PHYTOPLANKTON AND PLANT PRODUCTIVITY

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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

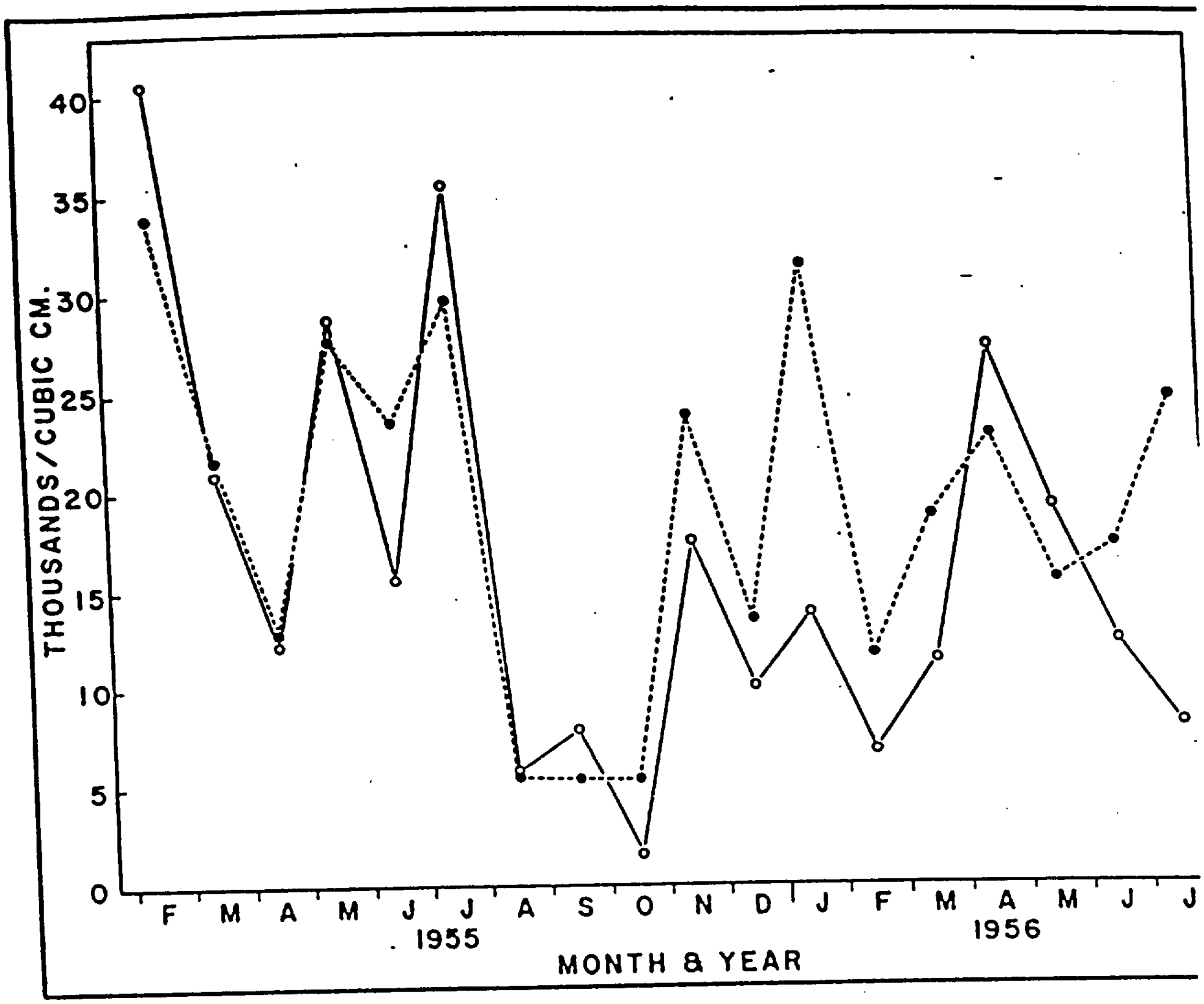

FIGURE 8. Total phytoplankton, Salton Sea. Average monthly number per cm³. Solid line = three miles offshore; dashed line = near shore.

