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## THE SURFACE CURRENTS OF THE NORTH SEA.

By T. WEMYSS FULTON, M.D., F.R.S.E., Scientific Superintendent,  
Fishery Board for Scotland.

(*With Map.*)

IN recent years the hydrography of the North Sea has been made the subject of careful investigations by a number of observers, particularly with respect to the movements of its waters. The distinguished Swedish scientists who have taken the leading part in this work have succeeded in throwing a great deal of light on the physical changes and movements which occur at different seasons in the waters of the Kattegat, Skagerrack and adjoining areas;<sup>1</sup> and the results have quite recently been brought into relationship with the fluctuations which take place from year to year in the produce of the herring fishery.<sup>2</sup>

In connection with certain fishery problems experiments were begun a few years ago by the Fishery Board for Scotland with the view of ascertaining the course and speed of the surface currents off the east coast of Scotland. These experiments have now been completed,<sup>3</sup> and I propose to give here a summarised account of the results. The most important object of the experiments, from a practical point of view, was to ascertain the part played by the surface currents in transporting the floating or pelagic eggs and larvæ of marine fishes. It is now well known that the eggs of all the food fishes, with the exception of the herring, skates, and rays, and a few unimportant species, are buoyant, and float as tiny, isolated spheres of glassy transparency, dispersed throughout the surface waters. This is so, for example, with the eggs of the cod, haddock, whiting, ling, etc., and all the flatfishes; and as the development of the embryos within the eggs may take in some cases several weeks, according to the species and the temperature of the water, during which time the egg is floating about in the sea, it is clear that they may be carried considerable distances before hatching occurs and the young fish escape. Further, the larvæ fish is very small and comparatively feeble, and it also may be carried a long distance by the current before it has grown sufficiently strong to contend against it.

It has also been proved that almost all the food fishes, certainly all the important ones, do not shed their eggs near the shore, within the three-mile limit, on the east coast, but farther off, and probably in many cases up to a considerable distance from the coast.<sup>4</sup> If these pelagic eggs, which float about for so many days or weeks exposed to the

<sup>1</sup> *Vide* Professor Pettersson's elaborate papers in the tenth volume of this journal.

<sup>2</sup> *Skageracks Tillstånd under den nuvarande Sillfiskeperioden*, af P. T. Cleve, G. Ekman, J. Hjort, O. Pettersson, Göteborg, 1897.

<sup>3</sup> *Fifteenth Annual Report of the Fishery Board for Scotland*, Part iii. p. 334.

<sup>4</sup> "The Spawning and Spawning-Places of Marine Food Fishes," T. W. Fulton, Part iii. *Eighth Annual Report of the Fishery Board for Scotland*, p. 257.

vicissitudes of the sea and weather, were to be shed near the shore, multitudes would be stranded and lost. The chief object of the experiments, then, was to ascertain the existence, direction, rate, and constancy of the surface currents over the great spawning areas off the east coast, so as to determine the biological relationship between these areas and any given stretch of the territorial seas. Do, then, great offshore spawning-grounds supply young fishes to the inshore waters opposite to them, or

