THE NON-TIDAL SURFACE CURRENT SYSTEM

OF THE

NORTHERN AND MIDDLE AREAS OF THE NORTH SEA,

AS ASCERTAINED BY

EXPERIMENTS WITH DRIFT-BOTTLES.

By

JOHN BARCLAY TAIT, B.Sc.,(Edin.)

* * *
* *
*

Thesis submitted for the Degree of Doctor of Philosophy of the University of Edinburgh. September, 1932.

Degree conferred, 16th December, 1932.

C O N T E N T S

F O R E W O R D

The present thesis consists of three papers recently published by His Majesty's Stationery Office in the series of "Scientific Investigations" issued under the authority of the Fishery Board for Scotland. The inclusive title and the sub-titles of these papers appear on the respective title-pages and are given in the foregoing Contents table. The relationship of the inclusive title to that under which this thesis is presented is discussed in the concluding chapter of the thesis.

Appended to the above publications are two shorter papers, one of which has also been published, the other having been communicated on behalf of the writer to the body named on the title-page. All five papers are original in form and in sub-:stance, the work having been performed at the Marine Laboratory of the Fishery Board for Scotland in Aberdeen, under the super-:vision of the Board's Scientific Superintendent, Alexander Bowman, D.Sc., F.R.S.E., on whose initiative the experiments dealt with in the main body of the thesis were carried out.

The experiments in question consisted in the liberation of large numbers of specially-prepared, floating bottles, from numerous widespread points in the Northern and Middle North Sea, the southern reaches of the Norwegian Sea and the Faroe-Shetland Channel. Primarily, they were designed to yield information of consequence to marine biological research in connection with the Northern North Sea fisheries and, already, the results so far obtained have been of service in this direction. It may be added that, along with the liberation of drift-bottles, physical observations of the temperature and salinity of the sea water were taken at practically every 'liberation-station' and this material is presently forming the subject of a separate study to which the drift-bottle interpretations are proving a valuable asset.

From the biological standpoint the original aim of the drift-bottle work was to obtain an understanding of matters relative to the passive transport of fish eggs, larval forms and indeed, all plankton. Physically, therefore, its immediate objective was the elucidation of surface water movements in the above areas, or, more specifically, the measurement of the quantity generally referred to as *the surface drift**, in its chief characteristics of direction and velocity. A definition of the term 'surface drift' is given in the concluding chapter to the thesis.

As/

* Underlining in typescript denotes italics.

As submitted, the main thesis consists of two parts. Part I is a statistical treatment, on fairly broad lines, of the data pertaining to the five years, 1910 to 1914 inclusive and is in the nature of an introductory to Part II. The latter comprises two sections, of which the first is a detailed analysis, on a cartographical basis, of the results of the 1910 liberations and the second, a similarly exhaustive study of the 1911 data. In order to complete Part II on the lines originally laid down in accordance with the exigencies of departmental economy, three more sections remain to be published at intervals, as circumstances allow. For the purposes of this thesis, however, the three papers now presented form a complete whole in so far as the analyses of the materials for the two years above-mentioned have resulted in new knowledge which has been taken to a definite climax and much of which is remarkably corroborated within these pages. This last circumstance also bespeaks the wider applicability of these analytical results than as representative merely of the two years in question.

Consequent upon the necessity of publishing this work in sections, each memoir, as it appeared, was concluded with a summary chapter based on the results obtained from each analysis. In a final chapter to the present thesis these results and especially their significance are discussed with somewhat greater latitude, introducing certain ideas conceived in the course of this investigation and pointing the way to further research.

J.B.T.

Aberdeen,
September 1932.

E R R A T U M

The writer's attention has been drawn to an error in spelling which occurs throughout the three published papers of this thesis. The Cape which is the north-west corner of Jutland is HANSTHOLM, not HANTSHOLM.

FISHERY BOARD FOR SCOTLAND

SCIENTIFIC INVESTIGATIONS

~~1930~~

~~No. II~~.

The Surface Water Drift in the Northern and Middle Areas of the North Sea and in the Faroe-Shetland Channel.

PART I: A Preliminary Report upon the Results of Scottish Experiments with Surface-Floating Bottles. 1910–1914.

(With One Chart.)

By

JOHN B. TAIT, B.Sc.

This Paper may be referred to as "Fisheries, Scotland, Sci. Invest., 1930, No. II."

EDINBURGH:
PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE.

To be purchased directly from H.M. STATIONERY OFFICE at the following addresses:
120 George Street, Edinburgh; Adastral House, Kingsway, London, W.C.2;
York Street, Manchester; 1 St Andrew's Crescent, Cardiff;
15 Donegall Square West, Belfast;
or through any Bookseller.

1930

Price 4s. od. *net.*

49-175-2-30.

CONTENTS

PREFACE

APROPOS of the title of this thesis, the broad conclusions which have been drawn from an intensive study of drift-bottle experimental records suggest the division of the entire North Sea into three regions, which may be designated respectively the Northern, Middle, and Southern Areas of the North Sea, and which correspond approximately with the average depth of the sea-floor beneath the surface. They may conveniently, although not rigidly, be defined as those areas situated to the north of, between, and southwards of latitudes 57° 30′ N. and 54° N. respectively.

A few words may be allowed in explanation of the delay in publishing the results of experiments completed twelve years ago. As was to be expected, a few years immediately after the cessation of hostilities in Europe were occupied mainly in the reconstruction and reorganisation of the scientific work pertaining to the fisheries. Routine work had to be placed afresh upon a smooth-working basis before accumulated records could be examined, and that by new personnel. Time was required by these newcomers to the staff, of whom the writer is one, to become familiarised with the conditions of a long-established service.

When the present records were put into my hands it was soon made clear that little would be gained and much might be lost by presenting the results of their examination in summary form. A preliminary survey of the data suggested that a carefully detailed study would be repaid. In this I have been generously guided by my chief, Dr. Alexander Bowman, to whom, along with those members of the staff who have assisted me in the preparation of this report, I wish to tender my grateful acknowledgments.

J. B. T.

ABERDEEN, *January* 1930.

The Surface Water Drift in the Northern and Middle Areas of the North Sea and in the Faroe-Shetland Channel.

INTRODUCTION.

General.

In their bearing upon many questions involved in the study of the fisheries, it has long been recognised that, in seas of such economic significance as the North Sea and its adjacent waters, non-tidal current systems are factors of prime importance. Indirectly, as has been pointed out by, amongst others, Scandinavian and German scientists, there can be no doubt as to the existence of a relationship between the flow of ocean currents and various other natural phenomena in the realms of climatology and land productivity. (see Appendix II).

The elucidation, by experimental means, of the current systems in and around the North Sea, with their variations not only from year to year, but from month to month, has engaged the attention of a number of investigators almost continuously since the year 1894, when Fulton initiated his well-known experiments with a view to the correlation of currents with the transportations of embryonic and larval forms.

The methods which are and have hitherto been employed to attain this objective may be divided broadly into two classes—direct and indirect. Of the latter, the chief are those based upon the distribution of density in the sea and upon a study of the plankton. Currents have been measured directly, here and there, by means of more or less exact machines, those bearing the names of Ekman, Jacobsen, Pettersson, and more recently, Carruthers, being perhaps the best known. But, apart from the method of computations based upon observations of temperature and salinity, the mode of attacking the problem, particularly of surface currents, which has until now been most extensively adopted, is that by the agency of specially designed floats of metal or wood, or by means of surface-floating, glass bottles. Already there has been published a number of papers embodying the results of such experiments in the North Sea and neighbouring waters, notably those of Fulton, Garstang, Gilson, Ryder, and Carruthers.

Of recent years the casting adrift of surface-floating bottles, in conjunction with other practical operations of research in connection with marine biology, has come to form an integral part of the Scottish programmes of work.

As a means of determining surface current systems generally, the desiderata for the most satisfactory outcome of the drift-bottle method must be regularity and continuity of operations, rather over a wide field than from one or two selected points, especially if these points are in proximity to the coast-line, in which regions purely tidal effects tend to mask the real objective of the experiments, namely the determination of the quantity known as "the surface drift."

When the above conditions have been satisfied over a period of years, the doubt which has been expressed concerning the reliability of results on account of the uncertainty as to how long drifters may have lain upon the beach prior to discovery may be so far dispelled as to be practically negligible.

Bearing in mind also that, so far as concerns the fisheries, one of the principal aims of experiments designed to ascertain the direction and velocity of flow of the uppermost layers in the sea is the correlation of these characteristics with the migrations of fish, or the distribution of plankton, fish eggs or larval forms, another objection has been raised against the drift-bottle method of investigation. This is to the effect that the drifters probably indicate the passage of only the most superficial stratum of water, upon which, it is averred, the propulsive effect of the wind may be considerably greater than upon sub-surface layers at a depth of even a metre or two beneath the surface, tending greatly to accelerate the flow in a given direction of the topmost layer, or even to propel it in quite a different direction to that in which the sub-surface layer is moving. In relatively shallow water areas near continental land such effects of wind influence have been revealed by drift-bottle results, but, as one outcome of the long series of experiments which form the basis of this report, there is reason to believe that, as a general rule, over a broad expanse of deeper water such as fills the Northern North Sea basin, similar phenomena are much less pronounced.

The advantages of the drift-bottle method over those involving current-meter work and the collection of temperature and salinity observations are (1) the relatively lower cost; (2) economy in time; and (3) the fact that drift-bottles may be thrown overboard during rough weather, when any work which involves the laying-to of the ship must be abandoned.†

Recapitulation and Collation of Previous Results.

Notwithstanding that there have appeared within comparatively recent years in the papers of Böhnecke (**1**) and Carruthers (**2**)* fairly comprehensive summaries of the work which has hitherto been accomplished in respect of non-tidal current systems in and around the North Sea, a recapitulation of the broad results accruing from such work were usefully considered before entering upon the examination of the present records.

In 1897 Fulton (3*b*) established the general surface current system within the North Sea as of the nature of a main drift-stream, having its immediate origin in the Faroe-Shetland Channel area and entering the North Sea by way of the openings between Shetland and the mainland of Scotland, thereafter flowing southwards along the British east coast as far as approximately the latitude of Spurn Head, Yorkshire, where an eastward deviation towards Continental shores takes place, the final movement being a northerly flow along the western coasts of Denmark and Norway. Subsidiary offshoots from this principal stream penetrate the bights formed by the Scottish coast and enter the Skagerak.

Further investigation, however, has proved that surface water movements in the North Sea are much more complex than as portrayed in Fulton's chart. In 1905, Pettersson (4) published a synoptic chart (pertaining to the summer of 1904) of the North Sea surface water circulation, which chart differs markedly in some respects from the former one. The southern limit of the cyclonic system of surface drift as established by Fulton is the chain of islands off the Dutch coast. According to Pettersson, whose work in this respect has since been corroborated, this limit is generally the Outer or Great Silver Pit at the southern end of the Dogger Bank, in the latitude of 54° N. Further, the same authority has shown diagrammatically that, about this region, the deviation in the direction of flow of the main drift-stream—eastwards and north-eastwards—is much sharper than indicated by Fulton, the stream heading directly towards the entrance to the Skagerak from the western side of the North Sea. Also, the waters which wash the shores of the Dutch islands Pettersson regarded as forming a separate and distinct stream, originating probably

* Bracketed numbers in heavier type refer to the bibliographical list, p. 30.

† For a fuller discussion of this matter see Appendix I.

to the west of, or within the English Channel and flowing into the North Sea through the Straits of Dover. Thereafter the stream follows the contour of the Dutch and German coasts to about longitude 7° E., where it bends more or less sharply northwards and joins the main North Sea cyclonic stream in the region off the Thyboron Canal on the west coast of Denmark.

With regard to the Skagerak Pettersson found that, normally, the influx of water thereto from the North Sea is limited to a narrow zone along the north-west Danish coast. On the northern side, a strong current *leaves* the Skagerak, close to and following the contour of the south Norwegian coast round Lindesnaes and away to the north. A branch from this stream deviates sharply westwards across the North Sea from off Jaederens Point, connecting, between the latitudes 57° and 59° N., the southward moving drift-stream on the west side of the North Sea with the opposite stream along the Norwegian coast, thereby postulating a closed system in respect of the movement of surface water in the Middle Area of the North Sea. It is to be observed that, as a general case, this system does not wholly agree with the synoptic surface current charts of Ryder (5) published in 1901. The results of the drift-bottle experiments inaugurated by this investigator led him to represent the surface water movement over almost the entire Northern Area of the North Sea as constituting a huge cyclonic swirl, bounded approximately on the north and south by latitudes 61° N. and 56° 30′ N., and on the west and east by longitudes 1° W. and almost 5° E. respectively, and this representation is strongly supported by the charts of Brown (6), which are based upon the results of *bottom* drift-bottle experiments.

Swirls or eddies, that is relatively slowly gyrating whirlpools, may be said to have been introduced into the conception of the North Sea surface water circulation by Fulton as a result of his experiments in the Moray Firth within which he deduced the existence of a small clockwise eddy, hereafter called the Moray Firth eddy and which, so far as is at present known, may or may not be merely a seasonal phenomenon. Some half-dozen more of these swirls or eddies have since been revealed in the surface waters of the North Sea. One of these, the largest, has already been mentioned in connection with the works of Pettersson, Ryder, and Brown, and since, as is stated by Bowman (7), and as is strongly indicated by a comparison of the results of Fulton, Ryder, and Brown, " there is a close connection between the surface and bottom currents " in at least the Northern Area of the North Sea, the last-mentioned author (Brown) may be credited with the beginnings of a suggestion that such another swirl may be operative in the surface waters off the mid-east Scottish coast between Fife Ness and Aberdeen. The work of Bowman on " The Distribution of Plaice Eggs in the Northern North Sea " further enhances this suggestion, and over the region off the east coast of Scotland south of Buchan Ness, Böhnecke, in his several surface current charts, has delineated a swirl which, like the other eddies similarly represented by this authority, apparently fluctuates in size and geographical position.

Wendicke (8), in 1913, published a chart in which a small counter-clock eddy, modified by Böhnecke in varying degree topographically according to the seasons, is placed in the bight formed by the western Schleswig-Holstein coast and the adjacent northern coast of Germany.

The remaining complexes of a similar nature occurring, at all events, in the surface waters of the North Sea and revealed for the first time, so far as the present writer is aware, in Böhnecke's charts, are situated approximately as regards position and when operative, over the following areas :—

(*a*) In the Skagerak, between the north-west Jutland and the south Norwegian coasts ; a counter-clock gyration.

(*b*) Off the south-west Norwegian coast, between Lindesnaes and Jaederens Point, called by Böhnecke, the Lindesnaes Swirl—counter-clock.

(*c*) In the area off Stavanger, Norway—counter-clock.

(*d*) and (*e*) One at either end of the Dogger Bank and named respectively the North-East and South-West Dogger Bank Swirls. Both gyrate counter-clockwise and appear also to function perennially, but, in like case to the others above noted, are variable in size and position, the former perhaps more so than the latter, depending in some way not yet fully appreciated upon the seasonal and other relationships which almost certainly exist among various physical factors, the chief of which probably are (1) the momenta of the Atlantic water streams entering the North Sea from the north and south, and that of the fresher water outflow from the Baltic during the warmer seasons of the year ; (2) the configuration of the sea bottom and that of the land masses within which the North Sea is contained ; and (3) the prevailing winds.

Before leaving the consideration of Böhnecke's excellent charts, it is to be observed that in only two of these, namely those for the months of November 1905 and August 1909, does the author represent the surface water circulation of the Northern North Sea area in a manner agreeing with the representations of Ryder and Brown.

In respect of the third of the above-mentioned factors affecting the hydrodynamics of the North Sea, mention has already been made of a certain correspondence found to exist between prevailing winds and at least superficial water displacement, particularly in shallow water areas adjacent to land where the correspondence between wind direction and velocity and the same characteristics of surface water drift may at times be very close. In more open-sea and consequently deeper regions of the North Sea basin, drift-bottle experiments do not appear under ordinary meteorological conditions to demonstrate the same intimacy between wind and drift, partly on account of the unavailability of suitable wind observations for an area over which winds are as a rule most variable. In this last fact also there is contained some explanation of the apparent lack of a close correlation between wind and drift over open sea areas, such as revealed by drift-bottle experiments initiated nearer land, in that these agents will, in the former case, have " sea room," so to speak, to respond again to the influence of a well-established current system after temporary deviations therefrom caused by the predominating effect for the time being of a strong wind.

The question in every case resolves itself into one of two forces acting at a point, their resultant being intermediate between the two. Consequently, the greater the momentum of a given drift-stream, the greater will be the force of the wind from a given direction necessary to deflect the stream from its direction of flow, and it is highly probable that momentum is greater in the surface layers of deep water where oceanic currents have greater play than in those of more landward sea areas.

Nevertheless, both Fulton and Carruthers have demonstrated that wind, blowing strongly for an indefinite period from a particular mean direction, may be so far effective as to cause a temporary yet complete transformation, on its western and southern boundaries, in the character of the main cyclonic system of drift governing the North Sea surface water circulation, reversing its direction of flow from eastwards to westwards in the south and from southwards to northwards in the west, the total effect being evident on occasions along the entire length of the British east coast, including the eastern shores of the Orkney and Shetland Islands.

As a factor influencing the general system of surface drift within the North Sea, the momenta of the inflowing Atlantic streams have been cited. It is now recognised that the " key " area, as it were, to the Northern and Middle Areas of the North Sea is the region of the Faroe-Shetland Channel. According to a comparatively recent investigation, namely that of Jacobsen and Jensen (**9**), much of whose work was confirmatory of that of Helland-Hansen (**10**) and Robertson (**11**), at least three types of water of distinctly different physical characteristics flow into the region bounded superficially by the curve : Orkney and Shetland Islands—Faroe Islands—the Butt of Lewis and the north coast of the mainland of Scotland. This fact, in conjunction with the obvious effect which must result from the steepness of the gradients of the sea floor on either side of the Channel proper, tends to produce a somewhat complicated and relatively quickly changing system of surface currents, a picture of which as they were computed for the period from 3rd to 14th May 1924 is given in Jacobsen and Jensen's paper above mentioned. The predominant surface-water drift, however, in this important region consists essentially of a fast-moving stream, emanating from the North-Eastern Atlantic Ocean and flowing in general direction north-eastwards along and to the immediate west of the 100-fathom bathymetric contour on the eastern side of the Channel. Offshoots from this main stream spill over the edge of the Continental Shelf, as defined by the above contour, and enter the North Sea, mainly, according to Robertson (11) and Jacobsen and Jensen (9), by way of the channels between Shetland and the mainland of Scotland. In this connection, however, it is to be observed that Helland-Hansen (10), in his interpretation of the Scottish hydrographical observations for the year 1902, found that the bulk of the Atlantic water which in that year entered the North Sea came by way *of the north of the Shetland Islands*, that is, through the opening between Shetland and Norway.

By means of hydrodynamical calculations it has been demonstrated by the above authorities that the velocity of the surface waters of the Atlantic stream to the west of the Shetlands fluctuates to a certain extent seasonally, and within narrower limits, annually, attaining a maximum of 12 to 16 miles per day in spring or early summer and a minimum of some 5 or 6 miles per day less in autumn or winter.

Similarly derived figures for the North Sea proper are not yet available so far as the present writer is aware, but Fulton's estimate, from his drift-bottle experiments, of the mean rate of the surface drift southwards along the British east coast is only between 2 and 3 miles per day. Similarly, in respect of the Southern Area of the North Sea, where the surface drift is in great measure governed by the influx of a stream of Atlantic water by way of the Straits of Dover, Carruthers, from his analysis of similar data, derived practically the same figure as a measure of the mean rate of flow of surface waters. The discrepancy between the latter figures and those obtained in respect of what might be termed in relation to the Northern Area of the North Sea, the " parent stream " in the Faroe-Shetland Channel, calls for further investigation. In the first place it is to be noted that each of the above authorities makes mention of more or less isolated instances of apparently much greater drift-speeds than 3 miles per day, but both writers have slumped such anomalies with extreme cases of the opposite nature and with intermediate records, the *average* conditions being estimated.

So far, then, as concerns the Northern and Middle Areas of the North Sea the position as regards a knowledge of the general system of surface drift remains somewhat obscure, it having been shown above that the results obtained by several investigators are to some extent contradictory when viewed from the standpoint of their applicability irrespective of season or even year. In fact, a study of the several charts which have been published strongly indicates that a general case will be established, if at all, only on the broadest of lines, and it is a moot point whether such a case would be of great practical value to fishery research in which the question of seasonal variation is an all-important one.

Taking for granted meantime that the above-mentioned indication of more or less wide variation (which may be seasonal, annual, or even intermittent) from mean conditions in the system of surface water drift operating in the Northern and Middle North Sea is true to fact, and considering the same in the nature of a working hypothesis, it would seem that the initial step in an attack on this problem should be the extraction in some detail of all possible information from the records of drift-bottle experiments embracing a number of years—consecutive if possible—and the investigation of relationships between the above areas and those adjacent, particularly the Faroe-Shetland Channel region and the Southern Norwegian Sea.

Source of the Present Data.

The data which form the basis of the present report are derived from extensive experiments with surface drift-bottles, carried out over the Northern and Middle Areas of the North Sea and in the Faroe-Shetland Channel during the five years 1910 to 1914 inclusive.

Immediate Object of the Experiments.

The motif of the above experiments may be put briefly thus :—

" To determine the direction and velocity of the drift of the surface waters in the Northern and Middle North Sea principally, during each of the above-mentioned years, and, if possible, to establish a general case."

Type of Bottle Employed.

The drift-bottle employed in these experiments was a six-ounce, square-section bottle of fairly stout green glass. Before being cast adrift each bottle was weighted by means of lead wound round the neck, sufficient to cause the drifter to float just beneath the sea surface, thereby obviating the direct action of wind upon the bottle itself. Enclosed in each drifter was a small numbered card ($5'' \times 1\frac{1}{2}''$) with directions, printed in English, German, and Scandinavian, as to its disposal by the finder, who was " earnestly requested to enclose it in an envelope, with a note stating when and where it was found, and to post it (without prepaying postage) addressed to The Scientific Superintendent, Fishery Board's Marine Laboratory, Aberdeen." No reward was offered in the case of these pre-war experiments.

Plan of Liberations.

During the above period of five years bottles were dropped overboard, usually in batches of five or ten, occasionally twenty or even twenty-five, at numerous more or less equidistant points along the lines of the cruises undertaken by the research vessel. Continuity of operations over as wide a field as possible was aimed at and the ensuing report will show that this end was remarkably well attained at least within the North Sea.

Method of Compiling Report.

To decide upon a method of working up and presenting the copious data resulting from such extensive experiments has been a matter of no little difficulty.

As each card and note bearing details of time and place of recovery of the particular drifter were received at headquarters, these details were entered in prepared record books and the number of days calculated during which the bottle, *presumably* in the first instance, had been afloat.

The most convenient arrangement of the records for examination purposes had next to be decided upon. In the first place, chart work being anticipated, it was necessary to record with reasonable accuracy the geographical positions of the numerous places where bottles had been recovered. The place-names given by the finders and entered in the record books had to be found with the aid of large-scale Admiralty charts. In this laborious task difficulty was frequently experienced on account of the recurrence in districts widely apart of the same place-name. This was particularly the case in regard to the Norwegian coast. When the post-mark failed to supplement sufficiently the information already given, the fixing of the point of recovery was almost out of the question. In these and other instances where place-names could not be located, valuable and kindly assistance was rendered by foreign colleagues to whom thanks are due.

The records were ultimately set out in the form of a running chronological table, of which the dates of liberation of series of bottles formed the basis. This table is appended to the present report. In connection with it, there are two points which call for remark at this stage, namely, the significance of the numbers in the first column, headed " Station No. " and that of the asterisks against certain of the entries in the last column of the table. Both have special reference to a cartographical analysis of the material which will form the subject of at least one subsequent report. It is mainly in view of this later work, to which they are indispensable, that the present records are herewith published *in extenso*, although their value for purposes of future reference and comparison must also be considered, because similar experiments have been carried out from time to time and on a fairly extensive scale since the year 1920.

It was soon apparent from a cursory survey of the magnitudes denoting the intervals of time between the dates of liberation and recovery of drifters, in conjunction with the relative geographical positions of liberation-stations and stranding-places, that any relationship which might exist between the points of origin and recovery of the drifters was on the whole an obscure one. Even the anticipation of such a relationship being in all probability seasonal did not facilitate much progress. Thus few deductions of any consequence accrued from the construction of charts connecting by straight lines the points of liberation and the corresponding points of recovery of returned bottles.

Also and in view of the fact mainly that liberation-stations were most numerous and widespread, without prearranged and systematised liberation operations at any one point or group of points, the direction-sector method of analysis employed by Carruthers (2) in his examination of the results of similar experiments in the Southern Area of the North Sea was not found to be readily adaptable to the Scottish case.

Another difficulty inherent in the Scottish data lay in the circumstance that, in the great majority of cases of recovery upon Continental and Scandinavian shores particularly, very long periods elapsed between the dates of liberation and recovery of drifters. These, of course, might be explained, at least partially as has hitherto been done, on the assumption that some time probably elapsed between the actual date of a drifter's stranding upon the beach and that of its discovery, were it not that among other things the very persistence of these long-period recoveries would seem to belittle such a hypothesis. Moreover, short-period returns from the same coastal districts, often arising from contemporary experiments initiated over approximately the same sea area, occurred with sufficient frequency on the whole to warrant their more serious consideration than as of the nature of " freak " cases merely. Accordingly, these more or less singular instances have been made the basis of an investigation into the histories of the long-period recoveries, yielding results which indicate very strongly that, in the majority of these latter cases, the time which may have been spent lying upon the beach is practically negligible in relation to the entire period between the dates of liberation and recovery.

For convenience, therefore, this interval (in days) between the dates of liberation and recovery of a drifter will be referred to in the following and subsequent reports as "the period of drift," or simply "the drift-period" of the bottle in question, and, unless ~~where~~ otherwise stated, the magnitude will be accepted as a true drift-period. That is to say, primarily, the probability of the drifter having lain for an appreciable time upon the beach prior to discovery will be neglected. This last assumption will have greater significance when the data come to be examined in much greater detail cartographically, the present report comprising a statistical treatment of the material on fairly broad lines, thus forming an introduction to the later analysis.

The investigation of possible relationships between wind and surface water drift does not form part of the present analysis. It is obvious in view of the wide field over which the Scottish experiments were inaugurated that such a study presents a very formidable problem, assuming at the outset that suitable wind data are available, covering at least the entire field outlined in Figure 1. The results which have been achieved from a study of the data as it stands are such that it has been considered desirable to publish these presently, leaving the investigation of inter-relationships between wind and drift to a later date.

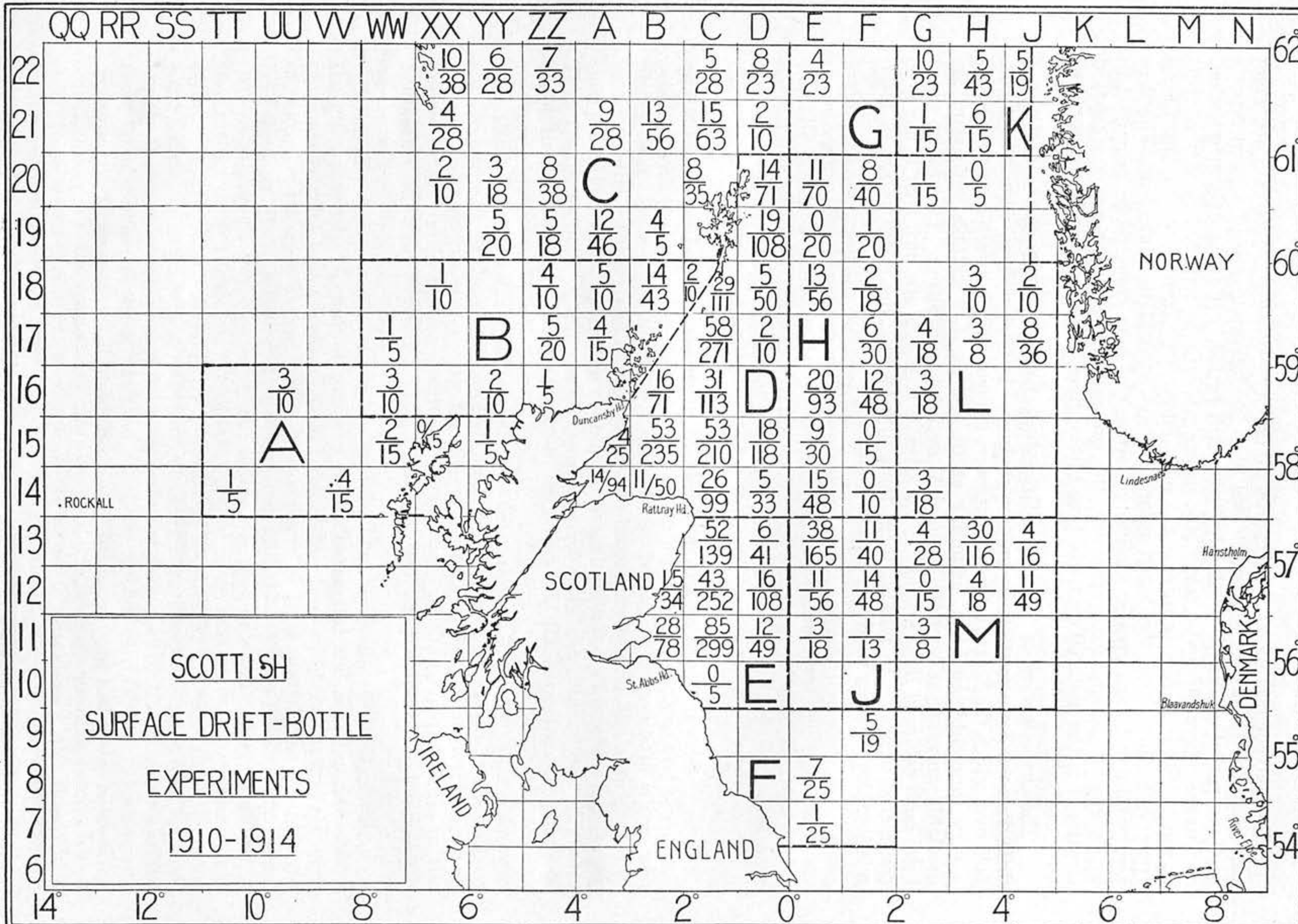

SCOTTISH
SURFACE DRIFT-BOTTLE
EXPERIMENTS
1910-1914
NORWAY
SCOTLAND
ENGLAND
IRELAND
DENMARK
ROCKALL
Duncansby Hd.
Rattray Hd.
St. Abbs Hd.
Lindesnaes
Hanstholm
Blaavandshuk
River Elbe

Figure 1.

STATISTICAL ANALYSIS OF THE DATA.

Introductory.

On the chart, Figure 1, there is shown the entire field covered by the Scottish surface drift-bottle liberation operations during the period between the years 1910 and 1914 inclusive. The total number of bottles set adrift within the area represented by a square on the chart is denoted by the denominator of the fraction in the square, the numerator representing the corresponding number of recoveries subsequently effected. Each square is defined by the letter heading the column in which it occurs, followed by the number, to be found on the left of the chart, specifying the appropriate row: thus A17, F14, etc.

During the above period of five years a total of 4825 bottles was liberated over the Northern and Middle Areas of the North Sea and the portion of the North-Eastern Atlantic Ocean bounded by the curve: Orkney and Shetland Islands—Faroe Islands—Rockall—the west and north coasts of Scotland north of latitude 57° 30′ N.

Recoveries to the number of 1096 bottles took place on British, Dutch, German, Danish, Swedish, Norwegian, Russian, and Faroe coasts, or at sea, after periods of drifting ranging from a few days to several years.

Of the total number of bottles returned, 45.5 per cent. stranded, or were picked up, within 100 days of the date of liberation. In the great majority of cases these recoveries were effected upon British coasts, near to which the bulk of the work of liberating drifters was carried out, as shown by a comparison of the figures on the chart. In respect of 13 bottles, drift-periods of over 1000 days were registered, the longest period of all being 2217 days between the dates of liberation and recovery.

General.

Obviously the first point of attack on the data at our disposal is the investigation of any broad relationships which may exist between the regions of liberation and recovery of drifters. A rapid cartographical survey of the material indicated that, in regard to locality, the distribution of recoveries were best studied by marking off into sections the entire coast-line embraced by the numerous stranding-places. The following are the coastal sections and other regions which have been suggested by experience as best differentiating the several classes of recoveries :—

(1) West coast of Scotland and the Outer Hebrides.

(2)* North coast of Scotland and the western shores of the Orkney and Shetland Islands.

(3)* Eastern shores of the Orkney and Shetland Islands, including Fair Isle.

(4) The shores of the Moray Firth; terminal points, Duncansby Head and Rattray Head.

(5) The Scottish coast between Rattray Head and St. Abbs Head.

(6) Between St. Abbs Head and the point on the Yorkshire coast on latitude 54° N.

(7) The English coast south of the point on latitude 54° N.

(8) Between Texel Island, Holland, and the mouth of the River Elbe, Germany.

(9) Between the mouth of the River Elbe and Blaavandshuk, Denmark.

(10) Between Blaavandshuk and Hantsholm, the north-west corner of Jutland.

* In view of the disposition, particularly of the Orkney Islands, instances occur in which it is difficult to classify the recovery as belonging to either Section 2 or Section 3. The point was settled by classifying according to the position relative to the Islands of the liberation-station, i.e. if the liberation-station lay to the west, the doubtful case was included in Section 2, and if the point of origin was to the eastwards or north-eastwards of the Island group the recovery in question was allotted to Section 3.

(11) Eastwards of a line joining Hantsholm and Lindesnaes, Norway, *i.e.* within the Skagerak.
(12) The south-west Norwegian coast between Lindesnaes and the point on latitude 62° N., where the bold contour of the Norwegian coast takes a more or less sharp bend towards the north-east.
(13) The Norwegian coast between latitudes 62° N. and 70° N.
(14) The Norwegian coast north of latitude 70° N.
(15) At sea.
(16) On the Faroe Islands

Upon consideration it will be further evident that, as the entire area over which liberations were carried out is so vast, little purpose would be served by treating these in entirety. After numerous small adjustments the Regional Liberation Areas A, B, C . . . M, defined on the chart, Figure 1, by heavy broken lines, were finally selected as the result of certain features which arose in course of the preliminary survey of the material.

In accordance with the above details Table I. was constructed.

TABLE I.*

Liberations.		Recoveries.																
Regional Area (Fig. 1).	No. of Drifters.	Frequency Distribution.																Totals.
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
A	55	4	3	2	—	—	—	—	—	—	—	2	—	—	—	—	—	11
B	148	—	11	8	2	—	1	—	—	—	—	5	2	12	1	—	—	42
C	525	—	9	21	—	—	—	—	—	—	—	2	4	75	9	3	3	126
D	1669	—	18	64	27	29	21	2	—	19	23	66	27	51	3	7	1	358
E	1005	—	—	—	1	85	74	1	1	10	9	30	10	28	3	5	—	257
F	69	—	—	—	—	—	—	—	—	—	1	11	1	—	—	—	—	13
G	23	—	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	4
H	488	—	—	10	—	2	1	—	—	3	12	32	13	20	2	2	—	97
J	340	—	—	—	—	4	—	2	1	3	8	28	9	21	1	1	—	78
K	115	—	—	9[1]	—	—	—	—	—	1	—	4	3	8	2[2]	—	—	27
L	138	—	—	—	—	—	—	—	—	—	2	7	12	5	—	1	—	27
M	250	—	—	—	—	—	—	—	1	—	9	33	4	7	1	1	—	56
Totals	4825	4	41	118	30	120	97	5	3	36	64	220	58	227	22	20	4	1096

[1] One bottle recovered on Fair Isle. [2] One bottle recovered on the Murman coast.

It may readily be ascertained from the above table that the greater proportion, nearly ~~namely~~ 60 per cent., of the bottles returned from the experiments under review came from Scandinavian ~~or~~ other Continental shores, principally the former.

Dealing firstly with some of the more unique features of Table I., it is to be observed that only 20 bottles out of the total 1096 returned were picked up at sea. Although *prima facie* it might appear to be otherwise, the fact is that a number of these sea recoveries are of little if any greater value towards the attainment of the object of the experiments than many of the "beached" bottles. Some of them were

* For convenience in printing only the numerals signifying coastal sections and other regions of recovery head the main columns of this Table, and all subsequent tables in this report with the exception of Nos. II. and XII.

picked up in such proximity to land that the probability of their having been refloated from the beach on a high tide cannot be altogether ignored. Others, generally imperfect drifters, were trawled from the sea floor, where it cannot be definitely known how long they may have lain prior to catchment. In these instances, as a rule, information concerning direction of drift only is derivable. Nevertheless, this factor obviously will be of some assistance in the investigation of the histories of bottles from contemporary liberations which have travelled farther and been brought up ultimately on shore.

Occasionally, sea recoveries yield an estimate also of the velocity of the surface water drift, from a consideration of the drift-period registered and the linear distance between the points of liberation and recovery. It might even be argued that when a drifter is picked up after a certain time from the surface waters of the open sea, a fairly accurate estimate of the direction *and* velocity of the drift should be possible, the factor of uncertainty regarding the actual time taken to arrive at the point of recovery being presumably eliminated in those instances. But, as a later and more detailed analysis will show, the phenomenon of closed systems of gyratory surface water movement very often obviates any assumption of a more or less direct relation between the linear distances presumably covered and the recorded drift-periods and this holds even in the above cited cases of recovery of drifters while still afloat in the surface waters of the open sea.

The paucity of entries in columns 7 and 8 of Table I. is a noticeable feature. Only eight bottles are known to have stranded on North Sea shores south of latitude 54° N., five upon the British coast, and three on Continental shores. The southernmost British coast recovery took place at Grainthorpe Sluice, Lincolnshire (latitude 53° 14′ N.), and the most westerly Continental stranding-place was on the Dutch Island of Texel in practically the same latitude. From these facts it may be inferred with safety that no bottle from the Scottish liberations found its way into the Southern Bight of the North Sea.

Four of the above drifters, three of them British and one a Continental recovery, emanated from the Regional Areas D and E, which, in view of Fulton's results, is not surprising. On the other hand, three of the total eight bottles recovered south of latitude 54° N. were put into the sea at a point in Area J, and still more unique, one in Area M. Consultation of the chronological table of liberations elicits the important information that the last-mentioned four bottles were despatched in the same season of the same year, namely in May and June 1913. Further search established the fact that, with the exception of the two bottles originating in the Regional Area D, the remaining six of the total eight all pertained to the experiments of the above year, the three British recoveries therefrom stranding during the month of October, and the three Dutch island returns during the previous August and September. There would appear, then, to have been something singular about the surface water movement of the North Sea during the year 1913. Further investigation on this point must be left over to an ensuing study of the present data on a cartographical basis.

Before passing to the consideration of other features of the above table, it is to be observed that, in regard to the proportions of drifters recovered upon British and Continental coasts south of latitude 54° N., Fulton's results (3, *b* and *c*) differ markedly from those of the experiments now under review. In his relatively short series of experiments between September 1894 and December 1896, comprising the liberation during this period in the North Sea north of latitude 55° N. and to the west of the Orkney and Shetland Islands, of 1834 surface drift-bottles and 1364 wooden slips, Fulton records the recovery of eleven of the former upon Yorkshire and Lincolnshire coasts south of latitude 54° N. and of seven drifters, either bottles or wooden slips, upon German and Dutch coasts west of longitude 8° E. The corresponding figures are as follows :—

	No. of Drifters Liberated.	Percentage recovered on British Coast S. of Lat. 54° N.	Percentage recovered on Continental Coasts W. of mouth of River Elbe.
Fulton's records . .	3198	0·34	0·22
Present records . .	4825	0·10	0·06

Fulton's British coast recoveries, with one exception, were found during the month of February 1895, but the seven Continental returns were not so consistent, one being picked up in August 1895, five in June, July, and August 1896, and the last in February 1897. So that, while in the light of the later and more extensive results the period embraced by Fulton's experiments seems to have been on the whole an abnormal one, so far as the drift of the North Sea surface water was concerned, the earlier data no doubt suggested the Dutch islands as being the normal southerly limit of the cyclonic system governing the North Sea surface-water movement.

Table I. shows that barely 38 per cent. of the total returns were from points on the British coasts. In view of the fact that more than half of the total number of bottles liberated during the five years in question were set adrift within the Regional Areas D and E, this return is smaller than might reasonably be expected, and becomes less significant when at least a fraction of the 728 drifters despatched within the Regional Areas A, B, and C is considered, for not only did a number of these strand upon the British coast, or among the neighbouring island groups, but a further number undoubtedly coursed for a time within the North Sea proper, as instanced by the entries in at least columns 11 and 12 of Table I. Furthermore, it is to be noted that not all the British coast recoveries originated within even the above-mentioned areas. This point will be further discussed in the sequel.

The majority of the returned drifters were found on German, Danish, Swedish, and Norwegian coasts. One-third of these stranded within the Skagerak. The proportion which *entered* the Skagerak is doubtless greater than one-third, since many of the drifters found upon the Norwegian coast to the north and west of Lindesnaes indicate, by a comparison of their drift-periods with those of recoveries upon Skagerak shores, that they, too, passed along the north-west Jutland coast, but were later emitted from this arm of the North Sea under the influence of the strong drift from the Baltic, operative along the south Norwegian coast during certain seasons of the year.

The Faroe-Shetland Channel Region.

Passing to the more particular examination of the figures in respect of Regional Areas, the first point to be noted is the considerable number of recoveries effected on the *eastern* shores of the Orkney and Shetland Islands from liberations carried out over Regional Areas A, B, and C. The routes by which these drifters arrived at their respective stranding-places, whether by way of the *north* of the Shetlands, or by the Channel between Shetland and Orkney, if these routes can be estimated, will form an important subject of investigation later.

Attention has already been drawn to the fact that, from operations in the above-mentioned Regional Areas, a number of bottles must have cruised for a time within the North Sea, as indicated by the resulting Skagerak and south Norwegian coast recoveries. It may be of importance later to note from Table I. that no bottle originating to the west of the Orkney and Shetland Islands was recovered upon Continental coasts south of Hantsholm, the north-west corner of Jutland, and only one was returned from a point on the British east coast south of Rattray Head, Aberdeenshire. The argument for a general case, however, is vitiated by the fact that liberation operations were not conducted within these areas during all four seasons of the year as shown by the following table :—

TABLE II.
Monthly Frequency of Liberations.

Regional Area.	Year.	Month.												No. of Drifters.
		Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	
A	1910	—	—	—	—	—	—	—	45	—	—	—	—	45
	1911	—	—	—	—	—	—	—	10	—	—	—	—	10
B	1910	—	—	—	—	40	—	—	25	—	—	—	—	65
	1911	—	—	—	—	5	—	—	45	—	—	—	—	50
	1912	—	—	—	—	—	8	—	—	—	—	—	—	8
	1913	—	—	—	—	—	—	10	—	—	—	—	—	10
	1914	—	10	—	—	—	5	—	—	—	—	—	—	15
C	1910	—	—	—	—	150	—	—	75	—	—	—	—	225
	1911	—	—	—	—	75	—	—	20	—	—	—	—	95
	1912	—	—	—	—	72	48	—	—	—	—	—	—	120
	1913	—	—	—	—	—	—	40	—	—	—	—	—	40
	1914	—	10	—	15	—	20	—	—	—	—	—	—	55
D	1910	—	—	—	71	86	—	—	—	—	—	80	—	237
	1911	—	60	10	125	20	40	35	5	40	57	—	—	392
	1912	—	—	—	—	40	95	28	—	16	—	24	—	203
	1913	—	—	140	140	50	60	—	—	—	—	—	—	390
	1914	—	152	5	100	—	125	65	—	—	—	—	—	447
E	1910	—	—	—	—	31	82	—	—	—	10	20	25	168
	1911	—	25	70	10	26	10	31	—	80	5	—	—	257
	1912	—	—	58	10	10	16	46	—	48	20	12	—	220
	1913	—	—	20	100	80	40	—	—	—	—	25	—	265
	1914	—	—	—	—	—	45	50	—	—	—	—	—	95
F	1913	—	—	—	—	—	—	—	—	—	69	—	—	69
G	1910	—	—	—	—	10	—	—	—	—	—	—	—	10
	1911	—	—	—	—	5	—	—	—	—	—	—	—	5
	1912	—	—	—	—	8	—	—	—	—	—	—	—	8
H	1910	—	—	—	—	75	—	—	—	30	—	—	—	105
	1911	—	30	—	—	35	—	10	45	—	—	—	—	120
	1912	—	—	—	—	40	8	—	—	—	—	—	—	48
	1913	—	—	—	10	10	20	5	—	—	—	—	—	45
	1914	—	20	—	50	—	50	50	—	—	—	—	—	170
J	1910	—	—	—	—	—	35	—	—	—	—	—	15	50
	1911	—	25	—	—	10	—	16	—	—	—	—	—	51
	1912	—	—	—	—	—	24	—	20	—	—	—	—	44
	1913	—	—	—	—	30	30	—	135	—	—	—	—	195
K	1910	—	—	—	—	50	—	—	—	—	—	—	—	50
	1911	—	—	—	—	25	—	—	—	—	—	—	—	25
	1912	—	—	—	—	35	—	—	—	—	—	—	—	35
	1913	—	—	—	—	—	—	5	—	—	—	—	—	5
L	1910	—	—	—	—	10	—	—	—	—	—	—	—	10
	1911	—	—	—	—	5	—	—	—	—	—	—	—	5
	1912	—	—	—	—	40	8	—	—	—	—	—	—	48
	1913	—	—	—	—	—	10	5	—	—	—	—	—	15
	1914	—	—	—	60	—	—	—	—	—	—	—	—	60
M	1910	—	—	—	79	—	65	—	—	—	—	—	—	144
	1911	—	—	—	—	—	—	24	—	—	—	—	—	24
	1912	—	—	—	—	—	32	—	—	—	—	—	—	32
	1913	—	—	—	—	—	—	50	—	—	—	—	—	50
Totals	.	—	332	303	770	1073	926	420	425	214	161	161	40	4825

The evidence in favour of bottles from Regional Areas A, B, and C having entered the North Sea is confined to the results of liberations carried out during the months between April and August inclusive, that is, practically during summer months only.

Regional Liberation Area A.

The only observation to be made at this stage in respect of the results pertaining to the Regional Area A is that the five entries in columns 2 and 3 of Table I. relate solely to recoveries upon the Orkney Islands, no bottle from these experiments having been found anywhere in the vicinity of the Shetland group. The experiments, however, are so meagre that too much stress cannot be laid upon this point.

Regional Liberation Area B.

TABLE III.

Liberations.		Recoveries.																
Month and Year.	No. of Drifters.	Frequency Distribution.																Totals.
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
May 1910	40	—	3	5	2	—	1	—	—	—	—	1	—	3	—	—	—	15
Aug. 1910	25	—	1	—	—	—	—	—	—	—	—	3	2	2	—	—	—	8
May 1911	5	—	—	1	—	—	—	—	—	—	—	1	—	—	—	—	—	2
Aug. 1911	45	—	3	—	—	—	—	—	—	—	—	—	—	3	1	—	—	7
June 1912	8	—	1	2	—	—	—	—	—	—	—	—	—	—	—	—	—	3
July 1913	10	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—	—	4
Feb. 1914	10	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
June 1914	5	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Totals	148	—	11	8	2	—	1	—	—	—	—	5	2	12	1	—	—	42

Table III. shows that the recoveries effected from experiments over Regional Area B were equally divided between British and Scandinavian coasts. In connection with the former it is to be observed that, of the eleven bottles returned from the coastal Section 2, four stranded on western shores of the Shetland Islands, there being no recovery effected upon the eastern side of the group. The points of origin of these four drifters, belonging to liberations of the months of August 1911, February and June 1914, fell within the adjacent rectangles A18 and B18, and the portion of C18 within the eastern boundary of Regional Area B. At the same time six of the Orkney Island returns originated in these same small rectangles, as also the isolated instance of the recovery on the British east coast south of Rattray Head. But the remaining nine drifters found on the Orkney shores came from points in Regional Area B, south of latitude 59° 30′ N., from which no Shetland Island strandings were recorded. Thus it is indicated that, in the neighbourhood of the above latitude in the north-eastern corner of the area in question, there may take place a division in a more or less easterly flowing surface current, part flowing northwards along the western side of Shetland and part deviating southwards into the North Sea between Fair Isle and the Orkneys. That this phase is not limited to summer months only is demonstrated by the two returns from Shetland resulting from the liberation operations in this area in the month of February 1914.

Regarding the Continental recoveries enumerated in Table III. it is apparent that at least one-third of the drifters, of which the broad histories are known, cruised for a time within the North Sea, stranding ultimately on Skagerak shores, or on the south-west Norwegian coast. The probability is that a proportion at least of the thirteen drifters found on the Norwegian coast north of latitude 62° N. also emanated from the North Sea. The seven drifters definitely known to have entered the North Sea did not all originate in the same small region of Area B, the rectangle WW16 being represented in columns 11 and 12 of Table III. in relation to the liberations carried out there in August 1910. In view of the fact that similar returns were made in respect of Regional Area A this was only to be expected.

Regional Liberation Area C.

TABLE IV.

Liberations.		Recoveries.																
Month and Year.	No. of Drifters.	Frequency Distribution.																Totals.
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
May 1910	150	—	4	16	—	—	—	—	—	—	—	1	—	15	1	1	2	40
Aug. 1910	75	—	—	—	—	—	—	—	—	—	—	1	1	17	1	—	—	20
May 1911	75	—	—	1	—	—	—	—	—	—	—	—	2	23	1	—	—	27
Aug. 1911	20	—	—	—	—	—	—	—	—	—	—	—	—	2	1	—	—	3
May 1912	72	—	2	—	—	—	—	—	—	—	—	—	—	4	2	3	—	11
June 1912	48	—	1	—	—	—	—	—	—	—	—	—	—	5	2	—	—	8
July 1913	40	—	—	4	—	—	—	—	—	—	—	—	—	5	—	—	—	9
Feb. 1914	10	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	2
April 1914	15	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1
June 1914	20	—	2	—	—	—	—	—	—	—	—	—	—	2	1	—	—	5
Totals	525	—	9	21	—	—	—	—	—	—	—	2	4	75	9	4	2	126

Barely one-quarter of the total number of recoveries resulting from experiments begun over the Regional Area C stranded upon British coasts—all of them upon the Orkney and Shetland Islands. The three bottles returned from Orkney had drifted from the rectangular areas XX22 and YY22. Provided it is possible from the accompanying records to estimate them, the routes followed by these three drifters should prove interesting. The remaining 27 " British " bottles were found among the Shetland Islands, nine on the west side and eighteen on the east. These did not all proceed from the rectangular areas adjacent to the Islands, the rectangles YY19, and ZZ20 to the west and D22 to the north being represented in the entries in column 3 of Table IV. The evidence as to routes indicates a general course from the west to the east side of the Shetlands by way of the north of these Islands.

The bulk of the returned drifters pertaining to Regional Area C stranded at points on the Norwegian coast north of latitude 62° N. A further six bottles, at least, undoubtedly entered the North Sea, and it may be of importance to note that two of these, one returned from the Skagerak and the other from the south-west Norwegian coast, originated to the west of longitude 4° W., namely in rectangle ZZ22, from which region it might reasonably be expected, in the light of previous knowledge, that drifters would proceed almost directly towards the Norwegian coast on the northern fringe of the Norwegian Atlantic Stream. Both the above bottles belonged to the series liberated in August 1910.

The two recoveries upon the Faroe Islands from the May 1910 experiments, as also the sea recovery to the west of the group, are interesting in that they point to the existence of a southerly flowing current to the east of the Islands and a northerly flowing drift on the west side, probably continuous and enclosing the Island group in an anticyclonic eddy.

Regional Liberation Area D.

TABLE V.

Liberations.		Recoveries.																
Month and Year.	No. of Drifters.	Frequency Distribution.																Totals.
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
April 1910	71	—	—	—	—	3	3	—	—	1	3	4	—	—	—	2	—	16
May 1910	86	—	—	2	1	1	2	2	—	15	1	—	—	—	—	2	—	26
Nov. 1910	80	—	—	—	—	8	—	—	—	—	2	5	—	—	—	—	—	15
Feb. 1911	60	—	—	—	—	—	—	—	—	—	4	9	—	1	—	—	—	14
Mar. 1911	10	—	—	—	5	—	—	—	—	—	—	—	—	—	—	—	—	5
April 1911	125	—	—	—	6	1	—	—	—	—	1	9	11	6	—	—	—	34
May 1911	. 20	—	—	—	1	—	—	—	—	—	—	4	—	—	—	—	—	5
June 1911	40	—	—	—	—	—	—	—	—	—	2	3	2	1	—	—	—	8
July 1911	35	—	—	—	—	—	—	—	—	—	—	4	—	—	—	—	—	4
Aug. 1911	5	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	1
Sept. 1911	40	—	—	—	2	—	1	—	—	—	—	—	—	4	—	—	—	7
Oct. 1911	57	—	2	6	3	—	—	—	—	—	—	—	—	1	—	—	—	12
May 1912	40	—	—	—	—	6	2	—	—	2	—	2	—	—	—	—	—	12
June 1912	95	—	1	1	2	2	2	—	—	—	3	5	—	1	—	—	—	17
July 1912	28	—	—	—	2	—	—	—	—	—	2	1	1	—	—	—	—	6
Sept. 1912	16	—	1	—	—	1	—	—	—	—	—	2	1	1	—	—	—	6
Nov. 1912	24	—	—	—	—	—	—	—	—	—	—	—	1	3	1	—	—	5
Mar. 1913	140	—	2	28	4	—	—	—	—	—	—	—	—	3	—	1	—	38
April 1913	140	—	4	20	1	3	—	—	—	—	—	—	2	6	—	1	—	37
May 1913	50	—	—	—	—	—	—	—	—	—	—	2	1	1	—	—	—	4
June 1913	60	—	—	—	—	4	11	—	—	—	1	4	1	—	—	—	—	21
Feb. 1914	152	—	5	2	—	—	—	—	—	—	1	3	5	11	—	—	—	27
Mar. 1914	5	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1
April 1914	100	—	1	1	—	—	—	—	—	—	1	5	1	1	—	—	—	10
June 1914	125	—	1	4	—	—	—	—	—	1	1	4	—	6	1	—	1	19
July 1914	65	—	1	—	—	—	—	—	—	—	1	—	—	5	—	1	—	8
Totals	1669	—	18	64	27	29	21	2	—	19	23	66	27	51	3	7	1	358

Somewhat less than half the total number of recoveries resulting from the liberation of 1669 surface drifters over the Regional Area D stranded upon British coasts. As has already been stated a larger proportion might well have been looked for in view of the proximity to land of the majority of the liberation-stations in this area.

A notable blank in the above tabulation of British coast recoveries occurs in respect of the experiments of the months of June, July and August 1911, indicating that, immediately following upon the operations pertaining to these months, there was little if any set of the surface water in towards the British east coast.

It will be observed from Table V. that no less than eighteen bottles found their way to the *western* shores of the Orkney and Shetland Islands—in one case to the north coast of the mainland of Scotland. These recoveries were not confined in origin to the liberations of a particular year, nor to those carried out in any one season. There must then have been operative at certain times a drift of surface water, *leaving* the North Sea and flowing westwards or north-westwards through the channels between Shetland and the mainland of Scotland into the Regional Area B.

Of the total 161 " British " recoveries, the proportion returned from the eastern shores of Orkney and Shetland is extraordinarily large in view of the general system of surface drift over the region under examination, as propounded by Fulton (3, *b* and *c*) and Robertson (11), and suggests probably some modification of the findings of these investigators. A close scrutiny of the chronological table (Appendix) reveals the important fact that 67 of the 82 drifters entered under headings 2 and 3 of Table V. stranded at points not only to the west, but to the *north* of their corresponding points of origin. This phenomenon again does not appear to have been confined to the experiments initiated during a particular season of the year. It is further to be noted that some of the bottles found on Orkney and even Shetland shores were set adrift well within the Moray Firth, pointing to the existence at certain times of a surface drift *northwards* from that region along the shores of the Orkney and Shetland Islands. This point will be further amplified in the cartographical analysis of the data.

In consideration of the scope of the liberation operations carried out in the waters of the Moray Firth, as defined by the sea area westwards of a line joining Duncansby and Rattray Heads, the total number of drifters picked up on the shores of the Firth is small. This is probably connected in some way with the above indicated features of the surface drift over the Regional Area D. Moreover, four of the 27 drifters returned from places on the Moray Firth coast-line originated at points outside the Firth altogether. Of the 388 bottles put overboard westwards of the above-mentioned imaginary line, 78 were ultimately returned, but only 23 of these stranded within the Firth, the bulk of the others crossing the North Sea to Danish, Swedish, and Norwegian coasts.

Resulting from the experiments of the month of May 1910 within the area under present examination, it is observed that two drifters stranded on the British east coast south of latitude 54° N. The remaining three of the total of five bottles returned from this coastal district during the entire period of the experiments belonged, as has already been pointed out, to operations conducted during the month of June 1913, in which season of that particular year apparently something abnormal took place in regard to the surface water movement of the North Sea. The 1910 results, even though they be somewhat unique, do not warrant the assumption of entirely abnormal characteristics of drift as do those of 1913, as, from the original data, a comparison of the positions of the respective liberation-stations will at once make clear, having in mind Fulton's chart.

In contrast to the results pertaining to Regional Areas A, B, and C, Table V. shows that a fair number of drifters from Area D stranded upon western Danish and Schleswig-Holstein coasts, and also a greater proportion of bottles were returned from within the Skagerak area.

Regional Liberation Area E.

TABLE VI.

Liberations.		Recoveries.																
Month and Year.	No. of Drifters.	Frequency Distribution.																Totals.
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
May 1910	31	—	—	—	—	8	3	—	—	—	—	—	—	—	—	—	—	11
June 1910	82	—	—	—	—	6	21	—	—	3	—	—	—	—	—	3	—	33
Oct. 1910	10	—	—	—	—	6	—	—	—	—	—	—	—	—	—	—	—	6
Nov. 1910	20	—	—	—	—	9	—	—	—	—	—	—	—	—	—	—	—	9
Dec. 1910	25	—	—	—	—	8	—	—	—	—	1	4	—	—	—	—	—	13
Feb. 1911	25	—	—	—	—	—	1	—	—	—	2	4	—	—	—	—	—	7
Mar. 1911	70	—	—	—	—	14	12	—	—	—	—	2	—	3	1	—	—	32
April 1911	10	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—	—	4
May 1911	26	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1
June 1911	10	—	—	—	—	—	—	—	—	—	1	—	—	1	—	—	—	2
July 1911	31	—	—	—	—	—	—	—	—	—	—	2	—	—	1	—	—	3
Sept. 1911	80	—	—	—	—	—	7	—	—	—	—	—	1	10	—	—	—	18
Oct. 1911	5	—	—	—	—	4	—	—	—	—	—	—	—	—	—	—	—	4
Mar. 1912	58	—	—	—	—	3	—	—	—	—	—	2	1	—	—	—	—	6
April 1912	10	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	2
May 1912	10	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	1
June 1912	16	—	—	—	—	—	4	—	—	4	1	—	—	—	—	—	—	9
July 1912	46	—	—	—	—	3	2	—	—	2	2	—	—	—	—	—	—	9
Sept. 1912	48	—	—	—	—	1	—	—	—	—	—	8	2	—	—	—	—	11
Oct. 1912	20	—	—	—	—	14	—	—	—	—	—	1	—	—	—	—	—	15
Nov. 1912	12	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	3
Mar. 1913	20	—	—	—	1	1	—	—	—	—	—	1	—	1	—	—	—	4
April 1913	100	—	—	—	—	6	4	—	1	—	—	2	1	—	—	1	—	15
May 1913	80	—	—	—	—	2	5	—	—	—	—	2	4	—	—	—	—	13
June 1913	40	—	—	—	—	—	8	1	—	—	—	—	—	—	—	—	—	9
Nov. 1913	25	—	—	—	—	—	—	—	—	1	2	—	—	—	—	—	—	3
June 1914	45	—	—	—	—	—	—	—	—	—	—	1	1	5	1	—	—	8
July 1914	50	—	—	—	—	—	—	—	—	—	—	1	—	5	—	—	—	6
Totals	1005	—	—	—	1	85	74	1	1	10	9	30	10	28	3	5	—	257

In the case of the results of experiments conducted over Regional Area E between 1910 and 1914, just over one-half of the total recoveries recorded took place upon the British coast, all except one south of Rattray Head, Aberdeenshire. Thus the present results would at first sight appear to be in greater conformity with those of Fulton in this area than we have seen to be the case in the above examination of the results pertaining to the Regional Area D. The isolated instance, however, of that drifter from the Region E having reached and stranded within the Moray Firth raises the question as to whether all bottles recovered upon the British coast from liberation-stations in Regional Area E were found at places to the south of the corresponding points of origin, which was, in fact, one of the results of the 1894-1896 experiments over the area in question, with the exception (noted by Fulton) of those of December 1896. A particular examination of the records shows that no fewer than 43 drifters were recovered to the north of the corresponding points of liberation, and this time there does appear to have been a connection between the season during which liberation operations were conducted and the loci of recovery of those drifters found upon the British coast. The months involved were mainly those of the first and last quarters of the year.

The lack of British coast recoveries from experiments begun during the months of May, June and July 1911 should again be noted (cf. Table V.), and in contrast to this the relatively large number of drifters apparently driven in towards the

British coast following upon liberations during May and June, October to December 1910, and again during March 1911.

The returns of drifters which had crossed the North Sea from the Regional Area under present examination are similar to those from Area D, in that the greater proportion of these recoveries took place within the Skagerak area and on the Norwegian coast between latitudes 62° N. and 70° N.

Table VI. also contains two of the unique records of the entire data, namely, the recoveries south of latitude 54° N., one on the British side and the other on the Continent. These have already been commented upon.

Regional Liberation Area F.

The Regional Area F was visited for the purpose of setting afloat surface drift-bottles only in the month of October 1913 and, as shown in Table I., eleven of the thirteen returns from these experiments stranded within the Skagerak, no bottle being recorded as having beached anywhere on the British coast.

Regional Liberation Area G.

During the month of May in each of the years 1910, 1911, and 1912, a series of drifters was despatched from a point in Regional Area G. Table I. indicates that only four recoveries resulted from these experiments. All four, which took place on the shores of Shetland, belonged to the series set adrift in May 1912, no returns whatever being made from the earlier experiments.

Regional Liberation Area H.

TABLE VII.

Liberations.		Recoveries.																
Month and Year.	No. of Drifters.	Frequency Distribution.																Totals.
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
May 1910	75	—	—	4	—	2	1	—	—	1	3	—	—	—	—	2	—	13
Sept. 1910	30	—	—	3	—	—	—	—	—	—	—	2	—	4	—	—	—	9
Feb. 1911	30	—	—	—	—	—	—	—	—	2	2	10	2	2	—	—	—	18
May 1911	35	—	—	—	—	—	—	—	—	—	3	2	1	3	—	—	—	9
July 1911	10	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1
Aug. 1911	45	—	—	—	—	—	—	—	—	—	1	5	4	2	—	—	—	12
May 1912	40	—	—	—	—	—	—	—	—	—	1	5	2	1	—	—	—	9
June 1912	8	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	2
April 1913	10	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1
May 1913	10	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	2
June 1913	20	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	2
July 1913	5	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	2
Feb. 1914	20	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	2
April 1914	50	—	—	—	—	—	—	—	—	—	2	3	—	2	—	—	—	7
June 1914	50	—	—	1	—	—	—	—	—	—	—	—	2	—	1	—	—	4
July 1914	50	—	—	2	—	—	—	—	—	—	—	1	—	—	1	—	—	4
Totals	488	—	—	10	—	2	1	—	—	3	12	32	12	21	2	2	—	97

The recovery upon Shetland and Orkney shores of drifters set afloat within the Regional Area H would at first sight appear to be irreconcilable with Fulton's well-known diagrammatic representation of the general system of surface drift over the Northern North Sea area. Whether or not this is the case as regards the years 1910 and 1914 cannot be investigated conveniently at this stage, but will form an important part of the cartographical analysis of the data.

It is to be observed, however, that the ten drifters concerned did not all proceed initially from the same quarter of the Regional Area under present examination. Those resulting from the experiments initiated during May 1910 and June and July 1914 were floated north of latitude 60° N. in the rectangles E.20, F.19, and F.20. Also, one of the sea recoveries belonging to a series of bottles liberated during May 1910 and picked up afloat some 36 miles south by east of Bressay Island, Shetland, originated in the rectangle E.18. But the three bottles returned, one from Shetland and two from Orkney, as a result of the September 1910 liberations, were put into the sea at points in rectangle E.15, considerably farther south in the Regional Area than the others above-mentioned.

Relative to the non-British coast recoveries from the experiments here considered the only point of note is, once again, the large proportion of returns from the Skagerak region.

Regional Liberation Area J.

TABLE VIII.

Liberations.		Recoveries.																
Month and Year.	No. of Drifters.	Frequency Distribution.																Totals.
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
June 1910	35	—	—	—	—	—	—	—	—	—	2	3	—	1	—	—	—	6
Dec. 1910	15	—	—	—	—	—	—	—	—	—	2	5	—	—	—	—	—	7
Feb. 1911	25	—	—	—	—	—	—	—	—	—	4	10	—	—	—	—	—	14
May 1911	10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
July 1911	16	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
June 1912	24	—	—	—	—	—	—	—	—	3	—	3	—	—	—	—	—	6
Aug. 1912	20	—	—	—	—	—	—	—	—	—	—	3	3	—	—	—	—	6
May 1913	30	—	—	—	—	—	—	—	1	—	—	2	2	—	—	—	—	5
June 1913	30	—	—	—	—	—	—	2	—	—	—	—	—	—	—	1	—	3
Aug. 1913	135	—	—	—	—	4	—	—	—	—	—	2	4	20	1	—	—	31
Totals	340	—	—	—	—	4	—	2	1	3	8	28	9	21	1	1	—	78

From all experiments begun in the Regional Area J, excepting those of the year 1913, returns were most frequently made from the Skagerak area as shown in Table VIII.

The only British coast recoveries recorded in respect of liberations within this area were those which had been set adrift during this exceptional year. The peculiar features of the year 1913 have already been remarked upon in the discussion of the Table I. The above table (Table VIII.) contains three of the instances there cited, namely the entries in columns 7 and 8.

The liberations of the month of August 1913 were carried out, on different days, from one and the same point—the intersection of latitude 57° N. with the prime meridian. In view of the unique results arising from the experiments of May and June of the same year, the distribution of the recoveries from the August 1913 experiments is peculiar, in that four of the 31 returns came from points on the mid-east Scottish coast to the west of the liberation-station, while the main bulk, to the number of 21 bottles, failed to strand within the North Sea at all, only two bottles being found within the Skagerak and four on the south-west Norwegian coast between Lindesnaes and latitude 62° N. Further investigation of this phenomenon must be left over meantime.

In spite of the fact that, as Table VIII. shows, so few drifters were liberated during May and July 1911, the Regional Area J is so central with respect to the entire North Sea that the total lack of recoveries from these small experiments is remarkable. It is to be observed in passing that this is not the only area in regard to which the results of the summer experiments of 1911 appear to differ from those of the other years considered, as reference to Tables V. and VI. will indicate.

Regional Liberation Area K.

TABLE IX.

Liberations.		Recoveries.																
Month and Year.	No. of Drifters.	Frequency Distribution.																Totals.
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
May 1910	50	—	—	3	—	—	—	—	—	1	—	1	—	2	1	—	—	8
May 1911	25	—	—	—	—	—	—	—	—	—	—	—	2	6	—	—	—	8
May 1912	35	—	—	6	—	—	—	—	—	—	—	3	1	—	1	—	—	11
July 1913	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Totals	115	—	—	9	—	—	—	—	—	1	—	4	3	8	2	—	—	27

It is unfortunate that the experiments carried out in the Regional Area K were so few and confined to the same month of the three years for which records are available, since the results accruing from the work begun there in 1910, 1911, and 1912 are obviously of some importance.

At this stage in our knowledge of the hydrography of the region in question it is somewhat surprising to find bottles originating therein "thrown back," as it were, upon the Shetland Islands and, in one case, on Fair Isle, midway between the Shetland and Orkney groups. Nor, as Table IX. shows, were those instances confined to a single year. The May 1910 experiments from which Shetland Island recoveries are recorded were initiated in rectangle G.22 and those of May 1912 in rectangles H.21 and H.22, that is, between longitudes 2° and 4° E. and north of latitude 61° N., an area outwith the conventional northerly limit of the North Sea.

That drifters emanating from Regional Area K coursed farther south into the North Sea than even the Shetland Islands or Fair Isle is proved by the resulting returns from the Skagerak area; probably also by those from the section of the Norwegian coast north of Lindesnaes to latitude 62° N., since these bottles most likely attained their stranding-places while cruising northwards along the Norwegian coast.

Regional Liberation Area L.

TABLE X.

Liberations.		Recoveries.									
Month and Year.	No. of Drifters.	Frequency Distribution.									Totals.
		8	9	10	11	12	13	14	15	16	
May 1910	10	—	—	—	—	—	—	—	—	—	—
May 1911	5	—	—	—	—	—	1	—	—	—	1
May 1912	40	—	—	1	3	1	2	—	—	—	8
June 1912	8	—	—	—	1	2	—	—	—	—	2
June 1913	10	—	—	—	1	—	—	—	—	—	1
July 1913	5	—	—	—	—	—	—	—	—	—	—
April 1914	60	—	—	1	2	9	2	—	1	—	15
Totals .	138	—	—	2	7	12	5	—	1	—	27

The returns from the experiments pertaining to the Regional Area L came with greatest frequency from places on the south-west Norwegian coast, as of course might be expected, but it will be part of the business of an ensuing report to explain if possible the anomalies contained in the above table, particularly the routes by which bottles reached and finally stranded within the Skagerak area and to the south of it, which instances were again representative of the experiments of more than a single year, although the season during which liberation operations were carried out was practically the same in each of the years concerned.

In fact, the entire records (see Table II.) show a scarcity as regards liberation operations carried out during the first and last quarters of the year, particularly in respect of the more open sea Regional Areas. This lack of data for the winter months is of special significance in regard to the Regional Area above considered, namely Area L, for, from a short series of experiments partly carried out in the rectangles G.15 and H.16 during the month of October 1903, Fulton (3*e*, p. 5) obtained notable results. "The earliest (*bottles*) to be returned," he records, ". . . came unexpectedly from the Shetland Islands." No similar records are contained in the 1910-1914 material and unfortunately, as has been indicated, no experiments strictly comparable with those of Fulton were performed within this period of five years.

Regional Liberation Area M.

TABLE XI.

Liberations.		Recoveries.									
Month and Year.	No. of Drifters.	Frequency Distribution.									Totals.
		8	9	10	11	12	13	14	15	16	
April 1910	79	—	—	5	15	1	3	1	—	—	25
June 1910	65	—	—	1	5	2	4	—	1	—	13
July 1911	24	—	—	3	4	1	—	—	—	—	8
June 1912	32	—	—	—	4	—	—	—	—	—	4
June 1913	50	1	—	—	5	—	—	—	—	—	6
Totals .	250	1	—	9	33	4	7	1	1	—	56

The results enumerated in Table XI. in respect of the work done in the Regional Area M indicate that under normal conditions the direction of the surface water movement over the said area during at least early summer months is such that floating objects will find their way in the majority of cases into the Skagerak.

It has already been inferred from the records pertaining to other areas that the year 1913 was probably an abnormal one in relation to the surface drift of the North Sea as a whole, and Table XI. contains one of the unique results of that year, namely the recovery of a drifter on the Dutch Island of Texel (column 8).

CONCLUDING GENERAL REMARKS.

In brief, then, the above short analysis leads to the following inferences, which are to be borne in mind in the approach to a more detailed examination of the data on the basis of an attempt to determine, so far as is possible, the history of each and practically every bottle between the dates of despatch and recovery.

Unfortunately, as regards the Faroe-Shetland Channel region, upon conditions in which it is now generally accepted the dynamical system of surface waters in the Northern and Middle North Sea mainly and immediately depends, the limitations of the present data permit only of statements of the most general application. Nevertheless, it is hoped that the broad deductions here given will contribute in some measure to an understanding of the general system of surface water movement over the eastern portion of this important area.

On the western side of the Channel there would appear to function at certain times an anticyclonic surface eddy enclosing the group of the Faroe Islands. Certain of the above results indicate also that surface-floating organisms which may be encountered in the area lying to the eastward and south-eastward of the Faroe group may be met with again, at some later time probably, in the north-western area of the North Sea to the immediate east of the Orkney and Shetland Islands.

The direction of flow of the surface waters from the Regional Area A to the Regional Area B, in summer months at least, would appear to be north-easterly, deviating gradually more eastwards on the northward passage, until, about latitude 59° 30′ N., the direction may become almost due east. Approximately on this same latitude and south-westwards of the southern extremity of the Shetland peninsula the drift-stream appears to divide, part turning northwards again, passing the Shetland Islands on the right and part taking an opposite course southwards into the North Sea between Fair Isle and the Orkney Islands. It is not unlikely that the former stream, namely that flowing northwards to the west of Shetland, enters the North Sea by way of the north of these Islands.

The records of drift-bottle experiments contain strong evidence that, superficially, at any rate, a greater inflow of water into the Northern North Sea area proceeds by way of the opening between Shetland and Norway than by way of the channels between Shetland and the mainland of Scotland, as deduced by Robertson (11). Indeed, it is suggested by certain results that on occasions surface water actually *leaves* the North Sea by way of the Scotland-Shetland Channels. At this stage it would appear as though the entry of surface water to the North Sea between Shetland and Norway were largely if not entirely confined to the western side of the opening, in spite of the fact that at least part of the impulse behind the stream as it crosses the conventional northerly limit of the North Sea, namely latitude 61° N., may be derived, as in the summers of 1910 and 1912, from regions between latitudes 61° and 62° N. within 60 miles of the Norwegian coast.

The north-western portion of the North Sea, represented by the Regional Area D, is apparently a somewhat complex region as regards translation of the superficial water layers. First of all, in respect of the Moray Firth area, there are the anomalies brought out in the above analysis, of the relatively small numbers of drifters returned from points on the coast between Duncansby Head and Rattray Head and the fact that some of these belonged to series of bottles set away outwith the boundaries of the Firth altogether—mainly at stations to the north of latitude 58° 30′ N. In conjunction with these phenomena may be taken, tentatively meantime, the evidence pointing to the existence—temporary at all events—of a surface current leaving the Moray Firth and flowing northwards off the eastern shores of Caithness and Orkney, thereafter sometimes coursing along the eastern and sometimes along the western shores of Shetland. In all likelihood this drift-stream, when in operation, consists merely of a narrow strip of contrary-moving water, and the suggestion is made that it signifies the escape of water pent up in the Moray Firth as a result of a strong flow from the more open sea to the north and north-east, towards this bay in the Scottish coast. This stream flowing northwards off the eastern coasts of the Orkney and Shetland Islands must at times check, almost if not quite completely, the influx through the Scotland-Shetland Channels, of superficial water from the region of the Faroe-Shetland Channel into the North Sea. Whether or no all, or even a majority of the drifters found for the most part on the eastern Orkney and Shetland shores, drifted ultimately northwards from the Moray Firth to their respective stranding-places, will receive special attention in a subsequent more detailed examination of the present data.

Farther south, but still on the western side of the North Sea, particularly in that area defined on the chart, Figure 1 by the Region E, the above results indicate, in contradistinction to those obtained by Fulton, that there are times when a northerly drift operates in the surface waters of the coastal margin of the area in question. The present results suggest that this is most likely to happen during the first and last quarters of the year.

As regards the more open waters of the mid-Northern and Middle North Sea, especially the latter, there is little doubt that at most times conditions at the surface are such that the water-drift heads mainly towards the Skagerak. Resulting from the Scottish experiments of 1910-1914, drifters in respect of which periods of less than a year had elapsed between the dates of liberation and recovery were found eastwards of a line joining Hantsholm and Lindesnaes during all months of the year, as the following table, constructed from the original data, demonstrates :—

TABLE XII.

Monthly Frequency of Skagerak Recoveries from all Liberations.

Month of Recovery	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
No. of Drifters recovered .	9	9	22	7	15	8	12	10	17	12	28	40
		(1)	(6)	(4)	(4)	(2)	(5)	(2)	(1)	(1)	(3)	(2)

[N.B.—The bracketed numbers refer to additional recoveries effected more than a year after the corresponding dates of liberation.]

The months showing greatest frequency of Skagerak recoveries are November, December, and March, thus agreeing with Carruther's finding (2) from similar experiments in the Southern North Sea during 1920 and 1921. It may be that the low figures above recorded for January and February are in some way due to irregularities in times and places of initiation of the Scottish experiments (see Table II.).

In concluding this preliminary report attention may again be directed to the broad facts (1) of the non-recovery of Scottish drifters at places south of latitude

53° N. on either side of the North Sea, thereby more or less distinctly differentiating the Northern and Middle North Sea from the Southern Area in respect of surface water movement and (2) the lack of returns from places south of latitude 57° N. of drifters which had been set afloat at points west of the Orkney and Shetland Islands.

As to particular years, that of 1913 seems to have been peculiar in some very definite way which may unfold itself in a later and more detailed analysis. During 1911 also there would appear to have been a distinct set away from the British east coast during summer months at least.

Finally, it must be clearly understood that the above results refer meantime ~~only~~ to the most superficial stratum of the sea areas concerned.

LIST OF PUBLICATIONS CITED.

(1) Böhnecke, G., " Saltzgehalt und Stromungen der Nordsee." *Veroff. d. Inst. für Meereskunde, N.F., A. Heft* 10. Berlin, 1922.

(2) Carruthers, J. N., " The Water Movements in the Southern North Sea, Part I. The Surface Drift." *Min. Agric. and Fish., Fish. Invest., II, Vol. III*, 2, 1925.

(3) Fulton, T. W. (*a*) " The Relation of Marine Currents to Offshore Spawning Areas and Inshore Nurseries." *Fishery Board for Scotland*, 13*th Report* (1894). Edinburgh, 1895.

(*b*) " The Currents of the North Sea and their Relation to Fisheries." *Ibid.*, 15*th Report* (1896). Edinburgh, 1897.

(*c*) " Additional Note on the Surface Currents of the North Sea." *Ibid.*, 18*th Report* (1899). Edinburgh, 1900.

(*d*) " The Surface Currents of the North Sea." *Scottish Geog. Mag.*, Vol. XIII, No. 12, 1897.

(*e*) " On the Spawning of the Cod (*Gadus morrhua*) in Autumn in the North Sea." *Pub. d. Circ.*, No. 8, 1904.

(4) Pettersson, O., " Uber die Warscheinlichkeit von periodischen und unperiodischen Schwankungen in dem atlantischen Strome und ihren Beziehungen zu meteorologischen und biologischen Phaenomenon." *Ur Svenska Hydrog. Biolog. Komm. Skrifter II.* Stockholm, 1905.

(5) Ryder, C., " Some Investigations relating to the Ocean Currents in the Sea between Norway, Scotland, and Greenland." *Naut. Met. Ann., Dan. Met. Inst.*, Copenhagen, 1901 and 1904.

(6) Brown, C. H. (*a*) " Report on the Deep Currents of the North Sea as ascertained by experiments with Drift Bottles." *North Sea Fish. Invest. Comm.*, 4*th Report.* (*Northern Area*) *Hydrography*, 1909.

(*b*) " Second Report on the Deep Currents of the North Sea as ascertained by means of Drift Bottles." *Fisheries, Scotland, Sci. Invest.*, 1913, II. (August 1914.)

(*c*) " Additional Notes on the Deep Currents of the North Sea as ascertained by Drift Bottles." *Fisheries Scotland, Sci. Invest.*, 1916, II. (March 1916.)

(7) Bowman, A., (*a*) " The Distribution of Plaice Eggs in the Northern North Sea." *Fisheries, Scotland, Sci. Invest.*, 1914, II., (August 1914.)

(*b*) " The Distribution of Plaice Eggs in the Northern North Sea, II." *Fisheries, Scotland, Sci. Invest.*, 1921, I., 1921.

(8) Wendicke, F., " Hydrographische und biologische untersuchungen auf den deutschen Feuerschiffen der Nordsee, 1910-11." *Veroff. d. Inst. fur Meereskunde, N.F., A. Heft* 3, November 1913.

(9) Jacobsen, J. P., and Jensen, A. J. C., " Examination of Hydrographical Measurements from the Research Vessels *Explorer* and *Dana* during the summer of 1924." *Cons. Intern. l'Explor. d. l. Mer., Rapp. et Proc. Verb.*, Vol. XXXIX. Report of the North-Western Area Committee for 1924 and 1925. May 1926.

(10) Helland-Hansen, B., " Report on Hydrographical Investigations in the Faroe-Shetland Channel and the Northern Part of the North Sea in 1902." *North Sea Fish. Invest. Comm.*, 1*st Report.* (*Northern Area*) *Hydrography*, 1905.

(11) Robertson, A. J., (*a*) " Report on Hydrographical Investigations in the Faroe-Shetland Channel and the Northern Part of the North Sea in the year 1903." *Ibid.*

(*b*) " Report on Hydrographical Investigations in the Faroe-Shetland Channel and the Northern Part of the North Sea during the years 1904 and 1905." *North Sea Fish. Invest. Comm.*, 2*nd Report.* (*Northern Area*) *Part I., Hydrography*, 1907.

(*c*) " Report on Hydrographical Investigations in the North Sea and Faroe-Shetland Channel during the year 1906." *Ibid.*, 4*th Report.* (*Northern Area*) *Hydrography*, 1909.

(*d*) " Report on Hydrographical Investigations in the North Sea and Faroe-Shetland Channel during the years 1907-1908." *Ibid.*

(*e*) " Report on Hydrographical Investigations in the North Sea and Faroe-Shetland Channel during the years 1909-1910." *Ibid.*, 5*th Report.* (*Northern Area*) *Hydrography*, 1913.

APPENDIX.

THE DATA: arranged in Chronological Sequence of Liberations.

List of Common Abbreviations.

