ZOOPLANKTON

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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

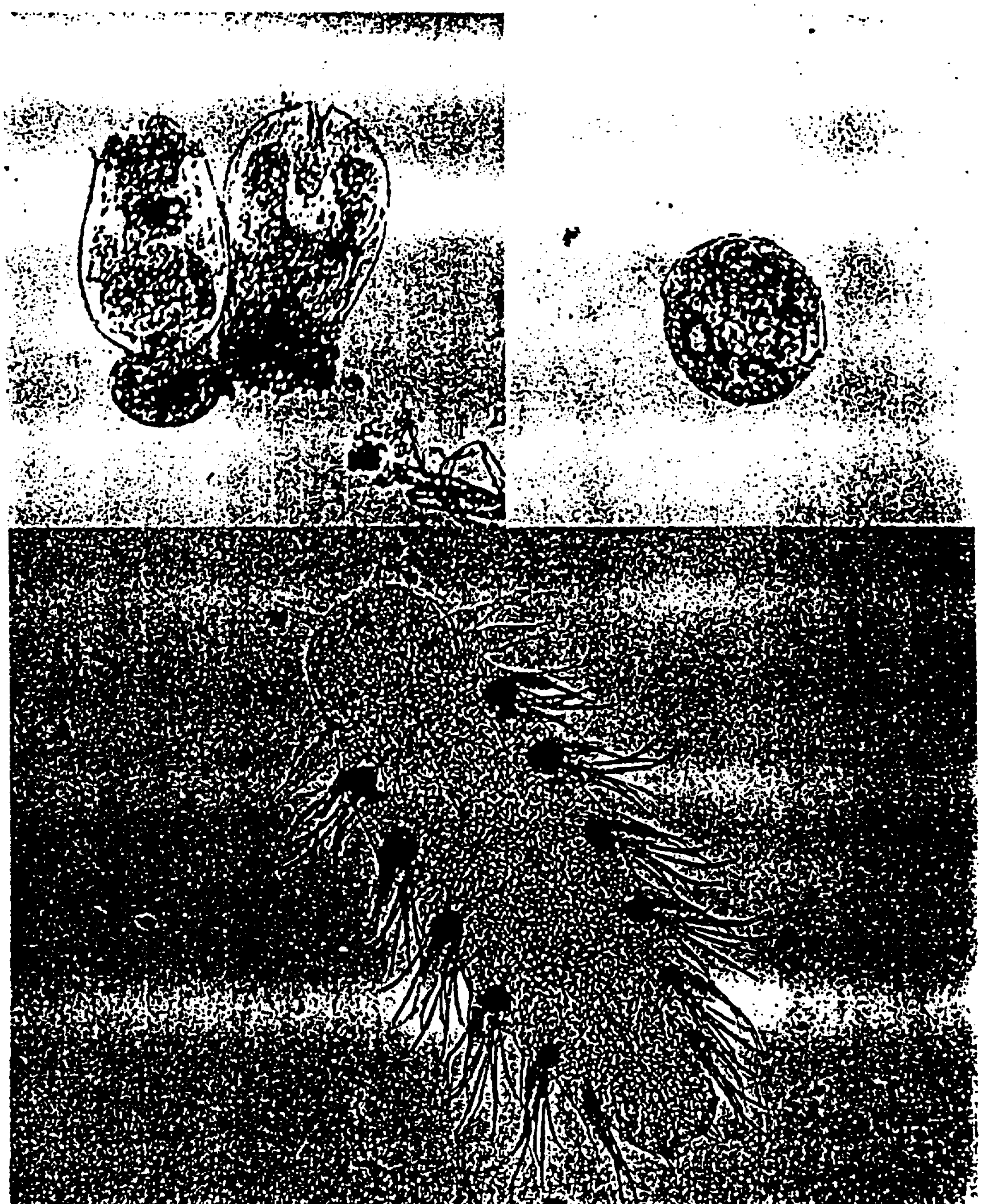

FIGURE 13. *Brachionus plicatilis*, adults, upper left. *Neanthes succinea*, egg, upper right; 6-segmented larva, below. Photos by Lars H. Carpelan.

