Hydrographic Features of the Water in the Neighbourhood of Plymouth during the Years 1921 and 1922.

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With Tables I–III, and Figures 1–6 in the Text.

DATA obtained during the cruises of the s.ss. *Huxley* and *Oithona* in the years 1903 to 1906 indicated a general seasonal movement of water into and out of the mouth of the English Channel. It was found that in the autumn, somewhat sooner or later and to a greater or less extent each year, water, of the high salt content characteristic of the open Atlantic in the north of the Bay of Biscay and to the south-west of the English Channel, began to move in a north-easterly direction into the mouth of the English Channel, extending in a tongue along the centre of the Channel and into the Irish Channel, which is characterised by water of lesser salt content.

This general movement of relatively high salinity water continued during the winter until the spring or early summer, when water of lesser salinity moved southward from the Irish Channel across the mouth past Ushant, and to some extent into the English Channel; the condition in August being that water of relatively high salinity which had entered the Channel during the winter months was cut off from Atlantic water of equal salinity by a less saline water-mass extending south from the Irish Channel.*

These general movements have been deduced from the data collected during the cruises in February, May, August, and November. To accurately depict the changing conditions and follow the movement of the water year by year would require frequent observations, more or less simultaneous, over a wide area—a condition of perfection which in practice could not be obtained without the use of several ships working almost continuously and in conjunction.

* Matthews, D. J. *Physical Conditions in the English Channel*, 1904–1906. 2nd Report (Southern Area) Internat. Invs. Mar. Biol. Assoc. Cd. 4641.
Physical Conditions in the English Channel, 1906. 3rd Report (Southern Area) Internat. Invs. Mar. Biol. Assoc. Cd. 5546.
Fisheries, Ireland Sci. Invest., 1913, IV, 1914.

During this period and subsequently* considerable use has been made of surface observations of cross-Channel steamers, the mean conditions of temperature and salinity of various areas of the Channel calculated and the departure from the " mean " conditions year by year tabulated. In the central area of the Channel, roughly between Portland and the Channel Islands, it was found during the quarterly cruises† that tidal mixing was so complete that the water was nearly always at the same salinity at all depths; and, in consequence, following the change in salinity of the surface samples gave evidence of the source and movements of the changing water-masses. There is little evidence that the slight differences in salt content would *per se* prove a physiological factor affecting the fauna; it is used merely as a means of deducing the general movements of the water in which the animals live.

During 1921 two cruises and during 1922 five cruises have been made by the s.s. *Salpa*, the Stations E1, E2, E3, N1, N2, N3, E6, and E7 being worked. In addition the Station E1, ten miles south-west of the Eddystone, has been worked monthly; from these monthly data there is great promise of being able to follow in detail how the physical condition and general movements of the sea in the neighbourhood of Plymouth vary one year with another, whereas in previous years so long a time had elapsed between each quarterly cruise that quite material changes might have taken place in the intervals and remained unnoticed. This area of the sea is of particular interest, since the biological features are being followed throughout the entire year in the course of the ordinary routine of the *Salpa*.

The itinerary and times of the cruises have been arranged in co-operation with the French and Irish Fishery Departments, the former undertaking a general review of the whole area to the south-west of the British Isles; this is published, together with the full data collected by the various ships, by the Conseil Permanent pour l'Exploration de la Mer. The report for 1921‡ has just been published.

During the two years, 1921 and 1922, several points of interest concerning the movements of the water-masses and general hydrographic conditions in the neighbourhood of Plymouth have arisen, which it is not out of place to discuss at the present juncture. The data were collected by and the cruises made under the direction of the late Mr. E. W. Nelson, of Dr. W. R. G. Atkins, and of the writer.

* Jee, E. C. *Min. Agri. Fisheries. Fishery Invest.*, Vol. I, Ser. III, Parts 1–6.

† Matthews. *Physical Conditions of the English Channel.* 3rd Report Internat. Invs. Mar. Biol. Assoc.

‡ Le Danois. *Rapport Atlantique*, 1921. Conseil Perm. pour l'exploration de la mer, May, 1923.

