near the focus of the scales. Their standard lengths were 223, 231, and 249 mm—at least 50 mm shorter than the fish taken earlier whose scales showed no annuli. These were apparently slow-growing members of the 1955 year-class that had remained small through the winter and then suddenly increased in the spring.

The appearance of the double brood might also be explained by spring and fall spawning. However, the gonads of the corvina indicated that maturation took place in the spring. Unfortunately the study had to be discontinued at a time when the young-of-the-year corvina were becoming abundant enough to provide samples that would have answered this question. A larger sample of adult fish in the fall would also have made it possible to state definitely whether some corvina matured in the fall or winter.

The most likely explanation of the double broods seemed to be the first one given, since there was no indication of a fall-spawning population. The designation of year-classes in the following discussion therefore was based on the interpretations that corvina spawning took place in the spring and that a double brood might or might not develop, depending on the availability of small fish as food for the young-of-year corvina.

Apparently only one brood was produced in 1952, 1954, and 1956, since members of these year-classes all had marks near the centers of their scales, but no clear annulus, when first taken in 1954, 1955, and 1957 respectively. The 1952 year-class fish were forming an annulus at the edge of the scales. These would all be slow-growing, or late-spawned fish in the present interpretation. There was little doubt as to the identification of the 1955 year-class (early-spawned), or the 1957 year-class, since there were no marks of any sort on the scales of the 1957 year-class fish in 1957, and only one rather clear annulus on the scales of the 1955 year-class fish when they were first taken in 1956. The designation of the other year-classes would be correct even if some of the groups originated from fall spawning. It could only be incorrect if the origin of the fish with marks near the focus of the scales were spawned earlier than April to June. This does not seem likely, because the fish collected in February 1957 were 56 to 90 mm long and must have been spawned either in the fall of 1956 or, as assumed here, in the late spring of 1956.

The mark near the focus of the scales which identified the late-spawned year-classes was usually quite clear and distinct, though as the scales increased in size it became difficult to consider it as being equivalent to the large and conspicuous annuli appearing farther out on the scales. In some of the 1954 year-class fish the mark or first annulus was rather indistinct. Six fish caught in 1956 and one caught in 1957 were included in this year-class on the basis of the great distance to the first annulus, even though an inner mark was not clearly seen.

Growth did not seem unusually rapid until a length of about 100 mm (3.9 in) was reached, when a period of spectacular growth began (Figure 73). The late-spawned groups apparently reached a standard length of about 380 mm (15.0 in) by their second winter. Early-spawned groups reached a length of about 300 mm (11.8 in) by their first winter. Growth slowed or stopped in each group during the winter and increased in the spring. In the older year-classes in 1956 and 1957 there was a period of little or no growth in June and July followed by an increase in August and September. This spring and fall growth brought the orangemouth corvina to standard lengths near 500 mm (19.7 in) by their third winter, judging by the performances of the 1952, 1954, and 1955 year-classes. Four fish of the 1952 year-class averaged 646 mm (25.4 in) in length when caught in May of their fifth year, 1956. One fish, probably of the 1953 year-class was 612 mm long when taken in May 1957. No 1952 year-class fish were taken in 1957.

Weight increases followed a pattern similar to that for length. The late-spawned groups reached weights of about $2\frac{1}{2}$ pounds by the second winter, $5\frac{1}{4}$ pounds by the third, and 11 pounds by the fourth. Early-

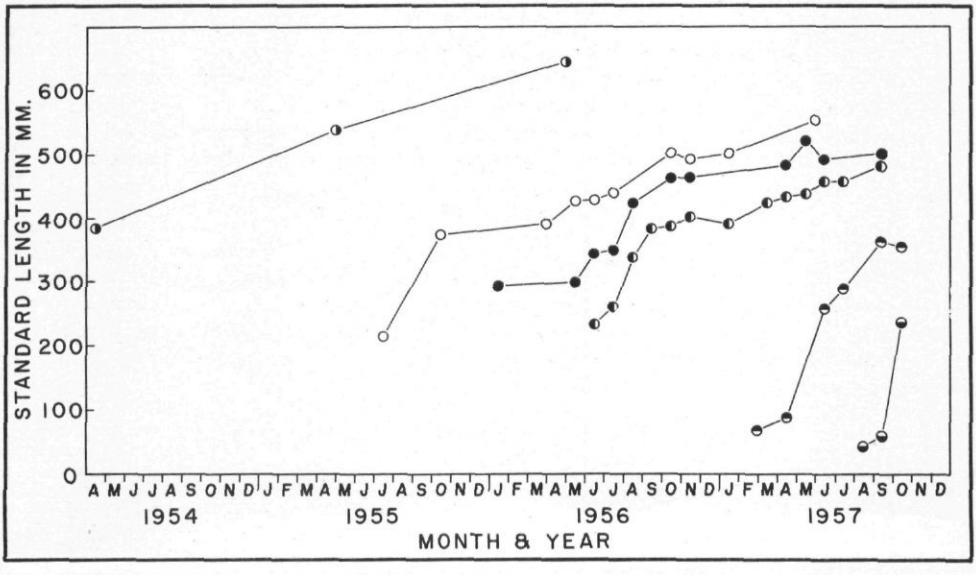


FIGURE 73. Average lengths of age-groups of orangemouth corvina from the Salton Sea. (Sample sizes in Table 54. ◑ = 1952 year-class (late) ; ○ 1954 year-class (late) ; ● = early 1955 year-class; ◐ = late 1955 year-class; ◓ = 1956 year-class (late) ; ◒ = early 1957 year-class.

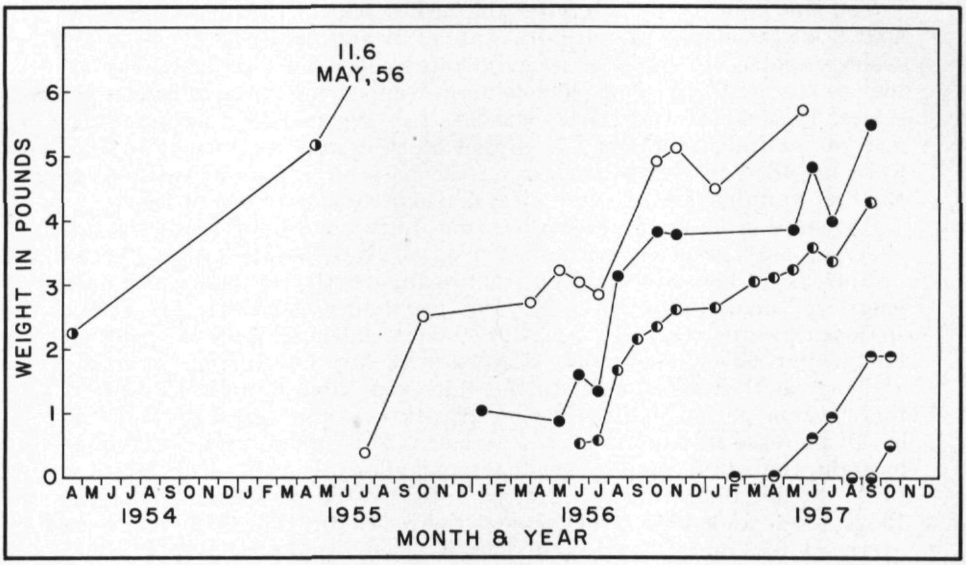


FIGURE 74. Average weights of age-groups of orangemouth corvina in the Salton Sea. ◑ = 1952 year-class (late); ○ = 1954 year-class (late); ● = early 1955 year-class; ◐ = late 1955 year-class; ◓ = 1956 year-class (late); ◒ = early 1957 year-class.

spawned groups, as shown by the 1955 year-class, reached 1 pound by the end of their first year, and $3\frac{3}{4}$ by the end of their second.

Abrupt weight loss might give some indication of spawning time, particularly where length increases continued. The loss of weight of the 1954 and early 1955 year-classes in June and July 1956, for instance might have been associated with spawning (Figure 74). Also, the loss of weight of the late 1955 year-class fish, which occurred between June and July 1957 was probably the result of spawning. In this case, the time apparently corresponded to the time of origin of the 1957 year-class corvina. Sample sizes are indicated in Table 54.

LENGTH-WEIGHT RELATIONSHIP

The relationship of weight to length in orangemouth corvina is curvilinear (Figure 75). As has been pointed out, the length-weight relationship probably differed during the year. Nevertheless, the variations seem to be within rather narrow limits, so that, on the average, estimates of weight from length using this curve are satisfactory for general purposes.

