SEARS FOUNDATION FOR MARINE RESEARCH
BINGHAM OCEANOGRAPHIC LABORATORY, YALE UNIVERSITY

JOURNAL OF MARINE RESEARCH

VOLUME V 1943 NUMBER 2

THE PHYTOPLANKTON OF THE GULF OF CALIFORNIA OBTAINED BY THE "E. W. SCRIPPS" IN 1939 AND 1940*

By

J. Y. GILBERT AND W. E. ALLEN
Scripps Institution of Oceanography
University of California
La Jolla, California

The waters of the Gulf of California are fabulously rich in marine life; they fairly teem with multitudes of fish of both commercial and sport varieties. To maintain these large numbers there must be correspondingly huge crops of their ultimate food—the phytoplankton. And, indeed, it was the enormous quantity of these microscopic plants that gave the Gulf its early and descriptive name—the Vermilion Sea. In 1939 and again in 1940 the "E. W. Scripps," research vessel of the Scripps Institution of Oceanography of the University of California, spent several months in these waters and among the data collected on these cruises were quantitative samples of this phytoplankton. It is with these samples that the present report deals.

The phytoplankton of the Gulf, or rather the diatoms which in this region are its main constituent, also plays a considerable geologic role. Bottom samples taken on these two cruises revealed that diatomaceous sediments are being laid down over large areas in the Gulf, probably under conditions similar to those which gave rise to the Miocene diatomaceous shales of the California coast region (Sverdrup and Staff, 1940).

* Contribution from the Scripps Institution of Oceanography, New Series, No. 183.

Prior to 1939 four series of phytoplankton samples had been collected in the Gulf of California. The first series was obtained in 1921 between April 7 and July 11 by the Expedition of the California Academy of Sciences (Allen, 1923); the second in November of 1935 by the Templeton Crocker Expedition (Allen, 1938); the third in 1936 between February 8 and March 20 by the Allan Hancock Expedition of 1936 (Allen, 1937); and the fourth by the Allan Hancock Expedition of 1937 (Cupp and Allen, 1938) between March 1 and April 4.

The 1939 cruise (Figure 30) of the "E. W. Scripps" was of a general oceanographical nature and between February 13 and March 19 the ship occupied 53 stations, which were spaced 15 to 20 miles apart along 9 lines across the Gulf; at 49 of these stations phytoplankton samples were obtained. For the first time the Gulf was systematically sampled and for the first time phytoplankton samples were collected from the surface down to 60 meters at intervals of 10 meters. All of the preceding series had consisted entirely of surface samples. The 1940 cruise (Figure 31), from October through December, was primarily concerned with the geology of the Gulf, but at twenty-two stations was phytoplankton collected in a somewhat limited area. At ten of these stations surface samples only were obtained.

The methods of collecting and enumerating the organisms were similar to those employed on the previous expeditions to the Gulf. Five liters of water, collected with the Allen closing bottle, were filtered through a net of No. 25 bolting silk and the concentrated sample preserved with a small quantity of formalin. The phytoplankton content of these concentrated samples was later determined by enumeration of the organisms in an aliquot portion in a Sedgwick-Rafter counting chamber.

A phytoplankton population is a crop in three dimensions and should be appraised from a number of samples varying in position in both horizontal vertical directions. Often when it is not possible, for one reason or another, to sample subsurface depths, the size of the population at the surface is used as an index of the total population in a water column and in this manner valuable information may be gained. Behind this latter procedure is the assumption, usually implicit, that the total population is proportional to the surface population. The use of this assumption is justified when the opportunity for more thorough sampling is lacking as was the case in the Gulf cruises prior to the 1939 cruise of the "E. W. Scripps." A difficulty arises, however, when these results, based on surface samples alone, are to be compared with the results of the 1939 and 1940 cruises when subsurface depths were sampled.

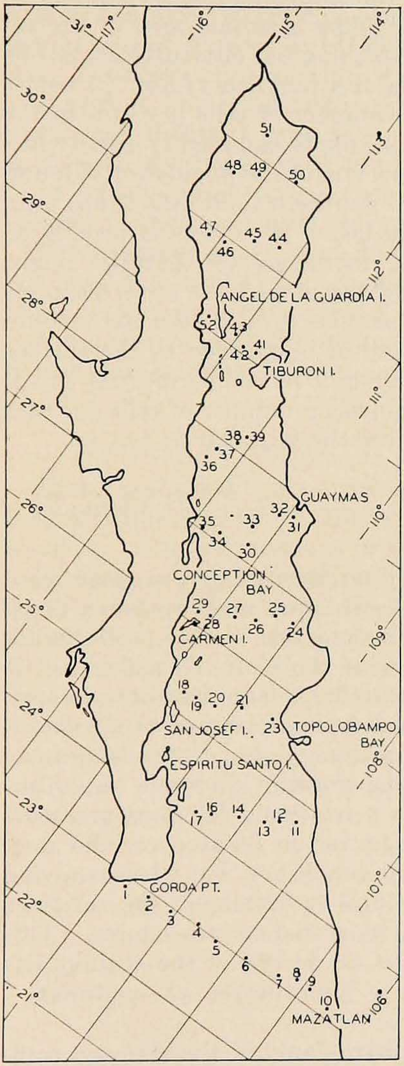

Figure 30. Location of stations at which phytoplankton samples were collected on the *E. W. Scripps* Cruise VII in 1939.