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

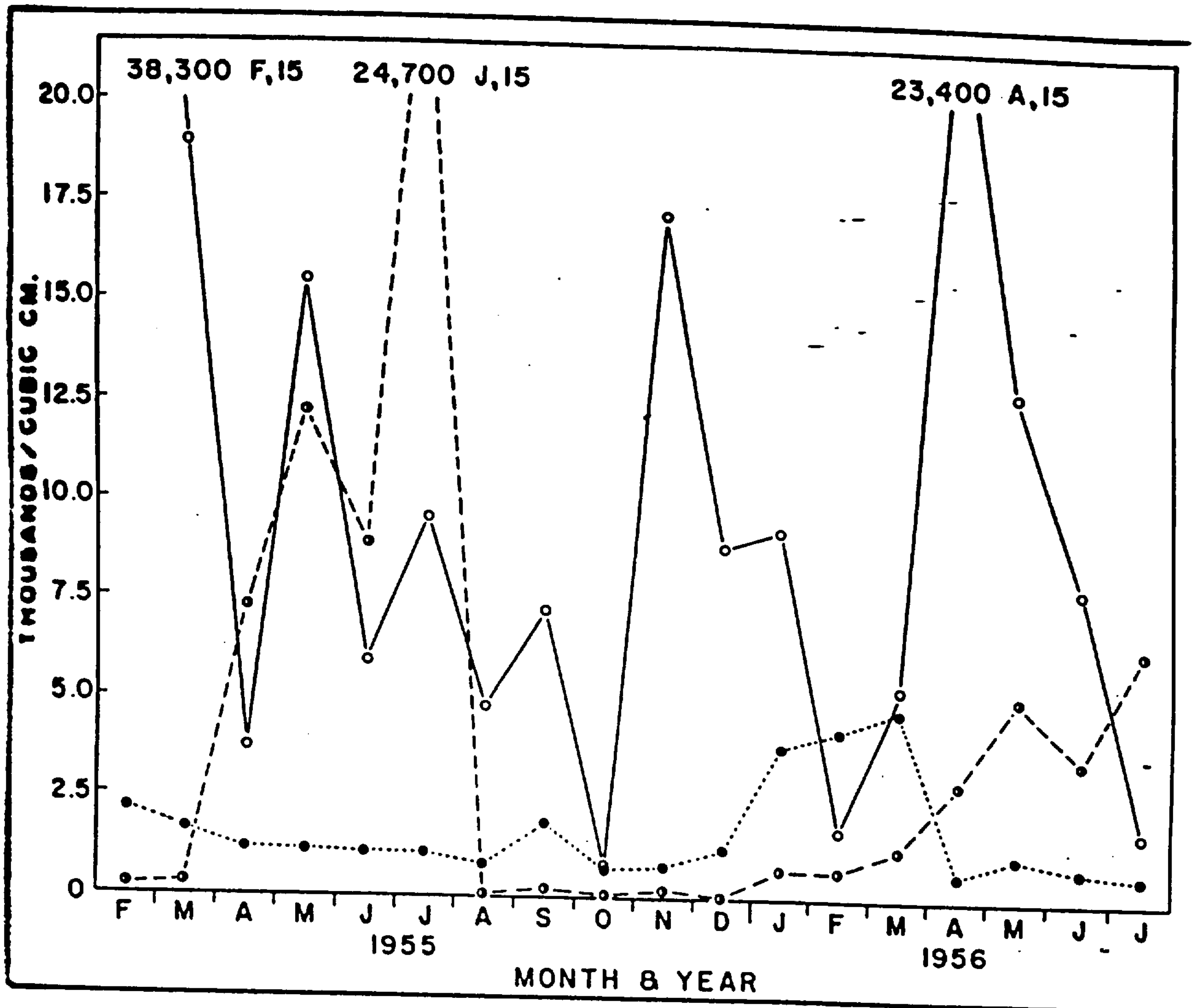

FIGURE 9. Average total numbers of diatoms, dinoflagellates, and green algae per month three miles offshore, Salton Sea. Solid line = diatoms; dashed line = green algae; dotted line = dinoflagellates.

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/cm³ 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/cm³ in a sample collected near shore.