ESTIMATES OF GROWTH FROM THE SCALES

No corvina shorter than 200 mm standard length were taken before 1957, so the scale method was used to estimate the length of all of the age groups at the time the first annulus was formed. Considering also the small size of most of the samples, and the fact that they were spread over a period of several years, the samples were pooled by using the annuli on the scales as reference points. In this way, larger samples re-

TABLE 54

Mean Lengths and Weights of Orangemouth Corvina From the Salton Sea, 1952-1957

Date	YEAR-CLASS																				
	1952			1953			1954			Early 1955			Late 1955			1956			Early 1957		
	Std. Lgth. mm	(No.)	Wt. Lbs.	Std. Lgth. mm	(No.)	Wt. Lbs.	Std. Lgth. mm	(No.)	Wt. Lbs.	Std. Lgth. mm	(No.)	Wt. Lbs.	Std. Lgth. mm	(No.)	Wt. Lbs.	Std. Lgth. mm	(No.)	Wt. Lbs.	Std. Lgth. mm	(No.)	Wt. Lbs.
1954																					
Spring	385	(5)	2.3																		
1955																					
Spring	538	(5)	5.2																		
July							215	(1)	0.4												
Oct.							375	(1)	2.5												
1956																					
Jan.										295	(2)	1.0									
Apr.							392	(2)	2.7												
May	646	(4)	11.6				429	(13)	3.2	300	(12)	0.9									
June							430	(8)	3.0	344	(3)	1.6	234	(3)	0.5						
July							441	(10)	2.8	350	(5)	1.3	261	(4)	0.6						
Aug.				557	(4)	6.3				425	(4)	3.1	339	(9)	1.7						
Sept.													385	(2)	2.2						
Oct.							503	(10)	4.9	463	(14)	3.8	338	(80)	2.3						
Nov.							494	(1)	5.1	465	(3)	3.8	403	(13)	2.6						
1957																					
Jan.							502	(2)	4.5				391	(12)	2.6						
Mar.													425	(1)	3.1	68	(10)	0.01			
Apr.										484	(10)	3.9	434	(41)	3.1						
May				612	(1)	8.9				521	(1)	4.0	439	(34)	3.3	88	(6)	0.02			
June							554	(3)	5.7	492	(1)	4.0	458	(5)	3.6	257	(1)	0.6			
July													458	(8)	3.4	290	(1)	0.9			
Aug.																			43	(8)	0.004
Sept.							507	(1)	5.0	501	(5)	5.5	483	(8)	4.3	363	(11)	1.9	58	(4)	0.01
Oct.																354	(17)	1.9	237	(3)	0.76

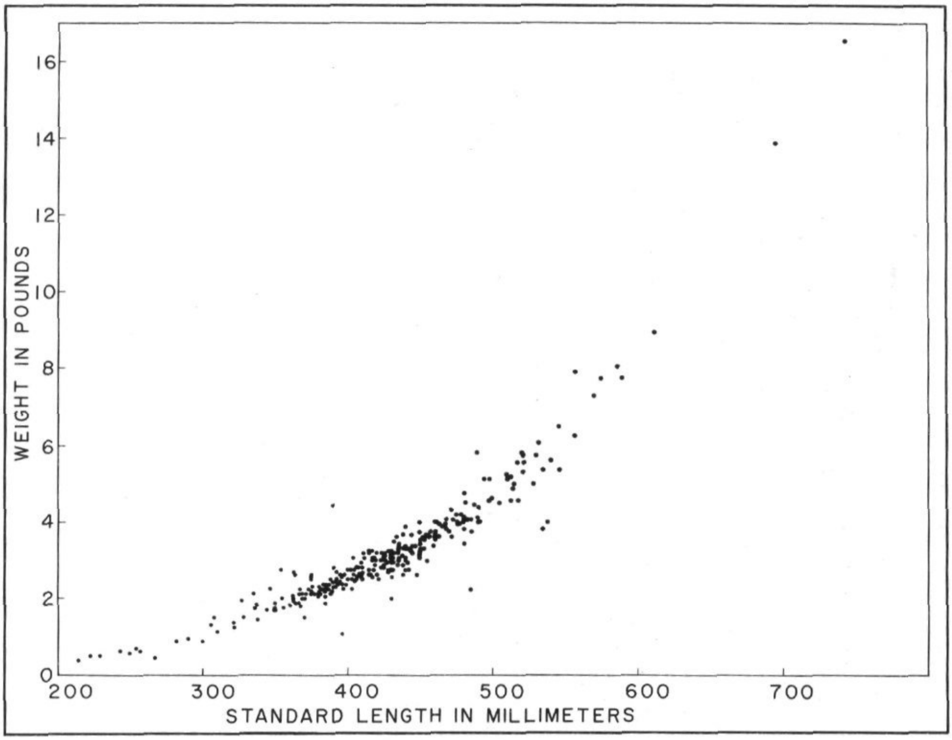


FIGURE 75. Length-weight relationship of orangemouth corvina in the Salton Sea.

ferring to restricted periods could be obtained and used to check the growth described at monthly intervals from the small, scattered samples.

Figure 76 shows the relationship of body length to scale length. The regression equation $\hat{Y} = 47.26 + 60.99\ X$, where X is scale length in inches times 29 and $\hat{Y}$ is the estimated body length, fails to pass through the points at the lower end of the distribution, where scale lengths times 29 are less than two inches. Possibly a curvilinear equation could be derived which would project a line through these points. Such a procedure might lead to further error in estimating the past growth of the larger fish because of possible differences in the body-scale relationship between year-classes. The points at the lower end of the distribution are from 1956 and 1957 year-class fish, which were not represented at the upper end of the distribution. Use of separate regressions for the year-classes would accomplish little, since it would still be necessary to project estimates beyond the parts of the lines for which observed points were available. It therefore seems best to rely on the linear regression derived from the combined sample, realizing that body lengths might be overestimated at early points on the scale by as much as 25 mm.

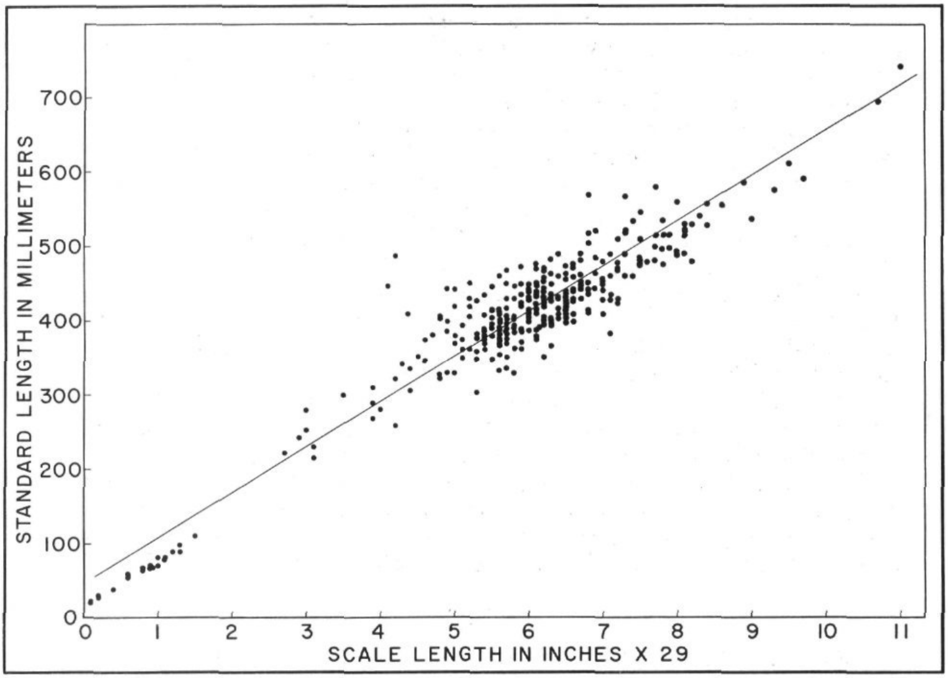


FIGURE 76. Relationship of body length and scale length of orangemouth corvina in the Salton Sea. (Regression equation $\hat{Y} = 47.26 + 60.90\,X$).

Table 55 shows the estimates of body length at the time of annulus formation on the scales of the various groups of corvina. The average distance to each annulus of each group was used in the regression equation to estimate the body lengths. Specimens collected through July 1957 were included.

