J. mar. biol. Ass. U.K. (1958) 37, 371–377
Printed in Great Britain

PHOSPHORUS AND SILICON IN SEA WATER OFF PLYMOUTH DURING 1956

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(Text-figs. 1–4)

Analyses of sea water collected during 1956 at the International Hydrographic Station E 1 (lat. 50° 02′ N., long. 4° 22′ W.) are given here in the same form as in earlier reports (Armstrong, 1954, 1955, 1957). The methods of collection and analysis were substantially unchanged.

I am obliged to Lt.-Cdr. C. A. Hoodless and the crew of R.V. *Sarsia* and to Capt. W. J. Creese and the crew of R.V. *Sula* for assistance at sea. It is a pleasure to acknowledge the help given by Dr S. M. Marshall in making the counts of organisms listed in Table 3, and that of Dr T. Peirson, Medical Officer of Health for Plymouth, in providing access to the daily weather records of the city. Salinities were determined by the Government Chemists Department.

RESULTS

Temperature and salinity

The lowest surface temperature recorded was 8·7° C on 26 March, and the highest was 15·7° C on 23 July.

The vertical distribution of temperature during the year is shown in Fig. 1. It shows no sharp stratification until July; although on 11, 16 and 24 April there were small temperature gradients, the top of the water column being warmer than the bottom by 0·67, 0·28 and 1·12° C respectively. Temperature gradients then increased until July, when there was a sharp thermocline at 10–15 m, which persisted, with some variation in depth until September; it had broken down by 23 October.

Salinities throughout the year are given as integral means for the water column in Table 1. It is seen that there was a significant rise in March to 35·41‰ and that high values persisted until July. Such saline water is unusual at Station E 1, figures of over 35·4 having been found only on six occasions out of sixty or so during the previous nine years. These unusual and persistent salinities give some grounds for supposing that during the spring months there may have been a consistent body of water at the station.

Phosphate

Vertical distribution is shown in Fig. 2, and integral mean concentrations in Table 1.

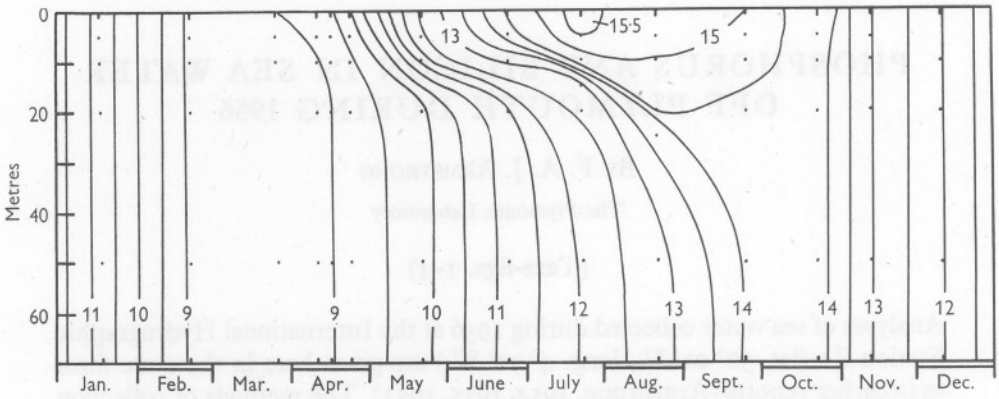

Fig. 1. Vertical temperature distribution at International Hydrographic Station E 1, 1956. Contour lines at 0·5° C intervals.

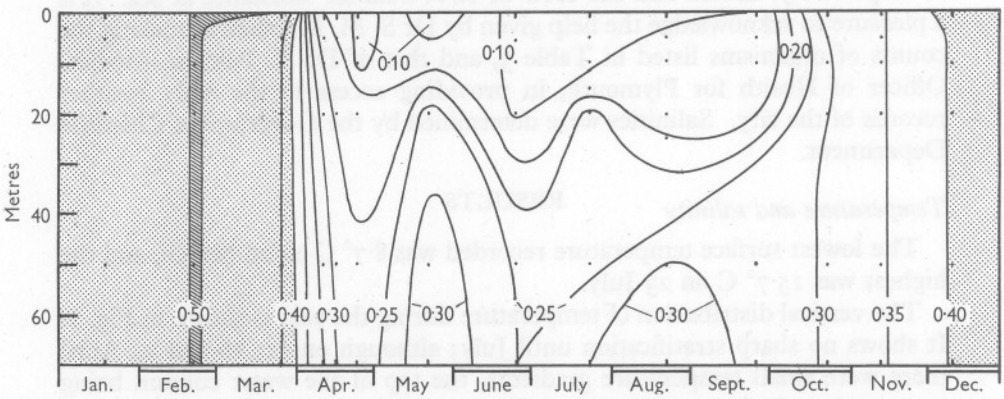

Fig. 2. Vertical distribution of phosphate at International Hydrographic Station E 1, 1956. Contour lines at 0·05 μg atom P/l. intervals.