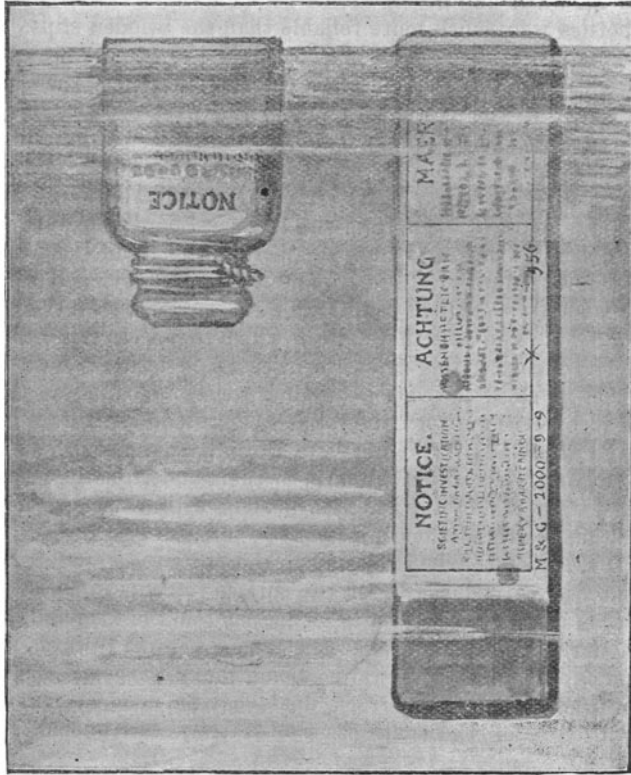


FIG. 1.—The Floats.

to those at a distance? Is there any fairly constant connection between them?

The method employed in the experiments was to throw into the sea, off various parts of the coast, a large number of floats or drifters, each having a number for its identification when recovered. This mode of ascertaining the direction of surface currents has been frequently made use of, as, for instance, by the U.S. Hydrographic Department, the Deutsche Seewarte, and the Prince of Monaco. Two kinds of floats were used, one-ounce wide-mouthed bottles of coarse glass, and strips of wood six inches in length by an inch in breadth. A printed card with

directions in English, German, and Danish was put inside the bottle, or tacked to the strip of wood, and the whole was rendered impervious to water by the use of melted paraffin-wax, the layer over the card attached to the wooden slip being transparent enough for the print to be read through it. As it is of importance in such experiments to have the floats almost submerged, in order to eliminate as far as possible the direct action of the wind on them, each float was carefully tested in sea-water, and was so weighted with lead wire or sheet-lead that it floated upright in the water and nearly submerged (Fig. 1). The results showed that the bottles were much more reliable than the wooden slips.

The experiments were begun in September 1894, and were continued until the spring of the present year. During that time the number of floats set adrift in the North Sea, or to the west of the Orkney and Shetland Isles, was 3553 (2074 bottles and 1479 wooden slips), and the number returned to me, up to March last, was 502.<sup>1</sup> From three or four to twenty or thirty floats were thrown overboard at the same time and place, most of them from the Fishery Board's steamer *Garland*, others from fishing boats, and from steamers sailing from Leith to Christiansand, Hamburg, and Rotterdam, and to the Orkneys and Shetlands. A number were also set adrift from H.M.S. *Research* between the Shetland and Faerøe Isles. The area therefore in which they were put into the sea was considerable, extending from the last-named islands down the east coast, as well as along the various steamer routes indicated on the chart. The floats recovered were found on the eastern side of Britain from the Orkneys and Shetlands, in the north, to Norfolk, in the south, and on the coasts of Holland, Germany, Denmark, Sweden, and Norway, where some were picked up north of the Lofoden Islands, within the Arctic Circle: they were thus scattered along nearly 2000 miles of coast.

From a study of the data relating to the floats recovered it has been shown that the normal course of the surface currents in the North Sea is southwards along the east coasts of Scotland and of England, as far as the neighbourhood of the Wash; it is then eastwards towards the coast of Denmark, and then northwards along the west coast of Norway; sometimes it enters the Skagerrack, floats having been stranded on the west coast of Sweden, the south coast of Norway, and on the shores of the Christiania Fjord.

In the northern area the floats which were put into the sea in the Faerøe-Shetland Channel, west of the Shetlands and Orkneys, and at various places in the neighbourhood of these islands, moved eastwards and southwards, as represented in the adjoining chart (Fig. 2). While most of those set adrift far to the west of the Shetlands were picked up on those islands, some of them were found on the north-west coast of Norway. Thus one, from lat.  $60^{\circ} 38\frac{1}{4}'$  N., long.  $5^{\circ} 35\frac{1}{2}'$  W., was found at Sörsmölen, near Christiansund, having travelled about 430 miles in 204 days. Others, from lat.  $60^{\circ} 2'$  N., long.  $7^{\circ} 4'$  W., were found in S. and N. Trondhjem, as far as 700 miles distant. In the southern part of the region the course of the floats was towards the south-east and south,