TABLE 55

Estimated Body Lengths at Time of Annulus Formation of Orangemouth Corvina in the Salton Sea

	Standard Length in mm (Number of Specimens in Parentheses)							
Year-Class	At First Annulus		At Second Annulus		At Third Annulus		At Fourth Annulus	
1952	111	(12)	371	(12)	512	(6)	589	(4)
1953	109	(5)	358	(5)	456	(5)	560	(1)
1954	80	(42)	380	(47)	558	(3)	----	
Early 1955	----		231	(47)	473	(21)	----	
Late 1955	116	(208)	410	(88)	----		----	
1956	101	(8)	----		----		----	
Totals								
Late-Spawned Groups	110	(275)	396	(152)	502	(14)	583	(5)
Early-Spawned Groups	----		231	(47)	473	(21)	----	

It would not be appropriate to determine an average length at each annulus for all the groups because of the known differences in their performance, due possibly to differences in actual age at the time of annulus formation. For this reason, the average lengths in Table 55 were separated into estimates for early- and late-spawned groups. The estimated lengths were in good agreement with the actual lengths of corvina taken in the late fall and winter (Figure 73). The average length reached by late-spawned corvina when the first annulus was formed was estimated as 110 mm (4.3 in.), at the second annulus as 396 mm (15.6 in.); at the third annulus, 502 mm (19.8 in.); and at the fourth, 583 mm (23.0 in.). The early- and late-spawned groups might have grown at the same rate after they reached about 100 mm, though the annuli appeared at different stages in the process. The slopes of the lines in Figure 73, for instance, seem to be very nearly the same. The 558 mm estimated length for 1954 year-class fish at the third annulus seemed high compared to the observed lengths, although this was perhaps not an unusual difference for so small a sample.

The mark near the focus of the scales apparently formed when the corvina (late-spawned) were between 75 and 100 mm long, though, for reasons discussed previously, this estimate is subject to the greatest error. The mark was considered a true annulus.

FOOD

Young-of-the-year corvina first fed on copepods, barnacle nauplii, and other plankters, and then changed to *Neanthes*. The change apparently came when the fish reached a length between 30 and 60 mm (1.2 to 2.4 in.). The young-of-the-year taken in August 1957 had either copepods, barnacle nauplii and cyprids, or *Neanthes* in their stomachs. Three of the smaller corvina, 21, 28, and 30 mm in standard length, had mostly copepods in their stomach, and a few larval barnacles. Four larger corvina, 57, 64, 68, and 71 mm long, had fed only on *Neanthes*. Young-of-the-year bairdiella were too large for these small corvina. Of 16 small corvina, 56 to 111 mm long, seined in the early spring of 1957, 10 had *Neanthes* in their stomachs. The other six had empty stomachs, but two of these had *Neanthes* remains in their intestines.

Undoubtedly, young corvina began feeding on bairdiella as soon as they became available. Bairdiella spawned from April through June each year, so that numbers of small fish became available in May. The late-spawned corvina, apparently passed the winter at a length of about 70 mm, and were able to feed on small bairdiella beginning in May each year. A specimen 81 mm in standard length, taken in May 1957, had its stomach bulging with young-of-the-year bairdiella.

Since the young corvina depended on *Neanthes* for food, they competed for a time with bairdiella. This competition has probably been quite severe, judging by the effects which have already been described within the bairdiella population. This was probably the reason for the rather slow increase in the population of corvina in the Salton Sea, as compared to the sudden population burst of the bairdiella.

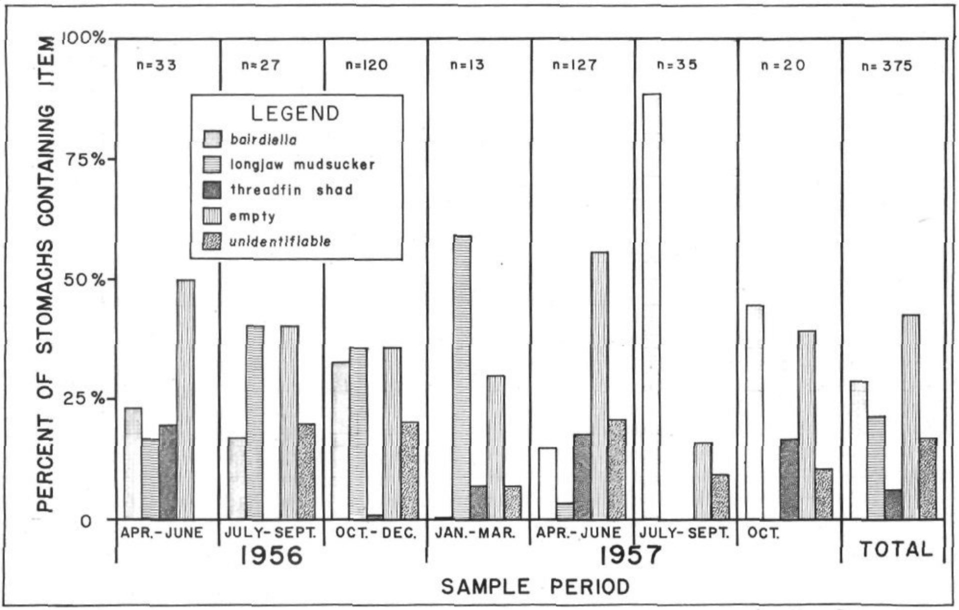


FIGURE 77. Relative percentages of various forage fishes in the stomachs of orangemouth corvina from the Salton Sea. Since more than one species may have been present, the bars in some cases add to more than 100 percent. The high percentage of empty stomachs and unidentified fish remains were mainly due to the fact that the nets were usually set for 24 hours.

The bairdiella was the most common food item of larger orangemouth corvina, followed by the longjaw mudsucker and threadfin shad (Figure 77). One corvina, caught near the mouth of the Alamo River, had the remains of a crayfish in its stomach.

It seems likely that the corvina will feed on any fish of appropriate size. A school or concentration of any of the forage species in the Sea might attract and hold a school of corvina until they have fed heavily. For instance, all 14 corvina in a sample caught on October 18, 1956, had their stomachs unusually full of mudsuckers: one contained five, another four, and the others from one to three. Obviously they had recently discovered a concentration of mudsuckers and had fed heavily on them. On the other hand, a sample of 52 corvina taken on October 3, 1956, included three which had three bairdiellas in their stomachs, 23 with one bairdiella and only two with mudsuckers.

It is probably not safe to generalize about seasonal changes in diet, because of the wide variation between the samples due to differences in locality and because of their small size. It would appear, however, that threadfin shad were eaten most heavily in the spring. The shad were attracted to the mouths of freshwater inlets at that time, as were the corvina, and were thus most available to the corvina. Since there was no repetition in the pattern of mudsucker occurrence in the stomachs, the decline in the latter part of 1957 could be explained by sampling variability.

GONAD MATURATION AND SEX RATIOS

The greatest number of ripe and nearly ripe corvina were caught in April and May during 1956 and 1957 (Table 56). The sample consisted primarily of 1955 year-class fish which were maturing for the first time in 1957, and their development might not have been representative of the population. It appears certain, however, that the 1955 year-class corvina spawned in late May or early June in 1957. Additional evidence came from the loss of weight which occurred at that time.

Gonads from 332 corvina were examined to determine sex and degree of development. Of the 261 fish whose sex could be determined, 130 were females and 131 were males. Where sex could not be determined most were 1955 year-class corvina, taken in the fall of 1956. To determine if any error had been introduced due to differences in recognizability of the sexes, samples taken in April, May, June, and July 1957 were investigated. A total of 76 males and 60 females was noted in these, while the sex of only one fish could not be determined. The observed numbers did not differ significantly from a 50:50 ratio (Chi-square = 1.8, df 1). It thus appeared that the sexes were in equal numbers in the Salton Sea.