Sc.	=	Scotland	Rect.	=	Rectangular
E.	=	England	nr.	=	near
Sh.	=	Shetland	btw.	=	between
Ork.	=	Orkney	Is.	=	Island
Nwy.	=	Norway	Lt.	=	Light
Sw.	=	Sweden	Hd.	=	Head
Dk.	=	Denmark	St.	=	Saint
Schl.-Holst.	=	Schleswig-Holstein	Gt.	=	Great

LIBERATIONS.						RECOVERIES.					
Station No.	Day of Month.	No. of Drifters.	Position of Station.			Place-Name.		Position.		Date.	Drift-Period (days).
			Latit. & Long.		Rect. Area.			Latit. & Long.		D. M. Y.	
						APRIL 1910.					
1	13	40	57° 25′ N.	3° 34′ E.	H.13	nr. Höjen,	Dk.	57° 43′ N.	10° 28′ E.	5.5.10	22
						Lister, nr. Farsund,	Nwy.	58° 06′ N.	6° 34′ E.	4.6.10	52
						8′ W. of Skagen,	Dk.	57° 43′ N.	10° 27′ E.	5.6.10	53
						nr. Hirtshals,	Dk.	57° 35′ N.	9° 57′ E.	5.6.10	53
						” ”	”	”	”	3.7.10	81
						” ”	”	”	”	6.7.10	84
						Thorup Strand,	Dk.	57° 08′ N.	9° 07′ E.	11.7.10	89
						nr. Lodbjerg Lt.,	Dk.	56° 49′ N.	8° 14′ E.	28.7.10	106
						8′ S.W./W. of Hantsholm,	Dk.	57° 02′ N.	8° 27′ E.	29.7.10	107
						nr. Lodbjerg Lt.,	Dk.	56° 49′ N.	8° 14′ E.	3.9.10	143

LIBERATIONS.					RECOVERIES.			
Station No.	Day of Month.	No. of Drifters.	Position of Station. Latit. & Long.	Position of Station. Rect. Area.	Place-Name.	Position. Latit. & Long.	Date. D. M. Y.	Drift-Period (days).
1	13	40	57° 25′ N. 3° 34′ E. (*Contd.*)	H.13	N. Gutvik, Namdalen, Nwy.	65° 07′ N. 11° 53′ E.	20.1.11	282*
					Bluk, Andenaes, Nwy.	69° 17′ N. 15° 59′ E.	23.1.11	285*
					nr. Hammerfest, Nwy.	70° 37′ N. 23° 41′ E.	23.3.11	344*
					Brännö, Göteborg, Sw.	57° 38′ N. 11° 45′ E.	18.6.15	1892*
2	15	39	56° 59′ N. 4° 10′ E.	J.12	nr. The Skaw, Dk.	57° 45′ N. 10° 38′ E.	9.5.10	24
					btw. Rubjerg and Hirtshals, Dk.	57° 30′ N. 9° 50′ E.	10.5.10	25
					The Skaw, Dk.	57° 45′ N. 10° 38′ E.	1.6.10	47
					Grundsund, Bohuslan, Sw.	58° 13′ N. 11° 25′ E.	3.6.10	49
					Hirtshals, Dk.	57° 35′ N. 9° 57′ E.	7.6.10	53
					” ”	” ”	2.7.10	78
					” ”	” ”	9.7.10	85
					Söndervig, Dk.	56° 08′ N. 8° 07′ E.	24.7.10	100
					Tranum, Dk.	57° 10′ N. 9° 25′ E.	25.9.10	163
					Hallerö, nr. Kristiansund, Nwy.	63° 17′ N. 7° 48′ E.	1.10.10	169*
					17′ S. of Bovbjerg, Dk.	56° 12′ N. 8° 07′ E.	14.10.10	182
3	23	10	57° 52′ N. 3° 38′ W.	A.14	St. Andrews, Fife, Sc.	56° 20′ N. 2° 47′ W.	24.5.10	31
					Mouth of River Eden, Fife, Sc.	56° 23′ N. 2° 48′ W.	1.6.10	39
					Tyne Dock, Northumberland, E.	55° 00′ N. 1° 26′ W.	26.6.10	64
4	25	11	57° 45′ N. 3° 32′ W.	A.14	Köpstadsö, Göteborg, Sw.	57° 38′ N. 11° 49′ E.	9.2.11	290*
					Fjand, Nissum Fjord, Dk.	56° 20′ N. 8° 07′ E.	18.2.11	299*
5	26	10	57° 48′ N. 3° 05′ W.	A.14	Newburgh, Aberdeen, Sc.	57° 19′ N. 1° 59′ W.	20.5.10	24
					Redcar, Yorks., E.	54° 37′ N. 1° 03′ W.	8.7.10	73
					nr. Bulbjerg, Dk.	57° 10′ N. 9° 00′ E.	15.1.11	264*
6	27	10	58° 01′ N. 3° 10′ W.	A.15	56′ E./N. of Peterhead, At Sea.	57° 52′ N. 0° 10′ W.	17.6.10	51
					Aargab, Dk.	55° 59′ N. 8° 09′ E.	18.2.11	297*
7	27	10	58° 14′ N. 3° 02′ W.	A.15	btw. Sonderhoe and Nordby, Fanö, Dk.	55° 23′ N. 8° 24′ E.	30.4.11	368*

8	28	10	57° 58′ N.	2° 38′ W.	B.14	nr. Alnmouth, Northumberland,	E.	55° 22′ N.	1° 33′ W.	17.7.10	80
						nr. Ringkjöbing,	Dk.	56° 05′ N.	8° 15′ E.	7.4.11	344*
						Grebbestad, Bohuslan,	Sw.	58° 42′ N.	11° 12′ E.	16.11.11	567*
9	28	10	58° 14′ N.	2° 51′ W.	B.15	58′ E./N. of Peterhead,	At Sea.	57° 58′ N.	0° 11′ W.	9.7.10	72
						Homborsund, nr. Christiansand,	Nwy.	58° 16′ N.	8° 31′ E.	25.11.11	576*
						MAY 1910.					
1	11	10	57° 30′ N.	1° 19′ W.	C.14	Estuary of River Tay,	Sc.	56° 29′ N.	2° 50′ W.	25.5.10	14
						nr. Withernsea, Yorks.,	E.	53° 42′ N.	0° 04′ E.	18.7.10	68
						Sutton-on-Sea, Lincs.,	E.	53° 18′ N.	0° 18′ E.	18.7.10	68
2	12	10	58° 11′ N.	0° 32′ W.	D.15	—		—		—	—
3	12	10	58° 55′ N.	0° 04′ E.	E.16	On Amrum Bank,	At Sea.	54° 40′ N.	7° 40′ E.	5.6.11	389
						Haurvig,	Dk.	55° 57′ N.	8° 10′ E.	11.6.11	395
						8′ S. of Lyngvig Lt.,	Dk.	55° 54′ N.	8° 10′ E.	4.7.11	418
4	12	10	59° 31′ N.	0° 37′ E.	E.18	36′ S./E. of Bressay Lt.,	At Sea.	59° 35′ N.	0° 32′ W.	9.6.10	28
						Forvie, Aberdeen,	Sc.	57° 21′ N.	1° 56′ W.	3.8.10	83
5	12	10	59° 52′ N.	1° 11′ E.	F.18	Dagebüll,	Schl.-Holst.	54° 44′ N.	8° 40′ E.	13.3.11	305*
6	12	10	60° 16′ N.	1° 53′ E.	F.19	Cunningsburgh,	Sh.	60° 02′ N.	1° 14′ W.	2.12.10	204
7	13	10	60° 45′ N.	2° 30′ E.	G.20	—		—		—	—
8	13	5	60° 35′ N.	1° 50′ E.	F.20	—		—		—	—
9	13	5	60° 34′ N.	1° 15′ E.	F.20	Snook Point, Holy Is.,	E.	55° 41′ N.	1° 51′ W.	2.11.10	173
10	14	5	60° 35′ N.	0° 29′ E.	E.20	Fladdabister,	Sh.	60° 03′ N.	1° 06′ W.	29.7.10	76
11	14	5	60° 17′ N.	0° 07′ W.	D.19	1½′ off Bu Ness, Fair Is.,	At Sea.	59° 32′ N.	1° 32′ W.	23.6.10	40
						Little Risa Is.,	Ork.	58° 52′ N.	3° 12′ W.	25.8.10	103
12	14	5	60° 05′ N.	0° 48′ W.	D.19	—		—		—	—

LIBERATIONS.						RECOVERIES.					
Station No.	Day of Month.	No. of Drifters.	Position of Station. Latit. & Long.		Rect. Area.	Place-Name.		Position. Latit. & Long.		Date. D. M. Y.	Drift-Period (days).
13	18	10	61° 02′ N.	1° 10′ W.	C.21	Lunning Hd.,	Sh.	60° 23′ N.	1° 04′ W.	16.7.10	59
						Levenwick,	Sh.	59° 59′ N.	1° 15′ W.	29.7.10	72
						East Ham, Mousa,	Sh.	60° 00′ N.	1° 11′ W.	4.8.10	78
						Cullensburgh, Bressay,	Sh.	60° 09′ N.	1° 03′ W.	7.8.10	81
						Dunnet Hd., Caithness,	Sc.	58° 37′ N.	3° 22′ W.	22.9.10	127
						Havnholmen, Torget,	Nwy.	65° 23′ N.	12° 05′ E.	4.2.11	262*
14	18	5	61° 14′ N.	1° 27′ W.	C.21	—		—		—	—
15	18	10	61° 42′ N.	2° 00′ W.	C.22	Vikan, Senienö,	Nwy.	69° 16′ N.	17° 08′ E.	19.1.11	246*
						Sunderö, Vesteraalen,	Nwy.	68° 50′ N.	14° 45′ E.	11.6.11	389*
16	19	10	61° 38′ N.	0° 40′ W.	D.22	7′ S. of Lerwick,	Sh.	60° 03′ N.	1° 06′ W.	17.8.10	90
						Cunningsburgh,	Sh.	60° 02′ N.	1° 14′ W.	30.8.10	103
						Bosselö, Outer Vigten,	Nwy.	64° 59′ N.	10° 47′ E.	12.4.11	328*
17	19	10	61° 35′ N.	0° 47′ E.	E.22	—		—		—	—
18	19	10	61° 34′ N.	2° 04′ E.	G.22	" Haswell's Geo,"	Fair Isle.	59° 32′ N.	1° 36′ W.	25.7.10	67
						Burö, nr. Bodö,	Nwy.	67° 14′ N.	13° 58′ E.	29.4.11	345*
						nr. Esbjerg,	Dk.	55° 28′ N.	8° 19′ E.	10.4.12	692*
19	20	10	61° 30′ N.	3° 03′ E.	H.22	—		—		—	—
20	20	5	61° 35′ N.	3° 35′ E.	H.22	btw. Stavaness and Collifield,	Sh.	60° 20′ N.	1° 05′ W.	18.8.10	90
21	20	5	61° 35′ N.	3° 50′ E.	H.22	—		—		—	—
22	20	5	61° 35′ N.	4° 05′ E.	J.22	i Vesteraalen,	Nwy.	?		25.1.11	250*
23	20	5	61° 19′ N.	3° 02′ E.	H.21	nr. Haroldswick, Unst,	Sh.	60° 46′ N.	0° 49′ W.	20.8.10	92
						On the Murman coast,	Russia.	69° 16′ N.	35° 15′ E.	27.4.11	342*
24	20	10	61° 06′ N.	2° 10′ E.	G.21	Klöfverö, Bohuslan,	Sw.	57° 53′ N.	11° 35′ E.	7.3.11	291*

25	20	10	60° 52′ N.	1° 10′ E.	F.20	E. coast of Flotta Is.,	Ork.	58° 49′ N.	3° 05′ W.	16.8.10	88
						Odness, Stronsay,	Ork.	59° 07′ N.	2° 33′ W.	10.12.10	204
						Kjoergaard,	Dk.	55° 41′ N.	8° 10′ E.	1.4.11	316*
26	21	10	60° 40′ N.	0° 17′ E.	E.20	6′ N. of Aberdeen,	Sc.	57° 15′ N.	2° 02′ W.	16.8.10	87
27	21	6	60° 31′ N.	0° 35′ W.	D.20	Kampen, Sylt,	Schl.-Holst.	55° 00′ N.	8° 22′ E.	10.2.11	265*
28	24	5	60° 42′ N.	1° 25′ W.	C.20	Hoganess, Yell,	Sh.	60° 30′ N.	1° 02′ W.	17.6.10	24
						Whalsay,	Sh.	60° 20′ N.	0° 55′ W.	21.6.10	28
29	24	10	60° 52′ N.	1° 43′ W.	C.20	West Isle, Skerries,	Sh.	60° 25′ N.	0° 47′ W.	22.6.10	29
						Swinning, Lunnasting,	Sh.	60° 23′ N.	1° 10′ W.	24.6.10	31
						Whalsay,	Sh.	60° 20′ N.	0° 55′ W.	27.8.10	95
						Sella Ness, Garth's Voe,	Sh.	60° 27′ N.	1° 17′ W.	6.1.11	227*
30	24	10	61° 16′ N.	2° 08′ W.	B.21	Gloup, Yell,	Sh.	60° 44′ N.	1° 04′ W.	27.6.10	34
						Challister Ness, Whalsay,	Sh.	60° 23′ N.	0° 58′ W.	7.7.10	44
						Kravik, nr. Tromsö,	Nwy.	69° 27′ N.	18° 22′ E.	3.5.11	344*
31	24	10	61° 18′ N.	2° 59′ W.	B.21	Maarup,	Dk.	57° 28′ N.	9° 48′ E.	28.1.11	249*
32	24	10	61° 27′ N.	3° 42′ W.	A.21	Havnholmen, Andenaes,	Nwy.	69° 20′ N.	16° 10′ E.	25.5.11	366*
33	25	10	61° 39′ N.	4° 45′ W.	ZZ.22	Risöy, Helgeland,	Nwy.	66° 37′ N.	12° 46′ E.	9.11.10	168*
						Fruholmen Lt.,	Nwy.	71° 06′ N.	24° 00′ E.	2.4.11	312*
34	25	10	61° 49′ N.	5° 36′ W.	YY.22	Hackness Point,	Ork.	58° 48′ N.	3° 08′ W.	12.12.10	201
						Sulens Lt., Fosen,	Nwy.	63° 51′ N.	8° 28′ E.	31.12.10	220*
						Kalvö i Valberg, Lofoten,	Nwy.	68° 11′ N.	13° 58′ E.	13.2.11	264*
35	25	10	62° 00′ N.	6° 12′ W.	XX.22	Brough Bay, Sanday,	Ork.	59° 15′ N.	2° 37′ W.	3.1.11	223
36	26	10	61° 45′ N.	6° 27′ W.	XX.22	Lobra, Suderö,	Faroe.	61° 31′ N.	7° 00′ W.	1.6.10	6
						" "	"	"	"	"	"
						Millbounds Bay, Eday,	Ork.	59° 12′ N.	2° 45′ W.	5.12.10	193
						Is. in Fleinvaer, Bodö,	Nwy.	67° 10′ N.	13° 47′ E.	10.4.11	318*
						Strönstad, Vesteraalen, .	Nwy.	68° 50′ N.	14° 45′ E.	28.4.11	337*
37	27	10	61° 12′ N.	6° 33′ W.	XX.21	. . . . .	At Sea.	61° 44′ N.	7° 48′ W.	23.6.10	27
38	27	10	60° 48′ N.	6° 16′ W.	XX.20	Engholmen, nr. Gorsen Is.,	Nwy.	62° 52′ N.	6° 52′ E.	7.2.11	256*
						Solforstrand, Vesteraalen,	Nwy.	68° 42′ N.	15° 00′ E.	11.8.11	441*

LIBERATIONS.						RECOVERIES.					
Station No.	Day of Month.	No. of Drifters.	Position of Station. Latit. & Long.		Rect. Area.	Place-Name.		Position. Latit. & Long.		Date. D. M. Y.	Drift-Period (days).
39	27	10	60° 08′ N.	5° 13′ W.	YY.19	Papa Stour,	Sh.	60° 20′ N.	1° 40′ W.	27.7.10	61
						Gletness, Nesting,	Sh.	60° 16′ N.	1° 06′ W.	27.8.10	92
						Gryllefjord, Senienö,	Nwy.	69° 22′ N.	17° 04′ E.	13.7.11	412*
						Vestsmölen,	Nwy.	63° 21′ N.	7° 50′ E.	1.9.11	462*
40	28	10	59° 44′ N.	4° 34′ W.	ZZ.18	Stensjöholmen, Helgeland,	Nwy.	64° 27′ N.	10° 46′ E.	14.2.11	262*
						Damholmen, Grebbestad,	Sw.	58° 45′ N.	11° 12′ E.	6.3.11	282*
						nr. Strönstad, Vesteraalen,	Nwy.	68° 50′ N.	14° 45′ E.	30.3.11	306*
						Melvik, Tromsö,	Nwy.	69° 39′ N.	18° 57′ E.	9.4.11	316*
41	28	10	59° 27′ N.	4° 06′ W.	ZZ.17	Newark, Sanday,	Ork.	59° 15′ N.	2° 30′ W.	21.6.10	24
						Brough Bay, Sanday,	Ork.	59° 15′ N.	2° 37′ W.	4.7.10	37
						nr. Tarbet Ness, Moray Firth,	Sc.	57° 52′ N.	3° 48′ W.	27.7.10	60
						nr. Wick, Caithness,	Sc.	58° 27′ N.	3° 06′ W.	3.8.10	67
						Newark Bay, Deerness,	Ork.	58° 55′ N.	2° 45′ W.	1.12.10	187
42	28	10	59° 10′ N.	3° 38′ W.	A.17	Taracliff Bay,	Ork.	58° 55′ N.	2° 42′ W.	10.6.10	13
						Dunnet Bay, Caithness,	Sc.	58° 37′ N.	3° 22′ W.	3.7.10	36
						Kirk Bay, Flotta,	Ork.	58° 49′ N.	3° 06′ W.	10.7.10	43
43	28	10	59° 38′ N.	2° 30′ W.	B.18	Kirk Ness, S. Ronaldshay,	Ork.	58° 48′ N.	2° 55′ W.	22.6.10	25
						Costa,	Ork.	59° 09′ N.	3° 12′ W.	9.7.10	42
						Eyemouth, Berwick,	Sc.	55° 53′ N.	2° 05′ W.	18.7.10	51
44	28	10	59° 40′ N.	1° 14′ W.	C.18	Burray Is.,	Ork.	58° 52′ N.	2° 53′ W.	24.6.10	27
						nr. Fraserburgh, Aberdeen,	Sc.	57° 41′ N.	1° 59′ W.	25.7.10	58
						Amrum Is.,	Schl.-Holst.	54° 39′ N.	8° 22′ E.	25.2.11	273*
						Nordstrand Is.,	Schl.-Holst.	54° 31′ N.	8° 50′ E.	27.2.11	275*
						nr. Höjer,	Schl.-Holst.	54° 57′ N.	8° 42′ E.	16.3.11	292*
						,, ,,	,,	,,	,,	,,	,,
45	29	10	59° 26′ N.	1° 20′ W.	C.17	. . . . . .	At Sea.	59° 23′ N.	1° 35′ W.	22.6.10	24
						Sonderhoe, Fanö,	Dk.	55° 21′ N.	8° 28′ E.	29.1.11	245*
						Nordby, Fanö,	Dk.	55° 25′ N.	8° 23′ E.	17.2.11	264*

						S. Farup, nr. Ribe,	Dk.	55° 17′ N.	8° 44′ E.	23.2.11	270*
						btw. Blaavandshuk & Skallingen	Dk.	55° 31′ N.	8° 13′ E.	20.9.11	479*
46	29	10	59° 10′ N.	1° 27′ W.	C.17	Hooge Is.,	Schl.-Holst.	54° 34′ N.	8° 32′ E.	5.3.11	280*
						Hornum, Sylt,	Schl.-Holst.	54° 45′ N.	8° 17′ E.	10.3.11	285*
						Nordby, Fanö,	Dk.	55° 25′ N.	8° 23′ E.	18.4.11	324*
47	29	10	58° 36′ N.	1° 46′ W.	C.16	Whitley Bay, Northumberland,	E.	55° 03′ N.	1° 26′ W.	30.10.10	154*
						btw. Saltburn & Marske, Yorks.,	E.	54° 35′ N.	1° 00′ W.	3.11.10	158*
						Kampen, Sylt,	Schl.-Holst.	55° 00′ N.	8° 22′ E.	5.2.11	252*
						nr. Blaavandshuk,	Dk.	55° 40′ N.	8° 09′ E.	7.2.11	254*
48	29	10	58° 09′ N.	1° 50′ W.	C.15	Husum,	Schl.-Holst.	54° 29′ N.	9° 04′ E.	17.2.11	264*
						Sylt,	Schl.-Holst.	54° 45′ N.	8° 18′ E.	22.2.11	269*
49	30	10	57° 18′ N.	1° 57′ W.	C.13	Buddon Ness, Forfar,	Sc.	56° 28′ N.	2° 44′ W.	12.6.10	13
						nr. Elie, Fife,	Sc.	56° 11′ N.	2° 49′ W.	20.6.10	21
						E. Hartlepool, Durham,	E.	54° 42′ N.	1° 12′ W.	18.7.10	49
50	31	7	56° 53′ N.	2° 12′ W.	B.12	Newbiggin, Northumberland,	E.	55° 11′ N.	1° 31′ W.	8.7.10	38
						nr. Leuchars, Fife,	Sc.	56° 23′ N.	2° 50′ W.	9.7.10	39
51	31	7	56° 41′ N.	2° 23′ W.	B.12	Leven, Fife,	Sc.	56° 12′ N.	3° 00′ W.	17.6.10	17
						nr. N. Berwick, Haddington,	Sc.	56° 04′ N.	2° 47′ W.	24.6.10	24
						btw. Saltburn & Marske, Yorks.,	E.	54° 35′ N.	1° 00′ W.	10.7.10	40
52	31	7	56° 15′ N.	2° 35′ W.	B.11	nr. Dunbar, Haddington,	Sc.	56° 00′ N.	2° 34′ W.	7.6.10	7*
						Fidra Is., Firth of Forth,	Sc.	56° 04′ N.	2° 49′ W.	7.6.10	7*
						nr. N. Berwick, Haddington,	Sc.	56° 04′ N.	2° 42′ W.	8.6.10	8*
						JUNE 1910.					
1	15	10	57° 09′ N.	1° 53′ W.	C.13	5′ S.E. of Girdleness,	At Sea.	57° 04′ N.	2° 00′ W.	25.6.10	10
						nr. N. Berwick, Haddington,	Sc.	56° 02′ N.	2° 36′ W.	18.7.10	33
						,, ,, ,,	Sc.	56° 03′ N.	2° 39′ W.	,,	,,
						Nordstrand Is.,	Schl.-Holst.	54° 31′ N.	8° 50′ E.	3.3.11	261
2	15	10	57° 09′ N.	1° 45′ W.	C.13	Burnmouth, Berwick,	Sc.	55° 51′ N.	2° 04′ W.	16.7.10	31
						Cockburnspath, Berwick,	Sc.	55° 56′ N.	2° 20′ W.	17.7.10	32
						Barnsness Lt., Haddington,	Sc.	55° 59′ N.	2° 30′ W.	18.7.10	33
						Goswick, Northumberland,	E.	55° 41′ N.	1° 53′ W.	18.7.10	33
						(Trawled)	At Sea.	54° 55′ N.	1° 45′ E.	23.10.10	130

			LIBERATIONS.		RECOVERIES.				
Station No.	Day of Month.	No. of Drifters.	Position of Station. Latit. & Long.	Rect. Area.	Place-Name.		Position. Latit. & Long.	Date. D. M. Y.	Drift-Period (days).
3	16	10	57° 10′ N. 1° 26′ W.	C.13	nr. Bass Rock, Firth of Forth,	At Sea.	56° 05′ N. 2° 35′ W.	17.7.10	31
					nr. Dunbar, Haddington,	Sc.	56° 00′ N. 2° 36′ W.	18.7.10	32
					,, ,, ,,	Sc.	,, ,,	,,	,,
					Tyninghame, Haddington,	Sc.	56° 01′ N. 2° 35′ W.	18.7.10	32
					nr. Hawick Burn, Northumberland,	E.	55° 27′ N. 1° 36′ W.	16.9.10	92
4	16	10	57° 13′ N. 0° 31′ W.	D.13	Nordstrand Is.,	Schl.-Holst.	54° 31′ N. 8° 50′ E.	18.2.11	247
					Westerland, Sylt,	Schl.-Holst.	54° 58′ N. 8° 20′ E.	25.2.11	254
5	16	10	57° 16′ N. 0° 22′ E.	E.13	nr. Nyminde Gab,	Dk.	55° 47′ N. 8° 11′ E.	14.4.11	302
6	16	10	57° 17′ N. 1° 16′ E.	F.13	Bjergehuse,	Dk.	56° 20′ N. 8° 07′ E.	4.2.11	233
7	16	10	57° 20′ N. 2° 12′ E.	G.13	. . . .	At Sea.	55° 15′ N. 5° 00′ E.	19.9.10	95
					Vestsmölen,	Nwy.	63° 23′ N. 7° 48′ E.	24.1.11	222*
					Vikan, Romsdal,	Nwy.	62° 54′ N. 6° 55′ E.	6.2.11	235*
8	16	10	57° 25′ N. 3° 35′ E.	H.13	Herö, Bohuslan,	Sw.	58° 01′ N. 11° 27′ E.	1.10.10	107
					Onsö, nr. Fredrikstad,	Nwy.	59° 13′ N. 10° 45′ E.	17.1.11	215*
					Andöen, Nordland,	Nwy.	69° 05′ N. 15° 34′ E.	8.4.11	296*
9	17	10	57° 20′ N. 3° 39′ E.	H.13	nr. Blokhus,	Dk.	57° 15′ N. 9° 36′ E.	9.10.10	114
					Fiskebäck, nr. Göteborg,	Sw.	57° 39′ N. 11° 51′ E.	10.11.10	146
					Topnaes, nr. Stavanger,	Nwy.	58° 58′ N. 5° 44′ E.	14.12.10	180
10	18	10	57° 01′ N. 3° 52′ E.	H.13	nr. Lodbjerg Lt.,	Dk.	56° 49′ N. 8° 16′ E.	29.9.10	103
					nr. Slotterö Lt., Bergen,	Nwy.	59° 55′ N. 5° 04′ E.	23.1.11	219*
11	20	10	56° 58′ N. 4° 15′ E.	J.12	—		—	—	—
12	21	10	56° 37′ N. 3° 42′ E.	H.12	Tryggö, Bohuslan,	Sw.	58° 24′ N. 11° 13′ E.	1.1.11	194
					Lausnaes, Flatanger,	Nwy.	64° 32′ N. 10° 55′ E.	27.4.11	310*
13	21	5	56° 34′ N. 2° 39′ E.	G.12	—		—	—	—

14	21	5	56° 29′ N.	1° 44′ E.	F.11	Naesö, Helgeland,	Nwy.	66° 33′ N.	12° 40′ E.	2.3.11	254*
15	21	10	56° 26′ N.	0° 50′ E.	E.11	Maseskars Lt., Bohuslan,	Sw.	58° 09′ N.	11° 22′ E.	31.1.11	224
						Natvig, nr. Christiansand,	Nwy.	58° 10′ N.	8° 02′ E.	26.3.11	278
						Ramsvik, nr. Hunnebostrand,	Sw.	58° 27′ N.	11° 18′ E.	23.7.13	1128
16	22	10	56° 22′ N.	0° 04′ W.	D.11	—		—		—	—
17	22	10	56° 19′ N.	0° 57′ W.	D.11	Marske, Yorks.,	E.	54° 36′ N.	1° 00′ W.	15.7.10	23
						btw. Marske & Saltburn, Yorks.,	E.	54° 35′ N.	0° 59′ W.	16.7.10	24
						Hammersea, Yorks.,	E.	54° 34′ N.	0° 51′ W.	16.7.10	24
						btw. Marske & Saltburn, Yorks.,	E.	54° 35′ N.	0° 59′ W.	16.7.10	24
						nr. Hammersea, Yorks.,	E.	54° 34′ N.	0° 52′ W.	17.7.10	25
						Marske, Yorks.,	E.	54° 36′ N.	1° 00′ W.	17.7.10	25
						Huntcliff, Yorks.,	E.	54° 35′ N.	0° 55′ W.	17.7.10	25
						Saltburn, Yorks.,	E.	54° 35′ N.	0° 58′ W.	18.7.10	26
18	22	11	56° 14′ N.	1° 52′ W.	C.11	Tynemouth, Northumberland,	E.	55° 02′ N.	1° 27′ W.	8.7.10	16
						Redcar, Yorks.,	E.	54° 37′ N.	1° 03′ W.	8.7.10	16
						nr. Whitby, Yorks.,	E.	54° 31′ N.	0° 40′ W.	16.7.10	24
19	22	11	56° 11′ N.	2° 29′ W.	B.11	Spittal, Northumberland,	E.	55° 46′ N.	2° 00′ W.	26.6.10	4*
						” ”	”	”	”	”	” 8*
						Scremerston, Northumberland,	E.	55° 45′ N.	1° 59′ W.	30.6.10	
						Newbiggin, Northumberland,	E.	55° 11′ N.	1° 30′ W.	7.7.10	15
						Saltburn, Yorks.,	E.	54° 35′ N.	0° 58′ W.	8.7.10	16
						Holy Is., Northumberland,	E.	55° 41′ N.	1° 48′ W.	28.7.10	36
						AUGUST 1910.					
1	8	5	59° 46′ N.	2° 21′ W.	B.18	Sack Fjord, nr. Strömstad,	Sw.	59° 00′ N.	11° 09′ E.	3.3.11	207
2	8	5	60° 02′ N.	3° 13′ W.	A.19	W. coast of Orlandet,	Nwy.	63° 41′ N.	9° 32′ E.	8.10.1	61
						Tusteren, nr. Kristiansund,	Nwy.	63° 11′ N.	7° 56′ E.	28.2.11	204
3	8	5	60° 17′ N.	3° 36′ W.	A.19	Fjeren, Tromsö,	Nwy.	70° 05′ N.	20° 00′ E.	26.7.11	352*
4	9	5	60° 26′ N.	4° 02′ W.	ZZ.19	—		—		—	—
5	9	5	60° 40′ N.	4° 50′ W.	ZZ.20	Leka, Namdalen,	Nwy.	65° 07′ N.	11° 36′ E.	26.1.11	170

LIBERATIONS.					RECOVERIES.				
Station No.	Day of Month.	No. of Drifters.	Position of Station. Latit. & Long.	Rect. Area.	Place-Name.		Position. Latit. & Long.	Date. D. M. Y.	Drift-Period (days).
6	9	5	60° 57′ N. 5° 47′ W.	YY.20	Skelbotten Fjord, Brönnöy,	Nwy.	65° 28′ N. 12° 18′ E.	3.3.11	206*
7	9	5	61° 15′ N. 6° 33′ W.	XX.21	Vikten, Lofoten,	Nwy.	68° 08′ N. 13° 20′ E.	29.3.11	232*
					Kjaervaer, nr. Bodö,	Nwy.	67° 14′ N. 13° 58′ E.	14.10.11	431*
8	12	5	62° 00′ N. 6° 12′ W.	XX.22	Bliksvaer, nr. Bodö,	Nwy.	67° 17′ N. 13° 59′ E.	27.1.11	168*
9	12	5	61° 49′ N. 5° 36′ W.	YY.22	—		—	—	—
10	13	5	61° 39′ N. 4° 45′ W.	ZZ.22	Hundvaagö, nr. Bergen,	Nwy.	60° 08′ N. 5° 08′ E.	26.5.11	286
					Vestsmölen,	Nwy.	63° 23′ N. 7° 44′ E.	5.10.11	418
11	13	5	61° 32′ N. 4° 19′ W.	ZZ.22	Hoddevik, Stadtlandet,	Nwy.	62° 06′ N. 5° 11′ E.	7.3.11	206
					Hamneskars Lt., Bohuslan,	Sw.	57° 54′ N. 11° 29′ E.	16.10.11	429
12	14	5	61° 27′ N. 3° 42′ W.	A.21	Storvik, Gildeskaal,	Nwy.	67° 03′ N. 14° 04′ E.	18.1.11	157*
					Sanderöy, Helgeland,	Nwy.	66° 37′ N. 12° 48′ E.	22.10.11	434*
13	14	5	61° 18′ N. 2° 59′ W.	B.21	Maasöval, nr. Trondhjem,	Nwy.	63° 45′ N. 8° 30′ E.	28.9.10	45
					Breivik, Vigten,	Nwy.	64° 50′ N. 11° 06′ E.	17.10.10	64
					Bremholmen, Hellesay,	Nwy.	69° 35′ N. 18° 02′ E.	23.1.11	162*
14.	15	5	61° 16′ N. 2° 08′ W.	B.21	Humlingsvaer, Fröien,	Nwy.	63° 44′ N. 8° 20′ E.	15.1.11	153
15	15	5	60° 58′ N. 1° 57′ W.	C.20	W. coast of Orlandet,	Nwy.	63° 41′ N. 9° 36′ E.	5.10.10	51
					N. of Smölen,	Nwy.	63° 28′ N. 7° 51′ E.	25.10.10	71
16	15	5	60° 40′ N. 1° 29′ W.	C.20	—		—	—	—
17	19	5	59° 40′ N. 3° 03′ W.	A.18	Danöen,	Nwy.	66° 03′ N. 12° 20′ E.	4.2.11	169*
					Fedje, nr. Bergen,	Nwy.	60° 46′ N. 4° 42′ E.	14.2.11	179
					Waukmill Bay, Ophir,	Ork.	58° 56′ N. 3° 05′ W.	23.2.11	188
					Gravningsund, nr. Fredrikshald,	Nwy.	59° 07′ N. 11° 22′ E.	3.3.11	196

18	19	5	59° 26′ N.	4° 07′ W.	ZZ.17	——		—		—	—
19	19	5	59° 14′ N.	4° 57′ W.	ZZ.17	——		—		—	—
20	20	5	58° 15′ N.	5° 52′ W.	YY.15	Crossbost, Lewis,	Sc.	58° 06′ N.	6° 28′ W.	25.8.10	5
21	22	5	58° 43′ N.	8° 00′ W.	WW.16	nr. Blokhus, Ervik, Stadtlandet, Melingsvaag, nr. Stavanger,	Dk. Nwy. Nwy.	57° 16′ N. 62° 10′ N. 59° 02′ N.	9° 36′ E. 5° 07′ E. 5° 45′ E.	3.2.11 2.3.11 5.8.11	165 192 348
22	23	5	58° 43′ N.	9° 06′ W.	UU.16	Pindön,	Sw.	58° 40′ N.	11° 13′ E.	20.7.11	331
23	23	5	58° 43′ N.	9° 45′ W.	UU.16	Copinshay, Mollösund, Bohuslan,	Ork. Sw.	58° 54′ N. 58° 04′ N.	2° 41′ W. 11° 29′ E.	28.10.10 30.8.11	66 372
24	24	5	57° 59′ N.	10° 34′ W.	TT.14	Newark Bay, Sanday,	Ork.	59° 16′ N.	2° 30′ W.	29.10.10	66
25	25	5	57° 44′ N.	9° 00′ W.	VV.14	Pierowall Bay, Westray,	Ork.	59° 19′ N.	2° 59′ W.	17.10.10	53
26	25	5	57° 47′ N.	8° 34′ W.	VV.14	Grenetote, N. Uist,	Sc.	57° 37′ N.	7° 27′ W.	22.9.10	28
27	25	5	57° 57′ N.	8° 11′ W.	VV.14	nr. Marwick Hd., Handa Is., Sutherland,	Ork. Sc.	59° 05′ N. 58° 23′ N.	3° 21′ W. 5° 10′ W.	3.10.10 12.10.10	39 48
28	25	5	58° 09′ N.	7° 42′ W.	WW.15	Sheabost Bay, Lewis,	Sc.	58° 20′ N.	6° 42′ W.	28.9.10	34
29	26	5	58° 24′ N.	7° 13′ W.	WW.15	——		—		—	—
						SEPTEMBER 1910.					
1	27	10	58° 12′ N.	0° 13′ E.	E.15	Boddam Voe, Dunrossness, Newark, Sanday, Tarven, nr. Trondhjem,	Sh. Ork. Nwy.	59° 56′ N. 59° 17′ N. 63° 50′ N.	1° 15′ W. 2° 28′ W. 9° 30′ E.	7.12.10 11.12.10 4.4.11	71 75 189*
2	27	10	58° 06′ N.	0° 15′ E.	E.15	8½′ W. of Skagen, Malmön, Outer Vigten, Namdalen, Borge, Lofoten,	Dk. Sw. Nwy. Nwy.	57° 42′ N. 58° 20′ N. 64° 56′ N. 68° 19′ N.	10° 28′ E. 11° 20′ E. 10° 54′ E. 13° 43′ E.	14.2.11 1.3.11 20.3.11 31.3.11	140* 155* 174* 185*
3	27	10	58° 04′ N.	0° 32′ E.	E.15	Newark, Sanday, Storvik, Helgeland,	Ork. Nwy.	59° 16′ N. 65° 35′ N.	2° 30′ W. 12° 15′ E.	11.12.10 8.9.11	75 346*

Station No.	Day of Month.	No. of Drifters.	LIBERATIONS. Position of Station. Latit. & Long.	Rect. Area.	RECOVERIES. Place-Name.		Position. Latit. & Long.	Date. D. M. Y.	Drift-Period (days).
					OCTOBER 1910.				
1	21	10	56° 55′ N. 1° 08′ W.	C.12	Belhelvie, Aberdeen,	Sc.	57° 16′ N. 2° 01′ W.	28.10.10	7
					,, ,,	,,	,, ,,	29.10.10	8
					,, ,,	,,	,, ,,	,,	,,
					Donmouth, Aberdeen,	Sc.	57° 11′ N. 2° 05′ W.	30.10.10	9
					Belhelvie, Aberdeen,	Sc.	57° 16′ N. 2° 01′ W.	31.10.10	10
					,, ,,	,,	,, ,,	2.11.10	12
					NOVEMBER 1910.				
1	3	10	57° 52′ N. 1° 43′ W.	C.14	Thyboron Canal,	Dk.	56° 44′ N. 8° 14′ E.	8.3.11	125*
					,, ,,	,,	,, ,,	21.3.11	138*
2	3	10	58° 06′ N. 1° 38′ W.	C.15	Hafstensund, Bohuslan,	Sw.	58° 45′ N. 11° 10′ E.	16.7.11	255*
					,, ,,	,,	,, ,,	9.5.16	2014*
3	3	10	58° 21′ N. 1° 33′ W.	C.15	Forvie, Aberdeen,	Sc.	57° 21′ N. 1° 56′ W.	15.12.10	42
					,, ,,	,,	,, ,,	16.12.10	43
					Whinnyfold, Aberdeen,	Sc.	57° 23′ N. 1° 52′ W.	16.12.10	43
					Slettestrand,	Dk.	57° 10′ N. 9° 24′ E.	5.3.11	122*
					Höjen,	Dk.	57° 45′ N. 10° 33′ E.	7.6.11	216*
4	4	10	58° 36′ N. 1° 29′ W.	C.16	N. Koster, Bohuslan,	Sw.	58° 52′ N. 11° 00′ E.	26.3.11	142*
5	4	10	58° 51′ N. 1° 24′ W.	C.16	Stonehaven, Kincardine,	Sc.	56° 58′ N. 2° 12′ W.	9.12.10	35
					Gourdon, Kincardine,	Sc.	56° 49′ N. 2° 17′ W.	10.12.10	36
6	4	10	59° 05′ N. 1° 18′ W.	C.17	—		—	—	—
7	4	10	59° 20′ N. 1° 13′ W.	C.17	Belhelvie, Aberdeen,	Sc.	57° 16′ N. 2° 01′ W.	12.12.10	38
					nr. Belhelvie, Aberdeen,	Sc.	57° 17′ N. 2° 00′ W.	12.12.10	38

8	4	10	59° 20′ N.	1° 03′ W.	C.17	nr. Donmouth, Aberdeen,	Sc.	57° 12′ N.	2° 04′ W.	9.12.10	35
9	28	20	56° 08′ N.	2° 48′ W.	B.11	nr. Dunbar, Haddington,	Sc.	56° 02′ N.	2° 37′ W.	3.12.10	5*
						,, ,, ,,	,,	,,	,,	5.12.10	7*
						,, ,, ,,	,,	,,	,,	,,	,,*
						St. Monans, Fife,	Sc.	56° 12′ N.	2° 46′ W.	5.12.10	7*
						,, ,, ,,	,,	,,	,,	,,	,,*
						Elie, Fife,	Sc.	56° 11′ N.	2° 48′ W.	5.12.10	7*
						nr. mouth of River Leven, Fife,	Sc.	56° 12′ N.	2° 59′ W.	5.12.10	7*
						Buckhaven, Fife,	Sc.	56° 10′ N.	3° 02′ W.	11.12.10	13*
						Kirkcaldy, Fife,	Sc.	56° 17′ N.	3° 09′ W.	11.12.10	13*
						DECEMBER 1910.					
1	7	5	56° 16′ N.	2° 17′ W.	B.11	Kinshaldy, Fife,	Sc.	56° 25′ N.	2° 48′ W.	11.12.10	4
						nr. mouth of River Eden, Fife,	Sc.	56° 24′ N.	2° 49′ W.	13.12.10	6
						,, ,, ,, ,,	,,	56° 22′ N.	2° 49′ W.	17.12.10	10
2	7	5	56° 20′ N.	1° 49′ W.	C.11	Montrose, Forfar,	Sc.	56° 43′ N.	2° 27′ W.	11.12.10	4
						,,	,,	,,	,,	,,	,,
						nr. mouth of River Ythan, Aberdeen,	Sc.	57° 19′ N.	1° 58′ W.	19.12.10	12
3	7	5	56° 24′ N.	1° 21′ W.	C.11	nr. mouth of River Ythan, Aberdeen,	Sc.	57° 18′ N.	2° 00′ W.	14.12.10	7
						,, ,, ,, ,, ,,	,,	,,	,,	,,	,,
						Bulbjerg,	Dk.	57° 09′ N.	9° 02′ E.	16.4.11	130
4	7	5	56° 28′ N.	0° 53′ W.	D.11	Faarup, nr. Lökken,	Dk.	57° 09′ N.	9° 16′ E.	25.2.11	80
						Vorupör, Thisted,	Dk.	56° 57′ N.	8° 22′ E.	5.7.11	210
5	8	5	56° 35′ N.	0° 10′ W.	D.12	Svangen Lt., Bohuslan,	Sw.	58° 48′ N.	11° 07′ E.	6.3.11	88
						nr. Morup, Hallanslan,	Sw.	56° 55′ N.	12° 22′ E.	24.10.11	320
6	8	5	56° 42′ N.	0° 35′ E.	E.12	Lönstrup, nr. Hjörring,	Dk.	57° 28′ N.	9° 49′ E.	22.2.11	76
						nr. Blokhus,	Dk.	57° 20′ N.	9° 41′ E.	24.2.11	78
						Skagen,	Dk.	57° 44′ N.	10° 32′ E.	2.3.11	84
7	8	5	56° 48′ N.	1° 19′ E.	F.12	Skagen,	Dk.	57° 44′ N.	10° 32′ E.	12.3.13	825
8	8	5	57° 24′ N.	1° 07′ E.	F.13	2′ S. of Hantsholm,	Dk.	57° 06′ N.	8° 35′ E.	3.2.11	57
						Thyboron Canal,	Dk.	56° 44′ N.	8° 14′ E.	7.2.11	61
						Tenungen Lt., Bohuslan,	Sw.	58° 34′ N.	11° 15′ E.	20.3.11	102

LIBERATIONS.						RECOVERIES.					
Station No.	Day of Month.	No. of Drifters.	Position of Station. Latit. & Long.		Rect. Area.	Place-Name.		Position. Latit. & Long.		Date. D. M. Y.	Drift-Period (days).
						FEBRUARY 1911.					
1	10	5	56° 16′ N.	2° 17′ W.	B.11	nr. Whitby, Yorks.,	E.	54° 30′ N.	0° 38′ W.	10.4.11	59
2	10	5	56° 20′ N.	1° 49′ W.	C.11	Rörö, nr. Göteborg,	Sw.	57° 47′ N.	11° 36′ E.	9.11.11	272
						btw. Lysekil & Smögen, Bohuslan,	Sw.	58° 20′ N.	11° 20′ E.	30.11.12	659
3	10	5	56° 24′ N.	1° 21′ W.	C.11	—		—		—	—
4	11	5	56° 28′ N.	0° 53′ W.	D.11	Vejrs Strand,	Dk.	55° 38′ N.	8° 07′ E.	10.9.11	211
						Lindesnaes,	Nwy.	57° 59′ N.	7° 03′ E.	10.12.11	302
5	11	5	56° 35′ N.	0° 10′ W.	D.12	Nyminde Gab,	Dk.	55° 47′ N.	8° 11′ E.	15.9.11	216
						Herö, Bohuslan,	Sw.	58° 01′ N.	11° 27′ E.	29.2.12	383
6	11	5	56° 42′ N.	0° 35′ E.	E.12	Dröbak, Christiania Fjord,	Nwy.	59° 40′ N.	10° 38′ E.	26.6.11	135
7	11	10	56° 48′ N.	1° 19′ E.	F.12	nr. Lyngvig Lt.,	Dk.	55° 56′ N.	8° 09′ E.	23.4.11	71
						nr. Rubjerg Lt.,	Dk.	57° 26′ N.	9° 46′ E.	1.5.11	79
						N. Koster, Bohuslan,	Sw.	58° 54′ N.	11° 00′ E.	8.5.11	86
						Lökken,	Dk.	57° 22′ N.	9° 42′ E.	13.5.11	91
						nr. Old Skagen,	Dk.	57° 43′ N.	10° 32′ E.	5.7.11	144
						Vesterhavet, Blaavandshuk,	Dk.	56° 04′ N.	8° 15′ E.	29.8.11	199
						nr. Bovbjerg Lt.,	Dk.	56° 32′ N.	8° 07′ E.	7.9.11	208
						Musö, Bohuslan,	Sw.	58° 38′ N.	11° 15′ E.	13.5.15	1552
8	11	10	57° 24′ N.	1° 07′ E.	F.13	Rodhus,	Dk.	57° 16′ N.	9° 35′ E.	17.4.11	65
						Thyboron Canal,	Dk.	56° 44′ N.	8° 14′ E.	25.4.11	73
						Lönstrup,	Dk.	57° 28′ N.	9° 48′ E.	1.5.11	79
						Tromö Is.,	Nwy.	58° 26′ N.	8° 50′ E.	5.5.11	83
						Otterö, Bohuslan,	Sw.	58° 40′ N.	11° 10′ E.	14.5.11	92

9	12	10	57° 59′ N.	0° 57′ E.	E.14	nr. Bovbjerg Lt.,	Dk.	56° 30′ N.	8° 08′ E.	25.4.11	72
						N. Koster, Bohuslan,	Sw.	58° 54′ N.	11° 00′ E.	9.5.11	86
						Nordstrand Is.,	Schl.-Holst.	54° 31′ N.	8° 50′ E.	7.6.11	115
						Rörö, nr. Göteborg,	Sw.	57° 47′ N.	11° 36′ E.	1.7.11	139
						Selöy, Helgeland,	Nwy.	66° 35′ N.	12° 46′ E.	13.10.11	243*
10	12	10	58° 42′ N.	1° 44′ E.	F.16	Tranum,	Dk.	57° 10′ N.	9° 25′ E.	7.5.11	84
						nr. Hirtshals,	Dk.	57° 36′ N.	10° 01′ E.	3.6.11	111
						Nordstrand Is.,	Schl.-Holst.	54° 31′ N.	8° 50′ E.	7.6.11	115
						13′ N. of Blaavandshuk,	Dk.	55° 46′ N.	8° 11′ E.	20.6.11	128
						nr. Hirtshals,	Dk.	57° 35′ N.	9° 55′ E.	6.7.11	144
						Egerö Lt., Egersund,	Nwy.	58° 27′ N.	5° 59′ E.	26.10.11	256
						Ulvingten, Helgeland,	Nwy.	65° 37′ N.	12° 09′ E.	10.11.11	271*
11	12	10	58° 34′ N.	0° 47′ E.	E.16	nr. Marsten Lt.,	Nwy.	60° 10′ N.	5° 00′ E.	13.3.11	29
						nr. Blokhus,	Dk.	57° 20′ N.	9° 40′ E.	17.4.11	64
						The Skaw,	Dk.	57° 45′ N.	10° 34′ E.	17.4.11	64
						Lysekil, Bohuslan,	Sw.	58° 17′ N.	11° 25′ E.	23.4.11	70
						N. Koster, Bohuslan,	Sw.	58° 54′ N.	11° 00′ E.	8.5.11	85
						Gjesöen, W. Sandöen,	Nwy.	58° 36′ N.	9° 02′ E.	26.7.11	164
12	12	5	58° 26′ N.	0° 08′ W.	D.15	nr. Thyboron,	Dk.	56° 43′ N.	8° 13′ E.	22.4.11	69
						nr. Dynekilen, Strömstad,	Sw.	59° 00′ N.	11° 13′ E.	22.5.11	99
						Blokhus,	Dk.	57° 16′ N.	9° 35′ E.	7.7.11	145
						Söndervig,	Dk.	58° 06′ N.	8° 07′ E.	14.7.11	152
13	12	5	58° 17′ N.	1° 03′ W.	C.15	nr. Thorup,	Dk.	57° 09′ N.	9° 16′ E.	15.8.11	184
						Biörnö, nr. Trondhjem,	Nwy.	63° 34′ N.	9° 28′ E.	28.8.11	197*
14	13	5	58° 08′ N.	2° 00′ W.	C.15	Hvalöer,	Nwy.	59° 05′ N.	10° 48′ E.	29.8.11	197
15	13	5	58° 00′ N.	2° 54′ W.	B.15	—		—		—	—
16	18	20	58° 10′ N.	2° 55′ W.	B.15	Klim Strand,	Dk.	57° 09′ N.	9° 13′ E.	6.9.11	200
						Tryggö, Bohuslan,	Sw.	58° 24′ N.	11° 13′ E.	28.3.12	404
17	19	10	57° 56′ N.	2° 27′ W.	B.14	Ulvösund, nr. Christiansand,	Nwy.	58° 07′ N.	8° 13′ E.	9.3.12	384
						nr. Marstrand, Bohuslan,	Sw.	57° 50′ N.	11° 41′ E.	28.3.12	403
18	19	10	57° 44′ N.	1° 58′ W.	C.14	btw. Söndervig & Bjergehuse,	Dk.	56° 15′ N.	8° 07′ E.	11.9.11	204
						Vorupör, Thisted,	Dk.	56° 57′ N.	8° 22′ E.	6.10.11	229
						Fykan, Bohuslan,	Sw.	58° 25′ N.	11° 14′ E.	12.11.11	266

LIBERATIONS.						RECOVERIES.					
Station No.	Day of Month.	No. of Drifters.	Position of Station. Latit. & Long.		Rect. Area.	Place-Name.		Position. Latit. & Long.		Date. D. M. Y.	Drift-Period (days).
						MARCH 1911.					
1	14	10	58° 10′ N.	2° 55′ W.	B.15	nr. Embo, Sutherland,	Sc.	57° 55′ N.	4° 00′ W.	19.3.11	5
						,, ,, ,,	,,	,,	,,	,,	,,
						nr. Golspie, Sutherland,	Sc.	57° 58′ N.	3° 59′ W.	20.3.11	6
						,, ,, ,,	,,	,,	,,	,,	,,
						,, ,, ,,	,,	,,	,,	,,	,,
2	21	10	56° 17′ N.	1° 58′ W.	C.11	Cockenzie, Haddington,	Sc.	55° 58′ N.	2° 56′ W.	3.4.11	13
						nr. Dunbar, Haddington,	Sc.	56° 00′ N.	2° 32′ W.	4.4.11	14
						Tyne Sands, Haddington,	Sc.	56° 00′ N.	2° 35′ W.	5.4.11	15
						Peffersands, Haddington,	Sc.	56° 02′ N.	2° 37′ W.	11.4.11	21
						1′ N. of Fife Ness,	Sc.	56° 17′ N.	2° 36′ W.	19.4.11	29
3	28	10	56° 22′ N.	1° 33′ W.	C.11	Goswick, Northumberland,	E.	55° 42′ N.	1° 54′ W.	8.4.11	11
						,, ,,	,,	,,	,,	,,	,,
						,, ,,	,,	,,	,,	,,	,,
						,, ,,	,,	,,	,,	,,	,,
						Northumberland coast at Holy Is.,	E.	55° 41′ N.	1° 53′ W.	17.4.11	20
						Holy Is., Northumberland,	E.	55° 41′ N.	1° 48′ W.	1.5.11	34
4	28	10	56° 40′ N.	1° 20′ W.	C.12	nr. Immanuel Hd., Holy Is.,	E.	55° 42′ N.	1° 48′ W.	10.4.11	13
						,, ,, ,, ,, ,,	,,	,,	,,	,,	,,
						Beal, Northumberland,	E.	55° 41′ N.	1° 52′ W.	12.4.11	15
						Scremerston, Northumberland,	E.	55° 44′ N.	1° 58′ W.	12.4.11	15
						Goswick, Northumberland,	E.	55° 42′ N.	1° 54′ W.	30.4.11	33
						Holy Is., Northumberland,	E.	55° 41′ N.	1° 47′ W.	5.5.11	38
5	29	10	56° 33′ N.	2° 22′ W.	B.12	1′ N. of Fife Ness,	Sc.	56° 17′ N.	2° 36′ W.	5.4.11	7
						btw. N. Berwick & Dunbar,	Sc.	56° 02′ N.	2° 37′ W.	5.4.11	7
						,, ,, ,,	Sc.	,,	,,	,,	7
						,, ,, ,,	Sc.	,,	,,	,,	7

						N. Berwick, Haddington,	Sc.	56° 03′ N.	2° 43′ W.	7.4.11	9
						Skaterow, Haddington,	Sc.	55° 58′ N.	2° 25′ W.	8.4.11	10
						nr. Dunbar, Haddington,	Sc.	56° 00′ N.	2° 32′ W.	10.4.11	12
6	29	10	56° 56′ N.	2° 04′ W.	B.12	Dunbar, Haddington,	Sc.	56° 00′ N.	2° 32′ W.	10.4.11	12
						” ”	”	”	”	27.4.11	29
						Rören, Finmarken,	Nwy.	70° 20′ N.	22° 22′ E.	3.5.12	401*
7	29	10	56° 58′ N.	1° 36′ W.	C.12	Sordýrö, nr. Trondhjem,	Nwy.	63° 23′ N.	8° 15′ E.	8.1.12	285*
						Burö, Froöerne,	Nwy.	63° 35′ N.	8° 24′ E.	17.2.12	325*
8	29	10	57° 00′ N.	1° 10′ W.	C.13	nr. Ryvingen Lt.,	Nwy.	58° 01′ N.	7° 41′ E.	11.12.11	257*
						Andenaes, Vesteraalen,	Nwy.	69° 20′ N.	16° 12′ E.	12.5.12	410*
						Orn, Bohuslan,	Sw.	58° 22′ N.	11° 19′ E.	1 3.4.13	746*
						APRIL 1911.					
1	8	8	58° 09′ N.	1° 50′ W.	C.15	—		—		—	—
2	8	8	58° 24′ N.	2° 00′ W.	C.15	Algeröen, nr. Bergen,	Nwy.	60° 23′ N.	4° 57′ E.	15.9.11	160
3	8	8	58° 24′ N.	2° 19′ W.	B.15	Kirkehavn, Flekkefjord,	Nwy.	58° 16′ N.	6° 38′ E.	30.9.12	541
4	9	8	58° 24′ N.	2° 39′ W.	B.15	Uggerby Strand,	Dk.	57° 35′ N.	9° 57′ E.	8.10.11	182
						Vesterhavet, nr. Hantsholm,	Dk.	57° 07′ N.	8° 41′ E.	14.10.11	188
						Agdenaes, nr. Trondhjem,	Nwy.	63° 39′ N.	9° 45′ E.	15.5.12	402
5	9	8	58° 24′ N.	3° 00′ W.	B.15	Svallingen, nr. Bergen,	Nwy.	60° 27′ N.	5° 16′ E.	15.10.11	189
						Könö, nr. Lysekil,	Sw.	58° 20′ N.	11° 10′ E.	5.11.11	210
						Limfjord,	Dk.	56° 43′ N.	8° 14′ E.	21.2.12	318
						nr. Grimstad,	Nwy.	58° 20′ N.	8° 34′ E.	21.5.12	408
6	9	8	58° 31′ N.	2° 48′ W.	B.16	nr. Fredriksvarn,	Dk.	57° 28′ N.	10° 32′ E.	28.10.11	202
						Vigerö, Romsdal,	Nwy.	62° 34′ N.	6° 02′ E.	12.11.11	217
						Kulö, Edö,	Nwy.	63° 17′ N.	8° 03′ E.	27.12.11	262
7	9	8	58° 33′ N.	2° 16′ W.	B.16	nr. Christiansand,	Nwy.	58° 07′ N.	8° 06′ E.	22.9.11	166
						btw. Blokhus & Lökken,	Dk.	57° 19′ N.	9° 39′ E.	25.9.11	169
8	9	8	58° 36′ N.	1° 46′ W.	C.16	Lökken,	Dk.	57° 22′ N.	9° 42′ E.	18.8.11	131
						Smölen,	Nwy.	63° 28′ N.	8° 01′ E.	8.11.11	213

LIBERATIONS.						RECOVERIES.						
Station No.	Day of Month.	No. of Drifters.	Position of Station.			Place-Name.		Position.		Date.	Drift-Period (days).
			Latit. & Long.		Rect. Area.			Latit. & Long.		D. M. Y.	
9	11	8	59° 10′ N.	1° 27′ W.	C.17	nr. Marsten Lt.,	Nwy.	60° 06′ N.	5° 10′ E.	10.9.11	152
						Visnes, Karmö,	Nwy.	59° 21′ N.	5° 13′ E.	16.9.11	158
10	11	8	59° 20′ N.	1° 03′ W.	C.17	Sulen, Sogne Fjord,	Nwy.	61° 10′ N.	5° 00′ E.	1.12.11	234
11	11	8	59° 26′ N.	1° 20′ W.	C.17	Alden, N. Bergenhus,	Nwy.	61° 20′ N.	4° 46′ E.	8.11.11	211
						Krakhelle Sund, N. Bergenhus,	Nwy.	61° 07′ N.	5° 02′ E.	6.12.11	239
12	11	8	59° 40′ N.	1° 14′ W.	C.18	Hennöen, Nordhordland,	Nwy.	60° 41′ N.	4° 45′ E.	9.10.11	181
						Sulen, Trondhjem,	Nwy.	63° 51′ N.	8° 28′ E.	30.5.12	415
13	13	8	60° 05′ N.	0° 48′ W.	D.19	Hellisöen, Nordhordland,	Nwy.	60° 45′ N.	4° 42′ E.	7.9.11	147
						Landrö, Sotrö,	Nwy.	60° 25′ N.	4° 58′ E.	18.9.11	158
						Jöen, Namdalen,	Nwy.	64° 37′ N.	11° 16′ E.	2.11.11	203
14	17	5	58° 00′ N.	2° 54′ W.	B.15	—		—		—	—
15	19	8	58° 10′ N.	2° 55′ W.	B.15	Nairn,	Sc.	57° 35′ N.	3° 51′ W.	21.5.11	32
						Shandwick Bay, Ross,	Sc.	57° 45′ N.	3° 55′ W.	31.5.11	42
						Rosehearty, Aberdeen,	Sc.	57° 42′ N.	2° 07′ W.	9.6.11	51
						nr. St. Combs, Aberdeen,	Sc.	57° 38′ N.	1° 53′ W.	14.6.11	56
						Gourdon, Kincardine,	Sc.	56° 50′ N.	2° 17′ W.	23.6.11	65
						Covesea, nr. Lossiemouth,	Sc.	57° 44′ N.	3° 21′ W.	30.6.11	72
16	19	8	57° 58′ N.	3° 21′ W.	A.14	Nairn,	Sc.	57° 35′ N.	3° 51′ W.	21.5.11	32
						Stensholmen, Bohuslan,	Sw.	58° 35′ N.	11° 17′ E.	9.11.11	204
17	25	10	56° 17′ N.	1° 58′ W.	C.11	Druridge Bay, Northumberland,	E.	55° 17′ N.	1° 33′ W.	3.6.11	39
						btw. Saltburn & Marske, Yorks.,	E.	54° 35′ N.	0° 59′ W.	6.6.11	42
						Seaton Sluice, Northumberland,	E.	55° 05′ N.	1° 28′ W.	10.6.11	46
						nr. Redcar, Yorks.,	E.	54° 37′ N.	1° 05′ W.	15.6.11	51

MAY 1911.

1	9	5	61° 16′ N.	2° 08′ W.	B.21	Akerö, Romsdal,	Nwy.	62° 48′ N.	6° 55′ E.	18.11.13	924
2	9	5	61° 18′ N.	2° 59′ W.	B.21	Gauk Vaerö, Vesteraalen,	Nwy.	68° 37′ N.	14° 22′ E.	19.4.12	346*
						Indre Kvarö, Helgeland,	Nwy.	66° 29′ N.	12° 58′ E.	22.5.12	379*
3	9	5	61° 27′ N.	3° 42′ W.	A.21	Gimsö, Lofoten,	Nwy.	68° 19′ N.	14° 14′ E.	7.9.11	121*
						Skraaven, Lofoten,	Nwy.	68° 10′ N.	14° 45′ E.	8.11.11	183*
						Solvoröerne, Helgeland,	Nwy.	66° 23′ N.	12° 40′ E.	20.6.16	1869*
4	10	5	61° 39′ N.	4° 45′ W.	ZZ.22	Titran Fröien,	Nwy.	63° 40′ N.	8° 22′ E.	1.3.12	296
5	11	5	61° 49′ N.	5° 36′ W.	YY.22	Garsen, nr. Molde,	Nwy.	62° 50′ N.	6° 49′ E.	25.11.12	564
6	11	5	62° 00′ N.	6° 12′ W.	XX.22	Lund, Namdalen,	Nwy.	64° 46′ N.	11° 37′ E.	10.9.11	122
						Skarsjöen, Lofoten,	Nwy.	68° 05′ N.	13° 35′ E.	6.12.11	209*
7	12	5	61° 12′ N.	6° 33′ W.	XX.21	——		—		—	—
8	12	5	60° 57′ N.	5° 47′ W.	YY.20	Kvitnes, Finmarken,	Nwy.	70° 40′ N.	29° 00′ E.	2.10.14	1239*
9	12	5	60° 40′ N.	4° 50′ W.	ZZ.20	Ostnaes, Harhamsö, Romsdal,	Nwy.	62° 38′ N.	6° 17′ E.	28.7.11	77
						Smölen,	Nwy.	63° 20′ N.	7° 59′ E.	24.12.11	226
10	13	5	60° 26′ N.	4° 02′ W.	ZZ.19	Kunna, Trovarne,	Nwy.	66° 56′ N.	13° 31′ E.	27.7.11	75*
						Kvalvik, Fredö,	Nwy.	63° 06′ N.	7° 53′ E.	22.8.11	101
11	13	5	60° 17′ N.	3° 36′ W.	A.19	Edöy, Nordmor,	Nwy.	63° 19′ N.	8° 13′ E.	17.11.11	188
						Donnä, Helgeland,	Nwy.	66° 14′ N.	12° 36′ E.	4.1.12	236*
						Lingvaer, Trondhjem,	Nwy.	63° 48′ N.	8° 33′ E.	30.4.13	718
12	13	5	60° 02′ N.	3° 13′ W.	A.19	Haroldswick, Unst,	Sh.	60° 46′ N.	0° 49′ W.	31.7.11	79
						Indre Stensund, Sulen,	Nwy.	61° 05′ N.	4° 45′ E.	15.9.11	125
13	13	5	59° 46′ N.	2° 21′ W.	B.18	S. Ronaldshay,	Ork.	58° 44′ N.	2° 55′ W.	2.6.11	20
						St. Hamburgö, Bohuslan,	Sw.	58° 33′ N.	11° 16′ E.	8.8.12	453
14	16	5	61° 02′ N.	1° 10′ W.	C.21	Harö, Romsdal,	Nwy.	62° 46′ N.	6° 26′ E.	28.8.11	104
						Rusö, Batalden,	Nwy.	61° 39′ N.	4° 47′ E.	8.9.11	115
						Krovaag, Trondhjem,	Nwy.	63° 40′ N.	9° 30′ E.	4.11.11	172

LIBERATIONS.						RECOVERIES.					
Station No.	Day of Month.	No. of Drifters.	Position of Station. Latit. & Long.		Rect. Area.	Place-Name.		Position. Latit. & Long.		Date. D. M. Y.	Drift-Period (days).
15	17	5	61° 42′ N.	2° 00′ W.	C.22	nr. Bodö,	Nwy.	67° 18′ N.	14° 22′ E.	19.9.11	125*
16	17	5	61° 38′ N.	0° 41′ W.	D.22	Flemsö, nr. Aalesund,	Nwy.	62° 41′ N.	6° 16′ E.	11.8.11	86
						Soetran, nr. Agdenaes,	Nwy.	63° 35′ N.	9° 35′ E.	18.9.11	124
						Lodingen, Nordland,	Nwy.	68° 24′ N.	16° 01′ E.	31.3.13	684*
17	17	5	61° 35′ N.	0° 47′ E.	E.22	—		—		—	—
18	17	5	61° 34′ N.	2° 04′ E.	G.22	Aspö, N. Bergenhus,	Nwy.	61° 13′ N.	4° 45′ E.	15.7.11	59
						Leka, Namdalen,	Nwy.	65° 06′ N.	11° 35′ E.	21.7.11	65
						Kleppe, Gt. Kallsö,	Nwy.	60° 08′ N.	5° 06′ E.	11.8.11	86
19	18	5	61° 30′ N.	3° 03′ E.	H.22	Leksenö, Trondhjem,	Nwy.	63° 35′ N.	9° 19′ E.	24.7.11	67
20	18	5	61° 35′ N.	3° 35′ E.	H.22	Veiholmen, nr. Smölen,	Nwy.	63° 31′ N.	7° 58′ E.	3.7.11	46
						Valdusund, Jossund,	Nwy.	63° 52′ N.	9° 49′ E.	7.7.11	50
21	18	5	61° 35′ N.	4° 05′ E.	J.22	Vaagö, Fröien,	Nwy.	63° 45′ N.	8° 35′ E.	27.6.11	40
						Dyrö, nr. Smölen,	Nwy.	63° 22′ N.	8° 13′ E.	23.8.11	97
22	18	5	61° 06′ N.	2° 01′ E.	G.21	—		—		—	—
23	18	5	60° 45′ N.	2° 30′ E.	G.20	nr. Torgvaer, Brönnöy,	Nwy.	65° 23′ N.	12° 02′ E.	10.6.12	389
24	19	5	60° 35′ N.	0° 29′ E.	E.20	Bremnes, Fröien,	Nwy.	63° 44′ N.	8° 40′ E.	30.8.11	103
						Odden, Nordmor,	Nwy.	62° 55′ N.	6° 54′ E.	14.9.11	118
25	19	5	60° 04′ N.	0° 33′ E.	E.19	—		—		—	—
26	19	5	59° 31′ N.	0° 37′ E.	E.18	Bjerregaard,	Dk.	55° 51′ N.	8° 10′ E.	15.9.11	119
27	19	5	58° 55′ N.	0° 04′ E.	E.16	Thorup,	Dk.	57° 09′ N.	9° 16′ E.	29.9.11	133
28	20	5	58° 11′ N.	0° 32′ W.	D.15	nr. Hantsholm,	Dk.	57° 07′ N.	8° 40′ E.	15.10.11	148

29	20	5	57° 30′ N.	1° 19′ W.	C.14	—		—		—	—
30	23	5	58° 05′ N.	2° 25′ W.	B.15	Portsoy, Banff,	Sc.	57° 41′ N.	2° 42′ W.	25.6.11	33
31	23	5	58° 17′ N.	1° 03′ W.	C.15	Lökken,	Dk.	57° 22′ N.	9° 42′ E.	12.10.11	142
						Slevik, nr. Fredrikstad,	Nwy.	59° 10′ N.	10° 48′ E.	6.11.11	167
						Asmalö, Hvalöerne,	Nwy.	59° 05′ N.	11° 00′ E.	18.3.12	300
32	24	5	58° 34′ N.	0° 47′ E.	E.16	Vangsaa, nr. Hantsholm,	Dk.	57° 01′ N.	8° 27′ E.	20.9.11	119
						Vigerö, nr. Aalesund,	Nwy.	62° 33′ N.	6° 01′ E.	11.11.11	171
33	24	5	58° 42′ N.	1° 44′ E.	F.16	—		—		—	—
34	24	5	57° 59′ N.	0° 57′ E.	E.14	nr. Bovbjerg Lt.,	Dk.	56° 31′ N.	8° 07′ E.	14.9.11	113
						Gronhoy, nr. Rubjerg,	Dk.	57° 19′ N.	9° 38′ E.	26.10.11	155
						Glesvaer, Gt. Sotrö,	Nwy.	60° 13′ N.	5° 00′ E.	20.12.11	210
35	24	5	57° 24′ N.	1° 07′ E.	F.13	—		—		—	—
36	25	5	56° 48′ N.	1° 19′ E.	F.12	—		—		—	—
37	25	5	56° 35′ N.	0° 10′ W.	D.12	—		—		—	—
38	25	6	56° 28′ N.	0° 53′ W.	D.11	—		—		—	—
39	25	5	56° 24′ N.	1° 21′ W.	C.11	—		—		—	—
40	25	5	56° 20′ N.	1° 49′ W.	C.11	. . . . .	At Sea.	55° 23′ N.	0° 20′ E.	4.8.11	71
41	25	5	56° 16′ N.	2° 17′ W.	B.11	—		—		—	—
						JUNE 1911.					
1	1	10	58° 26′ N.	0° 08′ W.	D.15	Brandesund, nr. Bergen,	Nwy.	60° 15′ N.	5° 10′ E.	30.10.11	151
						nr. Mollösund, Bohuslan,	Sw.	58° 04′ N.	11° 29′ E.	9.11.11	161
						nr. Aalesund,	Nwy.	62° 35′ N.	6° 07′ E.	17.9.12	474
2	2	10	58° 26′ N.	0° 08′ W.	D.15	nr. Fedje, Bergenhus,	Nwy.	60° 50′ N.	4° 37′ E.	7.9.11	97
						nr. Bovbjerg Lt.,	Dk.	56° 31′ N.	8° 07′ E.	14.9.11	104
						Svinklov,	Dk.	57° 09′ N.	9° 19′ E.	11.10.11	131

LIBERATIONS.					RECOVERIES.				
Station No.	Day of Month.	No. of Drifters.	Position of Station. Latit. & Long.	Position of Station. Rect. Area.	Place-Name.		Position. Latit. & Long.	Date. D. M. Y.	Drift-Period (days).
3	10	10	58° 26′ N. 0° 08′ W.	D.15	Lilores, Forstrand,	Dk.	56° 35′ N. 8° 08′ E.	19.9.11	101
					Thorup,	Dk.	57° 09′ N. 9° 16′ E.	30.9.11	112
4	12	10	58° 26′ N. 0° 08′ W.	D.15	—		—	—	—
5	19	10	56° 17′ N. 1° 58′ W.	C.11	nr. Lyngvig Lt.,	Dk.	56° 09′ N. 8° 06′ E.	10.12.11	174
					Dverberg, Andöen,	Nwy.	69°.07′ N. 15° 16′ E.	12.8.12	420*
					JULY 1911.				
1	6	5	59° 10′ N. 1° 27′ W.	C.17	nr. Grimstad,	Nwy.	58° 18′ N. 8° 36′ E.	28.11.12	511
2	6	5	59° 26′ N. 1° 21′ W.	C.17	—		—	—	—
3	6	5	59° 40′ N. 1° 14′ W.	C.18	—		—	—	—
4	13	8	56° 16′ N. 1° 15′ W.	C.11	Kragsundsgap, Orust,	Sw.	58° 02′ N. 11° 32′ E.	9.11.11	119
5	14	8	56° 20′ N. 0° 20′ W.	D.11	—		—	—	—
6	14	8	56° 23′ N. 0° 32′ E.	E.11	—		—	—	—
7	14	8	56° 25′ N. 1° 32′ E.	F.11	—		—	—	—
8	14	8	56° 29′ N. 2° 31′ E.	G.11	Klitmöller,	Dk.	57° 03′ N. 8° 31′ E.	29.9.11	77
					Entrance to Sogne Fjord,	Nwy.	61° 05′ N. 5° 10′ E.	10.11.11	119
					Gravningsund,	Nwy.	59° 07′ N. 11° 22′ E.	12.11.11	121
9	14	8	56° 32′ N. 3° 30′ E.	H.12	nr. Höjen,	Dk.	57° 42′ N. 10° 29′ E.	18.9.11	66
					nr. Christiansand,	Nwy.	58° 10′ N. 8° 00′ E.	5.11.11	114

10	14	8	57° 25′ N.	3° 35′ E.	H.13	nr. Hantsholm,	Dk.	57° 06′ N.	8° 35′ E.	7.9.11	55
						nr. Thyboron Canal,	Dk.	56° 42′ N.	8° 12′ E.	8.9.11	56
						Söndervig,	Dk.	56° 08′ N.	8° 06′ E.	15.9.11	63
11	19	10	56° 55′ N.	1° 08′ W.	C.12	Soröen, Finmarken,	Nwy.	70° 38′ N.	22° 00′ E.	25.2.13	587*
12	19	5	57° 24′ N.	0° 54′ W.	D.13	Sandö, Hvalöerne,	Nwy.	59° 01′ N.	11° 06′ E.	6.11.11	110
13	19	5	57° 53′ N.	0° 38′ W.	D.14	nr. Marstrand,	Sw.	57° 53′ N.	11° 35′ E.	9.11.11	113
14	19	5	58° 22′ N.	0° 23′ W.	D.15	—		—		—	—
15	19	5	58° 28′ N.	0° 10′ W.	D.15	—		—		—	—
16	19	5	58° 44′ N.	0° 11′ E.	E.16	—		—		—	—
17	20	5	58° 57′ N.	0° 30′ E.	E.16	nr. Veiholmen,	Nwy.	63° 31′ N.	7° 57′ E.	12.10.11	84
18	21	5	57° 45′ N.	1° 15′ W.	C.14	Hamneskars Lt., Bohuslan,	Sw.	57° 54′ N.	11° 29′ E.	16.10.11	87
						Grafvarne, Bohuslan,	Sw.	58° 21′ N.	11° 14′ E.	3.11.11	105
						AUGUST 1911.					
1	8	5	58° 23′ N.	1° 38′ E.	F.15	—		—		—	—
2	8	5	58° 42′ N.	1° 44′ E.	F.16	nr. Bovbjerg Lt.,	Dk.	56° 29′ N.	8° 07′ E.	14.10.11	67
						Fjertoft, nr. Aalesund,	Nwy.	62° 42′ N.	6° 20′ E.	28.1.12	173
3	9	5	59° 26′ N.	1° 47′ E.	F.17	Kvernö, Sogne Fjord,	Nwy.	60° 57′ N.	4° 48′ E.	11.10.11	63
						Moss,	Nwy.	59° 26′ N.	10° 40′ E.	6.11.11	89
						S. Hellsö, nr. Strömstad,	Sw.	58° 55′ N.	11° 09′ E.	25.8.12	382
4	9	5	59° 07′ N.	1° 15′ E.	F.17	Hillesöen, Bergenhus,	Nwy.	61° 39′ N.	4° 51′ E.	28.9.11	50
						Hvalöerne,	Nwy.	59° 05′ N.	11° 00′ E.	8.3.13	577
5	9	5	59° 31′ N.	0° 37′ E.	E.18	Ramsvik, Hunnebostrand,	Sw.	58° 27′ N.	11° 18′ E.	7.11.11	90
						btw. Arendal & Grimstad,	Nwy.	58° 20′ N.	8° 41′ E.	20.11.11	103
6	10	5	60° 07′ N.	0° 32′ E.	E.19	—		—		—	—
7	10	5	60° 34′ N.	1° 13′ E.	F.20	Skavö, N. Bergenhus,	Nwy.	61° 55′ N.	5° 02′ E.	13.11.11	95
						Skarvö, Hittern,	Nwy.	63° 35′ N.	8° 31′ E.	15.3.12	218

LIBERATIONS.						RECOVERIES.					
Station No.	Day of Month.	No. of Drifters.	Position of Station.			Place-Name.		Position.		Date.	Drift-Period (days).
			Latit. & Long.		Rect. Area.			Latit. & Long.		D. M. Y.	
8	10	5	60° 57′ N.	0° 37′ E.	E.20	Gt. Sotrö, nr. Bergen,	Nwy.	60° 19′ N.	4° 55′ E.	18.12.12	496
9	11	5	60° 58′ N.	1° 00′ W.	D.20	Skorö, nr. Tromsö,	Nwy.	70° 08′ N.	20° 00′ E.	20.6.12	314*
10	11	5	61° 08′ N.	1° 20′ W.	C.21	nr. Vadsö, Varanger Fjord,	Nwy.	70° 04′ N.	29° 45′ E.	30.5.13	658*
11	11	5	61° 17′ N.	1° 22′ W.	C.21	Titran, Fröien,	Nwy.	63° 40′ N.	8° 22′ E.	31.12.11	142
12	12	5	60° 42′ N.	0° 00′ W.	E.20	—		—		—	—
13	18	5	58° 55′ N.	5° 37′ W.	YY.16	—		—		—	—
14	21	5	58° 34′ N.	5° 36′ W.	YY.16	btw. Brough Hd. & Marwick Hd.,	Ork.	59° 07′ N.	3° 21′ W.	3.9.11	13
						Houton Cove, Ophir,	Ork.	58° 55′ N.	3° 11′ W.	15.10.11	55
15	21	5	58° 29′ N.	6° 51′ W.	XX.15	—		—		—	—
16	22	5	58° 20′ N.	7° 21′ W.	WW.15	nr. Moul Hd.,	Ork.	58° 59′ N.	2° 42′ W.	15.10.11	54
17	22	5	58° 35′ N.	7° 37′ W.	WW.16	—		—		—	—
18	23	5	59° 15′ N.	7° 10′ W.	WW.17	Skjötningsberg, Finmarken,	Nwy.	71° 02′ N.	26° 30′ E.	17.6.12	299*
19	23	10	59° 50′ N.	6° 16′ W.	XX.18	Veiholmen,	Nwy.	63° 31′ N.	7° 58′ E.	13.10.11	51
20	23	10	60° 07′ N.	5° 45′ W.	YY.19	Nykvaag, Vesteraalen,	Nwy.	68° 47′ N.	14° 29′ E.	23.11.12	458*
21	24	5	59° 30′ N.	3° 40′ W.	A.18	Quendale Sand,	Sh.	59° 54′ N.	1° 20′ W.	24.9.11	31
22	28	5	58° 57′ N.	4° 08′ W.	ZZ.16	Dragö, Svesfjorden,	Nwy.	64° 30′ N.	10° 46′ E.	8.2.12	164
23	28	5	59° 16′ N.	3° 50′ W.	A.17	Moldö, Fröien,	Nwy.	63° 51′ N.	8° 40′ E.	7.6.12	284

SEPTEMBER 1911.