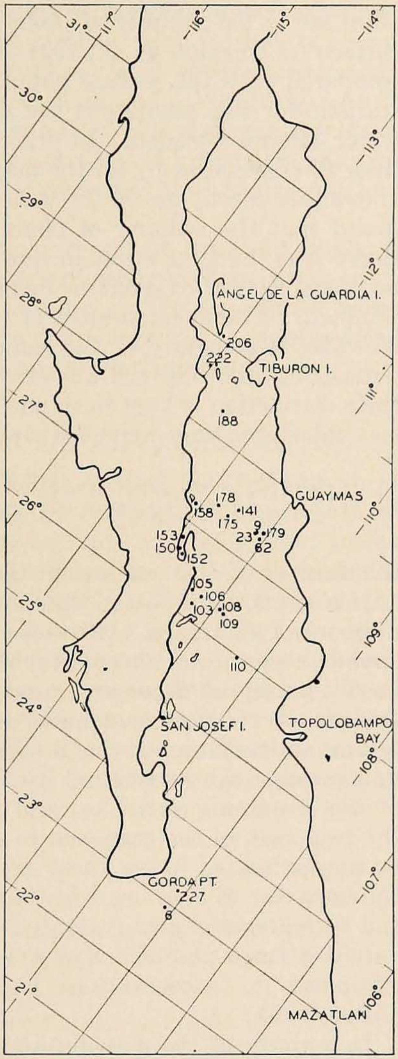

Figure 31. Location of stations at which phytoplankton samples were collected during the *E. W. Scripps* Cruise XVI in 1940.

A logical expression for the size of the total standing crop of phytoplankton is the number of plant cells under a certain area of the sea surface (cf. Bigelow et al., 1941) but this number obviously cannot be compared with the surface population of a previous cruise. A better statistic for this purpose is the mean number of cells per liter in the water column sampled. In practice the depth sampled is usually less than 100 meters, as by far the major portion of the population is found above this depth, and in the waters off Southern California it has been found that the number of plant cells below 60 meters is usually so slight that the time spent in sampling depths greater than this might be more profitably spent in increasing the number of water columns sampled. The mean number of cells per liter for this 60 meter column of water is generally of the same order of magnitude as the surface population and one will not err too greatly in comparing the two if their distinction is kept in mind. This mean number of cells per liter was calculated as a weighted mean from the formula:

$$M = \frac{\frac{1}{2}(N_0 + N_{60}) + N_{10} + N_{20} + N_{30} + N_{40} + N_{50}}{6}$$, where N_z is

the number of cells per liter at the depth indicated by the subscript z.

It is not to be expected that the data obtained on these two cruises, even when combined with those of the previous cruises, will yield a complete picture of the phytoplankton of the Gulf of California. It should hardly be necessary to point out that a large number of observations are required to achieve any valid understanding of the distribution and behavior of the plankton in any region. In the laboratory one variable can be isolated by keeping constant the more important of the remaining variables, and from a relatively few measurements the responses of the organism to changes in this isolated variable may be approximated under these artificial conditions, but when studying the behavior of organisms in their natural environment, the variables can be segregated and evaluated only by statistical procedures. This entails a large number of observations or, as one of the authors has expressed it, "observations having a high degree of continuity" (Allen, 1934).

In a study of the distribution of phytoplankton the primary complicating factors are the cloud-like distribution of the plankton and the transport of these "clouds" by the water currents. At any one spot both the magnitude of the quantity and the specific composition may change completely within a few hours. Thus, at noon on December 27 at station 179, an anchor station of the 1940 cruise, there was a mean population of 2,000 diatoms per liter with *Pseudoeunotia* *doliolus* and *Guinardia flaccida* making up almost half of this number; at 7:30 the next morning a second series of samples revealed a jump in numbers of diatoms to 161,400 cells per liter with *Bacteriastrum* sp. and *Chaetoceros* sp. constituting over 90 per cent of this population. The need of both continuity of observations and a knowledge of the water movements is very great. In the Gulf of California the latter is of particular importance due to the presence of a standing internal wave which causes complex water movements, both horizontal and vertical of the upper water layers.

The foregoing remarks should not, however, be taken to imply in any way that series of limited numbers of samples have little or no value. Certainly they can and do add much to our knowledge of the region under consideration and though they do not in themselves lead to complete solutions, they point the way to such solutions.

REGIONAL DISTRIBUTION OF PHYTOPLANKTON

Allen (1937) and Cupp and Allen (1938) divided the Gulf into three geographical regions for convenience in comparing abundances of diatoms. The region south of 25° N. latitude was designated as the "southern section," the region between 25° N. and 27° N. latitudes as the "middle section," and the Gulf north of 27° N. latitude as the "northern section." In the present paper the "inner" shallow region of the Gulf north of 29° N. latitude is distinguished from the "outer" Gulf region south of this latitude. The previous divisions have been retained for the outer Gulf as these divisions correspond to the regions between the antinodes of the standing internal wave and, consequently, the water masses of these three regions are more or less segregated from one another.