NUMBER OF EGGS

The number of eggs in the ovaries of three corvina were estimated using the volumetric method. The volume of the ovary was determined by water displacement. Three samples of 0.5 cc each were then separated and the eggs in each were counted. The total volumes of the ovaries were 112, 130, and 135 cc. In all three there were smaller, undeveloped eggs along with the larger eggs which were free in the ovary. Enlarged, free eggs were estimated as 380,000; 970,000; and 1,200,000

TABLE 56

Gonad Condition by Month of Orangemouth Corvina From the Salton Sea, 1956-1957

Date	Gonad Condition					
	Reabsorbing	Very Poorly Developed	Poorly Developed	Fairly Well Developed	Well Developed	Very Well Developed or Ripe
1956						
May	--	--	1	1	3	1
June	--	--	1	1	4	1
August	--	5	6	1	--	1
October	--	25	11	--	--	--
November	--	5	8	--	--	--
1957						
January	--	6	5	--	--	--
April	--	8	15	11	29	6
May	--	4	6	12	6	16
June	--	--	--	3	2	1
July	7	2	--	--	--	--
September	15	10	--	--	--	--
October	4	2	--	--	--	--

respectively. The ovaries were removed from females caught on April 30, 1957 and May 28, 1956.

MERISTIC COUNTS

The first dorsal fin usually contains nine spines and the second dorsal fin one spine followed by 20 rays. The number of rays may vary from 18 to 23, but is most commonly 19, 20, or 21 (Table 57). Three fish had two spines in the second dorsal fin. There was no deviation from two anal spines in 305 specimens. The number of anal rays varied from 6 to 10, but was usually eight. These counts agree with those given by Jordan and Evermann (1898), for *Cynoscion xanthulus,* though they made no mention of the number of specimens examined nor of the variability encountered. They gave the fin formulas as D IX — I,20; A II, 8.

Gill-rakers were counted in 285 of the Salton Sea corvina. The rakers were often difficult to count because they diminished in size anterior to the angle of arch. Some were reduced to knob-like processes. Only those were counted which extended in a flap or filament from the arch. The most common counts were 3 or 4 rakers on the upper limb of the arch, and 7 on the lower (Table 57).

ABNORMALITIES

A fairly high percentage of abnormal individuals occurred in the population of orangemouth corvina in the Salton Sea. This was somewhat unexpected, considering their competition with bairdiella during their early development. In general, however, the corvina abnormalities were as severe as those of the bairdiella. Two members of the late-spawned 1955 year-class had sharply upturned heads (Figure 78). Three others with less severely upturned heads were also observed. Three fish with upturned heads were taken together in a sample of 14 corvina. This was probably an indication of the common origin of a school which was sampled by the gill nets.

Seventeen (8.0 percent) of the late-spawned 1955 year-class were abnormal in some way (Table 58). Eleven (8.5 percent) in the samples of the other year-classes were also abnormal. Because of the small

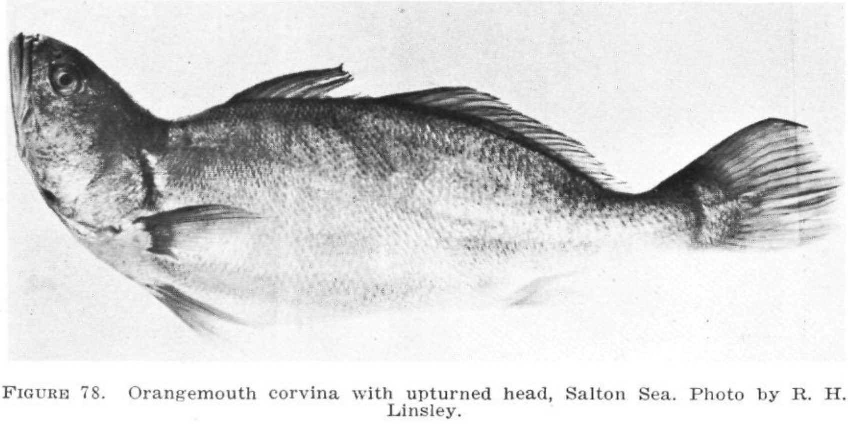


FIGURE 78. Orangemouth corvina with upturned head, Salton Sea. Photo by R. H. Linsley.

TABLE 57
Fin-Ray and Gill-raker Counts of Orangemouth Corvina From the Salton Sea

	Number of Elements																Sample Size
	1	2	3	4	5	6	7	8	9	10	– 18	19	20	21	22	23	
First Dorsal Spines	--	--	--	--	--	--	--	5	274	25	--	--	--	--	--	--	304
Second Dorsal Spines	301	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	304
Second Dorsal Rays	--	--	--	--	--	--	--	--	--	--	13	95	138	52	5	1	304
Anal Rays	--	--	--	--	--	1	76	219	7	1	--	--	--	--	--	--	304
Gill-rakers on First Arch																	
Upper Limb	--	4	156	122	3	--	--	--	--	--	--	--	--	--	--	--	285
Lower Limb	--	--	--	--	5	29	210	40	1	--	--	--	--	--	--	--	285

TABLE 58
Occurrence of Abnormal Orangemouth Corvina in the Salton Sea

Abnormality	Combined 1952, 1953, 1954, Early 1955 Year-Classes		Late Spawned 1955 Year-Class	
	Number Abnormal	Percent Abnormal	Number Abnormal	Percent Abnormal
Hunchback	9	6.9	3	1.4
Skewed Lower Jaw[1]	2	1.5	5	2.4
Upturned Head[2]	--	---	5	2.4
Missing Gill Arch	--	---	3	1.4
Snub-nose (pug-headed)[3]	1	0.8	2	0.9
Receding Lower Jaw	1	0.8	2	0.9
Twisted Spine	1	0.8	1	0.5
Missing Dorsal Fin	--	---	1	0.5
Malformed Opercle	--	---	1	0.5
Twisted Maxillary	1	0.8	--	---
Total Abnormal*	11	8.5	17	8.0
Total Sample	129	---	211	---

* The total abnormal may be fewer than the sum of the column above because some fish showed more than one abnormality.

[1] Figure 79.

[2] Figure 78.

[3] Figure 80.

samples, it could not be determined if there were any differences between the year-classes with respect to the frequency of particular kinds of abnormalities.

The abnormalities were in general much the same as those described for bairdiella. Two corvina had the first gill arch on the left side missing or reduced to a vestige, and one had the first arch on the right side missing. No blind corvina were ever observed. The frequency of abnormal individuals probably will decrease as the population increases. This has been the pattern, at least, in the case of bairdiella.

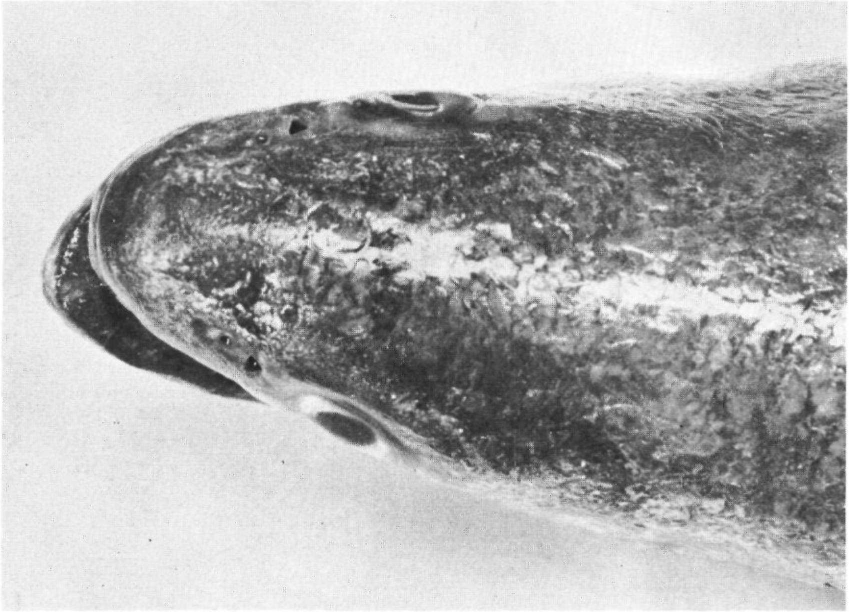


FIGURE 79. Orangemouth corvina with skewed lower jaw, Salton Sea. Photo by R. H. Linsley.

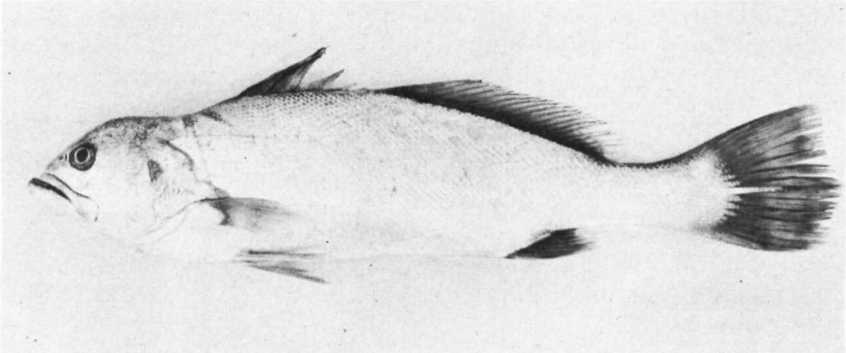


FIGURE 80. Orangemouth corvina with snub-nose (pug-headed), Salton Sea. Photo by R. H. Linsley.