1	11	10	56° 17′ N.	1° 58′ W.	C.11	nr. Hartlepool, Durham,	E.	54° 42′ N.	1° 12′ W.	7.10.11	26
						nr. Robin Hood's Bay, Yorks.,	E.	54° 27′ N.	0° 32′ W.	9.10.11	28
						W. Hartlepool, Durham,	E.	54° 42′ N.	1° 12′ W.	14.10.11	33
						Skinningrove, Yorks.,	E.	54° 34′ N.	0° 53′ W.	20.10.11	39
						Vigten, Namdalen,	Nwy.	64° 45′ N.	10° 45′ E.	5.10.12	390*
						Dverberg, Andöen,	Nwy.	69° 07′ N.	15° 16′ E.	19.4.13	586*
2	12	10	56° 23′ N.	1° 26′ W.	C.11	Herlö, S. Bergenhus,	Nwy.	60° 32′ N.	5° 00′ E.	17.12.12	462*
3	12	10	56° 32′ N.	1° 27′ W.	C.12	btw. Marske & Redcar, Yorks.,	E.	54° 36′ N.	1° 02′ W.	28.10.11	46
						Staithes, Yorks.,	E.	54° 33′ N.	0° 47′ W.	29.10.11	47
4	12	10	56° 43′ N.	1° 30′ W.	C.12	Linesöen, Björnör,	Nwy.	64° 00′ N.	9° 56′ E.	29.1.12	139*
						Haramsö, nr. Aalesund,	Nwy.	62° 39′ N.	6° 16′ E.	5.2.12	146*
5	12	10	56° 53′ N.	1° 32′ W.	C.12	Sveggen, nr. Kristiansund,	Nwy.	63° 06′ N.	7° 37′ E.	31.1.12	141*
6	12	10	57° 03′ N.	1° 34′ W.	C.13	—		—		—	—*
7	12	10	57° 13′ N.	1° 36′ W.	C.13	Veiholmen,	Nwy.	63° 31′ N.	7° 58′ E.	1.3.12	171
						Vedö, Hittern,	Nwy.	63° 32′ N.	9° 13′ E.	19.3.12	189*
						Hammervik, S. Fröya,	Nwy.	63° 41′ N.	8° 41′ E.	20.3.12	190
8	12	10	57° 22′ N.	1° 39′ W.	C.13	Blyth, Northumberland,	E.	55° 08′ N.	1° 30′ W.	28.10.11	46
						Humlingsvaer, Fröien,	Nwy.	63° 44′ N.	8° 20′ E.	13.2.12	154*
						Risö, nr. Tromsö,	Nwy.	69° 33′ N.	18° 43′ E.	10.5.12	241*
9	12	10	57° 31′ N.	1° 41′ W.	C.14	S. Shields, Durham,	E.	55° 00′ N.	1° 26′ W.	28.10.11	46
						Harö, Romsdal,	Nwy.	62° 45′ N.	6° 27′ E.	16.4.12	217*
10	12	10	57° 42′ N.	1° 59′ W.	C.14	S. Hatö, N. Fröya,	Nwy.	63° 39′ N.	9° 19′ E.	16.4.12	217*
						Langenaes, Vesteraalen,	Nwy.	69° 01′ N.	15° 10′ E.	26.4.12	227*
						Binnerö, Namdalen,	Nwy.	64° 53′ N.	10° 41′ E.	23.5.12	254*
11	15	10	57° 58′ N.	3° 21′ W.	A.14	nr. Fraserburgh, Aberdeen,	Sc.	57° 41′ N.	1° 59′ W.	2.10.11	17
12	19	10	58° 10′ N.	2° 55′ W.	B.15	nr. Fraserburgh, Aberdeen,	Sc.	57° 41′ N.	1° 59′ W.	4.10.11	15

LIBERATIONS.						RECOVERIES.					
Station No.	Day of Month.	No. of Drifters.	Position of Station. Latit. & Long.		Rect. Area.	Place-Name.		Position. Latit. & Long.		Date. D. M. Y.	Drift-Period (days).
						OCTOBER 1911.					
1	11	12	58° 10′ N.	2° 55′ W.	B.15	Latheron, Caithness,	Sc.	58° 17′ N.	3° 20′ W.	21.10.11	10
						" "	"	"	"	"	"
						" "	"	"	"	31.10.11	20
2	12	5	58° 30′ N.	2° 47′ W.	B.16	Waukmill Bay, Ophir,	Ork.	58° 56′ N.	3° 05′ W.	27.10.11	15
3	12	5	58° 42′ N.	2° 25′ W.	B.16	—		—		—	—
4	12	5	58° 54′ N.	2° 05′ W.	B.16	Papa Stronsay,	Ork.	59° 09′ N.	2° 35′ W.	23.10.11	11
						Eday,	Ork.	59° 10′ N.	2° 45′ W.	30.10.11	18
5	12	5	59° 06′ N.	1° 43′ W.	C.17	Elsness, Sanday,	Ork.	59° 13′ N.	2° 34′ W.	24.10.11	12
						W. coast of Deerness,	Ork.	58° 57′ N.	2° 46′ W.	27.10.11	15
						Backaskaill Bay, Sanday,	Ork.	59° 14′ N.	2° 38′ W.	4.11.11	23
6	12	5	59° 18′ N.	1° 22′ W.	C.17	Bergsöerne, Senienö,	Nwy.	69° 27′ N.	17° 16′ E.	1.5.12	202*
7	12	5	59° 30′ N.	1° 00′ W.	D.18	Stayabanks, Sanday,	Ork.	59° 14′ N.	2° 33′ W.	6.12.11	55
8	12	10	59° 44′ N.	0° 33′ W.	D.18	Flotta Is., Weisdale Voe,	Sh.	60° 12′ N.	1° 19′ W.	12.7.12	274
9	12	5	60° 10′ N.	0° 10′ W.	D.19	—		—		—	—
10	15	5	57° 26′ N.	1° 44′ W.	C.13	Peterhead, Aberdeen,	Sc.	57° 30′ N.	1° 47′ W.	19.10.11	4
						nr. Buchan Ness, Aberdeen,	Sc.	57° 28′ N.	1° 46′ W.	19.10.11	4
						Cruden Bay, Aberdeen,	Sc.	57° 24′ N.	1° 51′ W.	19.10.11	4
						" " "	"	"	"	"	4

						MARCH 1912.						
1	7	10	56° 17′ N.	1° 58′ W.	C.11	Jaederen,	Nwy.	59° 02′ N.	5° 40′ E.	6.9.12	183*
						nr. Marstrand, Bohuslan,	Sw.	57° 49′ N.	11° 44′ E.	17.3.13	375*
2	7	11	56° 39′ N.	1° 50′ W.	C.12	Belhelvie, Aberdeen,	Sc.	57° 16′ N.	2° 01′ W.	12.9.12	189
3	7	10	56° 42′ N.	2° 00′ W.	C.12	—		—		—	—
4	7	10	56° 58′ N.	1° 46′ W.	C.12	Vesterö Havn, Laesö,	Dk.	57° 16′ N.	10° 55′ E.	26.9.12	203
5	7	7	57° 08′ N.	1° 44′ W.	C. 13	nr. Peterhead, Aberdeen,	Sc.	57° 31′ N.	1° 48′ W.	22.3.12	15
						nr. Rattray Hd., Aberdeen,	Sc.	57° 37′ N.	1° 49′ W.	2.4.12	26
6	8	10	56° 56′ N.	1° 08′ W.	C.12	—		—		—	—
						APRIL 1912.					
1	24	10	56° 17′ N.	1° 58′ W.	C.11	Blyth, Northumberland,	E.	55° 07′ N.	1° 30′ W.	4.6.12	41
						W. Hartlepool, Durham,	E.	54° 42′ N.	1° 12′ W.	5.6.12	42
						MAY 1912.					
1	10	10	56° 17′ N.	1° 58′ W.	C.11	Holy Is., Northumberland,	E.	55° 41′ N.	1° 47′ W.	29.5.12	19
2	14	8	58° 00′ N.	2° 54′ W.	B.15	St. Andrews, Fife,	Sc.	56° 20′ N.	2° 47′ W.	9.6.12	26
						nr. Dunbar, Haddington,	Sc.	56° 00′ N.	2° 33′ W.	10.6.12	27
						1½′ N. of Fife Ness,	Sc.	56° 17′ N.	2° 37′ W.	13.6.12	30
						btw. Bamburgh & Holy Is., Northumberland,	E.	55° 39′ N.	1° 38′ W.	22.7.12	69
						St. Abb's Hd., Berwick,	Sc.	55° 55′ N.	2° 08′ W.	31.7.12	78
3	14	8	58° 08′ N.	2° 00′ W.	C.15	St. Andrews, Fife,	Sc.	56° 20′ N.	2° 47′ W.	14.6.12	31
						,, ,, ,,	,,	,,	,,	,,	,,
						Tentsmuir, Fife,	Sc.	56° 27′ N.	2° 49′ W.	22.7.12	69
4	14	8	58° 17′ N.	1° 03′ W.	C.15	Langeness,	Schl.-Holst.	54° 38′ N.	8° 33′ E.	27.11.12	197
						Ockholm,	Schl.-Holst.	54° 29′ N.	9° 03′ E.	16.12.12	216

LIBERATIONS.						RECOVERIES.				
Station No.	Day of Month.	No. of Drifters.	Position of Station. Latit. & Long.		Rect. Area.	Place-Name.		Position. Latit. & Long.	Date. D. M. Y.	Drift-Period (days).
5	15	8	58° 26′ N.	0° 08′ W.	D.15	Langö, nr. Strömstad,	Sw.	58° 57′ N. 11° 06′ E.	18.12.12	217
6	15	8	58° 34′ N.	0° 47′ E.	E.16	N. of Tyrhaug Lt., Edö,	Nwy.	63° 19′ N. 8° 13′ E.	10.1.13	240
						Flatholmen, Bohuslan,	Sw.	58° 16′ N. 11° 25′ E.	11.3.13	300
7	15	8	58° 42′ N.	1° 44′ E.	F.16	—		—	—	—
8	15	8	58° 50′ N.	2° 40′ E.	G.16	Havö, nr. Grimstad,	Nwy.	58° 18′ N. 8° 36′ E.	7.4.13	327
9	15	8	59° 03′ N.	4° 06′ E.	J.17	Smölen,	Nwy.	63° 25′ N. 7° 50′ E.	8.2.13	269
10	16	8	59° 07′ N.	4° 47′ E.	J.17	Marsten Lt., Bergenhus,	Nwy.	60° 09′ N. 5° 01′ E.	10.6.12	25
11	18	8	59° 16′ N.	3° 42′ E.	H.17	Vangsaa, nr. Hantsholm,	Dk.	57° 01′ N. 8° 27′ E.	15.10.12	150
						Reksten, N. Bergenhus,	Nwy.	61° 34′ N. 4° 49′ E.	25.11.12	191
						Naesö, Helgeland,	Nwy.	66° 33′ N. 12° 40′ E.	25.11.12	191*
12	18	8	59° 25′ N.	2° 46′ E.	G.17	nr. Fjällbacka, Bohuslan,	Sw.	58° 36′ N. 11° 17′ E.	16.12.12	212
						Midtfjord,	Nwy.	59° 04′ N. 10° 16′ E.	27.12.12	223
13	18	8	59° 35′ N.	1° 51′ E.	F.18	7′ W. of Lindesnaes,	Nwy.	58° 05′ N. 6° 57′ E.	17.3.13	303
14	19	8	59° 44′ N.	0° 56′ E.	E.18	Kinn, N. Bergenhus,	Nwy.	61° 34′ N. 4° 46′ E.	25.11.12	190
						nr. Lysekil, Bohuslan,	Sw.	58° 23′ N. 11° 37′ E.	7.3.13	292
15	19	8	59° 54′ N.	0° 02′ E.	E.18	Rossholmen, Bohuslan,	Sw.	58° 33′ N. 11° 10′ E.	27.11.12	192
						12′ S. of Hantsholm,	Dk.	56° 58′ N. 8° 24′ E.	8.12.12	203
						Raabjerg,	Dk.	57° 38′ N. 10° 20′ E.	20.12.12	215
						Aröy, Langesundsfjord,	Nwy.	58° 55′ N. 9° 48′ E.	12.3.13	297
16	19	8	60° 05′ N.	0° 48′ W.	D.19	4′ S. of Hirtshals,	Dk.	57° 34′ N. 9° 56′ E.	14.6.18	2217
17	21	8	61° 02′ N.	1° 10′ W.	C.21	—		—	—	—

18	25	8	61° 42′ N.	2° 00′ W.	C.22	. . . . .	At Sea.	[illegible]	[illegible]	[illegible]	[illegible]
19	25	8	61° 38′ N.	0° 41′ W.	D.22	N.W. coast of Smölen,	Nwy.	63° 26′ N.	7° 51′ E.	18.11.12	177
						Teistevik, Senienö,	Nwy.	69° 24′ N.	17° 00′ E.	18.4.13	328*
20	25	8	61° 35′ N.	0° 47′ E.	E.22	Sandwick, Unst,	Sh.	60° 42′ N.	0° 52′ W.	10.6.12	16
						Otterswick, E. Yell,	Sh.	60° 33′ N.	1° 03′ W.	13.6.12	19
						Vidlin Voe,	Sh.	60° 24′ N.	1° 08′ W.	29.7.12	65
						Norwick Bay, Unst,	Sh.	60° 49′ N.	0° 47′ W.	1.9.12	99
21	26	8	61° 34′ N.	2° 04′ E.	G.22	Otterswick, E. Yell,	Sh.	60° 33′ N.	1° 03′ W.	30.6.12	35
						Brough, S. Nesting,	Sh.	60° 22′ N.	0° 59′ W.	9.7.12	44
						Swinning, Lunnasting,	Sh.	60° 23′ N.	1° 10′ W.	23.7.12	58
						Kragerö, nr. Fredrikstad,	Nwy.	59° 10′ N.	10° 56′ E.	27.12.12	215
22	26	8	61° 30′ N.	3° 03′ E.	H.22	Skaw Voe, Whalsay,	Sh.	60° 23′ N.	0° 56′ W.	10.8.12	76
23	26	9	61° 35′ N.	4° 05′ E.	J.22	Bremanger,	Nwy.	61° 55′ N.	4° 58′ E.	18.6.12	23
						Lökvig, Finmarken,	Nwy.	70° 46′ N.	29° 17′ E.	8.6.13	378*
24	26	10	61° 16′ N.	3° 07′ E.	H.21	Cunningsburgh,	Sh.	60° 02′ N.	1° 14′ W.	7.8.12	73
						Cullivoe,	Sh.	60° 42′ N.	1° 00′ W.	20.8.12	86
						Herö, Bohuslan,	Sw.	58° 01′ N.	11° 27′ E.	17.12.12	205
						Tversted Strand,	Dk.	57° 35′ N.	10° 10′ E.	22.12.12	210
25	30	8	61° 16′ N.	2° 08′ W.	B.21	Sandvoe, Northvoe,	Sh.	60° 37′ N.	1° 21′ W.	15.9.12	108
						Akerö, Romsdal,	Nwy.	62° 47′ N.	6° 56′ E.	9.11.12	163
26	30	8	61° 18′ N.	2° 59′ W.	B.21	——		—		—	—
27	30	8	61° 27′ N.	3° 42′ W.	A.21	Aire of Clave, Unst,	Sh.	60° 48′ N.	0° 57′ W.	9.9.12	102
						Hastvaer, Fröien,	Nwy.	64° 00′ N.	9° 10′ E.	1.4.13	306
						Skarvfjord, Sorö,	Nwy.	70° 47′ N.	23° 08′ E.	7.9.13	465*
28	31	8	61° 39′ N.	4° 45′ W.	ZZ.22	——		—		—	—
29	31	8	61° 49′ N.	5° 36′ W.	YY.22	Kvalbö, Suderö,	Faroe.	61° 39′ N.	6° 59′ W.	12.6.12	12
						Lille Nordö, Gjesvaer,	Nwy.	71° 06′ N.	25° 20′ E.	21.4.13	325*
30	31	8	62° 00′ N.	6° 12′ W.	XX.22	15′ N. of Myggenaes Pt.,	At Sea.	62° 25′ N.	7° 25′ W.	13.6.12	13

LIBERATIONS.					RECOVERIES.				
Station No.	Day of Month.	No. of Drifters.	Position of Station. Latit. & Long.	Position of Station. Rect. Area.	Place-Name.		Position. Latit. & Long.	Date. D. M. Y.	Drift-Period (days).
					JUNE 1912.				
1	1	8	61° 12′ N. 6° 33′ W.	XX.21	Svaerholt, Finmarken,	Nwy.	71° 00′ N. 26° 45′ E.	30.7.13	424*
2	1	8	60° 57′ N. 5° 47′ W.	YY.20	Ronas Voe,	Sh.	60° 33′ N. 1° 30′ W.	27.12.12	209
3	1	8	60° 40′ N. 4° 50′ W.	ZZ.20	Haram, Sondmor,	Nwy.	62° 39′ N. 6° 11′ E.	9.10.12	130
					Smölen,	Nwy.	63° 23′ N. 7° 48′ E.	28.3.13	300
4	2	8	60° 26′ N. 4° 02′ W.	ZZ.19	Fröien,	Nwy.	63° 41′ N. 8° 37′ E.	18.11.12	169
					Vaerö, Lofoten,	Nwy.	67° 40′ N. 12° 40′ E.	2.12.12	183*
					Leksen, Trondhjem Fjord,	Nwy.	63° 35′ N. 9° 19′ E.	9.12.12	190
5	2	8	60° 17′ N. 3° 36′ W.	A.19	—		—	—	—
6	2	8	60° 02′ N. 3° 13′ W.	A.19	nr. Hammerfest,	Nwy.	70° 50′ N. 23° 15′ E.	12.7.14	770*
7	2	8	59° 46′ N. 2° 21′ W.	B.18	Sanday,	Ork.	59° 16′ N. 2° 30′ W.	23.6.12	21
					Hunday, Stronsay,	Ork.	59° 03′ N. 2° 35′ W.	3.7.12	31
					Evie,	Ork.	59° 07′ N. 3° 05′ W.	16.9.12	106
8	2	8	59° 40′ N. 1° 14′ W.	C.18	Maurice Haven, S. Ronaldshay,	Ork.	58° 44′ N. 2° 55′ W.	11.6.12	9
					nr. Whitby, Yorks.,	E.	54° 30′ N. 0° 38′ W.	3.10.12	123
					Sandöen, Tvedestrand,	Nwy.	58° 35′ N. 9° 05′ E.	7.1.13	219
9	3	8	59° 26′ N. 1° 20′ W.	C.17	Marwick Hd.,	Ork.	59° 06′ N. 3° 21′ W.	28.6.12	25
					Blaavandshuk,	Dk.	55° 35′ N. 8° 05′ E.	11.4.13	312
					Aargab,	Dk.	55° 59′ N. 8° 09′ E.	3.2.14	610
10	3	8	59° 10′ N. 1° 27′ W.	C.17	Newburgh, Aberdeen,	Sc.	57° 18′ N. 2° 00′ W.	7.8.12	65
					Stenbjerg, nr. Hantsholm,	Dk.	56° 51′ N. 8° 16′ E.	2.12.12	182
					Sarö, Hallandslan,	Sw.	57° 30′ N. 11° 56′ E.	10.12.14	920

11	3	7	58° 36′ N.	1° 46′ W.	C.16	Golspie, Sutherland,	Sc.	57° 58′ N.	3° 59′ W.	30.6.12	27
12	3	8	58° 09′ N.	1° 50′ W.	C.15	——		—		—	—
13	12	8	56° 21′ N.	1° 41′ W.	C.11	Holy Is., Northumberland,	E.	55° 41′ N.	1° 49′ W.	23.7.12	41
						Goswick, Northumberland,	E.	55° 42′ N.	1° 54′ W.	26.7.12	44
						2′ S. of Holy Is., Northumberland,	E.	54° 40′ N.	1° 46′ W.	7.8.12	56
						nr. Beal, Northumberland,	E.	55° 41′ N.	1° 52′ W.	8.8.12	57
						Langeness,	Schl.-Holst.	54° 38′ N.	8° 33′ E.	27.11.12	168
14	12	8	56° 30′ N.	0° 50′ W.	D.12	btw. Esbjerg & Hjerting,	Dk.	55° 29′ N.	8° 24′ E.	27.11.12	168
						nr. Lyngvig Lt.,	Dk.	55° 58′ N.	8° 09′ E.	2.12.12	173
						Fanö,	Dk.	55° 23′ N.	8° 24′ E.	17.12.12	188
						nr. Hviding,	Schl.-Holst.	55° 16′ N.	8° 37′ E.	24.2.13	257
15	12	8	56° 39′ N.	0° 02′ E.	E.12	Sonderhoe, Fanö,	Dk.	55° 20′ N.	8° 28′ E.	28.11.12	169
						nr. Husum,	Schl.-Holst.	54° 29′ N.	9° 03′ E.	17.12.12	188
						Fanö,	Dk.	55° 20′ N.	8° 28′ E.	30.7.17	1874
16	13	8	56° 48′ N.	0° 54′ E.	E.12	S. Vaderöarne, Bohuslan,	Sw.	58° 33′ N.	11° 04′ E.	13.2.13	245
17	13	8	56° 57′ N.	1° 45′ E.	F.12	Krageró, nr. Fredrikstad,	Nwy.	59° 10′ N.	10° 56′ E.	9.12.12	179
						Risö Göteborg,	Sw.	57° 38′ N.	11° 35′ E.	17.12.12	187
18	13	8	57° 06′ N.	2° 37′ E.	G.13	——		—		—	—
19	13	8	57° 12′ N.	4° 00′ E.	J.13	Tranum,	Dk.	57° 10′ N.	9° 25′ E.	3.11.12	143
						Kirköen, nr. Fredrikstad,	Nwy.	59° 04′ N.	11° 00′ E.	8.12.12	178
20	14	8	57° 19′ N.	4° 00′ E.	J.13	Hvalöerne,	Nwy.	59° 08′ N.	10° 54′ E.	16.10.12	124
						Bröfjorden, Bohuslan,	Sw.	58° 22′ N.	11° 25′ E.	23.5.15	1073
21	14	8	57° 23′ N.	3° 04′ E.	H.13	——		—		—	—
22	15	8	57° 30′ N.	2° 10′ E.	G.14	Sotefjord, Bohuslan,	Sw.	58° 30′ N.	11° 12′ E.	2.12.12	170
						nr. Egerö Lt.,	Nwy.	58° 28′ N.	5° 58′ E.	4.12.12	172
23	15	8	57° 34′ N.	0° 35′ E.	E.14	nr. Ryvingen Lt.,	Nwy.	57° 58′ N.	7° 29′ E.	10.1.13	209
						Flekkerö, nr. Christiansand,	Nwy.	58° 17′ N.	8° 00′ E.	21.2.13	251
24	15	8	57° 37′ N.	0° 33′ W.	D.14	Hallö Lt., Bohuslan,	Sw.	58° 20′ N.	11° 13′ E.	17.12.12	185

LIBERATIONS.						RECOVERIES.				
Station No.	Day of Month.	No. of Drifters.	Position of Station. Latit. & Long.		Rect. Area.	Place-Name.		Position. Latit. & Long.	Date. D. M. Y.	Drift-Period (days).
25	15	8	57° 39′ N.	1° 30′ W.	C.14	Hvalöerne,	Nwy.	59° 08′ N. 10° 54′ E.	7.3.13	265
26	18	8	58° 28′ N.	2° 48′ W.	B.15	Newburgh, Aberdeen,	Sc.	57° 19′ N. 1° 59′ W.	29.7.12	41
						5′ S. of Bridlington, Yorks.,	E.	54° 01′ N. 0° 12′ W.	29.9.12	103
27	18	8	58° 40′ N.	2° 27′ W.	B.16	Portsoy, Banff,	Sc.	57° 41′ N. 2° 42′ W.	23.7.12	35
28	19	8	58° 53′ N.	1° 58′ W.	C.16	Smölen,	Nwy.	63° 22′ N. 7° 54′ E.	14.2.13	240
29	19	8	59° 07′ N.	1° 30′ W.	C.17	Hallö Lt., Bohuslan,	Sw.	58° 20′ N. 11° 13′ E.	17.12.12	181
30	19	8	59° 20′ N.	1° 03′ W.	C.17	—		—	—	—
						JULY 1912.				
1	5	8	56° 14′ N.	1° 56′ W.	C.11	2′ N. of Berwick, Northumberland,	E.	55° 48′ N. 2° 01′ W.	22.7.12	17
						Cove, Berwick,	Sc.	55° 56′ N. 2° 20′ W.	22.7.12	17
						nr. Dunbar, Haddington,	Sc.	56° 02′ N. 2° 37′ W.	24.7.12	19
						,, ,, ,,	,,	,, ,,	,,	,,
						,, ,, ,,	,,	,, ,,	25.7.12	20
2	6	8	56° 24′ N.	1° 15′ W.	C.11	Nyminde Gab,	Dk.	55° 46′ N. 8° 11′ E.	8.12.12	155
						Blaavandshuk,	Dk.	55° 34′ N. 8° 05′ E.	15.12.12	162
						Sonderhoe, Fanö,	Dk.	55° 20′ N. 8° 27′ E.	28.12.12	175
3	6	6	56° 32′ N.	0° 33′ W.	D.12	nr. Ribe,	Dk.	55° 20′ N. 8° 40′ E.	18.6.13	347
4	6	8	56° 44′ N.	1° 33′ W.	C.12	—		—	—	—
5	6	8	56° 55′ N.	1° 08′ W.	C.12	—		—	—	—

6	8	20	58° 05′ N.	2° 30′ W.	B.15	nr. Lossiemouth, Elgin,	Sc.	57° 43′ N.	3° 16′ W.	23.7.12	15
						" " "	"	57° 42′ N.	3° 12′ W.	3.8.12	26
						Hvalöerne,	Nwy.	59° 05′ N.	10° 50′ E.	30.3.13	265
						Bjerregaard,	Dk.	55° 51′ N.	8° 10′ E.	12.9.13	431
7	8	8	57° 38′ N.	1° 25′ W.	C.14	Nyminde Gab,	Dk.	55° 47′ N.	8° 11′ E.	4.1.13	180
						Tungenaes, nr. Stavanger,	Nwy.	59° 02′ N.	5° 36′ E.	6.1.13	182
8	9	8	57° 07′ N.	0° 21′ W.	D.13	—		—		—	—
						AUGUST 1912.					
1	20	20	57° 00′ N.	0° 00′ W.	E.13	Fjällbacka, Bohuslan,	Sw.	58° 36′ N.	11° 15′ E.	30.11.12	102
						nr. Lysekil, Bohuslan,	Sw.	58° 17′ N.	11° 26′ E.	4.12.12	106
						Risör,	Nyw.	58° 43′ N.	9° 15′ E.	12.12.12	114
						Hummelsund, Korsfjorden,	Nyw.	60° 09′ N.	5° 00′ E.	2.1.13	135
						Veavaag, Karmö,	Nyw.	59° 18′ N.	5° 14′ E.	8.2.13	172
						Lister Lt.,	Nyw.	58° 07′ N.	6° 34′ E.	15.12.13	482
						SEPTEMBER 1912.					
1	12	8	56° 14′ N.	1° 56′ W.	C.11	Tentsmuir, Fife,	Sc.	56° 27′ N.	2° 49′ W.	6.10.12	24
						N. Tornby, nr. Hirtshals,	Dk.	57° 33′ N.	9° 54′ E.	16.12.12	95
2	12	8	56° 22′ N.	1° 15′ W.	C.11	N. Koster, Bohuslan,	Sw.	58° 54 ′N.	11° 00′ E.	20.8.13	342
3	13	8	56° 32′ N.	0° 33′ W.	D.12	—		—			—
4	13	8	56° 44′ N.	1° 33′ W.	C.12	Grötö, Bohuslan,	Sw.	58° 20′ N.	11° 23′ E.	27.12.12	105
						Skjaerholden, Christiania Fjord,	Nwy.	59° 00′ N.	10° 45′ E.	5.1.13	114
						Dyrenes, Fosenö,	Nwy.	60° 47′ N.	4° 55′ E.	1.3.13	169
5	13	8	56° 55′ N.	1° 08′ W.	C.12	E. Bukken, nr. Stavanger,	Nwy.	59° 12′ N.	5° 30′ E.	17.1.13	126
						Larvik,	Nwy.	59° 03′ N.	10° 05′ E.	8.3.13	176
						Tangen, Bohuslan,	Sw.	58° 27′ N.	11° 14′ E.	11.3.13	179
						Tjörnö, Bohuslan,	Sw.	58° 52′ N.	11° 09′ E.	15.4.14	579
6	13	8	57° 07′ N.	0° 21′ W.	D.13	Björlanda, Hisingen,	Sw.	57° 45′ N.	11° 47′ E.	31.3.13	199

LIBERATIONS.						RECOVERIES.					
Station No.	Day of Month.	No. of Drifters.	Position of Station.			Place-Name.		Position.		Date.	Drift-Period (days).
			Latit. & Long.		Rect. Area.			Latit. & Long.		D. M. Y.	
7	14	8	57° 38′ N.	1° 25′ W.	C.14	S. of Rattray Hd., Aberdeen,	Sc.	57° 35′ N.	1° 50′ W.	13.10.12	29
						nr. Akrehavn, Karmö,	Nwy.	59° 15′ N.	5° 11′ E.	15.12.12	92
						in Christiania Fjord,	Nwy.	59° 10′ N.	11° 10′ E.	1.1.13	109
						Notö, Sondmor,	Nwy.	62° 19′ N.	5° 42′ E.	5.3.13	172
						Gasö, Bohuslan,	Sw.	58° 14′ N.	11° 23′ E.	27.3.13	194
8	20	8	58° 05′ N.	2° 30′ W.	B.15	Strathy Bay, Sutherland,	Sc.	58° 36′ N.	3° 32′ W.	2.10.12	12
						OCTOBER 1912.					
1	26	20	57° 16′ N.	1° 53′ W.	C.13	Newburgh, Aberdeen,	Sc.	57° 19′ N.	1° 59′ W.	27.10.12	1
						” ”	”	”	”	”	”
						” ”	”	”	”	”	”
						” ”	”	”	”	”	”
						” ”	”	”	”	”	”
						” ”	”	”	”	”	”
						” ”	”	”	”	”	”
						” ”	”	”	”	”	”
						” ”	”	”	”	”	”
						” ”	”	”	”	”	”
						” ”	”	”	”	”	”
						Collieston, Aberdeen,	Sc.	57° 21′ N.	1° 56′ W.	28.10.12	2
						” ”	”	”	”	”	”
						Newburgh, Aberdeen,	Sc.	57° 19′ N.	1° 59′ W.	9.11.12	14
						nr. Rubjerg Knude,	Dk.	57° 23′ N.	9° 43′ E.	18.12.12	53
						NOVEMBER 1912.					
1	21	12	58° 30′ N.	2° 30′ W.	B.16	Torsteensvik, Toftö,	Nwy.	60° 30′ N.	4° 56′ E.	6.1.13	46
						Lerfjorden, Sorfolden,	Nwy.	67° 33′ N.	15° 39′ E.	8.4.13	138*
						Masö, Finmarken,	Nwy.	71° 02′ N.	24° 57′ E.	25.4.13	155*

2	22	12	57° 18′ N.	1° 22′ W.	C.13	Hasselöen, Vesteraalen,	Nwy.	68° 30′ N.	14° 50′ E.	18.2.13	88*
						11′ N. of Bodö,	Nwy.	67° 27′ N.	14° 43′ E.	24.2.13	94*
						Röst, Lofoten,	Nwy.	67° 31′ N.	12° 05′ E.	10.11.13	353*
3	22	12	60° 00′ N.	0° 20′ W.	D.19	Röst, Lofoten,	Nwy.	67° 31′ N.	12° 05′ E.	19.2.13	89*
						Kjerringö, Nordland,	Nwy.	67° 32′ N.	14° 48′ E.	28.2.13	98*
						MARCH 1913.					
1	13	20	60° 05′ N.	0° 48′ W.	D.19	Vatster, Mid-Yell,	Sh.	60° 35′ N.	1° 00′ W.	3.4.13	21
						Challister, Whalsay,	Sh.	60° 23′ N.	0° 58′ W.	8.4.13	26
						Leka, Namdalen,	Nwy.	65° 04′ N.	11° 33′ E.	4.7.13	113
2	15	20	59° 40′ N.	1° 14′ W.	C.18	Otterswick, E. Yell,	Sh.	60° 33′ N.	1° 02′ W.	8.5.13	54
						Gossaburgh, E. Yell,	Sh.	60° 32′ N.	1° 01′ W.	11.5.13	57
						Sandwick, Unst,	Sh.	60° 42′ N.	0° 52′ W.	14.5.13	60
						Aywick, E. Yell,	Sh.	60° 32′ N.	1° 04′ W.	14.5.13	60
3	15	20	59° 26′ N.	1° 20′ W.	C.17	Cunnister, N. Yell,	Sh.	60° 39′ N.	1° 03′ W.	4.5.13	50
						East Quarff,	Sh.	60° 04′ N.	1° 12′ W.	9.5.13	55
						Isbister, Whalsay,	Sh.	60° 21′ N.	0° 57′ W.	10.5.13	56
						Cuppaster, S. Yell,	Sh.	60° 29′ N.	1° 08′ W.	11.5.13	57
						Burra Ness, S. Yell,	Sh.	60° 30′ N.	1° 02′ W.	14.5.13	60
4	15	20	59° 10′ N.	1° 27′ W.	C.17	Start Pt., Sanday,	Ork.	59° 17′ N.	2° 24′ W.	29.4.13	45
						Mealsair, Cunningsburgh,	Sh.	60° 02′ N.	1° 14′ W.	8.5.13	54
						East Quarff,	Sh.	60° 04′ N.	1° 12′ W.	9.5.13	55
						Skillister, Nesting,	Sh.	60° 17′ N.	1° 09′ W.	12.5.13	58
						East Quarff,	Sh.	60° 04′ N.	1° 12′ W.	14.5.13	60
						" "	"	"	"	"	"
						Symbister,	Sh.	60° 21′ N.	1° 01′ W.	16.5.13	62
5	15	20	58° 36′ N.	1° 46′ W.	C.16	Haroldswick, Unst,	Sh.	60° 47′ N.	0° 50′ W.	7.5.13	53
						Funzie, Fetlar,	Sh.	60° 35′ N.	0° 47′ W.	10.5.13	56
						Bigga Is., Yell Sound,	Sh.	60° 30′ N.	1° 12′ W.	12.5.13	58
						Hagdale, Unst,	Sh.	60° 46′ N.	0° 49′ W.	12.5.13	58
						Gletness, Nesting,	Sh.	60° 09′ N.	1° 09′ W.	13.5.13	59
						Gluss Voe, Bardister,	Sh.	60° 30′ N.	1° 20′ W.	13.5.13	59
						Sandwick, Unst,	Sh.	60° 42′ N.	0° 52′ W.	14.5.13	60
						Vidlin Voe,	Sh.	60° 24′ N.	1° 08′ W.	14.5.13	60
						Aiths Voe, Bressay,	Sh.	60° 11′ N.	1° 05′ W.	1.6.13	78
						Elvis Voe, Bressay,	Sh.	60° 11′ N.	1° 05′ W.	15.6.13	92

LIBERATIONS.						RECOVERIES.					
Station No.	Day of Month.	No. of Drifters.	Position of Station. Latit. & Long.		Rect. Area.	Place-Name.		Position. Latit. & Long.		Date. D. M. Y.	Drift-Period (days).
6	15	20	58° 09′ N.	1° 50′ W.	C.15	8′ S. of Bressay, Sh.,	At Sea.	59° 59′ N.	0° 58′ W.	16.5.13	62
						Haroldswick, Unst,	Sh.	60° 47′ N.	0° 50′ W.	17.5.13	63
						Fröien,	Nwy.	63° 40′ N.	8° 32′ E.	19.2.14	341
						Kristiansund,	Nwy.	63° 06′ N.	7° 45′ E.	20.5.14	431
7	27	20	58° 10′ N.	2° 35′ W.	B.15	Latheron, Caithness,	Sc.	58° 16′ N.	3° 22′ W.	27.4.13	31
						Lybster, Caithness,	Sc.	58° 18′ N.	3° 17′ W.	28.4.13	32
						Latheron, Caithness,	Sc.	58° 16′ N.	3° 22′ W.	3.5.13	37
						nr. Brora, Sutherland,	Sc.	58° 01′ N.	3° 50′ W.	24.5.13	58
8	28	20	56° 55′ N.	1° 08′ W.	C.12	St. Fergus, Aberdeen,	Sc.	57° 28′ N.	1° 50′ W.	9.5.13	42
						nr. Lybster, Caithness,	Sc.	58° 17′ N.	3° 20′ W.	11.5.13	44
						nr. Grebbestad, Bohuslan,	Sw.	58° 52′ N.	11° 06′ E.	29.11.13	246
						Sulen i Fosen,	Nwy.	63° 51′ N.	8° 28′ E.	4.3.14	341
						APRIL 1913.					
1	3	20	56° 14′ N.	1° 56′ W.	C.11	Eyemouth, Berwick,	Sc.	55° 52′ N.	2° 06′ W.	7.4.13	4
						,, ,,	,,	,,	,,	,,	,,
						,, ,,	,,	,,	,,	,,	,,
						nr. Berwick, Northumberland,	E.	55° 42′ N.	1° 54′ W.	13.4.13	10
						Cruden Bay, Aberdeen,	Sc.	57° 23′ N.	1° 52′ W.	10.5.13	37
						Donmouth, Aberdeen,	Sc.	57° 10′ N.	2° 04′ W.	12.5.13	39
2	3	20	56° 22′ N.	1° 15′ W.	C.11	Bervie, Kincardine,	Sc.	56° 50′ N.	2° 17′ W.	10.5.13	37
						nr. Montrose, Forfar,	Sc.	56° 43′ N.	2° 27′ W.	11.5.13	38
						Belhelvie, Aberdeen,	Sc.	57° 16′ N.	2° 01′ W.	11.5.13	38
						,, ,,	,,	,,	,,	1.6.13	59
3	4	21	56° 32′ N.	0°33′ W.	D.12	nr. Mandal,	Nwy.	58° 00′ N.	7° 13′ E.	11.11.13	221

4	4	19	56° 44′ N.	1° 33′ W.	C.12	Ameland,	Holland.	53° 27′ N.	5° 38′ E.	13.8.13	131
						Sulen, N. Bergenhus,	Nwy.	61° 00′ N.	4° 45′ E.	24.11.13	234
5	4	20	56° 55′ N.	1° 08′ W.	C.12	69′ E.N.E. of Spurn Hd.,	At Sea.	54° 16′ N.	1° 34′ E.	13.9.13	162
						Edsvikskil, Bohuslan,	Sw.	58° 43′ N.	11° 12′ E.	27.11.13	237
6	8	10	58° 17′ N.	1° 03′ W.	C.15	. . . . . .	At Sea.	60° 20′ N.	0° 55′ E.	23.5.13	45
						Hvidingsö, nr. Stavanger,	Nwy.	59° 04′ N.	5° 24′ E.	25.10.13	200
						Frelsöen, Namdalen,	Nwy.	65° 00′ N.	10° 53′ E.	30.11.13	236
7	8	10	58° 08′ N.	2° 00′ W.	C.15	Aiths Voe, Cunningsburgh,	Sh.	60° 02′ N.	1° 14′ W.	8.5.13	30
						East Quarff,	Sh.	60° 04′ N.	1° 12′ W.	13.5.13	35
						Voe, Dunrossness,	Sh.	59° 55′ N.	1° 14′ W.	14.5.13	36
						Pool of Cletts, S. Ronaldshay,	Ork.	58° 48′ N.	2° 55′ W.	12.10.13	187
						Karmö,	Nwy.	59° 18′ N.	5° 14′ E.	5.12.13	241
8	8	10	58° 00′ N.	2° 54′ W.	B.15	Elsness, Sanday,	Ork.	59° 13′ N.	2° 35′ W.	6.5.13	28
						Newark, Sanday,	Ork.	59° 16′ N.	2° 30′ W	9.5.13	31
						N. Smölen,	Nwy.	63° 28′ N.	8° 01′ E.	4.9.14	514
9	9	10	57° 50′ N.	3° 18′ W.	A.14	Stronsay,	Ork.	59° 05′ N.	2° 35′ W.	7.5.13	28
						Newark, Sanday,	Ork.	59° 16′ N.	2° 30′ W.	7.5.13	28
10	9	10	57° 47′ N.	2° 46′ W.	B.14	——		—		—	—
11	9	10	57° 47′ N.	2° 22′ W.	B.14	Fraserburgh, Aberdeen,	Sc.	57° 41′ N.	1° 57′ W.	12.4.13	3
						Vik, Helgeland,	Nwy.	64° 27′ N.	10° 46′ E.	29.1.14	295
12	24	10	58° 09′ N.	1° 50′ W.	C.15	Elsness, Sanday,	Ork.	59° 13′ N.	2° 35′ W.	8.5.13	14
						Northwick Bay, Papa Westray,	Ork.	59° 22′ N.	2° 53′ W.	12.5.13	18
13	24	10	58° 36′ N.	1° 46′ W.	C.16	Rusness, Sanday,	Ork.	59° 16′ N.	2° 27′ W.	6.5.13	12
						Millbank, Eday,	Ork.	59° 12′ N.	2° 44′ W.	8.5.13	14
						Minar Lt., Calf of Eday,	Ork.	59° 14′ N.	2° 43′ W.	11.5.13	17
14	24	10	59° 10′ N.	1° 27′ W.	C.17	Hamarvoe, Northmavine,	Sh.	60° 28′ N.	1° 27′ W.	1.6.13	38
						Reawick, Sandsting,	Sh.	60° 11′ N.	1° 24′ W.	8.6.13	45
						Johnshaven, Kincardine,	Sc.	56° 44′ N.	2° 20′ W.	14.10.13	173
15	25	10	59° 40′ N.	1° 14′ W.	C.18	Hamnavoe, Papa Stour,	Sh.	60° 19′ N.	1° 43′ W.	21.5.13	26
						Echna Loch, Burray,	Ork.	58° 51′ N.	2° 55′ W.	22.5.13	27
						Veiholmen,	Nwy.	63° 31′ N.	7° 56′ E.	7.10.13	165
						Donnä, Helgeland,	Nwy.	66° 14′ N.	12° 36′ E.	17.10.13	175*

LIBERATIONS.					RECOVERIES.				
Station No.	Day of Month.	No. of Drifters.	Position of Station. Latit. & Long.	Rect. Area.	Place-Name.		Position. Latit. & Long.	Date. D. M. Y.	Drift-Period (days).
16	29	10	58° 00′ N. 2° 54′ W.	B.15	——		—	—	—
17	30	10	58° 08′ N. 2° 00′ W.	C.15	Sandside Bay, Deerness,	Ork.	58° 57′ N. 2° 43′ W.	8.5.13	8
					Mull Hd., Deerness,	Ork.	58° 58′ N. 2° 42′ W.	10.5.13	10
					Bay of Isbister, Firth,	Ork.	59° 02′ N. 3° 02′ W.	11.5.13	11
					,, ,, ,,	,,	,, ,,	21.5.13	21
					Methil, Fife,	Sc.	56° 11′ N. 3° 00′ W.	12.10.13	165
					Anstruther, Fife,	Sc.	56° 13′ N. 2° 42′ W.	14.10.13	167
18	30	10	58° 17′ N. 1° 03′ W.	C.15	Linklet Bay, N. Ronaldshay,	Ork.	59° 22′ N. 2° 25′ W.	10.5.13	10
					,, ,, ,,	,,	,, ,,	,,	,,
					Stromness Pt., N. Ronaldshay,	Ork.	59° 21′ N. 2° 26′ W.	11.5.13	11
19	30	10	58° 26′ N. 0° 08′ W.	D.15	Luröy, Helgeland,	Nwy.	66° 23′ N. 12° 50′ E.	29.11.13	213*
					Tusteren, Romsdal,	Nwy.	63° 09′ N. 7° 58′ E.	30.11.13	214
20	30	10	58° 34′ N. 0° 47′ E.	E.16	nr. Skaga, Helgeland,	Nwy.	65° 58′ N. 12° 15′ E.	25.1.14	270*
					MAY 1913.				
1	1	10	57° 59′ N. 0° 57′ E.	E.14	Mausund, nr. Trondhjem,	Nwy.	63° 51′ N. 8° 39′ E.	23.11.13	206*
					Havnöen, Helgeland,	Nwy.	65° 42′ N. 12° 25′ E.	2.12.13	215
2	1	10	57° 24′ N. 1° 07′ E.	F.13	Hisken, S. Bergenhus,	Nwy.	60° 10′ N. 4° 59′ E.	27.11.13	210
					Sulen, N. Bergenhus,	Nwy.	61° 08′ N. 4° 47′ E.	16.11.14	564
3	1	10	56° 48′ N. 1° 19′ E.	F.12	Schiermonnikoog Is.,	Holland.	53° 25′ N. 6° 12′ E.	20.8.13	111
					Rundö, Bohuslan,	Sw.	58° 55′ N. 11° 06′ E.	28.11.13	211
4	1	10	56° 42′ N. 0° 35′ E.	E.12	Honö, Göteborg,	Sw.	57° 41′ N. 11° 38′ E.	28.9.14	515

5	1	10	56° 35′ N.	0° 10′ W.	D.12	Sulen, N. Bergenhus,	Nwy.	61° 08′ N.	4° 47′ E.	21.11.13	204
						Golten, nr. Marsten Lt.,	Nwy.	60° 13′ N.	5° 01′ E.	1.12.13	214
						Tversted,	Dk.	57° 35′ N.	10° 11′ E.	26.12.13	239
6	2	10	56° 24′ N.	1° 21′ W.	C.11	Hartlepool, Durham,	E.	54° 42′ N.	1° 12′ W.	8.10.13	159
						nr. Whitby, Yorks.,	E.	54° 31′ N.	0° 40′ W.	9.10.13	160
						Spittal, Northumberland,	E.	55° 46′ N.	2° 00′ W.	10.10.13	161
7	2	10	56° 16′ N.	2° 17′ W.	B.11	nr. Kingsbarns, Fife,	Sc.	56° 19′ N.	2° 39′ W.	8.5.13	6
						" " "	"	"	"	9.5.13	7
						Redcar, Yorks.,	E.	54° 37′ N.	1° 03′ W.	27.10.13	178
8	13	10	58° 09′ N.	1° 50′ W.	C.15	—		—		—	—
9	13	10	58° 36′ N.	1° 46′ W.	C.16	Kladesholmen, Marstrand,	Sw.	57° 54′ N.	11° 35′ E.	30.11.13	201
10	13	10	59° 10′ N.	1° 27′ W.	C.17	nr. Jaederens,	Nwy.	58° 46′ N.	5° 50′ E.	1.12.13	202
11	13	10	59° 26′ N.	1° 20′ W.	C.17	Vingä, Göteborg,	Sw.	57° 40′ N.	11° 39′ E.	18.7.17	1527
12	14	10	59° 40′ N.	1° 14′ W.	C.18	Buköy, Helgeland,	Nwy.	65° 50′ N.	12° 05′ E.	16.1.14	247*
13	21	10	56° 55′ N.	1° 08′ W.	C.12	Reksten, N. Bergenhus,	Nwy.	61° 34′ N.	4° 49′ E.	24.11.13	187
						Skarhamn, Bohuslan,	Sw.	57° 55′ N.	11° 45′ E.	22.12.13	215
						Kolnes, nr. Stavanger,	Nwy.	58° 54′ N.	5° 36′ E.	25.1.14	249
14	21	10	56° 44′ N.	1° 33′ W.	C.12	—		—		—	—
15	21	10	56° 32′ N.	0° 33′ W.	D.12	—		—		—	—
16	22	10	56° 22′ N.	1° 15′ W.	C.11	—		—		—	—
17	22	10	56° 14′ N.	1° 56′ W.	C.11	2′ S. of Filey, Yorks.,	E.	54° 11′ N.	0° 17′ W.	5.11.13	167
						JUNE 1913.					
1	11	10	56° 17′ N.	1° 58′ W.	C.11	nr. Whitby, Yorks.,	E.	54° 30′ N.	0° 40′ W.	25.7.13	44
						" " "	"	"	"	"	"
						" " "	"	"	"	"	"

LIBERATIONS.					RECOVERIES.				
Station No.	Day of Month.	No. of Drifters.	Position of Station. Latit. & Long.	Position of Station. Rect. Area.	Place-Name.		Position. Latit. & Long.	Date. D. M. Y.	Drift-Period (days).
2	12	10	56° 24′ N. 1° 25′ W.	C.11	Filey, Yorks.,	E.	54° 11′ N. 0° 17′ W.	30.7.13	48
					Mouth of R. Tees, Northumberland,	E.	54° 39′ N. 1° 09′ W.	31.7.13	49
					Filey, Yorks.,	E.	54° 11′ N. 0° 17′ W.	12.10.13	122
3	12	10	56° 30′ N. 0° 50′ W.	D.12	Barnston, Yorks.,	E.	54° 00′ N. 0° 10′ W.	17.10.13	127
4	12	10	56° 36′ N. 0° 15′ W.	D.12	Grainthorpe Sluice, Lincs.,	E.	53° 14′ N. 0° 20′ E.	4.10.13	114
					Seaton Caren, Northumberland,	E.	55° 05′ N. 1° 28′ W.	7.10.13	117
5	13	10	56° 42′ N. 0° 20′ E.	E.12	Sutton-on-Sea, Lincs.,	E.	53° 18′ N. 0° 17′ E.	11.10.13	120
6	14	10	56° 48′ N. 0° 54′ E.	E.12	Withernsea, Yorks.,	E.	53° 44′ N. 0° 02′ E.	13.10.13	121
7	14	10	56° 54′ N. 1° 28′ E.	F.12	136′ N.E. by E.½ E. of Spurn Hd.,	At Sea.	55° 02′ N. 3° 00′ E.	12.11.13	151
8	15	10	56° 59′ N. 2° 03′ E.	G.12	——		—	—	—
9	15	10	57° 06′ N. 2° 38′ E.	G.13	Texel Is.,	Holland.	53° 12′ N. 4° 56′ E.	5.9.13	82
10	15	10	57° 12′ N. 3° 13′ E.	H.13	Ockerö, Göteborg,	Sw.	57° 43′ N. 11° 38′ E.	4.12.13	172
11	15	10	57° 18′ N. 3° 47′ E.	H.13	Strömstad,	Sw.	58° 56′ N. 11° 11′ E.	29.12.14	562
12	16	10	57° 18′ N. 3° 02′ E.	H.13	nr. Maseskar Lt., Bohuslan,	Sw.	58° 06′ N. 11° 19′ E.	25.11.13	162
					nr. Fiskebäckskil, Bohuslan,	Sw.	58° 15′ N. 11° 27′ E.	4.12.13	171
					Resö, Bohuslan,	Sw.	58° 48′ N. 11° 10′ E.	23.7.14	402
13	16	10	57° 30′ N. 2° 10′ E.	G.14	The Skaw,	Dk.	57° 45′ N. 10° 36′ E.	26.7.14	405
14	17	10	57° 32′ N. 1° 15′ E.	F.14	——		—	—	—
15	17	10	57° 35′ N. 0° 20′ E.	E.14	7′ E. of Lindesnaes,	Nwy.	57° 57′ N. 6° 54′ E.	4.12.13	170
					Honö, Göteborg,	Sw.	57° 41′ N. 11° 38′ E.	19.4.15	671

16	18	10	57° 38′ N.	0° 42′ W.	D.14	6′ S. of Göteborg,	Sw.	57° 36′ N.	11° 55′ E.	6.12.13	171
						2′ W. of Göteborg,	Sw.	57° 41′ N.	11° 53′ E.	19.12.13	184
17	21	10	58° 09′ N.	1° 50′ W.	C.15	Blyth, Northumberland,	E.	55° 08′ N.	1° 30′ W.	6.10.13	107
						Beadnell, Northumberland,	E.	55° 34′ N.	1° 39′ W.	12.10.13	113
						nr. Horden Colliery, Durham,	E.	54° 51′ N.	1° 20′ W.	22.11.13	154
18	22	10	58° 36′ N.	1° 46′ W.	C.16	Bamburgh, Northumberland,	E.	55° 36′ N.	1° 43′ W.	13.8.13	52
						Blyth, Northumberland,	E.	58° 08′ N.	1° 30′ W.	10.10.13	110
						nr. Hirtshals,	Dk.	57° 34′ N.	9° 52′ E.	11.12.13	172
						Gullholmen, Bohuslan,	Sw.	58° 11′ N.	11° 25′ E.	24.2.14	247
19	22	10	59° 10′ N.	1° 27′ W.	C.17	Boulmer Pt., Northumberland,	E.	55° 25′ N.	1° 35′ W.	7.9.13	77
						nr. Roker, Durham,	E.	54° 57′ N.	1° 21′ W.	8.10.13	108
						St. Abb's Hd., Berwick,	Sc.	55° 55′ N.	2° 08′ W.	10.10.13	110
						nr. Dunbar, Haddington,	Sc.	56° 00′ N.	2° 33′ W.	11.10.13	111
						Helvik, Ekersund,	Nwy.	58° 29′ N.	5° 54′ E.	31.1.14	223
20	22	10	59° 26′ N.	1° 20′ W.	C.17	Druridge Bay, Northumberland,	E.	55° 14′ N.	1° 32′ W.	10.10.13	110
						Harboöre,	Dk.	56° 36′ N.	8° 06′ E.	14.12.13	175
21	22	10	59° 40′ N.	1° 14′ W.	C.18	nr. N. Berwick, Haddington,	Sc.	56° 04′ N.	2° 44′ W.	8.10.13	108
						Musselburgh, Haddington,	Sc.	55° 57′ N.	3° 03′ W.	10.10.13	110
						Kirkcaldy, Fife,	Sc.	56° 05′ N.	3° 09′ W.	11.10.13	111
						nr. Amble, Northumberland,	E.	55° 28′ N.	1° 35′ W.	11.10.13	111
						nr. Newbiggin, Northumberland,	E.	55° 13′ N.	1° 31′ W.	20.10.13	120
						JULY 1913.					
1	12	20	60° 40′ N.	4° 50′ W.	ZZ.20	Grutness Voe,	Sh.	59° 53′ N.	1° 17′ W.	19.9.13	69
						" "	"	"	"	5.10.13	85
						Offersö, Salten,	Nwy.	68° 10′ N.	13° 34′ E.	20.1.14	192*
2	13	10	60° 02′ N.	3° 13′ W.	A.19	Fuglö, nr. Bodö,	Nwy.	67° 04′ N.	13° 48′ E.	4.12.13	144*
						Mausund, nr. Trondhjem,	Nwy.	63° 51′ N.	8° 39′ E.	9.12.13	149
						Sund, Lofoten,	Nwy.	68° 19′ N.	13° 55′ E.	8.3.14	238*
3	13	10	59° 46′ N.	2° 21′ W.	B.18	Sumstad, Björnör,	Nwy.	64° 12′ N.	10° 19′ E.	29.11.13	139
						Mostervik, Trondhjem,	Nwy.	64° 11′ N.	10° 14′ E.	30.11.13	140
						Melöy, Helgeland,	Nwy.	66° 49′ N.	13° 22′ E.	24.1.14	195*
						Vaagan, Trondhjem,	Nwy.	64° 00′ N.	10° 00′ E.	3.3.14	233*

LIBERATIONS.						RECOVERIES.					
Station No.	Day of Month.	No. of Drifters.	Position of Station.			Place-Name.		Position.		Date.	Drift-Period (days).
			Latit. & Long.		Rect. Area.			Latit. & Long.		D. M. Y.	
4	16	5	61° 02′ N.	1° 10′ W.	C.21	Whalsay,	Sh.	60° 22′ N.	0° 58′ W.	24.7.13	8
						Dales Voe, Lerwick,	Sh.	60° 12′ N.	1° 10′ W.	30.7.13	14
5	16	5	61° 42′ N.	2° 00′ W.	C.22	Lesund,	Nwy.	63° 20′ N.	8° 29′ E.	21.10.13	97
6	18	5	61° 30′ N.	3° 03′ E.	H.22	—		—		—	—
7	19	5	60° 40′ N.	3° 18′ E.	H.20	—		—		—	—
8	19	5	60° 34′ N.	1° 15′ E.	F.20	Sulen, nr. Fröien,	Nwy.	63° 51′ N.	8° 28′ E.	24.11.13	128
						Blomö, Bergenhus,	Nwy.	60° 32′ N.	4° 52′ E.	3.12.13	137
						AUGUST 1913.					
1	8	5	57° 00′ N.	0° 00′ W.	E.13	—		—		—	—
2	9	10	”	”	”	Montrose, Forfar,	Sc.	56° 43′ N.	2° 27′ W.	12.10.13	64
						Vigten, Namdalen,	Nwy.	64° 54′ N.	10° 46′ E.	29.11.13	112
3	10	10	”	”	”	Boröen, Hjeltefjorden,	Nwy.	60° 28′ N.	5° 04′ E.	27.2.14	201
4	11	10	”	”	”	Fröien,	Nwy.	63° 43′ N.	8° 40′ E.	23.11.13	104
						Kvalsund,	Nwy.	70° 35′ N.	24° 15′ E.	25.11.13	106*
						Rynö, Fröien,	Nwy.	63° 44′ N.	8° 41′ E.	29.11.13	110
						Brandsfjord, Trondhjem,	Nwy.	64° 12′ N.	10° 15′ E.	30.1.14	172
5	12	10	”	”	”	Ellingsöen, nr. Aalesund,	Nwy.	62° 30′ N.	6° 11′ E.	15.12.13	125
						Mausund, Trondhjem,	Nwy.	63° 51′ N.	8° 40′ E.	11.4.15	607
6	13	5	”	”	”	Tusteren, nr. Kristiansund,	Nwy.	63° 09′ N.	7° 58′ E.	1.1.14	141

7	14	15	,,	,,	,,	nr. Marsten Lt.,	Nwy.	60° 06′ N.	5° 06′ E.	10.12.13	118
						Tranaas, N. Trondhjem,	Nwy.	64° 39′ N.	11° 12′ E.	16.12.13	124
8	15	10	,,	,,	,,	Fylkesnaes, nr. Bergen,	Nwy.	59° 40′ N.	5° 15′ E.	25.11.13	102
						Vigerö, nr. Aalesund,	Nwy.	62° 32′ N.	6° 01′ E.	2.12.13	109
						Dyrö, nr. Smölen,	Nwy.	63° 22′ N.	8° 13′ E.	16.12.13	123
9	21	10	,,	,,	,,	Harö, Romsdal,	Nwy.	62° 45′ N.	6° 27′ E.	28.11.13	99
						Sulen, Fröien,	Nwy.	63° 51′ N.	8° 28′ E.	3.12.13	104
						Sandö, Romsdal,	Nwy.	62° 49′ N.	6° 35′ E.	17.6.14	300
						Aasvar, Helgeland,	Nwy.	66° 14′ N.	12° 19′ E.	5.3.17	1292*
10	22	5	,,	,,	,,	Ervik, Stadtlandet,	Nwy.	62° 10′ N.	5° 07′ E.	29.11.13	99
11	23	10	,,	,,	,,	Belhelvie, Aberdeen,	Sc.	57° 17′ N.	2° 01′ W.	11.10.13	49
						Sandvikvaagen, nr. Namsos,	Nwy.	64° 30′ N.	10° 30′ E.	2.12.13	101
						nr. Maseskar Lt., Bohuslan,	Sw.	58° 02′ N.	11° 27′ E.	5.12.13	104
						Lepsö, nr. Aalesund,	Nwy.	62° 36′ N.	6° 13′ E.	16.12.13	115
						Fisköen, nr. Aalesund,	Nwy.	62° 30′ N.	6° 02′ E.	14.4.14	234
12	24	5	57° 00′ N.	0° 00′ W.	E.13	Cowie, Kincardine,	Sc.	56° 58′ N.	2° 12′ W.	12.10.13	49
13	25	10	,,	,,	,,	Villa, Flatanger,	Nwy.	64° 32′ N.	10° 39′ E.	4.5.14	252
14	26	10	,,	,,	,,	Portlethen, Kincardine,	Sc.	57° 03′ N.	2° 07′ W.	14.10.13	49
						Brofjord, Bohuslan,	Sw.	58° 22′ N.	11° 25′ E.	23.12.13	119
						Myrevaag, Vaerlandet,	Nwy.	61° 18′ N.	4° 45′ E.	22.3.14	208
						Ramsö, Tusteren,	Nwy.	63° 10′ N.	7° 51′ E.	18.8.14	357
15	27	10	,,	,,	,,	—		—		—	—
						OCTOBER 1913.					
1	14	25	54° 52′ N.	0° 08′ E.	E.8	Skarhamn, Bohuslan,	Sw.	57° 59′ N.	11° 23′ E.	1.12.13	48
						N. Lyngby,	Dk.	57° 24′ N.	9° 44′ E.	2.12.13	49
						nr. Rubjerg Knude,	Dk.	57° 26′ N.	9° 46′ E.	3.12.13	50
						nr. Hirtshals,	Dk.	57° 35′ N.	9° 53′ E.	3.12.13	50
						Harboöre,	Dk.	56° 36′ N.	8° 06′ E.	3.12.13	50
						Skallerup Strand,	Dk.	57° 31′ N.	9° 53′ E.	5.12.13	52
						Lökken,	Dk.	57° 22′ N.	9° 42′ E.	5.12.13	52

LIBERATIONS.						RECOVERIES.					
Station No.	Day of Month.	No. of Drifters.	Position of Station.			Place-Name.		Position.		Date.	Drift-Period (days).
			Latit. & Long.		Rect. Area.			Latit. & Long.		D. M. Y.	
2	15	25	54° 28′ N.	0° 37′ E.	E.7	Morö, Bohuslan,	Sw.	58° 40′ N.	11° 08′ E.	29.11.13	45
3	16	19	55° 28′ N.	1° 33′ E.	F.9	nr. Hunnebostrand, Bohuslan,	Sw.	58° 28′ N.	11° 18′ E.	27.11.13	42
						Haftensund Lt., Bohuslan,	Sw.	58° 44′ N.	11° 11′ E.	27.11.13	42
						Bovallstrand, Bohuslan,	Sw.	58° 28′ N.	11° 18′ E.	2.12.13	47
						Kvalvig, Utsire,	Nwy.	59° 18′ N.	4° 52′ E.	13.2.14	120
						Resö, Bohuslan,	Sw.	58° 48′ N.	11° 11′ E.	17.7.15	639
						NOVEMBER 1913.					
1	13	25	56° 55′ N.	1° 08′ W.	C.12	Kjoergaard,	Dk.	55° 42′ N.	8° 10′ E.	6.1.14	54
						,,	Dk.	,,	,,	10.1.14	58
						nr. Ribe,	Dk.	55° 19′ N.	8° 46′ E.	27.2.14	106
						FEBRUARY 1914.					
1	10	10	57° 44′ N.	2° 37′ W.	B.14	S. Burra Is.,	Sh.	60° 03′ N.	1° 22′ W.	4.4.14	53
						Hirtshals,	Dk.	57° 35′ N.	9° 56′ E.	16.8.14	187
						Bovbjerg,	Dk.	56° 31′ N.	8° 07′ E.	19.8.14	190
						nr. Skagen,	Dk.	57° 43′ N.	10° 30′ E.	6.9.14	208
2	11	10	57° 44′ N.	3° 35′ W.	A.14	—		—		—	—
3	12	10	57° 53′ N.	3° 40′ W.	A.14	—		—		—	—
4	12	10	58° 27′ N.	2° 56′ W.	B.15	Skagen Lt.,	Dk.	57° 44′ N.	10° 38′ E.	13.8.14	182
5	13	10	59° 10′ N.	1° 27′ W.	C.17	Veiholmen,	Nwy.	63° 31′ N.	7° 58′ E.	12.5.14	88
						Gruting Voe,	Sh.	60° 12′ N.	1° 31′ W.	15.7.14	152

6	17	10	60° 31′ N.	0° 35′ W.	D.20	Norwick, Unst,	Sh.	60° 49′ N.	0° 48′ W.	22.2.14	5
						Colvidale, Unst,	Sh.	60° 43′ N.	0° 50′ W.	13.3.14	24
7	18	10	60° 55′ N.	0° 49′ W.	D.20	Grenvik, Helgeland,	Nwy.	65° 42′ N.	12° 28′ E.	6.5.14	77*
						Flovar, Tjötta,	Nwy.	65° 50′ N.	12° 24′ E.	4.6.14	106*
						Moldvik, Jöen,	Nwy.	64° 41′ N.	11° 20′ E.	13.6.14	115
						Myklevik, Lofoten,	Nwy.	68° 07′ N.	13° 48′ E.	28.6.14	130*
8	18	10	60° 58′ N.	0° 27′ W.	D.20	N. Solvaeröy, Helgeland,	Nwy.	66° 22′ N.	12° 39′ E.	22.5.14	93*
						Korsholmen, Helgeland,	Nwy.	66° 04′ N.	12° 20′ E.	6.6.14	108*
9	18	10	61° 01′ N.	0° 07′ W.	D.21	Fleinvaer, Gildeskaal,	Nwy.	67° 10′ N.	13° 45′ E.	20.5.14	91*
						Luröy, Helgeland,	Nwy.	66° 23′ N.	12° 50′ E.	1.10.14	225*
10	18	10	60° 42′ N.	0° 04′ E.	E.20	Herfjord, Björnör,	Nwy.	64° 00′ N.	9° 30′ E.	4.5.14	75
11	19	10	60° 35′ N.	0° 29′ E.	E.20	Laxnot, Sorfolden,	Nwy.	67° 33′ N.	15° 11′ E.	24.6.14	125*
12	19	10	60° 17′ N.	0° 08′ W.	D.19	Sauöen, Fröerne,	Nwy.	64° 00′ N.	9° 12′ E.	30.4.14	70
						Fjordholmen, Tjötta,	Nwy.	65° 37′ N.	12° 19′ E.	26.5.14	96*
						Lauvik, Lofoten,	Nwy.	68° 23′ N.	14° 27′ E.	5.10.14	228*
13	19	10	60° 05′ N.	0° 48′ W.	D.19	—		—		—	—
14	19	10	95° 36′ N.	0° 41′ W.	D.18	East Voe, Scalloway,	Sh.	60° 08′ N.	1° 16′ W.	11.3.14	20
15	20	10	59° 40′ N.	1° 14′ W.	C.18	Stenness, Northmavine,	Sh.	60° 29′ N.	1° 37′ W.	2.3.14	10
						Leka, Namdalen,	Nwy.	65° 07′ N.	11° 36′ E.	9.6.14	109
16	20	10	59° 26′ N.	1° 20′ W.	C.17	East Voe, Scalloway,	Sh.	60° 08′ N.	1° 16′ W.	7.3.14	15
17	20	10	59° 48′ N.	1° 56′ W.	C.18	Breakon, N. Yell,	Sh.	60° 43′ N.	1° 02′ W.	3.3.14	11
						Gutcher, N. Yell,	Sh.	60° 40′ N.	1° 00′ W.	7.3.14	15
18	24	5	57° 57′ N.	3° 20′ W.	A.14	—		—		—	—
19	24	5	58° 00′ N.	2° 54′ W.	B.15	Askroven, N. Bergenhus,	Nwy.	61° 31′ N.	4° 59′ E.	11.7.14	137
						Melveor, Bulandet,	Nwy.	61° 18′ N.	4° 40′ E.	24.7.14	150
20	24	5	58° 09′ N.	2° 42′ W.	B.15	—		—		—	—

LIBERATIONS.						RECOVERIES.					
Station No.	Day of Month.	No. of Drifters.	Position of Station.			Place-Name.		Position.		Date.	Drift Period (days).
			Latit. & Long.		Rect. Area.			Latit. & Long.		D. M. Y.	
21	24	7	58° 17′ N.	2° 35′ W.	B.15	Sjergaarden, nr. Slotterö,	Nwy.	59° 45′ N.	5° 04′ E.	5.5.14	70
						btw. Leröen & Bjelkerö, Bergenhus,	Nwy.	60° 13′ N.	5° 10′ E.	9.6.14	105
						Bulandet,	Nwy.	61° 17′ N.	4° 36′ E.	24.6.14	120
						MARCH 1914.					
1	10	5	58° 08′ N.	3° 31′ W.	A.15	Kvarheim Lt., Jaederen,	Nwy.	58° 32′ N.	5° 41′ E.	8.12.14	273
						APRIL 1914.					
1	4	10	57° 57′ N.	3° 20′ W.	A.14	Fleinöen, nr. Bodö,	Nwy.	67° 06′ N.	13° 50′ E.	15.5.15	406*
2	4	10	58° 04′ N.	2° 28′ W.	B.15	—		—		—	—
3	4	10	58° 13′ N.	1° 32′ W.	C.15	Slettestrand,	Dk.	57° 09′ N.	9° 24′ E.	5.9.14	154
						Husby Klit,	Dk.	56° 11′ N.	8° 07′ E.	6.9.14	155
4	4	10	58° 17′ N.	1° 03′ W.	C.15	nr. Lökken,	Dk.	57° 20′ N.	9° 40′ E.	23.8.14	141
						Kasholmen, Göteborg,	Sw.	57° 40′ N.	11° 46′ E.	7.4.15	368
5	12	10	58° 26′ N.	0° 08′ W.	D.15	Jaederen,	Nwy.	58° 44′ N.	5° 32′ E.	3.9.14	144
6	12	10	58° 54′ N.	0° 47′ E.	E.16	Husby Klit,	Dk.	56° 11′ N.	8° 07′ E.	26.7.14	105
7	12	10	58° 42′ N.	1° 44′ E.	F.16	nr. Nyminde Gab,	Dk.	55° 52′ N.	8° 10′ E.	2.7.14	81
						nr. Höjen,	Dk.	57° 45′ N.	10° 34′ E.	9.8.14	119
						Edsvikskil, Bohuslan,	Sw.	58° 43′ N.	11° 10′ E.	16.9.14	157
8	12	10	58° 50′ N.	2° 40′ E.	G.16	Blokhus,	Dk.	57° 16′ N.	9° 35′ E.	20.5.14	38
						nr. Ringkjöbing,	Dk.	56° 06′ N.	8° 15′ E.	1.8.14	111

9	13	10	59° 03′ N.	4° 06′ E.	J.17	Heggholmen, nr. Bergen,	Nwy.	60° 35′ N.	4° 48′ E.	27.4.14	14
						Veavaag, Karmö,	Nwy.	59° 18′ N.	5° 14′ E.	2.5.14	19
10	13	10	59° 09′ N.	4° 47′ E.	J.17	Sund, Gt. Sotrö,	Nwy.	60° 14′ N.	5° 09′ E.	1.5.14	18
						Torvestad, nr. Haugesund,	Nwy.	59° 22′ N.	5° 14′ E.	19.6.14	67
						Skagen,	Dk.	57° 44′ N.	10° 38′ E.	19.8.14	128
						2′ W. of Suderö, Faroe,	At Sea	61° 30′ N.	7° 20′ W.	6.7.16	815*
11	15	10	59° 31′ N.	4° 27′ E.	J.18	Solsvik, Gt. Sotrö,	Nwy.	60° 26′ N.	4° 59′ E.	24.4.14	9
						Eide, Gt. Sotrö,	Nwy.	60° 23′ N.	5° 00′ E.	10.12.15	604
12	16	10	59° 30′ N.	3° 27′ E.	H.18	Vingenaes, Gt. Sotrö,	Nwy.	60° 25′ N.	5° 01′ E.	11.5.14	25
						Bergsö, nr. Aalesund,	Nwy.	62° 20′ N.	5° 37′ E.	9.7.14	84
						Humlingsvaer, Fröien,	Nwy.	63° 44′ N.	8° 20′ E.	14.8.14	120
13	16	10	59° 28′ N.	2° 28′ E.	G.17	Rovaer, nr. Haugesund,	Nwy.	59° 27′ N.	5° 05′ E.	8.5.14	22
						Sandöen, nr. Bergen,	Nwy.	60° 27′ N.	4° 53′ E.	20.5.14	34
14	16	10	59° 28′ N.	1° 30′ E.	F.17	Koellareholm, Bohuslan,	Sw.	58° 42′ N.	11° 13′ E.	9.9.14	146
15	16	10	59° 31′ N.	0° 37′ E.	E.18	Horsvaer, Helgeland,	Nwy.	65° 20′ N.	11° 30′ E.	30.9.14	167
16	16	10	59° 36′ N.	0° 41′ W.	D.18	Thorup Strand,	Dk.	57° 08′ N.	9° 17′ E.	5.9.14	142
17	17	10	59° 26′ N.	1° 20′ W.	C.17	——		—		—	—
18	17	10	59° 40′ N.	1° 14′ W.	C.18	East Voe, Scalloway,	Sh.	60° 08′ N.	1° 16′ W.	27.4.14	10
19	17	10	60° 05′ N.	0° 48′ W.	D.19	Skerries,	Sh.	60° 26′ N.	0° 45′ W.	24.4.14	7
						Bulbjerg,	Dk.	57° 09′ N.	9° 02′ E.	20.9.14	156
20	20	10	60° 31′ N.	0° 35′ W.	D.20	——		—		—	—
21	20	10	60° 35′ N.	0° 29′ E.	E.20	Sandshavn, nr. Stadtlandet,	Nwy.	62° 15′ N.	5° 30′ E.	1.10.14	164
22	21	10	61° 02′ N.	1° 10′ W.	C.21	Herlö, S. Bergenhus,	Nwy.	60° 35′ N.	4° 57′ E.	23.7.14	93
23	21	5	61° 17′ N.	1° 27′ W.	C.21	——		—		—	—

LIBERATIONS.						RECOVERIES.					
Station No.	Day of Month.	No. of Drifters.	Position of Station			Place-Name.		Position		Date.	Drift Period (days).
			Latit. & Long.		Rect. Area.			Latit. & Long.		D. M. Y.	
						JUNE 1914.					
1	5	5	58° 00′ N.	2° 54′ W.	B.15	—		—		—	—
2	5	5	58° 36′ N.	1° 46′ W.	C.16	Gasö, Bohuslan,	Sw.	58° 14′ N.	11° 23′ E.	5.12.14	183
3	5	5	59° 10′ N.	1° 27′ W.	C.17	—		—		—	—
4	6	5	59° 26′ N.	1° 20′ W.	C.17	Maasvik, Tromsö,	Nwy.	69° 59′ N.	18° 47′ E.	21.6.15	380*
5	6	5	59° 40′ N.	1° 14′ W.	C.18	Valö, Helgeland,	Nwy.	64° 48′ N.	11° 22′ E.	4.4.15	302
6	6	5	60° 05′ N.	0° 48′ W.	D.19	Hellister, Weisdale,	Sh.	60° 14′ N.	1° 18′ W.	1.7.14	25
7	8	5	60° 17′ N.	0° 09′ W.	D.19	East Quarff, Helsö, Björnör,	Sh. Nwy.	60° 04′ N. 63° 32′ N.	1° 12′ W. 8° 23′ E.	5.8.14 24.5.17	58 1081
8	9	5	60° 31′ N.	0° 35′ W.	D.20	Bressay,	Sh.	60° 11′ N.	1° 06′ W.	30.7.14	51
9	9	5	59° 44′ N.	0° 09′ W.	D.18	Burra Ness, Yell,	Sh.	60° 38′ N.	0° 59′ W.	28.9.14	111
10	9	5	59° 31′ N.	0° 37′ E.	E.18	Utsire,	Nwy.	59° 18′ N.	4° 52′ E.	3.10.14	116
11	10	5	59° 28′ N.	1° 30′ E.	F.17	—		—		—	—
12	10	5	60° 00′ N.	1° 32′ E.	F.19	—		—		—	—
13	10	5	60° 04′ N.	0° 33′ E.	E.19	—		—		—	—
14	11	5	60° 34′ N.	1° 15′ E.	F.20	—		—		—	—
15	11	5	60° 35′ N.	0° 29′ E.	E.20	Eswick, Nesting,	Sh.	60° 16′ N.	1° 06′ W.	23.8.14	73
16	11	5	60° 38′ N.	0° 07′ W.	D.20	Hatleö, nr. Aalesund,	Nwy.	62° 21′ N.	5° 48′ E.	7.10.14	118

17	11	5	60° 44′ N.	0° 45′ W.	D.20	Samfrie, Yell Sound,	Sh.	60° 28′ N.	1° 09′ W.	16.5.15	339
						Altenfjord, Finmarken,	Nwy.	70° 11′ N.	23° 19′ E.	31.5.15	354*
18	12	5	61° 02′ N.	1° 10′ W.	C.21	Monsöen, Hittern,	Nwy.	63° 35′ N.	8° 28′ E.	2.10.14	112
19	12	5	60° 46′ N.	1° 35′ W.	C.20	—		—		—	—
20	12	5	60° 31′ N.	2° 00′ W.	C.20	—		—		—	—
21	12	5	60° 14′ N.	2° 22′ W.	B.19	Papa Stour,	Sh.	60° 19′ N.	1° 42′ W.	2.7.14	20
						” ”	”	60° 20′ N.	1° 40′ W.	7.7.14	25
						Kiran, Björnör,	Nwy.	64° 08′ N.	10° 08′ E.	9.10.14	119
						Karanes, Tromsö,	Nwy.	70° 07′ N.	19° 22′ E.	4.6.15	357*
22	13	5	59° 47′ N.	2° 45′ W.	B.18	Footabrough Voe,	Sh.	60° 14′ N.	1° 39′ W.	9.8.14	57
23	15	5	60° 00′ N.	0° 05′ W.	D.19	—		—		—	—
24	15	5	59° 36′ N.	0° 41′ W.	D.18	—		—		—	—
25	16	5	58° 55′ N.	0° 04′ E.	E.16	Bjoröen, nr. Bergen,	Nwy.	60° 19′ N.	5° 10′ E.	2.10.14	108
26	16	5	59° 05′ N.	0° 58′ W.	D.17	—		—		—	—
27	16	5	59° 14′ N.	1° 57′ W.	C.17	—		—		—	—
28	16	5	58° 54′ N.	2° 03′ W.	B.16	Tranö, Vestfjorden,	Nwy.	68° 11′ N.	15° 40′ E.	7.8.15	417*
29	16	5	58° 42′ N.	2° 25′ W.	B.16	Nyminde Gab,	Dk.	55° 47′ N.	8° 11′ E.	3.9.14	79
30	17	5	58° 08′ N.	2° 00′ W.	C.15	Lodingen, Nordland,	Nwy.	68° 24′ N.	16° 01′ E.	28.8.15	437*
31	17	5	58° 17′ N.	1° 03′ W.	C.15	Edsvikskil, Bohuslan,	Sw.	58° 43′ N.	11° 10′ E.	4.12.14	170
32	17	5	58° 11′ N.	0° 32′ W.	D.15	N. Koster,	Sw.	58° 54′ N.	11° 00′ E.	4.12.14	170
33	17	5	57° 30′ N.	1° 19′ W.	C.14	Suderö,	Faroe.	61° 35′ N.	7° 00′ W.	5.7.16	749*
34	19	5	57° 14′ N.	1° 36′ W.	C.13	Nordmjele, Vesteraalen,	Nwy.	69° 00′ N.	15° 02′ E.	3.6.15	349*
						Glasö, Flatanger,	Nwy.	64° 29′ N.	10° 45′ E.	29.1.16	589
35	19	5	57° 19′ N.	0° 56′ W.	D.13	Egerö,	Nwy.	58° 25′ N.	5° 59′ E.	21.12.14	185

LIBERATIONS.						RECOVERIES.					
Station No.	Day of Month.	No. of Drifters.	Position of Station.			Place-Name.		Position.		Date.	Drift-Period (days).
			Latit. & Long.		Rect. Area.			Latit. & Long.		D. M. Y.	
36	23	5	57° 26′ N.	0° 15′ W.	D.13	Langfjord, Finmarken,	Nwy.	70° 11′ N.	21° 45′ E.	15.7.15	387*
37	23	5	57° 35′ N.	0° 39′ W.	D.14	—		—		—	—
38	23	5	57° 59′ N.	0° 57′ E.	E.14	nr. Hammerfest,	Nwy.	70° 55′ N.	24° 30′ E.	14.6.17	87* 10
39	24	5	58° 26′ N.	0° 08′ W.	D.15	—		—		—	—
40	24	5	58° 34′ N.	0° 47′ E.	E.16	—		—		—	—
41	24	5	58° 42′ N.	1° 44′ E.	F.16	—		—		—	—
42	25	5	57° 54′ N.	0° 16′ W.	D.14	nr. Fjällbacka, Bohuslan,	Sw.	58° 36′ N.	11° 14′ E.	3.4.15	282
43	25	5	57° 30′ N.	1° 19′ W.	C.14	nr. Esbjerg,	Dk.	55° 30′ N.	8° 23′ E.	2.11.14	130
44	26	5	56° 35′ N.	0° 10′ W.	D.12	—		—		—	—
45	26	5	56° 28′ N.	0° 53′ W.	D.11	—		—		—	—
46	26	5	56° 02′ N.	1° 02′ W.	C.11	Engelvaer, Steigen,	Nwy.	67° 52′ N.	14° 38′ E.	27.4.15	305*
47	26	5	56° 02′ N.	1° 47′ W.	C.11	Reinskar, Tromsö,	Nwy.	69° 50′ N.	19° 45′ E.	15.6.16	720*
48	26	5	56° 16′ N.	2° 17′ W	B.11	nr. Hirtshals,	Dk.	57° 35′ N.	9° 54′ E.	12.5.15	320
49	26	5	56° 10′ N.	2° 45′ W.	B.11	Slavoret, nr. Bodö,	Nwy.	67° 22′ N.	14° 22′ E.	7.6.15	346*
						JULY 1914.					
1	4	5	58° 09′ N.	1° 50′ W.	C.15	—		—		—	—
2	4	5	58° 36′ N.	1° 46′ W.	C.16	Blaavandshuk,	Dk.	55° 34′ N.	8° 05′ E.	8.10.14	96

3	4	5	58° 42′ N.	2° 45′ W.	B.16	nr. Cejen, Kristiansund,	Nwy.	63° 31′ N.	7° 57′ E.	3.7.15	364
4	4	5	58° 54′ N.	2° 03′ W.	B.16	nr. Lyngö Lt., Tromsö,	Nwy.	69° 53′ N.	18° 25′ E.	25.6.15	356*
5	6	5	59° 10′ N.	1° 27′ W.	C.17	Tuquoy Bay, Westray,	Ork.	59° 17′ N.	2° 57′ W.	3.8.14	28
6	6	5	59° 26′ N.	1° 20′ W.	C.17	19′ S. by E. of Fair Isle,	At Sea.	59° 14′ N.	1° 26′ W.	9.7.14	3
7	6	5	59° 40′ N.	1° 14′ W.	C.18	—		—		—	—
8	8	5	60° 31′ N.	0° 35′ W.	D.20	—		—		—	—
9	8	5	60° 35′ N.	0° 29′ E.	E.20	Cunningsburgh, East Quarff,	Sh. Sh.	60° 02′ N. 60° 04′ N.	1° 14′ W. 1° 12′ W.	7.8.14 14.8.14	30 37
10	8	5	60° 34′ N.	1° 15′ E.	F.20	—		—		—	—
11	9	5	60° 00′ N.	1° 32′ E.	F.19	—		—		—	—
12	10	5	59° 28′ N.	1° 30′ E.	F.17	—		—		—	—
13	10	5	59° 31′ N.	0° 37′ E.	E.18	—		—		—	—
14	10	5	60° 04′ N.	0° 33′ E.	E.19	—		—		—	—
15	14	5	59° 36′ N.	0° 41′ W.	D.18	—		—		—	—
16	14	5	59° 00′ N.	1° 00′ W.	D.17	Lauvik, Lofoten, Sommerö, Tromsö,	Nwy. Nwy.	68° 23′ N. 69° 38′ N.	14° 27′ E. 18° 03′ E.	22.7.15 5.8.15	373* 387*
17	14	5	58° 55′ N.	0° 04′ E.	E.16	—		—		—	—
18	14	5	58° 48′ N.	0° 56′ E.	E.16	Sorösund, Finmarken,	Nwy.	70° 34′ N.	23° 28′ E.	8.3.16	603*
19	15	5	58° 42′ N.	1° 44′ E.	F.16	—		—		—	—
20	15	5	58° 34′ N.	0° 47′ E.	E.16	Klim Strand,	Dk.	57° 09′ N.	9° 13′ E.	29.9.14	76
21	15	5	58° 26′ N.	0° 08′ W.	D.15	—		—		—	—
22	16	5	58° 11′ N.	0° 32′ W.	D.15	—		—		—	—

LIBERATIONS.						RECOVERIES.				
Station No.	Day of Month.	No. of Drifters.	Position of Station.			Place-Name.		Position.	Date.	Drift-Period (days).
			Latit. & Long.		Rect. Area.			Latit. & Long.	D. M. Y.	
23	16	5	57° 30′ N.	1° 19′ W.	C.14	Leka, Namdalen,	Nwy.	65° 04′ N. 11° 33′ E.	14.4.15	272
24	16	5	57° 06′ N.	1° 05′ W.	C.13	—		—	—	—
25	21	5	56° 44′ N.	1° 33′ W.	C.12	—		—	—	—
26	22	5	56° 20′ N.	1° 49′ W.	C.11	Foerö, Sorfolden, Laanan, Helgeland,	Nwy. Nwy.	67° 31′ N. 15° 18′ E. 66° 22′ N. 12° 19′ E.	17.4.15 15.5.15	269* 297*
27	22	5	56° 16′ N.	2° 17′ W.	B.11	Barkestad, Vesteraalen,	Nwy.	68° 49′ N. 14° 49′ E.	25.7.15	368*
28	22	5	56° 02′ N.	1° 47′ W.	C.11	—		—	—	—
29	22	5	55° 45′ N.	1° 15′ W.	C.10	—		—	—	—
30	22	5	56° 02′ N.	1° 02′ W.	C.11	12′ E. of Christiansand,	Nwy.	58° 12′ N. 8° 20′ E.	15.3.15	236
31	27	5	56° 26′ N.	1° 52′ W.	C.11	Tlohusö, nr. Kristiansund, Harö, Romsdal,	Nwy. Nwy.	63° 05′ N. 7° 46′ E. 62° 45′ N. 6° 27′ E.	30.3.15 6.5.15	246 283
32	27	5	56° 43′ N.	0° 57′ W.	D.12	—		—	—	—
33	27	5	57° 00′ N.	1° 31′ W.	C.13	—		—	—	—

Printed under the authority of His Majesty's Stationery Office by
J. & J. Gray, Edinburgh.

Wt. 15114/0108 250 9/30 J. & J. G. G.2

FISHERY BOARD FOR SCOTLAND

SCIENTIFIC INVESTIGATIONS

~~1930~~

~~No. IV.~~

The Surface Water Drift in the Northern and Middle Areas of the North Sea and in the Faroe-Shetland Channel.

PART II, Section 1: A Cartographical Analysis of the Results of Scottish Surface Drift-Bottle Experiments commenced in the Year 1910.
(With Sixteen Chart Figures.)

By

JOHN B. TAIT, B.Sc.

This Paper may be referred to as
"Fisheries, Scotland, Sci. Invest., 1930, No. IV."

EDINBURGH:
PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE.
To be purchased directly from H.M. STATIONERY OFFICE at the following addresses:
120 George Street, Edinburgh; Adastral House, Kingsway, London, W.C. 2;
York Street, Manchester; 1 St Andrew's Crescent, Cardiff;
15 Donegall Square West, Belfast;
or through any Bookseller.

1930

Price, 2s. 6d. Net.

49-175-4-30

The Surface Water Drift in the Northern and Middle Areas of the North Sea and in the Faroe-Shetland Channel

PART II

INTRODUCTION

In introducing the first part of this work it was pointed out (Part I, p. 10) that a preliminary survey of the present experimental results, based upon the simple method of connecting by straight lines the points of liberation and recovery of drifters, did not lead to information of further consequence. Nor, for reasons already given, can a direction-sector method of analysis such as that employed by Carruthers (**2**)* be adapted successfully to the present material.

Recourse was had ultimately to a method similar to that used by Ryder (**5**) in 1901, with some of whose experiments the Scottish operations are comparable. Liberation-stations and points of recovery are plotted on blank charts, a new chart for each month's liberations in the first instance. Drift-periods are then studied collectively and individually with a view to tracing the approximate course pursued by each bottle during the time it was presumably at sea.

In estimating these courses it is regarded as axiomatic that the several bottles of the group despatched simultaneously from a particular point drift from that spot more or less in company and only gradually fall away from one another as they proceed on their way. The present writer is unable to accept, as of general applicability, Nielsen's statement† to the effect that some bottles of the group may immediately set off upon a course widely divergent from that taken by the remainder.

Further, in tracing curves to represent the courses of contemporarily drifting bottles, special care is exercised to avoid the acute intersection of any two curves over open-sea areas, so giving rise to the untenable hypothesis of superficial cross-drifts within the same small sea-area at one and the same time. The application of this condition to the present data proved to be somewhat difficult until the phenomenon of *swirls* came to be considered as a result of certain observations, to which reference will be made in the appropriate place in the text.

The conception of swirls must obviously be taken into account also in connection with another question commonly associated with drift-bottle experimental data, namely, that of the reliability of the figure expressing the difference in days between the dates of despatch and recovery of a bottle as a measure of the minimum time spent in passing from the point of liberation to the point of recovery, especially if the latter be on some distant and perhaps little-frequented shore. Hitherto, in discussions upon the results of drift-bottle experiments, frequent reference has been made to the probability of drifters having lain upon the beach for indefinite periods

* Bracketed numbers in heavier type refer to the List of Publications, Part I, p. 30.

† Nielsen, J. N. "Contribution to the Understanding of the Currents in the Northern Part of the Atlantic Ocean" (*Medd. f. Komm. f. Havund., Hydrogr.*, Bind. I, No. 11. Kobenhavn, 1908).

prior to actual discovery. So far as concerns the North Sea it is at least equally likely that the above-mentioned complexes, of which no fewer than six are believed to function at various times of the year within the area in question, constitute an important, perhaps even a major factor in the recorded drift-periods of a great many returned bottles. This applies particularly to those which, registering long intervals between the dates of liberation and recovery, are found upon Continental shores after crossing the North Sea from west to east.

In the case of the present results, further argument against the too frequent resort to the " lying-upon-the-beach " hypothesis is contained in the very persistence of long-period anomalies. At the same time the proportion of short-period returns, also from Continental shores, is not inconsiderable, and it is significant that both short-period and long-period bottles, belonging to contemporaneous liberations within a restricted sea-area (sometimes at the same liberation-station), have been returned from the same locality. Further, it frequently happens that numbers of long-period drifters, from experiments initiated in different seasons and over widely separated sea-areas, are found by different individuals at places some distance apart on a coastal section, *at or about the same time*. Finally, the return of bottles set adrift well within the boundaries of the North Sea, not only from the higher latitudes of Norway, but from the Murman coast of Russia, and still more surprising, from the vicinity of the Faroe Islands, is positive evidence that drift-bottles remain afloat for very long periods—long enough to cover the vast majority of the periods of drift recorded in respect of bottles found on Danish, Swedish, and southerly Norwegian coasts.

All of these facts strongly suggest that, in relation to the entire periods elapsing between the dates of liberation and recovery of drifters, the problematical portions of these times spent upon beaches are practically inconsiderable, except perhaps in a minority of cases. Hence, likely causes of delay to drifters *while these are still at sea* must first of all be sought and the above hypothesis invoked only when such investigations fail to produce a more satisfactory interpretation of the results.

