Chemical Constituents of Biological Importance in the English Channel. Part III. June–December, 1932. Phosphate, Silicate, Nitrate, Hydrogen Ion Concentration, with a Comparison with Wind Records.

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With 3 Figures in the Text.

When considering wind records, the Beaufort number, B, may with advantage be replaced by its cube, B^3. According to the Observer's Handbook of the Meteorological Office (1921), this is a measure of wind force :—

$$P=0\cdot0105B^3, \text{ where}$$

P=Force in lb., registered by a circular disc one square foot in area facing the wind as in the plate anemometer when the density of the air is normal, and

B=Beaufort number.

The relation between B and B^3 is :—

B	1	2	3	4	5	6	7	8	9
B^3	1	8	27	64	125	216	343	512	729

At Mount Batten Air Station, Plymouth, wind records are made three times daily. These values have been cubed and the mean taken as the daily, mean cube Beaufort number, to give a mean value of the amount of wind disturbance each day. They are plotted for three periods in Fig. 1. The directions *from* which the wind blew are shown by arrows on the graph. The mean cube Beaufort number may afford a more useful index of the capacity of the wind to cause mixing and turbulence in the sea than the Beaufort number itself.

The conditions found on August 16th, 1932, were directly related with the wind in the preceding month (Figs. 1B and 2). On June 16th and July 13th, at E1, the thermocline was found at 25 metres, above which the temperature gradients were practically uniform. But on July 27th, 28th, and 29th, mean cube Beaufort numbers, 165, 105, and 115 were registered. These winds mixed the water thoroughly down to 10 metres, to give a uniform temperature of about 17·4°–17·5°. Subsequently with quiet sunny weather, the surface layers warmed to about 18·7°. The layer between 10 and 20 metres, sandwiched between two thermoclines, was of exceptional stability and its chemical composition was very unusual.

Conditions in August, 1931, were very different (Fig. 1A). The ten days prior to August 26th, when a cruise was made, showed intermittent strong winds reaching up to a mean cube Beaufort number, 320, on the 20th. These caused very marked vertical mixing right to the bottom by

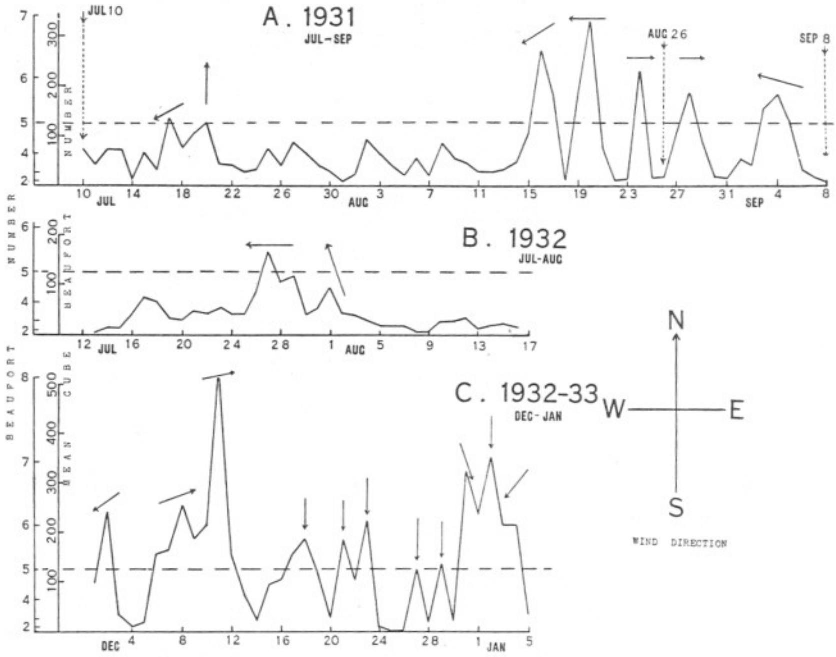

FIG. 1.—Daily Mean Cube Beaufort Numbers (Plymouth, Mount Batten). A. Between cruises on July 10th, August 26th, and September 8th, 1931, including stormy weather at end of period. B. Between cruises on July 13th and August 16th, 1932. C. December 1st, 1932, to January 5th, 1933. In each case a horizontal pecked line is drawn at mean cube Beaufort number, 125, equivalent to Beaufort number, 5. In each stormy period the direction *from* which the wind blew is shown by arrows.

the 26th, although complete uniformity was not attained until some days later (Part I, p. 681).