The dinoflagellates averaged about 1,000 cells per cm³ 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 cm³. Only small numbers of the green alga were present during the

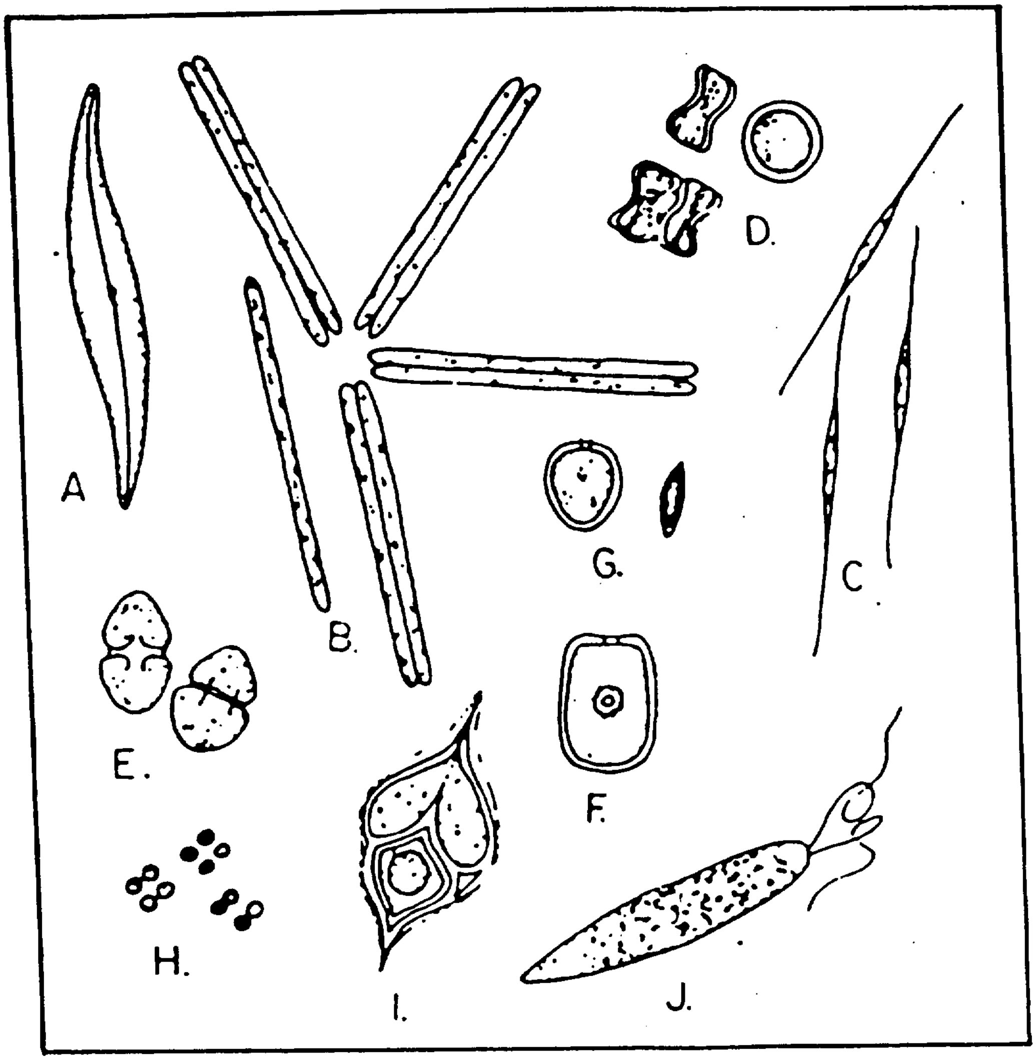

FIGURE 10. Representative phytoplankton organisms of the Salton Sea. A. *Pleurosigma* sp., B. *Thalassionema nitzschoides*, C. *Nitzschia longissima*, D. *Cyclotella caspia*, E. *Glenodinium* sp. F. *Exuviella marina*, G. *Exuviella compressa*, H. *Westella botryoides* (?), I. *Dictyocha* sp. (?), J.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