GENERAL CONSIDERATIONS AND RECOMMENDATIONS

BOYD W. WALKER, RICHARD R. WHITNEY, and LARS H. CARPELAN

FOOD CHAIN

The Salton Sea is a large "marine-like" body of water rich in basic food consisting of microscopic plants. In the interest of a sportfishery, as much as possible of this basic food should be converted into catchable gamefishes. Those normally considered as gamefishes are carnivores which do not feed directly upon the phytoplankton. Intermediate organisms are necessary to assimilate the phytoplankton, and then, in turn, serve as "bite-sized" particles for fish or for other intermediates in the food chain.

There are several food chains operating in the Salton Sea. The most important to the sportfishery is the chain: phytoplankton→ zooplankton→ detritus→ detritus-eating worm (*Neanthes*)→ worm-eating fish (bairdiella and sargo)→ fish-eating fish (corvina). Of seasonal importance is the phytoplankton→ zooplankton→ threadfin shad→ corvina chain. In the Salton Sea only the phytoplankton, which is found throughout, and the blue-green algae, which are restricted to the bottom in shallow, quiet areas, are actually capable of producing food. They do this by utilizing energy from the sun to combine the mineral elements of the Sea into complex food products. These foods can be eaten by animals which use them for growth or oxidize them to provide energy. The food substances oxidized for energy are broken down into their original, simple components which are no longer available as energy sources, but are available for re-use by plants. Each animal in a food chain passes on to its successor only a part of the food it has consumed; that is, there is a loss at each link in a food chain. Therefore, the shorter a food chain, the more efficient it generally is. The plankton-shad-corvina chain is the shortest and therefore, at least theoretically, the most efficient one present.

Most prominent is the plankton-detritus-*Neanthes*-bairdiella and sargo-corvina chain. The plankton organisms, upon death, sink to the bottom and form a layer of organic debris (detritus) which is rich in food materials. This detritus is eventually broken down into its simple components by bacteria and other organisms; however, this process is relatively slow and the detritus therefore represents a temporary reservoir of basic food materials. The detritus is eaten by the worm, *Neanthes,* which in turn is eaten by bairdiella and other small fish which provide food for the orangemouth corvina. The existing food chains are working quite successfully.

All organisms studied in nature seem to have good and bad years in terms of abundance. Therefore, the greater the number of parallel links in a food chain the smaller will be the influence if any one link is lost. In the present primary food chain, the phytoplankton is composed of a number of species and the loss of any one would not have much effect upon the total production.

Barnacle nauplii and *Neanthes* larvae are fairly abundant in spring; copepods and rotifers are abundant in summer, but in the winter zooplankton is sparse and this link (which may be by-passed) in the food chain is therefore weak during this season. The next link, the detritus, is fairly strong as long as the rest of the chain functions properly. In fact, the detritus acts as a buffer during minor disturbances because it functions as a reservoir of food materials. The weakest link in the major chain is that provided by the worm, *Neanthes,* because it has no parallel. To date the shad has not occurred in sufficient numbers to be of major importance, and could not support the corvina if the bairdiella and sargo populations were to decline suddenly due to failure of *Neanthes*. There is one species, the orangemouth corvina, at the end of the chain.

A factor that should be considered is the efficiency of utilization of each organism in the chain; in other words, how much of the available food does each "eat," and what percentage is passed on to the next link in the chain. The Salton Sea is a very productive body of water; per unit volume it produces more phytoplankton than fertile coastal ocean water.

It is not possible, with the data on hand, to illustrate the efficiency of transfer of nutriment at each link in the food chain in the Salton Sea. The general order of magnitude can be indicated, however, by inference from other studies of productivity. Harvey (1950) discussed production of living matter in food chains in the ocean. Considering such factors as annual mortality, rate of growth, and loss by respiration he estimated that 30 percent of phytoplankton production is used by the plants for their growth and respiration. The next link in the usual food chain in the ocean is a filter-feeding zooplankter, such as a copepod, which converts 70 percent of the plant production into animal tissue. This high efficiency of transfer holds only for rapidly-growing, short-lived filter-feeders. Longer-lived bivalves and worms are far less efficient; they convert only about 11 percent of the plant production into animal tissue.

Carnivorous fish convert 6 to 10 percent of their food into tissue. Thus, for 100 grams of plant tissue assimilated, Harvey estimated that:

70 grams become herbivorous, short-lived zooplankton.
11 grams become herbivorous, long-lived bivalves and worms.
4-7 grams (6-10 percent of 70 grams) become fish, feeding on zooplankton.
1 gram (6-10 percent of 11 grams) becomes fish, feeding on bivalves and worms.
0.1-0.4 gram (6-10 percent of 1-7 grams) becomes fish, feeding on fish.

Obviously the most efficient fishery would involve a plankton-feeding fish and the least efficient would be a sportfishery based on a carnivorous fish that eats other fish.

In the Salton Sea, because it grows to maturity within three to six months, *Neanthes* probably has an efficiency intermediate between a rapidly-growing copepod and a slow-growing bivalve. However, it feeds on detritus, which means that the plant material is first subject to bacterial degradation; because of their high rate of respiration, bacteria use much of the organic matter of the detritus, converting it to carbon dioxide and dissolved organic matter no longer available as food for *Neanthes*. So, although there may be fairly efficient utilization of the detritus by *Neanthes,* much of it is "wasted" by bacteria. *Neanthes* makes up for this inherent wastefulness because it is fast-growing, has a high reproductive potential, and is itself an excellent food. It has no hard exoskeleton, as do molluscs and crustaceans, and in addition, according to Zenkevich (1951), *Neanthes* has a higher proportion of proteins and fats, and less carbohydrates than molluscs or crustaceans.

Reproductive potential is another factor of importance to the food chain. Organisms with high reproductive potentials tend to make the most complete use of the available food by varying their population size to match the food supply. Organisms of lower reproductive potential cannot adjust their population size as rapidly to food fluctuations and tend to stabilize near the low point of their food supply. The detritus may seem to be a stabilizing factor, making food continuously available to *Neanthes*. However, during the summer when half the bottom area is anoxic, the *Neanthes* population is reduced. The bairdiella and sargo, with longer life cycles, would tend to be limited to the low point of the supply of food.

The present food chain in the Sea is reasonably efficient, even though there are weak links and inefficient steps in the conversion of plant production into gamefish. Gamefish production in the Salton Sea might be increased and stabilized by introducing other organisms of certain specific types, but extreme care must be used not to upset and destroy the present food cycle.

THE CHANGING ENVIRONMENT

The environmental conditions in the Salton Sea are undergoing a rather rapid transition. The most important and drastic change, in regard to the fauna of the Sea, is the increase in salinity. Although many controlling variables are involved which afford many chances for variation in the rate of increase, it seems probable that the salinity will increase about 0.4 parts per thousand per year. This would bring the salinity level to about 40 parts per thousand by 1975 and to about 50 parts per thousand by the year 2000. Although predictions as to what this will do to the biota are based on scattered, diverse, and not very direct information, it seems probable that the food chain in the Salton Sea will be seriously affected, and possibly destroyed by about 1980 or 1990. This time estimate is subject to considerable variation; there is no sure way of knowing when the biota will be affected.

Since it was realized from the start of the project that salinity fluctuation would be a problem, tolerance to this condition was considered a prime requisite when recommending animals for introduction. The present fauna consists largely of species which are tolerant to salinity changes, and so it is probable that it can exist about as long as any combination which might be considered. There seems little likelihood that introducing different animals could prolong the life of a sport fishery for more than a few years.

The only thing which could have a profound effect on the life of the fishery would be environmental control. To be effective, this would need to reduce drastically the rate of salinity increase. Since there is no conceivable method by which the addition of salts to the Sea might be stopped (the agriculture of the area is dependent upon this practice) it would seem that the only possibility of control would be to remove salts.