With this in mind, greater significance than hitherto is attached to the short-period return, and in the following analysis it is used as a basis of investigation into the histories of the longer-period recoveries.

The greatest difficulty lies in the endeavour to present the results of analysis in logical and at the same time chronological sequence. The full significance of earlier records is appreciated only when the entire range of the experimental results has been systematically reviewed. This circumstance involves the repeated revision and readjustment of numerous details in the light of fresh facts which are only gradually revealed as the work proceeds. Obviously, such step by step and somewhat irregular accumulation of information, necessitating very frequent back reference and interpolation, cannot be set out concisely in the form of a report. Moreover, a few of the ultimate deductions depend upon cumulative evidence afforded by numerous more or less isolated experiments.

In the following pages, therefore, while the data for the most part are treated in chronological sequence with respect to liberations, those pertaining to each calendar month being considered collectively and in the first instance independently, occasional digression and forward reference is found to be unavoidable. To obviate circumlocution, reference to the results of a particular station belonging to a month and/or year other than that in discussion at the moment are made in the following manner :—

" Station April$_{11}$6 " = Liberation Station No. 6, of April 1911.
" Station December$_{13}$14 " = Liberation Station No. 14, of December 1913.

The detailed data of liberations and recoveries are to be found in the Appendix to Part I of this report.

The system of station numbering is in accordance with the method of treatment of the data, the liberation-stations of each month being numbered consecutively and independently. The allocation of a new number to an entry in the chronological series of liberations is governed by a change in one or both of the two outstanding liberation factors, namely, the date and the position of despatch of a group of drifters.

On the various charts showing the courses estimated in respect of returns from liberations effected during specified periods, the liberation-stations are denoted thus—◎, the number beside each mark corresponding to that in the first column of the table, Appendix, Part I. At the points of recovery, marked by a dot only, the principal number represents the number of days between the dates of liberation and recovery of the drifter concerned, while the smaller, index number refers to the station at which the bottle originated. On several of the charts where a multiplicity of curves tends to obscure the reading of the diagram, recovery numbers will be found also at intermediate positions alongside the appropriate curve or group of curves. Where no recoveries ensued from the liberations made at a particular point, the same is denoted on the charts by a short thick line beneath the station mark. Depth contours where shown represent fathoms.

Regarding the accuracy with respect to geographical position of the liberation-stations, this doubtless varies to a certain extent, the more open-sea positions being possibly less accurately defined than those within or just beyond sight of land, the degree of precision depending upon weather and sea conditions during the cruise. The utmost variation, however, is probably within five or six miles of the true position. The lineal dimension of the various bottle-courses also has in general been measured to the nearest five sea-miles.

Not only is it found to be inconvenient on account of the dimensions of the chart which would then be required, but it is obviously unnecessary to enter every recovery upon a diagram, particularly those which take place in high latitudes on Norwegian and Russian coasts. Such omissions are denoted by an asterisk in the table of data, and where these are not specifically cited in the text the reader will readily deduce from the discussion of contemporary results the probable routes overtaken by the drifters concerned.

It may be well to repeat at this stage that, for reasons already indicated (Part I, p. 11), the question of inter-relationships between wind and surface drift-currents does not form an integral part of the present analysis, although meteorological conditions are in fact referred to in several places throughout the text. It will be seen, however, that these references are of a very general description, and are made only in respect of localised sea-areas in proximity to land and in support of the assumption in those areas of drift-courses which, to all appearances, are more or less anomalous in regard to direction principally. More intimate relationships between the main characteristics of the two phenomena of wind and surface water drift will form the subject of a separate investigation when the surface current system of the areas dealt with is more firmly established.

Finally, it should perhaps be mentioned that an item of considerable assistance in the work of interpreting drift-bottle experimental results, but one which on account of expense cannot always be published, is a second chronological table of the data, arranged this time on the basis of the *dates of recovery* of the drifters. The idea behind this arrangement of the material is that bottles stranding on the same coastal section within a short time of one another will, as a general rule, have followed the same route in the latter stages of their sea journeys. When the data are sufficiently numerous it may then be possible to argue not only forward, as it were, from the dates and positions of liberation operations, but backwards from the times and places of stranding of numerous drifters. Thus, in many cases of very long routes only the intermediate sections of these may remain somewhat doubtful, and even this uncertainty may be remedied by a judicious planning of future liberations.

* * * * * *

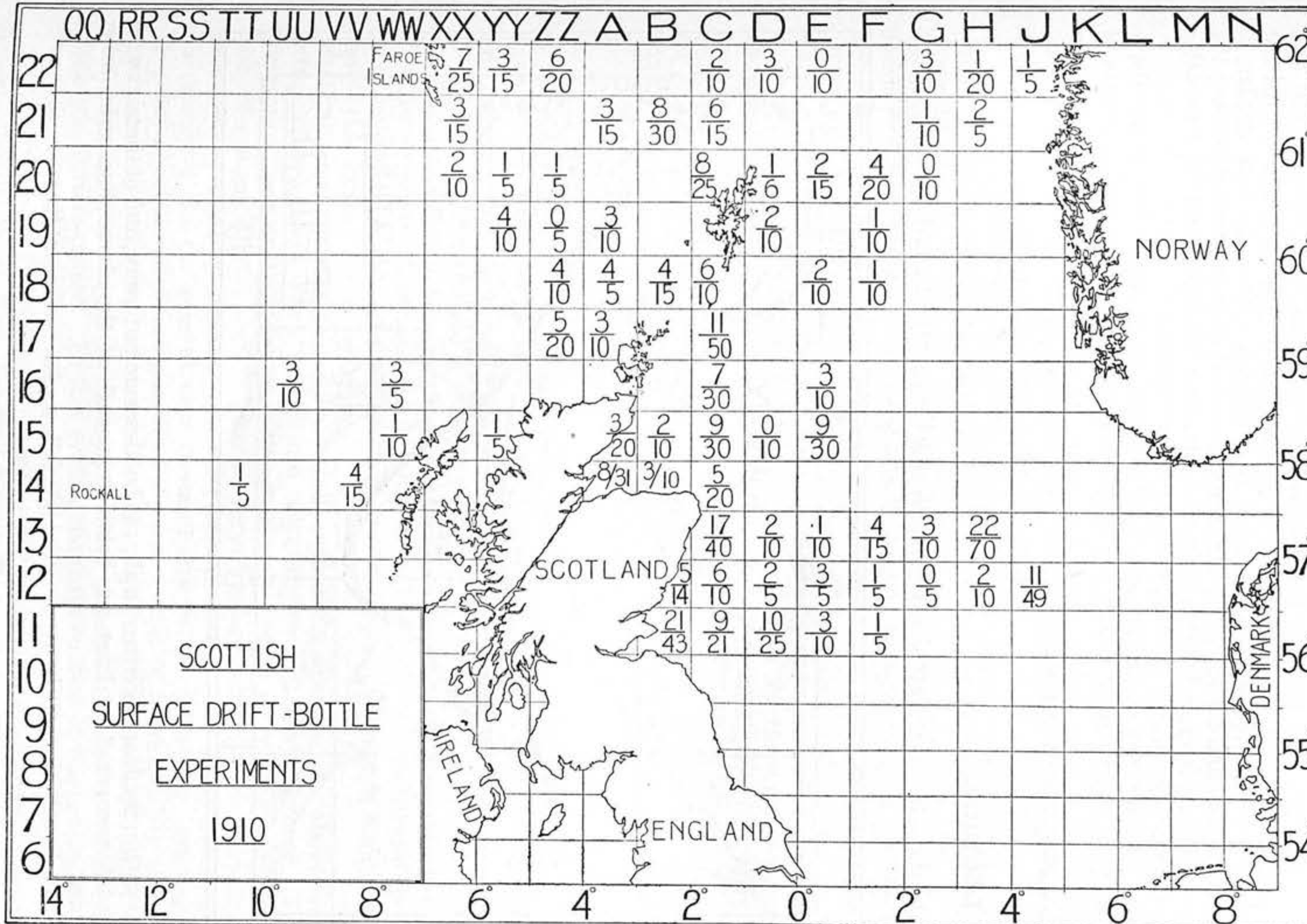


Figure 2*

* Fig. 1 appears in the first part of this paper, published separately as *Fisheries, Scotland, Sci. Invest.*, 1930, No. II.

EXPERIMENTS COMMENCED IN THE YEAR 1910

THROUGHOUT the year 1910, in the months between April and June, August and December, all four inclusive, the liberation of surface drift-bottles was carried out over a very wide area as demonstrated in Figure 2. This chart is similar in construction to Figure 1 (Part I), the denominator of each fraction signifying the number of drifters liberated within the rectangular area concerned and the numerator the corresponding number of bottles subsequently returned.

The total number of drifters set afloat over the entire region during the above eight months was 1109, of which 303 were later recovered, a percentage return of 27·3.

The experiments begun in each calendar month are considered separately.

* * * * * *

April Liberations.

The despatch of surface drift-bottles during the month of April 1910 was carried out from two stations over the region of the Great Fisher Bank and from seven

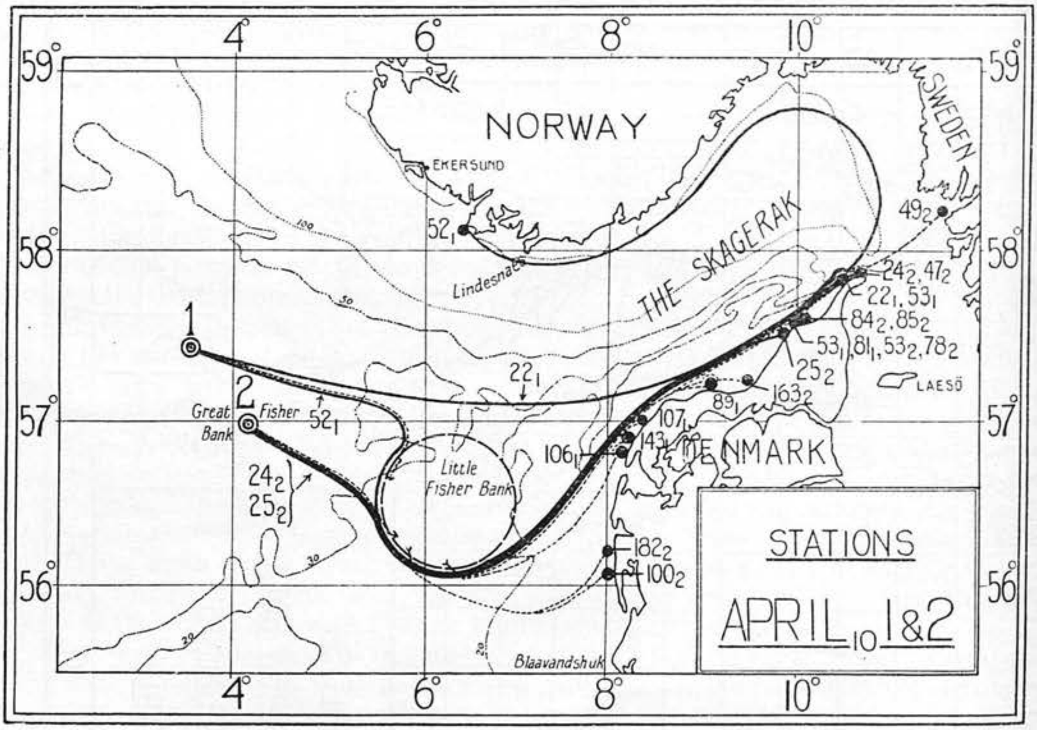


Figure 3

points within the Moray Firth. In all, 150 bottles were put away, and of these 41 were ultimately recovered, at least one bottle from each of the above nine series being returned.

The distribution of the recoveries is as follows :—

From Stations 1 and 2.

On the west Danish coast south of Hantsholm	5
On the north-west Danish coast between Hantsholm and the Skaw	13

On the west Swedish coast	2
On the Norwegian coast between Lindesnaes and Ekersund	1
On the Norwegian coast north of latitude 62° N.	4

From Stations 3 to 9.

On the east British coast between Buchan Ness and Flamborough Head . . .	6
On the west Danish coast between Fanö Island and Nissum Fjord	4
Eastward of a line joining Hantsholm and Lindesnaes, i.e. within the Skagerak . .	4
At sea	2

Experiments commenced on 13th April 1910 when forty bottles were liberated some thirty miles north and west of the Great Fisher Bank. Two days later thirty-nine drifters were put overboard at a point immediately over the bank. Recoveries from these two series may be examined together.

Obviously the most important returns for immediate consideration are those from Danish, Swedish, and south Norwegian coasts, and of these, three stand out from the others on account of the relatively short periods recorded as having been spent presumably at sea. The shortest-period bottle of all originated at Station 1, being picked up 22 days later on the north Jutland coast at a point two miles west of Höjen. From Station 2 one drifter was recovered near the Skaw after 24 days, and another between Rubjerg and Hirtshals after 25 days.

On the other hand, the majority of the recoveries pertaining to these two stations, although effected in proximity more or less to the three above-mentioned, registered drift-periods considerably in excess of 25 days. Further scrutiny of the magnitudes in question reveals the fact that they may be arranged in fairly well-defined groups as follows :—

TABLE XIII*

Number of recoveries .	3		5		5		3		1		1		1
Drift-periods . .	22–25		47–53		78–89		100–107		143		163		182
Average period . .	24		51		84		104		143		163		182
Differences . . .		27		33		20		39		20		19	

It is evident that the grouping of the drift-periods is not altogether fortuitous. In three cases the figures in the last line of Table XIII are practically the same —20 days—and in one of the remaining instances the difference is almost exactly double this figure.

Thus there appears to exist a certain periodicity amongst the above-recorded drift-periods, causing them to fall into more or less well-defined groups. On the assumption that drifters liberated simultaneously from a given point and returned from the same coastal section pursue very similar courses, such periodicity is indicative of some systematic, retarding influence upon the bottles during their sea passages. In the present case the majority of the drifters in question were obviously affected and, bearing in mind the axiom relating to cross-drifts, periodicity in their times of stranding upon the north-west Jutland coast is most readily, if not exclusively explained as the effect of a circulatory system in the surface waters through which the drifters passed. To this system the main courses of the bottles are to be regarded as being approximately tangential.

The surface-water swirls propounded by Böhnecke (1) at once suggest themselves, in particular the North-East Dogger Bank Swirl.

* For Tables I–XII, see Part I of this Report. *Fisheries, Scotland, Sci. Invest.*, 1930, No. II.

It is reasonable to suppose that the three shortest-period recoveries did not enter this eddy, and for the 22-day return from the vicinity of Höjen, north Jutland, an almost straight-line course from Station 1 may be assumed. Such is represented in Figure 3 and measures approximately 240 miles, thus postulating for this particular bottle an average daily rate of drift of 10·9 miles.

It cannot be argued, however, that the two shortest-period recoveries from the Station 2 series of bottles also passed eastwards *on the north side* of the swirl, since it must be accepted that a number of the drifters liberated at Station 1 *entered* the complex. These Station 2 bottles must have cruised round the southern periphery of the eddy, which may be taken therefore as having been orientated during April and perhaps May 1910 over the region of the Little Fisher Bank. A circle of certain size is described in Figure 3 to represent the system approximately in size and position.

In respect of these two recoveries from Station 2 the curves entered on the chart to represent their probable courses lead to the deduction of average velocities of 11·0 and 9·4 miles per day respectively.

The mean of the above three average velocity figures is 10·4 or approximately $10\frac{1}{2}$ miles per day, and on the basis of this figure the longer-period recoveries may be investigated with a view to finding the probable times spent under the dominant influence of the North-East Dogger Bank Swirl. Prior to and after delay due to eddy influence the drifters in question are assumed to have traversed routes approximately as defined by the broken curves on the chart. These routes were first of all traced on large-scale charts and measured to the nearest five miles, the number of days then being calculated which would have been occupied by each bottle in accomplishing a continuously progressive course from liberation-station to stranding-place (i.e. passing round the periphery of, but not entering the swirl) at an average daily rate of drift of $10\frac{1}{2}$ miles. The number of days remaining when these times are deducted from the full drift-periods may be taken as furnishing a measure of the time spent cruising within the eddy. These investigations are most conveniently set out in tabular form as follows, taking the recoveries in order of the magnitudes of their drift-periods.

TABLE XIV

Recovery.† (*a*)	Course in Miles, Exclusive of Eddy Circuits. (*b*)	Time in Days to Cover (*b*) at $10\frac{1}{2}$ Miles per Day. (*c*)	Residual Periods. (Days.) (*a*)–(*c*)
47_2	275	26	21
49_2	310	30	19
53_1	325	31	22
53_1	300	29	24
53_2	245	23	30*
78_2	245	23	55
81_1	300	29	52*
84_1	305	29	55
85_2	245	23	62
89_1	265	25	64
100_2	160	15	85
106_1	235	22	84
107_1	250	24	83
143_1	240	23	120
163_2	225	21	142
182_2	165	16	166

† Recoveries are denoted as they appear on the chart, Figure 3, and as explained on p. 6.

The main interest of the above table is contained in the last column, which gives the various times presumably spent within the North-East Dogger Bank Swirl. With due allowance for so-called "experimental error" these figures, excepting the two marked by an asterisk, may be looked upon as simple multiples of a constant factor of 20 days, and it is remarkable that the same quantity was derived from Table XIII as defining the periodicity in the magnitudes of the drift-periods.

Böhnecke (1) does not indicate what may be the physical characteristics of the Dogger Bank Swirls further than that they gyrate counter-clockwise. It may reasonably be assumed, however, that they are weakly centrifugal dynamically and that consequently, floating objects which become involved for a time in one or other of them will generally remain just within the periphery of the system, liable to escape fairly easily from its dominating influence.

For convenience, the eddy with which we are immediately concerned is assumed to have been circular in plan at the time of these experiments. The above figure of 20 days, then, would appear to be a measure of the time required by a drifter to complete one circuit of the system, cruising just within its circumference. As such it is proposed to call this quantity the *Period of Circuit* of the complex.

In the course of the seasons embraced by the above experiments, namely, between the middle of April and the middle of October 1910, there are two contingencies which may have arisen with reference to the North-East Dogger Bank Swirl as above defined. During these months it may have altered in position or in size, or perhaps both of these characteristics may have changed. Alteration of position would affect the fourth column of Table XIV, namely, the estimated mileage of a drifter's course exclusive of eddy circuits. But, so far as can be judged at present, it is equally likely that a more or less concomitant alteration—the effect of opposing influences—may have occurred in the dimensions of the swirl.

Omitting the shortest-period returns from Danish and Swedish coasts, the following table gives the correlation between recoveries effected east and south of Hantsholm, and the corresponding dates :—

TABLE XV

Recoveries.		(*a*) Number found East of Hantsholm.	
Total Number.	Dates.	(*b*) Number found South of Hantsholm.	
5	1st–7th June	(*a*)	5
5	2nd–11th July	(*a*)	5
3	24th–29th July	(*b*)	3
1	3rd September	(*b*)	1
1	25th September	(*a*)	1
1	14th October	(*b*)	1

It will be observed, firstly, that all the earlier recoveries, namely, those found prior to 12th July, took place within the Skagerak, and secondly, that with one exception those returned after the 23rd July stranded on the west Danish coast south of Hantsholm.

The above facts suggest a translation of the North-East Dogger Bank Swirl towards the south or south-west during the summer of 1910, the cause of which is probably to be found in an extension of the superficial area covered by the fresher water output from the Baltic during this season. Confirmation of the hypothesis is contained in the isothermal charts of the *Bulletin Hydrographique* for 1909–10 and 1910–11. Reference to the decade (10-day) isothermal charts for the period May to September 1910 shows that from the beginning of May until the second decade of June the mean temperature of the surface water in the Skagerak rose rapidly, decade by decade, the isotherms penetrating well into the Skagerak from the North Sea. During the second and last decades of June there was practically equilibrium as regards the surface temperature in that region. Note the apparent correspondence between this thermal phase and the entire absence during the same time-interval of returns from Danish or Swedish shores relative to these first experiments of April 1910.

The change of conditions by the first decade of July was very marked. The 15° C. isotherm was by this time pushed right outside the Skagerak and thereafter to the end of September the disposition of isotherms was such as to demonstrate the spreading over the North Sea from the mouth of the Skagerak of a superficial layer of fresher water.

The only other recovery from the above experiments which need be considered here is that returned from Lister in southern Norway after having been away from Station 1 for 52 days. To postulate that this drifter passed into the Skagerak by way of *the north side* of the above eddy leads to the deduction of a figure in respect of the mean velocity of drift much lower than 10$\frac{1}{2}$ miles per day. If it be accepted, however, that the bottle in question cruised round but did not enter the said swirl, as indicated in Figure 3, a route of approximately 540 miles must have been overtaken at an average daily rate of 10·4 miles.

Thus, apart from the value of these analytical results as applying to a particular epoch, it is to be noted that it is possible by means of drift-bottle experiments not only to deduce the existence of a swirl of surface waters, but to determine with fair accuracy its position and extent.

Figure 4

The next series of liberations was carried out between the 23rd and 28th days of April from seven stations—numbers 3 to 9 inclusive—situated within the Moray Firth.

The first observation to be made regarding the sixteen drifters recovered as a result of these operations is that none was found on the shores of the Moray Firth. Six bottles were returned during the months of May, June, and July 1910—two in each month—from points on the British east coast between Buchan Ness, Aberdeenshire, and Flamborough Head, Yorkshire. Two drifters were picked up at sea, 56 and 58 miles E.½N. and E. by N. of Peterhead on 17th June and 9th July 1910 respectively. The remainder found their way ultimately to Danish, Swedish, and south Norwegian coasts.

Reference to the Daily Weather Reports of the British Meteorological Office shows that for eight days prior to and for some time after the initiation of the experiments under review, the winds over the Moray Firth region blew mainly and sometimes strongly from the west quadrant, thus suggesting a probable cause of the non-recovery of drifters upon the shores of the Firth.

The Open-Sea Recoveries: To a certain extent, the magnitudes of the drift-periods, but more particularly the positions of recovery of the two bottles picked up by herring drifters from the surface waters of the open sea, do not favour the assumption of courses almost due east from the respective points of origin, namely, Stations 6 and 9. The two bottles concerned then may have attained their ultimate positions either from the south or from the north. On the former proposition, the bottles passed out of the Moray Firth along its south coast, cruised southwards along and more or less parallel to the mid-east Scottish coast and at some point on this route deviated eastwards and finally northwards. The last part of such a course, namely, the drift northwards so far off land, is inconsistent with all observations made hitherto over the area in question. The latter hypothesis, namely, that the drifters were cruising in a southerly direction when discovered, postulates that the bottles left the Moray Firth along its north-western coast, cruising in a north-easterly direction and thereafter at some point on the route were carried eastwards and finally southwards. In this connection it is to be recalled that in the statistical treatment of the entire data a deduction was made (Part I, p. 21) which supports the first-mentioned part of such a cruise and the normal direction of flow of the main surface drift-stream, as established by Fulton (3), affords corroboration of the second part.

Accepting the latter explanation, the question next arises as to how far north the drifters cruised before turning eastwards. From the results of the April experiments this fact cannot be ascertained, but there is, fortunately, a case occurring in the results of the liberation experiments of the following month—May 1910—which throws light upon and in fact probably answers this question.

On the 9th June 1910 a bottle liberated on 12th May was recovered at sea at a point 36 miles S. by E. of Bressay Light, Shetland—the point A in Figure 4. The April bottles with which we are concerned were recovered subsequent to the above date, the first on the 17th of June and the other on the 9th of July. Reference ahead to Figure 9 (*a*) will inform the reader of the course estimated for the above May bottle which originated at the position—Latitude 59° 31′ N.–Longitude 0° 37′ E. From this instance it may be deduced that from about the first week of June there was a connection in the latitude of Fair Isle between a north-easterly flowing drift-stream emanating from the Moray Firth and the normal southerly drift to the east of longitude 1° W.

Let it be assumed, then, that the 51-day sea-recovery from Station $\text{April}_{10}6$ passed over the point A on the same day as the recovery of the May bottle at that spot was effected, namely, on the 9th of June. The distance between the point A and the point of recovery of the former bottle measures about 102 miles and the corresponding difference between the dates of recovery is eight days, from which data a mean rate of drift of 12¾ miles per day is deduced relative to this latter portion at least of the course indicated in Figure 4 for the particular April bottle in question. As will be seen later, *this is practically the same figure as that reckoned* *for the above drifter from the May experiments over its entire course* as postulated in Figure 9 (*a*).

To be in conformity with the above cases it is obvious that the 72-day April recovery, found in proximity to and under the same circumstances as that originating from Station 6, must either have cruised farther north towards Shetland before turning southwards, or have been delayed prior to reaching the neighbourhood of the point A. The latter explanation is almost certainly the correct one, for, on the basis of the above average velocity figure, further evidence tends to show that *both* bottles were delayed in some way prior to reaching the latitude of Fair Isle. Such evidence is to be obtained by practical measurement of the full courses as these are represented by the curves in Figure 4 and division of the mileage so obtained by the corresponding drift-periods, when vectors of much less than $12\frac{3}{4}$ miles per day will result.

Here we must fall back upon and utilise one of Fulton's suggestions and assume that at the period of the present experiments a small clockwise eddy was functioning in the inner Moray Firth and dominating for some time drifters set afloat within and in the neighbourhood of its region of influence. It is a moot point whether the aforementioned prevalence of westerly winds during April 1910 would be sufficiently strong and persistent to "wash out" as it were this gyratory system,*

Acting upon the assumption of the eddy's existence at the time and taking for granted that, exclusive of eddy circuits, both the sea recoveries presently under discussion drifted over the courses plotted on the chart, Figure 4, at an average rate of $12\frac{3}{4}$ miles per day, an estimate may be made of the time spent within the circulatory system of surface waters. These times are found to be respectively 28 and 48 days, and it is also to be noted that the difference between the total drift-periods of the recoveries in question is 21 days, all of which figures suggest for the Moray Firth Eddy a *Period of Circuit* of about seven days. Such a period is in conformity with the size of the swirl as represented in Figure 4 by the broken elliptical curve.

The above point will be further amplified as the present analysis proceeds.

The British East-Coast Recoveries: The positions of recovery, the drift-periods, and the points of origin of the six drifters picked up on the British east coast are entered in Figure 4. It will be of further assistance to tabulate these *seriatim* according to their actual dates of discovery as follows :—

TABLE XVI

Station No.	Drift-period.	Date of Recovery.
5	24 days	20th May 1910
3	31 ,,	24th May 1910
3	39 ,,	1st June 1910
3	64 ,,	26th June 1910
5	73 ,,	8th July 1910
8	80 ,,	17th July 1910

It has been indicated already that the results of the experiments now under examination—those of April 1910—are closely related to those of the following month's liberations. In the study of the above recoveries reference must again be made to the May records. Therein is contained evidence pointing to a set westwards into the Moray Firth of at least the west flank of the southward moving main-stream

* although the said winds might be so far effective as to prevent bottles outwith the eddy boundary from stranding on the Moray Firth coastline.

drift along the British east coast, between the 21st of May and the 3rd of July 1910. This deviation appears to have taken place in the region about the point—Latitude 58° 00′ N.–Longitude 1° 30′ W.

The date of recovery—20th May 1910—of the first of the above-noted drifters suggests that the date, 21st May, marks almost exactly the time of commencement of this westward trend towards and into the Moray Firth, for the drifter discovered on the Aberdeenshire coast on 20th May must have experienced no such influence three or four days prior to being cast ashore, *provided* that its course immediately before stranding was a southerly one. On the other hand, this particular bottle may have attained its stranding-place *from the south*, drifting northwards along the coast under the influence of another eddy system, situated off the mid-east Scottish coast between Fife Ness and Aberdeen, which certain of the May results show was in operation at this time (see p. 27). In either case, this drifter and probably also the the remaining five tabulated in Table XVI must have passed out of the Moray Firth before the 20th of May 1910, the later-recovered bottles becoming involved for a time in the complex hereafter named the *Mid-East Scottish Coast Eddy*.

Another deduction from the experiments of the following month favours this conclusion. It has been estimated (p. 35) that the first bottle to pass a point east of Wick on a northward cruise did so on or about the 31st of May 1910. This finding precludes the assumption of a northerly course out of the Moray Firth in respect of at least the first three cases in Table XVI.

The broken curve in Figure 4 then represents the most probable line traversed by the above six bottles after escaping from the Moray Firth Eddy.

The Danish, Swedish, and South-Easterly Norwegian Coasts Recoveries: In order of date of discovery these are as tabulated below :—

TABLE XVII

(Station No.): Place of Recovery.	Date of Recovery.
(5) Near Bulbjerg, Denmark	15th January 1911.
(4) Kopstadsö, Sweden	9th February 1911.
(6) Near Ringkjöbing, Denmark	18th February 1911.
(4) Tjand, Nissum Fjord, Denmark	18th February 1911.
(8) Near Ringkjöbing, Denmark	7th April 1911.
(7) Fanö Strand, Denmark	30th April 1911.
(8) Grebbestad, Sweden	16th November 1911.
(9) Homborsund, South Norway	25th November 1911.

As indicated by the broken lines marking off the above table into three sections, the recoveries upon Danish, Swedish, and south-easterly Norwegian coasts resulting from the April experiments fall into three well-defined groups according to the actual dates of recovery. The fortunate circumstance that no fewer than two drifters comprise each group undoubtedly minimises, if it does not entirely preclude the factor of uncertainty regarding the actual date of stranding as distinct from the date of discovery, the more so as the individuals of each group were recovered at points on the coast more or less widely apart.

Consider the two drifters comprising the third group of Table XVII. The difference of nine days between the dates of recovery in conjunction with the relative positions of the stranding-places point to the fact that in all likelihood these two bottles kept more or less together all the way across the North Sea, even though they may have taken more than eighteen months to complete the journey.

The division of the remaining six entries in Table XVII into two groups is in accordance with the non-recovery upon Danish, Swedish, and south-easterly Norwegian shores during the month of March 1911 of any drifter from the April 1910 experiments in the Moray Firth. The examination of the results of later liberations of 1910, however, suggests that this hiatus is without significance, since no fewer than eighteen bottles belonging to 1910 experiments were picked up in that month (March 1911) on the coasts of Denmark and Sweden. In point of fact there appears to have been a concentration of such recoveries during the first *three* months of the following year, after a "blank" period, embracing, with the exception of a single recovery in November, almost the whole of the last quarter of 1910.

It will be of interest and at the same time instructive to consider the relative dispositions of the liberation-stations of 1910 from which drifters attained the above shores in the first quarter of 1911. These are plotted as "positive records" on Figure 5, with the date on which operations were carried out alongside each mark, also the number of drifters immediately concerned. The loci of recovery are denoted by the blocking of the appropriate sections of the coast-line.

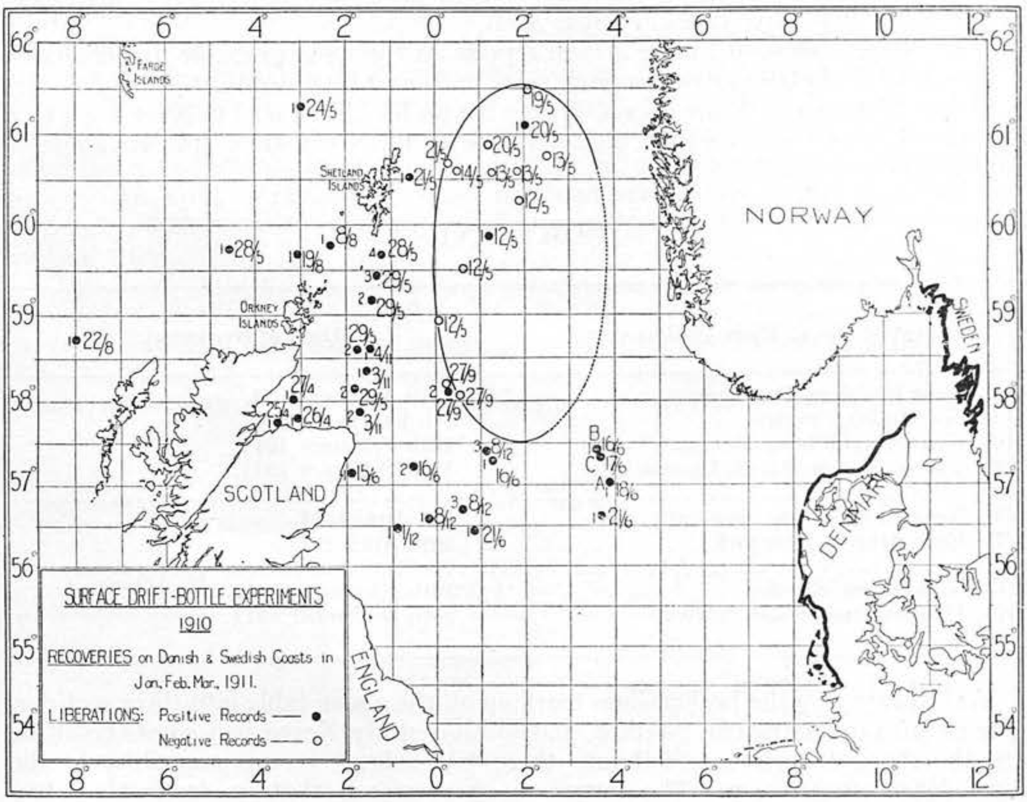


Figure 5

It is clear from a study of liberation-dates in conjunction with the relative distances of stations from the Danish and Swedish coasts that no direct relationship can be established between these two factors. For instance, there occur several cases like the following. Certain drifters despatched in the month of December 1910 were found in proximity to, but definitely earlier than others which had been cast adrift in the month of June 1910 from stations considerably nearer lineally to the Danish coast than were the December stations. Incidentally, it may be noted, as bearing upon the definition of the above-mentioned "blank" period, that the liberations of June 1910 resulted also in three recoveries between the 29th of September and the 9th of October 1910 on the shores of north-west Jutland and of Sweden. These three bottles originated at the points A, B, and C (Figure 5) respectively.

Concerning the majority, therefore, of the above recoveries, the April bottles amongst others, the argument is that on account of some retrogressive influence they were prevented from making their way *directly* from their respective points of origin to the coasts of Denmark and Sweden. In the light of knowledge so far accruing from the present analysis such interference may be put down to the effect upon the drifters' courses of one or more of the following systems :—

(*a*) The Moray Firth Eddy.
(*b*) The Mid-East Scottish Coast Eddy.
(*c*) The North-East Dogger Bank Eddy.

There is, however, one other surface water complex of the Northern North Sea within which a number of the drifters now being considered may have become involved. This system will be treated in more detail later, but as a preliminary to its establishment attention is directed towards the almost total lack of recoveries upon Danish, Swedish, and south-easterly Norwegian shores during the first three months of 1911, resulting from certain liberations, contemporaneous with many of those already considered, carried out within the area defined by the elliptical curve on the chart, Figure 5.

* * * * * *

May Liberations.

Liberations carried out during the month of May 1910 covered a very wide field. From the 11th to the 14th of the month bottles were set adrift from twelve different stations on lines between Aberdeen and the Viking Bank and between the latter region and Lerwick, Shetland. A further fifteen stations were operated between the 18th and 21st on a cruise proceeding some sixty miles north-northwestwards from Flugga, Shetland, thence eastwards towards the Norwegian coast to longitude 4° E. and back again to Lerwick. A third and fourth series of eight and six stations respectively lay approximately on two lines : (*a*) between the northern entrance to Yell Sound, Shetland, and the southern extremity of the Island of Osterö in the Faroe group ; and (*b*) between the southernmost point of Suderö, Faroe, and Marwick Head, Orkney. One station on the Faroe Shelf connected the two series. In continuation of this cruise one station, midway between Papa Westray, Orkney, and the Island of Foula, Shetland, connected with a line of five stations proceeding in the direction of Kinnaird Head, Aberdeenshire, from a point about fifteen miles south of Sumburgh Head, Shetland. Finally, on the two last days of the month thirty-one drifters were thrown overboard from four points in the coastal waters off the mid-east Scottish coast between the mouth of the River Ythan, Aberdeenshire, and Fife Ness.

From the above fifty-two stations a total of 452 drifters was despatched. Ultimately, 113 of these were returned. No recoveries were recorded in respect of liberations at eight stations.

In view of the scope of the above operations and the wide distribution of resulting recoveries, a general survey of the month's results is first of all given.

Liberation-stations and points of recovery were as usual plotted on a large scale chart, but all recoveries are not conveniently shown in detail on a chart of dimensions suitable for publication.

A prominent feature of the large-scale chart was the extraordinary concentration of recoveries upon the *eastern* shores of the Orkney and Shetland Islands and Fair Isle. This is conveniently indicated on Figure 6 by the partial "blocking" of these islands. Reference to the sources of the bottles in question reveals the fact that they proceeded, ultimately at least, towards Orkney and Shetland, from stations in some cases well over one hundred miles apart. Regarding the actual times of recovery, Table XVIII shows to within a fortnight the periods embraced by these returns.

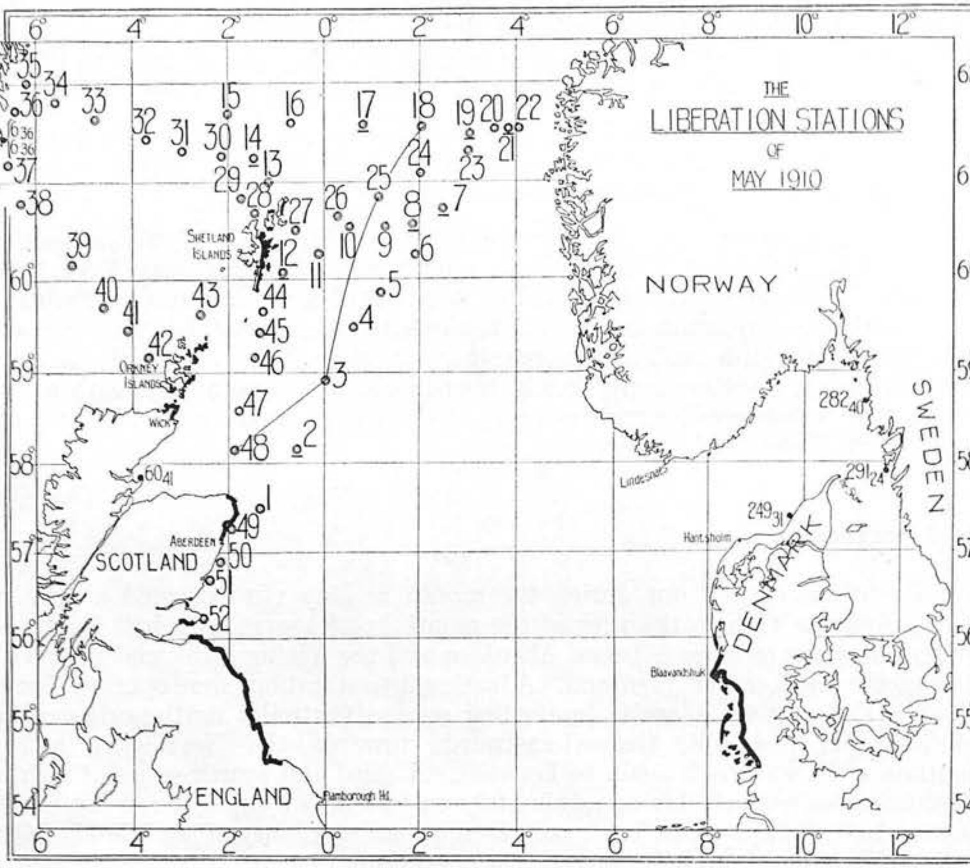


Figure 6

TABLE XVIII

Eastern Orkney-Shetland Recoveries

Station No.	Period of Recovery.															
	June.		July.		Aug.		Sept.		Oct.		Nov.		Dec.		Jan.	
	1–15	16–30	1–15	16–31	1–15	16–31	1–15	16–30	1–15	16–31	1–15	16–30	1–15	16–31	1–15	16–31
4	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
10	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
11	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—
13	—	—	—	2	2	—	—	1	—	—	—	—	—	—	—	—
16	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—
18	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
20	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
23	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
25	—	—	—	—	—	1	—	—	—	—	—	—	1	—	—	—
28	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
29	—	2	—	—	—	1	—	—	—	—	—	—	—	—	1	—
30	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—
34	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
35	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
36	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
39	—	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—
41	—	1	1	—	—	—	—	—	—	—	—	—	1	—	—	—
42	1	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—
43	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—
44	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
45	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Totals	2	10	5	5	2	8	—	1	—	—	—	—	5	—	2	—

From this table it is clear that the concentration of recoveries which took place mainly upon eastern shores of the Orkney-Shetland Islands occurred for the most part between the middle of June and the end of August 1910. With regard to the five bottles recovered during the first half of December 1910 it might at first be considered that these stranded at a very much earlier date than that upon which they were actually discovered, in fact, along with the bulk of the drifters enumerated in Table XVIII. As will be seen later, however, the records for the month of September 1910 contain certain evidence showing that this would not be a legitimate conclusion. Rather do these later records strongly suggest that the above five long-period drifters and probably also the two recovered early in January 1911 were "held up" *at sea* during the seven months between their dates of liberation and recovery.

In regard to the remainder of the British coast recoveries from this month's experiments, the majority of these, to the number of twenty-one, were effected upon the coast south of Kinnaird Head, Aberdeenshire, to nearly latitude 53° N. The following table (Table XIX) demonstrates that they also fall into two groups in accordance with the season in which recoveries were made, the larger group of eighteen bottles being found during the months of June, July, and August principally, the smaller group not being recovered until towards the end of the year as in the case of the corresponding group of Shetland-Orkney returns.

TABLE XIX

British East Coast Recoveries

Station No.	Period of Recovery.													
	May.		June.		July.		Aug.		Sept.		Oct.		Nov.	
	1–15	16–31	1–15	16–30	1–15	16–31	1–15	16–31	1–15	16–30	1–15	16–31	1–15	16–30
1	—	1	—	—	—	2	—	—	—	—	—	—	—	—
4	—	—	—	—	—	—	1	—	—	—	—	—	—	—
9	—	—	—	—	—	—	—	—	—	—	—	—	1	—
26	—	—	—	—	—	—	—	1	—	—	—	—	—	—
43	—	—	—	—	—	1	—	—	—	—	—	—	—	—
44	—	—	—	—	—	1	—	—	—	—	—	—	—	—
47	—	—	—	—	—	—	—	—	—	—	—	1	1	—
49	—	—	1	1	—	1	—	—	—	—	—	—	—	—
50	—	—	—	—	2	—	—	—	—	—	—	—	—	—
51	—	—	—	2	1	—	—	—	—	—	—	—	—	—
52	—	—	3	—	—	—	—	—	—	—	—	—	—	—
Totals	—	1	4	3	3	5	1	1	—	—	—	1	2	—

There would thus appear to have occurred during the year 1910, two definite impingements of surface water upon the British east coast, the first, probably the stronger, during summer months and the second during the following winter.

Two of the above returns deserve special mention in that they are included in an exceptionally small group of the total returns enumerated in Table I (Part I). The two recoveries concerned originated at Station 1 and were returned during the latter half of July 1910 from points south of latitude 54° N., thus indicating that during the summer of 1910 the normal southerly drift along the British east coast reached somewhat farther south than usual before deviating eastwards across the North Sea.

On the Continental side of the North Sea another concentration of recoveries from the May experiments occurred on Danish and Schleswig-Holstein coasts south of latitude 56° N. The drift-periods recorded for these bottles are again fairly consistent, seventeen of the twenty-two drifters returned from this stretch of coast registering periods of from 245 to 324 days. The remaining five periods exceeded 388 days. A table similar to that constructed for the Shetland and Orkney recoveries showed that the above seventeen drifters were recovered between 16th January and 30th April 1911, sixteen of them during the first three months of the year. With one exception all the twenty-two drifters which stranded upon this part of the coasts of Germany and Denmark were derived from stations situated to the east of the Orkney and Shetland Islands, but west of a curve passing through Stations 18, 25, 3, and 48 (see Figure 6).

Only three bottles stranded within the Skagerak as a result of the liberations of the month of May 1910. Two of these originated at points some 50 and 60 miles north-west of the Shetland and of the Orkney Islands respectively, namely, at Stations 31 and 40, and reached their stranding-places on the north-west Danish and west Swedish coasts during the first quarter of the following year.

On the Norwegian coast north of Lindesnaes the most southerly recovery took place a few miles south of latitude 63° N., between which and latitude 65° N. only four drifters stranded. The latter four bottles came from stations from which other recoveries are recorded as having taken place within the boundaries of the North Sea, although the liberation-stations themselves were situate outwith these boundaries. In fact, the records for the month under present examination contain sufficient evidence towards the safe assumption that in respect of the twenty-two drifters recovered north of latitude 62° 50′ N., the great majority, if not all of the bottles concerned cruised for a time within the North Sea. An exposition of this evidence is contained in Table XX which gives the frequency of the recoveries from the various stations, upon the following sections of the coast-line :—

A Eastern shores of the Orkney and Shetland Islands and the shores of the Moray Firth.
B The British east coast south of Kinnaird Head.
C Danish and Schleswig-Holstein coasts south of latitude 56° N.
D Within the Skagerak.
E The Norwegian coast north of latitude 62° 50′ N. (Including one bottle recovered on the Murman coast, Russia.)

TABLE XX

Station No.	*A*	*B*	*C*	*D*	*E*
1	—	3	—	—	—
3	—	—	3	—	—
4	1	1	—	—	—
5	—	—	1	—	—
6	1	—	—	—	—
9	—	1	—	—	—
10	1	—	—	—	—
11	2	—	—	—	—
13	5	—	—	—	1
15	—	—	—	—	2
16	2	—	—	—	1
18	1	—	1	—	1
20	1	—	—	—	—
22	—	—	—	—	1
23	1	—	—	—	1
24	—	—	—	1	—
25	1	—	1	—	—
26	—	1	—	—	—
27	—	—	1	—	—
28	2	—	—	—	—
29	2	—	—	—	—
30	1	—	—	—	1
31	—	—	—	1	—
32	—	—	—	—	1
33	—	—	—	—	2
34	1	—	—	—	2
35	1	—	—	—	—
36	1	—	—	—	2
38	—	—	—	—	2
39	1	—	—	—	2
40	—	—	—	1	3
41	5	—	—	—	—
42	3	—	—	—	—
43	1	1	—	—	—
44	1	1	4	—	—
45	1	—	4	—	—
46	—	—	3	—	—
47	—	2	2	—	—
48	—	—	2	—	—
49	—	3	—	—	—
50	—	2	—	—	—
51	—	3	—	—	—
52	—	3	—	—	—
Totals.	36	21	22	3	22

The twenty-two drifters found upon the Scandinavian coast north of latitude 62° 50′ N. originated at fourteen of the May stations. In respect of nine of these stations, Table XX shows that other recoveries were effected within, or immediately adjacent to the North Sea, on the British, or on German, Danish, or Swedish coasts.

The drift-periods of twenty-one of the above drifters lie between 220 and 462 days, the median period being 318, and the mean, 323 days. The exceptional bottle registered a period of 168 days. Nevertheless, another bottle from the same station was not found until 312 days after the date of liberation. A fair consistency then may be said to exist among the drift-periods of the northerly Scandinavian coast recoveries. Hence it is highly probable that all of them reached their ultimate stranding-places by way of at least the *Northern Area* of the North Sea. When the results of the experiments of August 1910 are examined it will be seen that this assumption relative to the May bottles is justified. Very much shorter drift-periods were registered by certain August bottles liberated in the Faroe-Shetland Channel and later found upon the Norwegian coast in the same latitudes as those belonging to the May experiments.

A point of interest and of some importance in connection with Table XX is that from Station 18 one drifter was recovered at a point in each of the three coastal Sections, A, C, and E. The last one of the three to be found was that in Section C, which was picked up 347 days later than that found on Burö Island, near Bodö, Norway—Latitude 67° 14′ N.-Longitude 13° 58′ E. This is only one instance of many which occur in the present records, pointing to the futility of an examination of the results of such experiments on the basis, merely, of a study of the relative positions of liberation-stations and stranding-places without at the same time giving serious consideration to the magnitudes of the drift-periods. Of course, a primordial necessity for the successful outcome of such an analysis is that experiments be conducted over a wide field and repeatedly, so that the resulting records may be sufficiently numerous.

The acceptance of the above assumption in regard to the routes overtaken by the drifters found in northerly latitudes of the Norwegian coast, taken in conjunction with the concentration of recoveries upon Danish and German coasts south of latitude 56° N. at once directs attention towards the great blank between these two coastal sections. As has already been pointed out only three returns were made from points between latitudes 56° N. and 62° 50′ N. From this fact it is fair to argue that probably very few of the bottles set adrift during May 1910 entered the waters of the Skagerak.

Mention has been made before (p. 19), in connection with five drifters liberated during May 1910 and recovered in the following December on the shores of Orkney and Shetland, of later records which indicate that the periods of drift recorded for these bottles were actually spent at sea. An important deduction arising from these same records holds the key also to the solution of the above problem concerning the lack of recoveries in southerly Norwegian latitudes resulting from the May experiments, and since, moreover, the fullest explanation of yet another phase of the May records depends upon the same findings, it will be convenient to deal with the results of the September liberations in parenthesis at this stage.

* * * * * *

September Liberations.

On the 27th of September 1910 ten surface drifters were liberated from each of three stations in close proximity to one another over the southern end of the Fladen Ground in the Northern North Sea Area.

First of all, it may be observed that, in like case to the results of the May experiments, no recovery from the September operations is recorded as having taken place anywhere on southerly Norwegian shores, while once again returns were made from the Skagerak shores of Denmark and Sweden and from the higher latitudes of Norway. Incidentally, it is interesting to note that apparently no bottle set adrift in September 1910 found its way to any point on the Danish coast south of Hantsholm, an observation which fell to be made regarding the results of all liberations in the Faroe-Shetland Channel during the five years under review.

The most important returns are obviously those three, of relatively short drift-periods, which stranded in the beginning of the month of December, one on the eastern side of the peninsula of southern Shetland and two in Newark Bay, Sanday, Orkney. The first was recovered four days prior to the other two, which fact, on the assumption that the days upon which the drifters were recovered were also the days upon which they stranded, indicates that they were coursing in a south to south-westerly direction before being beached.

By some means, then, the bottles cast adrift from the above three stations reached a point to the north of latitude 60° N. It would be in direct opposition to all evidence pertaining to the direction of drift of the surface waters over the region of the Fladen Ground to assume that the bottles there put into the sea in September 1910 proceeded at once in a northerly direction. That they first of all drifted towards the British coast is almost equally unlikely in view of the order of recovery of the three drifters, first on the Shetland coast and then on Orkney.

The most likely direction taken by the drifters from their respective points of origin was a south-easterly one for a short distance, and since the Shetland and

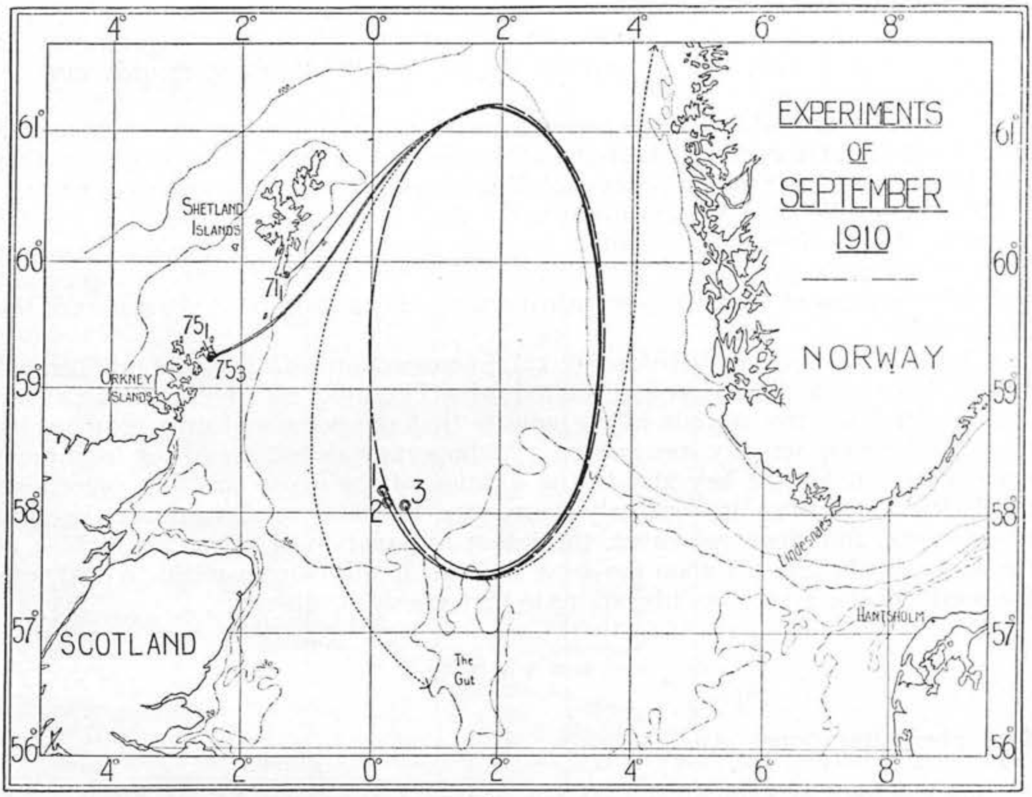


Figure 7

Orkney recoveries were effected considerably before those on Scandinavian and Danish coasts, it seems obvious that a deviation in their courses, eastwards and then northwards, occurred about latitude 57° 30′ N. Thereafter, it is more or less inferred here—evidence towards the assumption will appear from the analysis of the May results—the bottles probably passed round the eastern boundary of the Viking Bank and somewhere in the region of latitude 61° N. turned westwards, and so back again into the North Sea.

That is to say, the results of the September experiments point to the existence, in the surface waters of the Northern Area of the North Sea, of a huge counter-clock swirl or eddy within which it would appear that, amongst others, the much longer-period Shetland recoveries from the May experiments were held up for some months.

Certain of Fulton's results (3*b* and *e*) indicate the operation during the same months of the years 1896 and 1903 of this great closed system of surface water movement in the Northern North Sea. Also, from his analysis of the 1902 data of temperature and salinity for the region concerned, Helland-Hansen (10) suggested that such an eddy might well function, and Ryder (5), as has already been mentioned in the Introduction to Part I of this report, postulated the phenomenon as a general case.

In the records under present examination evidence is to be found in support of the finding that such an eddy operates practically throughout all seasons of apparently normal years. It is therefore proposed to call it the *Great Northern North Sea Eddy*, and as such, or simply as the Great Eddy, it will be referred to throughout this report.

As becomes gradually more evident, the concept of the Great Northern North Sea Eddy is of valuable assistance in the investigation into the histories of many of the recoveries effected upon Continental, more especially Scandinavian coasts. Herein lies the significance of the elliptical curve on the chart, Figure 5, and also to a certain extent that of the non-recovery on the Danish coast south of Hantsholm of bottles originating in the region of the Faroe-Shetland Channel, for it is conceivable that the Great Eddy may in a measure determine the ultimate stranding-places of bottles which come under its dominant influence.

There would appear to be two sections of the periphery of this swirl from which drifters tend most readily to escape its dominance, namely, in the vicinities of its northern and southern limits. From the former section drifters will generally proceed southwards into the North-Western Area of the North Sea, gradually drifting away from the Great Eddy. About the latitude of the eddy's southern limit these bottles will, as a rule, deviate eastwards and head finally in the direction of the Skagerak. A symmetrically similar route in relation to the Great Eddy boundary, diverging from the region of its southern limit, is apparently characteristic of a large number of bottles which come within its region of influence for a time, and are subsequently returned from the higher latitudes of Norway.

As represented in Figure 7, the geographical boundaries of the Great Eddy are approximately latitudes 57° 30′ N. and 61° 10′ N. on south and north, and longitudes 0° and 3° 30′ E. on west and east respectively. These approximate limits have been derived from experience gained throughout the analysis of all available data for the autumn months of the year when the system appears generally to attain maximum dimensions.

The September stations, then, were situated on or near to the periphery of the Great Eddy. A curve, commencing at Station 1 and passing almost immediately into the system, thereafter running close to the periphery until it gradually approaches and finally crosses the same in the region of the eddy's northern limit, to run more or less directly towards the southern extremity of Shetland, may be taken to represent the course of the drifter found there after 71 days' freedom. Such a route measures approximately 470 miles and consequently the average rate of drift of the bottle in question works out at just over $6\frac{1}{2}$ miles per day. Similar figures are derivable for the two Orkney returns.

The histories of the two September drifters returned from points within the Skagerak on 14th February and 1st March 1911 respectively are almost certainly linked with the histories of other recoveries effected in the same region and about the same time (see Figure 5), notably with those of recoveries ensuing from liberations carried out in the neighbourhood of "The Gut" on 8th December 1910. If it be assumed that the Skagerak recoveries from the September experiments accompanied the three Shetland-Orkney bottles on the greater part of their cruise round the Great Eddy, but, after escaping from the swirl, pursued a more southerly route approximately as indicated by the broken curve on Figure 7, the above average velocity figure indicates that they would attain the region of the December operations little more than a week after these had taken place.

With regard to the remainder of the recoveries which resulted from the liberations of the month of September 1910, these were effected on the Norwegian coast north of latitude 63° N. towards the end of March and the beginning of April 1911, and one isolated instance in the following September. It is not possible to say definitely whether the four bottles in question cruised into the Skagerak before being carried northwards along the Norwegian coast. If, however, the possibility of their having lain upon the beach is neglected, the fact is that, in respect of two of these returns—the 174 and 185 day bottles—courses can be postulated (leaving the Great Eddy about its southern limit and passing immediately northwards) which are in conformity, as regards time spent in the Great Eddy and the speed of drift over the entire route, with the foregoing returns from Shetland, Orkney, and the Skagerak.

* * * * * *

May Liberations—(*continued*).

Attention has already been directed to two of the three recoveries which resulted from the despatch of ten drifters on the 11th of May 1910 from Station 1 of that

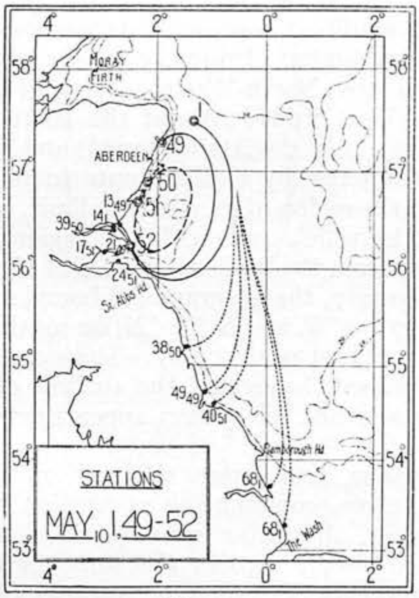


Figure 8

month. Arising from later liberations carried out over the same region, not only during the same month (Stations 49–52), but throughout the month of June following, a number of recoveries took place on the British east coast between the Forth estuary and Flamborough Head, about the same time—the middle of July—as the two instances above-mentioned.

The drift-period of 68 days recorded for each of the two English coast recoveries effected south of latitude 54° N. is overlong, in conjunction with other factors, for the postulation of a direct route for these drifters. The bulk of evidence derived from similar experiments (i.e. from drift-bottle records) undoubtedly suggests that the average velocity of the southerly drift over the region in question is in general greater than $3\frac{1}{2}$ miles per day. Moreover, were the assumption to be accepted of an almost straight-line course between the starting-point and the stranding-places of these two drifters, the question arises as to the cause of another bottle from the same station having been found, after only 14 days, so far off the line of such a direct route as the estuary of the River Tay.

Briefly, the explanation lies in the operation at this time in the surface waters off the mid-east Scottish coast of another swirl or eddy, hereafter called the Mid-East Scottish Coast Eddy. This clockwise circulatory system, as was pointed out in the Introduction to Part I, p. 6, was tentatively suggested by the work of Brown (6) on the *bottom* drift-currents of the Northern North Sea and later by Bowman (7). Also, Böhnecke (1) includes in his well known charts a surface water eddy functioning approximately over the area in question.

Normally, it appears that the area of dominant influence of the Mid-East Scottish Coast Eddy is as defined by the broken elliptical curve in Figure 8, but the results of the experiments commenced in this same region during the month of June 1910 clearly indicate that its dimensions for the period under review were greater.

On the basis of the June experiments, it is highly probable that the drifter from the Station $May_{10}1$, found at the mouth of the River Tay, traversed a route approximately as represented by the appropriate curve on the chart, Figure 8. Such a route of nearly 175 miles would be accomplished in the 14 days at an average rate of $12\frac{1}{2}$ miles per day.

Originating at Station 49 a drifter was found after 13 days on Buddon Ness, Forfarshire. The course postulated for this bottle, concentric with that of the short-period Station 1 recovery, measures to scale about 165 miles, thus furnishing an average velocity figure of 12·7 miles per day.

It is obvious that in respect of the remainder of the recoveries effected on the British coast north of latitude 56° N from the Stations 1, 49, 50, and 51, courses can be postulated which are variants of those above considered in detail, the longer-period bottles to the coasts of the northern English counties clearly showing that the Mid-East Scottish Coast Eddy dominated them until practically the end of the month of June.

The recoveries which resulted from the operations at Station 52 are unique as regards drift-periods amongst those from the other four stations at present under examination. Tidal influence, no doubt, was the main cause of three bottles from this point being washed up on the Haddington coast within eight days of their despatch.

The first of the more northerly May stations from which recoveries are recorded is Station 3. Three drifters of the ten liberated at this point were returned from the region of the west Danish and Schleswig-Holstein coasts south of latitude 56° N. more than a year after the date of despatch.

Of the series of bottles set adrift at Station 4, two were ultimately recovered, one after 83 days at Forvie on the east coast of Aberdeenshire and the other at sea, 36 miles S. by E. of Bressay Light, Shetland, after only 28 days. The former drift-period, together with the locus of recovery, suggests the Great Eddy, but the latter is obviously anomalous to the huge gyration.

The position of Station 4 was presumably at or near to the periphery of the Great Eddy* if the complex was actually functioning during May 1910. Other

* See remarks on the accuracy of Station positions, Introduction, p. 6.

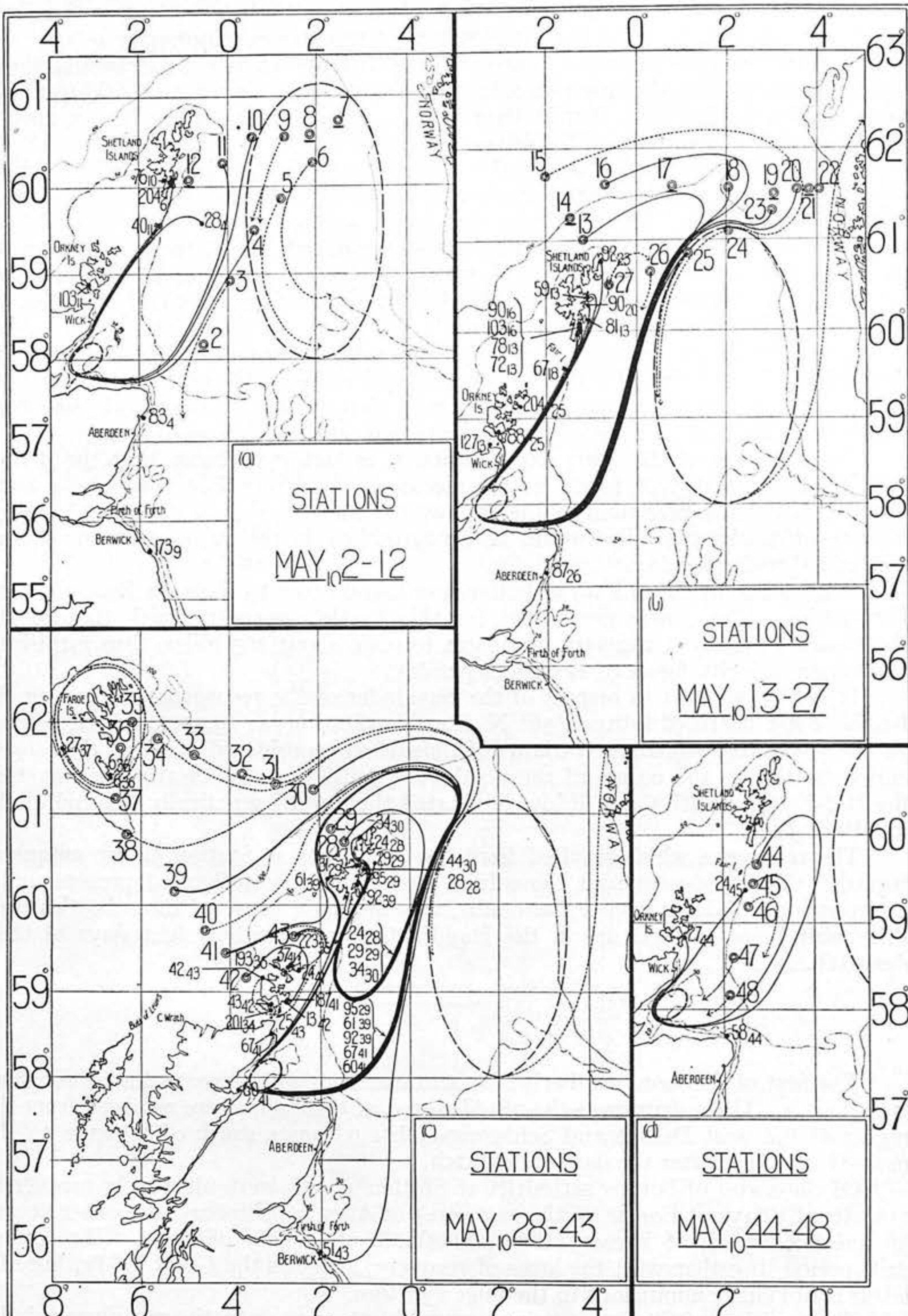

(a)
STATIONS
MAY 2-12
(b)
STATIONS
MAY 13-27
(c)
STATIONS
MAY 28-43
(d)
STATIONS
MAY 44-48
SHETLAND ISLANDS
ORKNEY IS
FAROE IS
NORWAY
WICK
ABERDEEN
Firth of Forth
BERWICK
C. Wrath

Figure 9

results from the same month's experiments indicate that it was so, although its superficial area was probably less during May than in the following September (see p. 25). It is conceivable, however, that under certain circumstances bottles liberated from the position of Station 4 might quickly escape the dominant influence of the swirl. During the week following upon the liberations in question, strong and persistent north-easterly winds blew over the entire area of the Northern North Sea.* It is highly probable, therefore, that the drifters set afloat at Station 4 set off in a south-westerly direction, gradually deviating westwards towards and into the Moray Firth as represented in Figure 9 (*a*). The entire route there laid down for the 28-day sea-recovery measures to scale some 355 miles, from which it is deduced that the bottle must have travelled at a mean rate of 12·7 miles per day, a figure, as has before been pointed out, in close agreement with that deduced from contemporaneous results of liberations in the Moray Firth during the previous month of April.

Regarding the longer-period bottle from Station 4 found on the Aberdeenshire coast, all that can be surmised at present is that it was held up within the Moray Firth Eddy until towards the end of July 1910, when presumably the drift westwards into the Moray Firth ceased to operate.

The results, a single recovery from each series, pertaining to Stations 5 and 6 clearly demonstrate the influence of the Great Eddy, particularly the return from Cunningsburgh, Shetland, in December 1910, of a drifter which originated at the latter point. The connection between this and the recoveries from the September experiments has already been discussed.

The sole recovery from the Station 9 series of drifters, namely, that effected in the following November on Holy Island off the Northumberland coast, suggests that the bottle in question escaped from the Great Eddy soon after the date of liberation, and was held up in the system of surface water movement within and to the north and east of the Moray Firth. At the same time it must also be recognised that a major portion of the time which elapsed between the dates of despatch and recovery of this particular drifter may have been spent, in like case to other drifters of contemporary origin, within the Great Northern North Sea Eddy.

From Station 10 a relatively short-period recovery was effected near Lerwick, Shetland, after 76 days. It is estimated that this bottle also travelled southwards from the point of liberation and into the Moray Firth following a route approximately as represented on Figure 9 (*a*). Exclusive of probable circuits of the Moray Firth Eddy the distance thus traversed would be about 410 miles. At an average speed of 12·7 miles per day, 32 days would be occupied in overtaking this course, leaving 44 days to be accounted for.

Two of the Station 11 series of bottles were ultimately returned, the more important recovery in consequence of its shorter drift-period being that found after 40 days in the vicinity of Fair Isle. Assuming a route such as represented in Figure 9 (*a*) (passing round the southern boundary of the Moray Firth Eddy), 27 of the 40 days would be taken up in covering the resulting 350 miles at a mean daily progress of 12·7 miles. In this case, therefore, 13 days remain to be explained.

From the analysis of the results of the April 1910 experiments in the Moray Firth region it was indicated that seven days was a probable Period of Circuit of the Moray Firth Eddy during this season. The above residual periods of 44 and 13 days obviously bear out this deduction.

The 103-day bottle from Station 11 found in the Orkneys apparently experienced much longer delay in the Moray Firth. Otherwise it must have lain a considerable

* See the Daily Weather Reports of the British Meteorological Office.

time on shore, which is more than probable in this instance, the stranding-place being little more than a huge rock standing out of the water.

The next group of stations to be operated during May 1910 were those shown in Figure 9 (*b*), namely, Stations 13 to 27. The cruise embracing these fifteen points occupied four days, from the 18th to the 21st inclusive.

The majority of the recoveries from these operations took place on the Shetland Islands between the 16th of July and the 30th of August of the same year.

Before entering upon the detailed analysis of the data a subsidiary deduction arising from the results pertaining to Stations 24 and 25 may be introduced with advantage at this point. From Station 24 the sole recovery was that effected on the west Swedish coast after 291 days, thus indicating the influence upon the drifter of the Great Eddy. Further, as will be seen in the following, Station 24 must have been situated southwards of the tracks of drifters from Stations 20 and 23 to the Shetlands, since these bottles cannot be assumed to have entered the Eddy proper. Again, the results from Station 25 lead to the deduction that this point of origin lay practically *on* the periphery of the Great Eddy, the shorter-period Orkney Island recovery from the station in question having deviated away from the Eddy on its southward passage, while the longer-period return from the same point belongs to the December group of Table XVIII. From these facts it may be concluded that the northern limit of the Great Eddy as it existed during at least the month of May 1910 lay some ten miles north of the 61st parallel, on or about longitude 2° E. This deduction makes all the more remarkable the recovery on the shores of Shetland during the summer of 1910 of bottles put into the sea so far north and east as Stations 20 and 23.

The particular analysis of the Shetland and Orkney returns from the present small group of experiments were most conveniently set out in answer to the following question. On the basis of the above-deduced figure of 12·7 miles per day, denoting the mean rate of progress of the drifters, and of the existence throughout the period concerned of the Great Eddy and the Moray Firth Eddy, can courses be traced in respect of the recoveries now under examination, which are consistent one with another and with those of contemporary results (Figure 9 (*a*)) and which account for the entire times recorded as drift-periods ?

The following table in conjunction with the chart, Figure 9 (*b*), supplies the answer to this query.

TABLE XXI

Recovery. (*a*)	Course in Miles, Exclusive of Eddy Circuits. (*b*)	Times in Days to Cover (*b*) at 12·7 Miles per Day. (*c*)	Residual Periods. (Days.) (*a*)–(*c*)
59_{13}	575	45	14
72_{13}	550	43	29
78_{13}	550	43	35
81_{13}	560	44	37
†127_{13}	465	37	90
90_{16}	600	47	43
103_{16}	600	47	56
67_{18}	450	35	32
90_{20}	540	43	47
92_{23}	550	43	49
88_{25}	345	27	61

† Recovered on Dunnet Head, Caithness-shire, mainland of Scotland.

The residual periods tabulated in the last column of Table XXI and denoting the times presumably spent within the Moray Firth Eddy, are remarkably consistent in that they are very nearly, and in some cases exactly, simple multiples of seven days, which factor may therefore be accepted now as representing the Period of Circuit of the Moray Firth Eddy at the time of these 1910 experiments.

The recovery effected on Dunnet Head, Caithness-shire, although consistent with the others comprising the above table, falls outwith those others in point of actual time of recovery, being in fact the isolated September entry in Table XVIII.

The fact implied in Figure 9 (*b*), to the effect that, so far as the North Sea proper was concerned, the channels between the mainland of Scotland and Shetland were closed for a short time to at least the superficial influx of water from the Faroe-Shetland Channel region, calls for further investigation, as also the peculiar set of the surface drift to the north of the Viking Bank. These points will be further considered when the results of the remainder of the month's experiments have been examined.

In the recovery near Aberdeen on 16th August 1910 of a drifter which was set afloat from the May Station 26, we have an instance similar to one depicted on the previous chart (Figure 9 (*a*)), and in respect of this second case the observations to be made are the same as formerly.

A glance at Figure 9 (*b*) is sufficient to substantiate the deduction already made (p. 23) in regard to the probable routes pursued by drifters returned from northerly Norwegian latitudes, except perhaps in the case of the single recovery from the Station 22 series of bottles. In view of the proximity to the Norwegian coastal current of the liberation-station in question, it cannot definitely be concluded on the evidence available that bottles set adrift thereat were "carried back," as it were, into the Northern North Sea complex of surface waters.

On the chart, Figure 9 (*c*), the most important results pertaining to the May Stations, 28–43, are set out diagrammatically. Except where otherwise stated, the curves represent the courses of the shortest-period returns from the various groups of drifters despatched at these points.

Continuing this analysis on the basis of an average rate drift of 12·7 miles per day, it can readily be ascertained by measurement that for certain of the returns from the Stations 28, 29, and 30 series of operations, courses embracing the Moray Firth are out of the question. The 24-day recovery at Hoganess, on the Island of Yell, Shetland, presumably coursed approximately as demonstrated in Figure 9 (*c*) by the curve commencing at Station 28, thus covering some 305 miles at the above daily rate of progress. The second return, belonging to the same group of bottles, may either have attained a more northerly point near the beginning of its course, or proceeded farther south than about latitude 59° N. before deviating westward and finally northwards, if the recorded drift-period is in fact a true one.

Similar observations fall to be made in respect of the two shortest-period recoveries from the Station 29 group of drifters, the shorter curve commencing at Station 29 and terminating at the Shetland Skerries, measuring to scale approximately 365 miles, which in 29 days would be accomplished at a mean rate of 12·6 miles per day. With regard to the third recovery, however, embracing the much longer period of 95 days, it is highly probable that the bottle in question reached the Moray Firth on its southward passage into the North Sea. For such a route as is represented for this bottle on the chart, 45 days would be occupied in covering a lineal distance of 570 miles, which is the proper dimension of the curve, exclusive of complications denoting circuits of the Moray Firth Eddy. Thus, 50 days were presumably spent within this complex and once again the figure is obviously related to the accepted Period of Circuit of the small swirl in the Moray Firth at the time of these experiments. The longest-period recovery of the Station 29 series belongs to the secondary group of Table XVIII, the drifter having doubtless become involved in the Great Eddy until towards the end of the year.

Starting from Station 30 two bottles ultimately beached on the Shetland Islands, one on the north coast of Yell, and the other on the Island of Whalsay. The former bottle, as can be ascertained from Figure 9 (*c*), is estimated to have taken what might be called the "inner route" to the Shetlands after passing into the North Sea. At a mean speed of 12·7 miles per day such a course of about 435 miles would occupy the full 34 days recorded as the period of drift of the bottle in question. The drift-period of the second recovery is obviously overlong to postulate a similar course for this drifter and measurement proves that 48 days would be required to cover a route embracing the inner reaches of the Moray Firth. So that, if the recorded drift-period of 44 days is a true one a course intermediate between these two must have been followed.

Recoveries from Stations 31–34 indicate that the drifters liberated from these points, without exception, cruised into the North Sea by way of the Great Eddy. The evidence in support of this inference arises from the afore-mentioned consistency in the drift-periods of all northerly Norwegian coast recoveries resulting from the experiments begun during May 1910, coupled with the facts that one drifter from Station 34 was recovered in the Orkney Islands on 12th December 1910 and another from Station 31 stranded on the north-west Jutland coast towards the end of January 1911.

The sole recovery from Station 35, namely, on one of the Orkney Islands, is represented as having made a circuit of the Faroe Islands before heading south-eastwards and eastwards towards the area to the north of the Shetlands and finally into the North-Western Area of the North Sea. The reason for this is to be found in the results from the next two stations, from the first of which two bottles were picked up on the east side of the Island of Suderö after six days. From the second point, namely, Station 37, one drifter was recovered at sea to the *west* of the Faroe group, after 27 days. It may reasonably be postulated that in these 27 days the drifter completely circled the Faroe Islands. Thus it would appear that, at this period at any rate, these Islands were enclosed in a swirl of surface waters.

Station 38 was situated so far south of Faroe, and beyond the edge of the neighbouring shelf, that it is not so likely that the two drifters ultimately returned from Norway set off from the point of despatch in a northerly direction and became involved in the eddy encircling the island group.

The shortest-period return from the series of bottles despatched at Station 39 was that found on the Island of Papa Stour off the west Shetland coast, after 61 days. Postulating a route eastwards for a short distance from the starting-point and then north-eastwards and into the North Sea by way of the area to the north of the Shetlands, thereafter penetrating the Moray Firth as in previous instances, and passing finally northwards to the stranding-place, this particular drifter must have covered approximately 690 miles, exclusive of circuits of the Moray Firth Eddy. At a mean rate of 12·7 miles per day 54 days would thus be occupied, the remaining seven days being doubtless taken up in coursing once round the said swirl. In all probability the 92-day *east* Shetland recovery from the same series, traversed a similar route, spending, it is estimated, some 37 days in the Moray Firth swirl.

Three drifters from Station 40 stranded on the Norwegian coast north of latitude 64° N. and one from the same point of origin was returned from the west Swedish coast, all after periods of drifting ranging from 262 to 316 days. It is to be observed that the drifter recovered on the Swedish coast was not the first of the four bottles to be picked up, thus ruling out the possible suggestion that the later courses of the Norwegian recoveries were necessarily continuations of that of the bottle returned from the Swedish coast. The apparent anomaly in the sequence of recovery of these bottles, as well as the broad locality of their stranding-places, is to be explained on the assumption that escape from the dominant influence of the Great Eddy was accomplished at different sections of the eddy's periphery.

Results pertaining to Station 41 are somewhat conflicting amongst themselves, and those from the three Stations 41, 42, and 43 do not fall into line, so to speak, with those from former stations of the same month.

Two drifters from Station 41 stranded on the Island of Sanday, Orkney, after only 24 and 37 days respectively, the latter, it is to be observed, on the north side of the Island. These drift-periods are too short to warrant the assumption of a passage round .the north of the Shetland Islands, in conformity, as regards the average daily speed of drift, with the numerous instances already discussed. On the other hand, as revealed by the data on the chart, Figure 9 (*c*), at least two drifters from the same starting-point undoubtedly reached the Moray Firth. Apart from the evidence afforded by the magnitudes of the drift-periods of these two recoveries, the probability of their having passed into the North Sea by way of the north of the Shetland Islands is further substantiated by the last return from the same series of liberations, namely, that found on 1st December 1910 in Newark Bay, Deerness, Orkney. This again is one of the instances belonging to the secondary group of Table XVIII, and the bottle in question almost certainly attained its stranding-place after issuing from the northern periphery of the Great Eddy, within which and along with many others it no doubt spent the intervening months of 1910.

Thus we have drifters from the same point of origin apparently pursuing widely divergent courses soon after their despatch. Without further explanation this position is untenable in view of the axiom underlying the whole of this analysis (Introduction, p. 4) regarding the divergence from one another of bottles set adrift simultaneously from one and the same point. Fortunately, the statistical analysis of the entire data referring to the region immediately concerned throws light upon the situation. It may be recalled that in regard to the north-eastern corner of the Regional Area B (Figure 1, Part I) an important deduction arose from a comparative examination of the districts of recovery of drifters liberated therein, to the effect that in the neighbourhood of latitude 59° 30′ N. in the area between the Shetland and Orkney Islands, " there might take place a division in a more or less easterly flowing surface current, part flowing northwards along the western shores of Shetland and part deviating southwards into the North Sea between Fair Isle and the Orkneys." It is highly probable that some such system was in operation during at least the latter part of May and the earlier days of June 1910.

In view, however, of the northerly flowing stream off the eastern shores of Orkney, carrying drifters to the Shetland Islands at the same time as the above-mentioned recoveries were effected on the Orkneys, it is obvious that the surface water moving southwards between Fair Isle and the latter group must have been restricted to the immediate neighbourhood of Orkney, and cannot have entered the North Sea proper. The recovery of one of the Station 43 bottles on the *west* coast of the mainland of Orkney further enhances this deduction. In short, the results from the three stations enumerated above strongly suggest that, at the period under present examination, the Orkney Islands were enclosed in a gyratory system of surface waters similar to that already deduced in respect of the Faroe group. The great differences between the magnitudes of the drift-periods of the earlier Orkney recoveries from these three stations cannot otherwise be satisfactorily explained.

The shortest-period return from the experiments commenced at Stations 41–43 is that belonging to the Station 42 series, found after 13 days in Taracliffe Bay, on the east coast of the mainland of Orkney. For such a course as represented by the curve in Figure 9 (*c*), measuring to scale some 90 miles, an average speed of drift of only seven miles per day is deduced in respect of this particular bottle. From this figure it is evident that the longer-period Orkney returns from the operations presently under review, namely, those found after: (*a*) 24 and 37 days from Station 41; (*b*) 36 and 43 days from Station 42; and (*c*) 25 and 42 days from Station 43, most likely coursed one or more times completely round the entire, or even part of the island group before finally stranding on the beaches.

Passing to the two western shore Moray Firth recoveries which resulted from the liberations at Station 41, the courses postulated for these two bottles measure 535 and 585 miles respectively, neglecting meantime possible circuits of the Moray Firth Eddy. These distances would be covered in 42 and 46 days at an average daily rate of progress of 12·7 miles. Thus, according to our assumptions, 18 and 21 days were spent in the performance of three circuits of the Moray Firth Swirl.

A unique recovery amongst the above records is that which took place at Eyemouth on the Berwickshire coast of Scotland 51 days after the date of its liberation at Station 43. It is perhaps significant in relation to the accuracy of the foregoing analysis of the May 1910 records, particularly as regards the figure deduced and employed to define the average daily speed of the surface water drift that, over the course of approximately 610 miles represented on the chart, Figure 9 (*c*) for this singular bottle, an average speed of about 12 miles per day must have been attained if the full 51 days were spent at sea.

Of the twenty bottles recovered as the result of the liberations carried out at Stations May_{10}44–48, one was picked up at sea only a few miles from the corresponding point of origin, one on the eastern shores of Orkney, another at Fraserburgh on the Aberdeenshire coast, two on the north-eastern English coast and the remainder on Danish and Schleswig-Holstein shores south of latitude 56° N.

That the last-mentioned drifters, after escaping from the complications within the Moray Firth and in the waters east of Orkney and Shetland, travelled considerable distances southwards off the British east coast and probably became involved in, or passed to the south of Böhnecke's South-West Dogger Bank Swirl, is evidenced by the two English coast recoveries from the Station 47 series effected on 30th October and 3rd November 1910 respectively.

The only returns which need be considered in detail are those two which were found: (*a*) on Burray Island, Orkney, after 27 days' freedom, from Station 44; and (*b*) at sea, 24 days after having been released from Station 45. These results support the above deductions relative to the surface water circulation in the North-Western Area of the North Sea during the period embraced by the Shetland and Orkney recoveries from the May experiments. For the two drifters in question the courses postulated on the chart, Figure 9 (*d*) represent 340 and 305 miles respectively, entailing average velocities of 12·6 and 12·7 miles per day.

The above treatment of the results derived from the comprehensive drift-bottle experiments inaugurated during the month of May 1910 presents some striking and apparently anomalous features relative to the trend of the surface water in the areas of the Northern North Sea and the Southern Norwegian Sea. The remarkable fact has already been commented upon, of the widespread regions from which drifters ultimately reached the shores of Orkney and Shetland—the majority of them by way of the Moray Firth—during a few weeks in the summer season of the year under review. It has been demonstrated, moreover, that these strandings were by no means fortuitous, but arose from a temporarily established movement of the surface waters in the North-Western Area of the North Sea. Certain aspects of this movement are capable of further measurement.