TABLE I—PHYTOPLANKTON, 1939: MEAN NUMBER PER LITER

Station	*Diatoms* Good Condition	Poor Condition	Total	Dinoflagellates	Ast. japonica
1	38200	2600	40800	40	67
2	3000	300	3300	20	
3	1200	100	1400	20	
4	4300	300	4600	40	
5	31800	2100	34000	80	
6	30300	2900	32200	20	
7	20900	2200	23000	60	
8	5900	1300	7200	660	
9	13500	2000	15600	80	
10	39100	8900	48000	840	
11	2300	300	2600	500	13
12	1400	300	1600	150	
13	25300	4600	29900	300	
14	30500	5800	36300	200	
16	20600	6400	27000	60	
17	1000	500	1600	80	
18	395500	47200	442700	100	1000
19	713000	117400	830400	200	1700
20	175700	66200	241900	170	250
21	1300	700	2000	90	
23	2600	1100	3700	20	
24	400	100	500	60	
25	300	200	500	60	
26	2400	500	2900	130	
27	1200	400	1600	100	
28	1000	300	1300	150	
29	4500	200	4600	130	
30	200	200	400	60	
31	1097000	86000	1183000	30	1028000
32	89900	155800	245700	220	156000
33	800	3700	4500	120	2100
34	1600	2000	3500	90	2000
35	73600	14200	87800	150	15200
36	3100	6400	9600	110	3200
37	60100	20500	80600	80	6500
38	6600	2300	8900	40	520
39	47600	9800	57500	140	4700
41	25600	1700	27300	1600	
42	10600	6600	17200	53600	
43	88900	35400	124300	36100	170
44	11700	4600	16300	33700	
45	97400	20800	118200	35300	
46	17500	14600	32100	34300	
47	21200	10800	32000	52900	
48	27900	5900	33800	29000	
49	1600	800	2400	46900	
50	79300	158400	237700	600	
51	4700	1600	6300	203400	
52	368200	60000	428200	19700	2900

TABLE I (cont.)

Station	*Nitz. seriata*	*Plank. sol*	*Pseud. doliolus*	*Rhiz. alata*	*Rhiz. bergonii*	*Thal. longissima*	*Gon. catanella*
1	11900	110	150	47	100	280	
2	710	73	50	5	32	37	
3	180	55	17	10	8	40	
4	190	200	370	37	15	150	
5	23100	540	200	40	500	420	
6	13800	420	1100	200	210	3100	
7	11200	180	380	37	120	520	
8	1200	1400	50	100	85	980	
9	1000	110	50	160	43	140	
10	5300	140	17	120	92	120	
11	510	77	33	58	10	1300	
12	600	100	83	68		320	
13	6200	770	1600	830	140	15600	
14	7200	410	580	510	70	13900	
16	3200	120	900	140		3800	
17	60	25	67	28	2	160	
18	6400	210	83	160		340	
19	9500	300	250			180	
20	330	260	1100	27		130	
21	300	25	180			5	
23	13	7	8			3	
24	47	8	110			3	
25	45	8					
26	270	20	100		2	7	
27	360	22	73			3	
28	130	7	130	2		3	
29	98	15	100				
30	8	100	20			12	
31	8700	37	170				
32	3400	7	530	33			
33	420		33	7		20	
34	330	13	100				
35	5800	27	170			7	
36	3600	40	380	7			
37	5400	7	180				
38	780	17	82				
39	6400	13	100				
41	1200		7	13		7	1600
42	330		240				53400
43	330		980				35900
44	25		25				33700
45	5300		2100				35000
46	1700	7	1600				33700
47	1400		1600			33	52200
48	1300		2100				27600
49	200						45300
50	73100		13		34		390
51	870		33				201300
52	5800		330				19700

TABLE I (cont.)

Station	*Ch. atlanticus*	*Ch. compressus*	*Ch. debilis*	*Ch. peruvianus*	*Ch. radicans*	*Ch. vanheurckii*	*Cosc. wailsii*
1	4500	950	1200	340	1500	550	
2	190	13		25	43		
3	210					47	
4	1100			53			
5	4200			250	17		
6	2200		50	90	470		
7	1400	33	47	140	1900	710	
8	350	220	200	43	17	100	
9	67	130	940	27			
10	150	3200	280	63			
11	73			48			
12	10			33	55	33	
13	170	50	100	340	100	180	
14	520		120	160	1100	220	
16	830	450	330	50	6200	400	
17	73	50		7	50	100	
18	150	14300	1600	7	139000	191000	
19	1900	25000	11200		27100	265000	
20	310	14000	1600	7	8600	87000	
21	95	17	270		33	130	30
23	7	17			42	33	3100
24	28					33	110
25	15					33	310
26	28	33	200			960	25
27	13		170			83	55
28		50	60			42	38
29			210		3500	280	20
30							57
31		6800	43500		11600	15400	
32	20	14000	5100		7500	14900	
33		83	250				
34	55	470	620		180	67	
35	290	2200	12000		9600	49000	
36	96	3700	3400		4600	4600	
37		3700	5600		8700	6700	
38	63	450	1200		1800	500	
39	33	7600	15900		6500	4100	
41		33	2500		2100	6200	
42		13	3500		2800	650	33
43	36	850	17000		46500	9200	17
44			4600		2300	980	
45		580	32900		6500	24500	
46	50	1100	6700		1900	1300	
47		100	5900		2600	1500	
48	180	170	530		14700	2000	
49			750				
50			117000				
51			3400				
52		24700	84500		128000	47700	

TABLE II—PHYTOPLANKTON. 1940

Station	Diatoms			Dinoflagellates
	Good Condition	Poor Condition	Total	
6	700	1100	1800	
9	900	700	1600	10
23	400	200	600	13
62	5300	200	5500	7
103*	31600	21200	53800	
105*	52400	12800	65200	
106*	23200	15400	38600	
108*	18900	2900	21800	
109*	97200	37800	135000	
110	200	100	400	
141	28400	4100	32500	
150*	29900	6100	36000	200
152*	20100	5000	25100	100
153*	98750	25600	124400	380
158*	5400	600	5900	50
175	154100	38400	192500	
178*	2300	640	2900	
179a	1700	400	2100	
179b	137400	24000	161400	
179c	107000	46800	153800	
188	1500	500	1900	
206	32000	3600	35600	
222	59300	13000	72300	
227	100	200	300	

* Designates surface sample. All other stations are represented by mean populations from zero to sixty meters depth.

SOUTHERN SECTION OF THE OUTER GULF

The previous expeditions to the Gulf had found this region to be characterized by the lowest phytoplankton populations of the entire Gulf. The only catches of any considerable size found in this region were made in 1921 off Espirtu Santo Island where catches of over 100,000 cells per liter were obtained in both April and June. A few populations of 10,000 cells per liter were also found in 1937 off Gorda Point, San Josef Island, and Mazatlan.