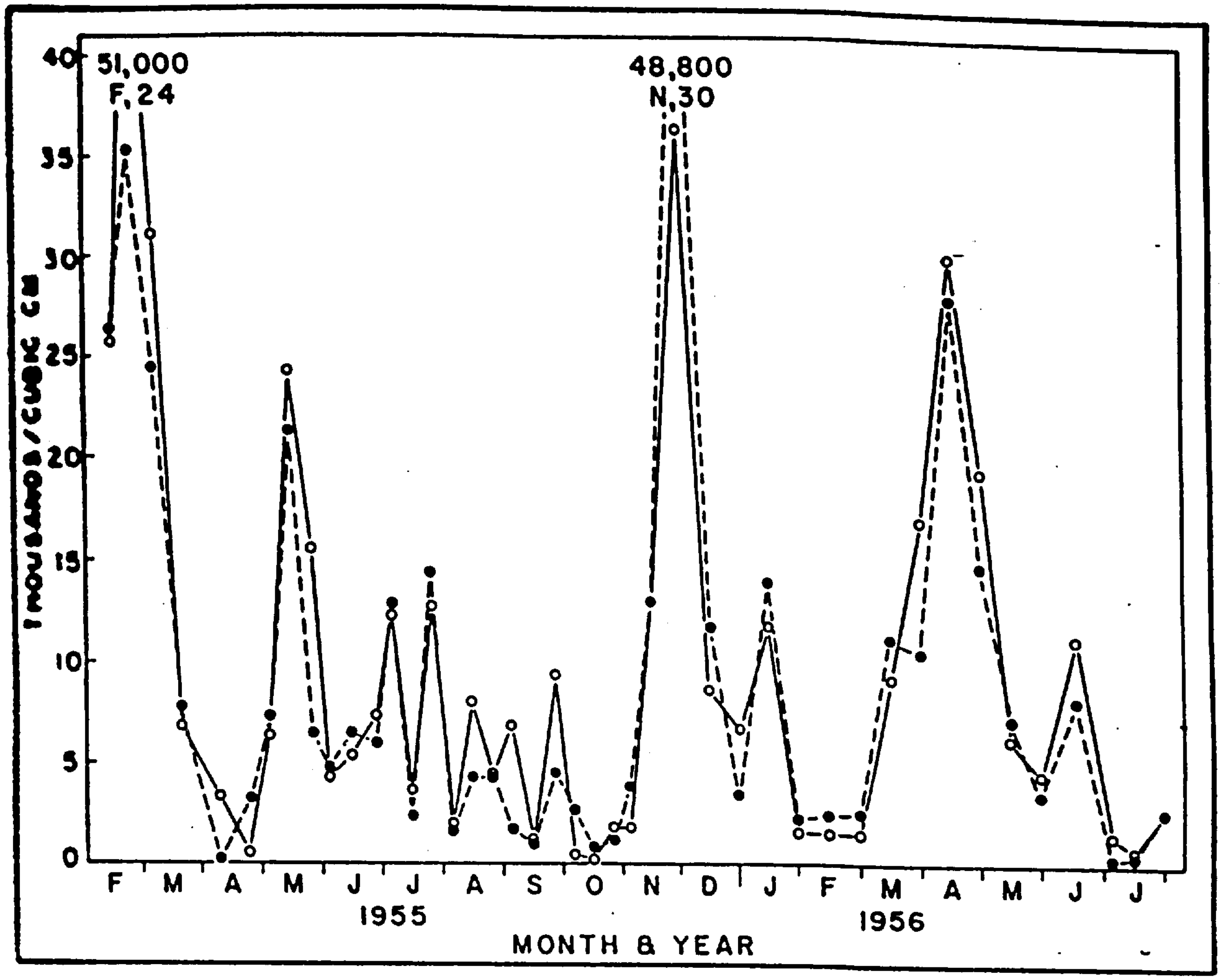

FIGURE 11. Total numbers of diatoms in individual collections, Salton Sea. Solid line = 3 miles offshore; dashed line = near shore.

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 curred 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