Removal of salts from the Sea is possible, and the low relief of much of the shoreline would aid such an undertaking. Whether or not this kind of project is justified becomes a matter of economics. Certainly not only the fishery, but also the value of the area for other recreation and for real-estate development, will be affected by the Sea's increasing salinity. Eventually it will become a brine lake, similar to the Great Salt Lake of Utah, if the salinity buildup goes unchecked.

The project was unable to investigate possibilities for salinity control. We can only point out the inevitable consequences of lack of control.

THE RATIONALE FOR MANAGEMENT RECOMMENDATIONS

There is little background information on which to base recommendations for managing the Salton Sea. It is an unusual biological situation. No definite information on the results of managing any area even closely approximating Salton Sea conditions has been available to us.

Our bases for management proposals, therefore, stem from our own limited findings, and certain hypotheses based on ideas from other areas. Of necessity, we have had to rely largely on information derived from studies of habitats quite different from those in the Sea. None of the conclusions drawn is unequivocal, and if viewed critically, they are at best only guesses. These conclusions are based on what we consider was the heaviest weight of the general evidence.

Faunal Composition

The primary consideration in determining a desirable fauna for the Salton Sea was the desire of the managing agency, the California Department of Fish and Game, to establish a sport fishery. This was mediated to some extent by the limited fauna already present in the Sea, and by other more general considerations. The various points are discussed below.

Gamefish

Opinions vary considerably as to what fishes qualify as gamefishes. Those most eagerly sought by American anglers have certain characteristics in common, however. They must be catchable on rod and line, and they should take artificial lures. When hooked they put up a good fight. The most popular marine types reach a reasonably large size (at least 10 to 30 pounds), but are still desirable at smaller sizes. Of perhaps lesser importance, but yet a very significant factor, they should be desirable for food.

We felt that the fish at the top of the food chain should have these attributes in addition to biological characteristics which would enable it to live, reproduce, and maintain a sizable population in the peculiar environment of the Salton Sea. The species chosen as the best probable choices were the corvinas. It was soon evident that one of them, the orangemouth corvina (*Cynoscion xanthulus*), had already become established in the Sea as a result of the general plantings by the California Department of Fish and Game.

There are other species, often referred to as panfishes, which are considered gamefishes by most sportsmen. They also may be caught on rod and line, usually will take artificial lures, and are good to eat, but they do not reach as large a size as the primary gamefishes. Usually their normal diet is lower on the food chain than that of the primary gamefishes, and often they serve as food for large fishes. This type of fish would also be a valuable component of the fauna, since it would provide some sportfishing as well as a connecting link in the food chain to the larger gamefish. The bairdiella, which also was already established, is in this category. The sargo, a superior panfish, is now present in large numbers in the Sea as a result of the 1951 introductions by the Department of Fish and Game.

Limitation of the Fauna

Our basic consideration has been to assist in developing a sportfishery, so we tend to restrict our recommendations to those actions which would seem to benefit the sportfishery directly. Anything that might endanger the fishery we tend to discourage. Without constantly considering the primary objective, we may destroy it while trying to develop some secondary goal.

We think it best to limit the fish fauna to a few forms, all of which, insofar as possible, can be caught on hook and line, and thus add to the sportfishery. Although a larger total fish production might be expected with a more diversified fauna, we think it probable that production of a particular gamefish is apt to be greatest with a limited fauna. This conclusion is based on the general results found in lakes and farm ponds in the United States. Although the data do not always agree, and the conclusion cannot be considered incontrovertible, the weight of the evidence supports this idea. It might be argued that the environmental conditions are too different to apply findings from freshwater lakes and ponds to the Sea. We see no reason why this should be true in this situation. In any case, there is not enough information from saltwater environments from which to draw any kind of generality.

Following this reasoning, we feel that a single large gamefish is probably the best solution, with one or possibly more species of the panfish variety. More than one species of panfish may be desirable to utilize the potential food available in the Sea. Two species of panfish are already established in the Sea (bairdiella and sargo), as well as four other forms which are forage fish. We consider it fortunate that three of the latter (mudsucker, pupfish, and mosquitofish) are evidently so confined to habitat that they should never became very numerous, and that the other (threadfin shad) seems to be largely a summer visitor, and cannot spawn in the Sea.

The entire food chain to the corvina is now channeled through a single invertebrate, *Neanthes*. This worm seems to support a huge population of fishes, but it may be the limiting factor in preventing even larger populations. Perhaps the food base at this level in the chain could be broadened. There are inherent dangers associated with any new introductions, however. We think it best to move slowly on new introductions until it is known what kind of fishing is produced by the present fauna. As long as fishing is satisfactory, we recommend a conservative attitude towards introducing new organisms in an attempt to make the fishing better.

MANAGEMENT RECOMMENDATIONS

Salinity Control

The feasibility of attempting to control the salinity of the Sea is dependent on economic factors. Not only the sportfishery, but other recreational values of the Sea, the surrounding real estate, and perhaps nearby agricultural developments, could be affected by the increasing salinity. It is recommended that possibilities for control be studied and considered in future development plans. Perhaps the cost of such control could be partially paid through commercial development.

Introduction of Submerged Aquatic Plants

There is no indication that introducing submerged aquatic plants would have any great effect on the sportfishery. The plants would undoubtedly be restricted to waters shallower than three feet because of the high turbidity. They might serve as hiding places for young fishes, but there is no indication such areas are lacking at present. Their value as a means to increase the lower links of the food chain is extremely doubtful, but they could be important as a new habitat for invertebrates. Perhaps the greatest danger from plant introductions is from the diverse and unknown invertebrate types which almost certainly are introduced at the same time. These unknowing introductions could be disastrous to fishery development. At the same time, they might provide an important new source of food. Our consideration of the total problem leads us to believe that introducing submerged aquatic plants is not justified from the standpoint of the sportfishery.

A good stand of submerged aquatic plants which serve as food for waterfowl would be of great value to the area surrounding Salton Sea, however. Because of this factor, we agree that experiments with such plants should be made, on the grounds that chances for benefits probably outweigh the chances for damage.

Submerged aquatics can be navigational nuisances. Boating is a well-established recreational use of the Sea and the boat launching channels are shallow. They could easily be choked by aquatic plants.

The increasing salinity of the Sea will limit the length of time that plants as well as animals can exist there.

Introduction of Additional Kinds of Animals

We recommend a conservative attitude towards introducing new animal forms. There is now a growing sportfishery, and there is the possibility that additional forms will do more harm than good. If the fishery is considered inadequate or if a decline in catch occurs; however, we recommend the following introductions and feel that any forms chosen should be tolerant of wide temperature and salinity fluctuations:

Zooplankters

We have been unable to secure any information on specific forms to introduce at the zooplankton level. Zooplankton is rich seasonally, and there seems no reason to introduce new forms unless they would reduce the seasonal fluctuations. We are not able to offer specific suggestions. In addition, we cannot suggest a reasonable method of securing pure cultures of any such organisms.

Larger Invertebrates

In one way, the weakest point in the present food chain is *Neanthes,* and it would be advantageous to establish organisms which would parallel or bypass it so that a failure of *Neanthes* would not have too great an effect upon the fish. An organism introduced into the Salton Sea should (1) feed on plankton or on detritus. It should **not** be a carnivore, such as a crab, which could completely destroy the *Neanthes* population. It should (2) be available to the existing fish sometime during its life cycle, yet elusive enough to withstand the heavy predation. The brine shrimp *Artemia* is an excellent fish food, grows well in Salton Sea water, and is easily available to fish, but apparently cannot withstand the heavy predation. Finally, (3) it should be of a size between about 0.25 and 3.0 inches, but could vary considerably depending upon its general form. It should be small enough to be taken by bairdiella and sargo, but if large enough it could also be eaten by corvina. In addition to the above characteristics, any organism introduced to strengthen the *Neanthes* link should be considered from the viewpoint of seasonal availability. An organism the size of *Neanthes* that would be most prevalent in summer, when the *Neanthes* population is lowest, would be of most value.

We recommend that mysids and amphipods be planted in the Salton Sea. One species of mysid and two species of amphipods form a large part of the bairdiella diet at San Felipe. It is hoped that these species might provide food at times when *Neanthes* is relatively unavaliable.

In addition, other forms of marine worms, especially species of *Capitella,* should be desirable.

We recommend against introducing molluscs, especially gastropods. Many fish worm-parasites have molluscs as obligate hosts at some stage in their life history, and the absence of such forms may help to prevent the occurrence of such parasites. Also, there is little chance that most molluscs could contribute heavily to the gamefish food chain.

