PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

On the Salinity of the Surface Waters of the Irish Sea

J. Proudman

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ON THE SALINITY OF THE SURFACE WATERS OF THE IRISH SEA

By J. PROUDMAN, F.R.S.

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1. Introduction

This paper contains a discussion of the observations on the salinity of the surface waters of the Irish Sea, which have been made by a number of authorities from the year 1905 until the end of 1939. Its objects are:

(1) To put on record the chief variations of the salinity in the central part of the sea during the whole period of observation.

(2) To calculate grand mean values of the characteristics of the salinity and of its seasonal variation for stations distributed over the whole area of the sea.

(3) To investigate the degree of correlation between the salinities at pairs of stations, and to find for what time-differences the coefficients of correlation attain maximum values.

(4) To investigate the degrees of correlation between the salinities at different stations and the rainfall and barometric gradients; and to find the time-lags which correspond to maximum correlation coefficients.

(5) To obtain from the correlation coefficients such indications as they may afford of the mean currents of the sea.

For the first and second of the above objects all the observations have been used, but the correlation coefficients given are based on the series of observations which began in 1934. Many correlation coefficients based on the earlier series have been evaluated, but they showed little concordance among themselves and were often in disagreement with those of the later series.

The unit of discussion is the mean value of all the salinities observed at a particular station during a particular month. Most of the observations previous to 1934 were taken with a frequency not greater than one observation on each of two consecutive days per month at each station, but the observations which began in 1934 have been taken three times per week at each station. The monthly mean values based on the later series should therefore have a much greater representative value than those based on the earlier series, and this may account for the difference in the degrees of consistency of the correlation coefficients.

All the determinations of salinity referred to in this paper have been made in accordance with Knudsen's *Hydrographical Tables* (1901). Jacobsen and Knudsen have recently (1940) defined 'salinity' with great precision; roughly it may be described as the number of grammes of salt in 1 kg. of sea water.

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The calculations of the present paper have been made by Miss H. M. Lewis of the University of Liverpool, with assistance from the staff of the Liverpool Observatory and Tidal Institute.

2. Observations

From about 1905 to 1914, the Fisheries Branch of the Department of Agriculture and Technical Instruction for Ireland carried out quarterly hydrographic cruises in accordance with the programmes of the *Conseil international pour l'exploration de la mer*. Water samples, both from the surface and from a number of depths, were taken at many stations. During part of this period the same authority organized the taking of surface samples from lightvessels off the Irish coast. The titrations were made partly by D. J. Matthews, partly by the Government Chemist in London and partly by the Irish Department, and the results were published by the *Conseil*.

Between 1905 and 1910 surface samples were taken once per week at the Cardigan Bay and Bahama Bank Lightvessels; the work was organized by the Marine Biological Association, and the salinities were published by the *Conseil*.

From 1907 to 1914 regular hydrographic cruises were carried out by the Lancashire and Western Sea Fisheries Joint Committee (referred to as L.W.S.F.C. in the tables of this paper), and assisted by grants from the Development Commission. At first the cruises were made quarterly but afterwards they were made more frequently. On each of these cruises the same stations were visited and from each station water samples were taken both from the surface and from a number of depths. The titrations were made and the results published by H. Bassett, then of the University of Liverpool.

From 1922 to 1925 surface samples were taken on two consecutive days each month from cross channel steamers at four stations between Holyhead and Dublin and at a number of stations between Fishguard and Rosslare. The work was organized by the Ministry of Agriculture and Fisheries and the salinities published by the *Conseil*.

From 1925 to 1931 a second and similar series between Holyhead and Dublin was organized by the Oceanography Department of the University of Liverpool and financed by the Ministry of Agriculture and Fisheries. The samples were taken and the titrations made by R. J. Daniel who published the results.

From 1928 similar series were taken on the steamer route between Land's End and Dublin, the work being organized by the Department of Lands and Fisheries for Ireland and the salinities published by the *Conseil*.

In 1934 the Oceanography Department of the University of Liverpool organized the taking of surface samples three times per week from a number of stations distributed over the whole of the Irish Sea proper. Since April 1939 this work has been financed by a grant from the Development Commission. Most of the titrations have been made under the direction of Daniel at the University of Liverpool, the remainder being made by J. R. Bruce at the Marine Biological Station at Port Erin. The salinities obtained up to the end of 1937 have been published by the *Conseil*.

3. Previous discussions

In 1907 M. Knudsen published 'Some remarks about the currents in the North Sea and adjacent waters' in which he said: 'The water-volume yearly leaving the Irish Sea, when deduced by means of Martin Knudsen's hydrographical theorem, may approximately be regarded as at least equal to the water-volume contained in the entire Irish Sea'.

In 1907 J. N. Nielsen suggested that there might be a south-going current off the eastern coast of Ireland; he based this suggestion on the report by Matthews (1905) of relatively fresh water off the fairway to the English Channel.