<sup>1</sup> About 70 others have since been returned.

and this was very obvious off the Moray Firth. The results show that the surface water passes from the Atlantic, in the neighbourhood of the

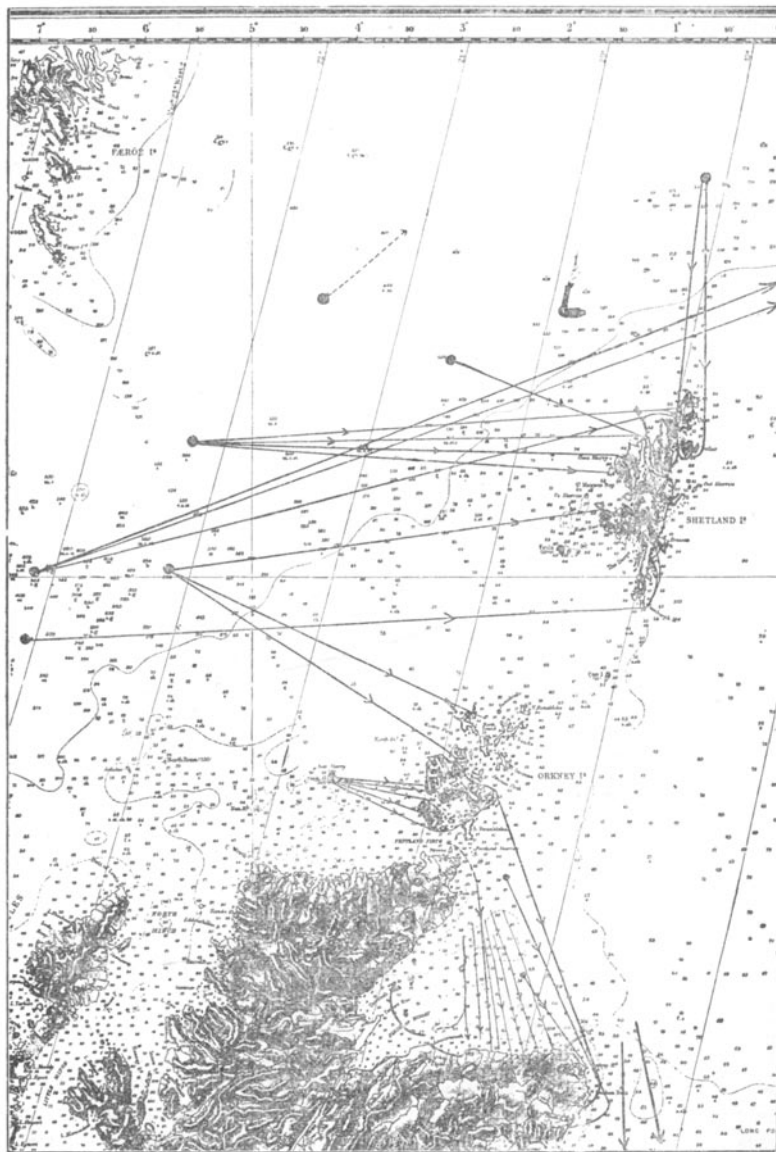


FIG. 2.—Floats in the Faerøe-Shetland Channel.

Orkney Islands, and moves southwards along the east coast. In the Moray Firth it was found that the great majority of the floats put into the sea to the east of a line drawn from Duncansby Head to the mouth

of the river Spey—parallel to the 3° of west longitude—were stranded on the north coast of Banff and Aberdeen, while those set adrift to the west of this line moved, as a rule, westwards, and then up along the coast of Sutherland and Caithness in a northerly direction. Thus, of fifty-nine set adrift to the west of the line mentioned, fifty-four were found within that line; of seventy-one set adrift to the east of the line, only two were found to the westward of it. It is clear from this statement that the general movement of the surface water, from off Duncansby Head, is southwards. It impinges on the south coast of the Moray Firth east of the Spey, and the great mass is then deflected eastwards.