In 1939 two lines of stations, 1 through 17, were occupied in this region. While the populations found were not exceptional from a quantitative point of view, they were larger on the whole than had been reported from it previously. All stations showed mean populations of at least 1,000 cells per liter and at 9 of the 16 stations the mean number of cells per liter exceeded 10,000.

In 1940 only two stations were occupied in this region; station 6 (Oct. 12) and station 227 (Dec. 14). The mean diatom populations at these two stations were 1,800 and 300 cells per liter respectively.

In 1939 the plankton flora of this region, stations 1 through 17, could readily be distinguished from that of the other regions by its predominantly oceanic character. In general, *Nitzschia seriata* was the dominant species, but true oceanic forms were consistently present and constituted a considerable portion of the phytoplankton. These oceanic forms included *Chaetoceros atlanticus*, *Ch. peruvianus*, *Thalassiothrix longissima*, *Planktoniella sol*, *Rhizosolenia alata*, *Rh. bergonii*, *Rh. calcar-avis*, and *Rh. imbricata* var. *shrubsolei*. In the other sections of the Gulf these diatoms were either completely absent or were found only in a few scattered instances.

At stations 13 and 14 *Thalassiothrix longissima* was the dominant species and occurred in numbers up to 30,000 cells per liter to constitute more than half of the phytoplankton populations of these stations. This is interesting because a microscopic examination of the diatomaceous mud at the bottom of the Gulf revealed great quantities of the broken frustules of this diatom. It is one of the three forms that make up the main portion of the identifiable diatom frustules found in the Gulf sediments. The other two forms are *Coscinodiscus* sp. and *Pseudoeunotia doliolus*. In this respect it is of interest to note that *P. doliolus* was also present in considerable numbers and while this species was found at practically every station in the Gulf, it was most numerous in this southern portion and in the northern region.

MIDDLE SECTION OF THE OUTER GULF

This region, 25° N. latitude to 27° N. latitude, had been previously found to have diatom populations larger than those of the southern section but still relatively poor as compared with the more northerly regions of the Gulf. In 1921 half of the 18 samples taken in this region contained over 10,000 diatoms per liter and at several stations around Carmen Island populations of over 100,000 cells per liter were found. However, in the series of 1935, 1936, and 1937 the only samples of large populations came from off Topolabampa Bay where a catch of over 500,000 cells per liter was obtained in 1937 and from Conception Bay where populations over 10,000 cells per liter were found in both 1936 and 1937.

In 1939 huge catches of diatoms were made in the southwestern portion of this region. Stations 18 and 19 had mean populations of 442,700 and 830,400 cells per liter respectively, and station 20 had a mean population of over 200,000 cells per liter. However, the populations at the other stations of the regions were all under 5,000 cells per liter so that with the exception of the extremely large abundances in the southwestern corner, the phytoplankton of this region was the poorest found in the Gulf in 1939.

The large phytoplankton assemblages at stations 18, 19, and 20 were composed largely of neritic *Chaetoceros* species,—*Ch. radicans, Ch. vanheurckii, Ch. socialis, Ch. compressus,* and *Ch. curvisetus.* These neritic *Chaetoceros* species were common throughout the Gulf and usually made up the major part of the larger populations. The phytoplankton of the remaining stations of this region was clearly distinguished from that of the rest of the Gulf by the presence of moderately large numbers of a *Coscinodiscus* form either identical with or a variety of *Coscinodiscus wailsii* Gran and Angst.*

With the exception of stations 42 and 43, this diatom was not found outside of this middle region. The absence of this form at stations 18, 19, and 20 and the presence at these stations of *Asterionella japonica,* the characteristic diatom of the adjacent northern section, suggests strongly that the upper water mass at these three stations had drifted into this middle region from the adjacent northern section.

In 1940 eight surface samples were taken in this region. Six of these had populations greater than 10,000 cells per liter and one, station 153, at the mouth of Conception Bay, had a population of over 100,000 cells per liter. *Hemiaulus hauckii, Nitzschia seriata,* and the usually neritic *Chaetoceros* species dominated these samples. *Coscinodiscus wailsii* was not found at this time.

NORTHERN SECTION OF THE OUTER GULF

This portion of the outer Gulf, from 27° N. latitude to 29° N. latitude, includes the Guaymas area in which catches of over three million cells per liter had been made in 1937. Populations of the same size were again found here in 1939. In 1937 the main constituents of this population were *Chaetoceros radicans, Ch. compressus, Ch. debilis, Asterionella japonica,* and *Skeletonema costatum.* In 1939 the samples from this area, stations 31 and 32, were almost a pure culture of *Asterionella japonica.* Station 31 for example had a surface population of four million diatoms per liter, of which 3,600,000 were *Asterionella japonica.* In 1939 this species was almost entirely confined to this northern section of the outer Gulf and served to distinguish the flora of this region from that of the rest of the Gulf.

In 1939, of the ten stations in this area, five had mean populations of over 50,000 cells per liter. The phytoplankton of this region was distinctly more abundant than that of the more southerly regions.

* This diatom was identical to Gran and Angst's *Coscindodiscus wailsii* (Gran and Angst, 1931) except for the beginning of a rosette at the center, irregularly placed spinulae on the valve surface, and two small thickened processes on the valve flange at an angle of about 120° apart.

Station 30, the poorest of the section, evidently belonged to the adjacent middle section as *Coscinodiscus wailsii* was found here, whereas *Asterionella japonica* was missing.