Vertical distribution.

The diagrams (Fig. 1) showing the vertical distribution of temperature and salinity bring out two noteworthy features. From May to the end of September the water down to depths of about 25 metres is tolerably distinct from the water below, except in July, 1922, when vertical mixing had undoubtedly taken place after a spell of boisterous weather. Also, when the rapid movement of water from a water-mass of high salinity is taking place, as in October, 1921, there are formed tongues of the higher salinity water penetrating horizontally into the surrounding water more rapidly than vertical mixing occurs.

The relation between the temperature of the surface water, that is, the surface 6 to 10 in. as sampled by dipping a wooden or leather bucket, and the water immediately below at about 5 meters depth, is of particular interest, since many of the previous conclusions on the hydrography of the English Channel have been deduced from data of the surface water collected in this way.

From the end of September to April, the less sunny and more windy months of the year, the surface water is very similar to the whole mass of the water below at E1, and the same condition was found at all the other stations worked during the November, February, and March cruises, the temperature being to within one degree of that of the water at 5 metres and of the whole mass of the water below.

During the summer months, however, wide differences between the temperature of the surface and water at 5 metres may occur, particularly in calm and sunny weather, when vertical mixing is at a minimum. The difference in both temperature and salinity between the surface and the whole mass of water is still greater, as is amply shown in the vertical distribution diagrams. In fact, it shows that little can be concluded from the study of surface water data alone during these months. The following data obtained in August, 1921, at Station E1, are significant, a fall in temperature on the surface of 1·6° being experienced in seven hours and a subsequent rise of 1·6° in four hours, the tidal stream running to the westward and then back again in an easterly direction during the rise in temperature.

	Station E1.	Temp.	Salinity.
Aug. 15, 6 p.m.,	Surface water . .	16·21	35·17
10 p.m.	,, . .	15·7	35·11
Aug. 16, 1 a.m.	,, . .	14·6	35·15
5 a.m.	,, . .	16·2	35·09
8 a.m.	,, . .	16·01	35·11

A comparison of the depth of the water layers of equal temperature at the same station after the lapse of twelve hours, when the whole

mass of water will have been swept back to nearly the same position by the tidal stream, is somewhat suggestive of undulatory movements of the layers, as is thought to occur in the Norwegian Sea.* It is proposed to carry out further work on this point when opportunity occurs.

STATION E1.

August 15, 1921. 6.5 p.m. to 7.5 p.m.			August 16, 1921. 6.20 a.m. to 7.20 a.m.		
Depth.	Temp.	Salinity.	Depth.	Temp.	Salinity.
5	—	—	5	16·02	35·09
10	15·6	35·09	10	16·02	35·13
15	—	—	15	15·77	35·13
20	13·79	35·22	20	13·68	35·21
25	13·42	35·30	25	13·59	35·19
30	—	—	30	13·51	35·18
40	13·33	35·22	40	13·38	35·14
50	—	—	50	13·30	35·13
60	—	—	60	13·27	35·16
70	—	—	70	—	—