On the east coast of Scotland, south of the Moray Firth, almost all the floats moved southwards, at all seasons of the year, as shown in the following table:—

I. Found to the South—		II. Found on Continent—	
1. On Scotch coast, . . .	58	1. In Norway, . . .	15
2. At sea off Scotch coast, . . .	2	2. In Sweden, . . .	1
3. On English coast, . . .	0	3. In Denmark, . . .	35
Northumberland, . . .	20	4. In Germany, . . .	4
Durham, . . .	10	5. In Holland, . . .	5
Yorkshire, . . .	26		—
Lincolnshire, . . .	2		60
Norfolk, . . .	0		
	—	III. Found to the North, <sup>1</sup> . . .	21
	58		
4. At sea off English coast, . . .	1		
	—		
	119		

Two things stand out conspicuously in the above table. The first is, that the floats stranded on the English coasts were stranded on the northern part. Only two were found in Lincolnshire, and none at all (of those set adrift on the east coast) on the coast of Norfolk. Thus, none was stranded south of the Wash, only two between the Wash and the Humber, and the great majority to the north of Flamborough Head. The second point is that, compared with the Moray Firth floats, a great number were stranded on the coast of Denmark, and comparatively few in Norway, while some were found on the coast of Holland and Germany. The great majority of those found on the coast of Scotland were stranded on the shores of Fife and East Lothian, some were found on the Isle of May, and others on the coast of Berwickshire. Only two were picked up on the coast of Forfarshire, and none in Kincardineshire or Aberdeenshire. They were, therefore, stranded, just as in the Moray Firth, on those parts of the coast which front the north. A considerable number were set adrift near the Bell Rock Lighthouse, and they were found mostly on the Scotch coast to the south, but some landed on the English coast; of others, put farther out at sea in the same area, the majority were found on the coast of England, and others on continental coasts.

The floats, which were found on the other side of the North Sea, moved, first of all, southwards along the east coast of England. This is shown by a large number of cases in which some of the same lot, set

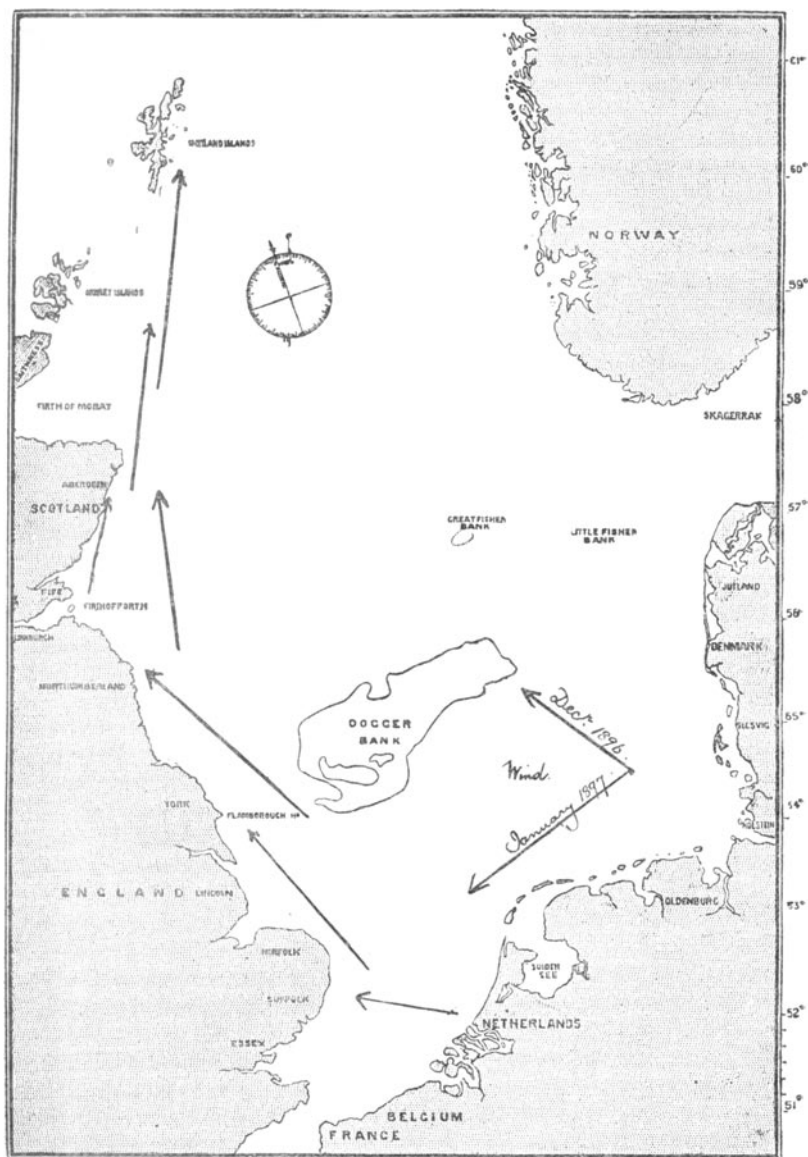
<sup>1</sup> These comprise those carried north by the reversed current (see p. 643) and some set adrift close to the shore.