Thus in July, 1932, three days of wind with mean cube Beaufort numbers around 125 were able to break down the stable layering down to 10 metres, but had little effect further down. In August, 1931, strong winds, around B^3, 200–300, acting for a longer period, were able to break down the thermocline completely. The mean cube Beaufort number brings out this factor much more clearly than the Beaufort number itself.

THE DISTRIBUTION OF NUTRIENT SALTS ON AUGUST 16TH, 1932.

The effect of the stratification of the water in mid-August on the distribution of silicate, nitrite, and pH is shown in Fig. 3, in which the scale relative to depth is the same as in Figs. 2, 3, and 5 in Part I and Fig. 1 in Part II.

High concentrations of silicate were found in the stable intermediate layer (Table I); 270 and 300 mg. SiO_2 per cubic metre were found at 15 and 20 metres respectively, compared with 110 mg. at 10 metres and 175 mg. at 25 metres. Between 10 and 20 metres there was a difference in density, σ_t, of 1·15 units, so that it would seem that dead diatoms were trapped on the thermocline and their skeletons re-dissolved. This occurrence thus

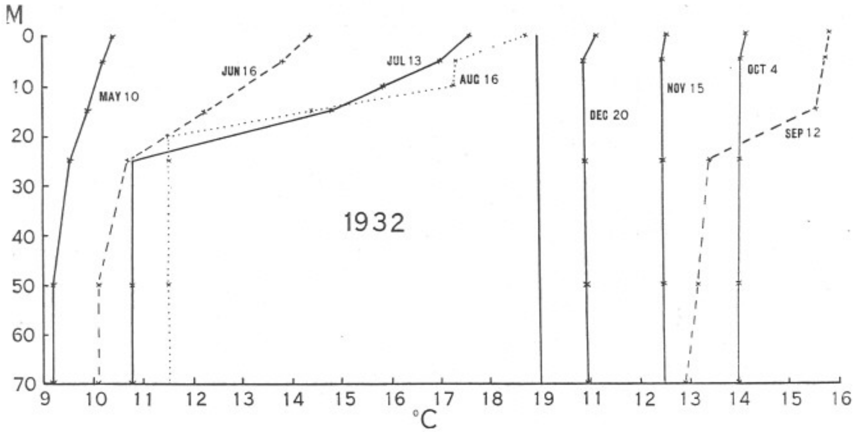

FIG. 2.—Temperature (°C.) at Station E1, Summer and Autumn, 1932.

provides yet further evidence for the rapid re-solution of silica in the summer months, suggested in Part I, p. 695. On August 16th, 1932, the average silicate content of the water column was 190 mg. per cubic metre. This fell, to give the usual September minimum, on September 12th (120 mg.), followed by a rise to 180 mg. on October 4th.

On August 16th also, extremely high values for pH were found at E1 at 15 metres. There can be no doubt as to the accuracy of these figures since they were found with cresol red, xylenol blue, and thymol blue, in each case with duplicate samples from different bottles. It should be stated that the samples had not been preserved since determinations of pH were not part of the programme. The determinations were made just twenty-four hours after collection with the buffers used in the previous year's work. These were still in good condition. Any error due to bacterial action in the samples or to absorption of carbon dioxide from the atmosphere would tend towards low values for pH and not high ones.

TABLE I.

Station E1.