In 1940 two stations, 175 and 179, of the ten occupied in this region had populations of over 100,000 cells per liter and two others, stations 141 and 222, had populations of over 30,000 cells per liter. The dominant species were neritic *Chaetoceros* species and *Bacteriastrum* species. *Asterionella japonica* was not found, but at station 188 a few species of *Coscinodiscus wailsii* were recorded.

INNER GULF REGION

In 1921 large diatom populations were found around Angel de la Guardia and Tiburon Islands and in the region to the north of these islands. In 1937 the region to the north of the islands was found to be very poor in phytoplankton, but exceptionally large diatom populations were found around the islands. From these series some suggestion was obtained that the area off the north end of Angel de la Guardia Island and the area off the southeastern portion of Tiburon Island were especially productive.

In 1939 these two areas off the islands were not visited, but in the rest of the inner Gulf region a completely different picture was obtained due to the presence of enormous numbers of the dinoflagellate, *Goniaulax catanella* (Whedon and Kofoid) or some species closely resembling it. Stations 41 and 50 were the only stations of this region that did not have large populations of this organism.

Diatoms were also present in large numbers in 1939. Ten of the twelve stations of this region had mean diatom populations of over 15,000 cells per liter and of these ten the mean populations of stations 43, 50, and 52 were over 100,000 diatoms per liter.

VERTICAL DISTRIBUTION

Our data are too few and our knowledge of the hydrographical conditions too vague to permit any serious attack on the problems of the vertical distribution of the phytoplankton,—especially in view of the fact that at a depth of 60 meters periodical vertical displacements of the order of 30 meters would be expected to accompany the internal wave.

In 1939 the depths of maximum populations of diatoms in good condition were distributed as follows:

0 meters	— 9 stations
10 meters	— 12 stations
20 meters	— 9 stations
30 meters	— 5 stations
40 meters	— 6 stations
50 meters	— 4 stations
60 meters	— 5 stations.

In counting the organisms a distinction was made between the cells in good condition and those in poor condition (frustules lacking chromatophores or obviously disorganized) as the percentages of these two often aid in interpreting the results of the counts. It is interesting in this respect to note that there was no correlation between the percentage of cells in poor condition and the depth of maximum population. Nor was there any definite relation between the depth of the maximum number of cells in good condition and the depth of the maximum number of cells in poor condition—the maximum number of cells in poor condition being found as often above as below the depth of the maximum number of cells in good condition—which is in agreement with the hypothesis that the density of the cell protoplasm is close to or equal to that of sea water.

TABLE III—Vertical Distribution of Diatoms at Deep Stations, 1940

Station	*Depth in Meters*	*Good Condition*	*Poor Condition*	*Total*
9	0	480	1600	2080
	10	0	560	560
	20	20	460	480
	30	520	2000	2520
	40	1760	120	1880
	50	200	100	300
	60	60	40	100
	100	100	110	210
	300	0	65	65
	500	0	15	15
	750	0	50	50
	1250	0	5	5
	1500	5	0	5
	1620	0	10	10
23	0	140	80	220
	10	0	220	220
	20	20	160	180
	30	120	360	480
	40	760	60	820
	50	1720	80	1800
	60	0	120	120
	500	0	10	10
	750	0	40	40

TABLE III (Cont.)

Station	*Depth in Meters*	*Good Condition*	*Poor Condition*	*Total*
62	0	11520	320	11840
	10	6240	80	6320
	20	12000	440	12440
	30	2880	160	3040
	40	1440	280	1720
	50	3600	40	3640
	60	320	260	580
	500	0	40	40
	1525	0	10	10
110	0	1840	160	2000
	10	0	120	120
	20	100	40	140
	30	140	40	180
	40	140	140	280
	50	180	100	280
	60	40	220	260
	500	20	20	40
	1000	0	160	160
	1260	0	50	50
	1510	0	25	25
141	0	38400	6240	44640
	10	30400	3840	34240
	20	48160	15160	63320
	30	41760	10560	52320
	40	25440	10080	35520
	50	5440	3120	8560
	60	640	480	1120
	300	60	380	440
	500	240	350	590
	600	20	110	130
	760	70	40	110
	1000	70	170	240
	1740	10	100	110
175	0	336600	34800	371400
	10	178800	39000	217800
	20	293400	58200	351600
	30	181200	57000	238200
	40	79800	21200	101000
	50	20000	6560	26560
	60	7200	7520	14720
	300	240	820	1060
	500	0	400	400
	600	320	400	720
	750	220	750	970
	900	5	45	50
	1000	400	3740	4140
	1710	520	6800	7320
	1850	28	532	560
	1780	0	196	196
	1880	252	1540	1792

TABLE III (Cont.)

Station	*Depth in Meters*	*Good Condition*	*Poor Condition*	*Total*
179	0	333600	45600	379200
	10	313200	51000	364200
	20	270600	40200	310800
	30	62600	17200	79800
	40	9520	5040	14560
	50	1720	2080	3800
	60	320	1000	1320
	775	200	1520	1720
	860	240	640	880
	1020	0	280	280
	1200	0	1360	1360
	1020	40	100	140
188	0	320	140	460
	10	540	540	1080
	20	920	340	1260
	30	2360	440	2800
	40	1520	280	1800
	50	1400	540	1940
	60	3760	960	4720
	300	0	3560	3560
	480	222	4662	4884
	530	110	1375	1485
	580	0	495	495
	630	55	1705	1760
	670	330	3245	3575
	750	0	15000	15000
227	0	0	200	200
	10	160	240	400
	20	320	680	1000
	30	60	100	160
	40	60	20	80
	50	20	100	120
	60	80	20	100
	1000	20	20	40
	2050	60	140	200

Nine of the 1940 phytoplankton stations are of special interest in that at these stations samples were taken down to great depths; at stations 188 and 23 samples were taken down to 750 meters, and at stations 9, 62, 110, 141, 175, 179, and 188 down to depths below 1000 meters. As would be expected the number of empty frustules greatly exceeded the number of living cells at depths below 60 meters, and there was usually a sharp decrease in the number of total frustules between this depth and 300 meters, followed by a more gradual decrease below 300 meters, so that at 750 meters only a few hundred, or at the most one or two thousand, cells per liter were found. The one exception to this was station 188 where 15,000 frustules were found at 750 meters (the greatest depth sampled) whereas populations of only a few thousand cells per liter were found in the upper layers.