adrift together, were found on the English coast, while others were picked up later on the coasts of Holland, Germany, and Denmark, and, later still, on the Swedish or Norwegian coast. For example, on 20th March 1895 ten bottles were set adrift near the Firth of Forth; on the 2nd April, thirteen days later, two were found on the coast of Northumberland, about 67 miles distant; two days afterwards, on the 4th April, another was found 82 miles distant, also on the coast of Northumberland; on the 20th May, after 61 days, a fourth was found near Spurn Point, Yorkshire, a distance of 202 miles; on 1st August, after an interval of 134 days, a fifth was picked up three miles north of Blokhuis, Denmark; and on 14th September a sixth, two miles north of Ringkjöbing, Denmark. It was also found that the course of the floats, thrown into the sea along the steamer routes, indicated the same southward movement of the surface water on this side of the North Sea, and a northward movement on the other side; but the dividing zone between these two areas of movement was found to shift at different times. Usually the floats put in on the Christiansand route, within 150 miles of the Scottish coast, passed south, and many were found on the coast of Denmark; those set adrift within 50 or 100 miles of the Naze moved northwards along the coast of Norway. On the route to Hamburg the same thing occurred. Floats put in on the western part were found to the south, on the coast of England. In some cases, where they were set adrift 150 and 200 miles SE. by E. of the Isle of May, they were found on the south-west coast of Norway. Those thrown in towards the other side were picked up to the north, on the coast of Denmark, in the Christiania Fjord, on the coast of Sweden, or the south coast of Norway.

The southward movement of the surface water along the east coasts of Scotland and England appears to be continuous at all seasons, for the floats, with an exception to be presently alluded to, were always carried in this direction. None of the bottles or slips was found south of Norfolk on our side of the North Sea, or south of the Helder on the other side; and these facts may be taken as showing that none of the surface water, passing down the east coast, escapes by the Straits of Dover. It appears to be all deflected towards the Continent in the neighbourhood of the Wash. The rate of the movement was found to vary very considerably according to the direction and force of the wind. With a strong wind behind, blowing in the same direction, the floats travelled about ten or twelve miles (knots) a day. The average rate, over long distances, was between two and three miles in the twenty-four hours.

With respect to the causes which produce this circulation of surface water in the North Sea a study was made of the direction and force of the winds, as shown by the daily meteorological observations at a number of Scottish, English, and continental stations. It was found that the prevailing wind at North Unst blew from WSW.  $\frac{1}{2}$  S. in 1895, and from WSW. in 1896; at Buchan Ness it blew from W. by S.  $\frac{1}{4}$  S. in 1895, and from SW. by W. in 1896; and at the Bell Rock from W. by N.  $\frac{1}{4}$  W. in 1895, and from W. by N. in 1896. The direction of the prevailing or effective winds at these three stations is indicated on the chart, and it will be observed that they blow at right angles to the course of the

current along the east coast. It is clear from these facts that the movement of the floats on the east coast of Scotland was not directly and



—Showing the Reversal of the Current.

immediately due to the action of the prevailing winds ; it is also clear that they are not, as has been sometimes contended, driven by the wind



independently of the movement of the water in which they are suspended. If they, or the surface water, were merely driven before the wind from the east coast of Scotland, the general course would be north-east and easterly, whereas we have seen that the almost invariable course is southerly, at right angles to the direction of the prevailing wind. That is, I think, an important point to establish.