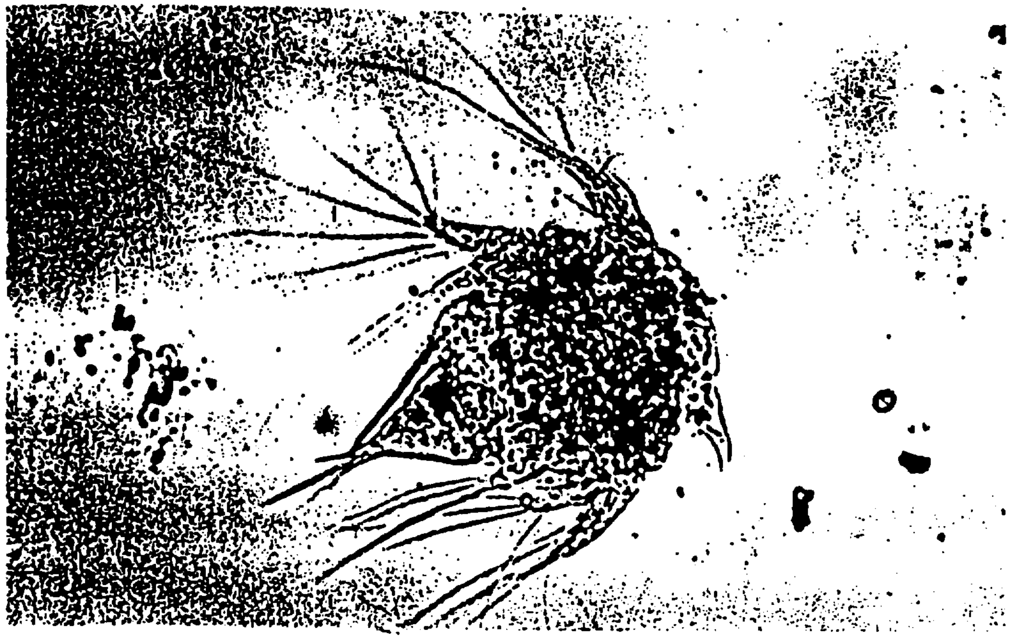

FIGURE 14. *Balanus amphitrite*, nauplius, above; cypris, below. Photos by Lars H. Carpelan.

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.