The specific composition changed considerably with depth. The majority of the weakly silicified, neritic diatoms such as *Chaetoceros radicans* and *Bacteriastrum* species disappeared between 60 and 300 meters and at 1000 meters very few representatives of these diatoms were found. The heavily silicified forms which were rarely present in large quantities in the surface layers increased, therefore, relatively with depth so that below 1000 meters the empty frustules of *Coscinodiscus, Thalassiothrix, Thallassionema, Pseudoeunotia,* etc. completely dominated the small residue of the diatom population.

The lists of species recorded for diatoms (table IV) and dinoflagellates (table V) are essentially the same as those recorded in other reports (e. g. Cupp and Allen, 1938), no significant differences being discernible.

TABLE IV—Diatoms Found in the Gulf of California in 1939 and 1940

Actinoptychus undulatus (Bail.) Ralfs	**Asterolampra marylandica* Ehr.
Asteromphalus heptactis (Breb.) Ralfs	*Asterionella japonica* Cl.
Bacteriastrum sp.	*Biddulphia* sp.
Chaetoceros affinis Laud. *Ch. compressus* Laud. *Ch. debilis* Cl. *Ch. didymus* Ehr. *Ch. lorenzianum* Grun. **Ch. pendulum* Karst. *Ch. radicans* Schütt **Ch. vanheurckii* Gran	*Ch. atlanticus* Cl. *Ch. curvisetus* Cl. **Ch. diadema* (Ehr.) Gran & Angst *Ch. lacinisosus* Schütt **Ch. messanensis* Castr. *Ch. peruvianus* Brightw. *Ch. socialis* Laud. *Chaetoceros* sp.
**Climacodium fraunfeldianum* Grun.	
Corethron criophilum Castr.	*Cor. hystrix* Cl.
**Coscinodiscus wailesii* (?) Gran & Angst	*Coscinodiscus* sp.
**Coscinosira polychorda* Gran	
**Dactyliosolen antarcticus* Cast.	*Dac. mediterranea* Perag.
Ditylum brightwellii (West) Grun.	*Eucampia zoodiacus* Ehr.
**Fragilaria* sp.	**Gossleriella tropica* Schütt
Guinardia flaccida (Castr.) Perag.	*Hemialus hauckii* Grun.
Lauderia borealis Gran	*Leptocylindricus danicus* Cl.
Lithodesmium undulatum Ehr.	**Licmophera lyngbyei* (Kutz.) Grun.
**Melosira* sp.	
**Navicula membranacea* Cl. *Navicula* sp.	**Nav. pelagica* Cl.
Nitzschia longissima (Breb.) Ralfs *Nitz. pungens* Cl.	*Nitz. seriata* Cl.

* Species not previously reported from the Gulf of California.

TABLE IV (cont.)

**Paralia sulcata* (Ehr.) Cl.	*Planktoniella sol* (Wall.) Schütt
Pleurosigma sp.	*Pseudoeunotia doliolus* (Wall.) Schütt
Rhizosolenia acuminata (Perag.) Gran	*Rhiz. alata* Brightw.
Rhiz. bergonii Perag.	*Rhiz. calcar-avis* Schultze
Rhiz. castracanei Perag.	*Rhiz. delicatula* Cl.
Rhiz. fragilissima Berg.	*Rhiz. imbricata* Brightw.
**Rhiz. robusta* Norm.	*Rhiz. hebetata* f. *semispina* (Hensen) Gran
Rhiz. setigera Brightw.	*Rhiz. stolterfothii* Perag.
Schroederella delicatula (Perag.) Pav.	*Skeletonema costatum* (Grev.) Cl.
**Stephanopyxis palmeriana* (Grev.) Grun.	**St. turris* (Grev. & Arn.) Ralfs
Surirella sp.	
Thalassiosira decipiens (Grun.) Jorg.	**Thal. gravida* Cl.
**Thal. pacifica* Gran & Angst	*Thal. rotula* Meun.
**Thal. subtilis* (Ostf.) Gran	
Thalassiothrix frauenfeldii Grun.	*Th. hetermorpha* Karst.
Th. longissima Cl. & Grun.	
Thalassionema nitzschoides Grun.	**Tropidoneis* sp.

*Species not previously reported from the Gulf of California.

TABLE V—Dinoflagellates Found in the Gulf of California in 1939 and 1940

Ceratium candelabrum (Ehr.) Stein	*Cer. furca* (Ehr.) Clap. et Lachm.
Cer. fusus (Ehr.) Duj.	*Cer. macroceros* (Ehr.) Cl.
Cer. kofoidii Jörg.	*Cer. pentagonum* Gourret
Cer. tripos (O. F. M.) Nitzsch	
Dinophysis caudata Saville-Kent	*Din. ellipsoides* Kof.
Goniaulax catanella Whedon & Kofoid	*Gon. polyedra* Stein
Goniaulax sp.	
Noctiluca miliaris Sur	
Peridinium crassipes Kof.	*Per. depressum* Bail.
Per. divergens Ehr.	*Per. oceanicum* Vanhöffen
Per. orbiculare Paulsen	*Per. ovum* Schiller
Per. pyriforme Paulsen	*Per. pellucidum* (Berg.) Schütt
Per. steinii Jorg.	*Peridinium* sp.
Phalacroma rotundatum (Clap. et Lachrm.) Kof. & Mich.	*Podolampas palmipes* Stein
Prorocentrum micans Ehr.	