Depth in metres.	Phosphate. P_2O_5, mg./m³. 1932 15/6	16/8	12/9	27/10	15/11	20/12
0	13	0	0*	24*	21*	22*
5	1	0	4	–	22	23
10	–	–	–	–	–	–
15	5	0	5	–	–	–
20	–	–	–	–	–	–
25	5	3	11·5*	–	22	25
50	–	2	11·5	–	21	27
68–70	13	–	15	–	20	30*
A	16/6	18/8	14/9	29/10	17/11	21/12

Depth in metres.	Silicate.‡ SiO_2, mg./m³. 15/6	13/7	16/8	12/9	4/10	15/11
0	75	98*	175†	230	210	175
5	55	55	100	105	200*	180
10	–	60	110	–	–	–
15	75	110	270*	105	–	–
20	–	–	300	–	–	–
25	65	110	175	105	160	–
50	80	140	190	140	190	190
68–70	70	120	220	105	170*	150*
A	17/6	14/7	17/8	13/9	6/10	16/11

Depth in metres.	Nitrite. N, mg./m³. 16/8	12/9	27/10	15/11
0	1·0	0·32	13·5	4·32
5	0·0	0·20	–	4·27
10	0·0	–	–	–
15	0·0	0·58	–	–
20	2·1	–	–	–
25	1·1	14·6	–	4·27
50	2·2	19·5	–	4·11
68–70	3·0	25·0	–	4·00
A	17/8	13/9	29/10	16/11

Station E1.

Carbon Dioxide System on August 16th, 1932.

Depth in metres.	pH_w	$pH_{12°}$	pCO_2§ (Atm. × 10^{-4})	ΣCO_2§ (c.c./l.).
0	8·24	8·30	2·3	43·9
5	8·29	8·35	2·0	42·9
10	8·30	8·36	1·9	42·8
15	8·45	8·48	1·2	41·0
20	8·27	8·27	2·1	44·6
25	8·27	8·27	2·1	44·6
50	8·27	8·27	2·1	44·6
69	8·27	8·27	2·1	44·6

Station E2.

Depth in metres.	P_2O_5 1932 15/11	SiO_2 13/7	SiO_2 15/11	Nitrite-N. 15/11
0	26	110*	135	2·04
5	26	75	110	1·95
10	–	75	–	–
15	–	175	–	–
25	27	175	140	1·98
50	27	155	140	1·96
75	27	–	–	1·95
87 or 91	26	155	110	2·13

L Surface Stations Nitrite—N.

Station.	mg./m³. 1932 12/9	15/11
L1	6·7	10·0
L2	4·25	9·8
L3	3·65	10·6
L4	1·86	13·3
L5	1·44	11·8
L6	0·42	12·2
E1	0·32	4·32
Mid E1–E2	–	4·08
E2	–	2·04

A. Date of analysis.
* Mean of duplicate analyses.
† Sample very cloudy. Reading after standing one hour in comparison tube ; approximate only.
‡ Samples from waxed bottles.
§ Derived from pH, temperature and salinity.

The 20-metre samples were indistinguishable from those drawn from 25, 50, and 69 metres (bottom).

The partial pressure and total volume of carbon dioxide, found from pH, salinity and temperature, by means of the tables of Buch *et al.* (1932), are given in Table I. The partial pressure at 15 metres was about half that at the surface. It would seem that photosynthesis was proceeding in the 15-metre layer which was not mixing with the layers above and below it. In this layer phosphate was undetectable and only 5 mg. P_2O_5 per cubic metre had been found a month previously. It is quite probable that the intense regeneration of silicate was accompanied by simultaneous phosphate formation and that this never accumulated sufficiently to become detectable, being used up as it was formed. A