No fewer than twenty-five bottles apparently drifted into the Moray Firth from the North Sea proper, the westward deviation evidently taking place about the latitude of 58° N. and between longitudes 1° and 2° W. On the basis of the assumption that all the bottles travelled at a uniform rate of 12·7 miles per day, the various times of crossing the 58th parallel may be shown to have fallen between the dates 21st May and 3rd July. Now, resulting also from the May experiments, three bottles were picked up on the Aberdeenshire coast, after the 24th of July. The argument arising from these circumstances is that the surface water drift westwards into the Moray Firth ceased some time between the 3rd and 24th days of July 1910.

The subsequent progress, in relation to certain fixed positions, of the above twenty-five drifters may be estimated in similar fashion, calculating back from the date and point of recovery of each bottle and tabulating all results. The following is the summation of such a table :—

TABLE XXII

Number of Drifters.	Point on Course.	Inclusive Dates.
25	Crossed Latitude 58° N.	21st May–3rd July.
19	Crossed Latitude of Wick	31st May–20th August.
16	Crossed Latitude of Fair Isle	7th June–27th August.
12	Crossed Latitude of Sumburgh Head	13th July–29th August.

It will be observed that a considerable time apparently elapsed between the passing of Fair Isle by the first drifter and the first bottle to pass Sumburgh Head on the 13th of July, the reason being that the former bottle was picked up from the sea in the vicinity of Fair Isle on the 9th of June. The first bottle to pass the three positions—Wick, Fair Isle, and Sumburgh Head—did so, according to the above measurements, on or about the following dates :—

Wick—4th July; Fair Isle—11th July; Sumburgh Head—13th July.

But there have not been taken into account in Table XXII the six instances from the May experiments where the bottles turned from their southward courses on or about latitude 59° N., drifted westwards, and finally northwards to Shetland, passing Fair Isle on the way. It is estimated that on the final stages of their courses these drifters crossed the latitude of Fair Isle between the 12th and the 21st of June 1910, and that of Sumburgh Head some two days correspondingly later. In this connection, also, another and new characteristic of the surface waters in the region of Fair Isle is brought out by certain of the experimental results so far considered, namely, that during at least the first half of the month of June there must have been in operation a small eddy of surface waters over the region covered by the rectangular area, C17 of the chart, Figure 1 (Part I). The results which point to this conclusion are : (i) the two sea recoveries from the April 1910 liberations in the Moray Firth (Figure 4), together with the sea recovery from the Station $May_{10}4$ series (Figure 9 (*a*)) ; (ii) the shorter-period Shetland recoveries from Stations $May_{10}28$, 29, and 30 (Figure 9 (*c*)) ; and (iii) the two returns belonging to Stations $May_{10}44$ and 45 which are examined in detail in Figure 9 (*d*).

Thus it appears that from about the 12th of June until towards the end of August 1910 the Channel between Fair Isle and Sumburgh Head was closed, superficially at least, to the influx of Atlantic water into the North Sea and further, for at least a decade prior to 1st of June and throughout the above months, apparently no water from the region of the Faroe-Shetland Channel passed, on the surface, eastwards into the North Sea across a line joining Wick and Fair Isle.

This important deduction from the results of drift-bottle experiments is not quite in accordance with the general scheme of things deduced by Robertson (11) in the area concerned, from his examination of data of temperature and salinity for each of the several years and seasons between 1903 and 1910. Helland-Hansen (10), however, from similar material, found that during the month of August 1902 Atlantic water "lay close to the northern part of the Scottish coast; it penetrated the Pentland Firth and the Sounds of the Orkneys, but did not, to any significant extent, pass through the opening between the Orkneys and Shetlands." Further, the same investigator found that in the autumn of the same year the supply of salt Atlantic water to the Northern North Sea had increased, and "from the distribution of salinities it is evident that *this influx of Atlantic water took place southwards from the Norwegian Sea, and not to any important extent between Shetland and the Orkneys from the Faroe-Shetland Channel.*" The above analysis of drift-bottle results clearly supports this view as applied also to the summer of 1910.

Further investigation of the results of drift-bottle experiments may throw more light upon this question of prime importance in relation to, in the first instance, the surface current system of the Northern North Sea, namely, the principal channel or channels by which, during the various seasons, water of Atlantic origin effects entry into the sea between Scotland and Norway.

In another particular, but one allied to the above, the foregoing interpretation of drift-bottle results does not harmonise with certain deductions based upon observational data of temperature and salinity for the same period of the year under review. Between the positions—Latitude 61° 34′ N.–Longitude 2° 04′ E. and Latitude 61° 35′ N.–Longitude 0° 47′ E., Robertson (11*e*) deduced a *northward* movement of surface water in May 1910. The reverse has been diagrammatically represented in Figure 9 (*b*), and it must be pointed out that, not only is a *southward* movement to be expected within the area in question as an effect of the rotation of the earth, but, according to Ekman's theory,* the configuration of the ocean bed is undoubtedly a predisposing cause of a pronounced swerve to the right of at least the surface drift-stream in passing from the deep waters of the Southern Norwegian Sea to those over the North Sea Continental Shelf. The movement is analogous to that found by Helland-Hansen and Nansen† in the area of the North-Eastern Atlantic Ocean north of the Azores.

In concluding the examination of the results pertaining to the month of May 1910, it may be remarked that the vector of $12\frac{3}{4}$ miles per day, which has been found to denote the mean rate of flow of the main surface drift-stream from the Faroe-Shetland Channel to the Southern Norwegian Sea, thence to the North-Western Area of the North Sea, is a high one in comparison with former estimates based upon similar material. Nevertheless, the following deduction made by Robertson from hydrodynamical calculations argues in favour of this high velocity. "Thus the surface velocity of the Atlantic Stream to the immediate north of Shetland was then (May 1910) about 13 nautical miles in twenty-four hours."

* * * * * *

* Ekman, V. W., "Ueber Horizontalzirkulation bei winderzeugten Meeresströmungen," *Arch. f. Mat. Astr. Fysk.*, XVII, 26, Stockholm, 1923.

† Helland-Hansen, B., and Nansen F., "The Eastern North Atlantic," *Geofysiske Publik.*, V, 2. Oslo, 1926.

June Liberations

Liberation operations in the month of June 1910 were carried out on the days between the 15th and 22nd inclusive from nineteen stations in the Middle Area of the North Sea, between the mid-east Scottish coast and the region of the Great Fisher Bank. In all, 182 bottles were despatched and of these, 27 were returned from points on the British east coast south of Fife Ness, six from the west Danish coast south of Hantsholm, eight from within the Skagerak, two from the Norwegian coast between Lindesnaes and Bergen, five from points on the same coast north of latitude 62° 50′ N., and three bottles were picked up at sea.

Examination of the records, or of Figure 10, shows that the results from Stations 1–3 and 17–19 form a group by themselves. Only one drifter out of the 31 recovered from these six stations was returned from Continental shores, and from none of the remaining 13 stations did any drifter ultimately reach the British coast.

Belonging to the Station 2 group of bottles, one drifter was picked up by a trawler on the south-western end of the Dogger Bank towards the end of the month of October of the year under review. This recovery may be taken as affording an indication of the approximate position during the autumn of 1910 of Böhnecke's South-West Dogger Bank Swirl, the northern and southern limits of which may have been defined respectively by the fifty-fifth and fifty-fourth parallels of latitude.

The above-mentioned twenty-seven drifters which stranded upon the east British coast were picked up, with one exception, between the 26th of June and the 28th of July, eighteen of them being discovered between the 15th and 18th days of the latter month and only two prior to the 30th of June. These dates are significant in view of the foregoing analysis of the May 1910 results as will be shown in the following.

Mention has already been made, in connection with the results from the May Stations 1, 49–52, of the extended area of dominant influence of the Mid-East Scottish Coast Eddy at the period of the present experiments. Under circumstances which, over the long period investigated, may be considered as fairly normal, it is quite to be expected that drifters set away from the position of Stations June$_{10}$1–3, will come under the influence of the above swirl of waters, but not so those set away from the position of the June Station 17. Yet a comparison of the results pertaining to this station with those from the two following, particularly with reference to drift-periods, clearly indicates that the drifters from Station 17 underwent deviations in their courses very similar to those sustained by the drifters put overboard at Station 18 and by a number of those from Station 19.

It is suggested, therefore, that during the month of June 1910 the region of influence of the Mid-East Scottish Coast Eddy was extended considerably seawards. Evidence in support of this inference is contained in the deductions arising from the results of the previous month's experiments.

Due north of the region under examination, it has been found that during the month of June the southward flowing drift-stream of surface waters was in great bulk being turned westwards into the Moray Firth. Consequently, the normal resistance to a tendency towards expansion on the part of the Mid-East Scottish Coast Eddy would be greatly diminished. It has also been deduced that the deflection westwards into the Moray Firth ceased about the end of June or the beginning of July, after which the influence tending to throw bottles up on the east British coast would obviously again become operative. The circulatory system of surface waters which had, during the month of June, extended its influence eastwards would experience increasing resistance to its expansion and the waters ultimately would be forced back towards the coast. This hypothesis is borne out by certain of the above-mentioned experimental results, namely, that of twenty-seven drifters recovered upon the east British coast from the June liberation stations off Aberdeen and off the Firth of Forth only two were recovered prior to the 30th of June, five between this date and the 8th of July and no fewer than eighteen between the 15th and 18th days of the latter month.

These results are now considered in more detail along with the others from the same points of origin, namely, Stations 1–3, 17–19.

The recovery, after only 10 days, at a point in the sea some five miles south-east of Girdleness Lighthouse, Aberdeen, of a drifter from Station 1, furnishes a good starting-point for this analysis. It may reasonably be inferred that the bottle pursued a course approximately as represented in Figure 10. In 10 days this route of 125 miles would be accomplished at an average rate of some 12½ miles per day, a figure consistent with that deduced formerly in respect of the almost contemporary surface water drift in more northerly regions.

Now suppose that, in continuation of the above course, the two drifters set away from the same point and found after 33 days near North Berwick on the Haddingtonshire coast of south-eastern Scotland, traversed a route such as indicated in Figure 10. The entire route from Station 1 would thus be one of 290 miles, which, at an average daily rate of progress of 12½ miles would occupy 23 days, leaving to be accounted for 10 of the total 33 days denoting the drift-period of each bottle. The relationship between this residual period and the drift-period of the above-discussed sea recovery is obvious, the stranded bottles having doubtless completed another circuit of the Mid-East Scottish Coast Eddy in the residual ten days before escaping to more open waters.

In order to avoid cumbersome detail in the elaboration of an analysis similar to much that has already appeared in this report, it will be sufficient perhaps to state that the same residual period of 10 days is deduced in respect of the first four of the five recoveries resulting from each of the two batches of liberations effected respectively at Stations 2 and 3, on the basis of a mean velocity figure of 12½ miles per day and post-eddy courses similar to and more or less concentric with that laid down in Figure 10 for the Station 1 recoveries. This period of 10 days, then, may be taken as defining the Period of Circuit of the Mid-East Scottish Coast Eddy during the month of June 1910.

The same practice applied to the returns recorded against Stations 17 and 18 establishes the conclusion that the drifters despatched therefrom and later thrown up on the east British coast did not complete a circuit of the Mid-East Scottish Coast Eddy as defined by the broken elliptical curve on Figure 10, but were influenced thereby in so far as they presumably passed northwards along this part of the Scottish coast before drifting seawards and latterly southwards towards the coast of Yorkshire principally. The eastmost curve shown on the chart represents the final stage of the route postulated for the Station 18 bottle found after 24 days near Whitby, Yorkshire. The appropriate curves for the remainder of the recoveries under present scrutiny would be intermediate between this and the curve for the Station 1 bottles, but to obviate confusion on the small scale diagram these are not entered.

Of the six drifters recovered from the series of eleven set afloat at Station 19, obviously three did not perform a circuit of the Mid-East Scottish Coast Eddy, their drift-periods of four and eight days precluding such an assumption. This is to be accounted for in all likelihood by the peculiar position of the liberation-station. Station 19 was probably situated on the line of division of the surface drift-stream approaching Fife Ness from the south-east, which stream, doubtless on account of the said promontory, generally divides into two branches, one turning into the Firth of Forth estuary and the other proceeding northwards across the entrance to the Firth of Tay.

In view of the intervening recovery on the south-west end of the Dogger Bank of one of the Station 2 bottles, it is almost certain that the drifter from Station 1

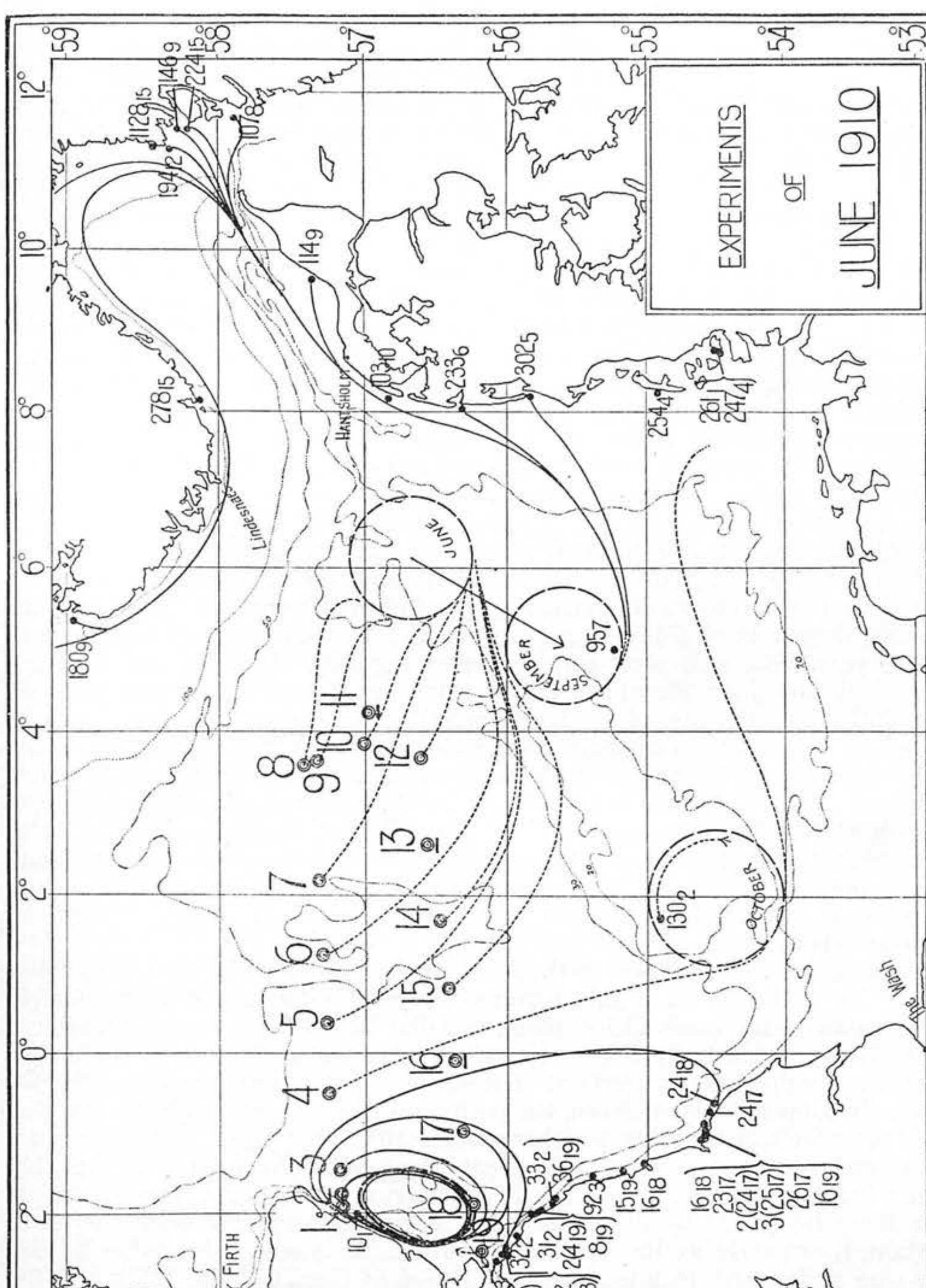

EXPERIMENTS
OF
JUNE 1910
MORAY FIRTH
The Wash
Lindesnaes
HANTSHOLM
JUNE
SEPTEMBER
OCTOBER

Figure 10

returned from Nordstrand Island at the beginning of the following month of March reached its destination by way of the South-West Dogger Bank Swirl. Similarly, the broad locality of the two recoveries belonging to the Station 4 group suggests that the bottles in question set out from the point of liberation in the direction of this same complex and became involved therein for some time. But, in this case, an estimate of the time presumably occupied in circuiting the South-West Dogger Bank Swirl may not be made with the same degree of confidence as in the cases of the North-East Dogger Bank Swirl, the Moray Firth Eddy and the Mid-East Scottish Coast Eddy, in view of the fact that another similar system situated in the waters off the adjacent coasts of Germany and Schleswig-Holstein may have influenced the routes, and consequently the drift-periods of the recoveries in question. It is more than likely that this German Bay Swirl was in operation during the period embraced by the two Schleswig-Holstein coast recoveries from Station 4, namely, the latter half of the month of February 1911, when strong westerly winds prevailed over the region in question. Such winds, according to Böhnecke (1), are particularly favourable to the formation and functioning of the said system.

The next result which throws any light upon the probable courses of the bottles set adrift from the remaining stations visited during the month of June is that one from Station 7 picked up at sea some 150 miles distant from its starting-point after 95 days, that is, on the 19th of September 1910.

It will be recalled that in the analysis of the results accruing from the liberations carried out over the region of the Great Fisher Bank during the month of April 1910, certain deductions were made concerning the influence upon the drifters of the North-East Dogger Bank Eddy, during the months between May and September of the same year. No such short-period returns from the shores of the Skagerak resulted from the June liberations in the same locality as from those of April. Consequently, if in the case of the later operations, time spent upon the beach be neglected, as it must be in consideration of the number of bottles involved, either the mean velocity of the drift over the region concerned was very much less than it had been two months previously, or *all* bottles, without exception this time, became involved for a time in the North-East Dogger Bank Swirl. The latter alternative is the more probable in view of the above-cited sea recovery from Station 7, prior to the date of which recovery none of the drifters belonging to any of the series despatched from Stations 5–15 was discovered on Danish, Swedish, or south Norwegian coasts.

Further evidence in relation to the April bottles indicated also that, until about the beginning of the month of July 1910, the above eddy functioned approximately over the region of the Little Fisher Bank, but that between July and September it was translated, evidently by the force of the fresher water efflux from the Baltic, in a south to south-westerly direction. The sea-recovery from the June experiments undoubtedly supports this inference, the position of the recovery probably marking the southerly limit of the eddy periphery at the time, that is, in September 1910.

The routes overtaken then by drifters set afloat at Stations 5–15 are probably fairly nearly represented in Figure 10 by the broken curves leading into the North-East Dogger Bank Eddy and by the whole curve leaving the complex when the latter had attained, or nearly so, its September position. It is obviously not so feasible in this case as formerly to investigate the Period of Circuit of the Eddy and the velocity of drift in the neighbouring areas, partly on account of the relative scarcity of data, but mainly owing to the absence from these later records of a short-period return upon which to base, within reasonable limits of accuracy, the necessary measurements and calculations.

* * * * * *

August Liberations.

During the month of August 1910, 145 surface drifters were liberated in batches of five from each of twenty-nine different stations, all of them outwith the North Sea. The first nineteen stations were disposed over the region of the Faroe-Shetland

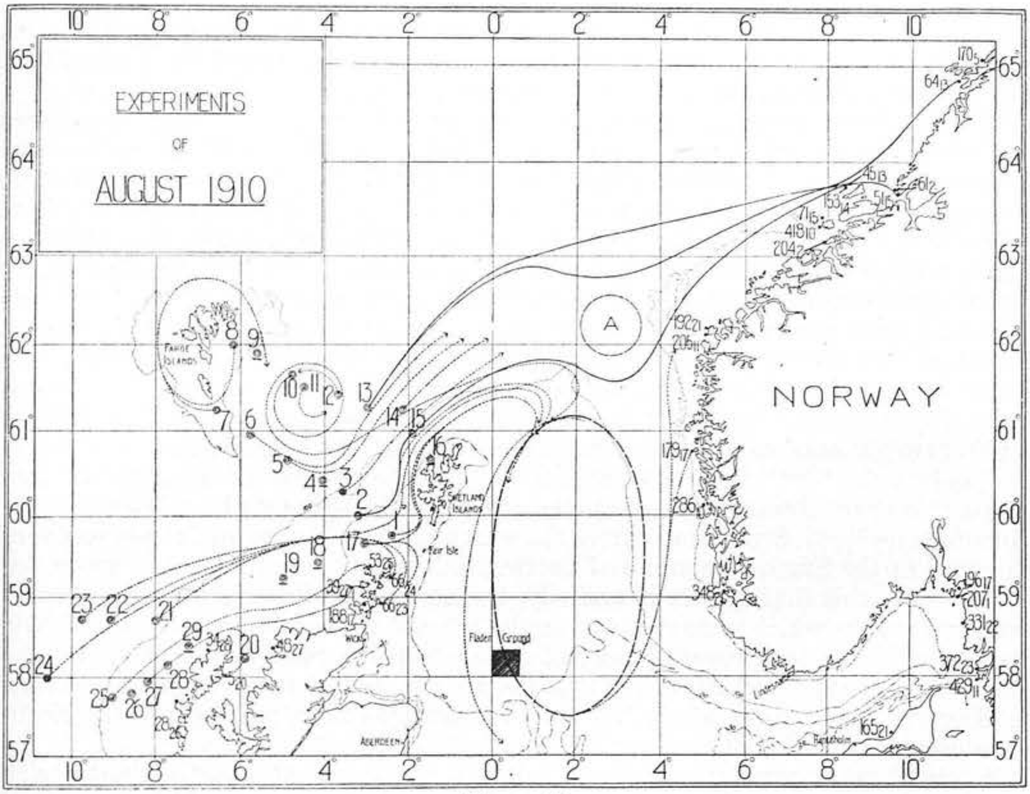


Figure 11

Channel and after one station in the Minch (between the Outer Hebrides and the mainland of Scotland) a further nine points were visited in the area immediately south-westwards of the Wyville-Thomson Ridge.

Recoveries totalling thirty-eight were subsequently recorded as a result of the above operations. These took place upon the following shores, no bottle being picked up from the sea :—

West coasts of the Outer Hebrides	2
East coasts of the Outer Hebrides	1
West coast of the mainland of Scotland	1
Western shores of the Orkney Islands	2
Eastern shores of the Orkney Islands	3
On the Shetland Islands	0
Within the Skagerak	6
The Norwegian coast between Lindesnaes and latitude 62° N.	3
The Norwegian coast between latitudes 62° N. and 64° N.	9
The Norwegian coast north of latitude 64° N.	11

The entire absence of returns from the Shetland Islands is a remarkable feature of the August records in contrast to those of the previous May, when the Faroe-Shetland Channel area was as intensively operated as regards the number of stations visited.

Fully one-half of the total number of bottles returned as a result of the August experiments were found on the Norwegian coast north of latitude 62° N. Included in this number are five bottles for which remarkably short drift-periods are recorded, the shortest, from the point of view of the minimum distance traversed and the time taken to cover this distance, being registered by that drifter despatched from Station 13 and recovered after 45 days at Maasoval, South Trondhjem, Norway. A more or less direct route from the point of liberation to the stranding-place, such as postulated in Figure 11, measures some 360 miles, which would be accomplished in 45 days at an average speed of 8 miles per day.

The question arises, however, as to the probability of the above-mentioned five bottles having drifted first of all into the North Sea by way of the north of the Shetland Islands and under the influence of the Great Eddy. To determine if possible the likelihood of this event, the relative disposition of the liberation-stations from which recoveries were effected : (*a*) within the North Sea or neighbouring bights or inlets ; and (*b*) on the Norwegian coast north of latitude 62° N., must be studied.

Drifters were returned from Danish, Swedish, and southerly Norwegian coasts which had been set away at Stations 1, 10, 11, 17, 21, 22, and 23, and the above-mentioned five short-period bottles originated at Stations 2, 13, and 15. Thus *no station occurs in both categories*, again in contrast to the result of a similar analysis of the May records. Stations 1, 17, 21, 22, and 23 were so situated that drifters therefrom might reasonably be expected to pass through the Fair Isle-Sumburgh Head Channel into the North Sea. But, according to the deductions arising from the May results, this channel was superficially closed until at least the 29th of August to the influx into the North Sea of water from the west and the record of an Orkney recovery belonging to the Station 17 group of bottles, although it be a relatively long-period one, supports this finding. It is unlikely, therefore, that drifters from the August Stations 1 and 17, which were operated on the 8th and 19th of the month respectively, entered the North Sea proper by way of the *south* of the Shetland Islands. On the other hand, there can be little doubt that the drifters from Stations 10 and 11 reached the Skagerak and south-westerly Norwegian coasts by a route passing into the North Sea by way of the *north* of Shetland.

Under these circumstances it is difficult to imagine how at least the short-period bottle from Station 2 to the more northerly Norwegian latitudes could have escaped a North Sea cruise. To explain the anomaly, for the evidence does not warrant the postulation in respect of the Station 2 drifter of such a long route, the time factor must be taken into consideration.

It is to be noted firstly that all four recoveries pertaining to Stations 10 and 11—the two recoveries from the Station 12 series of bottles might also be included—registered fairly lengthy periods of drift. In the second place the stations in question were situated within an area which more than one investigator has found to be peculiar in relation to the physical characteristics of the surface water masses. The region concerned lies midway between the Shetland and Faroe Islands, and at certain times, as has been demonstrated by Helland-Hansen (10) and by Jacobsen and Jensen (9), the opposing influences of a more or less southerly flowing drift-stream on the west side of the channel and of a north-easterly running current on the east side may induce the formation of an eddy over the area between the two. It is quite likely that this counter-clock circulatory system, which we may call the Faroe-Shetland Channel Eddy, was functioning in the neighbourhood of the August Stations 10, 11, and 12, and that drifters liberated thereat were detained in the vicinity for some time, probably long enough to allow of a deviation more to the eastward of the stream passing into the Norwegian Sea from the Faroe-Shetland Channel, thus carrying floating objects more nearly within reach of the influence of the Great Northern North Sea Eddy.

The broken curves in Figure 11, embracing Stations 10, 11, and 12, and expressive of the above hypothesis, do not then represent continuously progressive courses in respect of the bottles concerned. Two or more eddy circuits were probably accomplished before the bottles finally escaped from the predominant influence of the system and passed on towards the northern limit of the Great Northern North Sea Eddy.

It may therefore be accepted meantime that the five short-period recoveries above referred to reached their stranding-places by way of the Southern Norwegian Sea only.

The shortest-period recovery belonging to the Station 13 group of drifters has already been dealt with, and the route postulated for the 64-day recovery in the Vigten Islands, Norway, from the same point of origin would be accomplished in the time given at a daily rate of progress of not less than $7\frac{1}{2}$ miles. Following courses somewhat as indicated in Figure 11, the shortest-period returns pertaining to Stations 2 and 15 are in strict agreement with the first-mentioned Station 13 bottle, covering distances of approximately 485 and 405 miles in the times given, namely 61 and 51 days, at an average rate of 8 miles per day. It has been assumed that the Station 2 drifter passed over the position of Station 15, thereafter pursuing the same course as the bottle from the latter point to approximately the same stranding-place. The fifth short-period recovery, that is the second bottle to be returned from the series liberated at Station 15, will be commented upon later.

The only recovery from Station 1 was that effected after 207 days in Sack Fjord, between Strömstad, Sweden, and Fredrikshald, Norway. Presumably, as has been pointed out above, this bottle passed into the North Sea by way of the north of the Shetland Islands, as also some of the drifters liberated at Station 17, one of which was picked up on the same day as and not many miles distant from the Station 1 recovery. These two instances belong to the large group of Danish and Swedish coast recoveries effected during the first quarter of the year 1911 (see Figure 5). The shortest-period individuals of this group are those which originated over the region of "The Gut" in the beginning of December 1910, and the connection between the experiments of that month and those of August lies in the suggestion that the August bottles which ultimately found their way to the Skagerak, along with numerous others, spent the intervening time circuiting once round the Great Northern North Sea Eddy. The suggestion is further enhanced, and at the same time a closer connection established between the August experiments and those of December by a practical demonstration.

On the supposition that the Station August$_{10}$1 drifter found in Sack Fjord on 3rd March 1911 cruised into the Great Eddy by the route indicated in Figure 11 and thence southwards just within the western periphery of the complex, at an average rate of 8 miles per day—the vector above deduced in respect of contemporarily drifting bottles across the Southern Norwegian Sea—then the region of the southern end of the Fladen Ground (the hatched area on Figure 11) would be attained within at most two days of the inauguration in that quarter of the experiments of September from which, it will be recalled, two Skagerak recoveries resulted, also during the first quarter of 1911—one of them, in fact, two days prior to the August bottle and within 40 miles of it.

In respect of Stations 3, 5, 6, 7, 8, and 14, the recorded recoveries all took place, after long periods of drift, on the Norwegian coast north of latitude 63° N., most of them north of latitude 65° N. Their probable courses as they set out from the various stations are denoted on the chart by broken curves which have been stopped abruptly. It is obvious, in view of our fundamental axiom relating to cross-drifts, that the bottles from these stations cannot be regarded as having proceeded, in the first instance at all events, into the Great Northern North Sea Eddy. In parenthesis, the longer-period recovery belonging to the Station 2 group of bottles might thus be accounted for, but how else are the long periods registered by the recoveries belonging to Stations 3, 5, 6, and 14 to be explained? Apart from the resort to the theory of having lain upon the beach, the only other feasible explanation lies in the assumption of the existence at the time of a small swirl, first propounded, so far as the present writer is aware, by Helland-Hansen and Nansen,* and situated approximately in the area represented by the broken circle, A. Herein also probably lies the explanation of the anomaly of the second Station 15 recovery, namely, that returned from the Island of Smölen after 71 days, when another drifter from this Station, having proceeded at least a further 50 miles along the Norwegian coast, was found 20 days earlier.

The explanation of long drift-periods might, in part at least, be otherwise than above in regard to the drifters originating at Stations 7 and 8 on the Faroe Shelf, for one of the features of the analysis of the May records was the deduction of a circulatory system of surface waters enclosing the Faroe Islands. Furthermore, it is evident that drifters emerging from such a system, if it was in fact in operation during August 1910, may pass therefrom into the Faroe-Shetland Channel Eddy, and there be delayed for a further indefinite period.

Relative to Station 20, situated in the Minch, only one recovery was subsequently recorded, this having taken place on the Lewis coast about twenty miles south-west of the starting-point. The time presumably occupied in making this short journey was five days. The record may be useful in conjunction with others of later date, but as an isolated instance in the present experiments no further comment is meantime called for.

Passing finally to the consideration of recoveries accruing from the experiments inaugurated at Stations 21–29, these may be classified under two heads, according as the bottles in question obviously did, or presumably did not, enter the North Sea proper. This classification leads to a similar division into two groups of the liberation-stations themselves, the first group embracing Stations 21–24, which were situated beyond the Continental Edge as defined by the 100-fathom bathymetric contour, and the second group comprising Stations 25–29 inclusive, situated over the region of the Continental Shelf to the immediate west of the Outer Hebrides. The two groups of stations are, by their results, connected in virtue of subsequent recoveries upon the Orkney Islands, resulting from liberations at two of the stations in each. The characteristic feature of the data pertaining to the first four stations is the ultimate stranding of drifters therefrom on Danish, Swedish, and southerly Norwegian shores, while two Hebridean recoveries, and one upon the western mainland of Scotland differentiate the second group of stations from the first.

With reference first of all to the Orkney Island returns, a point to be noted in relation to the deeper water stations is that, contrary perhaps to what might be expected, it is from the two outermost stations of the group, namely, Stations 23 and 24, that the two Orkney Island recoveries were later effected. From the former point a second drifter is known to have ultimately reached the west Swedish coast. These facts, conjointly, point to the inference that the surface water in the region of the liberation-stations comprising the first group headed more or less in the direction of the August Stations 1 and 17, about which area it has previously been remarked, a division in the easterly flowing drift-stream appears to take place, part

* Helland-Hansen, B., and Nansen, F., "The Norwegian Sea, Its Physical Oceanography," *Rept. Norwegian Fish. and Marine Invest.*, Vol. II, 1909.

deviating northwards off the western shores of Shetland, and part turning southwards between Fair Isle and Orkney, the latter giving rise to a continuous clockwise circulation of surface waters round the entire group of the Orkney Islands. The latter phase of this hypothesis is supported by evidence available from the present data, by reason of the fact that the assumption, in respect of the Orkney bottles from Stations 23 and 24, of direct routes approximately as defined by the broken curves on Figure 11, entails also the acceptance of average drift velocities of only 4½ miles per day, which obviously do not conform to much of the foregoing analysis of the August records. Drift-velocities of the order of 8 miles per day follow only on the postulation of two complete circuits of the Orkney Islands in addition to the routes laid down on the chart.

Of the five Continental recoveries resulting from the above-mentioned four series of liberations, the shortest-period return was that found near Blokhus on the north Jutland coast on the 3rd day of February 1911, that is, 165 days after the date of its despatch from Station 21. Little hindrance to a continuously progressive course by way of the north of the Shetland Islands into the North-Western Area of the North Sea, thence by way of the Middle Area into the Skagerak, can have been experienced by this particular drifter, since, on the foregoing assumption relative to the route followed, a lineal distance of almost 1000 miles must have been overtaken at a mean rate of drift over the entire course of about six miles per day, a vector which is consistent with those deduced from the results of experiments commenced within the North Sea in the months following upon that presently under review.

The Hebridean recoveries recorded in respect of Stations 26 and 28 are singular on account of the magnitudes of the drift-periods registered, and also, in the former case especially, with reference to the relative geographical positions of liberation-station and stranding-place. Without further material of a similar nature, though of shorter drift-periods, little can be surmised with confidence regarding the courses presumably taken by these bottles. This applies also to the one from Station 27 returned after 48 days from Handa Island on the west coast of Sutherlandshire, Scotland, for from the same point of origin another bottle found its way to the west coast of the mainland of Orkney, being picked up near Marwick Head nine days *before* that found on Handa Island. A direct route for this case, as for that of the 53-day drifter found in Pierowall Bay, Westray, Orkney, and belonging to the Station 25 group, leads to the deduction once more of average drift-velocities of 4½ miles per day.

The consistency of the four Orkney Island recoveries must therefore be acknowledged, although the index of that consistency differs from that of the results pertaining to experiments begun in more northerly waters of the region of the Faroe-Shetland Channel. In connection with the latter results, the hydrodynamical calculations of Robertson (11*e*) again support the figure of 8 miles per day as defining the surface velocity in the region of the mid-Faroe-Shetland Channel north of the 60th parallel of latitude, during the month of August 1910.

* * * * * *

October Liberations.

Only one batch of drifters was despatched during this month. On the 21st, ten bottles were set adrift at the point—Latitude 56° 55′ N.–Longitude 1° 08′ W.—and of these, six were returned from the east Aberdeenshire coast in from seven to twelve days of the date of liberation.

The range of the drift-periods, assuming all six to be drift-periods in the true sense, indicates complexity in the surface current system of the area involved, and of course the Mid-East Scottish Coast Eddy is suggested. Taking the case even of the longest-period drifter, however, and postulating for it a course just outwith the normal boundary of the eddy as defined in Figures 8 and 10, the resulting average velocity figure works out at approximately 10 miles per day, and for similar courses in respect of the shorter-period bottles the vector would be in the neighbourhood of 20 miles per day. Even the lower of these estimates is almost inadmissible in view of the foregoing analysis of the August material in conjunction with much that follows pertaining to the two last months of the year, the trend of which examination is to show that from ~~May~~ June onwards to the end of the year 1910 the mean velocity of the surface water drift over the Northern North Sea as a whole, and as deduced from drift-bottle records became gradually less.

To interpret the October results reference must be made to meteorological records.* For a week prior to the initiation of the October experiment winds in the vicinity of Aberdeen were light and very variable. Commencing on the morning of the 21st, however, strong winds proceeding from the south-east quadrant were registered persistently for the next eight days.

In all probability, therefore, the October drifters set out from the starting-point more or less in a south-westerly direction, inclining more towards the land than they would have done under normal circumstances. It would appear that the south-

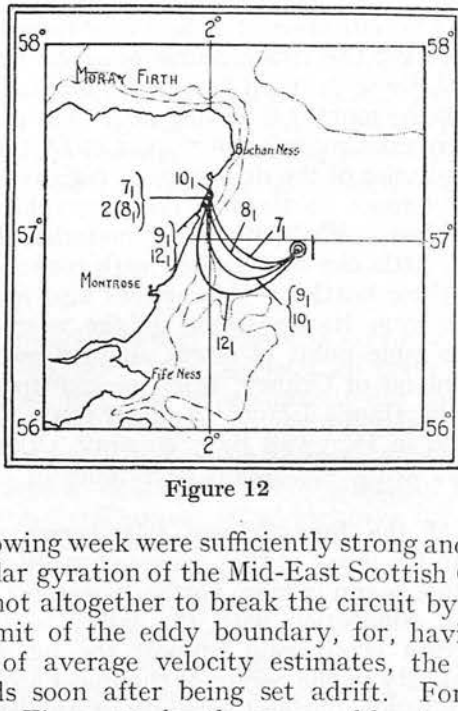


Figure 12

easterly winds of the following week were sufficiently strong and persistent to interfere materially with the regular gyration of the Mid-East Scottish Coast Eddy, producing a tendency to curtail if not altogether to break the circuit by displacing northwards the normal southerly limit of the eddy boundary, for, having due regard to the above-mentioned trend of average velocity estimates, the 7-day recovery must have deviated westwards soon after being set adrift. For such a course as is represented on the chart, Figure 12, by the curve of least convexity, the shortest-period recovery must have traversed nearly 40 miles at an average rate of from $5\frac{1}{2}$ to 6 miles per day. The remaining curves on the chart correspond to the longer-period returns, assuming the same rate of drift.

* * * * * *

November Liberations.

On the 3rd and 4th days of November 1910, eighty surface drifters were liberated in equal series of ten from eight stations in the North-Western Area of the North Sea between the latitudes of Rattray Head, Aberdeenshire, and Fair Isle in the Orkney-

* The Daily Weather Reports, issued by the British Meteorological Office.

Shetland Channel and between longitudes 1° and 2° W. On the 28th of the month twenty drifters were put overboard at a point in the Firth of Forth estuary off Elie Ness.

Twenty-four drifters in all were returned as a result of these operations.

All four recoveries belonging to the first two series of bottles stranded on Danish and Swedish shores. The first of the four stations from which strandings on the mid-east Scottish coast resulted is Station 3, from which also two drifters were later picked up on the Danish coast. From Station 4 the sole recovery took place on the Swedish coast, whilst all those recorded in respect of Stations, 5, 7, and 8 were returned from the mid-east Scottish coast between the mouth of the River Ythan, Aberdeenshire, and Montrose, Forfarshire.

Due doubtless to predominating tidal influence, the results from Station 9 are somewhat irregular, as has indeed been remarked in connection with the results of more than one series of liberations made in approximately the same locality, namely, those relative to Stations $May_{10}52$ and $June_{10}19$.

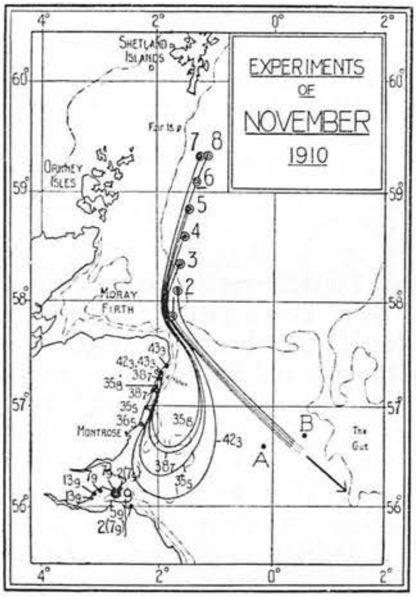


Figure 13

It is fairly evident from the above facts relating to the northerly stations that the drifters despatched therefrom set off on a south to south-westerly cruise, those from the northmost points passing to the west of the positions of the more southerly stations. Some few miles to the north-east of Kinnaird Head, the drifters apparently deviated slightly more towards the south, the results from Station 3 particularly suggesting that about this region a division took place in the southerly flowing drift-stream, part continuing an easterly deviation and heading seawards and part passing on to the eastern boundary of the Mid-East Scottish Coast Eddy, which the month's results indicate to have reasserted itself after the interference caused by strong south-easterly winds during the last week of October.

The winds registered at Aberdeen throughout the month of November 1910 were mainly from westerly quadrants, but the period embraced by the above-noted Scottish coast recoveries was again marked by fairly strong south-easterly winds which, it would seem, are inimical to the proper functioning of the Mid-East Scottish Coast Eddy. Without further information, however, the periods which may have been spent by the eight Scottish coast returns cruising within the said complex cannot be estimated with reasonable certitude. Fortunately a consideration of some of the experimental results of the following month is of assistance in this connection.

From three stations on a line passing eastwards from the May Island in the Forth estuary a number of bottles which were despatched on the 7th of December, reached points on the mid-east Scottish coast between Fife Ness and Buchan Ness in from seven to twelve days of the date of liberation. Average drift-speeds of from five to nearly eight miles per day are deduced for these bottles, from which it can be shown by measurement and calculation that none of the November returns from the same coast-line completed a circuit of the Mid-East Scottish Coast Eddy before the system was again modified by south-easterly winds in the beginning of December.

Curves are traced on Figure 13 to represent the probable routes taken by the shortest-period Scottish recovery pertaining to each of the November stations concerned. These routes are consistent with one another in that they would be covered in the corresponding times at an average daily rate of progress of about six miles.

The earliest Danish and Swedish coast returns from the November operations occurred during the first week of March 1911, that is, almost simultaneously with recoveries in the same region resulting from liberations effected on the 7th of December 1910 at the points A and B in Figure 13. The histories of the November bottles are thus closely linked with those of the following month's liberations.

* * * * * *

December Liberations.

From eight points, seven of which were situated on a line passing eastwards from the May Island in the Firth of Forth estuary to the point—Latitude 56° 48′ N.–Longitude 1° 19′ E.—the last station being about 36 miles north of this point, forty drifters were set afloat on the 7th and 8th of December 1910. Twenty of these were ultimately returned, eight from points on the mid-east Scottish coast, nine from the north-west Jutland coast and three from the west Swedish coast.

The results of the experiments of December 1910 are remarkable for the number of short-period bottles returned from both British and Continental coasts. Again, as was found from an examination of the previous month's records, there appears to have been a longitudinal division of the southward moving drift-stream off the east coast of Scotland. From the examination of all appropriate records pertaining to the period that division can be placed approximately along the dotted line *d* on Figure 14.

From Station 1 the shortest-period recovery was that effected midway between Tayport and Guardbridge, Fifeshire, after four days. The curve traced on the chart to represent the most likely course pursued by the drifter measures to scale some 20 miles, thus giving an average velocity figure of five miles per day. If six and ten days represent the true drift-periods of the remaining two bottles from this station returned from practically the same place as the first bottle, it is conceivable that the extra days' drifting was due to the drifters in question having been carried some distance into the Firth of Forth on a flood-tide and out again on an ebb.

An average velocity of $7\frac{1}{2}$ miles per day is derived from the assumption of a straight-line course for the two bottles from Station 2 recovered after 4 days each at Montrose. For the 12-day bottle returned from the east Aberdeenshire coast, the mileage indicated by the appropriate curve in Figure 14 is 65, which would be covered in 12 days at a speed of about $5\frac{1}{2}$ miles per day.

From Station 3 two bottles stranded on the east Aberdeenshire coast after 7 days each. These two drifters must have covered at least 55 miles, thus entailing the assumption of a mean rate of drift almost 8 miles per day.

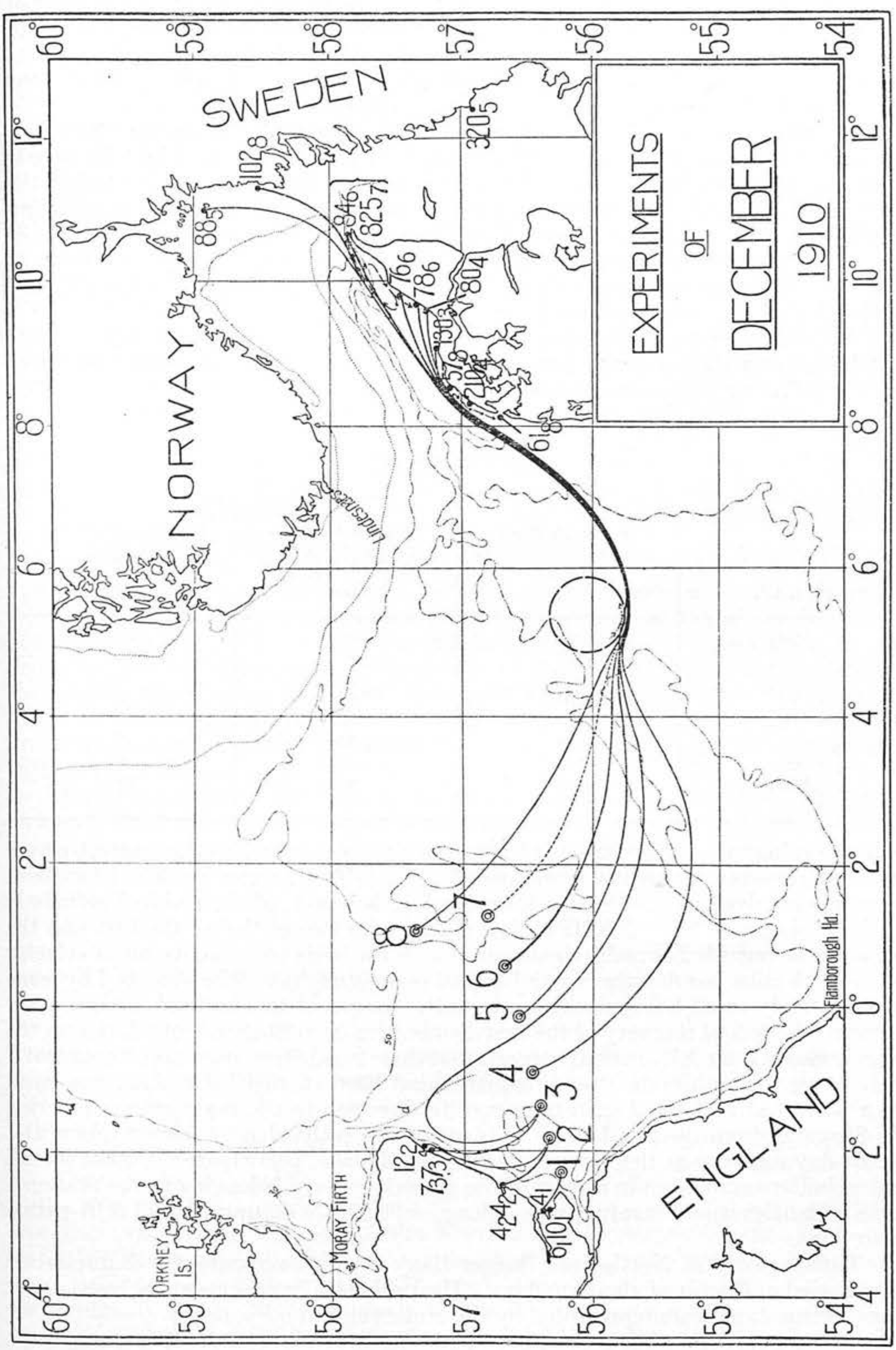

EXPERIMENTS
OF
DECEMBER
1910
NORWAY
SWEDEN
ENGLAND
ORKNEY IS.
MORAY FIRTH
Flamborough Hd.
Lindesnes

Figure 14

The variability of the above figures relating to the mean speed of the drift of surface waters off the mid-east Scottish coast during the early days of December 1910 is only to be explained by the extent to which the wind in different intensities affects the movement of superficial layers of fairly shallow water. It seems evident that that effect must sometimes be produced fairly rapidly.

The shortest-period Continental coast recovery from the December operations was that from Station 8 found on 3rd February 1911 near Hantsholm Light, Denmark. Assuming that this drifter pursued a continuously progressive course during the 57 days which elapsed between the dates of liberation and recovery, passing immediately to the south of the North-East Dogger Bank Swirl, which at this time of the year was probably situated more to the north-east of its September position as defined in Figure 10, its mean rate of drift would probably be in the neighbourhood of $5\frac{1}{2}$ miles per day over a route of some 315 miles.

With the curve representing this shortest-period recovery as guide, those pertaining to the shorter-period returns from Stations 3 to 6 were traced and measured and the following table constructed :—

TABLE XXIII

Recovery. (*a*)	Course in Miles Exclusive of Eddy Circuits. (*b*)	Time in Days to Cover (*b*) at $5\frac{1}{2}$ Miles per Day. (*c*)	Residual Periods. (Days.) (*a*)–(*c*)
130_3	500	91	39
80_4	440	80	—
88_5	485	88	—
76_6	370	67	9
78_6	360	65	13
84_6	410	75	9
61_8	290	53	8
102_8	445	81	21

According to the above table at least two more drifters besides the shortest-period Station 8 recovery apparently negotiated the North-East Dogger Bank Swirl without becoming involved in it. Further investigation, however, of the residual periods in the last column of Table XXIII indicates that only two of these—the first and the last—can be regarded as really significant, for on the basis of the above mean velocity figure of $5\frac{1}{2}$ miles per day the remaining four periods might well be absorbed by some comparatively small idiosyncrasy in the latter stages of the drifters' courses. For instance, the loci of recovery of the first two bottles from Station 6 in relation to the magnitudes of their drift-periods suggests that these two drifters may have "overshot," as it were, their ultimate stranding-places and been carried back along the coast by a narrow stream moving in the opposite direction to the main stream entering the Skagerak from the North Sea. It is indicated on the chart, Figure 14, how also the 84-day recovery at the Skaw may conceivably have participated in this reversal and a similar assumption in respect of the second recovery belonging to the Station 8 series of bottles would involve extra mileage sufficient to occupy the full drift-period of 61 days.

Thus, again, the North-East Dogger Bank Swiıl was apparently characterised by a Period of Circuit of about 20 days. The probable dimensions of the swirl under these circumstances are represented by the broken circle on Figure 14.

* * * * * *

SUMMARY DISCUSSION OF THE YEAR'S RESULTS

The first observation to be made regarding the system of surface drift-currents in the Northern and Middle Areas of the North Sea and in contiguous waters, as deduced in the foregoing analysis of the results of experiments with surface-floating bottles, is that it is by no means a simple system if the experimental results of 1910 can be taken as a broad indication of what generally happens in most years.

That the surface water circulation of the Northern North Sea Area depends substantially upon dynamic conditions in the Faroe-Shetland Channel region is now generally conceded, and the fact is borne out by the present records. But the North Sea "front," upon which is directed the main attack emanating from the North-Eastern Atlantic Ocean is not perhaps so consistently agreed upon. It has been pointed out that, from his observations upon physical data pertaining to the year 1902, Helland-Hansen (10) considered that the main bulk of Atlantic water which entered the Northern North Sea in that year came by way of the opening between Shetland and Norway, while, as regards succeeding years until 1910, Robertson (11) found in favour of the channels between Shetland and the mainland of Scotland as being the principal gateways for the entrance of surface water from the west into the Northern North Sea Area. The present examination undoubtedly enhances the former view as applied to the year 1910, but further investigation is necessary before defining a general case in this important matter.

In regard to the Faroe-Shetland Channel Area itself, particularly the south-western part of it, the results so far obtained are not conclusive. More intensive work in this region conjointly with that of the southern waters of the Norwegian Sea will probably yield more substantial data upon which to found inference and deduction. A more detailed knowledge also of the circulation of surface waters in the neighbourhood of the Faroe Islands with special reference to seasonal fluctuations would be of undoubted value. In the early summer of the year just reviewed, this group of islands was found to be enclosed within an anticyclonic swirl of at least surface waters.

A similar gyration appeared to be characteristic of the neighbourhood of the Orkney Islands throughout the summer, and probably also the autumn months of 1910. The genesis of this circulation embracing the Orkney group was an offshoot from the main drift-stream coursing north-eastwards along the eastern side of the Faroe-Shetland Channel. This subsidiary stream apparently headed for the channel between Shetland and Fair Isle, flowing in an easterly direction for a short distance approximately along the parallel of 59° 30′ N., but, finding its further progress towards the North Sea barred by a narrow stream flowing northwards on the east (i.e. the North Sea) side of the said channel, it was forced to divide, part turning to the left and passing northwards along the western shores of Shetland, and part deviating southwards through the opening between Fair Isle and Orkney. The same narrow stream, heading northwards off the eastern shores of Orkney, Fair Isle, and even Shetland, restricted the tributary stream from the north and west to the immediate neighbourhood of Orkney, forcing it backwards, as it were, through the Pentland Firth and the passages between the islands.

Perhaps the most significant outcome of the surface drift-bottle work performed in the Northern North Sea throughout the year 1910 is the establishment of what it has been proposed to name the Great Northern North Sea Eddy, the existence of which has long been suspected. Indeed, it almost follows from what has been known empirically for some time regarding the hydrodynamics of the waters on either side longitudinally of the Northern North Sea Basin, that such a system will function over the central area as the effect of a sort of hydro-couple, the arm of which lies approximately along the parallel of 59° 30′ N. latitude. The limits of the system during 1910 were approximately latitudes 57° 30′ N. and 61° 10′ N. on south and north, and longitudes 0° and 3° 30′ E. on west and east respectively. It is more than likely, however, that these limits vary, perhaps considerably, throughout any one year.

The concept of the Great Eddy is of valuable assistance in the investigation into the histories of long-period recoveries which, as is to be expected, are in the majority in the records of experiments similar to those examined. By far the greater number of these long-period bottles are without doubt actually at sea for the larger portion of the time registered between their dates of liberation and recovery, the circulation of the Great Eddy system once, or perhaps several times, accounting for much of the time hitherto supposed to have been spent upon the beach.

One effect, apparently, of this huge cyclonic swirl of waters is to deflect further to the right the surface water seeking entry into the North Sea from the southern latitudes of the Norwegian Sea, causing it to be restricted within narrow limits as it crosses latitude 61° N., heading in a south-westerly direction. It is probable, however, that this stream divides on the north-western boundary of the Great Eddy, part being absorbed, as it were, by the eddy system and carried southwards along its boundary, and part—the main part, probably—deviating gradually towards the east Scottish coast. On occasions, such as happened during the months of May and June 1910, this latter stream may again divide in the region of latitude 58° N., and between longitudes 1° and 2° W., one tributary turning more or less sharply westwards into the Moray Firth and the other continuing its southerly route.

That part of the stream which enters the Moray Firth from the North Sea proper, flowing westwards parallel to, but some distance off, the southern shore of the Firth, appears to lose its identity within a small eddy functioning in the inner reaches of the Moray Firth, but if the movement from the North Sea be long-continued the congested waters seek an outlet from the Firth in a north-easterly direction, giving rise to the aforementioned narrow stream along and off the eastern shores of Orkney and Shetland. This stream may not at first attain to the latitude of Shetland, but turn off eastwards approximately in the latitude of Fair Isle, thus establishing a connection again with the southerly flowing stream heading in the direction of the north-eastern corner of Aberdeenshire. On the other hand, the west flank of the southward moving steam from the Norwegian Sea may not reach the latitude 58° N. before deviating westwards and then northwards towards Shetland. This movement, when it occurs, most likely takes place about latitude 59° N., between which and the latitude of Fair Isle there may be found to function at certain times a small clockwise swirl or eddy.

The peculiar set of the surface currents in the region to the north of the Viking Bank during the month of May 1910, as indicated by the courses estimated in respect of drifters liberated therein, is worthy of further investigation. Such a pronounced and continued swerve to the right of the main drift-stream traversing this important region about the northern edge of the North Sea Continental Shelf is probably the cumulative effect of three major causes, namely: (i) the rotation of the earth; (ii) the configuration of the ocean floor; and (iii) the circulation of the Great Eddy.

There is little doubt that throughout spring and summer months at least, another eddy will normally be found to function in the waters off the mid-east Scottish coast between the latitudes of Fife Ness and Aberdeen. Consequent upon a deflection westwards into the Moray Firth of the bulk of the water moving southwards into the North Sea this eddy may be found to extend its influence considerably seawards, as in the months of May and June 1910. Again, fairly strong winds from the south-east quadrant of the compass are apparently inimical to the complete functioning of this complex.

Certain unique instances in the records of the 1910 experiments afford information as to the probable orientation at various times of the year of Böhnecke's North-East

Dogger Bank Swirl, and to a less extent of the South-West Dogger Bank Swirl. As is to be expected, the position of the former is to all appearances governed more or less by the seasonal dynamics of the Skagerak waters.

The results of the 1910 experiments show that drifters may find their way into the Skagerak during most months of the year, although there was apparent a distinct tendency for bottles to be held up off the Skagerak entrance during the last quarter of 1910 and until the first quarter of the following year.

In connection with this resistance to the progress of the drifters, certain results on closer scrutiny yielded some interesting information. In brief, it was found possible to estimate the approximate time required for a bottle to be carried once round the surface-water gyration called by Böhnecke the North-East Dogger Bank Swirl. This quantity, which it is proposed to call the Period of Circuit of the complex, depends of course upon the velocity of the surface drift-stream or streams in its immediate vicinity.

A similar quantity has been deduced in respect of the small anticyclonic swirl in the Moray Firth and also for that off the mid-east Scottish coast.

The Period of Circuit of the Great Eddy will not be so easily ascertained, not only on account of its size, but by reason of the fact that, on issuing therefrom, drifters may or may not become involved for an indefinite time within another such system, thus to a great extent precluding the possibility of estimating with reasonable certitude the periods spent within each or either. The same applies to the South-West Dogger Bank Swirl, for floating objects issuing from this circulation may pass into the North-East Dogger Bank Swirl before finally cruising towards and stranding upon Danish, Swedish, or Norwegian coasts.

Turning to the question of the velocity of the surface drift, the important feature of the present analysis is to enhance the value of the " unique cases " mentioned in footnotes and parentheses by former investigators, namely, the isolated instances of apparently extraordinarily fast-moving drifters.

Taking the short-period return as a basis for argument, the histories of the longer period recoveries have been investigated with due regard to the above-mentioned complexities in surface water movement and other factors detailed in the Introduction to the present report. The results of this method of examination have been expressed diagramatically in the various charts throughout the text. The most notable feature of these charts is the remarkable consistency which has been attained with regard to the routes estimated to have been followed by numerous drifters, a consistency which has not resulted from other methods of examination of similar material.

From the months of May and June onwards to the end of the year just reviewed, a gradual diminution in the mean rate of flow of the surface drift-current over the Northern North Sea generally has been demonstrated, from a maximum of some 13 miles per day during the late spring and early summer to between 5 and 6 miles per day in winter months. Where comparison has been possible, namely, in connection with the Faroe-Shetland region during the months of May and August, these estimates of drift-velocities derived from drift-bottle experimental data agree very closely with those obtained by hydrodynamical calculation based upon observational data of temperature and salinity.

In concluding this report, an attempt has been made to summarise the main features of the foregoing analysis in three synoptic charts, representing the " average " surface drift-current system in the Northern and Middle Areas of the North Sea and in the Faroe-Shetland Channel during the three quarters of the year 1910 commencing with the month of April. Obviously, the synchronisation of each of these charts cannot be perfect, but it must be conceded that over such an extensive field the approach towards synchronism is remarkable, the more so as, in the first place, the work of liberating the drifters was performed throughout from one and the same vessel, and further, since the large-scale operations commenced in 1910 were still of the nature of a pioneering effort and consequently were not conducted according to a prearranged plan, such as might now be formulated on the basis of the results so far obtained.

The quarterly synoptic charts are appended herewith (Figures 15, 16, and 17) and require little further comment. They explain themselves in so far as the main curves are concerned, while the broken curves represent more or less temporary deviations from a more strongly established system.

Again, it may be well to remind the reader that the subject-matter of this paper must be read as applying only to the most superficial stratum of water in the areas concerned until such time as the question of sub-surface drift-currents in relation to those at the actual sea-surface has been investigated experimentally.

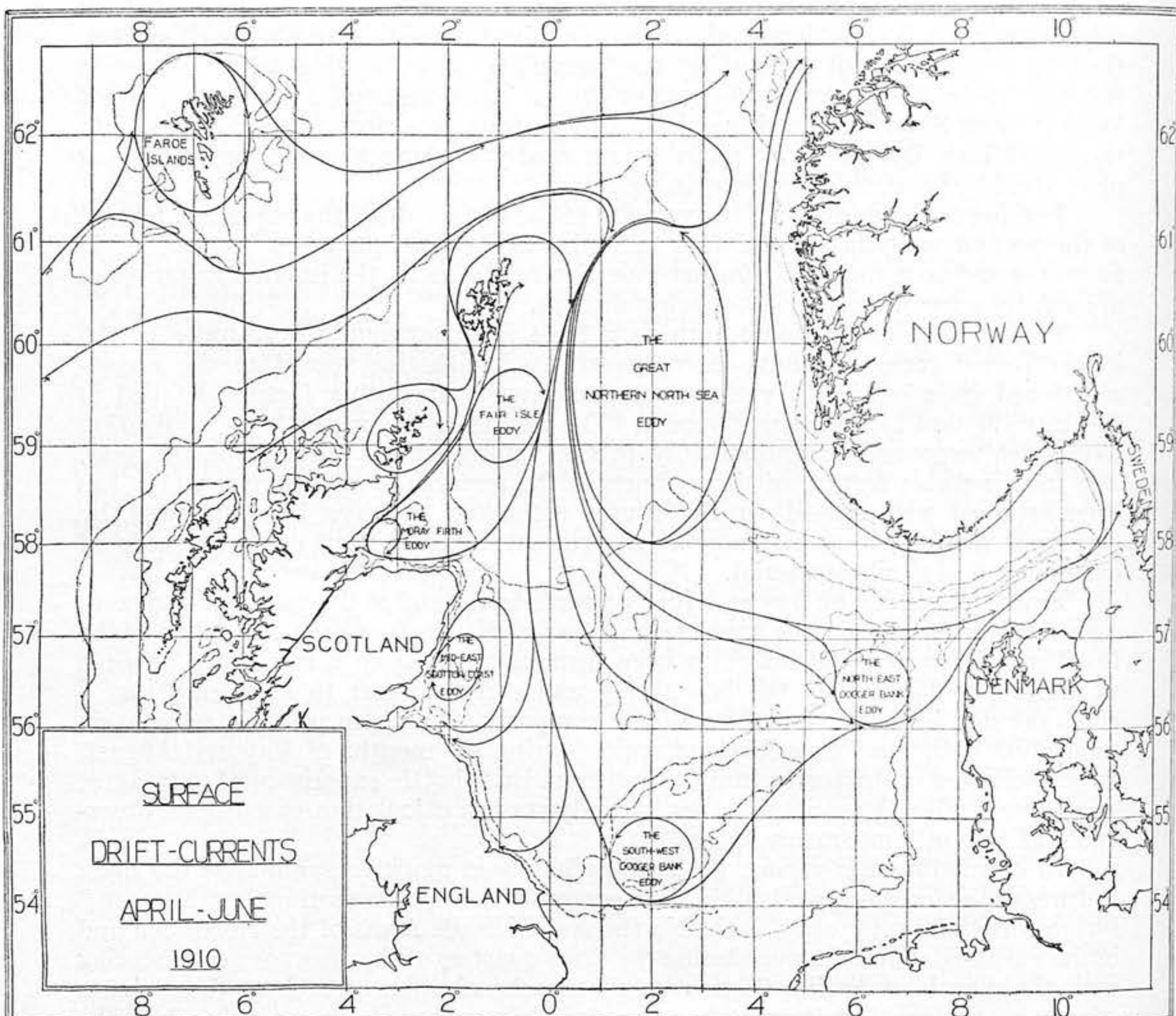


Figure 15

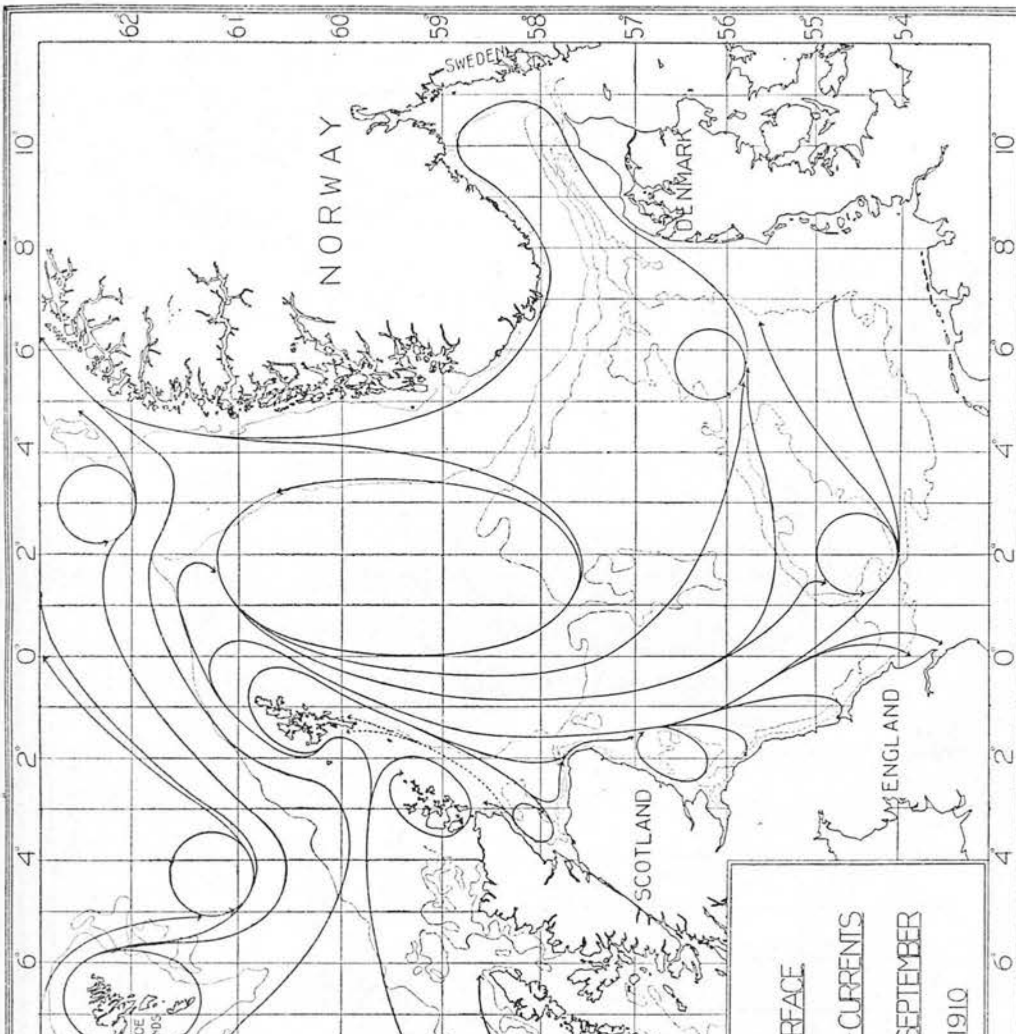

SURFACE
DRIFT-CURRENTS
JULY-SEPTEMBER
1910
NORWAY
SWEDEN
DENMARK
SCOTLAND
ENGLAND
FAROE ISLANDS
62°
61°
60°
59°
58°
57°
56°
55°
54°
10°
8°
6°
4°
2°
0°
2°
4°
6°
8°

Figure 16

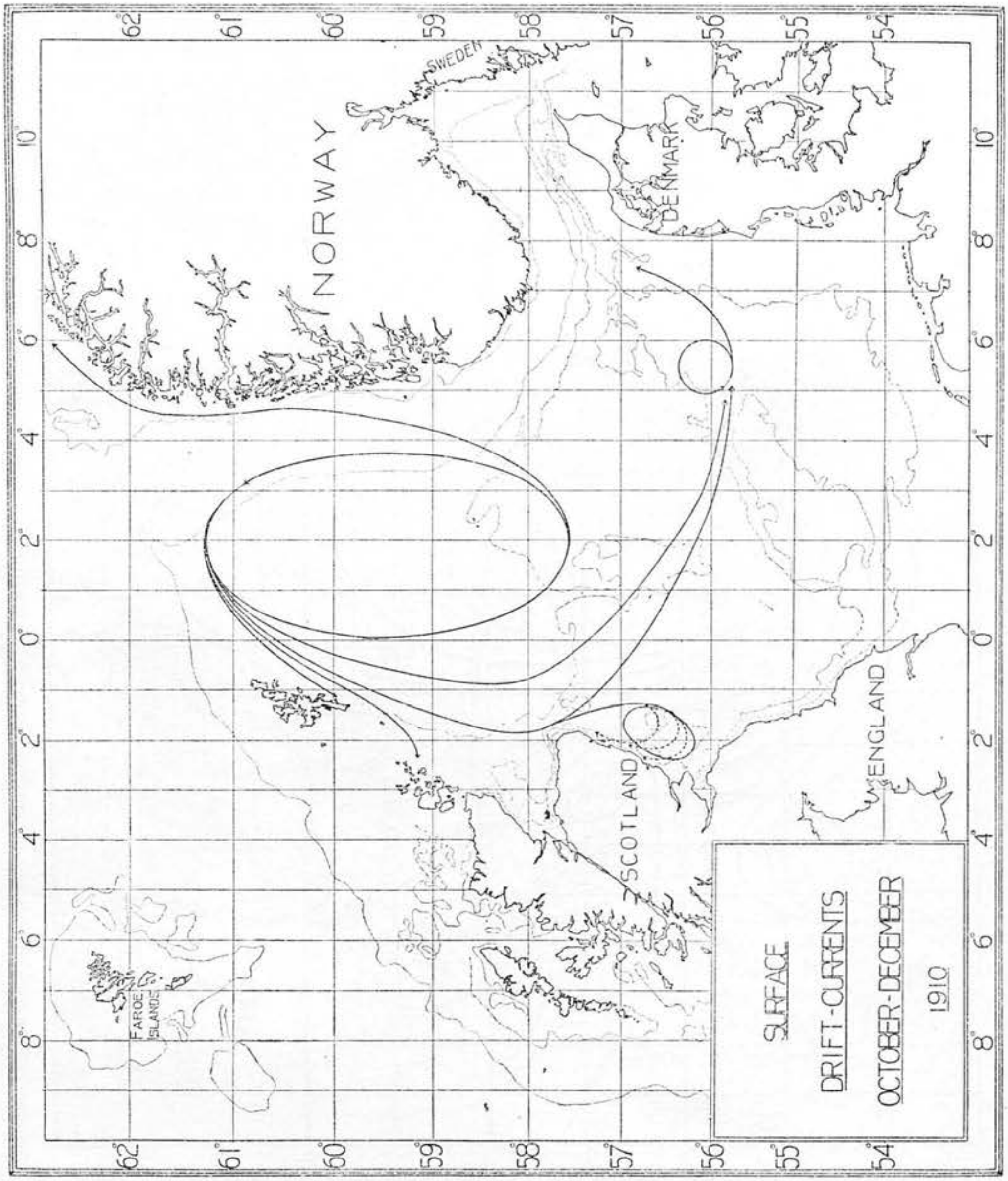


Figure 17

Printed under the authority of His Majesty's Stationery Office
by J. & J. Gray, St James Place, Edinburgh.

Wt. 3713/0223 250 10/30 J. & J. G. **G2.**

NEMO·ME·IMPUNE·LACESSIT

FISHERY BOARD FOR SCOTLAND

SCIENTIFIC INVESTIGATIONS

~~1931~~

~~No. III~~

The Surface Water Drift in the Northern and Middle Areas of the North Sea and in the Faroe-Shetland Channel

PART II, Section 2: A Cartographical Analysis of the Results of Scottish Surface Drift-Bottle Experiments commenced in the Year 1911

(With Sixteen Chart Figures and Two Curves)

By

John B. Tait, B.Sc.

This Paper may be referred to as
"Fisheries, Scotland, Sci. Invest., 1931, No. III."

EDINBURGH:
PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE.

To be purchased directly from H.M. STATIONERY OFFICE at the following addresses:
120 George Street, Edinburgh; Adastral House, Kingsway, London, W.C. 2;
York Street, Manchester; 1 St Andrew's Crescent, Cardiff;
15 Donegall Square West, Belfast;
or through any Bookseller.

1932

Price 4s. od. Net.

49-175-3-31.

CONTENTS

* *Fisheries, Scotland, Sci. Invest.*, **1930, IV.**

PREFATORY NOTES

THE following report, dealing with surface drift currents in the Northern and Middle Areas * of the North Sea and contiguous regions, as ascertained from a cartographical analysis of surface drift-bottle experimental records pertaining to the year 1911, is in continuation of two previous papers by the writer, published as :—

(*a*) *Fisheries, Scotland, Sci. Invest.*, 1930, No. II. (containing Figure 1, Tables I. to XII.).
(*b*) *Fisheries, Scotland, Sci. Invest.*, 1930, No. IV. (containing Figures 2 to 17, Tables XIII. to XXIII.).

Practical details concerning the initiation and objects of these drift-bottle experiments and a chronological arrangement of the numerous liberations, together with their results, are given in the first of these papers. The general principles underlying the method of analysis employed in the following pages and the conventions used throughout the text and on the several charts are explained in the Introduction to the second publication. Further, the sequences of Figure and Table numbers in the earlier volumes are continued in the present paper. In other respects, apart from the necessity of direct reference, a knowledge of the contents of the two papers above quoted is eminently desirable to a complete understanding of the following work.

In addition to information already submitted in one or other of the former publications, it may be mentioned that, at the present stage in the investigation of surface current systems by means of drift-bottles, no distinction is here drawn between the apparent rate at which a drifter passes through the surface waters of the sea areas concerned and the velocity of that which is at present known as *the surface drift*. This report also contains a more detailed examination of the data for 1911 than that followed in the survey of the 1910 material, (*b*) above. As explained in the sequel, this refinement of the analysis is the outcome of a necessary modification in the treatment of the results, the necessity arising from a paucity of the data essential to an examination conducted on exactly the same lines as before. The modification of the analytical method, in order to build up a logical argument, leads to a greater irregularity in the presentation of the 1911 results than that demanded by the previous year's analysis. The records accruing from the liberations carried out in each calendar month are again treated independently, in the first instance, but the exigencies of cohesive argument, to suit the purposes of a report, call for an arrangement of these monthly analyses not dictated by chronological sequence. The threads, however, are ultimately rewoven in the form of a time-velocity curve, which appears towards the end of the paper, and in the summary discussion of the year's work as a whole.

J. B. T.

ABERDEEN, *August* 1931.

* Defined in the preface to (*a*) above.

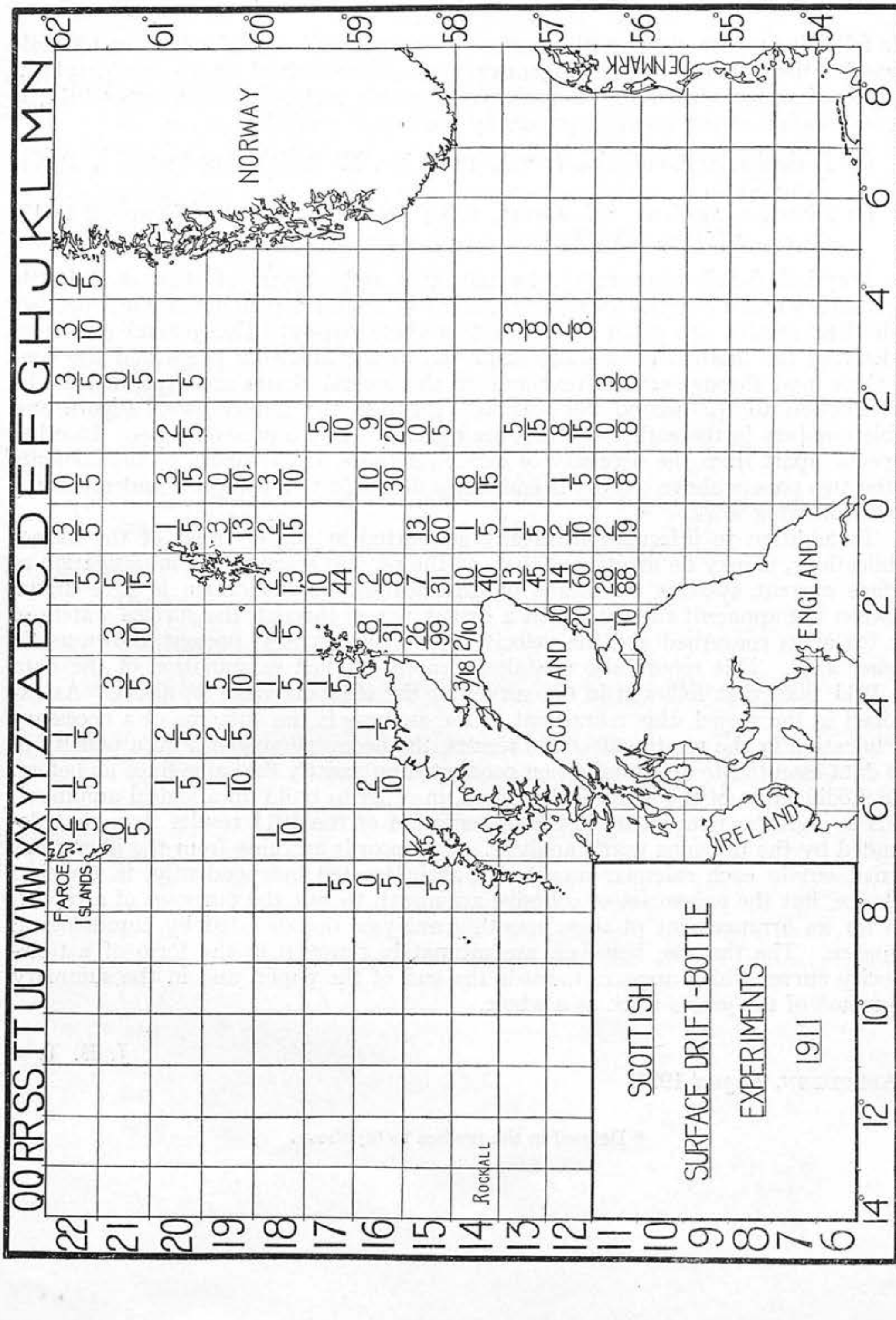

SCOTTISH
SURFACE DRIFT-BOTTLE
EXPERIMENTS
1911
NORWAY
DENMARK
FAROE ISLANDS
SCOTLAND
ENGLAND
IRELAND
ROCKALL

Figure 18.

The Surface Water Drift in the Northern and Middle Areas of the North Sea and in the Faroe-Shetland Channel

PART II, SECTION 2

EXPERIMENTS COMMENCED IN THE YEAR 1911.

INTRODUCTION.

BETWEEN February and October 1911, both months inclusive, 1034 surface drift-bottles were set afloat over the sea areas indicated on Figure 18. This total represents the sum of the denominators of the fractions entered upon the chart. The numerators of these fractions denote the numbers of recoveries subsequently recorded in respect of the liberations performed throughout the year within the given rectangles. As before pointed out, these rectangular sea areas are conveniently defined, with reference to a key chart such as Figure 18, by the letters at the head of the meridianal columns in conjunction with the appropriate numerals signifying horizontal rows, each of thirty minutes latitude. For example, Fair Isle, situated almost midway between Shetland and Orkney, lies within the rectangular area C18.

As a result of all the liberations of 1911, 272 bottles were ultimately recovered, a percentage return of 26·3, practically the same as that of the previous year. Since also the corresponding *numbers*—that is, of liberations and recoveries—are so nearly alike, it will serve a useful purpose to compare, statistically, the data for the two years 1910 and 1911, before passing to the more detailed cartographical analysis of the 1911 results.

First of all, as regards the liberations, Table II. shows that, whereas in 1910 little more than one-third of the total number of bottles set adrift throughout the year was despatched from points within the Regional Areas D and E (Figure 1), considerably more than half of the work of 1911 was carried out in those areas. In consequence, it is to be expected that, of the total number of recoveries resulting from the experiments of each year, the records for 1911 will include a greater proportion of British east coast returns than those for 1910. Actually, the reverse is the case, the percentages being 25·4 and 40·3 respectively.

On the basis of Fulton's well-known diagram of the general cyclonic surface water circulation of the Northern North Sea, it may be argued from the above facts that the westerly set, towards the British east coast, of the surface waters on the western side of the North Sea, was considerably less in 1911 than during the previous year. This matter is of fundamental importance to the ensuing analysis and is therefore investigated in greater detail at this stage.

A study of Tables III. to IX. and also, for information relative to the Regional Liberation Area A, of the Table of Data,* shows that, as regards 1910, an appreciable number of the British east coast recoveries emanated from liberations outwith the Regional Areas D and E. In percentage form the following table gives, in respect of each year and area, the ratio of the British east coast recoveries resulting from the liberations performed within the Area to the total return for the year.

* Appendix to *Fisheries, Scotland, Sci. Invest.*, 1930, II.

TABLE XXIV.

	D	E
1910 . .	7·3	20·1
1911 . .	9·2	15·4

The combined percentage for 1910 is thus still in excess of that for 1911, but, from the above figures, the anomaly of the latter year would appear to be restricted to the experiments begun in the Regional Area E, and hence to the coastline south of Rattray Head, Aberdeenshire; for Table VI. shows that no bottle from the Regional Area in question stranded on the western shores of the North Sea to the north of this headland. Yet another distinguishing feature of the results for the two years, however, although in great measure directly associated with the above, precludes the exclusive affirmation of this statement regarding the British east coast recoveries of 1911.

A significant proportion of the corresponding recoveries accruing from the 1910 experiments took place upon the eastern shores of the Orkney and Shetland Islands, including Fair Isle. (These are the returns which, in the majority, refer to liberations outwith the Regional Areas D and E.) The same contingency is much less evident in the 1911 records, as can be seen from a perusal of Tables III. to IX. In fact, in the latter year, only eight drifters were picked up on the above shores, as against 35 in 1910. Thirty of the 1910 recoveries belong to experiments begun in the month of May in that year and reference to the cartographical analysis of this month's results (Figure 9) will show the peculiar system of surface water movement which evidently accounted for the majority of these returns. Now in May 1911, practically the same regions were visited for the purpose of liberating drift-bottles, as a year previously, but, although the total percentage return is almost identical with that for 1910, namely, 25 per cent., no similar concentration of recoveries on the eastern shores of the Orkney and Shetland Islands resulted from the second year's experiments. The anomaly of the comparative dearth of British east coast recoveries during 1911 may therefore be extended to include the two groups of islands to the north of the mainland of Scotland. Incidentally, it should be noted in approaching the cartographical analysis of the 1911 records, that the surface water circulation apparently characteristic of the North-Western Area of the North Sea in the summer of 1910 does not appear to have been repeated a year later.

With regard, however, to the Regional Liberation Area D, in Table XXIV., the excess of the 1911 percentage of British east coast returns over the corresponding ratio for 1910 is yet to be explained.

In connection with those British recoveries already discussed it will be observed that the shores of the Moray Firth remain specifically unmentioned. A glance at Table V., column 4,* shows that, from liberations in Area D.during 1910, only one bottle stranded on the Moray Firth coastline, whereas, in the next year, no fewer than 17 drifters were returned from this district. Consequently, in view of the above inferences relative to a pronounced easterly trend of at least off-shore surface waters on the western side of the North Sea during 1911, it is doubtless from experiments inaugurated *and completed* within this bight of the Northern North Sea that the 1911 percentage in Table XXIV. is derived. This is the more readily understood when it is recalled that the 1910 analysis demonstrated the existence of a small gyratory movement of the surface waters in the inner reaches of the Moray Firth (the Moray Firth Eddy), with which the above-mentioned easterly trend of the more open-sea waters in 1911 would probably not interfere to an appreciable degree.

A final point of difference between the east British coast records for the two

* For the significance of column numbers see pp. 13 and 14 of *Fisheries, Scotland, Sci. Invest.*, 1930, II.

years concerns the southerly limit of recoveries on the western North Sea seaboard. From the 1910 experiments two drifters were found on the English coast south of latitude 54° N. No such record appears among the 1911 data.

The above evidence pointing to a marked " carry-away " of the surface water from the western side of the Northern North Sea during 1911 leads to the examination of the Continental recoveries, upon which, it appears, much of the interpretation of the 1911 records will depend.