SEASONAL VARIATION

The productivity of the Gulf of California, so far as this is represented by the size of the phytoplankton populations, appears to be relatively great, but the data are far too deficient in continuity, both temporal and spatial, to permit any definite conclusions. Populations of over 100,000 cells per liter have been found at various stations throughout the Gulf in every season it has been sampled, but whether this would have been found to be the case by a continuous investigation extending over this period of the year, from November through June, is not known. Since three of the six cruises occurred in February and March, our knowledge of this period is more complete. In two of these three cruises huge populations were found, and it appears probable that this is the period of larger populations (a little earlier than in the Gulf of Santa Catalina).

The evidence for the annual phytoplankton cycle is largely indirect. Bottom cores from the Gulf show alternating light and dark bands which when examined under the microscope prove to be layers of relatively pure diatomaceous material alternating with layers of less purely diatomaceous detritus. These layers have been interpreted as annual layers corresponding to seasonal changes in diatom populations (Sverdrup and Staff, 1940) and if so indicate large seasonal differences in phytoplankton production.* In addition the waters are reported to be clear and blue in late summer but are discolored with phytoplankton growth over large areas in late winter and spring.

In the beginning of November strong northwesterly winds set in which must result in upwelling and replenishment of the nutrients in the surface layers. At the same time vertical circulation is brought about in the shallower upper region of the Gulf by the cooling of the surface waters with resulting lowering of the stability. These conditions should result in greatly accelerated phytoplankton production. In early summer the northwesterly winds die out; the surface waters become heated and stratified; and the phytoplankton should rapidly exhaust the supply of nutrients and diminish in quantity. This picture is partly confirmed by the fact that the largest populations have been found in March.

GENERAL CHARACTERISTICS OF THE GULF OF CALIFORNIA

The Gulf of California is a sloping trough, roughly V shaped in cross section, approximately 700 miles long and 60 miles wide. At the entrance its waters communicate freely with those of the Pacific Ocean down to a depth of more than 3,000 meters. The bottom slopes upward toward the Gulf's head and is irregular with several deeper basins present. About 29° N. latitude the Gulf becomes quite shallow and a group of islands rise above the surface. Beyond this point there are two deeper basins on each side of Angel de la Guardia Island but from them northward the depth is less than 200 meters.

* It should be borne in mind, however, that the diatoms whose frustules make up the diatomaceous deposits are not the same as those that make up the bulk of the phytoplankton pulses.

The temperature and salinity of the deep water in the outer Gulf show that this water is of the same type as exists over large areas in the Central Pacific. The general water circulation is characterized by an inflow of deep water and an outflow of surface water, and as a consequence of this circulation deep water, rich in plant nutrients, is brought to the euphotic zone where the nutrients can be utilized by the phytoplankton. The main factor effecting this circulation in the outer Gulf is the wind, which from late fall to summer blows parallel to and out of the Gulf, bringing about upwelling and an outward transport of surface water.

In the upper Gulf, i. e. in the region of and north of Angel de la Guardia and Tiburon Islands, there are two basins with sill depths of less than 200 fathoms in which temperature, salinity, and oxygen curves (Sverdrup, 1940) show that basin conditions exist. In winter, at the same time the northwesterly winds are bringing about upwelling in the outer Gulf, the surface temperature is decreased by cooling, and convection currents develop in these basins and in the shallow region to the north of the islands.

Thus in both inner and outer regions of the Gulf the hydrographical features are conducive to high productivity. These two conditions, upwelling in the outer basin and convection in the inner basin, can fully account for the fertility of the Gulf without the necessity of considering the effect of the Colorado River which empties into the head of the Gulf. That vertical oceanic circulation can maintain an enormous amount of marine life in the absence of local terrestrial drainage is clearly shown by the great productivity of the waters off the West Coast of South America which is one of the most arid coastal regions in the world.

At the time of the 1939 cruise salinity, temperature, oxygen, and density curves showed upward displacements suggestive of upwelling at stations 23, 39, and, to a lesser extent, 31. However, the hydrographical conditions in the outer Gulf in 1939 suggest the existence of a standing internal wave. Such a wave could give rise to similar displacements or could reduce the displacements due to upwelling, and caution must be exercised in utilizing such profiles to locate the centers of active upwelling.

The distribution of mass at the time of the 1939 cruise showed alternating upward and downward displacements of the isopycnal surfaces, and the dynamic computations revealed a sequence of separate highs and lows of the isobaric surfaces. This suggested the existence in the outer Gulf of a standing internal wave having three nodes (Sverdrup, 1940). The distribution of the mean diameter of the particles of the bottom sediments was found to agree with the presence of such a wave (Revelle, 1940) and suggested that this wave is a permanent feature of the Gulf. A theoretical treatment by Munk (1941) further showed that the postulated characteristics of the wave were compatible with the physical features of the Gulf. Additional confirmation for the existence of this wave now appears in the distribution of the phytoplankton.

The presence of such a standing internal wave with three nodes would be associated with three circulation cells in the outer Gulf whose boundaries would be located at the antinodes and a fourth cell comprising the area north of the island region where the wave terminates. This internal wave would set up horizontal cellular currents having maximum velocities of the order of 50 cm/sec but having zero velocity at the antinodes or cell boundaries. The direction of these currents in the middle cell would be opposite to those in the southern and northern cells and these directions would be reversed every half period, i. e. about 3.5 days for a first order wave or 7 days for a second order wave. In the case of waves with periods as great as these, the deflecting force of the earth's rotation would modify the direction of these currents so as to bring about a circular flow instead of a simple oscillation in one direction. This cellular circulation would act as a barrier to intercellular flow and would tend to preserve for a time any differences in the plankton flora of the cells.