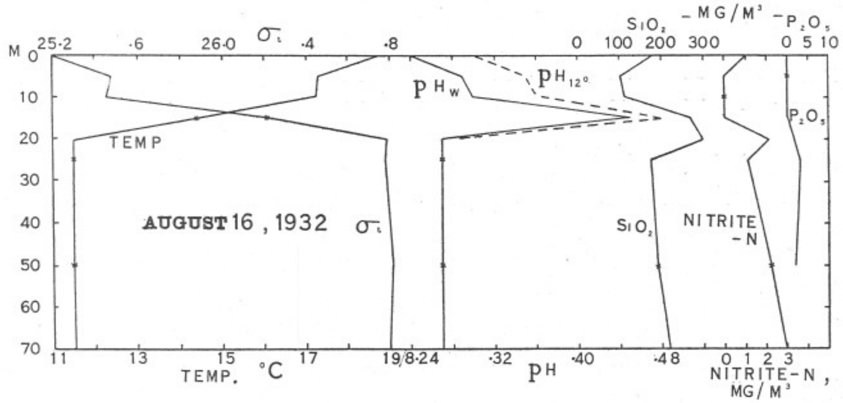

FIG. 3.—Conditions at Station E1 on August 16th, 1932. Temperature (°C.); density (σ_t); pH_W and pH_{12}°; SiO_2, nitrite-nitrogen and P_2O_5 (each mg./m^3).

similar consumption of carbon dioxide during a period when nutrient salts appeared scarce was noted in Part II (p. 738), a rapid fall in carbon dioxide occurring in June, 1931, when nutrient salts remained very low. This was especially the case above the thermocline.

Nitrite also showed a somewhat irregular distribution between the thermoclines on August 16th. By September the very stable stratification had begun to break down although a marked thermocline remained at 15–25 metres, above which the amount of nitrite was small. Beneath it conditions were similar to those found there by Atkins (1930) in August and September, 1928. The maximum amount (25·0 mg. N per cubic metre) was found at the bottom, suggesting that nitrification was then most active there.

On October 27th, the surface figure (13·5 mg. N per cubic metre) was probably typical of the whole water column and lies close to the figures found on October 2nd, 1928 (13·3 mg.), and October 20th, 1931 (11·5 mg.).

Later the amount of nitrite at E1 fell away, again in agreement with former years. But in or about December in each of the four years for which data are available, the inshore water has shown a notably higher nitrite content than the water at E1 (Table II). In 1930 and 1931, no

TABLE II.

EARLY WINTER VALUES FOR SURFACE NITRITE-NITROGEN (MG./M^3) FOR FOUR DIFFERENT YEARS.

Station	30/11/28	2/1/29	11/11/30	4/12/30	13/1/31	30/11/31	31/12/31	15/11/32
L1	6·0	9·5	—	—	—	10·1	5·3	10·0
L2	3·9	9·5	—	—	—	10·9	5·0	9·8
L3	3·3	9·2	—	—	—	11·8	4·7	10·6
L4	3·3	7·7	13·5	5·8	8·2	12·0	2·6	13·3
L5	—	5·6	—	—	—	13·9	1·6	11·8
L6	1·3	3·5	—	—	—	2·5	1·1	12·2
E1	1·4	3·1	2·1	2·05	0·37	0·87	1·13	4·32
Mid E1–E2	—	—	—	—	—	$\leq$1·5	—	4·08
E2	—	—	—	—	—	0·54	—	2·04

clear relation could be seen between the distribution of ammonia and nitrite. The cause of these high, mid-winter, inshore nitrite figures is not very evident.

It should be remembered that, when seasonal changes of nutrient salts in the English Channel are under consideration, exactly the same body of water cannot be examined on each cruise, so that it is not permissible to treat of events as occurring in a completely closed cycle (cf. Part I, pp. 678, § 3, and 708, § 4).

MIDWINTER PLANKTON OUTBURSTS, SUNSHINE AND WIND.

A "normal" figure for the daily mean cube Beaufort number, B^3, in December, calculated from the records for the nine years, 1924–32, is 102, equivalent to a "normal" Beaufort number of 4·7.

In 1925, between the cruises of November 11th and December 11th, phosphate at E1 fell by 13 mg. P_2O_5 per cubic metre at the surface, by 7 mg. at 10 metres, and by 6·5 mg. as an average of the whole column. For the ten days preceding the cruise of December 11th, sunshine averaged 3·6 hours a day (the normal for Plymouth for December is 1·58 hours) and the average value of B^3 was 55 (B=3·8). The weather was thus favourable to a surface outbreak.