In relation to the scarcity of British east coast recoveries from the second year's experiments, it will be recognised that an alternative to a larger proportion of strandings upon the eastern shores of the North Sea is, that the bulk of the 1911 returns came from the higher latitudes of Norway. It will be well, therefore, to know in the first place what proportions of the total recoveries for each year were effected on eastern North Sea shores (north to Lat. 62° N.), including in this category strandings upon the Danish, Swedish and Norwegian coasts of the Skagerak. These quantities, in percentage form, are given in the following table under the appropriate Regional Liberation Areas.

TABLE XXV.

EASTERN NORTH SEA AND SKAGERAK RECOVERIES.

Percentages of Total Returns for Each Year.

	A	B	C	D	E	H	J	K	M
1910	0·7	2·0	1·0	10·2	2·6	2·0	4·0	0·7	9·6
1911	0·0	0·4	0·7	18·0	4·4	11·8	5·1	0·7	2·9

There are two major contrasting features of Table XXV. which are worthy of fuller treatment.

Relative to liberations carried out to the west and north of Shetland, Orkney and the Outer Hebrides (Areas A, B and C) the proportion of 1911 drifters which finally beached upon eastern North Sea and Skagerak shores is decidedly less than that recorded in respect of the previous year. Tables III. and IV. show that the same applies to the British east coast returns emanating from these areas, although, it must be observed, actually fewer bottles were " laid down " in the second year. Nevertheless, the region was visited in the months of May and August in both years and the anomaly is quite appreciable, especially as regards the Regional Area B. Alternative explanations are possible and their consequences are to be borne in mind in the cartographical investigation of the histories of the bottles in question.

Either, as regards 1911 in contrast to 1910, a proportionately smaller number of drifters from the region to the west of Orkney and Shetland found access into the Northern North Sea, or, in the second year (1911), conditions were less favourable to the stranding of drifters upon North Sea or Skagerak shores. The latter hypothesis is conclusively refuted by the entries in Table XXV. under the North Sea Regional Areas.

On the basis of the former explanation, especially with reference to the Regional Areas A and B for which the above anomaly is greatest, it would appear as though, once again, in the superficial stratum at least, a direct current-connection by way of the channels separating Scotland from Shetland, between the waters of the Faroe-Shetland Channel and the North-Western Area of the North Sea, could not have been maintained for any length of time between the months of May and possibly September 1911. It is on record, however, that several drifters liberated in Regional Areas B and C during May and August 1911 cruised into the Northern North Sea. Their routes, therefore, doubtless lay through the southern reaches of the Norwegian Sea, thence southwards into the North Sea between Shetland and Norway. In this connection it is significant that, *in both years*, drifters were found on eastern North Sea or Skagerak shores which originated within the Regional Area K, thus suggesting a similarity in at least the *direction* of flow of the surface water drift over the northern edge of the Continental Shelf.

To return to Table XXV., a second significant feature of the data given there is, as indicated above, the relatively greater number of recoveries effected on the eastern side of the North Sea as a result of the 1911 liberations in all North Sea Regional Areas, excepting Areas K and M. A further comparison of the results for the two years, treating the recoveries in more detail, yields valuable information. The comparison may be based upon Tables I. to XI., the material of which is classified according to specified sections of the entire coastline upon which recoveries were effected. The data relevant to the present discussion are extracted from these tables and rearranged in Table XXVI. Both the numerical return and, to serve as a guide, this value as a percentage of the total recoveries for the year, are given in respect of each year and coastal section.

TABLE XXVI.

Eastern North Sea Coastal Sections.	1910 Experiments.		1911 Experiments.	
	No. of Recoveries.	Percentage of Total Return.	No. of Recoveries.	Percentage of Total Return.
Mouth of River Elbe to Blaavandshuk	21	6·9	2	0·7
Blaavandshuk to Hantsholm .	20	6·6	23	8·5
East of line joining Hantsholm and Lindesnaes, *i.e.* Skagerak shores	52	17·2	69	25·0
Lindesnaes to latitude 62° N. .	6	2·0	26	9·6

The most striking characteristics of Table XXVI. are the disparities between the numbers of recoveries which took place, firstly, on the Danish and Schleswig-Holstein coasts south of Blaavandshuk and secondly, on the Norwegian coast between Lindesnaes and latitude 62° N., that is, practically on the North Sea section of the Norwegian coast. The differences between the returns from these two coastal districts, it will be observed, are in opposite senses.

The fact that fewer 1911 bottles stranded on the coast between the mouth of the River Elbe and Blaavandshuk than was the case in regard to drifters liberated the year before, might, at a first reading, be correlated with the like result that several 1910 bottles were beached somewhat farther south on the English coast than were any of the recoveries from the second year's liberations. On the assumption that, in its broader features, the surface water circulation of the Northern and Middle North Sea Areas was essentially the same in both years, the joint circumstances might be taken to denote the operation in 1911 of a cyclonic circuit of smaller longitudinal dimensions than those which characterised the same system a year earlier. The suggestion receives a measure of support from the second great anomaly of Table XXVI., namely, the excess of 1911 recoveries over those registered in 1910, on the Norwegian coast between Lindesnaes and latitude 62° N. As will be shown, however, in the final section of this report, another explanation, based on certain indications afforded by the analysis of the 1910 material, can be advanced in relation to the latter phenomenon.

Moreover, a closer scrutiny of the 1910 data reveals the important fact that none of the 21 recoveries on the Danish and Schleswig-Holstein coast took place in the year 1910 at all. The two southernmost English coast recoveries belonging to the experiments of that year and effected south of latitude 54° N. occurred in the month of July 1910, but the earliest record from the above part of the Continental coast was dated the 29th of January 1911. Between this date and the 16th of March, seventeen 1910 bottles were picked up in the same region. These 17 bottles were set afloat between the middle of May and the middle of June 1910, mainly on the western side of the Northern North Sea. All of them were despatched north of latitude 57° N. and west of longitude 2° E. In only one case can it be said that the bottle was put out within the compass of an eddy movement. In other words, these drifters were liberated in the early summer of 1910 in " straight " streaming waters, which, according to the analysis of contemporaneous records for the region concerned, were flowing with a velocity of at least 12 miles per day. Notwithstanding, the above 17 drifters undoubtedly were held up *at sea* for no less than seven or eight months. The question of their having lain upon the beach for any length of time hardly arises, on account of their numerical strength, coupled with the degree of consistency evident among their drift-periods. The latter point is especially remarkable as these periods are of such great magnitude.

There can be little doubt that the above circumstances have an intimate bearing upon the surface drift of the North Sea generally in the first months of 1911. Fortunately the Scottish experiments were begun early in that year, the liberations carried out during the month of February 1911 covering a wide area of the Northern North Sea. As will be evident later, an explanation is forthcoming, from the analysis of these and other results for the year, of the concentration of 1910 bottles washed ashore in the south-eastern corner of the North Sea during the above-mentioned seven weeks. In passing, it may be well to observe once more that the first three months of 1911 are notable for yet another concentration of recoveries of 1910 drifters, namely, on the shores of the Skagerak.

The second point of difference presented by the data of Table XXVI. is, as already indicated, the increase in the number of returns recorded from the south-western coast of Norway as a result of the 1911 liberations. In discussing the obvious scarcity of 1910 strandings upon this coast, it will be recalled that an apparent characteristic of the Great Northern North Sea Eddy, as regards the issue of drifters from its dominant influence, was cited by way of explanation. Arguing " backwards," as it were, the 1911 results suggest some radical difference in the effective operation of this eddy in that year. This matter also should be noted in approaching the cartographical analysis of these records.

Recoveries on the Danish coast between Blaavandshuk and Hantsholm on the north-west corner of the Jutland peninsula were almost numerically equal in the two years under review. Skagerak returns from the 1911 experiments show a slight increase over those pertaining to 1910 and the only point which may be further looked into now is whether a " blank " period, similar to that noted in respect of the last quarter of 1910, occurred in the year following. This is the purpose of Table XXVII.

[TABLE XXVII.

TABLE XXVII.

1911 *LIBERATIONS.*

Time-Distribution of Skagerak Recoveries.

Month of Liberation.	Month of Recovery.											
	1911 Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1912 Jan.	Feb.	Mar.
February . .	4	10	2	5	2	1	—	2	1	—	1	3
March . .	—	—	—	—	—	—	—	—	1	—	—	—
April . . .	—	—	—	—	1	2	3	2	—	—	—	—
May . . .	—	—	—	—	—	1	3	1	—	—	—	1
June . . .	—	—	—	—	—	1	1	1	—	—	—	—
July . . .	—	—	—	—	—	2	1	6	—	—	—	—
August . .	—	—	—	—	—	—	—	3	—	—	—	—
Totals . .	4	10	2	5	3	7	8	15	2	—	1	4

As stated above, numerous Skagerak recoveries were registered in the first three months of 1911. Table XXVII. clearly demonstrates that this class of return was well maintained throughout the remaining months of the year, with a tendency to fall off in December. The two December returns were made on the 10th and 11th days of the month respectively, one from Lindesnaes and the other from just a few miles east of that point—really hardly within the Skagerak at all. The single recovery tabulated under February 1912 was effected on the 29th day of that month, so that this instance might be included among the March 1912 returns. Incidentally its drift-period embraced more than twelve months, the bottle in question having been liberated within the Regional Area E on the 11th of February 1911.

There would thus appear to have been a complete cessation of these Skagerak strandings, again over a period of three months, from the beginning of December 1911 until the end of February 1912. While this inference from the data is probably substantially true to fact too much stress cannot be laid upon it for the following reason.

The last liberations of 1911 to yield Skagerak returns were those of the month of August and although operations in the North Sea were continued in the next two months, no further Skagerak recoveries ensued. The work of September and October 1911, however, was carried out practically on the extreme western border of the Northern and Middle North Sea Areas. In these coastal regions local idiosyncrasies of drift play at times a predominant part, allowing few if any bottles to escape towards the open sea.

Nevertheless, in view of the system of surface drift which, according to the 1910 analysis, generally operates within the above areas as a whole, it is somewhat surprising to find that, although the liberations of September 1911 in the area adjacent to the mid-east Scottish coast resulted in no less than 15 Norwegian coast recoveries between latitudes 60° and 70° N., no Skagerak return appears in the records of these experiments.

A final point, of no small significance, which arises from the data of Table XXV., is the previously noted peculiarity of the entries under the Regional Liberation Areas K and M, when these are compared with the corresponding figures pertaining to the remaining North Sea Regional Areas. As regards Area K the percentage return from eastern North Sea and Skagerak shores was the same in both years. Liberations in Area M, however, resulted in relatively fewer recoveries of this denomination in 1911 than was the case in 1910—just the reverse of the state of affairs noted in respect of liberations in Areas D, E, H and J.

Table II. furnishes the reason for this apparently singular difference as regards Area M, in that only one-sixth of the number of bottles there set adrift in 1910 was despatched in the same area in the year following. Nevertheless, in conjunction with other factors, it is unfortunate from the point of view of the interpretation of the 1911 records that the area in question was visited in only one month of that year and that so few bottles were set adrift. Moreover, none of the eight recoveries ensuing from the experiments begun there in July 1911 registered a drift-period comparable for brevity with the shortest of those recorded in respect of returns from the liberations of April 1910 over the Great Fisher Bank.

Among the other factors above referred to is the conjugate one of such a large share of the work for 1911 having been inaugurated in the Regional Areas on the western side of the North Sea, greatly diminishing the probability of the occurrence of a sufficient number of short-period Continental recoveries upon which to base the analysis of the others. It will be recognised that this is a crucial matter, affecting fundamentally the means of investigation as adopted in the analysis of the 1910 material. From the report upon that work it is evident that, for a satisfactory interpretation of drift-bottle records on the lines given, at least a limited number of relatively short-period returns, fulfilling the rôle of " indicators " as to the scheme of things in a specified area and for a particular epoch, is essential.

Briefly, it may be stated that, in a preliminary survey of the 1911 material, the deficiency in this respect was found to be so pronounced as to necessitate a modification of the method of analysis as applied to the 1910 data. Eventually there was devised a method which is really an amplification of that utilised in the earlier examination and one which tends to an even more detailed and exacting analysis of the records.

As already mentioned the method which has been adopted in these analyses of drift-bottle records rests fundamentally on the short-period return which can be relied upon to give a fairly accurate estimate of the average direction and velocity of the bottle's drifting in the interval between its despatch and recovery. Having in mind the numerous complexities in the surface water circulation apparently characteristic of the Northern and Middle Areas of the North Sea, not all *relatively* short-period returns can be accepted as guides to the system of drift prevalent at a particular time. Accordingly, in the case of the 1911 results, the earliest and most dependable record from which these particulars could be deduced was sought and the derived velocity-estimate entered upon a *time-velocity diagram* constructed on the basis of the 1910 results. From the curve so obtained and subject to certain limiting assumptions suggested by the data, other velocities were evolved and tested by their fitness to elucidate the histories of longer-period and, in part, contemporarily drifting bottles.

Before entering upon the actual practice of the method, however, it will be necessary first of all to furnish the following addendum to the 1910 report :—

ADDENDUM TO THE REPORT * UPON THE 1910 DATA.

From the primarily significant returns upon which the analysis of the 1910 material is based it is possible with the aid of certain assumptions to construct a time-velocity curve.

* ***Fisheries, Scotland, Sci. Invest.*, 1930, IV.**

The first assumption is that the selected instances be taken to represent the surface water circulation of the Northern North Sea as a whole and the second, that the mean velocity estimated for the epoch embraced by the drift-period of each recovery was, in fact, the actual velocity of the surface drift on the mid-date of that epoch.

Only such instances are selected which involve no repeated retrogression in the routes followed by the bottles and which to all appearances are normal. With the requisite data for the construction of the curve (Figure 19), these instances are given in Table XXVIII.

TABLE XXVIII.

Unique Time-Velocity Data for 1910.

Liberation Station.	Drift-Period of Recovery. Days. (*a*)	Inclusive Dates of (*a*). Day/Month. (*b*)	Mid-date of (*b*). Day/Month.	Estimated Mean Velocity. Miles per Day.
$\text{April}_{10}1$ . .	22	13/4– 5/5	24/4	10·9
$\text{April}_{10}2$ . .	24	15/4– 9/5	27/4	11·0
$\text{May}_{10}1$ . .	14	11/5–25/5	18/5	12·5
$\text{May}_{10}4$ . .	28	12/5– 9/6	26/5	12·7
$\text{May}_{10}49$ . .	13	30/5–12/6	5–6/6	12·7
$\text{April}_{10}6$ . .	51	9/6–17/6*	13/6	12·75
$\text{June}_{10}1$ . .	10	15/6–25/6	20/6	12·5
$\text{August}_{10}1$.	207	8/8–29/9†	3/9	8·0
$\text{September}_{10}1$.	71	27/9– 7/12	1/11	6·5
$\text{December}_{10}1$.	4	7/12–11/12	9/12	5·0
$\text{December}_{10}8$.	57	8/12– 3/2	5–6/1	5·5

It is, of course, obvious that, in the cases of the longer-period bottles of 1910—those which for the most part are tabulated throughout the report and which are analysed on the basis of the velocities derived from the short-period "indicators"—the above principles cannot be applied with the same degree of accuracy. By treating with greater precision the periods represented by the various sections of the estimated routes, however, an attempt is made in the ensuing analysis to elucidate the history of every really significant recovery in conformity with a time-velocity curve. This applies mainly to drifters which were delayed in their sea-passages by reason of eddy influence.

* * * * * * *

Cartographical Analysis of the 1911 Records.

The cartographical analysis of the 1911 records may now be proceeded with as before by treating each month's experiments separately in the first instance. As, however, the preliminary survey of the data clearly demonstrated that the interpretation of the results accruing from the February liberations depended upon the construction put upon those registered in respect of the following month and as the latter results, independently, are more conclusive on the whole than the former, the

* Only that part of the route between the point A (Figure 4) and the point of recovery.

† From the liberation station to the southern end of the Fladen Ground (Figure 11).

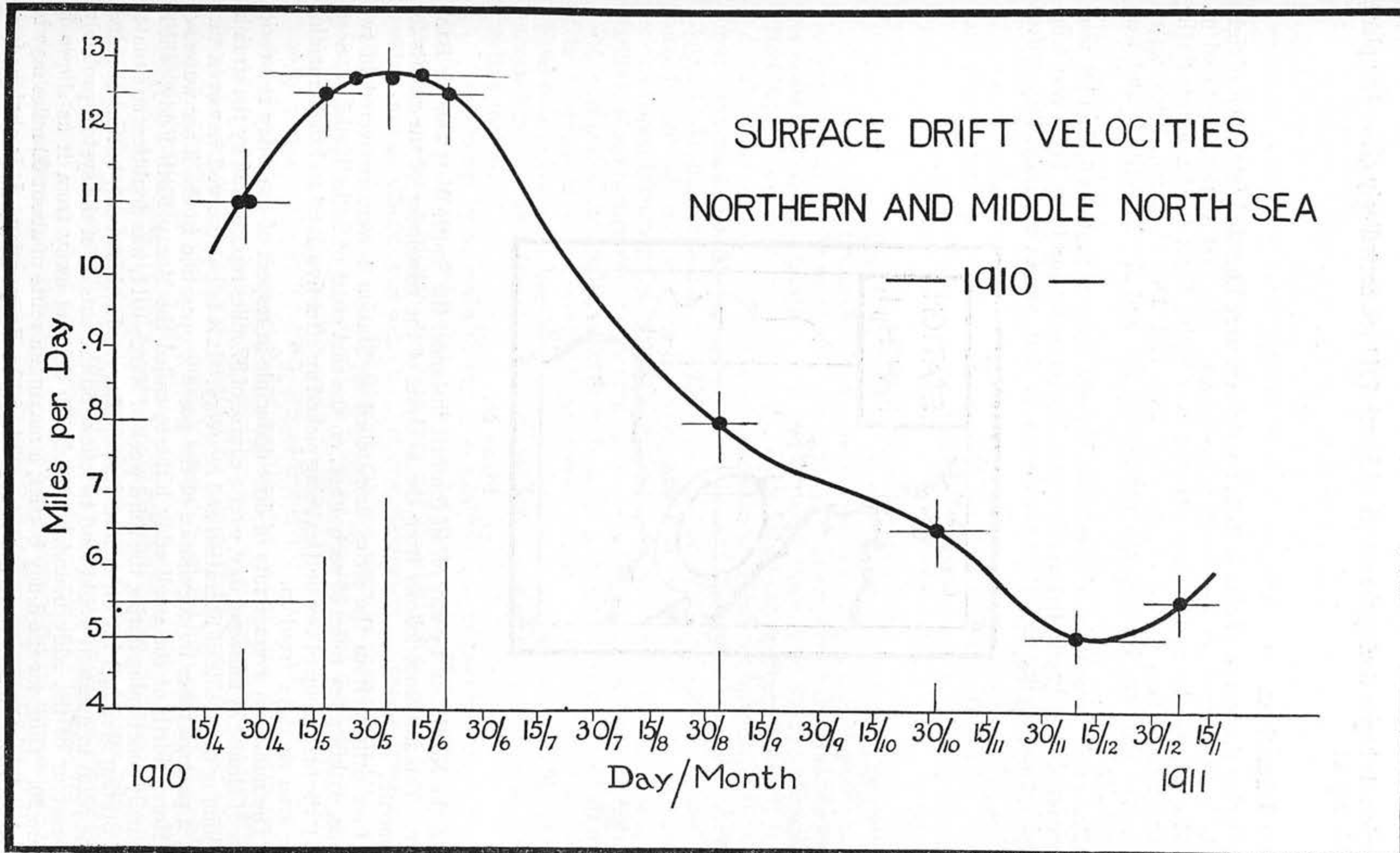


Figure 19.

N.B. Reproductions on squared mm. paper of this Figure and Figure 32 are given in pocket of cover.

experiments begun during the month of March 1911 are accordingly given first place in this report.

March Liberations.

During the month of March 1911, ten drifters were liberated from each of eight points in the waters off the Scottish east coast. The first station, operated on the 14th day of the month, was situated over Smith Bank in the Moray Firth; the remaining seven, visited on the 21st, 28th and 29th of March, being distributed over the area between the parallels of 56° and 57° N. latitude and west of longitude 1° W.

From only three series of liberations, namely, those at Stations 6, 7 and 8, were recoveries ultimately effected on other than British coasts and these, being very long-period bottles, require no further comment save that, almost certainly, they drifted

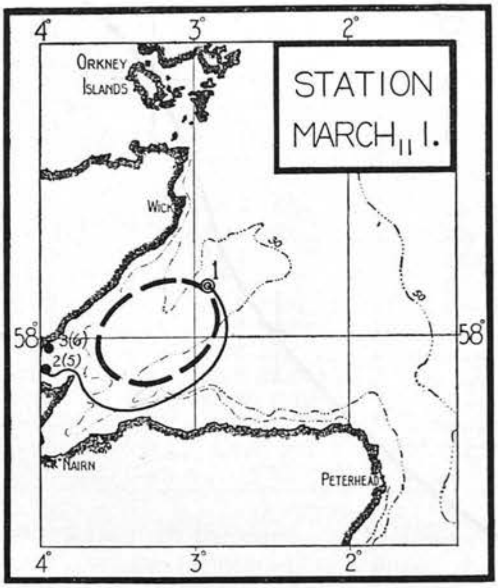


Figure 20.

across the North Sea by way of, in the first instance, the South-West Dogger Bank Eddy. This inference follows from the analysis of the remainder of the results for the month.

Five drifters from the series despatched at Station 1 were recovered in two groups, within a few miles of each other, on the east coast of Sutherlandshire, Scotland; the first group of two bottles being picked up after five days' and the remaining three after six days' freedom.

The minimum average rate of drift deducible in respect of the 5-day recoveries is one of almost $7\frac{1}{2}$ miles per day, over a course of 37 miles represented by the straight line joining the points of liberation and recovery. It is to be observed, however, that such a passage takes no cognisance of the possible operation in the inner waters of the Moray Firth of the small eddy hitherto called the Moray Firth Eddy, which, if actually functioning during the third week of March 1911, was doubtless so situated that Station March$_{11}$1 lay on or near its periphery. In this event, bottles liberated at the point in question would tend to follow, on the outside of the system probably, the contour of the eddy boundary, gradually drifting away from it as shown in Figure 20. Thus, for the 5-day bottles, a maximum route of about 60 miles may be postulated, entailing an average drift-speed of 12 miles per day. It is obvious from the chart how, on the latter hypothesis, a further 12 miles might be accomplished in the extra day by the three drifters found at Golspie.

It will now be demonstrated that the acceptance of a velocity of the above order of 12 miles per day is essential to the satisfactory explanation of the British coast recoveries accruing from the liberations at Stations $March_{11}2$ to 6.

The recovery during April and the first week of May 1911 upon the British east coast between the mouth of the River Tay and Holy Island, Northumberland, of 26 drifters which originated at Stations $March_{11}2$ to 6, is interesting in comparison with the result of an experiment begun in the same area some six weeks previously. From the earlier series of liberations only one bottle stranded, also in April, upon the British east coast, the remainder apparently being carried away from the western side of the North Sea.

The February bottle was beached near Whitby on the Yorkshire coast, that is, just outwith the limit of Figure 21. The March bottles, on the other hand, stranded somewhat farther north than this and, with reference to the localities of their stranding-places, they fall into two groups. One batch, comprising 12 bottles belonging to the series despatched at Stations 3 and 4, was returned from the vicinity of Holy Island, while the other group, made up of 14 drifters from Stations 2, 5 and 6, was found on Fife Ness and the section of the Haddingtonshire coast between Cockenzie in the Firth of Forth and Skateraw, a few miles south of Dunbar. This division of the recoveries into two groups corresponds with the longitudinal disposition of the liberation-stations, the more northerly group of recoveries resulting from the westerly or coastal liberations (Stations 2, 5 and 6), while those from the neighbourhood of Holy Island emanated from the more seaward stations, numbers 3 and 4.

The suggestion implied by these circumstances is that the histories of the drifters from Stations 2, 5 and 6 are distinct from those of the bottles set afloat at Stations 3 and 4. It may be said at once that, on these premises and with due regard to the maintenance of consistency in the mean direction and velocity of the surface drift in the region involved, the cartographical reconstruction of the routes of the several drifters is impracticable. The source of the difficulty lies in the fact that both short and long-period recoveries occur in each of the above-defined groups of strandings. The contemporaneous parts of these periods cannot all be accounted for, on the basis of a uniform rate of drift, by routes which do not seriously conflict with one another in time and direction, thus transgressing one of the fundamental concepts of this analysis.

By analogy with much of the 1910 analysis and in consideration also of the limited extent of the entire area embraced by those of the March 1911 experiments presently under discussion, the fact that the recorded drift-periods cover a fairly wide range is indicative of some form of complication in the courses pursued by the drifters. The instance of the February bottle recovered only in April along with the above March bottles supports this inference. By the same analogy the influence of an eddy system immediately suggests itself and it will be recalled that the examination of similar records for 1910 demonstrated the existence, under ordinary circumstances, of a closed anticyclonic circulation in at least the surface waters of the area under survey. The eddy, or swirl, has in fact been referred to as the Mid-East Scottish Coast Eddy and is represented, on Figure 15 for instance, as an elliptically-shaped system, the major axis of which extends from the latitude of Fife Ness nearly to that of Aberdeen.

Now a feature of the 1910 analysis was that conclusions regarding the existence of an eddy in any region traversed by drifters were arrived at from a consideration of the drift-periods involved. Depending upon the availability, or otherwise, of a unique record from which an estimate of the direction and velocity of the drift can be obtained, two distinct cases arise. With a velocity-estimate upon which to base calculations, few records are generally required to demonstrate the operation of an

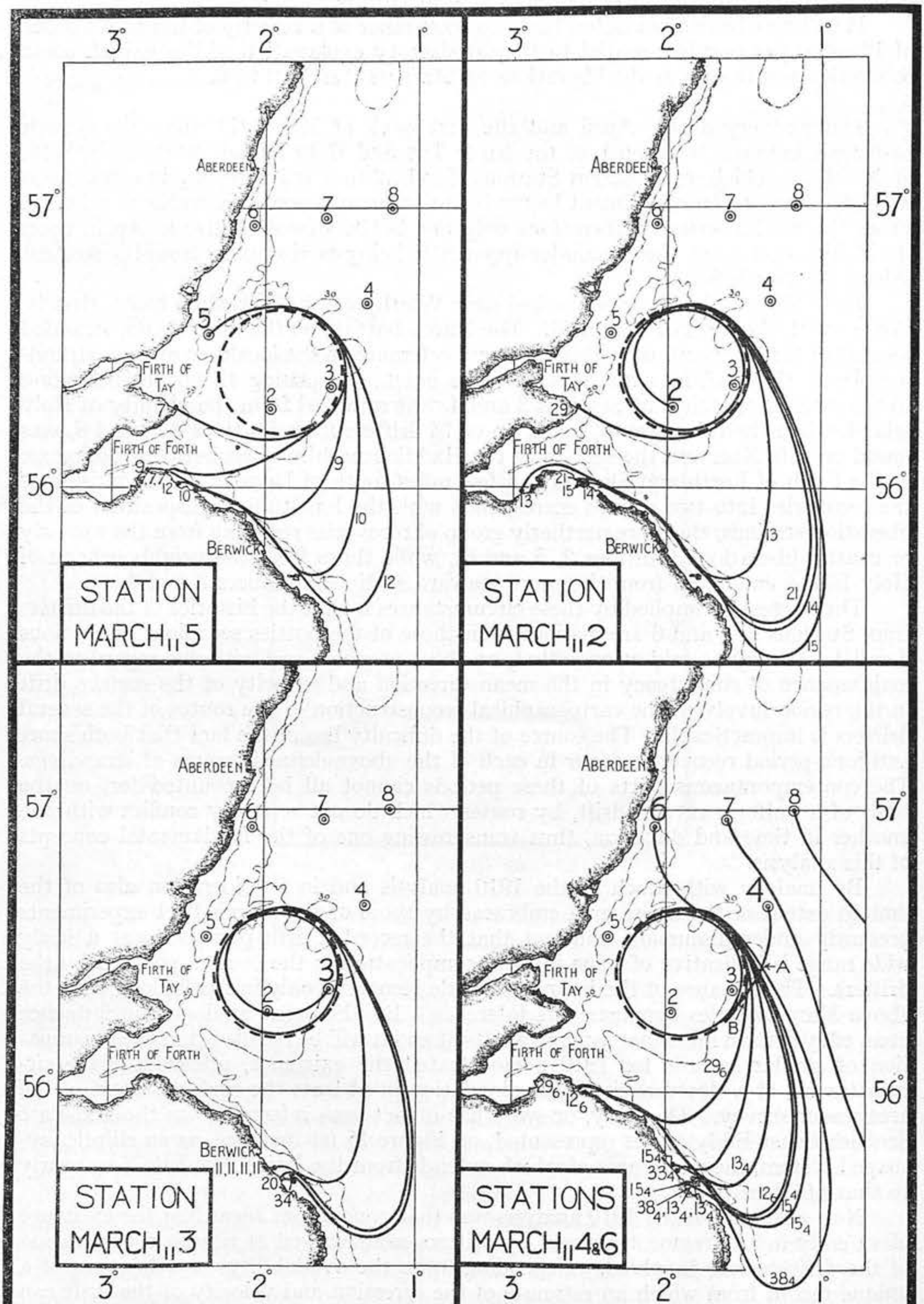

3°
2°
1°
57°
56°
ABERDEEN
FIRTH OF TAY
FIRTH OF FORTH
BERWICK
STATION
MARCH11 5
STATION
MARCH11 2
STATION
MARCH11 3
STATIONS
MARCH11 4&6

Figure 21.

eddy. On the other hand, as under the present circumstances, where no vector can be directly obtained, more numerous returns are necessary to establish the existence of a swirl in the area through which the drifters have passed. Provided this condition is fulfilled it is generally possible to observe traces of some system in the times of stranding of the bottles concerned if their sea-passages have been appreciably influenced by a gyratory movement.

We are thus led to examine the returns from the March 1911 experiments from the standpoint of the relative magnitudes of their drift-periods.

First of all, consider the two Fife Ness strandings. It will be observed that the shorter drift-period is *seven* days, and that the difference between the two drift-periods is 22 days, or three weeks practically. In actual fact only *two weeks* separate the dates upon which these recoveries took place, since liberations at Station 2, from which the longer-period bottle originated, were carried out eight days in advance of those performed at Station 5. Even this difference of two weeks, however, the orientation of the respective liberation-stations relative to Fife Ness is insufficient in itself to explain.

Nevertheless, these considerations suggest something not altogether fortuitous in the times of stranding of the two bottles in question. A similar indication is conveyed by the drift-periods, taken in order, of all five Station 2 returns. It seems significant that, no less than twice, an interval of about *one week* should elapse between successive strandings from liberations at Station 2, especially since all the recoveries concerned took place in the region of the entrance to the Firth of Forth, that is, within 20 miles of one another. Again, in respect of liberations at Station 3, all the recoveries from which were concentrated about the vicinity of Holy Island, there occur two intervals between successive strandings, one of *nine* days and the other of *fourteen* days. Among the Station 4 results also, this factor of weekly intervals is quite apparent. Averaging the first four drift-periods and subtracting the result from the mean of the two last periods the difference is, within half a day, *twenty-one* days. The six bottles were again found in close proximity to one another.

Obviously some systematic complication in the routes taken by the drifters is indicated by these investigations and from previous knowledge this complication may be put down to the Mid-East Scottish Coast Eddy.

To carry the analogy of the 1910 analysis still further the above-mentioned common factor of one week, or seven days, may be taken meantime to denote the quantity which has been termed the *Period of Circuit* of the complex, that is, the number of days required by a bottle to cruise once round the system. In this connection there is one amongst the March 1911 returns which is highly significant, to all appearances establishing the validity of the above inference. This is the 7-day Station 5 recovery (7_5) on Fife Ness. Observing the position of Station 5 and assuming in the adjacent waters the existence of an approximately circular eddy, the circumference of which passes close to the position of this liberation-station, it is evident that the swirl could have been of such a size that the bottle found on Fife Ness would have regained the vicinity of its starting-point in seven days had it continued to cruise round the periphery of the system instead of " sheering off " towards the land.

Even, however, if these conditions be accepted as applicable in the present case we are still not in a position to proceed far with the examination of the March 1911 records. Some idea of three important characteristics of the eddy must first of all be obtained. These are (i) its position at the time of these experiments ; (ii) its plan or shape ; and (iii) its superficial area. All three factors are in greater or less degree dependent upon the mean surface drift-velocity at the time and it has already been remarked that a reliable vector is not directly deducible from the data under consideration. Assuming, however, that an estimate of the drift-velocity has been obtained, several observations can be made in relation to the above factors concerning the Mid-East Scottish Coast Eddy.

As regards the position of the system at the time in question a first clue has already been given by the above argument relative to the 7_5 recovery on Fife Ness. Within limits, the position of the swirl is defined by the route pursued by this bottle, the length of the route depending of course upon the velocity of the bottle's passage. But other three 7-day recoveries are recorded against Station 5. All three bottles stranded at the same place on the *south* side of the Firth of Forth estuary and therefore, no doubt, followed the same route. Clearly, then, the swirl must have been so placed that the two routes from Station 5, one to Fife Ness and the other to the vicinity of North Berwick, were equal in length and there is reason to believe that appreciable sections of these routes were coincident. This narrows down the possible limits of the eddy's position very considerably. The simplest solution of the problem of the two courses is that the bottles concerned approached the Firth of Forth from a point to the eastward of its entrance, this point to be regarded also as the point of divergence of the two routes. Consequently, it may be taken that the southern limit of the circulatory system was marked approximately by the latitude of May Island, which is situated some six miles southward of Fife Ness.

In estimating the shape of the eddy there are two features of the data which, in conjunction with the relative positions of the liberation-stations concerned, should be taken into account. Firstly, it is to be observed that the most easterly station from which drifters apparently cruised into the complex is Station 4; and secondly, that no drifter from Station 7 seems to have participated in the gyration. The latter circumstance practically rules out the elliptical eddy represented on Figure 15, despite the fact that drifters belonging to Station 6 are to be included among those affected by the complication. From these considerations it is deduced that the plan of the swirl was approximately circular during the month of March 1911. Evidence derived from later experimental results for the year again points to this conclusion in respect of a later period.

Lastly comes the question of the size or superficial dimensions of the swirl. It is immediately obvious that, without an evaluation of the velocity of the drift in conjunction with the Period of Circuit of seven days, this characteristic cannot readily be estimated. Falling back upon the analysis of the Moray Firth coast recoveries from Station $\text{March}_{11}1$, it is there indicated that the drift-velocity lay between the values of $7\frac{1}{2}$ and about 12 miles per day. It will be made clear in the sequel that, within very narrow limits, the acceptance of a mean velocity of 12 miles per day is essential to a satisfactory account of the 26 returns from the British coast south of the River Tay.

On this basis and with due observance of the foregoing conditions, Table XXIX., in conjunction with the appropriate curves on Figure 21, furnishes the histories of the bottles in question. The figure is divided into four sections to obviate confusion among the curves.

TABLE XXIX.

MARCH 1911 *LIBERATIONS.*

British East Coast Recoveries south of River Tay.

Recovery.	Number of Complete Circuits of Eddy.	Total Mileage of Course.
13_2	0	156
14_2	0	168
15_2	0	180
21_2	1	252
29_2	3	348
$4(11_3)$*	0	132
20_3	1	240
34_3	3	408
$2(13_4)$	0	156
$2(15_4)$	0	180
33_4	3	402
38_4	3	456
$4(7_5)$	0	84
9_5	0	108
10_5	0	120
12_5	0	145
12_6	0	144
29_6	3	348

Taking into account the axiom relating to cross-drifts which underlies the whole of this work, the directional consistency of the various courses given on Figure 21 might be questioned as regards the entry into the Mid-East Scottish Coast Eddy of the Station 4 drifters, apparently in opposition to the drift indicated by the routes taken by some of the earlier escapes from the dominant influence of the swirl. In order to test this point the courses of all bottles to the line AB were measured and the dates calculated upon which, at a speed of 12 miles per day, the several drifters would cross this line. The Station 4 drifters would pass over the region in question on the 29th or 30th of March and, except for the three earliest returns from the Station 2 series, it can be shown that none of the other 23 drifters would cross AB before the 2nd of April. Even the three short-period Station 2 returns, however, do not conflict with the Station 4 bottles, because, on the same basis, the line AB would be crossed on the 26th of March, thus leaving an interval of three or four days, during which, there seems no reason to doubt, the direction of the surface drift in the small area concerned altered temporarily in the manner indicated by the graphical results of these investigations. In other words, concerning the small sea area about the line AB, the above results show a small oscillatory motion in the direction of flow of the surface drift-stream on the eastern boundary of the eddy, from about southerly on the 26th of March to south-westerly some two or three days later and back again to a southerly flow on the 2nd of April. Apparently it is to this oscillation and perhaps also to a shifting of the swirl that the division of the stranding-places into two groups is to be attributed.

At this stage there arises an important point bearing upon the above accepted speed of the drift off the east coast of Scotland during the months of March and

* *i.e.* **Four bottles originating at Station 3 and returned after 11 days each.**

April 1911. Arguing from a drift-speed of a little less than 12 miles per day an eddy of correspondingly smaller circumference would of course follow. To the same extent the lengths of the routes assigned to the four shortest-period Station 5 recoveries would be diminished. Nevertheless, although these two factors are taken to be directly associated—the charting of the routes leading at once to the placing of the swirl—it is evident that the above changes do not necessarily affect the *position* of this system as gauged by that of its centre. From the standpoint of the present discussion then, the important consequences of these conditions are that, while the routes of the Station 5 drifters to the new region AB would be shorter, those of the Station 4 bottles would be longer than denoted on the chart, Figure 21, thus tending to the convergence of the dates upon which the bottles in question would cross one another's tracks. On the strength of the axiom relating to cross-drifts such a position is untenable.

On the other hand, the interval between the two events might be increased by increasing the speed of the drift taken as a basis for measurement and calculation, but here again a limit is set by those of the Station 2 drifters which, without completing a circuit of the Mid-East Scottish Coast Eddy, proceeded southwards from the area across which the Station 4 bottles passed into the southern periphery of the circulation. This limit can be put at about 12½ miles per day.

Before passing from these results to the examination of those pertaining to the experiments of February 1911, it may be observed that a feature of Figure 21 is the implication of a coastal drift northwards along the coasts of Northumberland and the south-eastern Scottish counties to the Firth of Forth estuary. The recovery of a February bottle on the 10th of April at Whitby on the Yorkshire coast suggests that this anomaly, as part of a larger system of surface drift having its nucleus in the Mid-East Scottish Coast Eddy, extended southwards at least as far as the mouth of the River Tees.

* * * * * * *

February Liberations.

Series of five, ten and, in one instance, twenty bottles were set adrift between the 10th and 19th days of the month from 18 points in the North Sea to the west of longitude 2° E. and between latitudes 56° and 59° N.

In respect of two stations no returns are recorded. Only one drifter is known to have stranded upon the British east coast. This fact is somewhat remarkable in view of the positions relative to the Scottish coast of at least six of the liberation-stations which are set out in Figure 22.

The above phenomenon, associated with the results of the experiments launched in the month of February 1911, furnishes the first indication for the year of the pronounced easterly trend of the surface waters from the western side of the Northern North Sea, as deduced from the preliminary statistical treatment of the data forming the Introduction to this analysis.

The distribution of the Continental recoveries is as follows :—

West Danish and Schleswig-Holstein coasts south of Blaavandshuk	2
West Danish coast between Blaavandshuk and Hantsholm	12
North-West Danish coast between Hantsholm and the Skaw	13
West Swedish coast north of latitude 57° 30′ N.	14
South Norwegian coast, east of Lindesnaes	6
Norwegian coast between Lindesnaes and latitude 60° 10′ N.	2
Norwegian coast north of latitude 63° 30′ N.	3

Thus, more than half of the total number of bottles recovered as a result of the month's liberations were returned from within the Skagerak. Table XXX.

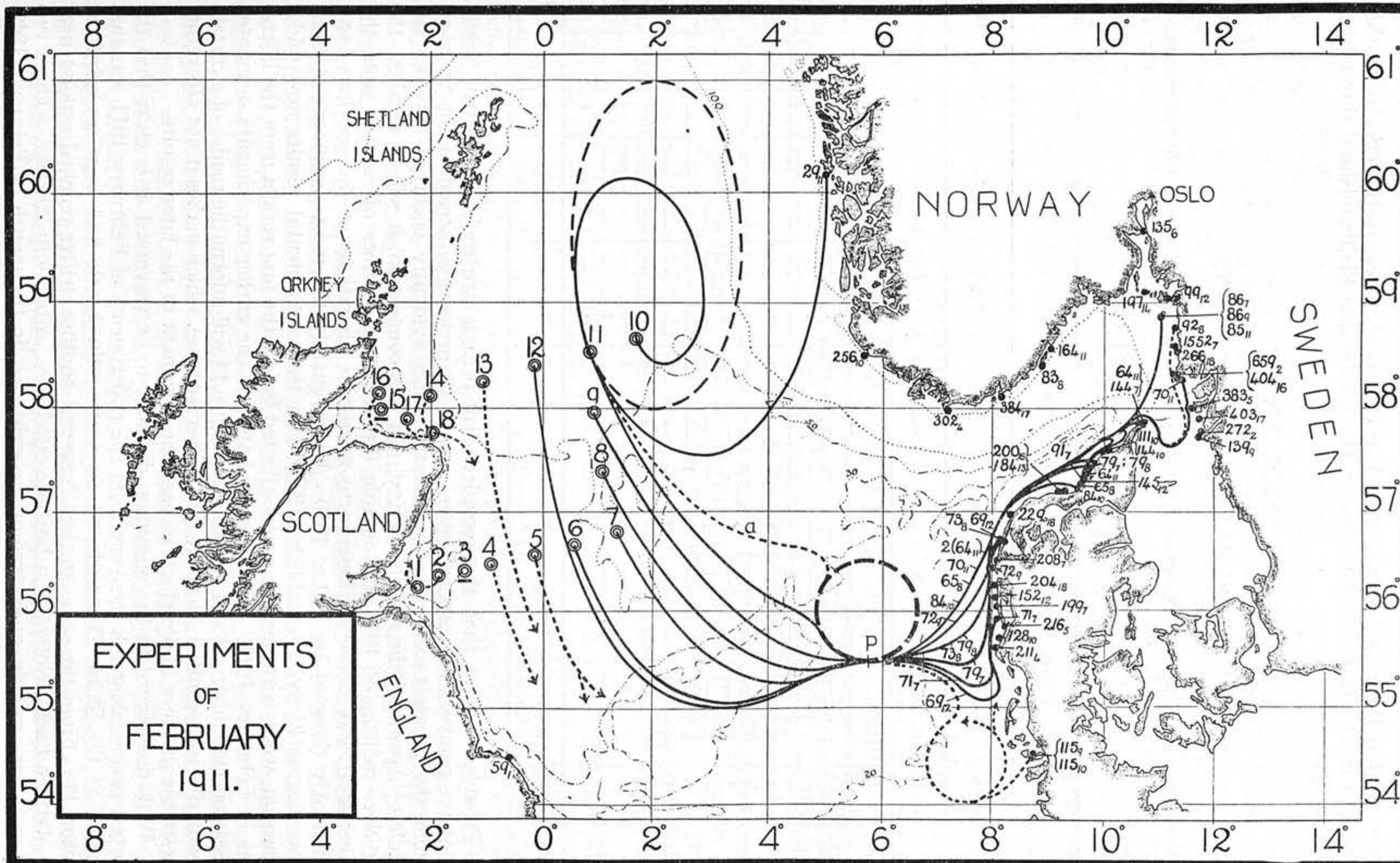

EXPERIMENTS
OF
FEBRUARY
1911.
SHETLAND
ISLANDS
ORKNEY
ISLANDS
SCOTLAND
ENGLAND
NORWAY
SWEDEN
OSLO
P

Figure 22.

gives to within 15 or 16 days the time-distribution of the recoveries effected in this region and on the Danish coast between Hantsholm and Blaavandshuk, throughout the year 1911.

TABLE XXX.

FEBRUARY 1911 *LIBERATIONS.*

Recoveries on Skagerak Shores and the West Danish Coast north of Blaavandshuk.

Time—Distribution.

Station No.	Period of Recovery.															
	Apr.	May		June		July		Aug.		Sept.		Oct.		Nov.		Dec.
	16–30	1–15	16–31	1–15	16–30	1–15	16–31	1–15	16–31	1–15	16–30	1–15	16–31	1–15	16–30	1–15
2	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
4	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1
5	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
6	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
7	1	3	—	—	—	1	—	—	1	1	—	—	—	—	—	—
8	2	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9	1	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—
10	—	1	—	1	1	1	—	—	—	—	—	—	—	—	—	—
11	3	1	—	—	—	—	1	—	—	—	—	—	—	—	—	—
12	1	—	1	—	—	2	—	—	—	—	—	—	—	—	—	—
13	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—
14	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—
16	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
18	—	—	—	—	—	—	—	—	—	1	—	1	—	1	—	—
Totals	8	9	1	1	2	5	1	1	2	5	—	1	—	2	—	1

Provided always that the recorded drift-periods are such in the true sense, the above recoveries are spaced over a very comprehensive period of the year, although the greatest concentration of strandings evidently occurred between the middle of April and the middle of May. In this connection, it will be recalled, the first *three* months of 1911 are notable for the large number of returns from the Skagerak area of bottles belonging to numerous liberations of the previous year, particularly those of December 1910. Unfortunately the most significant of these recoveries, as likely to establish a link with the experimental results now under discussion, were, with one exception, effected before the first return from the liberations of February 1911. The singular bottle of the earlier experiments originated at Station December $_{10}3$ and reference to Figure 14 will inform the reader of a certain irregularity in the initial stages of this drifter's course, which makes it not altogether a desirable instance upon which to base the argument of the later results.

With due regard to the minimum distance to be traversed, it is clear that the shortest-period Skagerak recovery from the experiments of February 1911 was that effected at the Skaw, Denmark, 64 days after the bottle had been set adrift at Station 11. From the same station, however, another drifter reached a point near the Marsten Light, Norway, in latitude 60° 10′ N., after only 29 days. These two instances are strongly suggestive of the existence, in the month of February 1911, of the Great Northern North Sea Eddy, Station 11 being situated on the south-western periphery of the complex.

The present records also show that, from the February liberations, other four short-period recoveries took place on the west Danish coast south of Hantsholm, as far as Lyngvig. It may be argued further, in the light of the experience of the 1910 analysis, that the longer-period bottles recovered on Danish, Swedish and south Norwegian coasts were probably delayed in course of their sea passages by the North-East Dogger Bank Swirl. This complex, then, was doubtless so situated that drifters passing immediately to the south of it, or emerging from it, during the month of April at least, approached the Danish coast about the latitude of 56° N. It may therefore be accepted, tentatively, that the centre of the eddy during the months of March and April 1911 was in the vicinity of the intersection of latitude 56° N. and longitude 6° E. In point of size regard is had meantime for the deductions arising from the experimental results of December 1910 (see Figure 14).

As a starting-point in the particular analysis of the February records the recovery effected near the Marsten Light, Norway, on the 13th of March 1911, may conveniently be taken.

From the work of Helland-Hansen (**10**) and Robertson (**11**)* it appears that, in general, sometime towards the end of one year, or in the first month or so of the next, there occurs a minimum in the momentum of the drift-stream flowing into the Northern North Sea from the region of the Faroe-Shetland Channel. It seems also that, at the same time, the superficial dimensions of the Great Northern North Sea Eddy are about a minimum. Towards the end of February a process of recovery is doubtless begun, as a general rule. As regards the year presently under review, however, and bearing in mind the corresponding facts of the 1910 analysis, the high velocity of 12 miles per day (derived from the analysis of the drift-bottle results pertaining to the month of March 1911 and applicable to the period between the middle of March and approximately the end of April) does not entirely support these contentions.

Following upon the possibility of a larger eddy circulation than that represented in Figure 22, which may be taken to define approximately the minimum extent of the system in 1910, the question of the position of Station $February_{11}11$ relative to it is resuscitated. It is reasonable to assume that, in the early part of the year, when the northward current along the Norwegian coast is doubtless at its narrowest, the Great Eddy is displaced eastwards of the position assigned to it on the above chart. Hence an enlargement of the area encompassed by the swirl need not mean that Station February $_{11}11$ was differently placed in relation to its periphery.

The position, then, as regards the postulation of a route in respect of the above-mentioned short-period recovery from the Station 11 series of liberations is similar to that of the short-period recoveries in the Moray Firth emanating from Station $March_{11}1$, in that the rate of drifting may have been anything from $7\frac{1}{2}$ to something less than 12 miles per day. If, however, the deductions arising from the analysis of the March records can be accepted as applicable to the Northern North Sea generally during the period of about six weeks immediately following upon the recovery of the above-mentioned February drifter, it is clear that the drift-speed in this particular case must have been greater than the lower of these limits and doubtless somewhat less than the higher figure. Along with an extension of the curve (Figure 19), the March results may be utilised to arrive at an estimate of the rate of the drift at the time in question.

The two last points of the curve are reproduced in Figure 32, which is to be found on page 79. Taking the 5-day recoveries from Station $March_{11}1$ and applying

* **Bracketed numbers in heavier type refer to the List of Publications, *Fisheries, Scotland, Sci. Invest.*, 1930, II, p. 30.**

the principles governing the construction of Figure 19, the average velocity of 12 miles per day may be looked upon as the actual velocity of the surface drift in the Northern North Sea area on the 17th of March 1911. This point is entered on the diagram and the curve continued from the preceding point, the abscissa of which is the date, 6th January 1911.

Now, the mid-date of the period of drift of the 29-day Station $\text{February}_{11}11$ return was the 27th of February. From Figure 32 the surface drift-velocity on this date was practically $9\frac{3}{4}$ miles per day. Moreover, according to the curve, the acceleration of the drift throughout the full interval of 29 days beginning 12th February 1911 was very nearly uniform ; so that the above vector can be taken as equivalent to the mean rate of drift of the bottle in question over its entire course between the liberation-station and the stranding-place. On this basis the appropriate curve on Figure 22 is constructed, measuring to scale approximately 280 miles. It is here, in the shape of the curve, that the significance of the postulate concerning the position of the Great Eddy at the time of these experiments is appreciable.

Turning now to the Skagerak returns resulting from the February liberations we have already seen from Table XXX. that, although in the main the actual dates of recovery involve the eight months between the middle of April and the middle of December 1911, a concentration of these strandings occurred in the latter half of April and the first two weeks of May. In passing, it is to be observed that these early returns, 17 in number, belong to the liberations carried out at Stations 7 to 12.

The three earliest records are of two Station 11 bottles and one from Station 8, found on the same day, the 17th of April, at three different places on the north-west coast of Denmark between Hantsholm and the Skaw. In none of these instances does a route by way of the southern boundary of the North-East Dogger Bank Eddy (without, however, becoming definitely involved in the circulation) yield an estimate of the mean velocity of the drift nearly approaching that recorded by the curve (Figure 32), for the mid-date of the drift-period. These dates are respectively the 16th of March for the Station 8 bottle and the 16th-17th March for the two belonging to the Station 11 series.

According to the velocity-curve, which at its present stage does not go beyond the latter date, the surface drift-velocity at this time was 12 miles per day. Obviously, unless the velocity continued to be uniformly accelerated after the 17th of March at the same rate as during the previous four or five weeks, the 12 miles per day vector cannot, in the above three cases, be accepted as an expression of the mean rate of the drift between the 11th or 12th of February and the 17th of April, the dates of despatch and recovery of the three bottles in question. All depends upon events after the 17th of March 1911.

Referring back to the analysis of the 26 British coast recoveries accruing from the liberations at Stations $\text{March}_{11}2$ to 6, it is there shown that, within narrow limits, an average vector of about 12 miles per day yields a sound practical explanation of all 26 returns. The recorded drift-periods range from 7 to 38 days, embracing the six weeks between the 21st of March and the 5th of May 1911. It follows, therefore, that the mid-dates of the 26 drift-periods also involve an appreciable interval of time, namely, the three weeks from March 28 to April 17, during which, apparently, any variation in the surface drift-velocity was comparatively slight. This velocity, it is already deduced, was approximately 12 miles per day on the 17th of March, so that, from the gradient of the velocity-curve prior to this date, the vector characteristic of the above period of three weeks ensuing 28th March was doubtless of somewhat greater magnitude. It can be demonstrated graphically, by further treatment of the March experimental records on the same lines as in Figure 21, that this vector probably did not attain $12\frac{3}{4}$ miles per day. After the 17th of April there is no immediate evidence to show whether a positive acceleration again set it, but the results of later experiments in the same year veto the suggestion entirely, indicating that, within the above three weeks interval, a maximum drift-velocity was registered.

Now, the time-range of the above 26 returns extended from 3rd April to 5th May, with a maximum number of recoveries between the 5th and 10th days of the former month. This space of six days occurs almost exactly midway between the 17th of March—the time co-ordinate of one of the cardinal points on Figure 32—and the 30th of April, the latter date covering, as it were, all but two of the 26 returns. Let it be supposed that there was some connection between the acceleration of the drift-speed and the dates of stranding on the British east coast and that, in the six days mentioned, the surface drift-velocity in the Northern North Sea generally attained a maximum of about 12·6 miles per day—almost the same maximum as, according to the analysis of the 1910 data, was reached in that year, although somewhat later in the season. Further, assume the velocity-curve to be symmetrical about this period as regards the arc subtended by the 12 miles per day ordinate. That is to say, the velocity of the drift was again 12 miles per day on or about the 30th of April 1911.

The practical analysis of those Skagerak and west Danish coast recoveries from the February experiments which took place on or before the first day of May 1911 can now be entered upon, assuming the position of the North-East Dogger Bank Eddy at the time to have been as laid down in Figure 22.

Apparently no drifter proceeded into the Skagerak by way of the sea area to the north of the above-mentioned circulation. All bottles from Stations 7 to 12 are to be regarded as having cruised for a time within the complex and, on escaping from it, as having passed eastward and north-eastward from the latitude of its southern limit. For each of the ten returns made prior to the 2nd of May 1911, a route by way of this region is entered upon Figure 22. In Table XXXI. are given the data pertaining to the accomplishment of the said routes, exclusive of circuits within the North-East Dogger Bank Eddy, at an average rate of 11 miles per day, arrived at in the following manner.

The drift-periods concerned may each be divided into two nearly equal portions by the date 17th March, the bottles in question having been liberated on the 11th or 12th of February. For the interval between these dates the gradient of the velocity-curve is practically constant ; so that for the first portion of the several drift-periods the mean rate of drift may be taken as equivalent to the actual velocity on the mid-date of the interval, namely the 28th of February. The vector for this date is 9·9 miles per day.

To obtain a mean velocity estimate for the second portion of the drift-periods, join by a straight line the points on the velocity-curve for which the abscissæ are 17th March and the appropriate recovery date, reading off on this line the ordinate corresponding to the mid-date of the interval. The value thus obtained is in the neighbourhood of $12\frac{1}{4}$ miles per day. Hence, for practical purposes, the mean of these two vectors, approximately 11 miles per day, may be regarded as an expression of the average rate of the drift of each bottle over its entire course.

[TABLE XXXI.

TABLE XXXI.

FEBRUARY 1911 *LIBERATIONS.*

Recoveries on Skagerak Shores and the West Danish Coast north of Blaavandshuk.

Histories.

Recovery. (*a*)	Course in Miles exclusive of Eddy Circuits. (*b*)	Time in Days to cover (*b*) at 11 Miles per Day. (*c*)	Residual Periods (Days). (*a*)−(*c*)=(*d*)
2 (64_{11})	480	44	20
70_{11}	555	50	20
72_{9}	335	30	42
65_{8}	485	44	21
73_{8}	345	31	42
79_{8}	420	38	41
71_{7}	325	30	41
79_{7}	425	39	40
69_{12}	535	49	20

Evidently, from the relationship of the higher to the lower quantities in the last column of Table XXXI., the North-East Dogger Bank Eddy was again characterised by a Period of Circuit of 20 days during the months of March and April 1911. It may be objected, on viewing Figure 22 that, in order to bring about this relationship, a certain manipulation in the latter stages of the courses of a number of the drifters appears to be necessary. These relatively small adjustments, however, have an underlying significance.

Arising from the data of Table XXXI. the routes followed by the several drifters may be divided into two main portions—(i) a *pro*gressive and (ii) to all intents, a *retro*gressive portion. The progressive part (i) may be further sub-divided into two sections ; the first, from the liberation-station to the point of entry into the North-East Dogger Bank Eddy and the second, from the point of emergence from that system to the stranding-place. To simplify the argument it will be legitimate to assume that all points of entry into and emergence from the swirl were coincident, say at P (Figure 22).

In each of the ten cases concerned the two sections of the progressive part of the route were, in point of time, interrupted by a period of about 20 or about 40 days. Consequently, on the basis of Figure 32, it must be concluded that, while for the initial sections of all ten routes, that is, to the point P, the mean velocities were practically the same, and likewise, although to a less extent probably, those for the final stages of the routes, the velocity difference between the two sections was quite appreciable. In practice, therefore, the progressive parts of the routes must be bisected at P in such a ratio as to show these equalities and this difference. At the same time the fundamental rule of directional consistency among the various curves is to be complied with. Table XXXIa, in conjunction with Figure 22, furnishes the solution to this problem.

[TABLE XXXIa.

TABLE XXXIa.

Recovery.	Course in Miles to P.	Mean Velocity to P.	Arrival at P.	Departure from P.	Course in Miles from P.	Mean Velocity from P.
$2(64_{11})$	255	9·7	Mar. 10	Mar. 30	225	12·5
70_{11}	255	9·7	,, 10	,, 30	300	12·5
72_{9}	235	9·6	,, 8	Apr. 17	100	12·5
65_{8}	220	9·5	,, 6	Mar. 26	265	12·0
73_{8}	220	9·5	,, 6	Apr. 15	125	12·5
79_{8}	220	9·5	,, 6	,, 15	200	12·5
71_{7}	200	9·4	,, 4	,, 13	125	12·5
79_{7}	200	9·4	,, 4	,, 13	225	12·5
69_{12}	350	10·2	,, 18	,, 7	185	12·3

Comparing the entries in column three of the above table with the ordinates of the points on the curve of velocities corresponding to the mid-dates of the intervals between the dates of liberation and arrival at the point P, it is found that these agree very closely. To obtain the dates of departure from the point P after one or two circuits of the eddy were accomplished, according to the data in the last column of Table XXXI., exactly 20 or 40 days are added to the several dates of arrival at P. Thereafter, on the basis of the 64_{11} recoveries mainly, the final stages of the courses from the point P are estimated so as to give mean velocities, for this part of the cruise, of between 12 and 12½ miles per day, thus conforming, within narrow limits, to the velocity-curve, Figure 32.

Further interesting features arise from the above operations, enhancing the value of the analytical results of Tables XXXI. and XXXIa. In the first place it will be observed that the chronological sequence of entries into the North-East Dogger Bank Eddy corresponds with the distances of the various liberation-stations from the point P. The dates of emergence from the swirl, taken in order, lead to an arrangement of another kind and to the elucidation of certain differences in the nature of the strandings upon the north-west Danish coast.

The earliest escape from the North-East Dogger Bank Swirl was that of the 65_8 return, for which drifter a fairly direct course into the Skagerak along its southern side is estimated, starting from P on the 26th of March. But, before being beached, it appears that this bottle cruised along almost the entire length of the north-west Danish coast into Tannisbugt where it doubled back, as it were, in closer proximity to the land and presumably under the influence of a narrow coastal strip of contrary-moving surface water.

This theory of a reversal of the surface drift current along the Danish coasts of Tannisbugt and Jammerbugt about the middle of April 1911 is supported by the relation to each other of the stranding-places of the two 64_{11} recoveries, which in fact were picked up on the same day as the 65_8 bottle. The stranding-places of all three bottles are widely separated, so that coincidence of discovery hardly enters into the question. The two Station 11 bottles, if they were together, are estimated to have set off from the point P in the same direction as, and four days after, the Station 8 drifter. On this basis, and assuming that the "twin" bottles still kept company, a coastal reversal of the surface drift to the north-east of Hirtshals explains the anomaly of the different stranding-places attained on the same day. Alternatively, the Blokhus bottle may either have lain upon the beach for a day or two or have been delayed in some other fashion—such as by taking the initial route *a* (Figure 22)—in course of its sea-passage, thus finally making a direct landing upon the Danish coast.

But the fact is that the same or similar assumptions in the case of the 65_8 drifter cannot be given effect in Figure 22 without seriously impairing the all-round consistency of the remainder of the results presently under discussion.

In regard to the 70_{11} return from Lysekil, Sweden, for which bottle a final route embracing a portion of the northern area of the Kattegat is inferred, an alternative route might conceivably involve an eddy movement in Tannisbugt or Jammerbugt. On the other hand, as will be seen when the results of the April 1911 liberations come to be examined, there seems to have been a tendency for some of the 1911 bottles to round the promontory of the Skaw and make a detour within the waters of the Kattegat, before proceeding northwards along and off the west Swedish coast.

Next in order of escape from the North-East Dogger Bank Eddy come the recoveries 69_{12}, 71_7 and 79_7, 73_8 and 79_8, and finally 72_9, the dates of emergence from P being the 7th, 13th, 15th and 17th days of April respectively, drifters belonging to the same liberation-series and spending approximately the same interval of time cruising within the complex, presumably emerging together.

In the same order consider the courses estimated to have been taken by these drifters immediately after their withdrawal from the point P. It is to be observed that, successively, these courses gradually diminish in curvature, pointing to some systematic waxing and waning influence upon at least the surface waters of the region concerned, between the end of March and the middle of April 1911.

In this connection, meteorological phenomena, particularly as regards wind strength and direction for the period and area involved, are of interest as no doubt having a bearing upon the suggested hydrographic variations at the sea surface. Following upon a week of mainly light easterly winds registered at Fanö Island off the nearby mainland, a strong north wind sprang up on the 3rd of April and thereafter, for at least ten days, although the velocity was seldom very high, the northerly component steadily predominated, with a tendency for the direction from which the wind blew to shift round from the north-east to north-west and latterly, about the 14th or 15th of the month, to west. The sea area in question sounds less than twenty fathoms, so that it is quite likely that persistent winds of even low velocity will have an appreciable effect upon the flow of the superficial stratum of water, as seems to be the case to some extent off the mid-east Scottish coast* and also in the southern bight of the North Sea.†

In relation to the two recoveries 79_7 and 79_8, of the above group, which took place on the north-west Danish coast on the 1st of May 1911, it will be observed from Figure 22 that direct landings are deduced, in contrast to the two returns, 64_{11} and 65_8, effected on the same coastal section on 17th April. That is to say, the narrow coastal reversal of the drift in Tannis and Jammer Bugten, apparently characteristic of the mid-month of April, was " corrected," as it were, by the end of the same month.

The above-discussed anomaly in the direction of the surface drift in the region to the west of Blaavandshuk doubtless explains two unique results of the month's experiments, namely, the recovery of two drifters, one each from Stations 9 and 10, upon Nordstrand Island on the 7th of June 1911.

Assuming a fairly close correlation between wind and surface water drift over the area in question it may be deduced that the hydrographic variation set in shortly after the 3rd of April and, from the instance of the 72_9 recovery, approximately normal conditions were evidently regained about the 17th of the same month. On this basis, the Nordstrand Island return pertaining to the Station 9 series of liberations does not fit too well into the scheme of things as ascertained by the above analysis, in that, theoretically, this drifter should have followed the same route from P as the 72-day bottle from the same liberation-series. It is conceivable, however, that the former bottle outstripped its fellow in course of two circuits of the North-east Dogger Bank

* *Fisheries, Scotland, Sci. Invest.*, 1930, IV. † J. N. Carruthers (2).

Eddy, escaping from the system at P a day or two in advance of it, thereafter deviating eastward and south-eastward into the German Bay. Alternatively, it may have completed a third circuit of the swirl before setting definitely away from it on or about the 7th of May and it is noteworthy that, at this period, northerly winds were again registered at Fanö and also at Cuxhaven. By analogy, therefore, with the above circumstances relative to the period following the 3rd of April, the Station 9 drifter ultimately recovered on Nordstrand Island may have proceeded south-eastwards from P about the end of the first week of May.

As regards the Station 10 drifter returned from the same locality, we have as yet no analysed record upon which to found the argument for the unique case, but, to avoid digression at this stage, it may be stated that, in this instance, a closer connection with the above phenomenon can be established, the bottle in question setting away from the point P on or about the 2nd of April 1911.

The question arises, however, as to the probability of these two Nordstrand Island bottles remaining in the region of the German Bay for periods of one and two months respectively. The only criterion by which this matter may be gauged is contained in a qualitative survey of the relevant wind data, for, as already pointed out, Böhnecke (**1**) formulated with reference to the winds, the conditions favourable and unfavourable to the functioning of a cyclonic eddy in the area concerned. From the Daily Weather Reports issued by the British Meteorological Office it is gathered that, throughout the months of April and May 1911, wind conditions were distinctly favourable to the existence of the German Bay Swirl until perhaps towards the end of the latter month, when southerly and south-easterly winds became fairly persistent, but it is to be noted that, on the day before the two recoveries were effected, fairly high north to north-westerly winds blew over the region about Nordstrand Island.

The inference that the above two drifters remained for such a long period in the same locality is further enhanced by the fact of there having been recovered on the west Danish coast south of the Thyboron Canal, on the 20th of June, the 14th of July, the 29th of August, and the 7th of September respectively four drifters belonging to three of the series of liberations already considered. As will be seen from the examination of the results of experiments begun in the month of April 1911, the southern limit of the North-East Dogger Bank Eddy was probably no farther south, towards the end of June, than latitude 56° N. and the drift-stream carrying bottles away from its influence apparently headed at once in the direction of the Skagerak. Hence, it would seem that the 128_{10}, 199_{7}, 152_{12} and 208_{7} drifters attained their respective stranding-places by way of a coastal current flowing northwards from the German Bay along the west coast of Denmark.

Before passing from the consideration of the results pertaining to Stations $\text{February}_{11}7$ to 12, and although the velocity-curve does not yet extend beyond the date 30th April 1911, some of the slightly longer-period drifters from these stations to Denmark and Sweden, particularly such as were found in the first half of May 1911, may be examined at this stage.

The first return from these shores after the 1st of May 1911 was that of the 84-day Station 10 bottle found at Tranum, Denmark. It also happens to be the one from the above-defined May group of recoveries which stranded at a point nearest to the point P. The position of Station 10 is, however, peculiar among the other liberation-stations of February 1911, being within the region of influence of the Great Northern North Sea Eddy. Obviously, in view of the course assigned to the shortest-period Station 11 recovery effected near the Marsten Light, Norway, a direct route towards either the North-East Dogger Bank Eddy, or the entrance to the Skagerak, cannot be accepted for the Station 10 bottles. Briefly, the following are the particulars of the route laid down on Figure 22 for the above-mentioned shortest-period return resulting from this series of liberations. It will be observed that the course is assumed to follow those of the Station 11 drifters from the position of that liberation-station.

Preliminary Analysis.

Drift-Period		**84** days.
Total progressive course	**705** miles ;	
which, at 11 miles per day, would occupy		**64** days ;
leaving to be accounted for by eddy influence . . .		**20** days.

Particular Analysis.

Inclusive dates of drift-period : Feb. 12 to May 7.		
Course to P	**525** miles ;	
which, at 10·8 miles per day, occupied		**49** days.
∴ Date of arrival at P, April 2 ; ∴ ,, ,, departure from P, April 22—		**20** days.
Course from P to Tranum	**180** miles ;	
to be accomplished in		**15** days,
at a uniform speed of **12·0** miles per day.		

The initial part of the course estimated in the above instance is quite in conformity with the likely effect of the Great Eddy gyration upon the behaviour of the bottle. Reviewing its history as given by the above details the drifter falls into line, so to speak, with the ten cases already discussed. Again, 20 days appear to have been spent in the performance of one circuit of the North-East Dogger Bank Eddy and, on emerging therefrom, the bottle in question evidently proceeded directly towards Hantsholm, the north-west corner of the Jutland peninsula, and thence eastwards to Tranum, covering this latter part of its course in 15 days at an average rate of about 12 miles per day.

It will be observed that the distance from the point P to Tranum was accomplished between the 22nd of April and the 7th of May, the mid-date of the interval being 30th April, for which day, therefore, on the lines of previous arguments, the above vector of 12 miles per day may be regarded as defining approximately the rate of the surface-drift in the Northern North Sea area. *The same result has already been arrived at from quite another source* ; so that the one corroborates the other

From the above record also, we may advance the velocity-curve beyond the 30th of April to the 7th of May, taking for granted that, in the short interval between the 22nd of April and the latter date, the surface-drift velocity was uniformly retarded. The ordinate of the new point is the vector 11·5 miles per day.

A further six February drifters were returned from the Skagerak region during the first two weeks of May 1911, four of them between the 5th, 8th and 9th days of the month inclusive, the remaining two on the 13th and 14th.

On 5th May a drifter belonging to the Station 8 series was picked up on Tromö Island off the south Norwegian coast. Presumably this bottle escaped from the North-East Dogger Bank Eddy in company with one or other of its fellows above detailed, that is, either on the 26th of March or on the 15th of April 1911. In the former case a route from P of not less than 480 miles was accomplished if time spent upon the beach is to be neglected and if the consistency of the numerous contemporary velocities is to be maintained. Such a course means that, either eddy movements in Tannis or Jammer Bugten retarded the progress of the drifter, or a wide circuit of the northern area of the Kattegat was made en route to Tromö Island. From the foregoing discussion relative to the earlier recoveries either eventuality is feasible as a consideration of the dates involved will make clear. If, however, two circuits of the North-East Dogger Bank Swirl were executed before the bottle in question set definitely away from P on the 15th of April, it is necessary to postulate an almost straight line course from the neighbourhood of Hantsholm to the stranding-place in order to be in keeping with the requirements of Figure 32 ; for, from P, the route followed would probably be the same as that laid down for the 73 and 79-day drifters belonging to the same series (measuring about 160 miles to the Hantsholm area) and the total mileage from P to Tromö Island cannot be assessed at more than 240.

On the 8th and 9th of May, three drifters, one each from Stations 7, 9 and 11, were picked up on Nord Koster Island, off the Swedish coast, in latitude 58° 54′ N. The Station 7 bottle probably left the point P on the 13th of April along with those from the same station for which drift-periods of 71 and 79 days are recorded, thus leaving 25 days for the accomplishment of the route from P to Nord Koster Island. Following the course of the 79_7 recovery from P to the vicinity of Hirtshals, thence more or less directly to its destination, a distance of about 310 miles would be covered in the time given at an average rate of exactly 12·4 miles per day, which estimate is somewhat high in consideration of the trend of the velocity-curve between the date of emergence from the North-East Dogger Bank Eddy at P and that of recovery upon Nord Koster. It is quite likely, however, that the bottle in question set more sharply north-eastwards from P, thus eliminating some 10 miles of the above distance and entailing an average drift-velocity of approximately 12 miles per day, more in keeping with the foregoing analysis. Similarly, the 86_9 return from the same locality fits into the general scheme, but as regards the 85_{11} bottle, either a double circuit of the North-East Dogger Bank Eddy was accomplished in less than 40 days, or some time was spent in eddy movements off the north-west coast of Jutland, or in the Kattegat.

A fourth return from the Station 7 series of liberations came from Lökken, Denmark, on the 13th of May, that is, 91 days after despatch. To assume that this drifter took off from the point P on the 13th of April, in company with either the 71_7 or 79_7 bottles, does not, on the basis of a mean drift-speed nearly approaching that demanded by the velocity-curve, account for the full 30 days due to the final stage of the route. On the other hand, the assumption of a third eddy circuit leaves only 10 days for the accomplishment of the distance from P to the stranding-place. Even giving effect to the indications of the experimental results pertaining to the month of April 1911, which suggest a slow northward translation of the North-East Dogger Bank Eddy as the season advanced, this distance was probably no less than 150 miles. An additional three or four days, however, allotted to this portion of the bottle's history, satisfies the argument of the curve of velocities and it will be conceded, in view of the length of the entire drift-period, namely, 91 days, coupled with the involutions of the estimated route, that this discrepancy is within the limits of error allowable in such an analysis.

Lastly, on Otterö Island off the Swedish coast, in latitude 58° 40′ N., a bottle was found on 14th May which originated at Station 8. A route similar to that devised for the 73 and 79-day Station 8 returns, taking in the northern area of the Kattegat, conforms to the requirements of Figure 32, in that a distance of 340 miles from P to the stranding-place would be overtaken at a mean rate of about $11\frac{3}{4}$ miles per day.

From the general appearance of the chart, Figure 22, particularly with reference to the directions of the curves from those stations already considered, it can be deduced with safety that bottles from Stations $\text{February}_{11}2$ and 4, perhaps also from Station 5, headed in the direction of, and became involved in, the *South-West* Dogger Bank Eddy. Moreover, from Station 2, the drifters concerned were no doubt held up for a time in the Mid-East Scottish Coast Eddy, which the sole recovery from Station 1 suggests to have been operative at the time. Circumstances in this region during March and April 1911 are fully investigated in the analysis of the results of experiments begun in the former month.

The above inference relative to the influence of the South-West Dogger Bank Swirl is supported by the fact that, as exhibited in Table XXX., the drift-periods of bottles from Stations 2, 4 and 5, recovered upon Danish, Swedish and South Norwegian Coasts, are much greater than those of similar returns made in respect of the more easterly liberations. The same applies to the Danish and Skagerak recoveries resulting from the liberations at Stations February$_{11}$13 to 18. Further examination of the results pertaining to those stations is vitiated at the outset by the fact that, almost certainly, in some cases, more than one circulatory system of surface-water movement had its effect upon the routes and consequently the drift-periods of the bottles concerned.

The almost total lack of returns from the British east coast, from all February liberations, has already been commented upon. From Stations 15 to 18, at least, such records were to be looked for. Reference to meteorological observations for the period and region concerned afford some explanation of their absence.

Stations 14 and 15 were operated on the 13th and Stations 16 to 18 on the 18th and 19th days of the month. For five days prior to the 13th of February 1911 the winds registered at Nairn and Aberdeen were on the whole from the south-west quadrant, although high velocities were seldom attained. But, on the 12th, these winds began to blow more strongly and consistently over the Moray Firth area and were maintained for quite a week, thus no doubt influencing the surface waters to such an extent as to cause them to leave the said area in a more or less easterly direction. There is no evidence to warrant an assumption on the lines of the deduction formulated on the results of liberations in this same region during the month of April of the previous year, when drifters left the Moray Firth along its north-western shore, heading in a north-easterly direction.

* * * * * * *

The results next to be considered are those belonging to the experiments begun during the month of August 1911, since, in the records compiled for the months between April and July inclusive, there occurs no single instance of recovery which, with reasonable assurance, can be utilised as a basis for further discussion.

August Liberations.

Throughout the month of August 1911, 125 surface drift-bottles were set afloat in groups of five, and on two occasions ten, from twenty-three liberation-stations, nine of which were situated within the North Sea between latitudes 58° and 61° N. and longitudes 0° and 2° E. Three stations in alignment lay immediately north from Flugga, Shetland, and the remaining eleven to the west of Orkney, Shetland and the Outer Hebrides.

A total of 24 returns from the following coastal districts are recorded against 17 stations:—

Shetland Islands	**1**
Orkney Islands	**3**
West Danish coast	**1**
West Swedish coast	**2**
Skagerak section of the Norwegian coast	**3**
Norwegian coast north of latitude 60° N.	**14**

The results of the month's liberations are remarkable for the number of short-period recoveries recorded as having taken place, not only on Shetland and Orkney shores from the liberation-stations situated west and south-west of these Islands, but on Danish, Swedish and Norwegian coasts, as far north as latitude 63° 31′ N., from several points in the Northern North Sea area and, in one isolated case, from a Faroe-Shetland Channel station.

The last-mentioned return is particularly fortunate. Without it, and not-

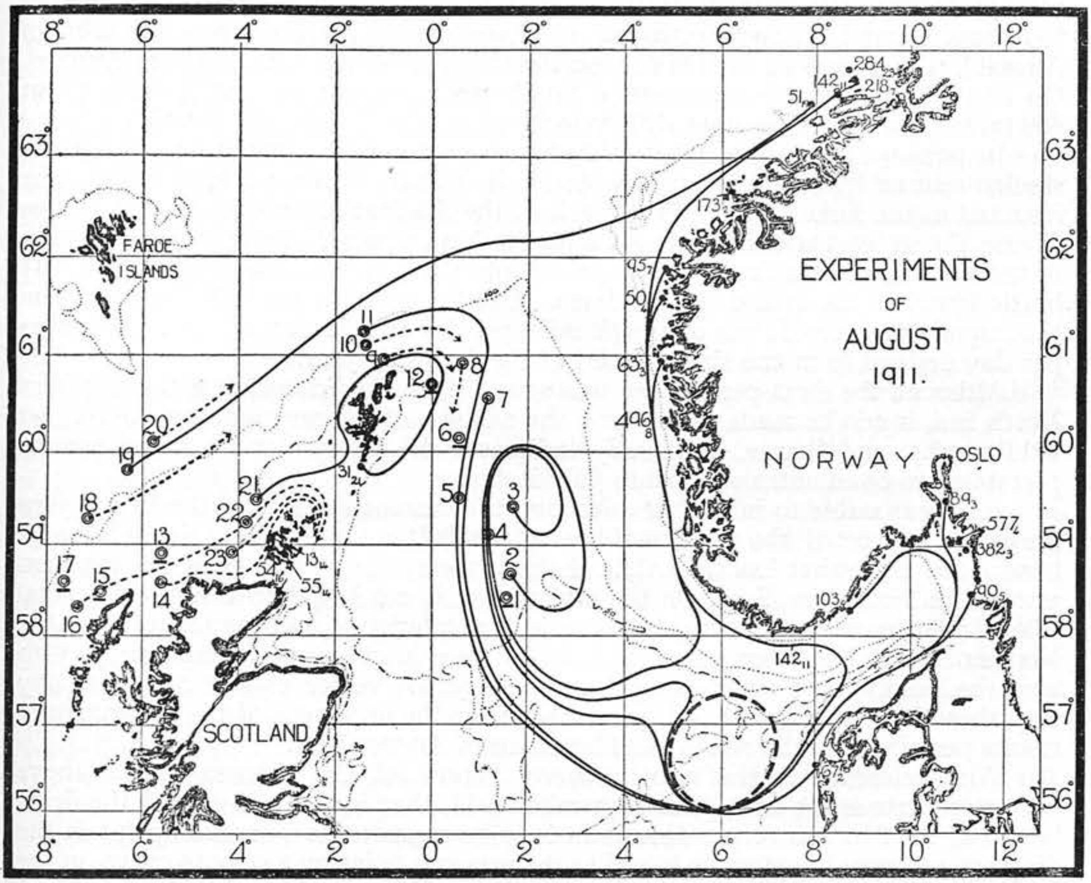


Figure 23.

withstanding the fact of there being other short-period recoveries pertaining to the experiments of August 1911, the analysis of the records for that month and, it may be added, the previous four months, must needs have been founded upon some arbitrarily chosen standard of velocity, which in its turn would doubtless have required considerable modification by the laborious and none too scientific process of trial and error. As it is, and for the reasons given below, this singular result furnishes a most convenient starting-point for the investigation of the August records and upon its interpretation also the detailed examination of the results of the April, May, June and July liberations indirectly depends.

From each of Stations August$_{11}$2 to 5 and 7, at least one drifter stranded on Danish, Swedish, or Norwegian shores within 100 days of the date of liberation. The magnitudes of these drift-periods, however, do not bear any obvious relationship to one another, such as, for instance, what might be called a geographical relationship, pointing broadly to the system of surface drift responsible for the order of their stranding. This circumstance indicates complexity in the courses of the drifters concerned, which is not surprising in view of the positions of the above-mentioned liberation-stations relative to the area which, in the corresponding season of the previous year, was encompassed by the Great Northern North Sea Eddy. In addition, and with reference to those August bottles subsequently found in the region of the Skagerak, the contingency of the North-East Dogger Bank Swirl is to be considered.

The short-period Norwegian coast recovery emanating from Station August$_{11}$19 is in a different category. There is little doubt that in this case an almost direct passage was made from the liberation-station in the mid-Faroe-Shetland Channel to Veiholmen Island off the Norwegian coast, occupying 51 days from the 23rd of August. A mean rate of drift of not less than 9 miles per day was therefore attained. On Figure 23 the curve representing this bottle's course measures to scale about 480 miles, entailing an average drift-velocity of nearly 9½ miles per day.

In passing, it may be noted that the above record is comparable with three similar returns from those experiments of the month of August 1910 which were initiated in the same region. From each of the Stations August$_{10}$2, 13 and 15 (see Figure 11), at least one drifter is estimated to have pursued an almost direct course to the Norwegian coast, stranding in practically the same latitude as the above 1911 bottle found on the Island of Veiholmen. But the speed of the drift deduced from the August 1910 records was only *eight* miles per day as against the vector of 9½ miles per day derived from the single record of the following year.

Although the short-period Station August$_{11}$19 bottle did not enter the Northern North Sea, it can be made to subserve the analysis of the remainder of the August 1911 results, and thence, as already indicated, the interpretation of the records pertaining to the months of April to July inclusive.

It is reasonable to infer that, although the current systems of the two regions are closely connected, the velocity of the surface drift in the Northern North Sea area is normally somewhat less than that of the contemporary drift across the southern area of the Norwegian Sea. On the other hand, it can be taken as a fairly general rule that in sea regions possessing oceanic characteristics, such as for instance the Northern North Sea basin, no event in which time is an essential factor occurs with a marked suddenness approaching instantaneity. A vector of nine miles per day may therefore be used with safety as a basis for the argument of the experimental results pertaining to the North Sea liberations of August 1911.

With reference to the velocity-curve, Figure 32, the abscissa of the above vector-ordinate is the date, 18th September 1911, that is, the mid-date of the drift-period of the 51_{19} recovery. This point is to be regarded as a cardinal point in the diagram and may therefore be joined to the previous point by a smooth curve, in the manner given. Using this curve as a guide, the problem now is to obtain a consistent explanation, firstly, of the August results and, thereafter, of the records compiled from the liberations of the previous four months.

At the outset, the two short-period recoveries emanating from Station August$_{11}$3 are significant in relation to the corresponding returns pertaining to Stations 2 and 4. One bottle from Station 3 reached Oslofjord in 89 days, whilst another was returned from Kvernö, on the Norwegian coast, in latitude 60° 57′ N., after only 63 days. On the above premises, that is, by applying the principles of Figure 32, it can be shown diagrammatically that the 63-day drifter did not enter the Skagerak in company with its fellow, if the longer drift-period of the Skagerak recovery is accepted as such in the true sense. Still less can a route by way of the Skagerak be advanced for the 50-day Station 4 recovery effected on Hillesöen, 40 miles north of Kvernö, Norway, and it is to be noted that no short-period *Skagerak* recovery resulted from the liberations at this station. Having regard, therefore, to the relative positions of Stations 3 and 4, it is evident that the bottles from the former point did not at once drift towards the Skagerak. The same holds in the case of the Station 2 drifters, despite the fact that one of them was returned after only 67 days from a point a few miles south of the Skagerak entrance. In contrast to the Station 4 results it is to be observed that no short-period *Norwegian coast* recovery is recorded against Station 2.

These considerations may be summarised briefly as follows. The Station 2 results include a short-period recovery in the region of the Skagerak, but none on the Norwegian coast about the latitude of 60° N., while, in regard to Station 4, the facts are in the reverse order. Station 3, on the other hand, claims a short-period return under each head and therefore occupies an intermediate position between Stations 2 and 4.

The practical solution of this problem is contained in Figure 23 and the several drift-velocities mentioned in the ensuing discussion will be found to lie close about the curve of velocities when plotted against the mid-dates of the drift-periods concerned.

The 50_4 recovery obviously pursued the most direct route of the above-mentioned four short-period returns from the North Sea liberations of August 1911. A course of 455 miles is represented on the chart. In 50 days this distance would be accomplished at a mean daily rate of 9·1 miles. Similarly, the 63_3 drifter may be regarded as having covered a mileage of about 570 at an average speed of 9 miles per day. The major part of this drifter's course is assumed to have been almost identical with that of the 50_4 bottle.