In 1908 the *Conseil international* published a 'Short review of hydrographical conditions in the seas investigated by the Council', in which a summary was given of the chief features revealed by the Irish observations up to that date. It was stated that 'the low temperature (in August) along the Irish coast will find the easiest explanation if we suppose that a south-going current predominates, here carrying the water from the North Channel southwards towards St George's Channel'. (See also the isothermal chart for August in Proudman, Lewis and Dennis 1937.)

From 1909 to 1915 Bassett published a number of discussions on the distribution of the salinities which he and others had determined. He constructed charts of surface salinities for the mean conditions in the months of June in 1906, 1907 and 1908, and for February, May, August and November of 1909. He insisted on the northward flow of water through the Irish Sea which was indicated by the course of his isohalines. He gave much attention to hydrographic conditions outside the Irish Sea and to the weather following these conditions.

In 1913 Matthews discussed the distribution of the salinities from the samples taken on the Irish cruises during the years 1909–12. He calculated five grand mean values for the salinity at each depth at each station, viz. one for each of the four times of the year at which cruises were made and one for all the cruises made in the period. Based on these grand mean values he published vertical sections and charts for the sea-surface and bottom.

In all the above-mentioned discussions it is pointed out that, over most of the Irish Sea proper, there is little change of salinity between the sea-surface and the bottom. This fact greatly enhances the significance of a study of the salinities at the surface only.

In 1925 G. P. Farran and J. I. Spicer discussed some of the salinities which had been determined for the Irish lightvessels. They calculated monthly mean values and anomalies, and their results have been used in constructing table 3 below.

4. Observations used in the present discussion

Table 1 gives a list of the stations with their positions and the periods of observation, in so far as they have been used in the present investigation. The positions of the stations are shown in figure 1. All the observations mentioned in § 2 are included

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TABLE 1. LIST OF STATIONS, WITH POSITIONS AND PERIODS OF OBSERVATIONS

Station	Lat. N.	Long. W.	Periods of observation
Fishguard to Rosslare, half-way	52° 08′	5° 40′	May 1934 to Dec. 1939
Bardsey L.H.	52 45	4 48	,, ,, ,,
Nr. Holyhead	53 20	4 44	,, ,, ,,
Holyhead to Kish, half-way	53 20	5 16	,, ,, ,,
Nr. Kish L.V.	53 19	5 52	,, ,, ,,
Chicken Rock L.H.	54 02	4 50	,, ,, ,,
Liverpool Bar L.V.	53 32	3 31	,, ,, ,,
Morecambe Bay L.V.	53 54	3 31	,, ,, ,,
Stranraer to Larne, half-way	54 57	5 28	Mar. 1935 to Dec. 1939
Coningbeg L.V.	52 02	6 40	Mar. 1909 to Mar. 1915
South Arklow L.V.	52 40	5 57	Oct. 1905 to Dec. 1906
Skulmartin L.V.	54 32	5 26	,, ,, ,,
Bahama Bank L.V.	54 20	4 13	Oct. 1905 to Aug. 1910
Cardigan Bay L.V.	52 24	5 00	Oct. 1905 to Aug. 1909
L.W.S.F.C. I	54 00	3 30	Feb. 1907 to Sept. 1914
II	54 00	3 47	,, ,, ,,
III	54 00	4 04	,, ,, ,,
IV	54 00	4 20	,, ,, ,,
V	53 53	4 46	,, ,, ,,
VI	53 43	4 44	,, ,, ,,
VII	53 33	4 41	,, ,, ,,
Holyhead to Dublin I	53 20	4 54	July 1925 to Oct. 1931
II	53 20	5 10	,, ,, ,,
III	53 20	5 27	,, ,, ,,
IV	53 20	5 43	,, ,, ,,
Holyhead to Dublin I	53 19	4 56	May 1922 to Apr. 1925
II	53 19	5 15	,, ,, ,,
III	53 19	5 33	,, ,, ,,
IV	53 19	5 55	,, ,, ,,
Irish Cruises 1	54 33	5 20	Feb. 1909 to Aug. 1914
2	54 36	5 08	,, ,, ,,
3	54 37	4 56	,, ,, ,,
7	54 00	5 49	,, ,, ,,
8	54 00	5 32	,, ,, ,,
9	54 00	5 14	,, ,, ,,
10	54 00	4 58	,, ,, ,,
12	53 40	5 48	Feb. 1909 to Feb. 1912
13	53 40	5 31	Feb. 1909 to Nov. 1911
14	53 40	5 14	,, ,, ,,
15	53 41	4 56	Feb. 1909 to Aug. 1914
16	53 22	5 46	,, ,, ,,
17	53 21	5 30	,, ,, ,,
18	53 21	5 12	May 1909 to Aug. 1914
19	53 21	4 55	Feb. 1909 to Aug. 1914
21	53 02	5 45	,, ,, ,,
22	53 03	5 30	Feb. 1909 to Aug. 1911
23	53 02	5 12	Feb. 1909 to May 1914
24	53 03	4 56	Feb. 1909 to Nov. 1911
31	52 29	6 00	,, ,, ,,
32	52 27	5 45	,, ,, ,,
33	52 26	5 27	,, ,, ,,
34	52 24	5 10	Feb. 1909 to May 1914
35	52 10	6 08	,, ,, ,,
36	52 08	5 51	Feb. 1909 to Aug. 1914
37	52 06	5 36	Feb. 1909 to May 1914
38	52 04	5 20	,, ,, ,,