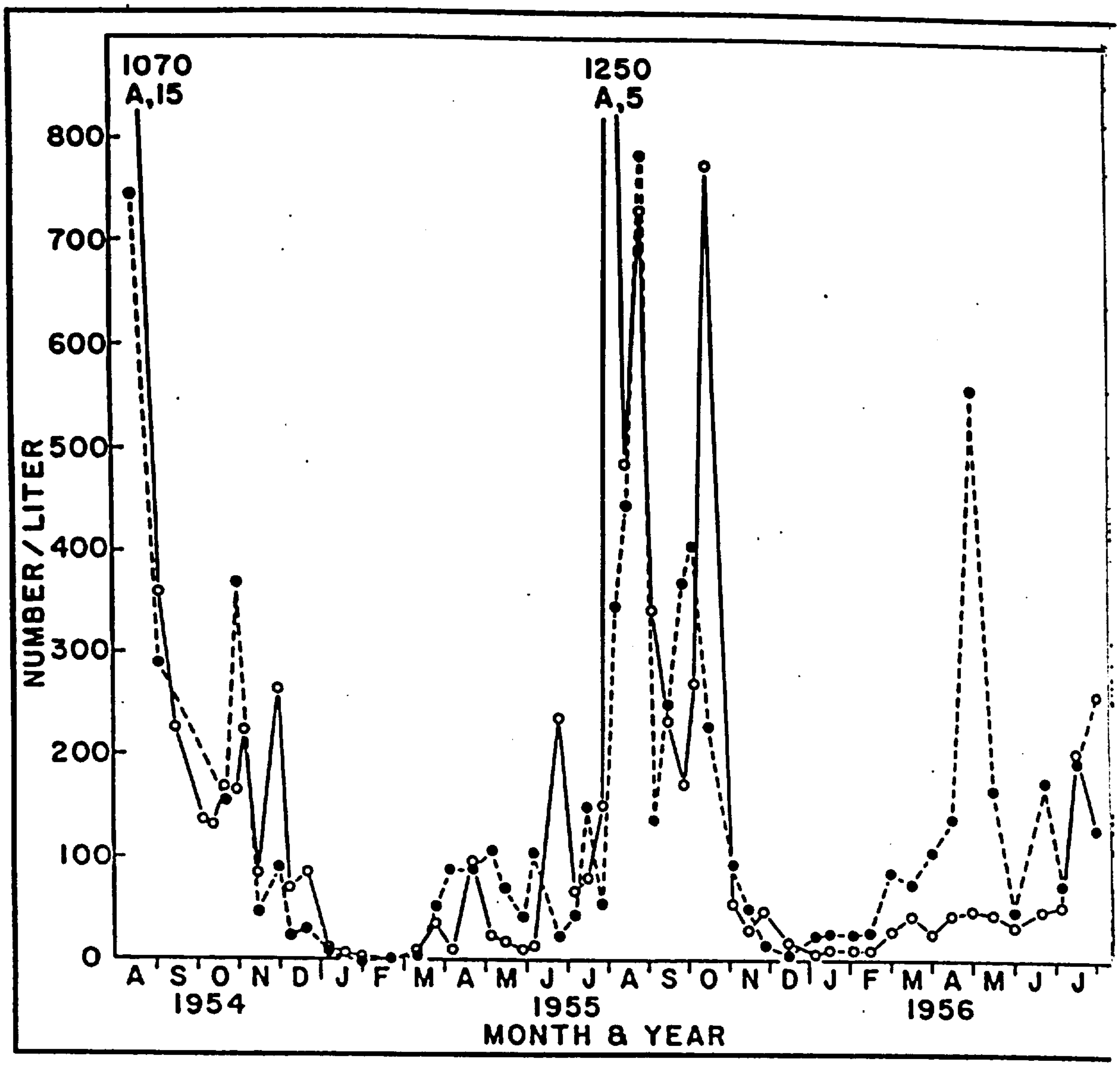

FIGURE 16. Total zooplankton in the Salton Sea, 1954-1956. Three miles offshore (solid line) and 100 yards from shore (dotted line). Offshore collections show average numbers for surface, mid-depth (six meters) and near bottom (12 meters). The near-shore stations show average numbers for surface and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