It were best now to give the analysis of the two Skagerak recoveries emanating from Station 5, for, from these results, the approximate size and position of the North-East Dogger Bank Eddy may be gauged. Routes by way of the southern limit of the complex measure 560 miles in the case of the 90-day return from Sweden and 665 miles for the 103-day recovery on the south-west Norwegian coast. At a mean velocity of 8·9 miles per day these distances would entail 63 and 75 days respectively, leaving 27 and 28 days to be accounted for. It is perhaps significant that these residual periods are almost identical, although their magnitudes are appreciably greater than that previously deduced as signifying the Period of Circuit of the North-East Dogger Bank Eddy, namely, 20 days. The larger period is substantiated by the analysis of the experimental results pertaining to the months of April and July, principally. In the summer of the year under review, the region of activity of the North-East Dogger Bank Swirl was considerably extended by reason of its coalescence with another circulatory system, operative sometimes as a separate entity in the waters off Lindesnaes. The latter circulation was named the Lindesnaes Eddy by Böhnecke (**1**), who first drew attention to the phenomenon of the coalescence of the two systems.

To revert to the Station 3 results the 89-day drifter subsequently found near the town of Moss in Oslofjord was doubtless somewhat separated from its fellow—the 63-day return—while on its southward passage under the influence of the Great Northern North Sea Eddy. The latter bottle apparently deviated a little more sharply eastwards across the North Sea between latitudes 57° and 58° N., just failing to come within the range of attraction of the North-East Dogger Bank Eddy, which undoubtedly directed the further progress of the 89-day bottle ultimately recovered in the Skagerak area. The swirl cannot, however, have definitely absorbed the bottle within its gyratory movement, since the route laid down on Figure 23 represents some 795 miles which would take up the full 89 days in its accomplishment at a mean daily rate of 8·9 miles.

Similarly the 67_2 bottle was probably only guided, as it were, by this complex, traversing a distance of 605 miles at an average speed of nine miles per day.

The only other recovery which need be considered at this stage is the 95_7 return from Skavö Island near Vaagsö, Norway, in latitude 61° 55′ N. Obviously, in view of the course estimated in respect of the drifters despatched from Station 5, this Station 7 bottle is to be regarded as having circumnavigated the North-East Dogger

Bank Eddy. It cannot further be held that its route lay by way of the inner waters of the Skagerak, since, to be in conformity with the above cases, this particular bottle must be looked upon as having cut across the entrance to the Skagerak, thereafter cruising northwards along the Norwegian coast. In this way a mileage of 850 would be covered at the mean daily speed of 8·9 miles.

The next group of returns to which attention is directed is that comprising recoveries on the Shetland and Orkney Islands.

The only Shetland recovery took place in Quendale Bay on the extreme south end of the mainland, 31 days after being floated at Station August$_{11}$21. In the light of previous deductions relative to the system of surface-drift apparently characteristic of the region midway between the Orkney and Shetland Islands, in the summer at all events, it may be inferred that this drifter cruised into the north-western corner of the North Sea by way of the west and north of the latter island group and it is to be noted as very relevant to the above result that, for two days prior to the discovery of the bottle, strong south-easterly winds blew over the district. The route given on Figure 23 measures to scale about 280 miles which, in 31 days, would be overtaken at a mean rate of nine miles per day, this vector complying with the curve of velocities.

Originating at Station 14 on the 21st of August a bottle was picked up 13 days later between Marwick Head and Brough Head on the west coast of the mainland of Orkney. At present it is possible to assume only a fairly direct route for this bottle, such as is indicated on the chart. The 90 miles there represented would thus be covered at an average velocity of nearly seven miles per day which, of course, hardly agrees with the findings above detailed. The vector, as read from the velocity-curve, should be 9·1 miles per day. By reason of this discrepancy in regard to the mean speed of the bottle's drifting the present record resembles the corresponding results obtained from the similarly placed liberations of August 1910, suggesting, in the first instance, some complication in the routes traversed between the region where liberations were carried out and the western shores of Orkney.

A similar explanation might be advanced in respect of the Station 16 drifter found upon the same coast on the 15th of October 1911, but the drift-period is a lengthy one and a third Orkney recovery (the second pertaining to Station 14) effected upon the same day but on a different part of the mainland, suggests that the former bottle may not have attained its stranding-place directly from the west.

It will be recalled that the results of certain experiments commenced during the months of May and August 1910 demonstrate that, on occasions, the waters in the immediate neighbourhood of the Orkney Islands gyrate with an anticyclonic motion round the group. It appears that such was the case during the six weeks between the beginning of September and the middle of October 1911. On this assumption the two longer-period August 1911 bottles above-mentioned no doubt set off from their respective starting-points—Stations 14 and 16—in a north-easterly direction, subsequently passing round the northmost of the Orkney Islands and thereafter cruising southwards in the near neighbourhood of their eastern shores, to be carried westwards through one or other of the channels between the various islands, or through the Pentland Firth, repeating the circuit probably twice.

The above explanation cannot be taken to cover the shorter-period Station 14 bottle, on the grounds of the inconsistent average velocity which would thereby ensue—this time in a positive sense relative to that given by the velocity-curve. The theory of complex surface water movements in the region west of Orkney is not therefore entirely discounted by the inference from the other two Orkney returns of an anticyclonic surface drift enveloping these islands.

All other recoveries from the August 1911 experiments took place in the higher latitudes of Norway and, for the most part, after very long periods of drifting. Doubtless the greater number of these pursued courses embracing the Northern North Sea, as can be gauged by examining the shortest-period return from among this group, namely, the 142_{11} recovery at Titran on the Island of Froya, Norway, in latitude 63° 40′ N. A course such as that indicated on Figure 23, at an average velocity of about 7·8 miles per day, would account for the traverse in 142 days of the distance of 1115 miles represented by the curve. The mid-date of the period of drift of this particular bottle was the 21st-22nd of October 1911, and plotting this point on Figure 32, it is found to lie in close proximity to those derived from the analysis of the recoveries consequent upon the liberations of October 1911.

* * * * * * *

From the foregoing analyses of the records evolved from the liberations of February and August 1911, the proposition arises of an accession to the area encompassed by the North-East Dogger Bank Eddy, occurring some time in the intervening period of five months. According to the interpretation of the February results, the swirl of waters usually functioning in the region off the north-east end of the Dogger Bank was, throughout at least the greater part of the month of April, of normal dimensions, as defined by a Period of Circuit of 20 days. The enlargement of the system prior to the end of August is inferred from the analysis of two records pertaining to the experiments begun in that month and the inference is substantiated by further evidence to be given forthwith.

It is also pointed out that this expansion of the circulatory complex of surface waters in the region to the west of the Skagerak entrance, in the summer of 1911, was doubtless due to the coalescence of two like systems. The phenomenon was deduced by Böhnecke from a study of temperature and salinity observations. For the year under present survey the event is deduced directly from drift-bottle data and, moreover, can be timed with remarkable precision.

As a first step in the working out of this proposition the records pertaining to the liberations of April 1911 are now considered.

April Liberations.

Between the 8th and 19th of April 1911, eight bottles were despatched from each of 16 stations in the region to the north of, and within, the Moray Firth. On the 25th, ten drifters were set afloat at a point about 20 miles due east of Fife Ness. Thirty-eight subsequent recoveries, representative of operations at 15 stations, are recorded, the various stranding-places being distributed as follows :—

From Stations 1 *to* 16.

Moray Firth shores between Tarbet Ness and Rattray Head	6
Mid-East Scottish coast	1
North-West Danish coast between Thyboron and the Skaw	5
East Danish coast	1
West Swedish coast	2
Norwegian coast south of latitude 59° N.	3
„ „ between latitudes 59° and 62° N.	10
„ „ „ „ 62° and 65° N.	6

From Station 17.

The east English Coast between Holy Island and Flamborough Head	4

It has already been remarked that none of the above recoveries can be made at once to subserve the analysis of the others. This point is clearly demonstrated by a consideration of the major features of the month's results before proceeding to their analysis on a more constructive principle.

With one exception, the six bottles picked up on the southern shore of the Moray Firth and the single recovery on the mid-east Scottish coast originated at Station 15, the exceptional case belonging to the Station 16 series of drifters. Both stations were situated within the area normally influenced by the Moray Firth Eddy and, apart from this complication, there is no suggestion, in the present data, of a system of surface drift embracing the entire North-Western Area of the North Sea such as was deduced from the experimental results of April and May 1910. The drift-periods, ranging from 32 to 72 days, registered by the above seven recoveries can therefore be taken as indicating only the activity of this local swirl during the months of April, May and June 1911.

As a direct outcome of surface drift-bottle experiments it may be said that one of the primary causes of derangement of surface drift systems over relatively shallow and landward sea areas is a change in the direction and force of the wind. Now the above inference argues the persistence of the Moray Firth Eddy for a period of at least ten weeks during which the winds over the area varied considerably, although moderate intensities were seldom surpassed. As conditions in this respect were similar for some weeks prior to the commencement of these April experiments, there is no apparent reason to doubt the existence of the swirl onwards from the first week of March, when its presence was inferred from the result of a single experiment launched on the first day of that month over the region of the Smith Bank. It is therefore the more remarkable that no Moray Firth coast recovery resulted from other liberations of the month of April 1911 than those carried out at Stations 15 and 16. This applies particularly to Stations 4, 5 and 6, in virtue of their close association, geographically, with the inner waters of the Moray Firth.

Likewise none of the four English coast recoveries ensuing from the liberations at Station $April_{11}17$ registered a drift-period upon the basis of which a direct route can be assumed. Here again an eddy system—the Mid-East Scottish Coast Eddy—was doubtless responsible for the contingency of fairly long periods of drifting and, once again, certain of the experimental results pertaining to the month of March 1911 afford an analogy. It is further of importance to observe in relation to these April results that, as regards the locality of the stranding-places, no similar return was made in respect of the more northerly liberations of the month. Evidently all bottles from Stations $April_{11}2$ to 13 drifted eastward across the North Sea, some to strand upon Danish, Swedish and Norwegian shores.

Turning, then, to these Continental recoveries, it is first of all to be noted that, with one long-period exception (318_5), no April bottle stranded on the Danish coast south of the entrance to the Skagerak. This fact of itself is important in view of the extreme westerly positions within the Northern North Sea of the liberation-stations concerned, suggesting, although perhaps not conclusively, on account of the magnitudes of the drift-periods entailed, that the drifters in question did not become involved in the South-West Dogger Bank Eddy in course of their passages across the North Sea.

In effect, however, conclusive proof *is* obtained when the above fact is considered in conjunction with another striking feature of the month's results, one to which attention has already been directed. Despite the practical significance of the foregoing deductions bearing upon the dynamical conditions, during April and May 1911, in the surface waters of the Moray Firth and the sea area adjacent to the British east coast almost as far south as Flamborough Head, Yorkshire, there is not a single record of a recovery in either region emanating from the series of liberations at Stations $April_{11}2$ to 13 inclusive. Moreover, since there exists no warranty for the postulation of a system of surface drift in the North-Western Area of the North Sea,

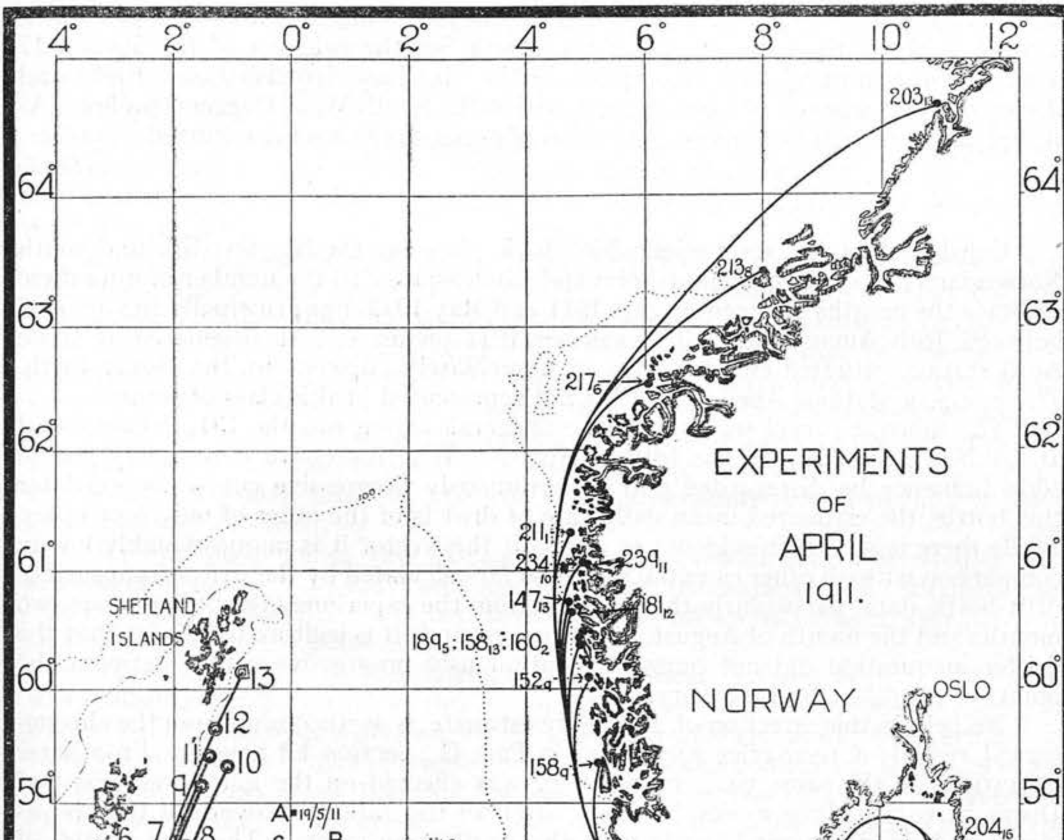

EXPERIMENTS
OF
APRIL
1911.
NORWAY
OSLO
SHETLAND
ISLANDS
DENMARK
A 19/5/11
B 24/5/11
C 10/6/11
D 14/7/11
E 14/7/11
P

Figure 24.

during April 1911, on the lines of that determined for the spring and early summer of the previous year, it may be accepted that the initial direction taken by the above April bottles was in the main a southerly one. Then, from off the north-eastern corner of Aberdeenshire, these drifters apparently deviated rapidly south-eastward and eastward, heading finally towards North Jutland. Had they first of all proceeded farther south on the western side of the North Sea the evidence of the Station 17 results is in favour of their absorption in the Mid-East Scottish Coast Eddy and thereafter, in a number of cases at least, within the South-West Dogger complex. As stated above the data afford no indication of either event having occurred.

Consider first the recoveries which took place on Danish, Swedish and south Norwegian coasts between Hantsholm and Lindesnaes. To the number of nine these embrace the months between August 1911 and May 1912, but principally the interval between 18th August and 9th November 1911 inclusive. All originated at those April stations situated either within, or immediately adjacent to, the Moray Firth. The group of stations $\text{April}_{11}9$ to 13 is not represented in this class of returns.

The shortest-period recovery in the Skagerak region was the 131_8 drifter found at Lökken, Denmark, on the 18th of August. If retrogressive movements due to eddy influence be disregarded and a continuously progressive course assumed for this bottle, the estimated mean daily rate of drift is of the order of only four miles. While there is no direct evidence to discredit this vector it is unquestionably low in comparison with all other essential values so far calculated by the writer from surface drift-bottle data, particularly those arising from the experiments of the previous two months and the month of August. On these grounds it is legitimate to infer that the drifter in question did not pursue a continuously progressive course between the points of liberation and recovery.

No help in this direction of a velocity estimate is forthcoming from the chronological record of recoveries mentioned in Part II., Section 1,* page 6. From later liberations in the same year, no recovery was effected on the north-west coast of Denmark within three weeks, before or after, of the date of recovery of the above-mentioned shortest-period bottle from the April experiments. The next bottles of contemporary origin to be picked up on Skagerak shores were found respectively on the 22nd and 25th of September. Between the 18th and 29th days of the same month six other drifters were returned from the north-west Danish coast. These were liberated at the points A, B, C, D and E (Figure 24) on the dates there specified. That is to say, the shortest-period recoveries in this locality during the second half of September 1911, although set afloat in the open waters of the Middle North Sea Area, were liberated more than two months beforehand. The influence of the North-East Dogger Bank Eddy is, of course, suggested, and the only conclusion to be arrived at in regard to the April bottles is that they too were held up in this complex along with others from both earlier (February 1911) and later liberations.

At the present stage, therefore, the furthest argument which may be advanced in regard to those April bottles subsequently returned from the Skagerak area is that their courses to the region of the North-East Dogger Bank Eddy were doubtless practically synchronous, since liberations at the stations represented by these returns, namely, Stations 4 to 8, were carried out almost simultaneously on the 9th day of the month. For further aid in the elucidation of the records, recourse must be had to the curve of velocities (Figure 32), constructed, so far, on the basis of the February-March results and those pertaining to the experiments of August 1911.

First of all arises the question of the position of the North-East Dogger Bank Eddy during the period embraced by the above experiments begun on the 9th of April.

By referring to the velocity-curve all the foregoing factors relative to the passages

* ***Fisheries, Scotland, Sci. Invest.*, 1930, IV.**

of the drifters concerned across the North Sea, it is readily estimated that these bottles from Stations 4 to 8 would reach the swirl area sometime about the mid-month of May 1911 and a comparison of Figures 22 and 23 suggests a more northerly orientation of the system at this time than that given on the former chart. Whatever translatory movements of the complex as a whole there may have occurred in the interval between the months of March and August 1911, the net result seems to have been small, so that, with reasonable certitude, it may be taken that the required position was very nearly as given on Figure 24. Until there arises evidence to the contrary the dimensions of the eddy will be defined by the Period of Circuit of 20 days deduced from the analysis of the February results. In passing, it may be observed that a like position and extent were assigned to this entity in the corresponding season of the previous year (Figure 3).

A simplifying factor adopted in the analysis of the February 1911 records may also be applied to those about to be examined. That is, all points of entry into and emergence from the above-mentioned circulation may be regarded as having been coincident, say at the point P, Figure 24. Again, however, it may be objected that, on this basis, the contingency of further translation of the entire complex in the interval between these two events is overlooked, but it will be clear from the analysis of the July 1911 results, which follows later, and also from Figure 23, which interprets cartographically the data relative to the August experiments, that this contingency can have been of little moment. Its effects would certainly be well within the limits of accuracy of this analysis.

Our starting-point is the shortest-period Continental return from the April experiments, namely, the 131_8 recovery at Lökken, Denmark, on the 18th of August. The history of this drifter were best investigated " backwards," as it were, from its stranding-place to the point of liberation.

From the point P to the stranding-place a linear distance of about 165 miles was doubtless accomplished in the manner suggested by the appropriate curve on Figure 24. At a mean daily rate of $9\frac{1}{4}$ miles this passage would be overtaken in 18 days, so that the drifter in question escaped from the dominating influence of the North-East Dogger Bank Eddy at the point P on the 31st of July. Reference to Figure 32 will inform the reader that the above vector of $9\frac{1}{4}$ miles per day is the ordinate corresponding to the mid-date of the interval between 31st July and 18th August and therefore conforms to the principles of that diagram as applied to cartographical measurements such as that just performed.

The question of the time spent in cruising within the eddy next arises, and as a basis for its determination the Period of Circuit of 20 days is used in conjunction with the above estimate as to the approximate date of entry into the complex. On these premises it appears in the case under immediate examination that 80 days, signifying four complete circuits of the gyration, were thus occupied. This fixes the date of entry into the system in this instance at the 12th day of May.

Thus, 33 days of the total drift-period remain to be allocated to that portion of the route between the position of Station 8 and the point P. In this connection, it may be recalled, certain conditions as to the direction of the route in its initial stages are demanded by some of the deductions which have been made above. Further, the linear dimension of this part of the drifter's journey must satisfy Figure 32, which requires that the distance be accomplished in the time given at a mean velocity of 12·1 miles per day, this vector being derived as follows :—

In view of the shape of the curve of velocities between the inclusive dates, 9th April and 12th May, it would not be quite accurate to accept the vector-ordinate, $12\frac{1}{4}$ miles per day, corresponding to the mid-date of the interval (April 26), as equivalent to the mean velocity of the surface-drift throughout the entire period of 33 days. A better estimate is obtained by averaging the vectors for the mid-dates of the two halves of the period, the result being the above figure of 12·1 miles per day.

The required mileage is therefore approximately 400, represented by the appropriate curve on Figure 24.

Examined in similar fashion, the shorter-period Danish, Swedish and southerly Norwegian coasts recoveries pertaining to Stations April$_{11}$2 to 8 furnish the material for Table XXXII., which is so constructed as to facilitate further explanations. The case of the 131_8 drifter is included in the table.

TABLE XXXII.

APRIL 1911 *LIBERATIONS.*

Stations 2 to 8 Inclusive.

Histories of Principal Recoveries.

Re-covery. (a)	Course in Miles to P. (b)	Time for (b) at 12·1 Miles per Day. (Days.)	Arrival at P. (c)	Course in Miles from P. (d)	Rate for (d) in Miles per Day. (e)	Withdrawal from P. (f)	Residual Periods. — Days. — (f) − (c) = (g)	(g) − 60 days. (h)
160_2	395	33	May 11	620	9·25	July 10	60	0
131_8	400	33	„ 12	165	9·25	„ 31	80	20
213_8	400	33	„ 12	890	8·90	„ 31	80	20
189_5	420	35	„ 14	670	9·00	Aug. 2	80	20
166_7	410	34	„ 13	445	9·10	„ 4	83	23
217_6	420	35	„ 14	820	8·75	„ 10	88	28
169_7	410	34	„ 13	165	9·00	Sept. 7	117	57
182_4	410	34	„ 13	180	9·00	„ 18	128	68
188_4	410	34	„ 13	130	9·00	„ 30	140	80
210_5	420	35	„ 14	310	8·90	Oct. 1	140	80
202_6	420	35	„ 14	235	9·00	„ 2	141	81

On the chart the curves appropriate to the above table are consistent as regards direction, and further, the sections of these curves between the several liberation-stations and the North-East Dogger Bank Eddy at the point P are practically synchronous, representing the progress of the drifters concerned between the 8th or 9th of April and the 11th to the 14th of May 1911. Also, the final sections of the routes from P to the various stranding-places are mutually in agreement, since the mean rates (column (*e*), Table XXXII.) at which they were accomplished conform to the principle underlying the curve of velocities.

It will be observed that the courses of all bottles included in this table and found beyond the Skaw in the line of drift, embrace a portion of the Kattegat north of the Island of Laesö. This circumstance is suggested at once by the somewhat unusual position of the 202_6 recovery at Fredrikshavn on the *east* coast of Denmark and partly also by that of the 210_5 recovery at Komö, on the Swedish coast. Even these small sections of the routes concerned are consistent as regards time. An examination of the dates in column (*f*) of the above table, in conjunction with the chart, demonstrates this point. Bottles which escaped from the North-East Dogger Bank Swirl after the 10th of July 1911, or, more exactly, between the 31st of July and the 10th of August and, again, on 1st and 2nd October, apparently cruised further into the Kattegat than the 160_2 drifter.

There is also distinct evidence of periodicity in the second last column of the above table, the period being one of 20 days, that is, the same as was deduced from the analysis of the February 1911 records and from the comparable material of 1910 and denoting the Period of Circuit of the North-East Dogger Bank Swirl, ostensibly between the middle of May and the beginning of October 1911.

The question, however, of variation in the size and position of the complex during these months is to be considered at this stage. As already pointed out, a comparison of the charts constructed on the argument of the February and August results clearly indicates a transformation in at least the size of the eddy system prior to the end of the latter month. Consequently, the greater number of those April bottles above detailed were without a doubt involved in the process, since the majority of them were not recovered until after the third week of September. It is also suggested that the change was the result of the coalescence of two like systems, the second functioning separately, to begin with, in the region south-west of Lindesnaes.

In the first place, as affecting the later stages of the routes taken by the April bottles from P and having regard to the original positions of the component swirls, the southern limit of the resultant system, after coalescence, would almost certainly be, if anything, farther north than that of the North-East Dogger Bank Eddy as represented on Figure 24. According to Figure 23, however, the position of this limit was evidently much the same towards the end of August as in the month of May, so that, for present purposes, any change in the position of the system, as gauged by that of its southern boundary, may be regarded as having no measurable significance. This being so, and with due regard to the above-mentioned periodicity of 20 days suggested by the residual periods, it would seem to be paradoxical to argue from these data an amplification of the area covered by the North-East Dogger Bank Swirl, for the anomalies of periodicity are not, except perhaps in two cases—those of the 217_6 and 182_4 returns—outwith the limits of so-called " experimental error." Any further explanation, then, to gain precedence over that already given, should absorb these anomalies into a more comprehensive scheme.

The first four residual periods are exactly simple multiples of 20 days. Therefore, it may be inferred that, prior to the 2nd of August 1911—the date upon which the fourth bottle emerged from the swirl—no extension of the area encompassed by the circulation occurred.

According to Table XXXII., however, the next two escapes took place on the 4th and 10th days of August respectively. Calculating from the dates of arrival at the point P and assuming the constancy of the swirl, the bottles in question should theoretically have withdrawn from P on the 1st and 2nd of the month respectively. Taking for granted that these discrepancies are indicative of expansion of the North-East Dogger Bank Swirl an attempt may be made to gauge this expansion quantitatively, that is, to find the Period of Circuit of the enlarged system.

Although it is argued above that the original eddy remained constant in size until the 2nd of August 1911, that is, until the completion of four circuits by those April bottles which entered it between the 11th and the 14th of May, a number of these drifters which were retained within the gyration after that date were, of course, influenced by any change in its dimensions ; so that the residual periods in excess, not of eighty days, but of *sixty* days, must be studied. These are tabulated in column (*h*) of Table XXXII.

In the sequence of (*h*) values a distinct break occurs after the sixth one, namely, 28 days, the next figure being just double this magnitude. Also, the last three periods are practically the same and again are nearly related in an obviously simple manner with 28 days. These findings strongly suggest that the expansion of the North-East Dogger Bank Swirl was not a prolonged process and was therefore the outcome of more or less immediate coalescence with another similar gyration rather than either (i) a gradual accession of centrifugal force within the original eddy, or (ii) a diminishing resistance to a tendency towards expansion. It appears that coalescence took place about the 2nd of August, causing drifters still within the system, but nearing the point P, to be delayed in their exit from the circulation. From the relationship of the sixth (*h*) value to the next and the last three, and further, recalling the analytical results pertaining to Station $\text{August}_{11}5$, we may deduce the Period of Circuit of the new system to have been approximately 27 days. The case of the 182_4 recovery remains anomalous, perhaps on account of some local idiosyncrasy of drift such as a coastal reversal in Jammer Bugt, similar to that deduced in respect of this same region from certain of the February 1911 results. An explanation on these lines is indeed suggested by the apparently inverse relationship of the drift-periods of the two $\text{April}_{11}4$ returns to the distances of the two stranding-places from the point P.

Before passing to other results, it may be pointed out that one advantage of the above interpretation of the April records so far examined in detail over that entailing the constancy of the North-East Dogger Bank Swirl from May to October 1911, is that, in the cases of those drifters for which long residual periods are deduced, the number of circuits of the complex which must be assumed is diminished by one. Later results, however, establish more firmly the significance of these deductions.

Turning now to the investigation of the results recorded against Stations $\text{April}_{11}9$ to 13, it has already been remarked that no west Danish coast or Skagerak recovery resulted from the liberations at these points. Of the ten bottles subsequently returned, eight were picked up on the Norwegian coast between Stavanger and latitude 62° N., the remaining two attaining higher latitudes on the same coast.

These facts suggest at a first reading that the bottles in question did not drift towards and into the North-East Dogger Bank Swirl, but came under the influence of the Great Northern North Sea Eddy. On several grounds this hypothesis may be challenged. In the first place the initial routes given on Figure 24 for the drifters despatched from the Moray Firth region are not consistent with the view that the surface drift over the area embraced by Stations 9 to 13 was in the direction necessary to carry floating objects into the Great Eddy. Even if this were so and the bottles in question did in fact cruise round this system, the proportion of recoveries subsequently effected on the Norwegian coast outwith the North Sea is exceedingly small, especially when it is known that other drifters of different origin, but belonging to 1911 liberations, were found about the same times and places as the two instances above-mentioned. But more conclusive is the fact that, on the same coast, between Stavanger and latitude 62° N., two drifters, emanating from liberations carried out in the southern reaches of the Norwegian Sea in the following month (May 1911), stranded nearly one month and two months respectively *before* the earliest discovery of an April bottle in the same locality.

The balance of evidence, then, points to a surface drift in a southerly direction through the stations under present discussion ; one and the same with that which carried the drifters from Stations 2 to 8 towards and into the North-East Dogger Bank Swirl. On this basis Table XXXIII. is constructed and, in conjunction with the relevant curves on Figure 24, gives account of the histories of the recoveries pertaining to Stations $\text{April}_{11}9$ to 13.

TABLE XXXIII.

APRIL 1911 *LIBERATIONS.*

Stations 9 to 13 Inclusive.

Histories of Principal Recoveries.

Recovery. (*a*)	Course in Miles to P. (*b*)	Time for (*b*) at 12·0 Miles per Day. (Days.)	Arrival at P. (*c*)	Course in Miles from P. (*d*)	Rate for (*d*) in Miles per Day. (*e*)	Withdrawal from P. (*f*)	Residual Periods. — Days. — (*f*) − (*c*) = (*g*)	(*g*) − 60 days. (*h*)
152_9	445	37	May 18	600	9·25	July 7	50	—
158_9	445	37	,, 18	560	9·20	,, 17	60	0
234_{10}	450	38	,, 19	710	8·75	Sept. 11	115	55
211_{11}	465	39	,, 20	725	8·90	Aug. 19	91	31
239_{11}	465	39	,, 20	710	8·75	Sept. 16	119	59
181_{12}	480	40	,, 21	680	9·10	July 25	65	5
147_{13}	515	43	,, 26	605	9·30	,, 4	39	—
158_{13}	515	43	,, 26	625	9·25	,, 12	47	—
203_{13}	515	43	,, 26	990	9·00	,, 15	50	—

Despite somewhat greater anomalies in the residual periods (column (*g*)) the data of Table XXXIII. obviously support the deductions already made from Table XXXII. Moreover, some of the above anomalies may be more apparent than real. In the compilation of Table XXXIII. due attention is paid to the consistency of the various routes beyond the Skaw, in relation to the dates of withdrawal from the point P. It is conceivable, however, that, in the region north of the Skaw, the position of a drifter in the surface cross-section of the stream—that is, whether it is cruising near the northern edge, or in mid-stream, or on the southern border of the stream—may determine, independently of calendar time, the further progress of the bottle, either into the Kattegat or more or less abruptly northwards towards the south coast of Norway.

For instance, in the case of the 203_{13} recovery, the route charted embraces a wide sweep of the Kattegat north of Laesö. If, on the other hand, this bottle is assumed to have followed the same route within the Skagerak as the 147_{13} drifter, a course of 915 miles from P would be accomplished in 102 days at a mean rate of nine miles per day. In this event the residual period would be one of 58 days, the bottle leaving P on the 23rd of July. A residual period of this magnitude conforms to the theory that the North-East Dogger Bank Swirl retained its usual dimensions until the beginning of August 1911.

Similarly, the Kattegat course of the 158_{13} bottle is restricted by that of the 158_9 recovery, in accordance with the inference based upon the date-sequence at P on the commencement of the final stages of the routes. Disregarding this restriction and assuming a longer course within the Kattegat for the 158_{13} bottle, its residual period may be brought as near as we please to 40 days, instead of, as in Table XXXIII., 47 days.

The 152_9 return is more decidedly a misfit.

Within reasonable limits, then, and with one exception, all the bottles which escaped from the North-East Dogger Bank Eddy before the beginning of August 1911 show residual periods which are almost exactly divisible by 20 days. In two of the remaining three cases the anomalies are quite distinct and, from the corresponding (*h*) values, bear out the suggestions of the former table.

The logical sequel to the foregoing analysis of some of the April records is the

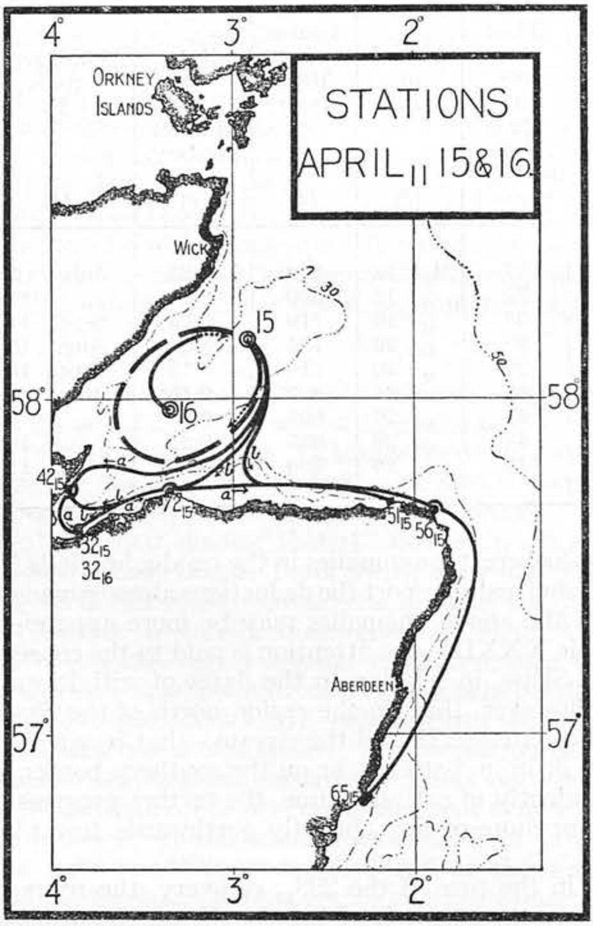


Figure 25.

presentation of the results obtained from a close study of certain of the July 1911 experiments, which corroborate in a remarkable way the above findings relative to the fusion of the North-East Dogger and Lindesnaes Eddies on or about the 2nd of August 1911. Nevertheless, in order to obviate digression in subsequent pages, the analysis of the remainder of the April records is first of all given.

To return to the Moray Firth coast recoveries from the liberations at Stations April_{11}15 and 16, and including with their examination that of the contemporaneous record of a Station 15 recovery at Gourdon on the mid-east Scottish coast, an attempt may be made to reconstruct diagrammatically the histories of the bottles concerned, again with the aid of Figure 32.

As has already been pointed out (page 38), the magnitudes of the drift-periods registered by these seven bottles practically affirm the existence of the Moray Firth Swirl during the months of April, May and June 1911. Unfortunately, these magnitudes, in conjunction with the relative positions of the stranding-places, afford no further clue as to the routes followed after escape from the complex was accomplished. For instance, it is known that, at certain times, a narrow coastal stream flows eastward along the entire length of the southern Moray Firth shore. There is no indication from the actual order in which the above bottles were returned that such was the case during the last ten days of May and the month of June 1911, but, assuming the proposition meantime, the following table may be constructed on the basis of an average daily rate of drift of 10½ miles, this vector being the mean of the seven velocities at which, according to the velocity-curve, the paths of the drifters concerned exclusive of eddy circuits would be traversed. Further, the position of Station 15 may be regarded as the point at which drifters issued from the eddy and the measurements in the second column of Table XXXIV. relate to the curves *a* on Figure 25.

TABLE XXXIV.

APRIL 1911 *LIBERATIONS.*

Stations 15 and 16.

Moray Firth and Mid-East Scottish Coast Recoveries.

Recovery. (*a*)	Course in Miles exclusive of Eddy Circuits. (*b*)	Time in Days to cover (*b*) at 10½ Miles per Day. (*c*)	Residual Periods (Days). (*a*) − (*c*) = (*d*)
42_{15}	53	5	37
32_{15}	63	6	26
32_{16}	93	9	23
72_{15}	80	7½	64½
51_{15}	118	11	40
56_{15}	126	12	44
65_{15}	185	17½	47½

Within the limits of error allowable in such an analysis the quantities in the last column of Table XXXIV. are simple multiples of seven days, which period, on more than one occasion in the analysis of the 1910 data, was shown to denote the Period of Circuit of the Moray Firth Eddy.

On the other hand, several of the drifters in question may have attained their stranding-places by more direct routes after leaving the swirl. Fulton (**3***b*) was probably the first authority to adduce experimental evidence pointing to a division in the southward-flowing surface drift stream into the Moray Firth, this division occurring approximately along the meridian, 3° W. longitude. On this basis, the curves marked *b* on Figure 25 may be taken to represent the courses of the above bottles and in Table XXXIVa. are given the corresponding measurements and calculations.

TABLE XXXIVa.

Recovery. (a)	Course in Miles exclusive of Eddy Circuits. (b)	Time in Days to cover (b) at 10½ Miles per Day. (c)	Residual Periods (Days). (a) − (c) = (d)
42_{15}	55	5	37
32_{15}	53	5	27
32_{16}	80	7½	24½
72_{15}	35	3	69
51_{15}	51	5	46
56_{15}	58	5½	50½
65_{15}	118	11	54

Although two of the residual periods of Table XXXIVa. are 50 per cent. " out," it is obvious that these investigations are not sufficiently conclusive to lend a bias in favour of either the *a* or the *b* routes exclusively. It is not unlikely, in view of the wide period embraced by the recoveries, that, in actual fact, a combination or perhaps an alternation of the two systems indicated above, caused some bottles to be carried far into the Moray Firth and some to drift eastwards towards the north-east corner of Aberdeenshire after their escape from the Moray Firth Eddy.

There remains to be considered of the April 1911 experiments the results pertaining to Station 17, four bottles from which were recovered between the 3rd and 15th of June on the east coast of England between Druridge Bay, Northumberland, and Redcar, Yorkshire.

Liberations at this station were carried out on the 25th of April, and it is to be noted that, about this period, a number of March bottles liberated in the same region stranded on the above section of the north-eastern English coastline. These drifters, it is estimated, proceeded ultimately from an eddy system characterised by a Period of Circuit of about seven days, the mean speed of the drift in its neighbourhood being approximately 12 miles per day. By the month of May 1911, the velocity of the surface drift in the North Sea generally had apparently fallen off to a certain extent. In the same way as in the above analysis of the Moray Firth experimental results, that is, by reference to the curve of velocities, the vector of 10½ miles per day may be taken to denote the mean rate of progress of the four drifters immediately concerned, after their escape from the Mid-East Scottish Coast Eddy.

On this basis the data in question are analysed with the results shown in Figure 24 and Table XXXV. The Mid-East Scottish Coast Eddy is again reckoned to have been circular in plan at the time of these experiments and situated in the same locality as given in Figure 21. There is some justification for these assumptions in the position, relative to this eddy, of the stranding-place of the 65_{15}April bottle, which, according to the foregoing analysis, left the Moray Firth along its southern shore in the beginning of the month of June.

[TABLE XXXV.

TABLE XXXV.

APRIL 1911 *LIBERATIONS.*

Station 17.

British East Coast Recoveries.

Recovery. (a)	Course in Miles exclusive of complete Eddy Circuits. (b)	Time in Days to cover (b) at $10\frac{1}{2}$ Miles per Day. (c)	Residual Periods (Days). (a)−(c)= (d)
39_{17}	165	16	23
46_{17}	175	17	29
42_{17}	205	20	22
51_{17}	205	20	31

The relationship observable among the residual periods of Table XXXV. favours the validity of the assumptions and deductions upon which it is based. Apparently, the Period of Circuit of the Mid-East Scottish Coast Eddy, during the weeks embraced by these four drifters between their dates of liberation and recovery, was again about seven days, the rate of the drift southwards along the British east coast averaging, towards the end of May and in the beginning of June 1911, about $10\frac{1}{2}$ miles per day.

The analysis of the results compiled from the experiments of July 1911 follows immediately, as certain of these results clinch the matter of the coalescence of the Lindesnaes and North-East Dogger Bank Eddies during the summer of that year.

* * * * * * *

July Liberations.

Between the 6th and 21st days of July 1911, 116 drifters were liberated over the North-Western and Middle Areas of the North Sea from 18 stations disposed as represented on Figure 26. A total of 16 returns from the following coastal sections is recorded against 10 stations :—

West Danish coast between Ringkjöbing and the Skaw	5
West Swedish coast	4
South Norwegian coast east of Lindesnaes	4
Norwegian coast north of latitude 61° N.	3

Of these 16 recoveries, seven registered drift-periods of less than 90 days. These were found mainly upon the Danish coast and originated principally from the eastmost of the stations visited during the month. The actual dates of stranding fall within the three months between September and November 1911 inclusive, thus linking up with the similar instances occurring in the records for the months of April and August 1911.

A unique recovery was that effected " on an island near Veiholmen " on the 12th of October, that is, on the day previous to the recovery, on Veiholmen itself, of the 51_{19}August bottle. As establishing an apparent connection between the experiments of the two months this singular result may be considered first.

The drifter in question was despatched from Station $July_{11}17$ on the 20th day of the month, thus recording a drift-period of 84 days. The mid-date of this period lay between the last day of August and the first of September, when, according to Figure 32, the velocity of the surface drift in the Northern North Sea generally was approximately 9·2 miles per day. On this basis and with due heed to the findings from the analysis of the August results the course represented on Figure 26 is estimated, measuring to scale about 770 miles. It will be observed that the given route involves

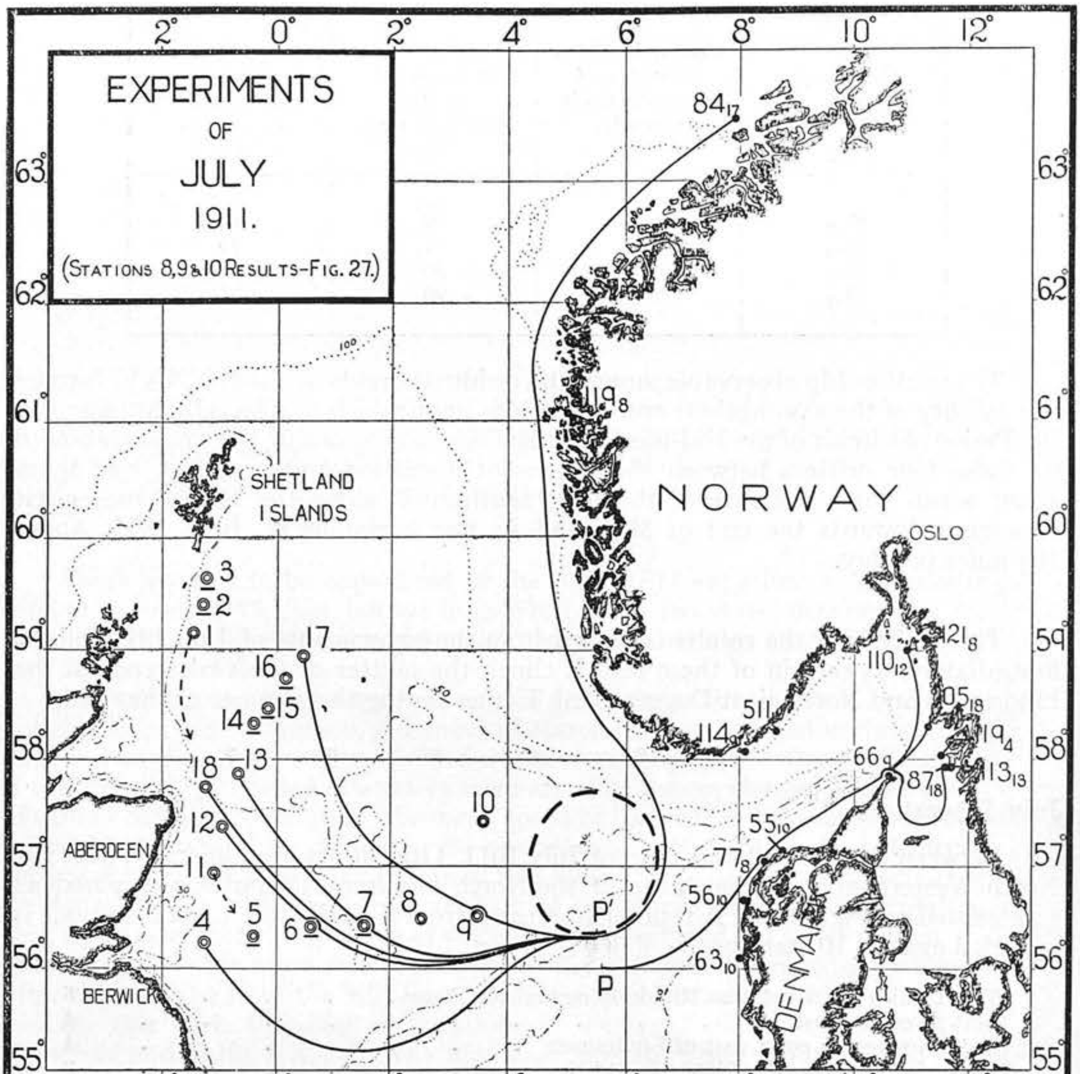


Figure 26.

no eddy circuit. Nevertheless, a natural inference from the shape of the curve is that the *extended* North-East Dogger Bank Eddy lay within the bight formed over the area of the Little Fisher Bank ; in other words, that this bight was the direct result of eddy influence, knowing from the foregoing analysis of the April and August records that, about the epoch involved, at least one eddy system was in operation in the above-mentioned neighbourhood. That it was the enlarged North-East Dogger Bank Swirl which directed the drift of the July bottle under present scrutiny follows from the combination of these two deductions. Firstly, according to the April analysis, coalescence of the original North-East Dogger Bank Eddy with the Lindesnaes Swirl took place on or about the 2nd of August 1911 ; and secondly, in conformity with Figure 32, the bottle in question would not attain the region of the point P′—the southern limit of the gyration—until practically the 17th day of the same month. At all events, the combined circulation may be taken as having been situated on the 17th of August 1911 about the position given in Figure 26 and, in this connection, comparison with Figure 23 suggests that the enlarged system moved gradually southwards, after its formation, to the position given on the latter chart. This matter is of importance to the ensuing analysis. The size of the complex is already settled, at least tentatively, by the Period of Circuit of some 27 days, derived from the results of the April and certain of the August experiments.

As already indicated, the accuracy of the above estimate concerning the date upon which the two eddy systems merged is remarkably enhanced by the detailed examination of some of the July records. These are the eight recoveries accruing from the liberations at Stations $\text{July}_{11}8$, 9 and 10, which were situated in close proximity to the scene of this hydrographic transformation. On the basis of even a temporarily established system of surface drift over the region involved, and making use of a range of velocities within the limits suggested by the foregoing analyses, it was found to be impracticable to reconstruct with the requisite over-all consistency, the histories of these returns.

A satisfactory interpretation of these July records is forthcoming only when the moral pointed by the April analysis is given effect in the cartographical investigation of the problem. This is done in Figure 27 for the reading of which a " key " is provided. Further assistance in this direction is afforded by the numbers which appear at intervals along each route on Figure 27. These numbers are the drift-periods of the recoveries concerned and each is repeated several times along the appropriate curve. Since no two of the seven magnitudes detailed are identical, it is unnecessary to append the usual index number representative of the point of origin. It will be observed, however, that an index number, in Roman character, does accompany each magnitude, the idea being that, in the complications of the diagram, the various routes may be traced by following the sequence of these Roman numerals in respect of each return. For example, the course of the 66_9 recovery will be picked out by following the figures 66i, 66ii, 66iii, 66iv, and so on.

Now the approximate position of the North-East Dogger Bank Eddy about the middle of the month of August 1911, that is, shortly after its coalescence with the Lindesnaes Swirl, has already been deduced from the instance of the 84_{17}July return. The resultant complex at the time in question is represented in Figure 27 by the broken elliptical curve in the more northerly position. It is to be borne in mind that, following upon its formation, this system moved gradually southwards.

Stations $\text{July}_{11}8$, 9 and 10 were operated on the 14th of that month, when, according to the analysis of the April 1911 records, the components of the above eddy formation were functioning as separate entities. Let it be supposed that, about the middle of July 1911, the two systems occupied the positions given by the broken circles on Figure 27.

The superficial area of the original North-East Dogger Bank Eddy is gauged by the Period of Circuit of 20 days derived from the detailed examination of the results of the February liberations and also from the shorter-period returns relative to the experiments begun during April. Information concerning the position and size of the Lindesnaes Swirl is forthcoming from the analysis of a number of records consequent upon the liberations carried out during the month of May 1911. These follow later. According to the analysis of the August data the position of the combined eddy system towards the end of that month was such that its southern limit was defined fairly nearly by the 56th parallel.

On these premises we shall proceed to demonstrate by a rigid analysis of the histories of all eight returns from the liberations at Stations $\text{July}_{11}8$, 9 and 10, firstly,

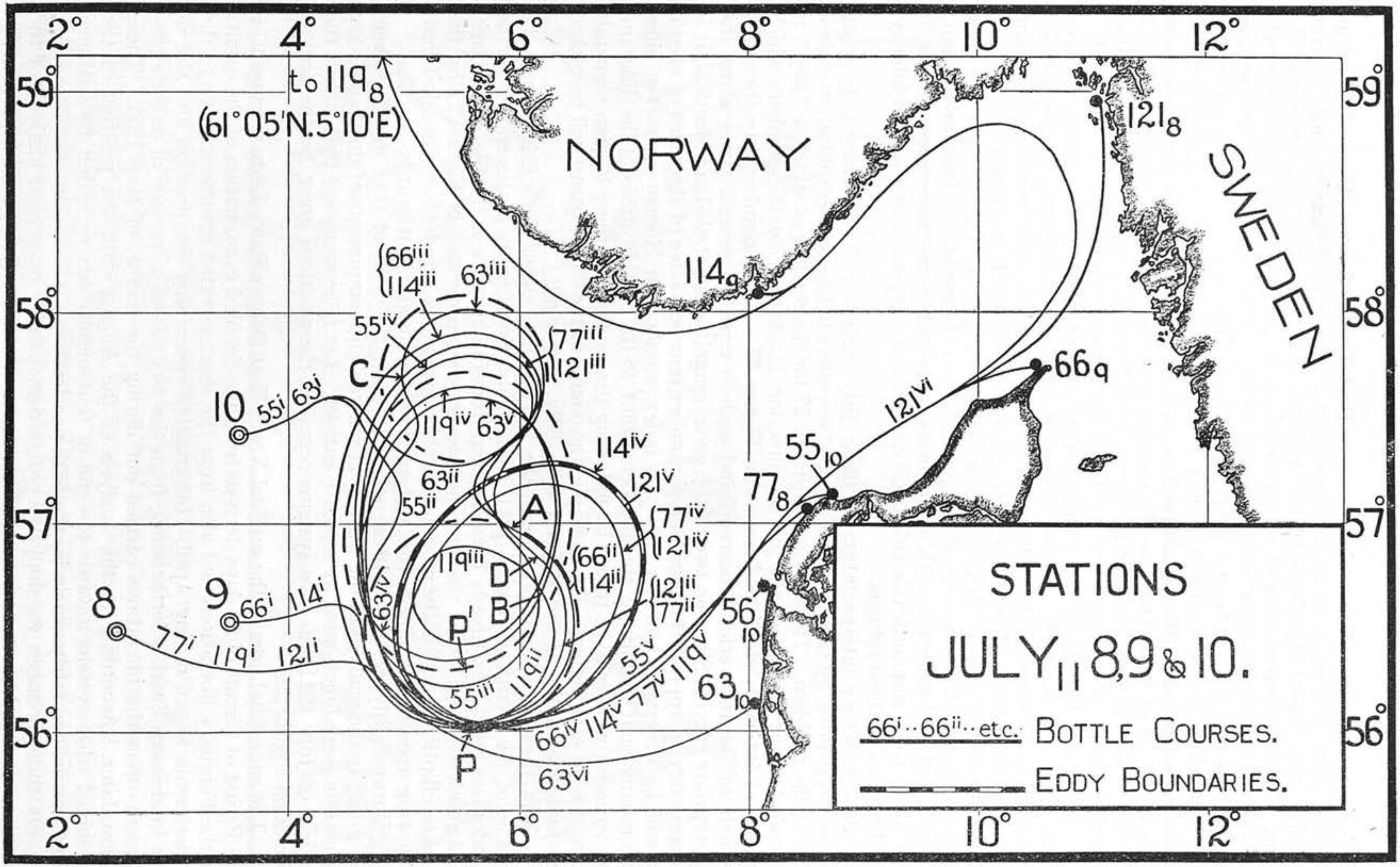
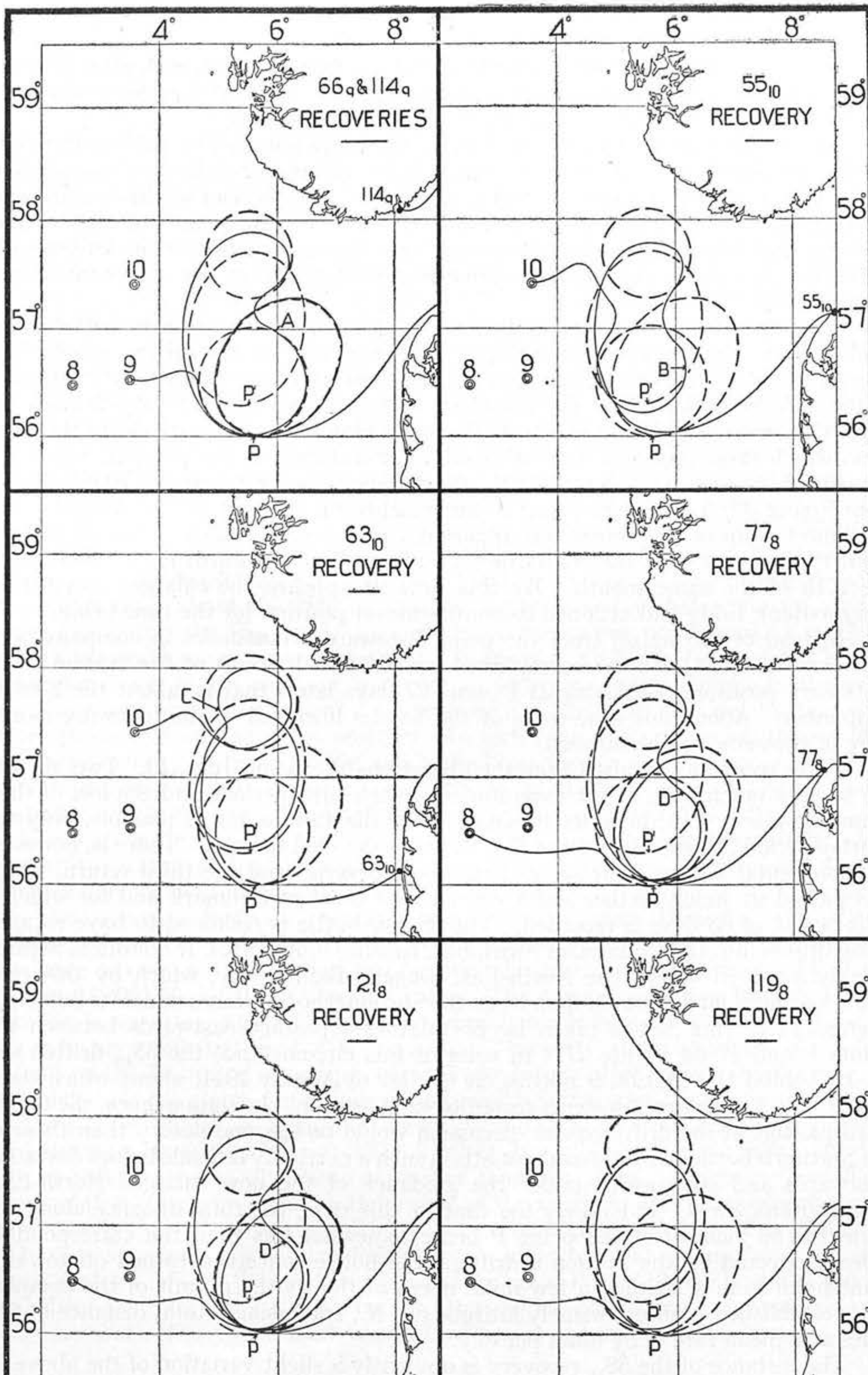

NORWAY
SWEDEN
to 119₈
(61°05'N. 5°10'E)
STATIONS
JULY 11 8, 9 & 10.
66ⁱ··66ⁱⁱ··etc. BOTTLE COURSES.
EDDY BOUNDARIES.
2° 4° 6° 8° 10° 12°
59° 58° 57° 56°
A B C D P P'

Figure 27.



Key to Figure 27.

that coalescence of the Lindesnaes and North-East Dogger Swirls took place between the 1st and 2nd of August 1911; and secondly, that the resultant complex commenced almost immediately a slow translatory movement southwards.

The practical solution of the problem of the route followed by each drifter commences from the curve of velocities, from which the vector-ordinate corresponding to the mid-date of the period of drift is obtained. The product of this quantity by the magnitude of the drift-period, in days, yields an estimate of the mileage covered. The practical issue thereupon resolves itself into the construction of curves mutually consistent as regards time and direction and conforming to the above-mentioned hydrographic transformations.

From the disposition of the diagram, Figure 27, the Station 9 drifters were doubtless the first to come under eddy influence, that of the original North-East Dogger complex. It is estimated that the 66_9 recovery coursed over nearly 610 miles in the manner indicated by the key-chart and at an average rate of 9·2 miles per day. One or two significant points on the curve may be noted, particularly the dates upon which these positions were attained. For instance, to the point A, where the curve is about to cross latitude 57° N., the distance is approximately 170 miles, and, from Figure 32, it is deduced that A was reached on the first day of August. The northmost point on the course was apparently passed on the 10th of August and the point P, from which the 66-day bottle set off immediately towards Hantsholm, about the 27th of the same month. By this time, it appears, the enlarged North-East Dogger Bank Eddy had attained its southernmost position for the time being.

Instead of setting off from the point P towards Hantsholm in company with its fellow, the 114_9 drifter accomplished an additional circuit of the system in its stationary position, re-arriving at P some 27 days later, that is, about the 23rd of September. About this time some of the bottles liberated in the following month were in the same neighbourhood.

Three recoveries resulted from the liberations at Station $\text{July}_{11}10$. Two of these are so very much alike in the magnitudes of their drift-periods and the loci of their stranding-places that, in order to simplify the diagram as far as possible, only the shorter-period return, namely the 55_{10} bottle, is detailed thereon. There is, however, a fundamental difference between these two recoveries and the third return, which was picked up much farther south on the west coast of Denmark and for which a drift-period of 63 days is recorded. The 55-day bottle is reckoned to have escaped being drawn into the Lindesnaes Swirl, but, turning southwards, it doubtless became quickly involved within the North-East Dogger Bank Eddy, which by this time was a few miles farther north than when the Station 9 bottles came under its influence. Cognisance of this fact is taken by postulating a passage eastwards between the points P and P′ on Figure 27. In spite of this circumstance the 55_{10} drifter was (at B) behind the Station 9 bottles on the 1st of August 1911, about which date, apparently, the separate systems ceased to exist as such. In consequence, the northward passage of the drifter under discussion would be less undulatory than those of the Station 9 bottles and it would not attain such a northerly latitude before deviating westwards and southwards under the guidance of the now enlarged North-East Dogger Bank Swirl. It is likely too that in this case, the total distance along the route to the vicinity of the point P being somewhat less than the corresponding mileage covered by the Station 9 drifters, the bottle concerned turned off towards Hantsholm from a latitude a few miles north of the southern limit of the complex in its established position, namely latitude 56° N., traversing a total distance of 510 miles at a mean rate of $9\frac{1}{4}$ miles per day.

The instance of the 56_{10} recovery is obviously a slight variation of the above.

On the other hand the 63_{10} return does not conform to similar treatment. It seems that this bottle drifted first of all into the Lindesnaes Swirl in the manner shown by the key diagram. On the 1st of August the point C would be reached and in regard to the position of this point relative to the Lindesnaes Eddy, it is to be observed how it corresponds with the position of A in relation to the other complex. Before drifting finally southwards to the region of the point P the bottle under present scrutiny probably negotiated a complete circuit of the combined swirl in an intermediate position. As the course is laid down in Figure 27 the distance from the starting-point, Station 10, to the vicinity of the point P′ is practically 280 miles. According, therefore, to Figure 32, the date of crossing the longitude of P′ was approximately the 13th of August, that is, only four days before the complex attained the position such that its southern limit was defined by the latitude of P′. Consequently, the 63_{10} curve passes eastwards a few miles to the north of P′ and, as a corollary to this, the northerly limit thereafter attained by the bottle in question was doubtless below that of the eddy in its position of the 17th of August. These inferences are given due effect on the chart. The entire course run by this bottle was one of 580 miles overtaken in 63 days at a mean daily rate of 9·2 miles.

The three recoveries resulting from operations at Station $\text{July}_{11}8$ are each of special interest in at least one particular. Bottles from Station 8 doubtless entered the North-East Dogger Bank Swirl a little to the north of P. Thereafter, until they arrived back at this point for the first time, the 77- and 121-day recoveries are estimated to have followed a course intermediate between those laid down for the 66_9 and 55_{10} bottles. This deduction arises from the circumstance that the 170-mile mark, in this case the point D, reached on the first day of August, falls between A and B. The first re-arrival in the neighbourhood of the point P may be calculated to have taken place about the 25th of August, that is, two days before the 66_9 drifter and one day after the 55_{10} bottle doubled the corresponding point to make straightway for the north-west corner of Jutland. If we may put it so, the Station 8 bottles under discussion at the moment were not so fortunate, being caught in the swirl movement and compelled to make a circuit of it. The swirl had not by this time quite attained its southernmost position. In fact, from this analysis it follows that the above-mentioned more or less established position was taken up on the 26th or 27th of August 1911. After the first circuit of the complex the 77-day bottle escaped and proceeded towards the Skagerak entrance, but the 121-day return evidently accomplished an additional round of the eddy before drifting into the less complicated waters of the Skagerak. In both cases the entire routes represented on Figure 27 are of such lengths that, occupying the full drift-period in each instance, they were accomplished at an average daily rate of progress defined by the vector-ordinate of the velocity-curve corresponding to the mid-date of each drift-period. The same is true of the 119-day return from the entrance to the Sogne Fjord, in latitude 61° 05′ N., on the Norwegian coast. The course estimated for this bottle, however, is peculiar. To conform to the foregoing analysis in all essential particulars it is to be accepted that the bottle in question " missed " the coalescence of the two systems on the 1st or 2nd of August, being drawn into a " tightened " swirl formation as depicted on the chart, before advancing northwards under the dominance of the resultant larger gyration. The northmost point reached corresponds to a mileage from the starting-point of about 330. That is, by calculation from Figure 32, the date of this event was doubtless no earlier than the 18th of August. It will be observed that the curve denoting the course of the bottle in question passes beneath the northerly limit of the combined eddy system in its position of the 17th of August 1911, thus agreeing with the conditions above indicated and arising from the sum of this analysis. From the neighbourhood of the point P the 119-day bottle evidently headed for the Skagerak, drifting far into that region before finally making its way along the south Norwegian coast, round Lindesnaes and away to the north.

Before summarising the details of this analysis as regards the union of the North-East Dogger and Lindesnaes Eddies, attention is directed to the remainder of the July experimental results.

Once again the dearth of British east coast recoveries may be remarked upon, also the fact of no return having resulted from the liberations at no less than eight stations.

By reason of the magnitudes of their drift-periods only five out of seven recoveries call for detailed investigation. All five took place on the eastern seaboard of the Skagerak, between the middle of October and the 9th of November 1911. The routes estimated for these bottles are represented on Figure 26 and the various details concerning them are tabulated below. It will be observed that the routes are broken at the point P′, recommencing at the point P. The reason for this of course follows from the above analytical results, and the scheme conforms to these findings, as a study of the following data clearly reveals.

TABLE XXXVI.

JULY 1911 *LIBERATIONS.*

Stations 4, 12, 13 and 18.

Histories of Principal Recoveries.

Recovery. (*a*)	Course in Miles to P¹. (*b*)	Rates to P¹ in Miles per Day. (*c*)	Arrival at P¹. (*d*)	Course in Miles from P. (*e*)	Rates from P in Miles per Day. (*f*)	Withdrawal from P. (*g*)	Residual Periods. — Days. — $(g)-(d)=$ (*h*)
119_4	270	9·4	Aug. 11	290	8·75	Oct. 7	57
110_{12}	250	9·3	,, 15	275	8·75	,, 6	52
113_{13}	250	9·3	,, 15	280	8·75	,, 8	54
87_{18}	265	9·3	,, 18	280	8·75	Sept. 14	27
105_{18}	265	9·3	,, 18	230	8·8	Oct. 8	51

The periodicity among the quantities in the final column of Table XXXVI. is self-evident and strongly supports the findings already obtained, for, by column (*d*), these bottles did not attain the southern periphery of the North-East Dogger Bank Swirl until shortly after coalescence had taken place and, once again, it is demonstrated that a Period of Circuit of about 27 days apparently characterised the new eddy.

The routes entered for the 119_4 drifter, if substantially correct, show to what extent, during the month of July 1911 at least, the previously deduced carry-away of surface water from the off-shore region of the British east coast was operative. From previous experiments of the year under review we know that, in close proximity to the position of Station $\text{July}_{11}4$, the Mid-East Scottish Coast Eddy was functioning until at least the end of the month of May. Later results show that it was in existence in the month of September. Despite these circumstances the bottles despatched from Station $\text{July}_{11}4$ on the 13th of that month seem at once to have drifted away from the area of liberation.

Reviewing the above investigations relative to the coalescence of the North-East Dogger Bank and Lindesnaes Swirls in the summer of 1911, it may be allowed at this stage to draw attention to the abundance of information which can accrue from experiments such as these. It might even be claimed that conclusive proof of the fact of coalescence, and almost the precise date on which the phenomenon occurred, is furnished by the sum of these analytical results. It is difficult to conceive how, if the inferences drawn from these drift-bottle experimental results of April, July and August 1911 are not fundamentally true to fact, such consistency could have been attained in the diagrammatic reconstruction of the histories of the recovered bottles.

Further, once the scheme is propounded and accepted, or in other words, once it is definitely known that this particular phenomenon in the case of the North-East Dogger and Lindesnaes Eddies is likely, under certain circumstances, to occur, it is but a short step forward to prepare for the measurement of the event by the simple procedure of " sowing " drift-bottles in the area between the north end of the Dogger Bank and the Great Fisher Bank. In fact this region may even now be looked upon as a " key " area, for the time which elapses before drifters, which are set afloat in this part of the North Sea, strand upon Danish, Swedish or south Norwegian shores should yield fairly definite information as to the state of affairs in the surface waters off the entrance to the Skagerak.

* * * * * * *

In the foregoing argument of the July results it is indicated that particular information relative to the Lindesnaes Eddy is implicit in at least a number of the records compiled from the experiments begun during the month of May 1911. In other respects also the results of the May experiments, on interpretation, throw additional light upon much that has preceded this, especially as regards the peculiarities of the initial stages of the routes laid down for drifters liberated within the area of the Great Northern North Sea Eddy during February and August 1911. The May records are therefore now dealt with.

May Liberations.

During the month of May 1911, a total of 206 surface drifters was despatched from 41 points within the North Sea north of latitude 56° N. and on two lines between Shetland and Faroe.

The subsequent returns, to the number of 53, are distributed as follows :—

Eastern shores of Shetland	1
,, ,, ,, Orkney	1
Southern shore of the Moray Firth	1
At sea—North Sea	1
Danish coast between Blaavandshuk and the Skaw	7
West Swedish coast and Oslofjord	3
Norwegian coast between latitudes 60° and 62° N.	5
,, ,, north of latitude 62° N.	34

The liberation-stations and, within the limits of the chart, the recoveries emanating therefrom are set out in Figure 28. Some of the broader aspects of the month's results are considered first, since they exhibit certain peculiarities which should be observed in approaching the more detailed cartographical analysis of the records.

First of all, in comparison with the closely related experiments of exactly a year before, the almost entire absence of Orkney-Shetland recoveries from the liberations of May 1911 may be commented upon. Apparently, as already remarked in the Introduction to this report, the system of surface drift operative in the North-Western Area of the North Sea in the summer of 1910 was not repeated, at least to the same extent, a year later. At the same time, it is specially to be noted in regard to the two May 1911 bottles returned from Shetland and Orkney, one from each region,

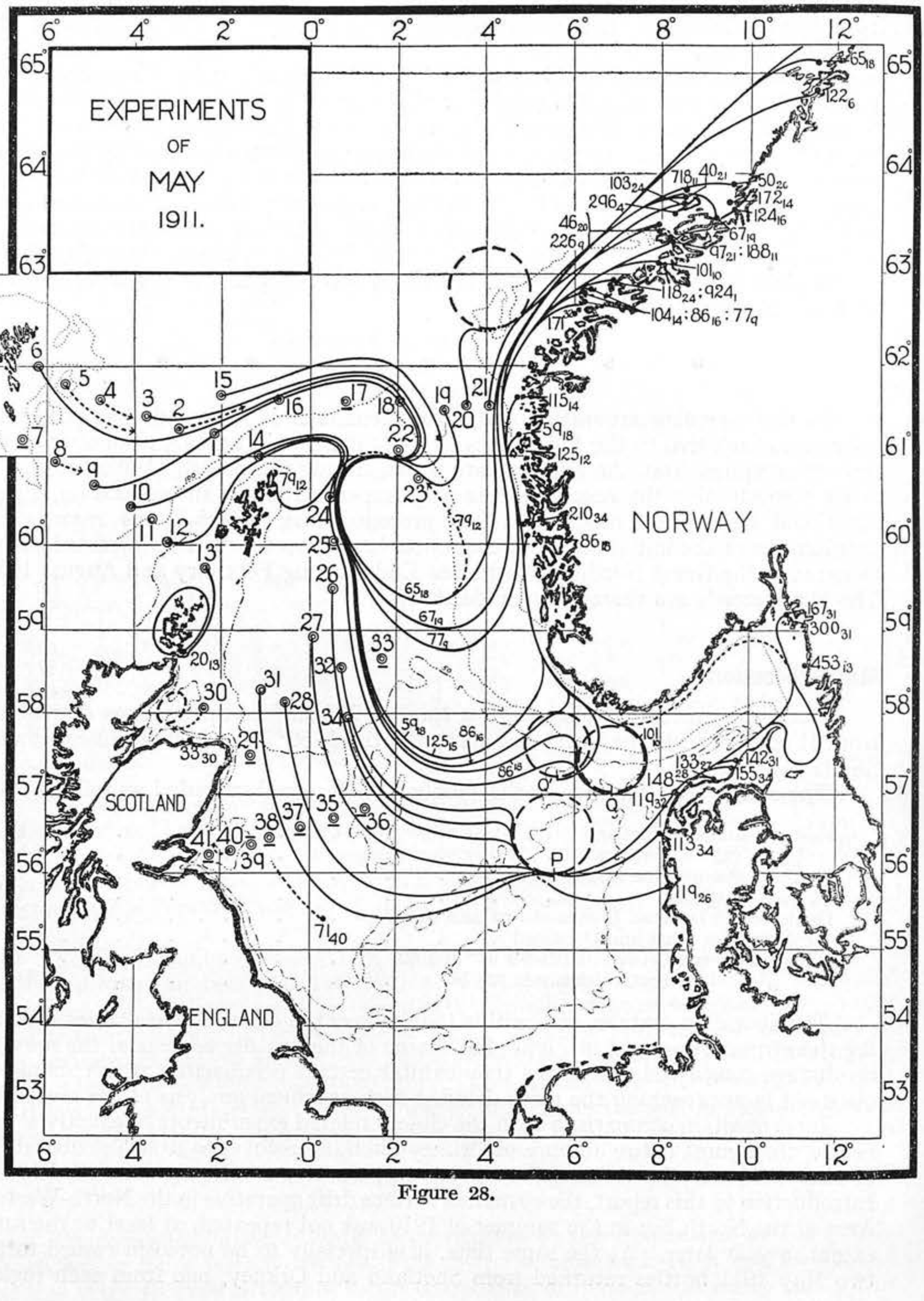


Figure 28.

firstly that they originated at points situated to the *west* of a straight line joining Sumburgh Head, Shetland, and Start Point, Sanday Island, Orkney, and secondly, that both stranded on the *eastern* side of the islands. Neither of the drift-periods registered is abnormally long and, taken all together, the above facts indicate at least a westward trend, towards the Islands, of the offshore surface waters on the North Sea side of Shetland and Orkney, during the months of June and July 1911.

This deduction is enhanced by the record of a south Moray Firth coast recovery, on the 25th of June 1911, from the series of bottles liberated at Station $May_{11}30$, which was situated in the open waters of the outer reaches of the Firth. The drifter in question was " away " for 33 days and the explanation of this long drift-period for such a short *real* distance between the points of liberation and recovery undoubtedly lies in the circumstance that the bottle was carried westward into the Moray Firth Eddy and there delayed for about three weeks before finally drifting towards Portsoy in Banffshire. By reason of its recovery-date the record is associated with some of those pertaining to Station $April_{11}15$—see Figure 25.

A conspicuous feature of Figure 28, one which is the more remarkable in the light of the foregoing discussion, is the indication of an almost total lack of returns consequent upon liberations at Stations $May_{11}29$ and 35 to 41 inclusive, which were situated in the area between the mid-east Scottish coast and " The Gut." Of the 41 bottles despatched from these eight points only one was ultimately recovered and that at sea, on the 4th of August 1911, at a spot some 90 miles S.S.E. of Station 40, where it was set afloat 71 days before. Information is lacking as to whether this bottle was taken from the surface of the sea, or trawled from the bottom. In the former event, it can be argued from the magnitude of the drift-period that the bottle experienced some retarding influence in its progress southwards from the point of liberation and for this delay the Mid-East Scottish Coast Eddy was no doubt responsible, since bottles liberated within its region of activity on the 25th of April 1911 are estimated to have been similarly held up until the end of the month of May. The fact that four of these April bottles stranded between the 3rd and 15th days of June on the coasts of Northumberland and Yorkshire renders still more singular the non-recovery of a May bottle on the same stretch of coastline.

On the other hand, if the May bottle subsequently recovered at sea was in fact held up in the Mid-East Scottish Coast Eddy until the latter half of July 1911, it is curious that no drifter from any of the above-mentioned May 1911 stations was later picked up on west Danish or Skagerak coasts, in view of the result of liberations at Station $July_{11}4$, which was situated in close proximity to the swirl. Moreover, from other May 1911 liberations in the waters north of the region between " The Gut " and the mid-east coast of Scotland, nine bottles were recovered during the months of September, October and November 1911 upon these shores, mainly upon the Danish coast north of Blaavandshuk. It is important to note that, except for one other recovery, similar as regards its stranding-place, but registering a drift-period in excess of one year, these nine drifters constitute the total return from the above coastal sections in respect of the May 1911 experiments and further, that they emanated from the liberations at the six stations within the triangle formed by joining the positions of Stations 26, 31 and 34.

In the foregoing regional classification of the recoveries resulting from the month's liberations the largest group numerically is that specifying the 39 returns from the Norwegian coast north of latitude 60° N. In six cases the drifters were away for periods in excess of 18 calendar months. On the other hand, 11 bottles were found within 100 days of the corresponding dates of liberation. The following table gives, to within 15 or 16 days, the time-distribution of these 39 recoveries and the stations at which they originated :—

TABLE XXXVII.

MAY 1911 *LIBERATIONS.*

Norwegian Coast Recoveries North of Latitude 60° *N.*

Time-Distribution.

Station No.	Period of Recovery.														
	June	July		Aug.		Sept.		Oct.		Nov.		Dec.		Jan.	After Feb. 29, 1912.
	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-31	1-15	
1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
3	—	—	—	—	—	1	—	—	—	1	—	—	—	—	1
4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
6	—	—	—	—	—	1	—	—	—	—	—	1	—	—	—
8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
9	—	—	1	—	—	—	—	—	—	—	—	—	1	—	—
10	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—
11	—	—	—	—	—	—	—	—	—	—	1	—	—	1	1
12	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
14	—	—	—	—	1	1	—	—	—	1	—	—	—	—	—
15	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—
16	—	—	—	1	—	—	1	—	—	—	—	—	—	—	1
18	—	1	1	1	—	—	—	—	—	—	—	—	—	—	—
19	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
20	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—
21	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—
23	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
24	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—
32	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—
34	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
Totals	1	3	4	2	4	5	2	—	—	3	1	1	2	1	10

Thus, fully half of the Norwegian coast returns from the May 1911 liberations were accomplished before the end of the month of September in the same year. Then, for a period of six weeks, involving the whole of the month of October, no returns are recorded, to be followed by a secondary group of recoveries in the months of November, December and January.

Examined more closely, Table XXXVII. shows that those May 1911 bottles subsequently found upon the Norwegian coast north of latitude 60° N. originated at points situated, in the extreme, some hundreds of miles apart, *i.e.* from the eastern and south-eastern Faroe submarine plateau to within a few miles of the Norwegian coast. It will be recalled that this was also the case in connection with the concentration of strandings upon the eastern shores of Orkney and Shetland from the liberations of May 1910.

Even among the shorter-period 1911 returns from Norway are numbered bottles which were despatched at points in the Faroe-Shetland Channel area. In fact, only the last 4 of the 22 stations included in Table XXXVII. were situated within the conventional boundaries of the North Sea and the question of the route by which the bottles from the remaining 18 stations ultimately reached the Norwegian coast, whether by way of the Northern North Sea, or directly north-eastwards through the southern area of the Norwegian Sea, is an all-important one.

In the first place, the five Norwegian coast returns pertaining to the North Sea liberation-stations were not the first of this class to be discovered. The earliest recoveries belonged to the series of bottles liberated at Stations 9, 10, 16, 18, 19, 20 and 21 and, except in two instances, took place north of latitude 62° N. The two exceptional recoveries, effected, one within the limits of, and the other just 13 miles beyond, the North Sea section of the Norwegian coast, began their careers at Station 18, which, in contradistinction to the corresponding experimental results of 1910, is the *only* station of the May 1911 group, situated outwith the North Sea proper, in respect of which two distinct classes of recoveries are recorded, namely, (i) such as were effected within the North Sea, or in the Skagerak, and (ii) those which took place in the higher latitudes of the Norwegian coast.

From these considerations, therefore, the question of the entry into the North Sea, of drifters liberated during May 1911 in the Faroe-Shetland Channel region and in the southern part of the Norwegian Sea, cannot wholly be answered, although the results of the experiments commenced at Stations 12 and 14 do indicate that drifters from the region of the Continental Shelf to the west of Shetland cruised into the Northern North Sea during the month of May 1911 before finally making their passage northwards along the Norwegian coast. It might indeed be pressed that the mere fact of North Sea recoveries having resulted from the liberations at these two stations and Station 18 is indicative of the operation during May 1911 of a surface current system, along the northern edge of the Continental Shelf, analogous to that deduced from the experimental records relative to the month of May 1910 and delineated in Figure 9.

Further enlightenment on this important matter is to be sought in a more rigid analysis of the data for the month, taking as the starting-point the Station 18 results, which claim first attention, not only because they include at least one instance in each of the above-mentioned two classes of recoveries, but on account of the short drift-periods registered by the three returns recorded against this station. With reference to the loci of recovery the three drift-periods do not appear to bear any direct relation to one another, so that the problem of the routes overtaken is to be investigated on the usual basis of consistency in direction and mean velocity of progress, the latter factor subject to the velocity-curve.

From the liberations at Station 18 on the 17th of May the shortest-period return was that from the Island of Aspö in North Bergenhus (latitude 61° 13′ N.), 59 days after despatch. For obvious reasons the assumption of a direct route in this case is at once to be ruled out. It is practically without question that the drifter reached its stranding-place from the south, in common with all other returns from the Norwegian coast, and this in turn presupposes a Northern North Sea itinerary.

The mid-date of the drift-period of the 59_{18} recovery was the 16th of June, when, according to Figure 32, the surface drift-velocity in the Northern North Sea was about 10·1 miles per day. Taking this vector as an expression of the mean rate of drift of the above bottle over its entire course, occupying the full drift-period, the lineal dimension of that course works out at 596 miles. As to direction, it may be argued by analogy with the corresponding experiments of the previous year that the bottle's course within the Northern North Sea was governed largely by the Great Eddy circulation. A closer scrutiny of this and certain other results from the May 1911 experiments, however, suggests a modification of the system in that year from the representation given in Figure 15 for instance and referring to 1910.

Attention has already been drawn to the fact that the significant Danish coast and Skagerak recoveries arising from the present experiments belonged exclusively to six series of liberations carried out within a restricted sea area. From these same liberations there resulted only two Norwegian coast recoveries outwith the Skagerak and in comparison with the bulk of the remainder listed in Table XXXVII., these two bottles registered long drift-periods. With reference to the route followed by the 59_{18} bottle, however, the magnitudes of these periods are of less importance than the positions of the stations (numbers 32 and 34) from which the drifters originated.

Within 70 miles north of the triangular area defined by Stations 26, 31 and 34, lay Stations 24 and 25. Unfortunately, no recovery is recorded against the latter station, but from Station 24, *only* Norwegian coast strandings eventually ensued. Two are noted and their drift-periods are intermediate between those of the above-discussed returns pertaining to Stations 32 and 34 and that of the shortest-period Station 18 bottle. It will be evident later that one of the periods is almost exactly comparable with that registered by a third return emanating from the liberations at Station 18. The important point to observe now is that the course of the 59_{18} recovery, by reason of the above circumstances, doubtless passed southwards on the east side of Stations 24, 32 and 34, but nearer to the first-mentioned station than the latter two.

A further item of circumstantial evidence, which, as it happens, is of immediate service in the diagrammatic construction of the course of the 59_{18} recovery, is the fact that, although Station 26 was practically midway between and in longitudinal alignment with Stations 24 and 32, no Norwegian coast recovery resulted from the liberations at this point, the sole return coming from the west coast of Denmark. The undulatory section of the course plotted on Figure 28 is thus explained, but only in part. The deviation is of still further significance. Neglecting it, difficulty is experienced in tracing a route of the requisite length, to comply with the above deductions and also to pass clear of surface water complications known to exist at the time in proximity to the regions through which the drifter almost certainly cruised. Moreover, on the evidence of the data for the month, it is incumbent upon the investigator to consider all reasonable deviations in the bottle's course before giving the same a bias towards the Skagerak.

About 60 miles farther south on the Norwegian coast, namely, on the Island of Great Kallsö in latitude 60° 08′ N., a second drifter belonging to the Station 18 series was picked up nearly a month *later* than the first recovery. On the basis of an average daily rate of drift of 9·8 miles, the vector being derived from the velocity-curve in the usual way, a course of no less than 843 miles can be advanced. Moreover, the same limitation as regards the passage of the bottle into the waters of the Skagerak area is applicable in this case as in that of the shortest-period return.

With a view to maintaining some degree of directional consistency in the courses of these two bottles, the difference in the lengths of the routes may be explained by the influence of an eddy gyration upon the longer-period drifter. The date and place of recovery of the latter bottle, in conjunction with the conclusions derived from the analyses of the results of experiments begun in April, July and August 1911, afford a clue as to where this retarding influence had effect. Prior to the 2nd of August an eddy was functioning in the region off Lindesnaes—the Lindesnaes Eddy. With reference to Figure 32 it can be shown that the 86_{18} bottle, recovered on the 11th of August, doubtless withdrew from this swirl formation before the beginning of that month.

The position and size of the Lindesnaes Eddy in the epoch of the present experiments is of some consequence and from the data these characteristics can be gauged fairly nearly. The interpretation of the July results indicated that this system was of somewhat smaller extent superficially than the North-East Dogger Bank Swirl, which was operating a few miles to the south or south-westward of it. Without entering into detail, which is implicit in the following figures, the present results show that, during the month of July 1911, the Lindesnaes Eddy moved slowly north-westwards. It will be sufficient to consider only two positions of the entity, namely, so far as concerns the May 1911 drifters, the extreme positions. These are given approximately in Figure 28. The point Q is to be regarded as the point of entry into the swirl and Q′ the corresponding point of exit from the system.

Reverting to the 86_{18} recovery, it can be shown with the aid of Figure 32 that, to the point Q, a distance of approximately 490 miles would be covered in 48 days at a mean speed of $10\frac{1}{4}$ miles per day and from Q′ to the stranding-place, 22 days would be occupied in traversing 210 miles at an average daily rate of 9·35 miles. On this basis the date of the bottle's withdrawal from Q′ was the 20th of July 1911. Sixteen days of the total drift-period thus remain to be allotted to that part of the course within the Lindesnaes Swirl, and in comparison with the Period of Circuit of 20 days which has been deduced in respect of the North-East Dogger Bank Eddy, this residual period of 16 days seems appropriate to one circuit of the Lindesnaes system.