except those taken from 1922 to 1925 between Fishguard and Rosslare and the one station on the Land's End to Dublin route which falls within the Irish Sea proper. Several of the series are so short as to have little statistical value. The results of all the individual determinations of salinity, except those for 1938 and 1939, have been published as indicated in § 2.

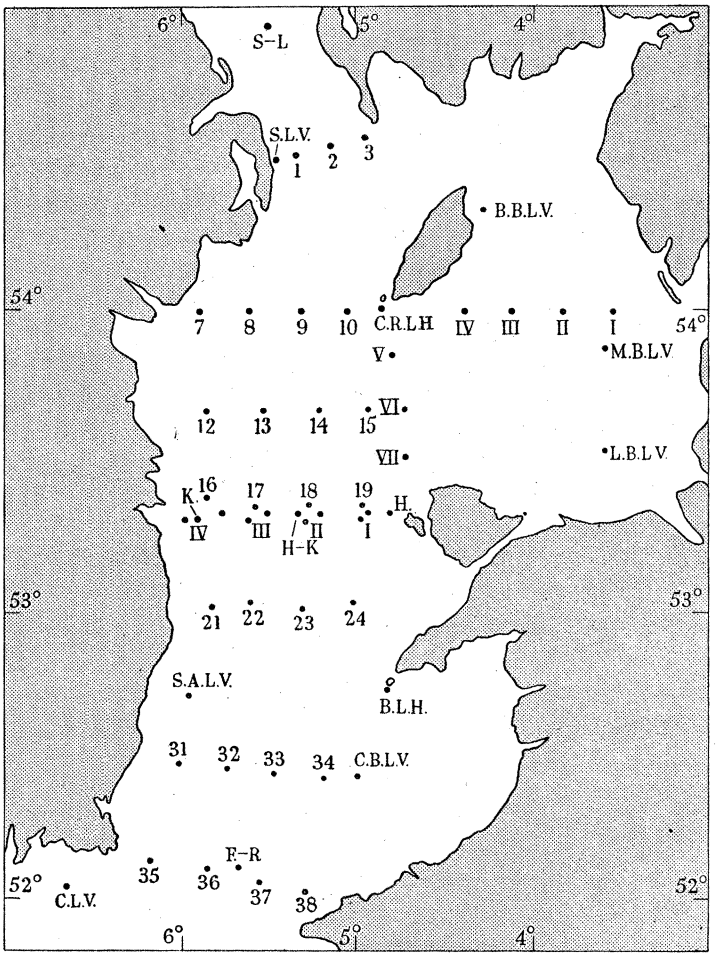

FIGURE 1. Positions of Stations. Initials correspond to names in table 1.

From May 1934 to March 1939 samples from Port Erin Bay were also taken three times per week and titrated by Bruce. The salinities followed those for Chicken Rock very closely. On this account and also because the station was a coastal one, the salinities were not published and the observations were discontinued. They are not used in the present paper.

In subsequent tables we shall write: 'Holyhead' and 'Holyhead-Kish' for the two stations which are near Holyhead and half-way between Holyhead and Kish Light-vessel respectively, with similar contractions in other cases.

The individual titrations carried out by Daniel in the 1925–31 series can be regarded as accurate to 0·01 °/₀₀; those carried out under his direction in the 1934–39 series can be regarded as accurate to 0·02 °/₀₀. All grand mean values can be regarded as accurate to the order given in the table, viz. 0·01 °/₀₀.

5. Particular mean values

For all the observations considered, average values over each particular calendar month and year were made for each station. These form the basis for the whole of the present discussion.

In order to put on record the chief variations of the salinity over the central part of the sea, which is also the part in which observation has been most extensive, during the entire period of observation, table 2 has been constructed. Each entry in this table gives an average value for the three or four stations on the line joining Holyhead and Dublin.

On looking at the yearly mean values of table 2, we see that from 1909 to 1914 there is a general increase, from 1922 to 1930 there is another general increase, while from 1934 to 1939 there is a general decrease, and that each of these progressions is over much the same range.