In 1926, between the cruises of December 13th and 31st, phosphate fell by 5 mg. P_2O_5 (surface), 7 mg. (5 metres), and 7 mg. (average content). For the sixteen days preceding the 31st, sunshine averaged 3·2 hours and B^3 averaged 80 (B=4·3). On December 23rd, 24th, and 25th, the values of B^3 were 165, 125, and 165, thus putting up the average. During most of the period conditions were favourable to a surface outbreak. The strong northerly winds at Christmas account for the depletion extending right to the bottom.

In 1930–31, between the cruises of December 4th and January 13th, phosphate fell by 10 mg. (surface) and 3·1 mg. (average). The surface fall was, in large part, due to the mixing in of the enriched surface layer found on December 4th, but the fall in the average content would seem to indicate a definite outbreak. Over the whole intervening period of 39 days, sunshine averaged 2·1 hours per day and B^3 averaged 51. For the nine days immediately preceding January 13th, sunshine averaged 4·3 hours and B^3, 14. But for this period the parallel between quiet sunny weather and a plankton outburst may not be as close as this summarised picture suggests.

On November 30th, 1931, at four stations across the Channel, L4, E1, Midway, and E2, surface values for phosphate as P_2O_5 were 5·5–7 mg. lower than at 5 metres, suggesting a preceding, quiet, sunny spell. This was far from being the case. Between November 22nd and 29th daily mean cube Beaufort numbers were: 63, 301, 53, 259, 215, 105, 3, 23. Such a period of wind must have led to thorough mixing of the surface waters. Two days only were sunny and the last two days, which were quiet, had only 0·7 hours of sunshine between them. The weather was thus decidedly unfavourable for a plankton outburst.

We see that on three occasions, midwinter outbursts, inferred from a fall in the phosphate content of the water, followed on periods of sunny weather with light winds. On a fourth occasion there was no relation whatever between outburst and weather.

The Effect of Wind on the Bottom Fauna and on the Herring Fishery.

On January 5th, 1933, s.s. *Salpa* caught large numbers of *Upogebia deltaura* and *Thyone raphanus* with the otter trawl in 18–21 fathoms in Bigbury Bay. Examination of the gut of fishes has shown Upogebia to be one of the commonest fish foods in the Plymouth area, but it is seldom caught in numbers in either trawl or dredge (Steven, 1930). It is an agile burrowing animal beyond the reach of the ordinary fishing-gear. The habitat of Thyone is similar. Therefore only intense disturbance of the bottom could have put them in a position to be caught by the trawl. Probably Upogebia had been so buffeted by the storm as to be insensible to the approaching trawl. December was characterised by very stormy weather and between December 31st and January 4th, the daily mean cube Beaufort number reached 350 and never fell below 216. In other words the wind blew continuously with force 6 or greater, causing heavy seas and consequent disturbance of the bottom fauna (Fig. 1, C.).

Periods of stormy weather have been found to be followed by improved catches of herring (Ford, 1933). For this investigation, wind records on the Beaufort scale proved very useful, but it is felt that the mean cube Beaufort number, studied in conjunction with the direction of the wind, may prove yet more convenient as it emphasizes the periods of really rough weather. When dealing with large quantities of weather data, the possibility which it gives of grouping or averaging records may prove of value.

SUMMARY.

In August, 1932, marked stratification of the water in the English Channel led to an unusual distribution of minor chemical constituents. Two thermoclines were present, between which high silicate values were found, indicating rapid re-solution of silica as found in former summers; pH was also very high at 15 metres.

In or about December in four years, nitrite in inshore waters has been found much in excess of that present in the open Channel.

The "mean cube Beaufort number" is suggested as a useful practical measure of sea disturbance. Three out of four midwinter plankton outbursts, inferred from a fall in the phosphate content of the water, have followed periods of sunny weather with little wind.

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