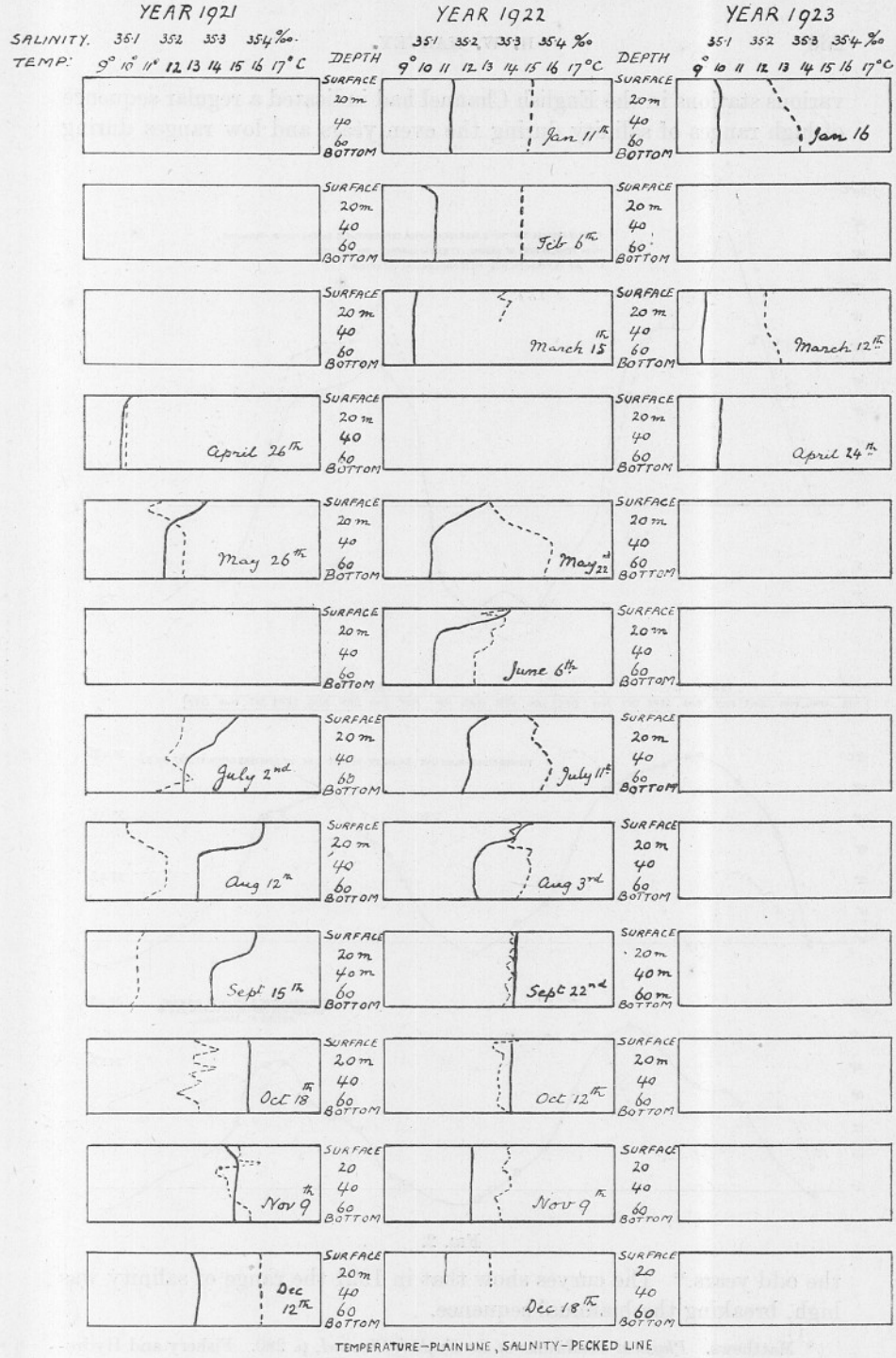
A very well-marked discontinuity of the temperature gradient was found at E1 in June and July, 1923. In July on one occasion a fall of $3\frac{1}{2}^{\circ}$ was found to occur between $12\frac{1}{2}$ and $17\frac{1}{2}$ metres; unfortunately, owing to the ship rolling, it was not possible to find the precise depths (from about 14 to 17 metres) within which the change occurred. The discontinuity layer remained for three hours at the same depth, and then during the next three hours rose about $2\frac{1}{2}$ metres, while on one occasion at a position one mile distant from E1 the discontinuity layer was 2 to 3 metres higher than at E1.

Seasonal variations at Station E1.

The average temperature and salt content of the layer of water above 25 metres was compared with that of the " deep water " below 25 metres, and further with the mean air temperature and with the temperature of the ground on Plymouth Hoe, curves being drawn to show the values month by month. The warm late autumn of 1921 is very apparent, and is coincident with a drift of relatively warm high salinity water from the south-west during October and November. This indicates that this drift not only decreased the rate of fall of temperature of the surface layers of the sea, but of the air and of the ground as well, in this way exerting a well-marked influence upon the local climate.