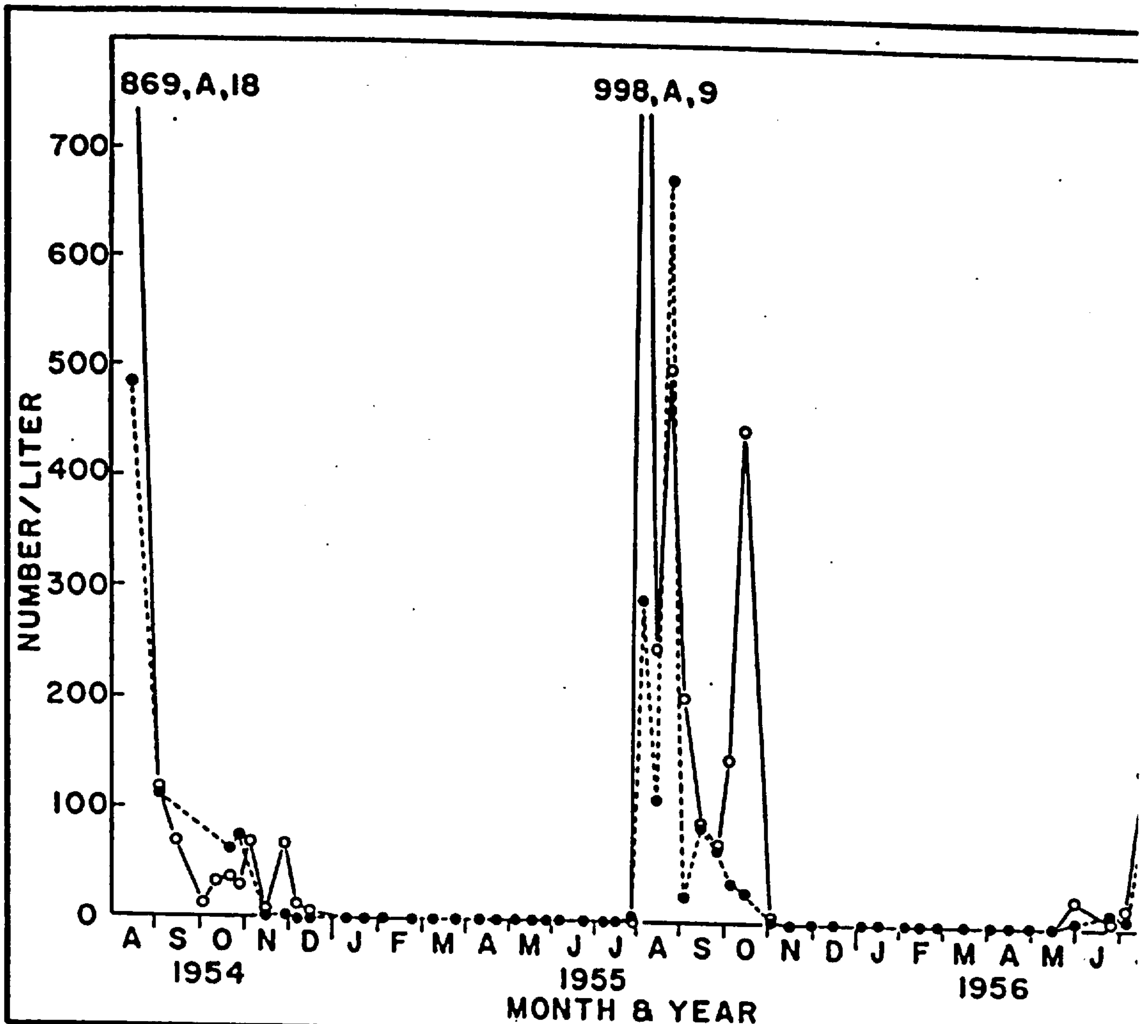

FIGURE 17. Seasonal variation in numbers of *Brachionus* in the Salton Sea. Averag numbers three miles offshore (solid line) and 100 yards from shore (dotted line

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

Brachionus was very numerous in the first quantitative plankton co lection made, which was on August 18, 1954 (Figure 17). The popul: tion declined during autumn and the rotifer disappeared from tl water near shore in November and from offshore in December 195 After an absence during winter and spring, *Brachionus* reappeared i the near-short plankton on July 27, 1955 when there were four per lit at the surface. On August 9, 1955, at the surface three miles from sho there were 1,283 per liter, the greatest number found in any samp during 1954-56. A sample from mid-depth (six meters) had a simil number (1,277 per liter), and a sample from just above the bottom (1 meters) had 435 per liter. The average number in the vertical wat column was, thus, 998 per liter. The number near shore on August was not as great: there were 200 per liter at the surface and 387 at tl bottom, for an average of 293. Adults were prevalent in August, Se tember, and October of 1955. There were smaller numbers in Noven ber: the average per liter offshore was three on November 2, and o each on November 15 and 28. None was found in December. In 195