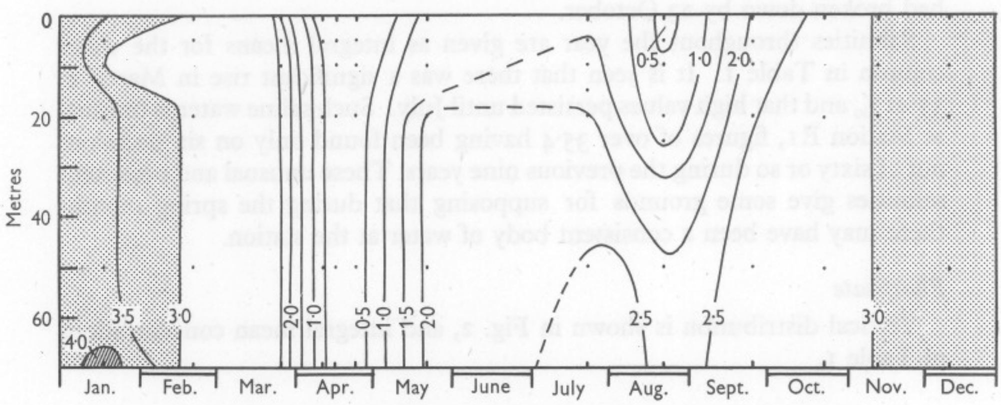

Fig. 3. Vertical distribution of silicate at International Hydrographic Station E 1, 1956. Contour lines at 0·5 μg atom Si/l. intervals.

The maximum found was 0·50 μg atom P/l. on 21 February. This is about the usual value of recent years; the unusually high (0·58–0·59) ones of February and March 1955, were transitory. On 26 March, just after 2 days of bright weather, phosphate was 0·46 μg atom P/l. and phytoplankton was readily visible to the unaided eye in samples from all depths. Sunny anticyclonic weather continued, and while it lasted observations were repeated, on 11, 16 and 24 April, in order to follow chemical changes during the spring growth of plants.

TABLE 1. INTEGRAL MEAN CONCENTRATIONS IN WATER COLUMN AT STATION E1

Date	Salinity (‰)	Phosphate-P (μg atom P/l.)	'Total-P' (μg atom P/l.)	Silicate (μg atom Si/l.)
17. i. 56	35·27	0·46	0·59	3·61
21. ii. 56	35·32	0·50	0·60	2·87
26. iii. 56	35·41	0·46	0·58	2·52
11. iv. 56	35·43	0·25	0·51	0·61
16. iv. 56	35·42	0·20	0·49	0·08
24. iv. 56	35·43	0·17	0·50	0·27
22. v. 56	35·42	0·27	—	1·90
25. vi. 56	35·43	0·16	—	—
23. vii. 56	35·43	0·21	—	2·29
22. viii. 56	35·37	0·22	—	1·41
25. ix. 56	35·30	0·19	—	2·51
23. x. 56	35·30	0·31	—	2·72
13. xi. 56	35·34	0·34	—	3·05
10. xii. 56	35·37	0·41	—	3·08

TABLE 2. SUNSHINE ON PLYMOUTH HOE (22 MILES FROM STATION E1)

		1956		1893–1952, mean for 60 years	
Period	Days	Total sunshine (h)	Mean per day (h)	Total sunshine (h)	Mean per day (h)
26 Mar.–10 Apr.	16	111·1	6·9	81·5	5·1
11–15 Apr.	5	17·8	3·6	28·6	5·7
16–23 Apr.	8	87·6	10·9	53·6	6·7
Total for period	29	216·5	7·5	163·7	5·6

Table 2 shows total and mean daily hours of sunshine on Plymouth Hoe, about 22 miles from Station E1, for the period 26 March to 23 April 1956, and also the mean figures from the daily records, for the same period, for 60 years from 1893 to 1952. There was more sunshine in 1956. It was noticed that only 4 days (29 March and 12, 13 and 14 April) had less than 3 h of daily sunshine.