Table 2. Monthly mean values of salinity (°/₀₀) on the Holyhead-Dublin line

Series	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	M
Irish Stations 16, 17, 18, 19	1909	—	34·09	—	—	34·38	—	—	34·20	—	—	34·12	—	34
	1910	—	34·09	—	—	34·10	—	—	34·18	—	—	34·29	—	34
	1911	—	34·49	—	—	34·28	—	—	34·19	—	—	34·14	—	34
	1912	—	34·59	—	—	34·48	—	—	34·41	—	—	34·60	—	34
	1913	—	34·63	—	—	34·56	—	—	34·31	—	—	34·62	—	34
	1914	—	34·48	—	—	34·48	—	—	34·44	—	—	—	—	34
Holyhead to Dublin I, II, III, IV	1922	—	—	—	—	34·08	34·05	34·27	34·10	34·09	33·60	34·35	34·40	34
	1923	34·22	34·16	34·44	34·21	34·35	34·30	34·23	34·17	34·28	34·18	34·33	34·26	34
	1924	34·23	34·19	34·21	34·24	34·48	34·23	34·36	34·26	34·39	34·43	34·56	34·66	34
	1925	34·61	34·54	34·33	34·45	—	—	—	—	—	—	—	—	34
	1925	—	—	—	—	—	—	34·06	34·22	34·27	34·29	34·42	34·44	34
	1926	34·56	34·60	34·53	34·53	34·33	34·51	34·27	34·29	34·10	34·17	34·31	34·42	34
	1927	34·24	34·04	34·50	34·42	34·33	34·35	34·36	34·23	—	34·39	34·44	34·61	34
	1928	34·53	34·58	34·62	34·47	34·45	34·40	34·43	34·40	34·34	34·41	34·67	34·65	34
	1929	34·50	34·69	34·68	34·66	34·61	34·54	34·51	34·39	34·46	34·36	34·29	34·58	34
	1930	34·95	34·41	34·38	34·27	34·40	34·38	34·28	34·35	34·37	34·56	34·49	34·45	34
	1931	34·47	34·30	34·17	34·17	34·05	34·02	34·18	34·11	34·17	34·27	—	—	34
Holyhead Holyhead-Kish Kish	1934	—	—	—	—	34·38	34·46	34·45	34·45	34·60	34·57	34·39	34·49	34
	1935	34·47	34·40	34·44	34·39	34·41	34·45	34·44	34·41	34·31	34·33	34·34	34·37	34
	1936	34·49	34·64	34·42	34·45	34·47	34·50	34·45	34·38	34·36	34·29	34·35	34·31	34
	1937	34·31	34·29	34·22	34·30	34·28	34·28	34·26	34·16	34·24	34·09	34·05	34·13	34
	1938	34·16	34·13	34·13	34·11	34·08	34·09	34·07	34·08	34·10	34·17	34·06	34·20	34
	1939	34·08	34·13	34·14	33·97	33·96	33·98	34·08	34·16	34·17	34·34	34·13	34·39	34

6. Grand mean values and standard deviations

For each separate series of observations at each station, a grand mean of all the yearly mean values has been calculated. The results are given in table 3 and figure 2.

TABLE 3. GRAND MEAN VALUES AND STANDARD DEVIATIONS

Station	Grand mean value ‰	s.d. Yearly mean values ‰	s.d. Monthly mean values ‰	Seasonal variation: Amplitude Mean ‰	Amplitude s.d. ‰	Date of max. Mean	Date of max. s.d. days
Fishguard-Rosslare	34·91	0·14	0·21	0·18	0·12	29 Oct.	18
Bardsey L.H.	34·33	0·16	0·21	0·02	0·10	20 Sept.	232
Holyhead	34·21	0·21	0·23	0·06	0·08	17 July	116
Holyhead-Kish	34·46	0·15	0·21	0·13	0·07	28 Feb.	34
Kish L.V.	34·18	0·13	0·17	0·04	0·07	20 Nov.	81
Chicken Rock L.H.	34·17	0·15	0·19	0·09	0·11	24 Apr.	39
Liverpool Bar L.V.	32·12	0·33	0·58	0·38	0·23	21 Sept.	54
Morecambe Bay L.V.	32·68	0·21	0·46	0·41	0·22	6 Aug.	34
Stranraer-Larne	34·13	0·15	0·23	0·06	0·12	17 Apr.	39
Coningbeg L.V.	34·72	0·05	0·13	0·08	0·06	23 Oct.	36
South Arklow L.V.	34·20	—	—	—	—	—	—
Skulmartin L.V.	34·06	—	—	—	—	—	—
Bahama Bank L.V.	33·59	0·23	0·23	0·13	0·08	17 Oct.	40
Cardigan Bay L.V.	34·49	0·13	0·24	0·28	0·11	18 Nov.	15
L.W.S.F.C. I	32·89	0·31	—	—	—	—	—
II	33·48	0·28	—	—	—	—	—
III	33·83	0·23	—	—	—	—	—
IV	34·08	0·21	—	—	—	—	—
V	34·24	0·16	—	—	—	—	—
VI	34·28	0·15	—	—	—	—	—
VII	34·17	0·21	—	—	—	—	—
Holyhead-Dublin 1925–31 I	34·45	0·14	—	0·06	0·12	30 Mar.	58
II	34·49	0·10	—	0·12	0·13	6 Mar.	63
III	34·39	0·13	—	0·16	0·05	31 Jan.	33
IV	34·25	0·14	—	0·09	0·07	22 Jan.	39
Holyhead-Dublin 1922–25 I	34·36	0·14	—	0·08	0·18	28 May	107
II	34·40	0·16	—	0·04	0·15	3 Mar.	216
III	34·26	0·17	—	0·13	0·02	1 Dec.	7
IV	34·11	0·18	—	0·15	0·04	17 Oct.	31
Irish Cruises 1	34·05	0·18	—	—	—	—	—
2	34·01	0·13	—	—	—	—	—
3	33·92	0·18	—	—	—	—	—
7	34·02	0·16	—	—	—	—	—
8	34·12	0·17	—	—	—	—	—
9	34·18	0·22	—	—	—	—	—
10	34·23	0·22	—	—	—	—	—
12	33·98	0·15	—	—	—	—	—
13	34·08	0·06	—	—	—	—	—
14	34·16	0·11	—	—	—	—	—
15	34·32	0·19	—	—	—	—	—
16	34·22	0·19	—	—	—	—	—
17	34·35	0·19	—	—	—	—	—
18	34·47	0·16	—	—	—	—	—
19	34·39	0·16	—	—	—	—	—
21	34·09	0·12	—	—	—	—	—
22	34·22	0·06	—	—	—	—	—
23	34·25	0·08	—	—	—	—	—
24	34·38	0·08	—	—	—	—	—
31	34·37	0·10	—	—	—	—	—
32	34·56	0·04	—	—	—	—	—
33	34·76	0·16	—	—	—	—	—
34	34·72	0·08	—	—	—	—	—
35	34·70	0·09	—	—	—	—	—
36	34·86	0·04	—	—	—	—	—
37	34·85	0·04	—	—	—	—	—
38	34·78	0·06	—	—	—	—	—