In addition to this intracellular circulation there will be tendencies for intercellular circulation due to alterations in the distribution of mass brought about by the tangential stress of the wind and thermohaline changes in density. This will result in the frequent breakdown of the intercellular barriers and the transport of water masses across the antinodal regions. Any floral differences reflecting the presence of the internal wave will, therefore, be transitory in nature.

This internal wave greatly complicates the interpretation of the hydrographical data. As was mentioned previously, profiles of the physical properties of the water showed a large upward displacement at station 23. Such an upward displacement usually indicates upwelling and a consequent rich supply of nutrients in the surface layers. Yet this region was found to be extremely poor in phytoplankton. This raises the question as to whether the upward displacements of the isolines really indicated active upwelling. It is quite possible that this distribution of properties reflects the presence of the internal wave rather than upwelling. An anti-cyclonic circulation in this middle cell would be accompanied by upward displacements of the sigma-t surfaces along the shores and a downward displacement in the center; a condition which would simulate upwelling. This distribution of density would be reversed in the next half period when the anti-cyclonic circulation changed to a cyclonic one and any upwelling in this area would then be masked. Since the circulation in the adjacent cells is opposite in direction to that in the middle cell, the latter appears to be the case off Guaymas where a slight upward displacement of the isopycnals was accompanied by an extremely large diatom population.

On the other hand, it is equally possible, in the absence of any data and neglecting any intrinsic factors preventing the diatoms from responding to an increase in nutrients, to attribute the low populations of the middle region to zooplankton grazing. Also, other seasons of the year, or other years, may show differences in conditions.

SUMMARY

The examination of the distribution of the phytoplankton in the Gulf of California in 1939 disclosed four distinct phytoplankton types; an oceanic type at stations 1 through 17, a *Coscinodiscus wailsii* type at stations 21 through 30, an *Asterionella japonica* type at stations 31 through 39, and a *Goniaulax catanella* type at stations 41 through 52. The distribution of these types corresponds exactly to the locations of the circulation cells which would be predicted in the presence of a standing internal wave as postulated by Sverdrup and constitutes confirmative evidence for the existence of this wave.

In agreement with the results of previous cruises to the Gulf, the phytoplankton populations of the northern sections of the Gulf were found to be larger on the whole than those from the southern section. This indicates that upwelling is most active in the northern section of the outer Gulf (the Guaymas area) where slight upward displacements of the isopycnal surfaces were found in spite of an opposing tendency of the distribution of mass accompanying the internal wave.

Indirect evidence indicates that the seasonal phytoplankton cycle is dependent upon the process of upwelling in the outer Gulf and upon convection in the upper, shallow region. These two processes are initiated in late fall when northwesterly winds bring about upwelling and when surface cooling lowers the stability of the water masses in the basins and shallow areas of the upper Gulf. At the onset of summer when the northwesterly winds die out and the surface waters become heated and stratified, these processes and the spring phytoplankton growth terminate. The fact that the largest populations have been found in March supports this picture and suggests that this is the period of maximum productivity.

Phytoplankton samples from depths greater than 300 meters were obtained in 1940 and indicate that the majority of the weakly silicified cells were dissolved above this depth and that the numbers of frustules cleansed of cell contents greatly exceeded the number of cells in apparently good condition.

REFERENCES

ALLEN, W. E.

1923. Observations on surface distribution of marine diatoms of Lower California in 1921. Proc. Cal. Acad. Sci. *12:* 437–42.

1934. The importance of continuity in marine plankton investigations. Fifth Pac. Sci. Cong. California, 1933, Proc. *3:* 2051–55.

1937. Plankton diatoms of the Gulf of California obtained by the G. Allan Hancock Expedition of 1936. The Hancock Pacific Expeditions, The Univ. So. Calif. Publ. *3:* 47–59.

1938. The Templeton Crocker Expedition to the Gulf of California in 1935—the Phytoplankton. Trans. Amer. Micr. Soc. *67:* 328–35.

BIGELOW, H. B., LILLICK, L. C., SEARS, M.

1941. Phytoplankton and plankton protozoa of the offshore waters of the Gulf of Maine. Part I—Numerical Distribution. Trans. Amer. Phil. Soc. N. S., *31:* 149–91.

CUPP, E. E. AND ALLEN, W. E.

1938. Plankton diatoms of the Gulf of California obtained by Allan Hancock Pacific Expedition of 1937. The Hancock Pacific Expeditions, The Univ. So. Calif. Publ. *3:* 61–74.

GRAN, H. H. AND ANGST, E. C.

1931. Plankton diatoms of Puget Sound. Publ. Puget Sound Biol. Sta. *7:* 417–519.

MUNK, W. H.

1941. Internal waves in the Gulf of California. Sears Foun., J. Mar. Res. *4:* 81–91.

REVELLE, R. R.

1939. Sediments of the Gulf of California. Geol. Soc. Amer., Bull. *50:* 170–71.

SVERDRUP, H. U.

1941. The Gulf of California: Preliminary discussion of the cruise of the "E. W. Scripps" in February and March, 1939. Sixth Pac. Sci. Cong., Calif., 1939, Proc. *3:* 161–66.

WHEDON, W. F. AND KOFOID, C. A.

1936. Dinoflagellata of the San Francisco Region. I. On the skeletal morphology of two new species, *Gonyiaulax catanella* and *G. acatanella:* Univ. Cal. Pub. Zool. *41:* 25–34.