During the years 1903 to 1908 cruises made every three months to

* *Depths of the Ocean.* Hjort. 1912, pp. 279–280.



TEMPERATURE—PLAIN LINE, SALINITY—PECKED LINE

SALINITY & TEMPERATURE AT VARYING DEPTHS AT STATION E1.

FIG 1.

various stations in the English Channel had indicated a regular sequence of high ranges of salinity during the even years and low ranges during

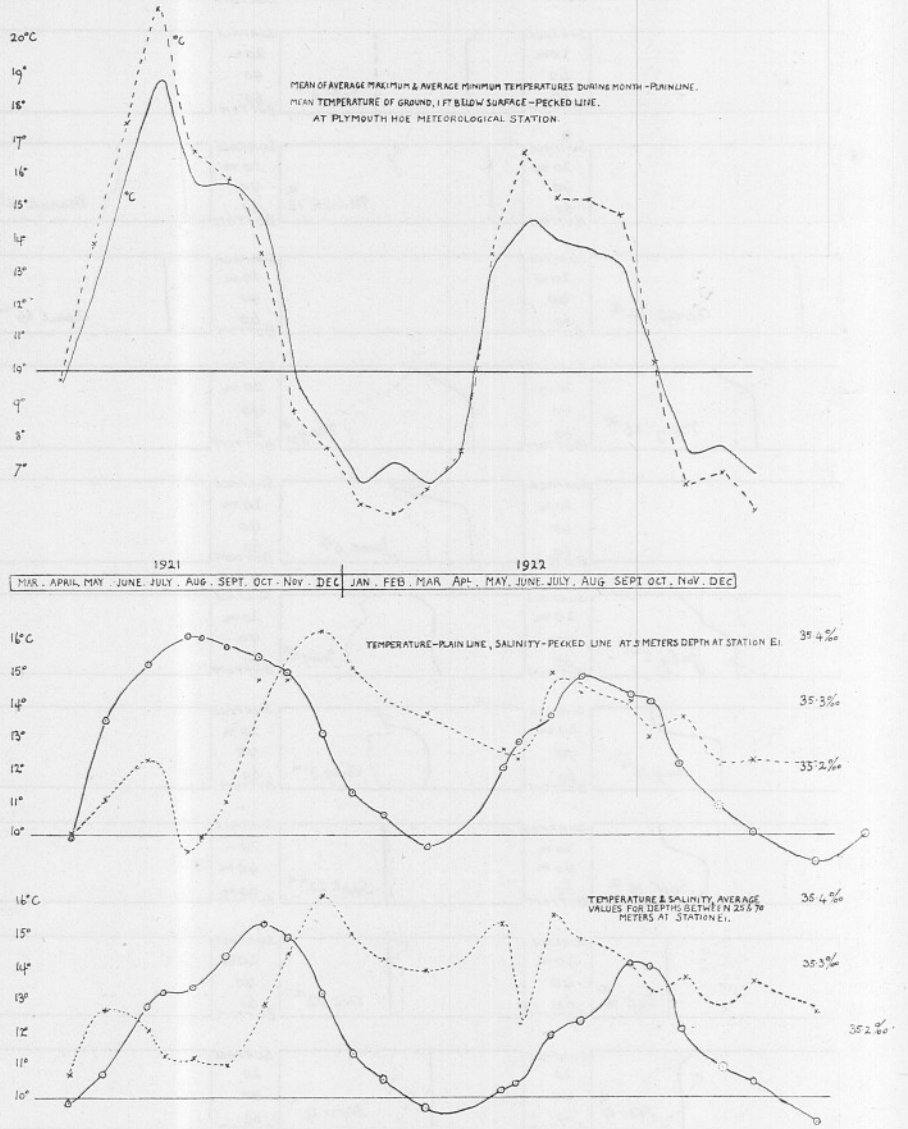


FIG. 2.

the odd years.* The curves show that in 1921 the range of salinity was high, breaking the biannual sequence.