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

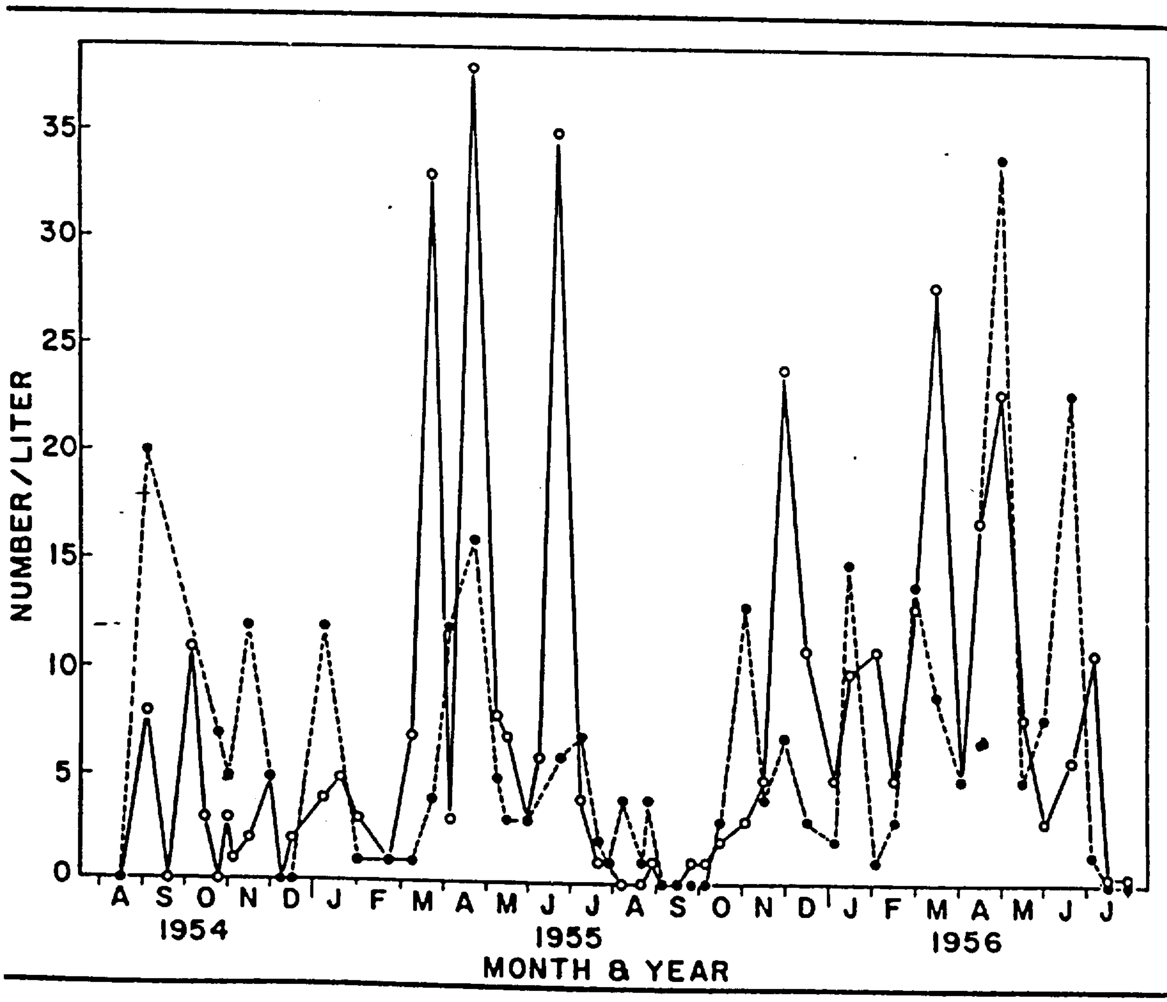

FIGURE 18. Seasonal variation in numbers of eggs and larvae of *Neanthes* in the Salton Sea. Three miles offshore (solid line) and 100 yards from shore (dotted line). Numbers are the averages of samples from surface, mid-depth (six meters) and bottom (12 meters) offshore, and from surface and bottom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