Fishes

We feel that no additional plantings should be made unless the present fish fauna does not furnish an adequate sportfishery. Further, any future introductions of fishes should be confined to panfish or game species as previously defined.

The fishes of the family Sciaenidae are apparently the best group from which to select desirable forms. The two best areas from which fishes might be taken are the upper Gulf of California, and the lagoon area of the Texas coast.

We consider *Micropogon megalops,* a sciaenid fish of the upper Gulf of California, the best candidate for future introduction. It should serve as food for *Cynoscion* without competing with it, and at the same time provide good fishing. There is some possibility that it would not be entirely dependent on *Neanthes* as food, but could partially exist by direct feeding on the organic mat. Some were introduced in 1950 and 1953 (Table 25) but there is no sign that they became established. We would expect that several thousand individuals would be needed to insure success under present conditions.

General Management Methods

A continuing program of limited biological sampling and creel census will be necessary to insure intelligent management of the Sea. Sampling bairdiella, sargo, and corvina populations to secure information on growth and catch rates should provide an index for the relative success of these species. If the growth rates are judged too low, compared to indications of the population size, this may be considered as evidence that the food chain is weak. If the bairdiella shows the greatest reduction, the *Neanthes* link probably is weak; and if the corvina shows an unusual drop this would indicate weakness at the panfish level. Absolute population estimates were impractical during the original research, and are probably impossible for routine management. It is therefore necessary to base continued management on fairly simple checks, such as relative growth studies and catch rates.

Attempts should also be made to ascertain what changes, if any, are taking place in the fauna. These determinations can only be qualitative, in all probability, but it will be valuable to know if new forms have become established. In addition to limited plankton and bottom sampling, diet studies on the fishes would be of particular value in discovering changes in the food chain. Systematic checking through the season would be desirable, but probably will not be possible. Sampling no oftener than once a year could be exceedingly valuable.

Rate of Harvest of Fishes

The biological conditions in the Sea are such that the fishes near the end of the food chain should be harvested at a high rate. The game fishes grow rapidly at least in early years, and their reproductive potentials are high. Moreover, the life of the fishery is limited by the Sea's rapid increase of salinity. Bairdiella have already shown themselves capable of producing an overpopulation, and there are signs that the sargo may be on the way to doing the same thing. Based on biological information alone, we see no reason to limit the take of bairdiella and sargo by sportfishermen. There is probably little danger of over-fishing the corvina, but a generous limit might be wise during the early years of the fishery. We can see no reason for a closed season on any of the fishes.

SUMMARY

HISTORY

The Salton Sea lies in a basin, called the Salton Sink or Cahuilla Basin, whose lowest elevation is 273 feet below sea level.

In 1905 a flood cut through irrigation headworks and for two years the full flow of the Colorado River entered the basin. The Salton Sea, formed by this flooding, was 45 miles long, 17 miles wide, and about 80 feet deep in 1907. The break in the headworks was repaired in 1907, redirecting the Colorado River into the Gulf of California.

The maximum surface elevation in 1907 was —195 feet. Due to evaporation, the level fell to —250 feet by 1925, and fluctuated between —250 and —243 until 1935. Increased irrigation in the surrounding areas raised the level to —240 feet in 1948 and to —235 feet in 1956.

Various estimates have been made of the level at which evaporation and inflow will balance and stabilize the surface elevation. Blaney (1954) estimated —220 feet, an elevation which might be reached between 1970 and 1985. It seems likely, however, that restricted use of water in the Imperial and Coachella Valleys will result in stabilization at about the present level of —235 feet.

PHYSICAL AND CHEMICAL ASPECTS

Seasonal differences in rates of water inflow and of evaporation caused fluctuations in the surface elevation from —236 to —234.5 during the study period. The concurrent dilution and concentration of the water was reflected by salinity changes which ranged from 31.4 to 33 0/00.

Although the salinity was only slightly below that of the oceans, the ionic composition differed from marine water because it results from evaporation of Colorado River water.

The greatest depth of the Sea was 12 meters (about 40 feet).

Water temperatures ranged from 10 to 36 degrees C (50-97 degrees F) during the study period. Although in spring and summer the surface was at times as much as 5 degrees warmer than the bottom, there was no lasting thermocline and for most of the year there was little difference in temperature between surface and bottom.

The concentration of dissolved oxygen was about 10 mg/L throughout the water column in winter, and there seemed to be adequate oxygen at all seasons except in summer when there were short periods of bottom anoxia.

High concentrations of sulfide (85 μg-at/L) and ammonia (50 μg-at/L) were present at the bottom in summer.

The salinity of the Sea increased from 3.6 0/00 (in 1907) to a high of 40 0/00 in 1948. It then decreased, due to greater inflow of water, to the 33 0/00 present during the study period.

If the surface elevation is stabilized at the present level of —235 feet, the salinity will increase at a rate of about 0.4 0/00 per year. By about

1975 a salinity of 40 0/00 might be reached, and this concentration might limit continued existence of the marine organisms now in the Sea.

PHYTOPLANKTON

The only macroscopic plants in the Sea were blue-green algae. Nine species grew on the bottom in shallow water.

Single-celled planktonic algae were the principal plants. *Nitzchia longissima* and *Cyclotella caspia* were the most numerous diatoms; *Glenodinium* sp. and *Exuviella compressa* were the numerically important dinoflagellates.

The diatoms and dinoflagellates were present all year, but with relatively small populations in summer, when a small green alga was predominant. The small size of the green alga made it insignificant relative to the mass represented by the larger diatoms and dinoflagellates.

Tests of oxygen production showed greatest algal productivity in winter (January and February) and in late summer (August and September). Calculated carbon fixation ranged from 0.1 to 1.9 grams per cubic meter per day, for an average of 0.75 grams per cubic meter per day. This is about four times the average daily carbon fixation in fertile coastal sea water.

The yearly plant production was estimated at about 2.5 tons (dry weight) of plant material per acre per year, or about 550,000 tons yearly in the entire Sea.

INVERTEBRATE FAUNA

The number of invertebrate animals was very limited. Six major groups were represented: Protozoa, Rotifera, Bryozoa, Nematoda, Polychaeta, and Crustacea.

Only four species were considered important to the problems of the sportfishery: the pileworm, *Neanthes succinea;* a rotifer, *Brachionus plicatilis;* a copepod, *Cyclops dimorphus;* and a barnacle, *Balanus amphitrite.*

The barnacle was in large numbers (650/L in April 1956) in the plankton. Few settled from November through February. The maximum settlement was in March and April, but they continued to settle in large numbers until October. The highest observed rate of settling was 200 barnacles per square inch per day.

Barnacle growth was greatest in summer when a basal diameter of 8-9 mm was reached in 30 days. During the coldest part of the year the growth was one-tenth the summer rate.

In summer sexual maturity was reached in less than 30 days.

The barnacle was not an important source of food for fish.

ZOOPLANKTON

Four species of invertebrate animals were significant in the zooplankton. A rotifer, *Brachionus plicatilis,* and a copepod, *Cyclops dimorphus,* were present from June to December, absent in winter and spring, and most numerous in summer. These two species are planktonic throughout their life cycle.

A nereid worm, *Neanthes succinea,* and a barnacle, *Balanus amphitrite,* have planktonic larvae; the adult worms settle to the bottom and the adult barnacles attach to any solid surface. Planktonic stages of the worm and barnacle were present year round with periods of maximum spawning in spring (March to June) and smaller peaks in autumn (September to November).

The worm was absent from depths greater than 9 meters (which represents more than half the total area of the Sea) during summer, apparently due to bottom anoxia accompanied by high concentrations of sulfide and ammonia.

Maximum numbers collected were: *Brachionus*—1,200 per liter; *Cyclops*—535 per liter; *Neanthes*—87 per liter; *Balanus*—650 per liter.

PILE WORM, *Neanthes*

Spawning took place at irregular periods each month and was evidently not correlated with phases of the moon. On any particular night, spawning was restricted to a three-hour period following sunset.

Maximum settlement of planktonic larvae occurred during spring (540,000 per square meter per month in April), with a secondary maximum in late fall after a low in summer and early fall (10,000 per square meter per month in October).

Winter growth rates, as indicated by maximum segment numbers on worms in settling jars, were about half of those in summer. Many worms evidently reached maturity within 30 days during the summer months.