* Matthews. *Physical Conditions of the English Channel*, p. 280. Fishery and Hydrographical Investigations in the North Sea and Adjacent Waters, 1906 to 1908.

During 1921, in July, there was a marked check in the increase of temperature of the "deep water" at E1, coincident with a fall in salinity.

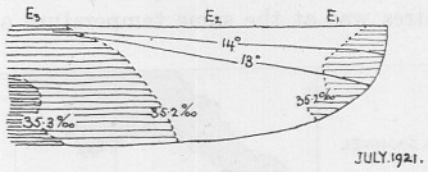


FIG. 3.

Reference to Table I and the sectional diagram from Plymouth to Ushant indicates that a tongue of slightly less saline and colder water from the south of the Irish Channel had extended up the centre of the English Channel.

TABLE I.

YEAR 1921. Average Temperature and Salinity of Water below 25 meters.

Station N_2 49° 45′ N. 6° 21′ W.	July	11·23° C. 35·11°/$_{oo}$
	Nov.	13·44° C. 35·26°/$_{oo}$
Station N_1 49° 14′ N. 5° 51′ W.	July	11·10° C. 35·22°/$_{oo}$
Station E_1 50° 02′ N. 4° 22′ W.	July	12·8° C. 35·20°/$_{oo}$
	Nov.	14·97° C. 35·32°/$_{oo}$
Station E_2 49° 27′ N. 4° 42′ W.	July	12·37° C. 35·16°/$_{oo}$
	Nov.	14·51° C. 35·34°/$_{oo}$
Station E_3 48° 34′ N. 5° 13′ W.	July	12·82° C. 35·30°/$_{oo}$
	Nov.	Ca35·5°/$_{oo}$

A very rapid rise in salinity commenced early in September, and the temperature of the "deep water" continued to rise until unusually late (mid October), after which it fell slowly while the salinity continued to rise. The surface layers attained their maximum temperature earlier at 5 metres in August, or about one month after the maximum ground and air temperature, and fell slowly until the end of November.

A surface sample of water taken off Ushant (E3) in November had a salinity of 35·48 per cent, considerably more saline than the water off the Scillies (N2), and it may be presumed that the water drifting into the Plymouth area during this period of rapid rise in salinity was the north-westerly drift of warm water from the Bay of Biscay (transgression estivale des eaux chauds).*

At the end of October the ground temperature on Plymouth Hoe was 11°, or 3° higher than at the same time in the following year, while the

* Le Danois. Cons. Perm. Int. pour l'exploration de la mer. *Rapport Atlantique.* 1921.

temperature of the deep water at E1 was 15°, 2° higher than in the following year.

During the year 1922, at the end of April, E1 water both at 5 metres and below 25 metres was at the same temperature as in the previous

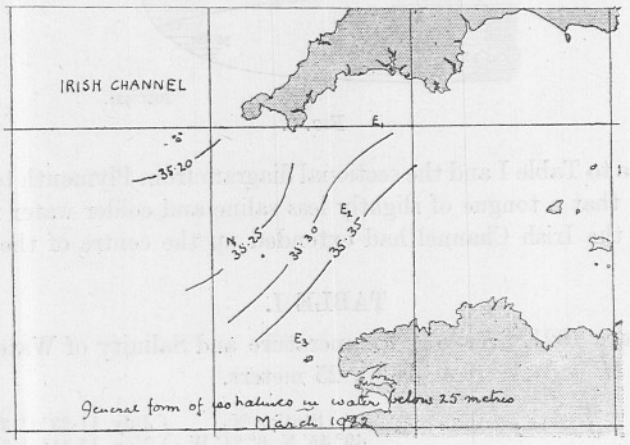


Fig. 4.