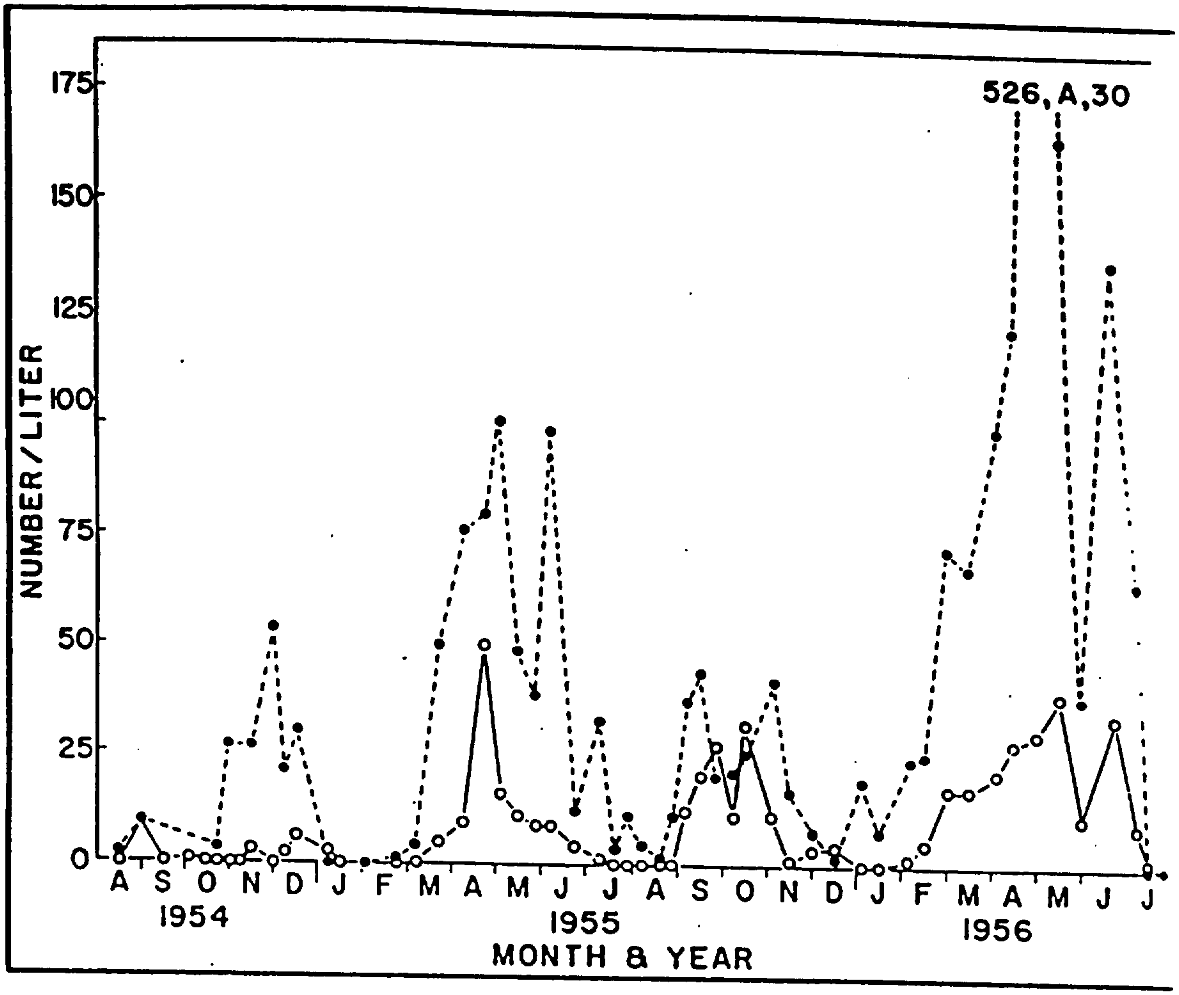

FIGURE 19. Seasonal variation in numbers of the nauplii and cypris of *Balanus* in the Salton Sea. Three miles offshore (solid line) and 100 yards from shore (dotted line). Numbers are the averages of samples from surface, mid-depth (six meters) and bottom (12 meters) offshore, and from surface and bottom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