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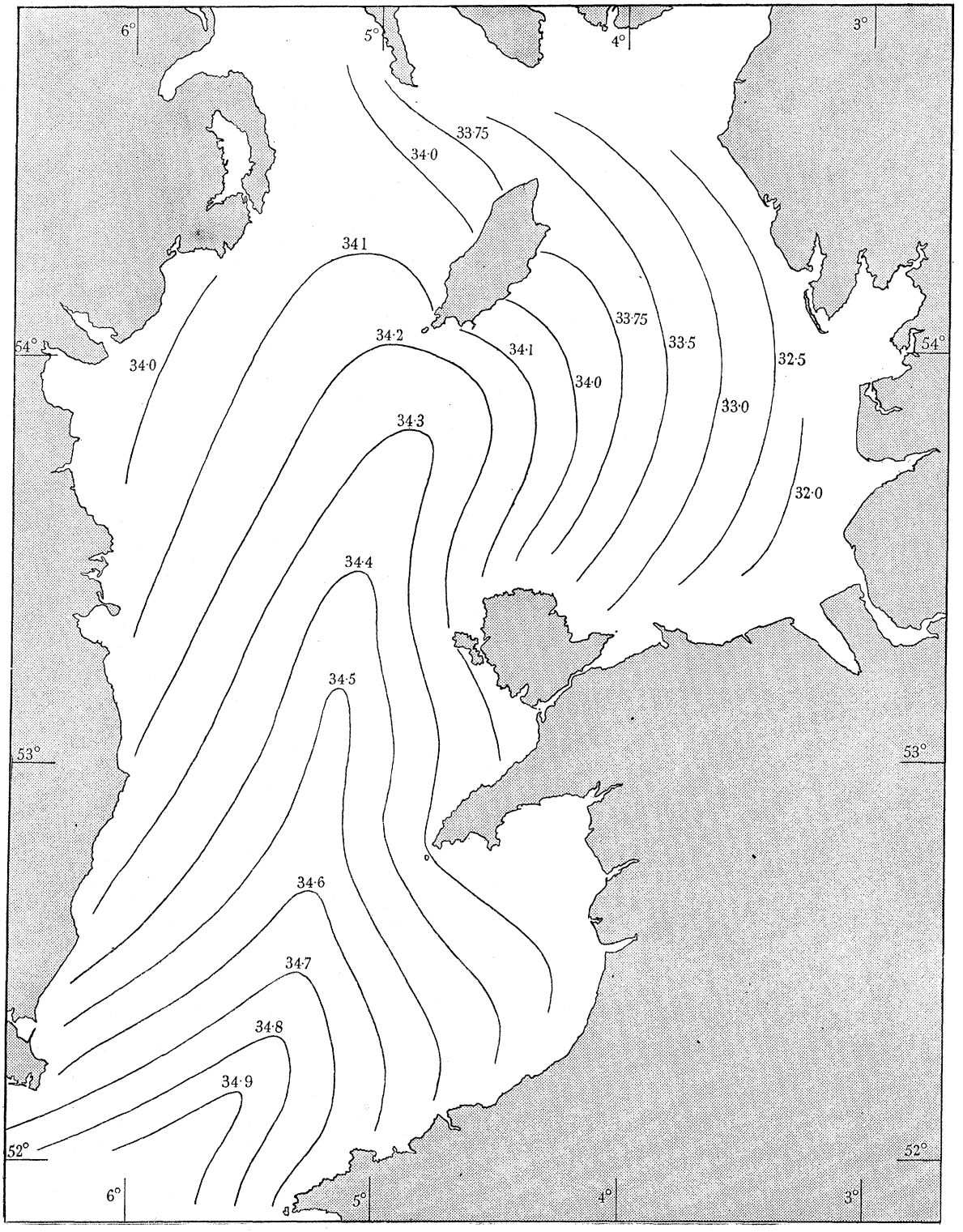