That the wind, however, has a most important influence on the movement of the surface waters was shown by a very remarkable reversal of the current in December 1896, and January of this year. Floats were returned to me from parts of the east coast lying to the north of the places where they were set adrift. This occurrence was so unusual that at first I thought a mistake had been made in recording their numbers, but it was soon apparent that this was not the explanation, and that, in reality, the surface water was moving rapidly northwards along the whole east coast from Norfolk to the Shetlands, as shown in Fig. 3. Some of the floats returned belonged to groups which had been put in a considerable time before, numbers of which had been previously picked up to the south as usual, and they were, no doubt, well on their way to the Continent when the reversal took place. Some were set adrift in December and January off the east coast of Scotland and England, and they rapidly moved northwards. Others, which were thrown into the sea near the Hook of Holland, travelled westwards, and were stranded in large numbers on the coast of Norfolk. On examining the wind observations it was found that the prevailing winds in December blew from a southerly and easterly direction, and in January from the east and north-east, as follows:—

	N. Unst.	Buchan Ness.	Bell Rock.	Shields.	Yarmouth.	Helder.	Skaw.
Dec. 1896,	S. $\frac{3}{4}$ E. 36	SE. by S. $\frac{1}{4}$ E. 29	S. by W. 8·3	SE. by E. $\frac{1}{4}$ S. 9·3	SE. $\frac{1}{2}$ E. 19·5	WSW. $\frac{1}{4}$ W. 4	S. 2
Jan. 1897,	SE. $\frac{1}{4}$ E. 12	ENE. 19·7	E. 13·5	NE. by N. $\frac{1}{2}$ E. 22	ENE. 10·5	E. by S. $\frac{1}{4}$ E. 20 75	NNE. $\frac{1}{2}$ E. 9·75

It was also found that strong winds and gales from south, south-east, east-south-east, and south-south-east, had prevailed for about ten days in the early part of December and later, and also from the same general direction in the beginning of January, but more easterly; and that from the 12th to the 25th January strong winds, rising to gales, blew from north-east and east-north-east. The effective wind in January, at all the stations combined, came from east-north-east.

The above case, where the surface current was reversed owing to the action of strong and continuous winds from the south, east, and north-east, helps to explain, in my opinion, the normal movement southward along our east coast, and northward along the continental coast. In the early part of December the wind from the south would drive the water northwards; but later, when this northward movement was very marked, the gales were coming from an easterly and north-easterly direction. The surface water was therefore driven towards the coast of England, and, so to speak, heaped up there. It could not escape to the