Neanthes were most abundant in the bottom mat at depths between 15 and 25 feet. This is the zone of maximum development of the organic mat. They were least abundant at depths greater than 25 feet, and were absent from these depths during late summer due to anoxic conditions.

The standing crop of *Neanthes* in the Sea was estimated at 14,500 tons in the fall of 1956. This amount, based on 125 pounds per acre in fall, might be greater (about 300 pounds per acre) in spring, and less (75 pounds per acre) in summer.

FISHES

In 1949 there were four species of fishes in the Sea: desert pupfish, *Cyprinodon macularius;* mosquitofish, *Gambusia affinis affinis;* striped mullet, *Mugil cephalus;* and longjaw mudsucker, *Gillichthys mirabilis.* None of these could provide a sportfishery.

The California Department of Fish and Game, during the years 1949 to 1956, introduced large numbers of many species of fishes from San Felipe, Baja California, with the hope of establishing a sportfishery.

Three of the introduced species are now established in the Sea: bairdiella, *Bairdiella icistius;* orangemouth corvina, *Cynoscion xanthulus;* and sargo, *Anisotremus davidsoni.*

Shortfin corvina, *Cynoscion parvipinnis,* have also been recovered in the Sea, but there is no evidence that it has reproduced.

Threadfin shad, *Dorosoma petenense,* entered the Sea in 1955 from the Colorado River.

The desert pupfish and the mosquitofish were confined to the extreme marginal areas of the Sea, and were of little importance. The longjaw mudsucker was more widespread, and formed a minor item in the diet of the orangemouth corvina. It was not a serious competitor with the gamefishes in the Sea.

THREADFIN SHAD

Threadfin shad entered the Sea from irrigation laterals in 1955.

They were present at all times of year, but appeared to be most numerous during summer months.

Recruitment was from fish entering through freshwater inlets. There was no spawning in the Sea.

They are planktonic feeders, and thus may develop an important additional food chain to the orangemouth corvina, providing a direct link between plankton and corvina.

STRIPED MULLET

The striped mullet, once abundant in the Salton Sea, is now scarce.

The recruitment was from young fish, produced in the Gulf of California, that reached the Sea through the Colorado River, irrigation canals, and drains.

Recruitment was almost entirely stopped when the Imperial Dam and the All-American Canal were completed in 1942.

Nearly all of the mullet in the Sea in 1956 were 14 or more years old.

BAIRDIELLA

Sixty-seven bairdiella, *Bairdiella icistius* (Jordan and Gilbert), were introduced into the Salton Sea by the California Department of Fish and Game in 1950 and 1951.

First successful spawning was in 1952, and the fish is now firmly established in the Sea.

Spawning occurred from April to August, with a decided peak in May, but spawning after the middle of June produced very few fry.

Bairdiella eggs were broadcast in the open water, where they tended to float just under the surface. Spawning took place in the evening from 6 to 10 PM, Pacific Standard Time.

The eggs hatched in 24 hours at 72 to 74 degrees F., which was the water temperature during the peak of the spawning season.

A dominant year-class was produced in 1953 which grew slowly, suppressed the growth of 1952 year-class fish, and prevented success of the 1954, 1955, and 1956 year-classes. The 1953 year-class fish reached a length of only 76 mm in their first year, while 1952 year-class fish had reached at least 100 mm.

The fish of the 1953 year-class increased only slightly in length each year. This growth occurred during the spring when the most food was available.

Fish of the 1952 year-class showed no increase in average length after 1953.

Bairdiella moved toward shore in the summer and away from shore in the winter. The movement was probably influenced by the availability of food, as shown by weight gains and losses.

Mortalities occurred annually in the Salton Sea, most commonly in the late summer or early fall. Large numbers of dead fish were washed up on shore. They were losing weight at the time of the kills. *K* factors of 1.6 or less coincided with kills.

Minor fish kills might have occurred at times due to oxygen shortage, though the main effect of the oxygen depletion in deeper waters was the elimination of the food supply.

Serious abnormalities were common in fish of the 1952 year-class, and 23 percent showed some evident deformation. Only one percent of the fish of the 1953 year-class showed similar abnormalties. The percentage of abnormal fish in the 1952 year-class dropped in 1953. The change in percentage of abnormal fishes almost certainly was due to a great change in competition and predation in 1953.

An annulus formed on scales of 1953 year-class fish each spring when the fish increased in length after a period of dormancy.

Fish of the 1952 year-class failed to form annuli on the scales in some years, so that in 1956 most of them had fewer annuli than the younger, smaller fish of the 1953 year-class.

FOOD OF BAIRDIELLA

The pile worm, *Neanthes succinea,* formed practically the entire diet of bairdiella over 30 mm long.

Young fish ate barnacle nauplii and all stages of copepods. They also consumed a significant number of bairdiella eggs and larvae.

The food intake of adults was heavier at night, correlating with the spawning of *Neanthes.*

The most important limiting factor for bairdiella was the scarcity of *Neanthes* during the summer and early fall. These periods coincide with anoxic conditions in the deeper waters of the Sea.

Food for bairdiella was most abundant during the spring.

Experiments indicated that fish with full stomachs required more than 16 hours to complete gastric digestion.

ORANGEMOUTH CORVINA

Small numbers of orangemouth corvina, *Cynoscion xanthulus,* were planted in the Salton Sea in 1950, 1951, and 1952 by the California Department of Fish and Game.

First successful spawning in the Salton Sea occurred in 1952, and continued each year thereafter.

A gradual increase in the population of corvina was shown by the increased catch, especially of later year-classes, in gill nets and seines.

A population of 40,000 corvina in 1956 was estimated from recaptures of fin-clipped corvina introduced from the Gulf of California. The estimate included year-classes up to and including the 1955's The 1956 and 1957 year-classes were about 20 times as abundant as the previous year-classes had been at comparable ages.

In 1955, two groups of corvina with different growth rates appeared apparently from a spring spawning. Availability of small fish as food was thought to explain their differences in growth.

After an initial slow phase, the corvina grew very rapidly, typical year-classes reaching weights of 2½ pounds by their second winter, 5¼ pounds by their third, and 11 by their fourth. Faster-growing segments of the 1955 and 1957 year-classes reached weights of 1 pound by the end of their first year, and 3¾ pounds by the end of their second.

Corvina up to about 30 mm fed on copepods, barnacle nauplii, and cyprids. At a length between 30 and 60 mm they shifted to feeding on the pile worm. This caused severe competition with bairdiella which also utilized *Neanthes* for food. Most young-of-the-year corvina grew at about the same rate as bairdiella, so they were unable to feed on fish until the following spring, when spawning bairdiella produced a new supply of small fish. In some years, as in 1955 and 1957, groups of faster-growing corvina apparently reached a sufficient size by the fall of the first year to feed on bairdiella. There was an immediate increase in growth rate at this time.

Large corvina fed primarily on bairdiella, but also mudsuckers and threadfin shad.

The gonads of the orangemouth corvina matured in April and May.

The number of eggs per female was estimated as 400,000 to 1,000,000.

Eight percent of the corvina in the Salton Sea showed some abnormality.

GENERAL CONSIDERATIONS AND RECOMMENDATIONS

The most important food chain to the sportfishery is: phytoplankton → zooplankton → detritus → detritus eating worm *(Neanthes)* → worm-eating fish (bairdiella and sargo) → fish-eating fish (corvina).

The weakest link in this chain is at the level represented by *Neanthes*. This single species is the only organism in the Sea converting detritus into food for bairdiella and sargo. This stage in the chain is probably strong as regards to efficiency, however.

Of secondary importance is the food chain: phytoplankton → zooplankton → threadfin shad → corvina.

Management recommendations are based solely on biological grounds, and only those actions which would directly benefit the fishery are encouraged.

We think it best to limit the fish fauna to a few forms. In this way production of the most desirable species should be highest.

We recommend a conservative attitude toward introducing new forms. New fishes should be planted only if the present fishery proves inadequate.

Zooplankters which would strengthen the food chain during summer would be desirable.

Mysids and amphipods would strengthen the food chain at the *Neanthes* level, and should be introduced.

Sampling of the bairdiella, sargo, and corvina populations should be continued to secure information on growth and catch. At least qualitative checks on the faunal composition should also be continued.

We recommend high rates of fish harvest. We see no reason for special limits on bairdiella or sargo, or for a low limit on the orangemouth corvina, or for closed seasons.

Methods to control the salinity of the Sea should be investigated.

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