FIGURE 2. Lines of equal mean salinity.

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As the grand mean values relating to different series refer to different periods of years, difficulties are inevitable in the attempt to construct such a chart as that of figure 2. This chart is in agreement with all the results of the 1934–9 series, of the L.W.S.F.C. series, of the series at or near lightvessels other than that at South Arklow, and of the series at the Irish Stations 1, 2, 3, 7, 8, 9, 10, 15, 19, 35, 36, 38. It indicates salinities lower than those of the 1928–31 series at the Holyhead-Dublin stations I, II, III and these are among the most reliable. It also indicates salinities lower than those of the Irish stations 16, 17 and higher than those of the Irish stations 12, 13, 14, 21, 22, 23, 31, 33, 37.

The grand mean values have been subtracted from the corresponding particular monthly and yearly mean values, and the differences have been called monthly and yearly *anomalies* respectively. These anomalies form the basis for the calculation of the standard deviations and of the correlations.

For the standard deviation, or s.d., of a set of anomalies, we take

$$\sqrt{\left(\frac{\Sigma a^2}{n-1}\right)},$$

where Σa^2 denotes the sum of the squares of all the anomalies of the set. The results are given in table 3.

Speaking generally, the standard deviations, both of the yearly mean values and of the monthly mean values, increase as the grand mean values decrease. This indicates that the greater the proportion of fresh water the more variable is this proportion. Such a relationship would be expected from the irregular nature of the supply of fresh water.

7. Seasonal variations

Corresponding to each station and calendar year for which twelve monthly mean values have been determined, two quantities A and B have been calculated, which give a harmonic representation

$$A\cos\theta + B\sin\theta$$

of the excess of the monthly mean values over the yearly mean value. The angle θ increases by 360° in a calendar year and may be taken as zero on 16 January. The quantities A and B were obtained by multiplying the monthly anomalies by

$$2,\ 2,\ 1,\ 0,\ -1,\ -2,\ -2,\ -2,\ -1,\ 0,\ 1,\ 2$$

and

$$0,\ 1,\ 2,\ 2,\ 2,\ 1,\ 0,\ -1,\ -2,\ -2,\ -2,\ -1$$

respectively, adding and then dividing each sum by 12·93. The greatest values obtained for $(A^2+B^2)^{\frac{1}{2}}$ are 0·69 °/₀₀ for Morecambe Bay in 1936 and 0·64 °/₀₀ for Liverpool Bar in 1935.

Grand mean values $\overline{A}$ and $\overline{B}$ of A and B were next evaluated for each station, and also the standard deviations σ_A and σ_B respectively of A and B from $\overline{A}$ and $\overline{B}$. The quantities

$$R = \sqrt{(\overline{A}^2+\overline{B}^2)}, \quad \frac{365}{360}\tan^{-1}\frac{\overline{B}}{\overline{A}}$$

are taken respectively as the amplitude of the mean seasonal variation and the number of days from 16 January of the date of the maximum of the mean seasonal variation. The quantities

$$\sqrt{\left\{\left(\frac{\overline{A}}{R}\right)^2\sigma_A^2+\left(\frac{\overline{B}}{R}\right)^2\sigma_B^2\right\}}, \quad \frac{365}{2\pi R}\sqrt{\left\{\left(\frac{\overline{A}}{R}\right)^2\sigma_B^2+\left(\frac{\overline{B}}{R}\right)^2\sigma_A^2\right\}}$$

are taken as the standard deviations respectively of the amplitude and of the date of the maximum of the seasonal variation.

The results are given in table 3, but some of them are based on series so short as to have little significance. We notice that the standard deviation of the amplitude is of the same order as the mean value of the amplitude itself, and that the standard deviation of the date of the maximum may be very considerable.

It thus appears that, although for any particular station and year there may be a well-marked variation, yet the amplitudes of such variations change much from year to year.