south through the narrow and shallow Straits of Dover, and it therefore moved northwards along the English coast. The floats put in off the coast of Holland in January travelled to the coast of Norfolk; none, even at this period, was got farther south. If the wind, as above explained, could cause a reversal of the movement of the water, for most of the time at right angles to the direction in which it was blowing, it would appear probable that the same cause produces the normal movement which the experiments have shown to take place. The prevailing westerly and south-westerly winds must tend to heap up the surface water on the shallow continental coasts, especially of Denmark; the water cannot escape to the south for the reasons already stated, and it passes northwards, an indraught of surface water from the neighbourhood of the Orkneys passing down the east coast. Other possible conjoined causes must also be kept in view, such as the tidal stream and the rotation of the earth. The conclusions may be summed up as follows: (1) That there is at all seasons a fairly constant, slow circulation of the surface water in the North Sea, Atlantic water entering round the north of Scotland and between the Orkneys and Shetlands, and passing southwards along the east coasts of Scotland and England, as far as the neighbourhood of the Wash, then in an ENE. direction towards the coast of Denmark, and then northerly along the Danish coast. The surface water may or may not enter the Skagerack and penetrate to the west coast of Sweden and the south coast of Norway. The main body passes up the west coast of Norway and joins the Atlantic stream. The limit between the north-going eastern stream and the south-going western stream varies greatly, probably according to the prevailing winds; as a rule, the extent of the former is greater. (2) The movement of the surface water in confined areas, like the western part of the Moray Firth and the Firth of Forth, is irregular, and depends upon variations in the winds and the tides. (3) That, while the general circulation of the surface water in the North Sea is as above described, the current may be deflected by the wind, or even, under exceptional meteorological conditions, reversed. (4) That the speed of the movement is usually about two or three geographical miles a day, but may be much accelerated or retarded by the action of the wind. (5) That the principal cause of the circulation is probably the influence of the prevailing winds, driving the water towards the eastern side and tending to heap it up there.

It has been stated that the primary object of these experiments had reference to certain problems in connection with marine fishes, and a brief statement of some of the results may be of interest. The prevalence of a normal southerly movement of the surface water along the east coast of Scotland and England will tend to carry the floating eggs and larvæ of the food fishes in the same direction; so that spawning-grounds situated off any given part of that coast will furnish young fishes to the territorial seas farther south. From what is known experimentally as to the duration of the period of development within the eggs of different species at different temperatures, the rate of the movement of the surface water in which they are suspended, and the temperature of the water, it is possible to calculate approximately the distance the eggs may be

carried. For example, plaice spawn early in the year when the surface water is cold, and about twenty-three days elapse before the young fish issues from the egg under natural conditions. Even with a movement of the water so slow as two or three miles a day it will be seen that the floating eggs of the plaice may be carried a considerable distance before hatching occurs. Moreover, the pelagic period of the young fish—that is, before it settles on the bottom as a “flatfish,” and while it is comparatively helpless—extends to several weeks, and during this time it may be carried much farther to the south. It is much the same with other species, such as cod, haddock and saithe, which spawn early; but with summer-spawning forms hatching occurs much sooner owing to the higher temperature of the water, and their eggs are not transported so far from the breeding-grounds. Every season billions of these floating eggs of the food fishes are shed into the sea and carried away by the surface current. One would therefore expect a corresponding migratory movement of the growing and adult fishes in the opposite direction, and this has been actually proved to occur with at least one form, the plaice. Many hundreds of this species were marked and liberated in the Firth of Forth and St. Andrews Bay, and it was found that their movement was northwards along the coast, several being recaptured in the Moray Firth after the lapse of a year or more; one, indeed, was caught off the north coast of Caithness more than two hundred miles from the place where it was marked and put into the sea. The direction of the surface current, as I have above described it, also explains the enormous abundance of young flatfishes in the great bight formed by the north coast of Holland and the western coast of Schleswig-Holstein, and on the shallow coast of Denmark. The multitude of young flatfishes in these regions is so great that the English trawlers for some time bound themselves by a voluntary agreement not to fish there, in order to prevent the immense capture of immature fish. And in Denmark, especially in the Limfjord, young plaice abound to such an extent that they are now being transplanted to other waters.

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### SOLAR ECLIPSES.

By THOMAS HEATH, B.A., First Assistant Astronomer,  
Royal Observatory, Edinburgh.

THE coming total solar eclipse of January 22nd, 1898, which is now attracting the attention of the scientific world, has been greatly enhanced in importance by the almost complete failure of most of the eclipse parties who left this country for Northern Europe and elsewhere in the autumn of 1896, a result due to the miserable weather experienced on that occasion. Its interest and importance would have been great in any case, because of the number of questions with reference to the sun's physical constitution which have still to be decided, and which can be approached only when the sun is totally eclipsed. It is somewhat unfortunate that the duration of totality is no more than two

### AFTER DR FULTON'S INVESTIGATIONS



J.G. Bamberger