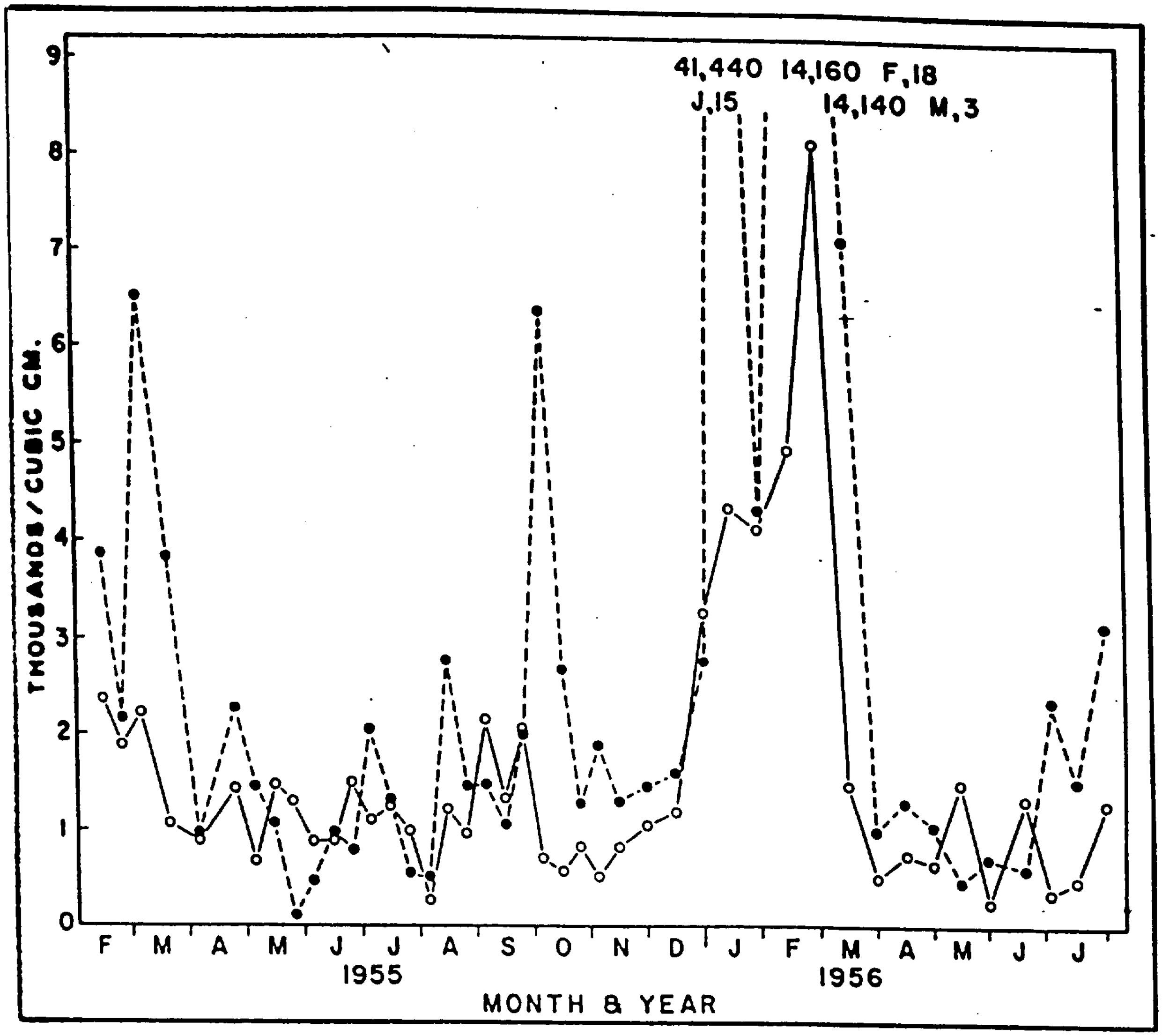

FIGURE 12. Total numbers of dinoflagellates in individual collections, Salton Sea. Solid line = 3 miles offshore; dashed line = near shore.

Glenodinium sp. (Figure 10,E) is dumb-bell shaped, 10-16 μ in diameter and 20-25 μ long. Although fewer than 100 per cm³ 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 cm³ 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 cm³ 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 cm³, at the shore station on January 16, 1956, and the greatest number in any collection, an estimated 100,000 per cm³, 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) shaped 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

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 .214
January 12	0.7	0.175	1.4 .750
February 1	1.2	0.3	2.4 .286
March 16	0.35	0.09	0.8 .474
April 12	0.5	0.125	1.1 .589
May 24	0.45	0.11	1.1
June 15	0.4	0.1	1.0 .536
July 8	0.4	0.1	1.0
August 15	1.3	0.32	3.2 1.715
September 16	1.6	0.4	3.6 1.930
October 27	0.2	0.05	0.45 .241
November 15	0.4	0.1	0.8 .424

.16 × 1.4375 .770

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) $\times$ 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 $\times$ 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