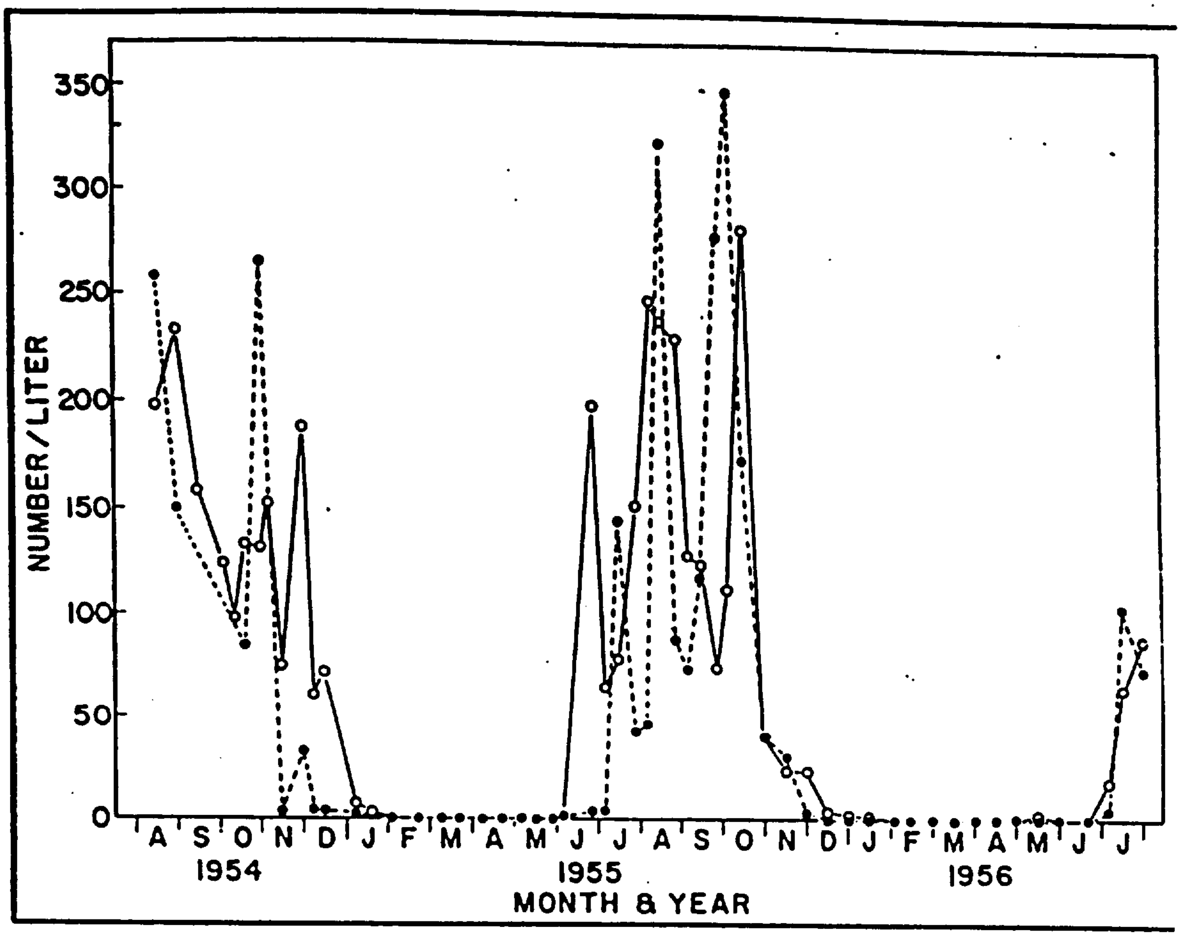

FIGURE 20. Seasonal variation in numbers of *Cyclops* in the Salton Sea. Three miles offshore (solid line) and 100 yards from shore (dotted line). Numbers are the averages of samples from surface, mid-depth (six meters) and bottom (12 meters) offshore, and from surface and bottom (three meters) near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