8. Correlation coefficients

For the correlation coefficient between two sequences, each of n terms, of which a typical corresponding pair is v_1, v_2, we take

$$\frac{\frac{1}{n}\Sigma v_1 v_2 - m_1 m_2}{\sqrt{\left(\frac{1}{n}\Sigma v_1^2 - m_1^2\right)}\sqrt{\left(\frac{1}{n}\Sigma v_2^2 - m_2^2\right)}},$$

where m_1 and m_2 are respectively the mean values of the terms in the two sequences and Σ denotes summation over all the n terms.

As a measure of the persistence of the anomalies of salinity at a single station we have calculated the correlation coefficients between the anomalies at a station and those at the same station a stated number of months later. The results for four stations are given in the following table:

Interval months	Fishguard-Rosslare	Holyhead-Kish	Liverpool Bar	Stranraer-Larne
1	0·77	0·65	0·48	0·60
2	0·54	0·61	0·27	0·24
3	0·25	0·42	0·02	0·24

Table 4 gives the correlation coefficients between the monthly anomalies at one station and those at another station a stated number of months later. In the table the second station of each pair is that for which the later salinities are taken.

TABLE 4. CORRELATION COEFFICIENTS

Stations	n	Interval (months) 0	1	2	3	4	5	6
Fishguard-Rosslare Bardsey	68–62	0·54	0·55	0·42	0·34	0·26	0·21	0·21
Bardsey Holyhead	68–62	0·53	0·47	0·46	0·37	0·47	0·49	0·50
Fishguard-Rosslare Holyhead-Kish	68–62	0·13	0·19	0·32	0·40	0·48	0·49	0·37
Holyhead-Kish Holyhead	68	0·60	—	—	—	—	—	—
Holyhead-Kish Kish	68	0·28	—	—	—	—	—	—
Holyhead-Kish Chicken Rock	68–62	0·62	0·71	0·79	0·71	0·59	0·47	0·40
Holyhead Liverpool Bar	68–62	0·38	0·44	0·45	0·45	0·32	0·19	0·15
Liverpool Bar Morecambe Bay	68–65	0·60	0·26	0·00	−0·18	—	—	—
Chicken Rock Morecambe Bay	68–62	0·31	0·43	0·53	0·53	0·46	0·35	0·19
Chicken Rock Stranraer-Larne	58	0·48	0·49	0·45	0·39	0·32	0·33	0·39

		Interval (months) 0	3	6	9	12	15	18
Holyhead-Kish Stranraer-Larne	58–56	0·13	0·23	0·18	0·40	0·33	—	—
Fishguard-Rosslare Stranraer-Larne	58–50	−0·43	−0·18	−0·01	−0·06	−0·15	−0·01	0·27

To illustrate the degree of stability of these correlation coefficients and also to show the results obtained from the earlier observations, we give the following five sets of determinations of the correlation between the salinity at Fishguard-Rosslare and that at Holyhead-Kish.

Series	Interval (months) 0	1	2	3	4	5	6
1905–14	0·06	—	—	0·29	—	—	0·14
1922–25	−0·10	−0·04	0·08	0·18	0·29	−0·02	−0·21
1934–36	0·05	0·17	0·30	0·49	0·66	0·55	0·39
1934–37	0·02	0·19	0·36	0·53	0·73	0·73	0·61
1934–39	0·13	0·19	0·32	0·40	0·48	0·49	0·37

From table 4 we see that many of the coefficients have values which indicate significant correlation. For some pairs of stations they reach a maximum for an interval of several months.

9. Correlation of salinity with rainfall

For a representative rainfall we have taken the averages of the monthly values for Dumfries, Douglas, Liverpool, Holyhead, Aberystwyth, Armagh, Dublin and Newcastle (Wicklow), and have treated these averages exactly like the monthly mean values of salinity. The representative nature of the average rainfall is shown by the coefficients

$$0{\cdot}87,\ 0{\cdot}91,\ 0{\cdot}78,\ 0{\cdot}89,\ 0{\cdot}91,\ 0{\cdot}78,\ 0{\cdot}76,\ 0{\cdot}85 \quad (n=48)$$

which give the correlations between monthly anomalies of the average rainfall and the anomalies for the same months of the rainfall at the individual stations in the above order.

As a measure of the persistence of the anomalies of this representative rainfall we have calculated the correlation coefficients between the monthly anomalies and those a stated number of months later. The results for intervals of 1, 2, 3 months are respectively 0·11, 0·16, −0·10. These indicate a much smaller degree of persistence than that of the anomalies of salinity.

Table 5 gives the correlation coefficients between the monthly anomalies of the representative rainfall and those of the salinity at each station, a stated number of months later. Most of these coefficients are negative, as one would expect, but many of the individual values are so low as to have very little significance. Some of the largest values refer to Liverpool Bar and to Morecambe Bay, with intervals of several months, and again this is what one would expect. But it is noteworthy that similar values refer to Fishguard-Rosslare with intervals of 5 and 6 months.