Integral mean concentrations fell to 0·17 μg atom P/l. during the period, the change being greatest in the upper layers and less marked below 20 m, as shown in Fig. 4. By themselves these phosphate observations are not particularly significant and resemble changes in earlier years. They are of interest, however, if taken together with the silicate analyses below.

Afterward, phosphate remained low in the upper layers (minimum 0·05–0·06 μg atom P/l. on 25 June) until September. By 23 October, when the water column had become isothermal, phosphate had also become uniform vertically, and increased until the end of the year.

Total phosphorus

Determinations were discontinued after April. The maximum integral mean value was 0·60 μg atom P/l. on 21 February. The March and April values show that to some extent the element is conserved during the spring outburst of plants.

Silicate

Vertical distribution is shown in Fig. 3, and integral mean concentrations in Table 1.

The maximum integral mean concentration of 3·6 μg atom Si/l. was found on 17 January, although the vertical distribution was not uniform, being 4·2 at 70 m and 3·0 at 10 m, increasing again to 3·5 at the surface. The surface was very slightly warmer (0·04° C) than the bottom. A decrease to 2·9 μg atom Si/l. had occurred by 21 February, temperatures then being uniform. Possibly the water mass was changing in January, though there is no other evidence for this.

Changes during the period 26 March to 24 April are shown, with the corresponding phosphate changes, in Fig. 4. During the first 21 days silicate decreased almost linearly, and on 16 April most of it had been removed from the water at all depths. Even at 50 and 70 m there remained only 0·08 and 0·09 μg atom Si/l. This is well below the photosynthetic zone, and the 'compensation point' as defined by Jenkin (1937) could hardly have been deeper than 40 m. After a further 8 days silicate, particularly in the deep water, had increased again somewhat, though phosphate had continued to fall.

During the summer months silicate concentrations fluctuated rather, mostly in the top 20 m. Vertical uniformity was re-established by 23 October, after which silicate increased slightly as is usual.

Integral mean concentrations

These are shown in Table 1 (and have already had mention). The decreases representing consumption of nutrients in the spring may be taken as: phosphate 0·34 μg atom P/l., and silicate probably 2·78 μg atom Si/l. if the January figures be excluded.

Plankton

Samples from 10 and 50 m taken on 16 and 24 April were preserved and were examined by Dr S. M. Marshall, who made duplicate counts of 10 ml. and gave the results listed in Table 3. She commented that only the 10 m

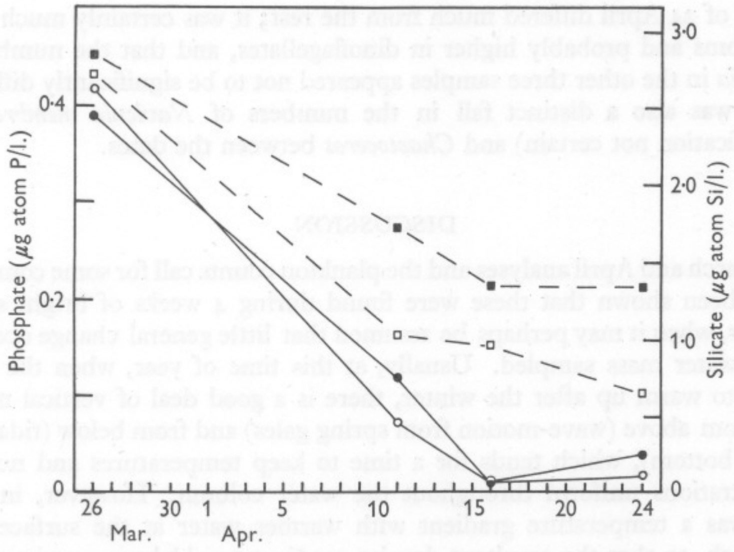

Fig. 4. Phosphate and silicate at 5 and 50 m at International Hydrographic Station E1, 26 March to 24 April, 1956. Phosphate at 5 m, □; at 50 m, ■. Silicate at 5 m, ○; at 50 m, ●.