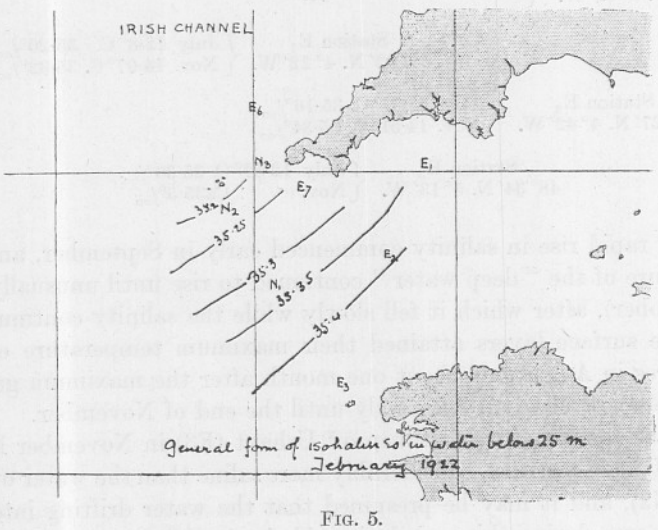


Fig. 5.

year. The latter part of June and early July were marked by boisterous weather, and vertical mixing took place. This can be seen on comparing the diagram of vertical distribution for July 11 with those for June 6 and August 3. This condition is further reflected in the curves of temperature at 5 metres and below 25 metres, the rate of temperature increase

of the warmer 5-metre layer being checked by mixing with the colder water below. The deep water in its turn suffered a slight rise in rate of temperature increase.

Considering the salinity, the fall in June, February, and March appears due to a southerly drift from the southern part of the Irish Channel, which ceased in May. The general arrangement of the isohalines (Figs. 4 and 5) in the deep water, as found during the February and March cruises, illustrates this point.

The data for the period early May to the end of July (see Table II) indicate water-masses of relatively high salinity, which had entered the Channel early in the year, moving westward particularly off the English coast. Gehrke* has shown on theoretical grounds that more water enters the English Channel from the westward than escapes into the North Sea, and that a portion must, therefore, turn back and escape in a north-westerly direction.

TABLE II.

Year 1922. Average Temperature and Salinity of Water below 25 meters.

Station N_2 49° 46′ N. 6° 21′ W.	Feb.	10·25° C.	35·21‰
	Mar.	9·39° C.	35·18‰
	May	10·34° C.	35·21‰
	July	12·34° C.	35·24‰
	Nov.	11·67° C.	35·25‰
Station N_1 49° 14′ N. 5° 51′ W.	Feb.	—	—
	Mar.	9·82° C.	35·25‰
	May	10·56° C.	35·34‰
	July	10·9° C.	35·29‰
	Nov.	11·77° C.	35·28‰
Station E_1 50° 02′ N. 4° 22′ W.	Feb.	10·51° C.	35·33‰
	Mar.	9·62° C.	35·27‰
	May	10·11° C.	35·37‰
	July	11·99° C.	35·39‰
	Nov.	12·07° C.	35·28‰
Station E_2 49° 27′ N. 4° 42′ W.	Feb.	10·62° C.	35·42‰
	Mar.	9·90° C.	35·39‰
	May	10·62° C.	35·34‰
	July	12·70° C.	35·36‰
	Nov.	12·30° C.	35·29‰
Station E_3 48° 34′ N. 5° 13′ W.	Feb.	10·80° C.	35·44‰
	Mar.	10·19° C.	35·37‰
	May	11·03° C.	35·30‰
	July	11·70° C.	35·34‰
	Nov.	12·57° C.	35·32‰

The water at 5 metres reached its maximum temperature early in August, as in the previous year, and after the middle of October cooled rapidly. The deep water reached its maximum temperature some five

* Gehrke. The mean velocity of the Atlantic currents running north of Scotland and through the English Channel. Publ. de Circonstance, No. 50. Copenhagen. Also Matthews. *Fisheries.* Ireland Sci. Invest., 1913, IV.

TABLE III.