Table 5. Correlations of salinity with rainfall

		Interval (months)									
Station	n	0	1	2	3	4	5	6	7	8	9
Fishguard-Rosslare	68–63	0·30	0·20	−0·01	−0·11	−0·26	−0·42	−0·41	−0·22	−0·05	0·14
Bardsey	68–63	−0·18	−0·01	−0·04	0·02	−0·09	−0·06	−0·26	−0·08	0·01	0·05
Holyhead	68–66	−0·06	−0·02	−0·05	−0·03	−0·11	−0·11	−0·06	—	—	—
Holyhead-Kish	68–63	−0·02	0·17	0·23	0·28	0·08	0·14	−0·04	−0·06	−0·11	−0·13
Kish	68–66	0·19	−0·06	−0·18	−0·31	−0·09	−0·02	−0·19	—	—	—
Chicken Rock	68–66	−0·19	−0·10	−0·14	0·01	0·12	0·11	0·03	—	—	—
Liverpool Bar	68–64	0·40	−0·15	−0·31	−0·38	−0·21	−0·30	−0·26	−0·03	−0·08	—
Morecambe Bay	68–64	−0·07	−0·43	−0·47	−0·37	−0·27	−0·29	−0·02	0·19	0·39	—
Stranraer-Larne	58	−0·15	−0·18	−0·20	−0·09	0·14	0·03	0·05	—	—	—

10. Correlation of salinity with barometric gradients

For a particular monthly mean value of atmospheric pressure at a station we have taken the average of the readings at all the hours of observation available and reduced to sea-level. One of the gradients used is based on the excess of the atmospheric pressure at Bidston over that at Blacksod Point, while the other is based on the excess of atmospheric pressure at Eskdalemuir over that at Pembroke. These two gradients correspond roughly to a south wind and to an east wind respectively.

Table 6 gives correlation coefficients between the monthly anomalies of the two barometric gradients and those of the salinity at each of four stations a stated number of months later. These coefficients indicate very little correlation between the wind and salinity. But a south wind appears to decrease the salinity at the Stranraer-Larne Station, and a west wind appears to decrease the salinity at the Holyhead-Kish Station. The first of these results corresponds to the distribution noted in the next section, viz. that at the Stranraer-Larne Station the salinity decreases towards the south. The second corresponds to the relatively low salinity near Kish.

TABLE 6. CORRELATIONS OF SALINITY WITH BAROMETRIC GRADIENT

		Pressure increment from Blacksod to Bidston Interval (months)			Pressure increment from Pembroke to Eskdalemuir Interval (months)		
Salinity station	n	0	1	2	0	1	2
Fishguard-Rosslare	68	0·18	0·23	0·13	−0·11	0·04	0·10
Holyhead-Kish	68	−0·03	0·10	0·04	0·38	0·26	0·21
Liverpool Bar	68	0·30	0·06	−0·16	−0·10	0·19	0·18
Stranraer-Larne	58	−0·11	−0·49	−0·32	0·14	0·18	0·23

11. MEAN CURRENTS

Figure 2 indicates a mean current from south to north, entering the sea through St George's Channel and leaving it through the North Channel; it also indicates an influx of fresh water from the land on both sides of the sea. Since the rainfall exceeds the evaporation, there must also be an influx of fresh water over the whole area of the sea. The fresher water is continually mixed with the salter water and the mean result is the regime corresponding to figure 2. Owing to this mixing the direction of the mean current of salter water from the south will cut the lines of equal salinity so as to pass from regions of higher salinity to regions of lower salinity, but the angle between the two may be very small.

It is noteworthy that the mean salinity at the Stranraer-Larne Station is higher than that at any point of the North Channel shown in figure 2. This must also be an effect of mixing, as past this Station the mean current must flow away from the Irish Sea, i.e. in the direction of increasing salinity. In this instance the water from the Irish Sea is mixed with the salter water from the Atlantic to the north of Ireland. The fact that the salinity at Stranraer-Larne is under other influence than that coming from the Irish Sea is shown by the correlation coefficients of table 4. There is only small correlation with Chicken Rock and Holyhead-Dublin, and no significant correlation with Fishguard-Rosslare.

At the four stations between the Mull of Galloway and Skulmartin L.V. the mean salinities increase steadily towards the west, though the differences are small and the Skulmartin series is very short. This fact, coupled with the higher salinity at Stranraer-Larne, may indicate a south-going current of relatively salt water near the shore off

the north-east coast of Ireland. Such a current would be in harmony with the suggestions of Nielsen and the *Conseil international* as mentioned in § 3, and also with the results of a year's observations of currents at the Skulmartin L.V. (Proudman 1939) which gave a mean current towards the south-east.

If we assume that the maximum correlation coefficients between the anomalies of salinity at a pair of stations indicates that the same water has passed from one station to the other in the corresponding interval, then we get the following estimates for the steady part of the drift through the Irish Sea.

Stations	Intervals months
From Fishguard-Rosslare to Holyhead-Kish	$4\frac{1}{2}$
From Holyhead-Kish to Chicken Rock	2
From Chicken Rock to Morecambe Bay	$2\frac{1}{2}$

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