TABLE 3. ORGANISMS IN 20 ML SEA WATER CENTRIFUGED

April 1956. Station E1

	16. iv. 56		24. iv. 56	
	10 m	50 m	10 m	50 m
Paralia sulcata	35	—	—	1
Coscinodiscus sp.	1	1	—	—
Thalassiosira sp.	2	2	—	15
Lauderia	3347	2720	980	3631
Stephanopyxis	5	7	1	13
Rhizosolenia				
Straight needle type	57	55	48	46
R. stolterforthii	77	119	30	126
Other *affines* types	108	57	43	114
Chaetoceros				
Phaeoceros	283	152	10	93
Hyalochaete	450	320	90	90
Biddulphia	3	—	—	—
Cerataulina	23	23	4	10
Eucampia	2	19	—	20
? *Navicula membranacea*	319	411	58	177
? Naviculid	2	2	1	1
Totals	4714	3888	1265	4337
Prorocentrum	—	—	1	1
Dinophysis and *Phalacroma*	1	1	6	—
Gymnodinian	—	—	2	—
Peridinium various spp.	13	11	28	20
Ceratium fusus	—	—	1	—
? Cyst	—	—	2	—
Distephanus	1	1	—	—
Tintinnid	—	—	—	4
Naked ciliate	—	—	1	—
Phaeocystis colonies	—	—	—	4
Temora nauplius	1	—	—	—
Oithona nauplius	1	—	—	—

Much detritus in all samples.

sample of 24 April differed much from the rest; it was certainly much lower in diatoms and probably higher in dinoflagellates, and that the numbers of *Lauderia* in the other three samples appeared not to be significantly different. There was also a distinct fall in the numbers of *Navicula membranacea* (identification not certain) and *Chaetoceros* between the dates.

DISCUSSION

The March and April analyses and the plankton counts call for some comment. It has been shown that these were found during 4 weeks of bright settled weather, when it may perhaps be assumed that little general change occurred in the water mass sampled. Usually, at this time of year, when the water begins to warm up after the winter, there is a good deal of vertical mixing both from above (wave-motion from spring gales) and from below (tidal drag on the bottom), which tends for a time to keep temperatures and nutrient concentrations uniform throughout the water column. However, in 1956 there was a temperature gradient with warmer water at the surface after 26 March, so that the resultant density gradient would have restricted that part of vertical mixing due to wave-motion turbulence. Indeed, in April, the phosphate figures also show a gradient, increasing toward the bottom. It is likely that less restricted vertical mixing took place between 11 and 16 April, which included three dull rather cold days with winds of force 5. The temperature gradient decreased, and so also did that of phosphate.

In these otherwise stable conditions silicate concentrations fell sharply, and by 16 April were very low, not only in the euphotic zone, but at the bottom. During 3 weeks the ratio of silicon to phosphorus removed from solution was 2·44:0·26 by atoms or just over 8:1 by weight. The silicon:phosphorus ratio in diatoms is found, by chemical analysis, in the range 16:1 to 50:1 (Vinogradov, 1953). Since the counts show that in size and numbers diatoms predominated over other organisms in the water, this suggests that they were deficient in silicon.

There seem to have been considerable numbers of diatoms in the deepest water; the counts show that this was so at 50 m. Some diatoms no doubt are carried out of the illuminated zone by turbulence. There is evidence too that at times they may lose buoyancy and sink rapidly (Marshall & Orr, 1928; Riley, 1941; Steele, 1956). Jenkins (1955) has shown that at Station E1, in March 1953, there was more chlorophyll in material filtered from bottom water than from the layers above. The counts of 24 April suggest either that diatoms in the upper water have been removed by some selective agency or that some have fallen into deeper water.

It is possible that diatoms in the deep water, out of the illuminated region, had continued to absorb silicate up to 16 April even if unable to make normal growth. Afterwards, many may have been eaten and voided by copepods, or may have died quickly, so that some silicate was returned to solution by 24 April.

The continued uptake of silicate, in the dark, by diatoms deficient in silicon, was observed by Lewin (1954), with cultures of *Navicula pelliculosa.*

SUMMARY

The results of analysis of sea water from the International Hydrographic Station E1 during 1956 are presented in graphical form and as integral mean values for the water column of 70 m. The seasonal variation is shown; it appears that consumption of phosphate in the spring outburst of plants was 0·34 μg atom P/l., and that of silicate 2·78 μg atom Si/l. The spring outburst was followed more closely than usual in the period 26 March to 24 April during 4 weeks of rather bright weather. Nearly all the silicate in the water was taken up, and some phosphate left, and it seems that the rapidly growing diatoms, which predominated at the time, were deficient in silicon. It is suggested that in the deep water they continued to absorb silicate, although not receiving enough light for growth and division.

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