	1921						1922											
	May 27	Aug. 12	Aug. 15	Oct. 21	Nov. 9	Dec. 21	Jan. 11	Feb. 6	Feb. 11	Mar. 15	Mar. 29	May 22	June 6	July 11	Aug. 3	Sept. 22	Oct. 11	Nov. 9	Dec. 18
L_1 surface	13·9	16·2	15·9	16·0	11·59	10·62	10·01	8·2	7·8	8·5	8·0	14·4	13·8	13·8					
														14·5	14·60	14·6	13·8	10·3	9·7
bottom	12·47													14·21	13·88				
L_2 surface	12·78	15·4	15·6	15·98	13·01	11·41	10·10	8·8	7·93	8·8	8·4	13·0	13·3	14·1					
														13·9	13·8	14·5	14·1	10·5	9·9
bottom	11·67													12·97	13·68	14·4			
L_3 surface	12·22	15·3	15·7	15·99	14·04	11·78	10·27	8·9	8·3	8·9	8·6	12·9	12·6	14·1	14·3	14·6	14·1	11·2	10·2
bottom	11·35													12·40	12·93				
L_4 surface	11·75	15·5	15·7	15·95	14·29	12·34	10·31	9·2	8·9	9·2	8·7	12·9	12·8	15·3					
														14·2	14·22	14·4	14·25	—	10·5
bottom	10·98													12·32	12·80				
L_5 surface	12·04	15·3	15·5	15·86	14·39	12·64	11·11	9·5	9·2	9·3	8·9	12·3	12·8	14·0	14·35	14·4	14·3	11·8	10·9
bottom	10·97													12·10	12·66	13·33			
L_6 surface	13·30	15·5	15·4	15·74	14·29	12·79	11·17	9·9	9·8	9·5	9·1	12·6	12·8	14·1	14·55	14·6	14·2	12·1	10·9
bottom	10·79													11·91	12·33	14·24			
			14·6																
			16·21	15·55	14·30														
E^1 surface	13·5	16·13	15·7	15·63	14·96	12·94	11·23	9·9	9·9	9·6	9·7	12·8	13·95	12·8	15·0	14·3	14·2	12·2	10·9
5 m.	13·49	16·17	(15·6)	15·51	15·00	13·13	11·29	10·51		9·64		12·70	13·89	12·36	14·58	14·21	14·10	12·19	
below 25 m.	10·79	13·29	13·33	15·39	14·97	13·13	11·34	10·51		9·62		10·11	10·32	11·99	12·38	14·17	14·01	12·07	
Ground temp. on Hoe 1ft. below surface*	15½	16½	16½	13	10½	6½	6	5½	5½	6½	7	14½	15½	15½	15½	14	11½	7½	

Temperatures in degrees Centigrade. * From curve of monthly means.

weeks later in September, which was a month earlier than the maximum in the previous year. Since July the salinity had been falling. A rapid fall in temperature occurred throughout the whole water-mass after the middle of October, whereas in 1921 a rapid fall did not occur until the middle of November.

The data obtained between July and November (see Table II) are insufficient to give an indication whence the increasingly warm water

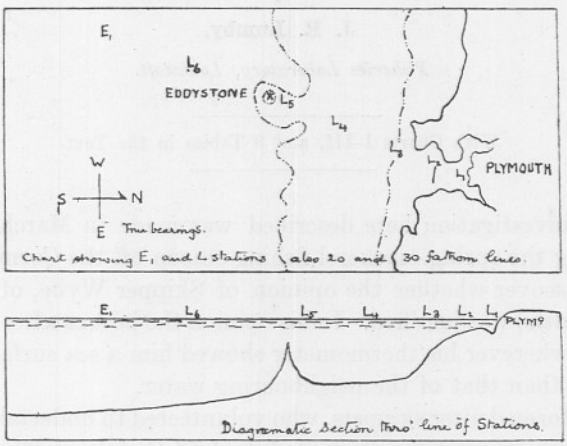


FIG. 6.

below 25 metres came, after the surface water had reached its maximum temperature in August.

Table III shows the conditions inshore along the line of stations between Plymouth Hoe and E1, the positions of which are given on the map (Fig. 6) together with the twenty and thirty-fathom line.

Two noteworthy features are apparent. The maximum temperature of the sea lags behind the temperature of the ground. As the shore is approached both greater and more rapid variations in temperature are experienced.