Turning now to the 65-day recovery belonging to the Station 18 group of bottles, it is obvious, from a consideration of its drift-period and its stranding-place in relation to the above two recoveries that, as regards its course, something radically different from the courses of the latter bottles must be proposed. Preserving as far as possible consistency of direction and velocity, a route of 650 miles is represented on Figure 28. It is clear from the chart that a curtailed course within the Northern North Sea, in the manner indicated, is to a certain extent justified by the above-discussed peculiarity in the routes estimated for the other two bottles from the same liberation-station. The courses given for certain of the August bottles (Figure 23) liberated in the region concerned, gives further credence to this interpretation. It is not improbable that the deviation of the 65_{18} drifter from its fellows was even less rapid than as delineated on the chart, by reason of the north-easterly drift along the Norwegian coast north of about latitude 62° 30′ N. being appreciably faster than that governing the contemporary surface water circulation within the Northern North Sea.

Since, in connection with the results pertaining to Station 18, mention is made of the records accruing from the liberations at Stations 24, 26, 32 and 34, the cartographical interpretation of these records may now be given.

Of the Station 24 series of bottles two were ultimately recovered on the Norwegian coast north of latitude 62° N., as previously stated. The shorter-period return attained the more northerly stranding-place. By the route given on Figure 28 both bottles are estimated to have traversed about 370 miles to the point Q. At an average speed of 10·3 miles per day 36 days would thus be accounted for.

From Q′ the 103-day recovery presumably coursed a distance of about 475 miles in 51 days, leaving Q′ on the 8th of July. The residual period of 16 days establishes a relationship between this drifter and the 86_{18} return.

In the case of the 118-day bottle from Station 24, the residual period works out at 36 days, which is sufficiently near to warrant the conclusion that two circuits of the Lindesnaes Eddy were made prior to the 30th of July, on which day, apparently, the bottle in question set out from Q′. This date is quite significant in view of the analytical findings arising from the data for April and July 1911 in regard to the date of coalescence of the Lindesnaes Swirl with the North-East Dogger Bank Eddy.

The only remaining Norwegian coast returns emanating from the North Sea liberations of May 1911 are those recorded against Stations 32 and 34, and, as can be seen from Table XXXVII., the two recoveries in question, on account of the magnitudes of their drift-periods, belong to a well-marked secondary group in this class of return. By means of the customary measurements and calculations it can be demonstrated practically beyond doubt that the primary cause of this grouping lay in the phenomenon of the coalescence, in the first days of the month of August 1911, of the two eddy-systems above-mentioned.

In comparison with the Station 24 returns it is clear that, of the two instances under discussion, even the shorter-period recovery (which also attained the more northerly stranding-place) could not have commenced its passage northwards from Q′ until after the Lindesnaes Eddy had ceased to function as a separate entity. But from the disposition of the curves from Stations 18 and 24, it is more than likely that the drifters despatched at Stations 32 and 34 cruised into the original North-East Dogger Bank Swirl. Even so, and allowing for the 171_{32} drifter a route from the point P to the stranding-place embracing the northern area of the Kattegat, the bottle's escape from the complex situated off the entrance to the Skagerak cannot have taken place until after the 2nd of August 1911.

The last remark applies also to the west Danish coast and Skagerak recoveries ensuing from the same two series of liberations and equally to those from the remaining four points, with which, by reason of these results, Stations 32 and 34 are associated. None of the nine drifters concerned left the point P before the beginning of September. From the routes given on Figure 28 from the respective liberation-stations into the North-East Dogger Bank Eddy, it can be shown that the dates of arrival at P lay between the 14th and 24th days of June. Thereafter, two circuits of the original eddy appear to have been accomplished before these May bottles became involved in the complicated system of drift which has been elucidated in detail by the cartographical analysis, on Figure 27, of certain very appropriate July records.

With the foregoing analytical results as an approximate guide, the remainder of the month's records, especially the Norwegian coast returns, may be further examined.

Of all the May bottles returned from Norway, the shortest-period records relate to the series of bottles liberated at Stations 20 and 21. Three drifters despatched from these two points reached the vicinity of Trondhjem Fjord in from 40 to 50 days. The geographical relationship of the two liberation-stations to the northerly flowing current along the Norwegian coast suggests, in these three cases, the accomplishment of fairly direct routes. This, however, entails the assumption of mean daily rates of drift of only four to five miles. On the other hand, the drift-periods are too short to cover even a curtailed North Sea cruise on the lines of that laid down for the 65_{18} drifter, although it may be recalled that, a year previously, from exactly the same position as Station $May_{11}20$, one drifter ultimately beached upon the Shetland Islands.

A possible interpretation of the three drift-periods depends again upon the theory of eddy influence, the eddy being situated within 100 miles north of the area in which the drifters were set afloat. Such a system is diagrammatically represented in Helland-Hansen and Nansen's chart of the Norwegian Sea circulation, published in 1909.* On this basis, the three recoveries in question are analysed with customary reference to the curve of velocities. The results are as follows :—

* B. Helland-Hansen and F. Nansen : The Norwegian Sea. Its Physical Oceanography. *Report on Norwegian Fishery and Marine Investigations*, Vol. II., 1909, No. 2, p. 9.

[TABLE XXXVIII.

TABLE XXXVIII.

MAY 1911 *LIBERATIONS.*

Stations 20 and 21.

Histories of Principal Recoveries.

Recovery. (*a*)	Course in Miles exclusive of Eddy Circuits. (*b*)	Rate at which (*b*) overtaken. (*c*)	Days to cover (*b*) at rate (*c*). (*d*)	Residual Periods. — Days. — (*a*) − (*d*) = (*e*)
40_{21}	190	10·3	18	22
46_{20}	200	10·2	20	26
50_{20}	250	10·2	25	25

The residual periods are thus fairly uniform and, within reasonable limits, Table XXXVIII., in conjunction with the relevant curves on Figure 28, may be said to give account of the drifters concerned.

A second recovery in approximately the same region resulted from the Station 21 series of liberations, but after the much longer period of 97 days. Analysed on the above principle the residual period is one of 88 days and is not therefore in very close association with the mean of the three residual periods pertaining to the earlier returns. Station 21, however, was situated so near to the Norwegian coast that an alternative route seems out of the question. There appears, then, to be no better explanation of the anomaly of the longer-period Station 21 return than that the drifter lay undiscovered upon the beach for some days.

The estimation of the initial direction taken by the bottles despatched from Station 19 presents some difficulty in view of the intermediate position of this liberation-point between Stations 18 and 20, through which two stations the drift of surface waters was apparently in opposite directions in the month of May 1911. But, taking account of all relevant circumstances, particularly the probability of the single recovery resulting from the Station 15 liberations having cruised within the Northern North Sea, the evidence points, on the whole, to a like happening in the case of the 67_{19} drifter, which, therefore, on the basis of Figure 32, traversed a distance of 670 miles on a path similar to that laid down for the 65_{18} bottle.

Passing on to the experiments begun at stations situated west of Station 18, the first point from which a short-period Norwegian coast recovery ensued is Station 16. After 86 days from the 17th of May, a bottle belonging to this station was found on the Island of Flemsö, in latitude 62° 41′ N. A chart comparison of this instance with that of the 59_{18} bottle suggests a fairly close relationship between the two and, on this inference, the course given on Figure 28 for the Station 16 bottle is derived. The curve measures to scale about 840 miles, overtaken in the time given at a mean speed of 9·8 miles per day.

The route given for the above drifter leads to the interpretation of a second recovery pertaining to Station 16. The 124-day bottle picked up about 55 miles further north on the Norwegian coast doubtless entered the Lindesnaes Eddy after the manner of the 86_{18} bottle. To the point Q approximately 575 miles would be covered in 56 days at an average rate of $10\frac{1}{4}$ miles per day and from Q′ a further 54 days would be required to reach the stranding-place, the latter part of the journey commencing in the last week of July. Fourteen days, therefore, are left to be accounted for by a circuit of the Lindesnaes Swirl and this figure compares well with those derived from the 86_{18} and 103_{24} returns.

Only one of the Station 15 group of bottles was ultimately recovered, being found in the neighbourhood of Bodö (67° 18′ N., 14° 22′ E.), 125 days after the date of liberation. From the position of Station 15 it is of course possible that this drifter passed eastwards into the complication which retarded the progress of bottles from Stations 20 and 21. On the other hand, a North Sea itinerary for the Station 15 bottle provides a simpler analysis of its drift-period and one which conforms in greater degree to the general scheme of Figure 28, involving no time spent in gyratory movements.

The mid-date of the drift-period was the 19th of July 1911, from which the mean rate of progress of the bottle in question over its entire course was about $9\frac{1}{2}$ miles per day. This entails a mileage of nearly 1200. The simplest curve to this dimension and following out the above suggestions is that which, proceeding into the Northern Area of the North Sea as indicated on Figure 28, coincides with the 59_{18} curve, practically to the stranding-place of that drifter, thereafter following the direction of the route taken by the 65_{18} bottle.

There can be no doubt that the Station 14 bottles, two of which were returned from Norway after 104 and 115 days respectively, passed into the North Sea soon after being set adrift. It is to be observed particularly, however, that *only* Norwegian coast recoveries resulted from this series of liberations. It is not therefore permissible to argue that the drifters from this point entered the Northern Area of the North Sea immediately on rounding the northmost of the Shetland Islands, for, in this event, the courses of the bottles would almost certainly pass through the triangular area defined by Stations 26, 31 and 34. The significance of such routes has already been fully explained.

The magnitudes of the two drift-periods, together with the fact that the shorter-period recovery stranded farther north on the Norwegian coast than its fellow, are suggestive of eddy influence and a comparison of these results with the Station 24 records is instructive. Taking for granted that the Station 14 bottles passed over the position of Station 24 and drifted along the path of the curve traced from that point into the Lindesnaes Eddy, the following analysis of the returns under immediate investigation can be made.

Both bottles, travelling at a uniform rate of $10\frac{1}{4}$ miles per day, would reach the point Q on the 45th day after liberation. The shorter-period recovery would require 44 days to complete the final " straight " portion of its passage from Q′, and the 115-day bottle, 33 days for the like phase of its history. Residual periods of 15 and 37 days ensue from these determinations.

The first quantity is almost exactly in agreement with similar periods already deduced from certain other of the month's records and presumably denotes the Period of Circuit of the Lindesnaes Swirl. The second period, however, is at least four days in excess of the time necessary, on the same basis, to accomplish a double circuit of the system. Examined more closely it is revealed that the period of 37 days signifies the bottle's escape from the eddy at Q′ on the 6th of August, that is *four* days after the system had, by our former analyses, joined forces with the North-East Dogger Bank complex. Under these circumstances, it is reasonable to suppose that the excess four days elapsed after the completion of the drifter's journey.

The earliest record pertaining to Station $May_{11}3$, that is, the 121-day return from the Lofoten Islands, is comparable with the 125_{15} bottle. It may confidently be accepted then that the Station 3 drifter also cruised into the Northern North Sea, probably following a route within that area similar to the course estimated in the latter case. In both instances, it should be mentioned, exact coincidence of the

North Sea courses with that of the 59_{18} bottle entails a total mileage a little in excess of that deduced from a strict application of the principle of the velocity-curve. As, however, more than half of the bottles' full courses traversed regions where, it is safe to assume, the surface drift velocity is generally somewhat greater than that prevailing in the same epoch within the Northern North Sea Area, this circumstance, rather than discounting the accuracy of the analysis, might be looked upon as substantiating the argument, on page 34, from which one of the cardinal points on the velocity diagram is derived, namely, the vector-ordinate, nine miles per day, corresponding to the date, 18th September 1911.

On the other hand, due attention must be paid to the wider significance of the North Sea routes laid down for the 65_{18} and 67_{19} bottles. Apparently, in the month of May and possibly June 1911, the Great Northern North Sea Eddy was not only of much smaller dimensions than in the corresponding months of the previous year, but was centred in a more northerly position. This matter will be referred to again in the summary discussion of the analytical results of the work for the whole year. The point to note at this stage is the possibility that some of the bottles subsequently returned from the higher latitudes of Norway, especially those belonging to liberations in the Southern Norwegian Sea and the more westerly districts of the Faroe-Shetland Channel, may have been involved for a time in this " tightened " circulation, thus cruising no farther into the North Sea than about latitude 59° N. This hypothesis gains support from the fact that, in one or two cases of longer-period recovery on the Norwegian coast, the postulation of routes leading into the Lindesnaes complication entails the argument that the bottles were retained in this system until after the 2nd of August 1911, that is, until after the Lindesnaes Swirl had lost its separate identity. On the grounds that no Skagerak recovery resulted from these same liberations, while, as already demonstrated, a number of strandings took place in this region from certain other liberations of the month, the argument is hardly permissible. The second recovery recorded against Station 3 is a case in point.

With reference to the northerly line of liberations between Shetland and Faroe the only other recovery which need be particularised is the 122_6 bottle found near Lund in Namdalen, Norway (64° 46′ N., 11° 37′ E.), on the 10th of September 1911. The results of experiments launched in the same area almost exactly a year before suggest that from Station $May_{11}6$ the bottles there set afloat would drift away first of all in a southerly direction. The present data, however, furnish no indication of a complete circuit of the Faroe Islands having been made before the drifters in question set off finally towards the east. To represent the course presumably taken by the 122-day bottle into the Northern Area of the North Sea a curve is traced on Figure 28. Thereafter, within the North Sea, the route is defined by the curve relevant to the 59_{18} bottle among others detailed above. The entire course measures about 1175 miles which is the distance required to occupy the full drift-period of 122 days.

From liberations on the southern line of stations, transverse to the Faroe-Shetland Channel, two short-period Norwegian coast strandings resulted, each from a different station, but both registering almost the same drift-period, although the stranding-places were many miles apart. On the chart, Figure 28, a course is planned for the 77_9 return which conforms to the requirements of the curve of velocities, in that a distance of 770 miles would be overtaken in 77 days at a mean speed of 10 miles per day, the vector, as usual, corresponding to the mid-date of the period of drift on the above curve. It will be observed that the estimated route lies through the positions of Stations 1, 16 and 18 and that a " fore-shortened " cruise within the Northern North Sea is required to meet the conditions of Figure 32.

The short-period Station 10 recovery is more difficult to reconcile with the results already obtained. Obviously, from the appearance of Figure 28, a course over at least a portion of the Northern North Sea must, in this case, be accepted. Assuming, therefore, that the path of the drifter was, for the greater part, coincident with the course laid down for the 65_{18} bottle, a distance of about 860 miles would be traversed. The mean drift-speed consequent upon this assumption is nearly $11\frac{1}{2}$ miles per day, which is about $1\frac{1}{2}$ miles per day greater than that recorded by the velocity-curve for the mid-date of the bottle's drift-period, namely, the 20th of June 1911. As, however, the greater part of the route inevitably lay through the relatively fast-moving current from the Faroe-Shetland Channel towards and along the Norwegian coast, the higher vector derived from this instance is no doubt largely explained by the circumstance. In this respect the record is in the same category as the shortest-period Station 3 return and the single recovery pertaining to Station 15, for the analyses of these two records afford similar indications of an accelerated surface current northwards along the Norwegian coast.

The detailed examination of the second Station 10 return not only supports the contention of a modified North Sea cruise for the above bottle, but is of further value in the matter of the position of the Lindesnaes Eddy about the end of the month of June 1911. On the basis of Figure 32 this bottle covered a total distance of nearly 985 miles at a uniform speed of $9\frac{3}{4}$ miles per day. Applying this result to the construction of a representative curve on Figure 28 it can be shown diagrammatically that, following the direction taken by the Station 24 bottles from the position of that liberation-point to the Lindesnaes Eddy at Q, the present drifter would accomplish the above distance only if it did not become definitely involved in the gyration. This bottle evidently proceeded almost immediately northwards from Q towards and along the Norwegian coast, being merely guided by the circulatory movement, to execute this comparatively sudden change of direction from east to north.

Among others, the Norwegian coast recovery belonging to the Station 12 series of bottles furnishes an instance where it cannot be accepted that escape from the dominance of the Lindesnaes Eddy took place before the event of the coalescence of that system with the North-East Dogger Circuit. As already pointed out, to assume that, in such a case, the drifters concerned were at all involved in either of these complications conflicts with the fact of there being no record of a Skagerak or Danish coast recovery from the same or similarly situated liberations of the month. The interpretation of these records would seem to lie in the operation of the much restricted Great Northern North Sea Eddy, retaining these bottles for some time in the area of the North Sea between latitudes 59° and 61° N. The following analysis illustrates the point.

The more unique and therefore more important record pertaining to Station $\text{May}_{11}12$ is the 79-day recovery effected near Haroldswick on the east side of the Island of Unst, Shetland, on the last day of July. From the curve of velocities it may be argued that this bottle traversed a " straight " course of nearly 790 miles. Including almost two complete circuits of the above-mentioned eddy, the bottle being " thrown off," as it were, in the second circuit, this mileage can be exactly accounted for in the manner indicated on Figure 28. Such a course as that represented on the chart is in accordance also with the evidence drawn from other and similar data from the month's experiments, to the effect that the stranding-place was doubtless attained almost directly from the east and not to any significant extent from the south, as in the like instances of recovery accruing from the May 1910 experiments.

This must also apply to the 20-day Orkney return from operations at Station $\text{May}_{11}13$. The drift-period is markedly too short to give credence to a route northwards from the starting-point and encompassing the Shetland Islands and is overlong for the assumption of a direct course from liberation-station to stranding-place. The period is exactly absorbed, however, on the understanding that, before being washed ashore, the bottle in question made a complete circuit of the Orkney Islands. This phenomenon of an anticyclonic surface drift encircling these islands has already been deduced on more than one occasion in the course of this work, for example, from the results of the experiments of May and August 1910 and of August 1911.

The single recovery ensuing from the liberations at Station $\text{May}_{11}30$ has received sufficient mention on page 59 and this analysis might be concluded with a further comparison of the May 1911 experiments with those begun in the corresponding month of the previous year over the same widespread areas in the Northern North Sea, the Southern Norwegian Sea and the Faroe-Shetland Channel.

An essential point of similarity between the two sets of results is the strong implication of the curves on Figures 9 and 28 to the effect that, in both years, the dynamic connection between the waters of the Faroe-Shetland Channel and the Northern North Sea lay principally through the region of the Southern Norwegian Sea. In other words, the main impulse behind the Northern North Sea surface water circulation appears to have been propagated almost exclusively through the opening between Shetland and Norway and not to any significant extent by way of the passages between Shetland and the mainland of Scotland. Further, and concerning the same phenomenon, the striking peculiarity of the direction of the surface drift-stream along the northern edge of the Continental Shelf, which was the outcome of the 1910 analysis, is again revealed in the above treatment of the 1911 data.

As a predisposing cause of the tortuous deviations of the surface drift current in the northern gateway to the North Sea the Great Eddy circulation has been cited.* As a closed system, this entity in 1911 appears to have been confined within very much narrower limits, north and south particularly, than a year before. In Figure 28 the complex retains its elliptical shape, but its major axis is inclined at an angle of nearly 30° to the meridian of 2° E. with which the corresponding dimension of the 1910 circuit coincided.

Instead of being held up within the above eddy, as were so many of the 1910 bottles, a greater proportion of the 1911 drifters apparently passed into the smaller complications situated off the entrance to the Skagerak. Despite this circumstance, the number of May 1911 bottles subsequently recovered on Skagerak shores is not significantly larger than that of similar returns from the May 1910 liberations.

It may be noted too that, in marked contrast to the results of the previous year's liberations, no recovery from the May 1911 experiments was effected on Danish and Schleswig-Holstein coasts south of Blaavandshuk. It has already been demonstrated —Introduction page 9—that this feature has no immediate connection with the absence of returns in 1911 from the British coast south of about latitude 54° 30′ N. In 1910 at least two strandings took place below latitude 54° N. The indication of this difference between the results for the two years is that, in the summer of 1911, the drift-stream emanating from the north and flowing southward approximately parallel to the British east coast did not push so far south on the west side of the North Sea as in the preceding year. The eastward trend of the stream appears to have been more rapid in the second year, an inference which is borne out not only by the statistical examination of the data for the two years, but by a comparison of the charts relating to the two summers.

* * * * * * *

June Liberations.

Actually, only two points, both of them within the North Sea, were visited for the purpose of liberating drift-bottles in the month of June 1911. At the first of these, situated over the south-western edge of the Fladen Ground, 10 bottles were set adrift on four separate occasions, on the 1st, 2nd, 10th and 12th days of the month. At the second point—Station 5 on Figure 29—again 10 bottles were liberated, the date of this despatch being the 19th of June.

In all, 10 drifters were recovered as a result of these operations, two of them on the Norwegian coast north of latitude 62° N. after more than a year's freedom. Four bottles were picked up during September and October 1911 on the Danish coast

* *Fisheries, Scotland, Sci. Invest.*, **1930, IV., p. 52.**

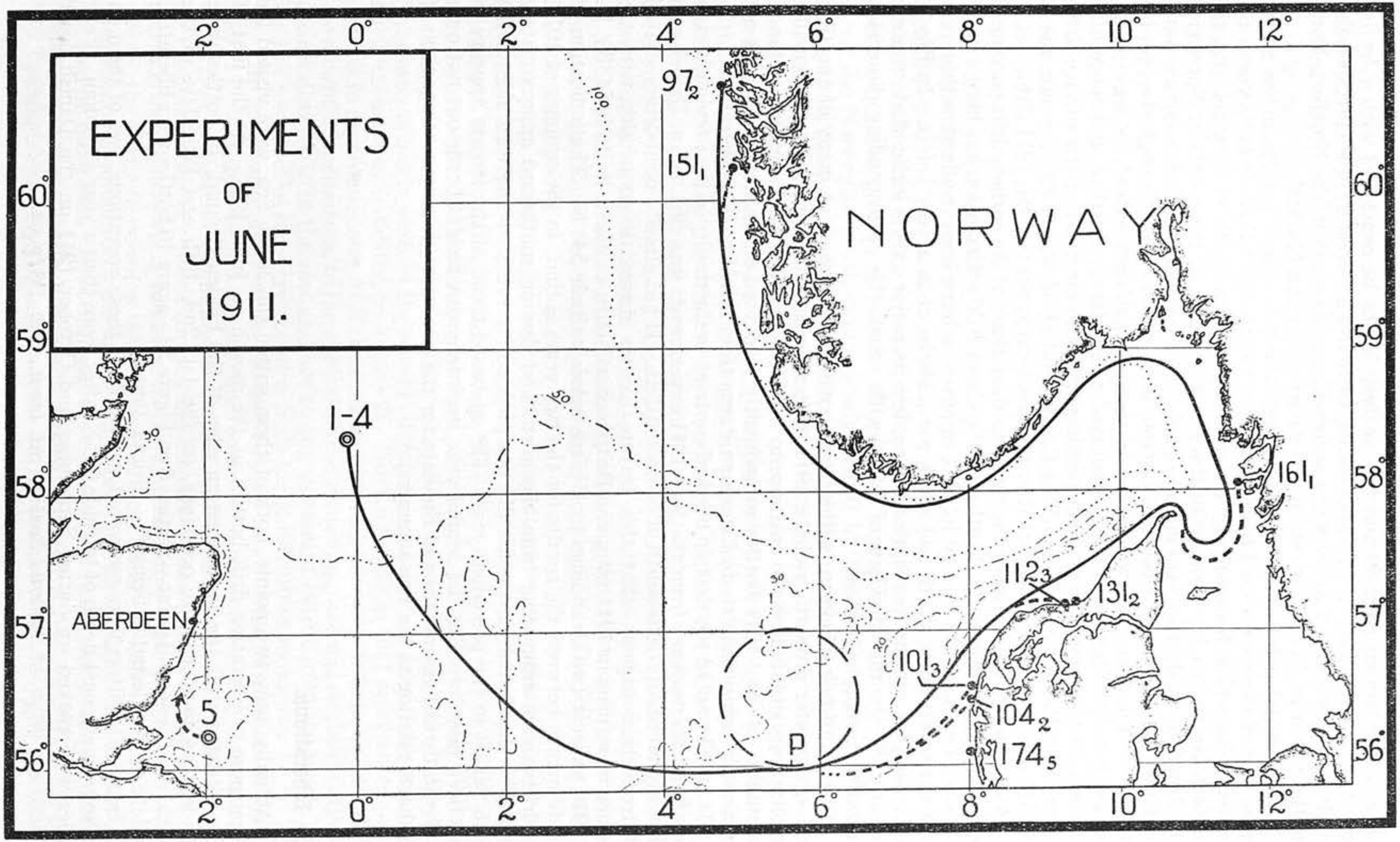

EXPERIMENTS
OF
JUNE
1911.
NORWAY
ABERDEEN
1-4
5
P
97_2
151_1
161_1
112_3
131_2
101_3
104_2
174_5

Figure 29.

between Ringkjöbing and Hirtshals and another, emanating from Station 5, was returned from this same coastal section in the month of December. One bottle was found on the west Swedish coast in November and the remaining two on the Norwegian coast between latitudes 60° and 61° N. in September and October respectively.

With particular attention to the direction of the curves passing over the region of the Fladen Ground, a glance at Figures 26 and 28 urges the conclusion that the bottles set afloat at Stations $\text{June}_{11}1$ to 4 would drift towards the North-East Dogger Bank Swirl, where, on the basis of Figure 32, they would arrive in the beginning of the following month. It is equally clear from a perusal of the dates and places of recovery of the eight bottles concerned that, with the possible exception of the shortest-period return, none of the others quitted the region of the above eddy until some time after its coalescence with the Lindesnaes complex.

The complicated involutions of the actual process of this combination having been fully worked out for certain most convenient records from the experiments inaugurated in the month of July 1911, it is unnecessary to elaborate this point further with reference to the above June results.

Only the above-mentioned shortest-period recovery which, incidentally and neglecting the two longest-period returns, attained the most northerly stranding-place, need be considered in detail at this stage. The bottle referred to was returned from the vicinity of Fedje Fjord, in latitude 60° 50′ N., 97 days after liberation at Station 2. According to the curve of velocities this drifter covered a total distance of about 920 miles at a mean daily rate of $9\frac{1}{2}$ miles. By this calculation, it can be demonstrated graphically, there is insufficient time to allow of a complete circuit of the original North-East Dogger Bank Swirl. To absorb the full drift-period, therefore, the course estimated for this bottle is made to pass a little way into the Kattegat, a postulate which receives support from the analysis of some of the previous records for the year, notably certain of those pertaining to the experiments of April.

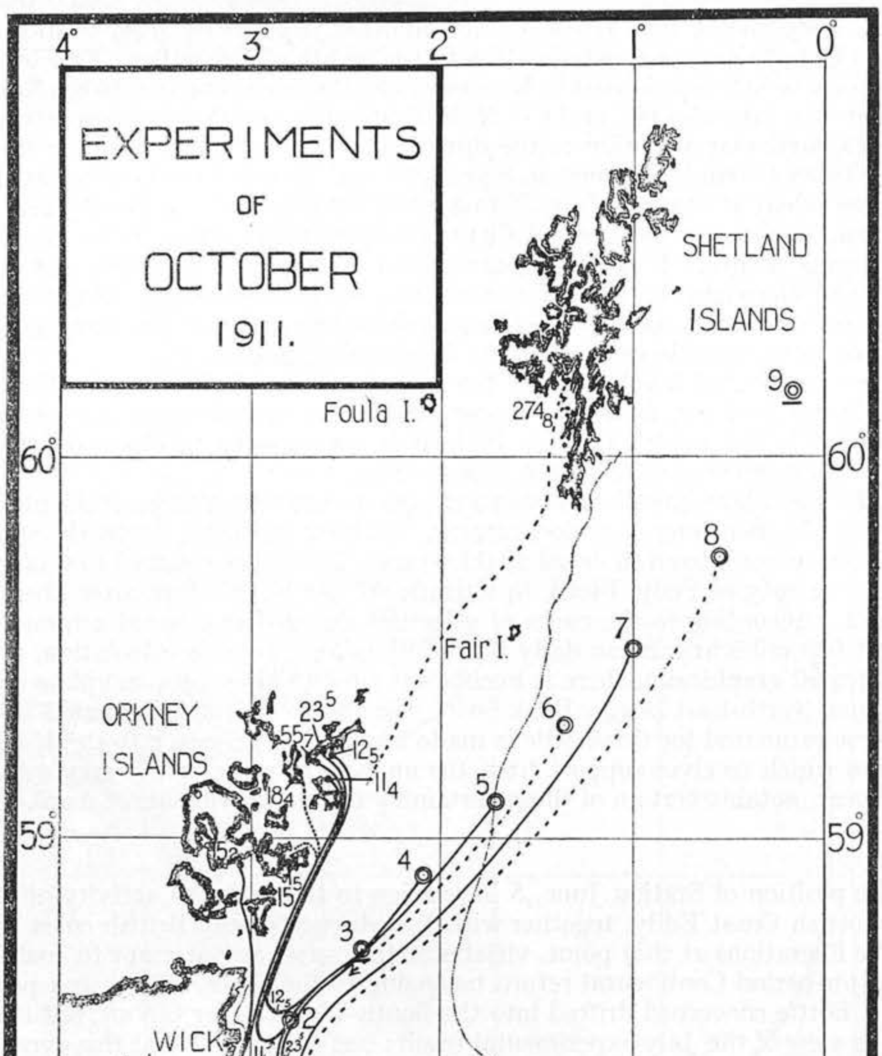
The position of Station $\text{June}_{11}5$ in relation to the region of activity of the Mid-East Scottish Coast Eddy, together with the absence of any British coast recovery from the liberations at that point, vitiates at the outset any attempt to analyse even the shorter-period Continental return belonging to the series. There is a possibility that the bottle concerned drifted into the South-West Dogger Circuit, but it is more likely, in view of the July experimental results (see Figure 26), that this gyration was avoided and that, after leaving the mid-east Scottish coast region from a latitude higher than that of the liberation-station, the drifter passed fairly rapidly eastwards and into the North-East Dogger Bank Eddy. In any event, two complications were doubtless encountered in the interval between the middle of June and the middle, practically, of December 1911, when the recovery took place on the west coast of Denmark, near Lyngvig Light.

* * * * * * *

At its present stage the curve of velocities extends only to the date 18th September 1911. It is from the results of the October 1911 experiments that the curve can be advanced further. These results are therefore now taken.

October Liberations.

The work of despatching drift-bottles was continued during the month of October 1911 on a line of nine stations commencing over Smith Bank in the Moray Firth and running north-eastwards for about 150 miles. These stations were visited on the



EXPERIMENTS
OF
OCTOBER
1911.
SHETLAND
ISLANDS
Foula I.
Fair I.
ORKNEY
ISLANDS
WICK
ABERDEEN
4°
3°
2°
1°
0°
60°
59°
58°

Figure 30.

11th and 12th days of the month, 12 bottles being cast adrift at the first point and five from each of the remaining eight, with the exception of Station 8, from which 10 bottles were liberated. On the 15th of the month a further five bottles were set afloat at a point a few miles off Buchan Ness, Aberdeenshire.

Recoveries from the above experiments totalled 16, the most significant being those seven returned from Orkney and one from Shetland. The points of origin of these drifters were Stations 2, 4, 5, 7 and 8. Three recoveries took place on the north-western shore of the Moray Firth, all three emanating from Station 1. Likewise, all four bottles picked up on the north-eastern corner of Aberdeenshire belonged exclusively to the last group of bottles to be despatched. Only one recovery was effected on a foreign coast, namely, on the Island of Senienö in Northern Norway. This bottle registered a drift-period of about six and a half months.

Among the recoveries effected upon the shores of Orkney none stands out clearly as an index of the probable routes overtaken by the others. At first sight it would appear to be unfortunate that the stranding-place of the only recovery from the Station 2 group of drifters is somewhat inaccessible to the open sea, but, as will be evident in the following, the practical analysis of the drift-period of the bottle in question does lead to a consistent explanation of most of the other returns from these islands.

The positions, relative to each other, of the liberation-station and the stranding-place at once indicate a northerly drift of surface waters towards Orkney from the region of the Moray Firth, but a direct course for the Station 2 drifter leads to the deduction of a low mean rate of drift to which the remaining returns cannot be made to conform, having regard to the several requirements of this analysis. It is conceivable, however, that this bottle cruised first of all in a southerly direction into the Moray Firth and was to a certain extent influenced by the Moray Firth Eddy, which the results from Station 1 indicate to have been in operation at the time. On this hypothesis, a course of about 120 miles is represented on Figure 30, thus entailing an average daily rate of progress of eight miles. It will be observed that the estimated route passes round the boundary of the Moray Firth Eddy.

A similar course into the Moray Firth obviously cannot be advanced for the earlier Station 4 recovery as this would mean the assumption of a drift-speed almost double of that deduced above. But, arising from the route accepted in regard to the Station 2 bottle, it is evident that, in the area off Wick, contrary-flowing drift-streams passed in fairly close proximity to each other ; so that a drifter proceeding southwards on the western edge of the stream making in that direction might readily pass over into the northerly directed current in this region. In the case of the 11-day Station 4 bottle a course of about 90 miles would be covered in this manner at a uniform rate of just over eight miles per day.

A second recovery resulting from operations at Station 4 was effected on the Island of Eday, Orkney, seven days after the first bottle. Clearly, the same route to within 15 miles of the stranding-place, as that laid down for the earlier return is inadmissible in view of the difference between the drift-periods, the two stranding-places being in practically the same latitude. On the other hand, a course by way of the southern boundary of the Moray Firth Eddy for the longer-period drifter argues a mean rate of drift of not less than nine miles per day. Some minor deviation in the bottle's passage, perhaps in the near vicinity of one or other of the Orkney Islands, may have been responsible for a delay of several days in the time of stranding.

From Elsness, Sanday, a bottle belonging to the Station 5 group was returned after only 12 days. A route almost identical with that estimated in respect of the earlier Station 4 recovery would be accomplished in this interval at an average rate of eight miles per day. From the same island of the Orkney group, almost from the same stranding-place, a second Station 5 bottle was returned after 23 days, the longer period suggesting a route by way of the periphery of the Moray Firth Eddy.

Thus a course of about 190 miles would be overtaken in the time recorded at an average velocity of $8\frac{1}{4}$ miles per day.

A third bottle emanating from Station 5 and found on the western shore of Deerness, Orkney, registered a drift-period of 15 days. In comparison with the above cases this bottle seems to have been influenced by some peculiarity of the drift other than revealed so far by this analysis, since, to have come by way of the inner Moray Firth it must needs have travelled at an average rate of about 12 miles per day and the hypothesis that the full 15 days were occupied in traversing a route similar to that of the 12-day recovery on Sanday Island entails a drift-velocity of only six miles per day.

Obviously, the longer route, embracing the Moray Firth Eddy, is indicated by the magnitude of the drift-period registered by the sole recovery pertaining to Station 7. Even so, the lineal distance of 225 miles to Sanday Island was doubtless overtaken in less than 55 days. At a mean daily rate of eight miles only 28 days would be required. The remaining 27 days are to be explained by eddy circuits and the magnitude of the residual period is in conformity with such an explanation, since it has been several times established in course of this analysis that the Period of Circuit of the Moray Firth Eddy is in general about seven days.

A single recovery was the ultimate outcome of operations at Station 8 and this took place on the Island of Flotta in Weisdale Voe, Shetland. The date of recovery was the 12th of July 1912 and under the circumstances little purpose would be served by investigating at the present stage the probable history of this very long-period bottle. The record, nevertheless, is useful as demonstrating a continuation northwards beyond Fair Isle of the drift-stream which apparently had its source in the waters of the Moray Firth.

In the light of the above instance it may be inferred that the drifter belonging to the series despatched from Station 6 and returned from northern Norway cruised northwards on the west side of the Shetland Islands and either re-entered the North Sea to come under the influence of the Great Eddy, or proceeded at once towards the Norwegian coast.

It is of interest to compare the foregoing analytical results, especially their cartographical interpretation, with the courses preferred against two bottles, liberated in the month of August 1911 in the area to the west of Orkney and the Outer Hebrides and subsequently found on the same day, the 15th of October, at different places in the former group of islands. Here again, if the explanations vouchsafed in all these cases are fundamentally true to fact, may be demonstrated the precision with which at least *surface* hydrographic changes can be measured by means of drift-bottles.

The cause of the apparently long delay in the stranding of the two August bottles is ascribed to the operation of an anticyclonic drift encompassing the Orkney Islands. On the other hand, the explanation advanced in relation to the final stages of the routes overtaken by those Orkney recovered bottles liberated and, in all but two cases, returned during the month of October 1911, is at first sight in direct opposition to the existence of an anticyclonic circuit within the region in question.

A consideration, however, of the various dates involved shows that the results of the August and October liberations, as interpreted in these pages, do not conflict with each other. Rather they may be taken to signify a reversal in the direction of the surface drift along and off the eastern shores of Orkney, the transformation taking place round about the middle of October 1911, or, as nearly as can be gauged, between the 12th and 19th days of that month.

All three recoveries from the liberations at Station 1, in the Moray Firth, were effected at the same place on the eastern, that is, the Moray Firth, shore of Caithness-shire. The fact that one drifter was picked up 10 days later than the other two indicates, of course, the influence of the Moray Firth Eddy. This difference between the magnitudes of the drift-periods might also suggest that, in the month of October 1911, the Period of Circuit of the complex was in fact *ten* days and not seven days, but the consequences of such an assumption in the analysis of the remainder of the month's results are such as to seriously impair the over-all consistency above obtained.

A course of about 160 miles, involving two complete circuits of the eddy, can be demonstrated practically for the 20-day recovery at Latheron. To preserve the consistency of the analysis, however, especially as regards drift-speeds, it is accepted that the two 10-day bottles soon escaped from the dominating influence of the Moray Firth Swirl and drifted towards Tarbet Ness, to be turned northwards on approaching the shallower waters of the Dornoch Firth. In this way a course of about 80 miles would be accomplished.

Little can be said in explanation of the results from the final series of liberations for the year, namely, those carried out in close proximity to Buchan Ness and from which four drifters stranded on the nearby coast after four days each. It is most probable that these bottles set away from Station 10 in a south-westerly direction and were turned westwards into Aberdeen Bay—perhaps under the influence of a strong ebb tide—thereafter making their way northwards again along the Aberdeenshire coast.

By referring the above-deduced velocities to the time-velocity diagram (Figure 32) in the customary manner, that is, taking for granted that these mean velocities denote *actual* velocities on the mid-dates of the several drift-periods involved, the velocity-curve may now be extended practically to the end of the month of October 1911.

* * * * * * *

September Liberations.

On the 11th and 12th days of this month, ten surface drifters were liberated at each of 10 points off the Scottish east coast between the Firth of Forth and Kinnaird Head, Aberdeenshire. Two stations within the Moray Firth were visited on the 15th and 19th respectively, ten bottles being despatched in each case.

Twenty-five returns were subsequently recorded. Ten of these came from the British east coast and the remaining 15 from the Norwegian coast north of latitude 60° 30′ N. In fact, of the latter, those which were recorded within a year of their dates of liberation were found to the north of latitude 62° 30′ N., that is, outwith the bounds of the North Sea. It is noteworthy that no recovery was effected in the Skagerak region.

Eight of the British coast recoveries were located within about 60 miles of one another, between Blyth in Northumberland and Robin Hood's Bay, Yorkshire. All were returned during the month of October 1911. Four belonged to the Station 1 series, two originated at Station 3 and one at each of Stations 8 and 9. The drift-periods registered by these bottles are of such magnitudes that the assumption of direct courses in the cases of even the shortest-period drifters entails a mean drift-speed of only four miles per day. Not only is this figure inconsistent with much of the foregoing analysis, but the evidence to be derived from some of the earlier Norwegian coast returns from the same experiments suggests that it is too low.

A further examination, however, of the drift-periods of the British returns reveals the fact that, as in the case of the similar data pertaining to the experiments begun in the month of March 1911, they are more or less periodic, thus :—

TABLE XXXIX.

Drift periods	26	28	33	39	46	46	46	47
Mean periods	27		33	39	46			
Differences		6		6		7		

The implication of the above figures is self-evident. On the basis, therefore, of the operation of a swirl of surface waters with a Period of Circuit of seven days, in the area off the Estuary of the Tay, as represented on Figure 31, the following table, in conjunction with the series of curves on the chart, shows how closely the histories of the eight British coast recoveries are doubtless related.

TABLE XL.

SEPTEMBER 1911 *LIBERATIONS.*

Histories of British East Coast Recoveries.

Recovery.	Number of Days in Eddy.	Course in Miles exclusive of Eddy Circuits.	Mean Daily Speed of Drift outwith Eddy. (Miles per Day.)
26_1	7	170	8·9
28_1	7	185	8·8
33_1	14	170	8·9
39_1	21	160	8·9
46_3	28	160	8·9
47_3	28	165	8·7
46_8	28	160	8·9
46_9	28	160	8·9

Plotting the quantities in the last column of Table XL. against the mid-dates of the respective periods of drift it is found that the points so obtained lie on or close to the velocity-curve.

With regard to the return of two bottles from the vicinity of Fraserburgh, one each from Stations 11 and 12 in the Moray Firth, it may safely be inferred from the magnitudes of the drift-periods that the Moray Firth Eddy was in operation at the time of these experiments, a deduction which is substantiated by the results of experiments initiated during the following month.

The almost identical courses given on Figure 31 for the above two bottles yield figures, in relation to the mean rate of drift, of between $8\frac{1}{2}$ and 9 miles per day, thus conforming to the exigencies of the velocity-curve (Figure 32).

In view of the extreme probability of those drifters which ultimately reached the more northerly latitudes of the Norwegian coast having negotiated more than one surface water complication in their courses within the North Sea area, little purpose would be served by an attempt to estimate the several times spent on various likely sections of the routes eastward across the North Sea and subsequently northward along the Norwegian coast.

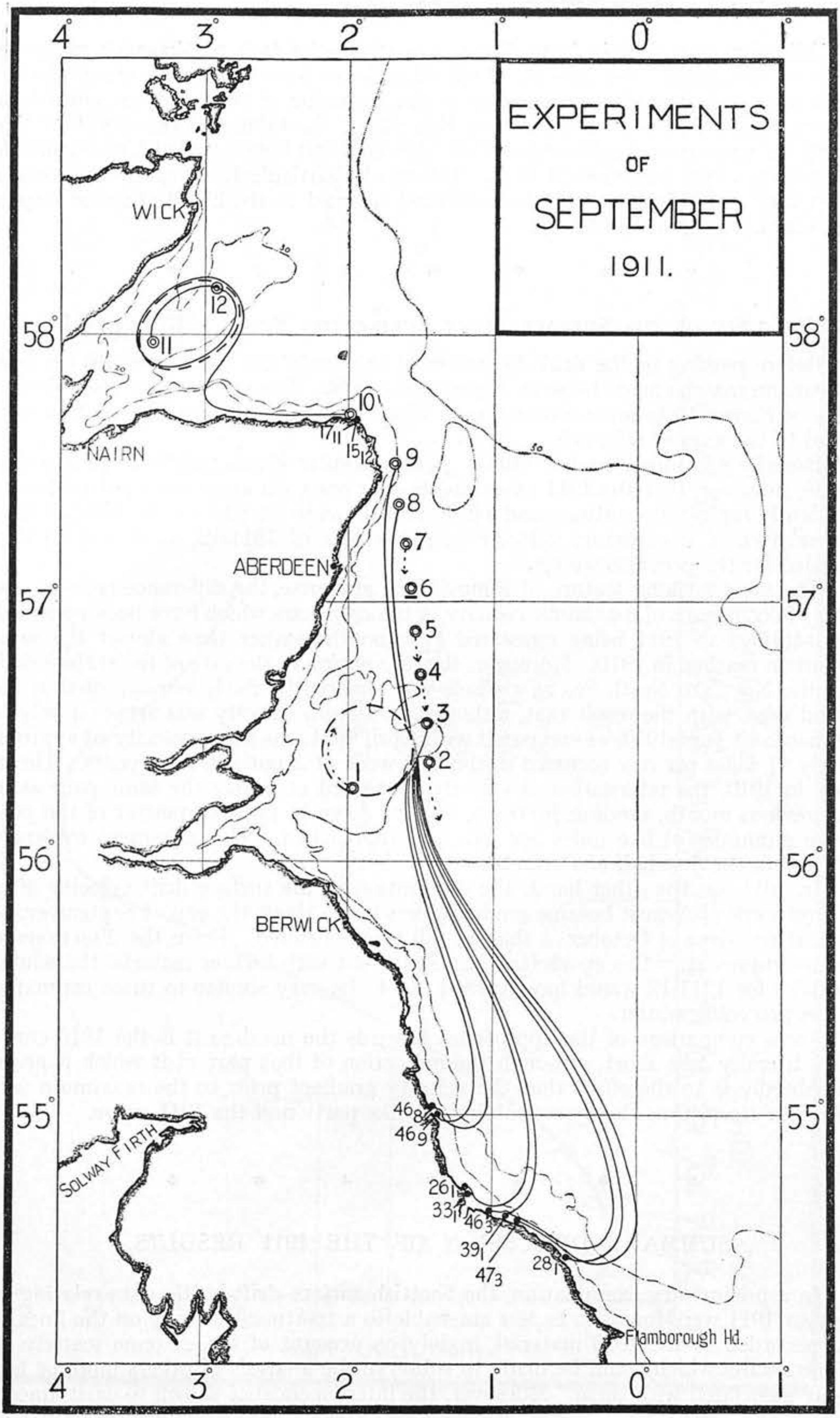

EXPERIMENTS
OF
SEPTEMBER
1911.
4°
3°
2°
1°
0°
1°
58°
57°
56°
55°
WICK
NAIRN
ABERDEEN
BERWICK
SOLWAY FIRTH
Flamborough Hd.
30
20
1
2
3
4
5
6
7
8
9
10
11
12
17₁₁
15₁₂
46₈
46₉
26₁
33₁
46₃
39₁
47₃
28₁

Figure 31.

Attention has already been directed to the entire lack of Skagerak recoveries from the September experiments. Such might have been expected towards the end of the year presently under review, or in the beginning of 1912, but, as pointed out at some length in the Introduction to this paper, the tabulated records show that during the three months, December 1911, January and February 1912, no significant Skagerak recovery was effected at all. This result, particularly as regards the months of January and February 1912, is in marked contrast to the like findings in respect of the same two months of 1911.

* * * * * * *

VELOCITY OF THE SURFACE DRIFT DURING THE YEARS 1910 AND 1911.

Before passing to the final discussion of the analytical results for 1911 a brief comparison may be made between Figures 19 and 32. For this purpose the velocity-curve of Figure 19 is superimposed upon Figure 32 in its appropriate position with regard to the axes of reference.

Broadly speaking, the two curves possess similar characteristics. It is unfortunate, however, that the 1911 experiments over open sea areas were not prolonged sufficiently far into the autumn and winter months as to afford some definite information relative to a minimum velocity in the winter of 1911-12, analogous to that recorded for the previous winter.

The most striking feature of Figure 32 is, of course, the difference between the times of occurrence of maximum velocity in the two years which have been reviewed, that attained in 1911 being registered two months earlier than almost the same maximum reached in 1910. Moreover, the diminution in the rate of the surface drift over the Northern North Sea as a whole was apparently much more gradual in the second year, with the result that, although maximum velocity was attained only in the month of June 1910, as compared with April 1911, the same velocity of approximately $9\frac{1}{4}$ miles per day occurred in the first week of August in both years. Thereafter, in 1910, the retardation of velocity continued at nearly the same pace as in the previous month, tending, however, to slow down in the last quarter of the year as the minimum of five miles per day was approached. This minimum evidently occurred in the first half of December.

In 1911, on the other hand, the diminution in the surface drift velocity after the first week of August became gradually less until, about the end of September, or the first few days of October, a sharper fall was registered. From the directions of the two curves after this epoch it seems likely that with further material the winter velocities for 1911-12 would have turned out to be very similar to those estimated for the preceding winter.

For a comparison of the approaches towards the maxima it is the 1910 curve which literally falls short, although the indication of that part of it which is given undoubtedly is to the effect that the velocity gradient prior to the maximum was somewhat steep, thus closely resembling the like portion of the 1911 curve.

* * * * * * *

SUMMARY DISCUSSION OF THE 1911 RESULTS.

In a preliminary examination, the Scottish surface drift-bottle data relating to the year 1911 were found to be less amenable to a treatment exactly on the lines of that accorded to the 1910 material, mainly on account of the extreme scarcity of unique results which could be made to subserve the analysis of others more or less closely associated with them. Moreover, the interdependence shown to exist among

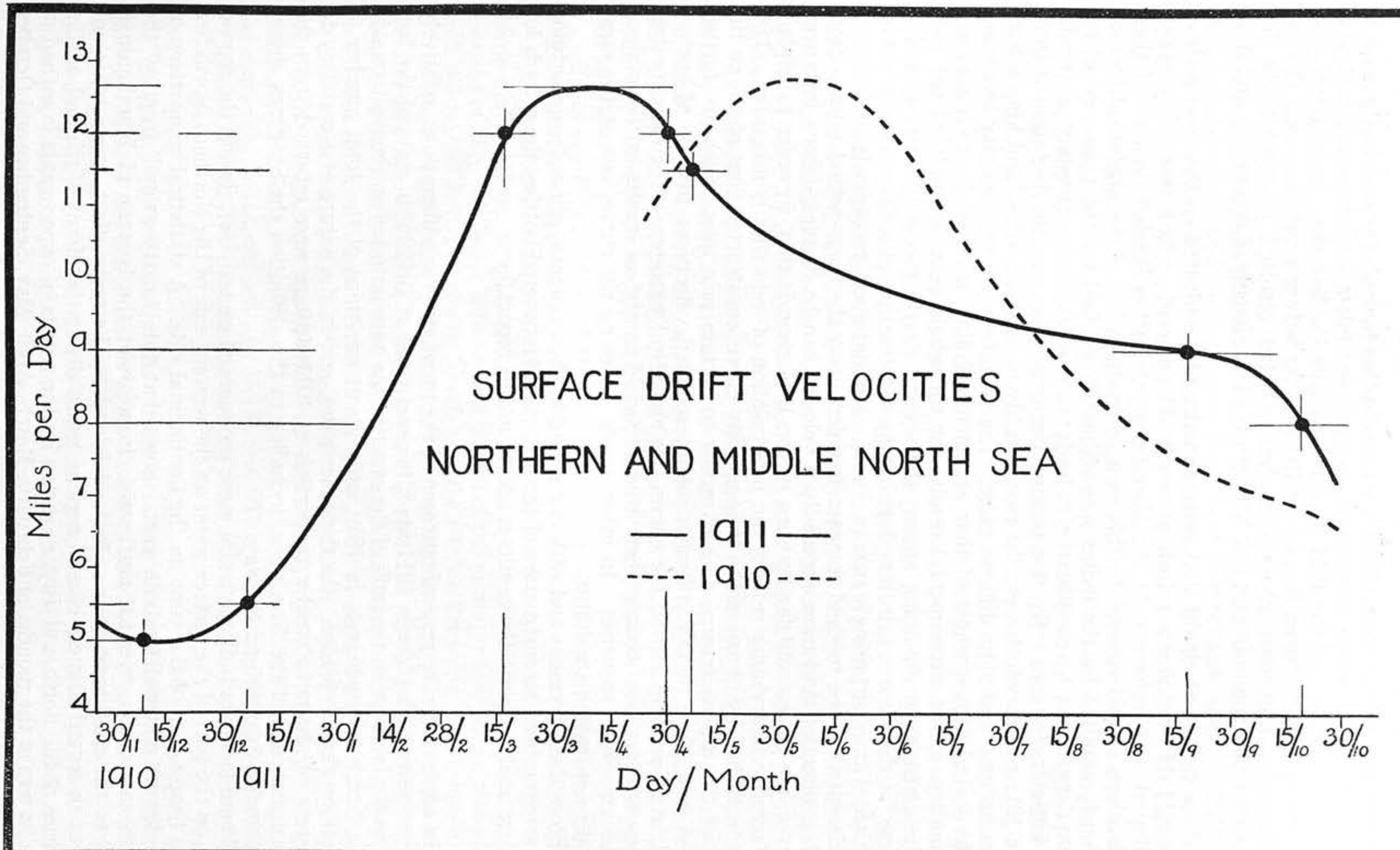

SURFACE DRIFT VELOCITIES
NORTHERN AND MIDDLE NORTH SEA
1911
1910
Miles per Day
13
12
11
10
9
8
7
6
5
4
30/11 15/12 30/12 15/1 30/1 14/2 28/2 15/3 30/3 15/4 30/4 15/5 30/5 15/6 30/6 15/7 30/7 15/8 30/8 15/9 30/9 15/10 30/10
1910
1911
Day/Month

Figure 32.

so many of the 1910 records, effectively contributing towards the sustained argument of the results of the entire year's work, was very much less in evidence in a first essay on the " evaluation " of the 1911 returns. Despite the fact that, in the latter year, experiments were initiated in each of the months between February and October inclusive, the numerous liberations thus effected resulted in remarkably few recoveries forming an obvious link between the experiments of one month and those of another.

There can be no doubt that, with experiments conducted on the same scale as those of 1911, yielding a return of nearly 30 per cent., which was fairly evenly distributed with reference to the liberations, at least a limited number of these relationships should ensue. In this belief a modification of the analytical method previously adopted by the writer was ultimately devised for the treatment of the present data, but such a modification as leads to a more exacting analysis of practically each individual record. By this means connections were established among those of the 1911 results which were the more readily understood, thus furnishing a basis for the argument of more difficult cases. The validity of the method may be gauged by the logical consequences of that argument, leading, as they do, to a coherent explanation of the experimental results for the whole year, exemplified not only by the consistency obtaining among the several charts giving the cartographical histories of the returned drifters, but by the construction of a time-velocity curve, to which, within surprisingly narrow limits, each and every recovery is subject.

Essentially, the method is again founded upon the short-period return, from which a direction and more especially a velocity can be derived. Such instances, however, are so few and far between in the 1911 records that, in order to explain satisfactorily intervening results, the interpolation of velocities is necessary. This is accomplished by means of the time-velocity curve, constructed, first of all, on the basis of the unique returns and according to certain principles which are further carried into effect in the utilisation of interpolated velocities—that is, of vectors which are " read-off " from the curve—for analytical purposes. The supreme test of these vectors is, of course, their fitness to yield consistent results in the analysis of the numerous recoveries. In other words, by using the curve, one at the same time demonstrates its validity.

From these premises and with due regard to the axiomatic principles underlying the cartographical reconstruction of the histories of recovered bottles, the records for 1911 are analysed with the results set forth in this report.

In contrast to the general outcome of the previous year's liberations, relatively few recoveries took place in 1911 upon the east coast of Britain, in spite of the fact that, in the latter year, the bulk of the experiments were initiated on the western side of the North Sea, whereas, in 1910, only about one-third of the total number of liberations were so placed. On the other hand, and in the nature of a corollary to this state of affairs, a greater proportion of 1911 drifters were returned from the eastern seaboard of the North Sea, including in this definition the Skagerak shores of Denmark, Sweden and Norway.

These facts are indicative of a more pronounced easterly set, during the second year, on the part of the surface water on the western side of the Northern North Sea and a heaping up of the same on the Continental side. A statistical comparison of the relevant material for both years shows that this " carry away " from *off* the British east coast extended northwards from about the latitude of Flamborough Head to the northmost of the Shetland Islands. The same effect, however, is not evident in regard to more coastal regions, especially in the Moray Firth and off the estuaries of the Forth and Tay, as shown by the results of experiments launched in these waters in the months of February, March, April, May, September and October 1911.

On the whole, however, the interpretation of the experimental results for 1911 is fundamentally the same as that which was evolved from the investigation of the material for the previous year.

With reference first of all to the region west of Orkney and Shetland, embracing the Faroe-Shetland Channel and the area over the Wyville-Thomson Ridge, the second year's data, independently, are even less adequate as a basis for conclusively detailed statement concerning the prevalent surface water movements in that area, but the broad issues of their analytical treatment corroborate the essential findings of the former analysis, especially as regards the close hydrodynamical relationship between this region and the Northern North Sea.

For the second time, and in succeeding years, liberations carried out in the month of August over the area of the Continental Shelf to the west of the mainland of Scotland and the Outer Hebrides resulted in a number of recoveries upon the Orkney Islands, but *none* upon Shetland, pointing to a differentiation between the surface currents of the northern and southern reaches of the Faroe-Shetland Channel. This differentiation, it has already been deduced, takes the form of a division—approximately in the latitude of 59° 30′ N., or 59° 45′ N., in the area between Orkney and Shetland—in the drift-stream approaching immediately from the west towards the Fair Isle-Sumburgh Head Channel. One part of the divided stream turns more or less sharply northward, passing along the western shores of Shetland. The other offshoot deviates with like suddenness in a southerly direction, keeping close to the *eastern* shores of Orkney, and, if conditions are favourable, involves the Orkney group in an anticyclonic eddy. Certain of the experimental results pertaining to the month of May 1911, besides those accruing from August liberations, support this thesis.

As regards the last-mentioned phenomenon, namely, the circulation round Orkney, conditions unfavourable to its operation appear to have set in about the middle of October 1911, for, while the August results indicate the presence of such a system until at least the beginning of October, the Orkney Island recoveries ensuing from the liberations of the latter month are incompatible with the same local circumstances.

From the 1911 analysis nothing is added to previous information relative to a similar anticyclonic gyration enveloping the Faroe Islands, nor to the phenomenon of a small eddy sometimes located midway between Faroe and Shetland. At the same time, evidence is again available pointing to a direct current connection, in the months of May and June, between the waters of the eastern Faroe submarine plateau and the waters of the Northern North Sea, the connection being established by way of the north of Shetland. This would appear to signify a southerly directed current on the east side of Faroe, thereafter turning east and north-east, forming in mid-channel a modified loop within which, although the examination of the data does not reveal its existence in 1911, a small cyclonic eddy might function. Later in the season, about the month of August, the north-easterly current flowing along the edge of the Continental Shelf to the west of Shetland, apparently proceeds on a more northerly-directed course with, therefore, less tendency to turn eastward again and subsequently southward into the North Sea. This deduction, it may be observed, is common to the analyses pertaining to both years which have so far been dealt with.

In the present report also, the system of surface water drift in the Northern and Middle Areas of the North Sea is again shown to have been extremely complicated in the particular year under survey. Nevertheless, the term " system " is quite legitimately applied, since, on the broadest view, the latest analysis discloses once more the fundamental cyclonic motion propounded by Fulton in 1897, with the same difference as was brought out by the 1910 analysis, to the effect that the momentum of this cyclonic stream is derived in greatest measure from the north, that is, through the opening between Shetland and Norway and not to any significant extent by way of the channels between Shetland and the mainland of Scotland. This matter, which will be further alluded to in another connection, is obviously of prime importance in any question concerning the water economy of the North Sea as a whole.

The analogy of the two years, 1910 and 1911, goes much further than this. The major complications in the surface water movements of the above-mentioned areas, as ascertained from the 1910 analysis, are again revealed in the course of the elucidation of the 1911 records. The Great Northern North Sea Eddy, one at least of the Dogger Bank Swirls and the closed gyratory systems off the Scottish east coast appear to have been operative throughout the greater part of the latter year, with one or two important modifications from the representations of these systems given in the charts for 1910.

Particularly is this the case in regard to the Great Northern North Sea Eddy, which seems to have had a more precarious existence during 1911 than a year before. As a closed system its region of activity in the second year was evidently very much restricted and the cartographical interpretation of the results of the liberations of February, May and August 1911 implies a certain amount of longitudinal movement on the part of this complex. There is some justification, too, in the foregoing analytical results, for the suggestion that this movement was of a rhythmical character. The point will be further discussed when the matter of drift-velocities is considered, but it may be noted now that, in May 1911, the system was situated in a more northerly position than that which it occupied three months before, namely, in the month of February. Three months *later* the eddy had reverted almost to its February position.

A further point of difference in the mode of operation of the Great Eddy in 1911, as compared with the previous year, is that, while retaining its elliptical shape, the major axis of this ellipse, defined fairly nearly in 1910 by longitude 2° E. was, in the next year, inclined at an angle of about 30° to this meridian, corresponding roughly with the compass directions N.N.W.-S.S.E. In great measure, this factor no doubt accounts for the remarkable preponderance of 1911 recoveries, as against those registered in the previous year, upon the North Sea section of the Norwegian coast between Lindesnaes and latitude 61° N., and also for the much smaller return from places on the British east coast in respect of 1911 liberations in open sea areas.

Associated to some extent with the functioning of the above circulation is the undulatory nature of the path of the main drift-stream which, as an offshoot from the Norwegian Atlantic Stream emanating from the Faroe-Shetland Channel and passing eastward through the southmost reaches of the Norwegian Sea, bends sharply southward and south-westward (following closely the contour of the northern edge of the Continental Shelf) to cross latitude 61° N. and enter the Northern North Sea almost half-way between Shetland and Norway. It is highly significant that this striking peculiarity in the direction of the surface drift in the northern entrance to the North Sea is for the second time, in consecutive years, deduced from the results of drift-bottle experiments.

On this same theme of the passage of surface water into the Northern North Sea from the region of the Faroe-Shetland Channel, a preliminary survey, on statistical lines, of the 1911 data, strongly supports the contention of the 1910 analysis to the effect that, hydrodynamically, the direct link between those areas lies by way of the north of the Shetland Islands and so through the seaway between them and the Norwegian coast. The more intimate cartographical investigations of the present paper endorse this finding. Incidentally also it appears that, " in the height of the season," only a matter of 50 or 60 miles on the Norwegian side of the above opening is occupied with surface water definitely escaping from the North Sea.

On the other hand, the data for 1911 are not so conclusive as those for the previous year in regard to the closure, even temporarily, of the channels between Shetland and the mainland of Scotland. In particular, the widespread liberations of May 1911 did not yield evidence of a similar nature to that from which, for the corresponding season of 1910, this phenomenon was deduced. Nevertheless, from the meagre evidence which is to hand and by inference from the directions of the curves in the North-Western North Sea on several of the charts, it can be argued that, again in 1911, any influx of surface water into the North Sea by way of these channels was by no means of the same significance as the flow from the north.

To be more explicit the 1911 records do not reveal the existence, during the summer of that year, of a system of surface drift in the North-Western Area of the North Sea, involving a narrow, northerly flowing current off the eastern shores of Orkney and Shetland, such as that demonstrated for the corresponding period of 1910. The experimental results pertaining to the month of May 1910 have, however, their analogue in this respect in the records compiled from the liberations of October 1911. The analysis of the latter data strongly suggests the operation of a reversal of the southerly drift in the eastern neighbourhood of Orkney and perhaps extending north to Shetland. This applies to the latter half of the month of October.

Following from these considerations, and in some degree consequent upon the peculiar position of the Great Eddy throughout 1911, the main drift-stream heading southwards into the North Sea appears to have expanded laterally over the North-Western Area after being " shouldered off," as it were, by the circulatory complex. Nevertheless, apart from its southerly impetus, the tendency of the drift was towards the east rather than the west. This was more markedly the case in the Middle Area of the North Sea, where, as far west as longitude 1° W. and in summer months particularly, the eastward deviation was so pronounced as to carry extremely few, if any, bottles of open-sea origin into the South-West Dogger Bank Swirl, which, as a result, enters hardly at all into the discussion of the 1911 data.

On the other hand, the similar complex situated as a rule over the north-eastern end of the Dogger Bank is concerned in the histories of a very large number of the recoveries accruing from the 1911 experiments and, as in the case of the Great Eddy, circumstantial evidence again points to a seasonal translation of the swirl, first northwards in the early part of the year and later southwards. The amplitude of this movement does not appear to have been so great as in the case of the Great Eddy, but there is little doubt that the two movements were in some way related, probably in the manner suggested below. Another phenomenon, however, concerned with the North-East Dogger Bank Eddy and one which did not arise from the 1910 analysis, forms the substance of a considerable section of the present report, being worked out in great detail from the results of three experiments very fortunately placed in relation to the above complex and another similar system functioning in the area off Lindesnaes. The latter Böhnecke named the Lindesnaes Eddy.

Until the end of the month of July, in fact, almost precisely until the 2nd of August 1911, the North-East Dogger Bank Swirl, which in the three or four months prior to this date was moving gradually northwards from the region over the Tail End of the Dogger Bank, was characterised by what the present writer has termed a *Period of Circuit* of 20 days. The same magnitude, it will be recalled, was deduced under similar circumstances from the previous year's drift-bottle material. At the same time, there seems to have been in existence to the south-west of Lindesnaes a smaller cyclonic eddy to which the analysis of certain of the year's results attribute a Period of Circuit of approximately 16 days. This circulation was also subject to a slow translatory movement westwards in the month anterior to the 2nd of August. On or about this day, however, the present analysis almost conclusively asserts that these two systems " joined forces " by coalescence with each other, the resultant complex having a Period of Circuit of about 27 days and according to further evidence commencing almost immediately a southerly movement, which continued until the end of August or the beginning of September.

The elucidation of this phenomenon from a study of drift-bottle records is a striking tribute to the value of such experiments, demonstrating the potentialities of carefully planned liberations over selected areas in respect of which information of a hydrographical nature is desired. In the case in point, useful information can obviously be derived, as to surface hydrodynamical conditions off the entrance to the Skagerak, from a consideration of the times of strandings upon west Danish and Skagerak shores, perhaps also on southerly Norwegian coasts, of drifters despatched from points in the area between the north end of the Dogger Bank and some 30 miles north of the Great Fisher Bank. The experimental results of the two years now reported upon indicate that this information should be forthcoming in from three to six weeks after the date of the inauguration of experiments in this region.

During 1910, one effect apparently of the North-East Dogger gyration was to withhold, temporarily, from further progress towards and into the Skagerak, numerous drifters liberated in various months over a wide area of the Northern and Middle North Sea, outwith the region encompassed by the Great Eddy. The " blank " months of 1910, so far as Skagerak recoveries are concerned, comprised almost the whole of the last quarter of the year. In the first three months of the next year, however, these bottles which had been so delayed were found in significantly large numbers upon shores bounding the Skagerak. Despite expectations to the contrary, justifiable in view of the above-mentioned complications in the surface current system off the Skagerak entrance, the same tendency is less a feature of the 1911 records. At least two returns of this class are recorded in each of the twelve months of the second year. There is, nevertheless, a suggestion of a " blank " period, in relation to the Skagerak recoveries resulting from the 1911 liberations, comprising the interval between the beginning of December 1911 and the end of February 1912, although, by reason of the disposition in time and place of the later liberations of the former year, too much stress cannot be laid on this result.

Another coastal region remarkable for the number of recoveries found upon it in the first three months of 1911 is the section of the Danish and Schleswig-Holstein coasts south of Blaavandshuk. The drifters in question emanated mainly from the liberations of May 1910 and were doubtless delayed in their sea passages by eddy influence. The significance of these returns is more clearly demonstrated by their discussion in conjunction with the results pertaining to the earlier 1911 experiments, from the standpoint of the mean velocity of the surface drift within the Northern North Sea during the first quarter of 1911.

Before passing, however, to the question of the drift-velocities attained in the year under immediate examination, the two eddies functioning in proximity to the east coast of Scotland, one in the Moray Firth and the other in the offshore waters of the Tay estuary between latitudes 56° and 57° N., may be referred to briefly. There is reason to believe that the first-mentioned circuit was established in the inner Moray Firth throughout the greater part of 1911 and cannot therefore be designated merely a seasonal phenomenon. Its Period of Circuit is again estimated at seven days, thus agreeing with the 1910 figure. Off the mid-east Scottish coast conditions were somewhat different in 1911 from the previous year, especially as regards the shape and therefore the area covered by the Mid-East Scottish Coast Eddy, which, in two distinct epochs of the second year, is reckoned to have been of smaller superficial area, defined by an approximately circular boundary and a Period of Circuit of only seven days, as against the corresponding magnitude of ten days accorded to the same system functioning within an elliptical perimeter in the summer of 1910.

Perhaps the most remarkable outcome of these analyses of surface drift-bottle records—not only as regards 1911, but in respect also of 1910, the data for which were somewhat less rigorously examined—is the construction, on the basis of the analytical findings for each year, of time-velocity curves. Both curves exhibit similar characteristics. In that for 1910 a maximum and a minimum velocity are registered. The 1911 curve, on the other hand, shows only a maximum, the premature cessation of open-sea liberations in that year being responsible for the termination of the curve before minimum velocity was attained. Nevertheless, the tendency of the curve in its final phase strongly suggests that the same minimum as recorded in the first half of December 1910, namely, five miles per day, was reached approximately about the same period of 1911. The two maxima, however, although of practically the same magnitude, namely, $12\frac{1}{2}$ to $12\frac{3}{4}$ miles per day, occurred at distinctly different times in the two years under discussion, the difference being one of two months. Maximum velocity in 1910 was reached only in the month of June, whereas, in the following year, this event took place in April.

In contradistinction to the final portions of the two curves it is the 1910 velocity-curve which, in its primary portion, is foreshortened on account of the lack of early material. Fortunately, the 1911 experiments commenced in the month of February, thus enabling a link to be established between them and the liberations of December 1910, mainly through the velocity-curve. Notwithstanding, the initial portions of both curves indicate a rapid acceleration in the velocity of the surface-drift in the early part of both years.

Now, there is sufficient reason to believe, or at least to suggest, that, as applied to the second year, this last-mentioned phenomenon had a direct bearing upon a certain class of recoveries effected in considerable numbers during the first quarter of the year. This is the afore-mentioned return, comprising, for the most part, bottles which were set afloat in the month of May 1910 and which stranded in the said interval on the shores of Denmark and Schleswig-Holstein to the southward of Blaavandshuk. Further investigations may throw more light on this matter.

Comparison of the curves between the times of maxima and minima leads to another consideration of no small import in regard to 1911. In 1910, the retardation of velocity was much faster than in the following year. In fact, in 1911, the diminution in the rate of flow of the surface drift was, according to the velocity-curve, almost negligible throughout the greater part of the month of September. The question arises, however, as to whether, in actual fact, the retardation of velocity was continuous from about the middle of April 1911 onwards to the end of the year.

Attention has already been drawn to certain changes in the positions, during the spring and summer months, of the Great Northern North Sea and the North-East Dogger Bank Swirls. These changes, it has been pointed out, suggest a rhythmical translatory movement on the part of these systems, first northwards between the months of February and May inclusive, and, in the next three months, southwards again. These events, in turn, indicate corresponding fluctuations in the *momentum* of the surface current from the north, probably giving rise to a small secondary maximum in velocity towards the end of the month of August 1911. Provided the data are sufficient the matter is one for investigation from the standpoint of temperature and salinity variations over the areas involved. The magnitude of this acceleration, however, would doubtless be so small as not to affect materially the substance of the analyses given in these pages. Nevertheless, the point raised is worthy of careful consideration, illustrating once again the great utility of surface drift-bottle experiments, not only as an independent piece of work, but in conjunction with the usual observations of temperature and salinity.

Finally, the broad features of the present report, which, it must be emphasised, applies in the first instance *only* to the superficial stratum of water in the sea areas investigated, are summed up in three quarterly synoptic charts appended herewith (Figures 33, 34 and 35). Each chart gives, as nearly as possible from the foregoing analytical findings, the average surface current conditions in the Northern and Middle Areas of the North Sea mainly, for the specified three months of 1911.

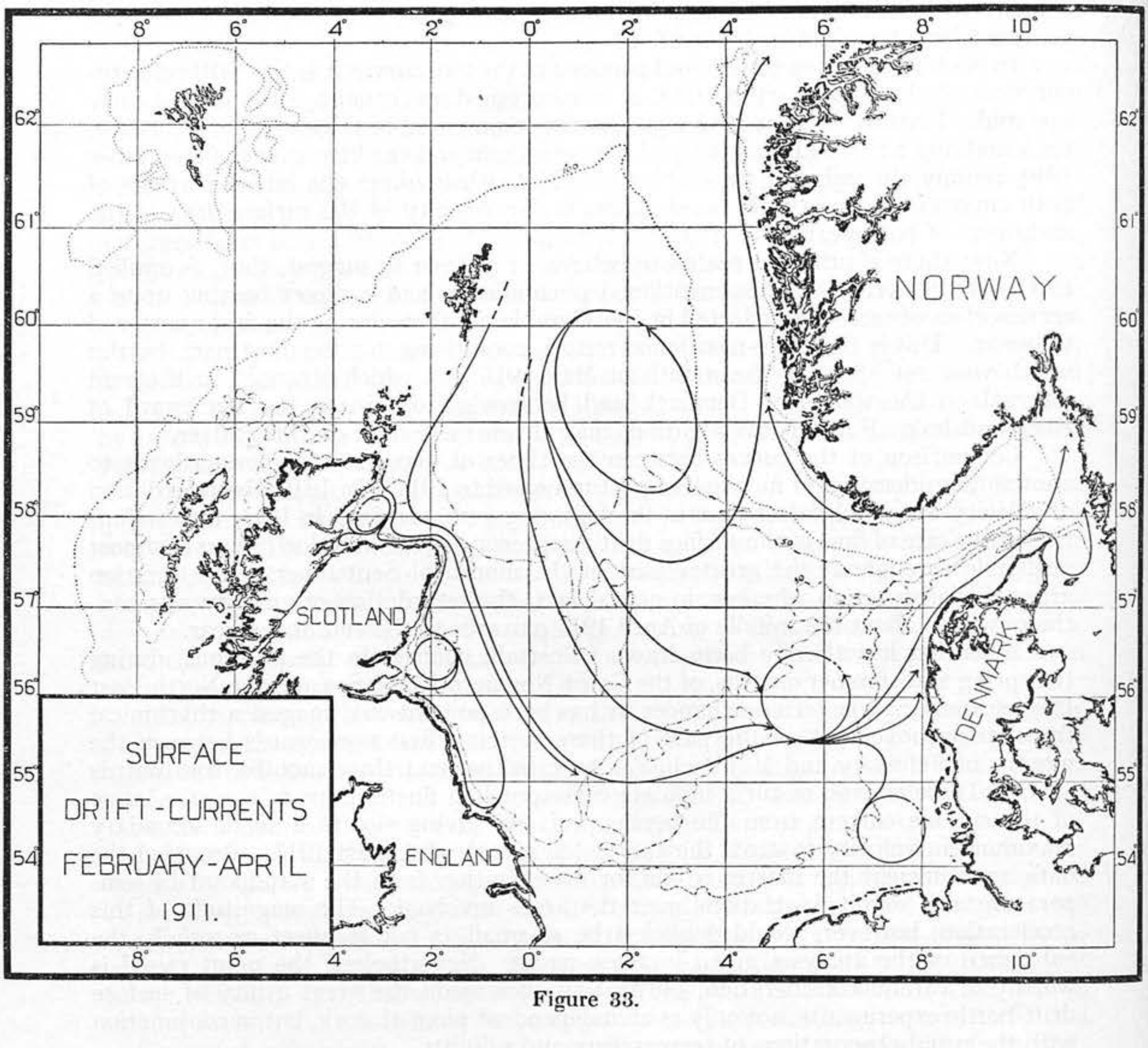

SURFACE
DRIFT-CURRENTS
FEBRUARY-APRIL
1911.
NORWAY
SCOTLAND
ENGLAND
DENMARK
8° 6° 4° 2° 0° 2° 4° 6° 8° 10°
62° 61° 60° 59° 58° 57° 56° 55° 54°

Figure 33.

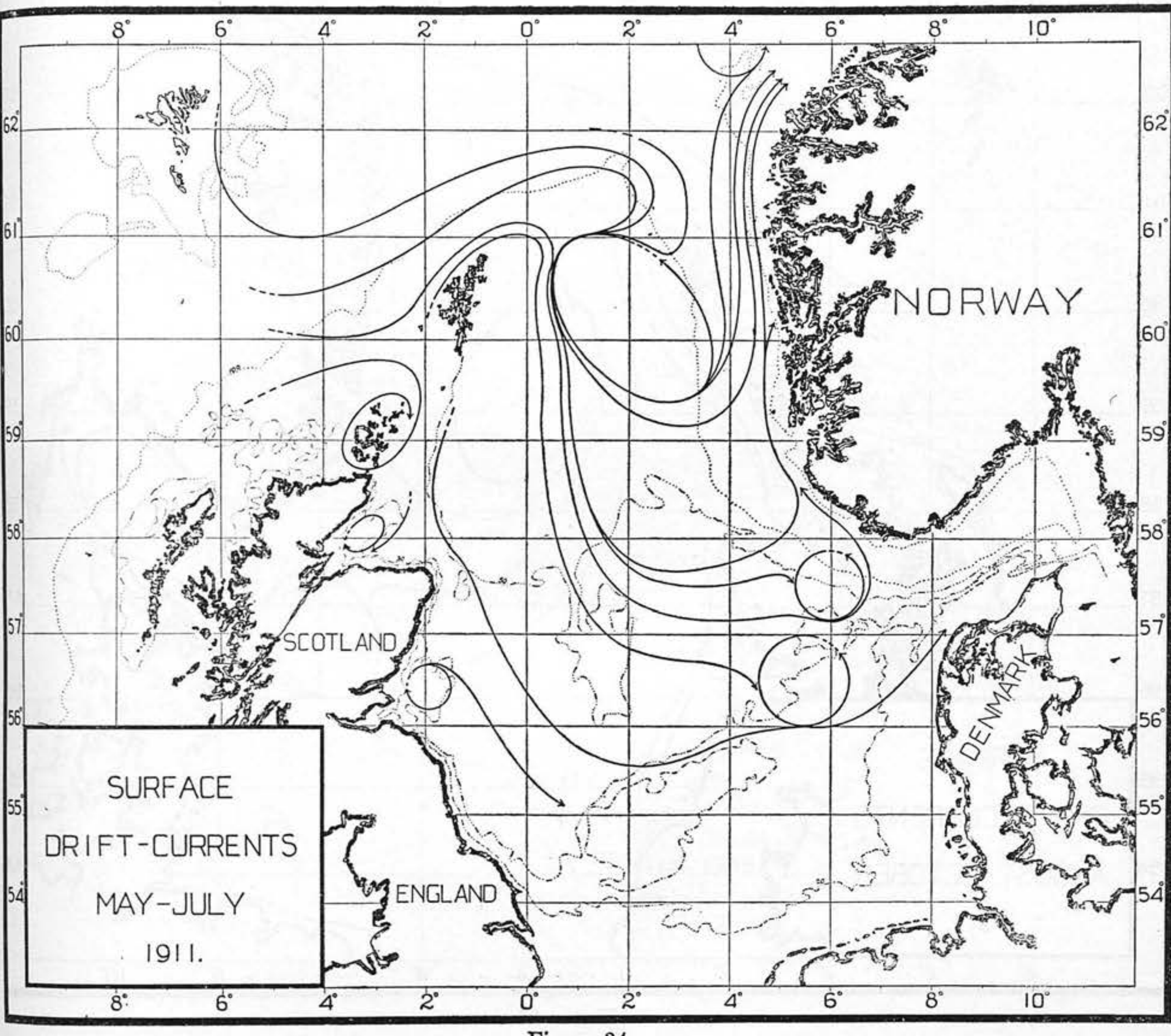

SURFACE
DRIFT-CURRENTS
MAY-JULY
1911.
NORWAY
SCOTLAND
ENGLAND
DENMARK
8°
6°
4°
2°
0°
2°
4°
6°
8°
10°
62°
61°
60°
59°
58°
57°
56°
55°
54°

Figure 34.

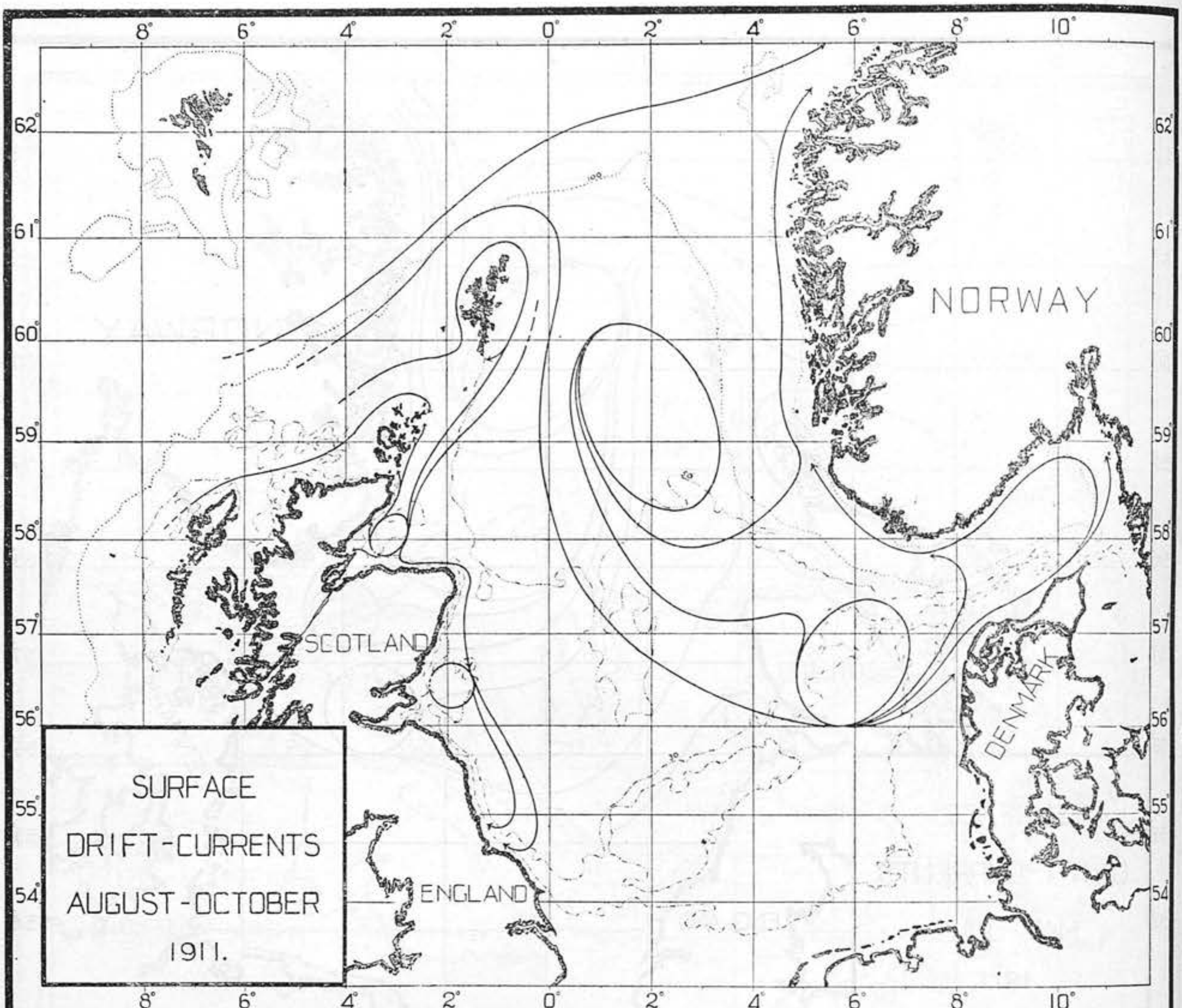


Figure 35.

Printed under the authority of HIS MAJESTY'S STATIONERY OFFICE by
J. & J. Gray, St James Place, Edinburgh.

Wt. 8812/45 250 2/32 J. & J. G. **G.2**

CONCLUDING CHAPTER.

I.

THE SURFACE DRIFT.

In the foreword to this thesis it is stated that the immediate and principal object of the large-scale experiments, the results of which form the subject of these pages, was "the measurement of the quantity generally referred to as the surface drift."

The term 'surface drift' has been variously defined as 'the excess of one tidal pulsation (or stream) over the other', 'the net translation of surface water past a fixed point, or over the ground, as it were,' and by such like descriptions. In the writer's opinion definitions of this nature are inadequate. In certain respects they appear also to be inaccurate.

At the outset, there are several factors, apart from the influence due to tides as such, which cause, or at least give rise to, movements in the uppermost layer of the sea; all of which factors have a bearing, in greater or less degree according to circumstances of time and place, upon that which is called the surface drift and which we assume to be measured by such agents as drift-bottles. Taken singly, the effects of these factors are as yet but imperfectly known. Still less are their relative results duly appreciated over such a wide expanse as the Northern and Middle North Sea areas.

Nevertheless, it may be argued that tides, in a strictly fundamental sense, involve only vertical oscillations of the sea-water particles. The horizontal translations which are associated with tides on the oceanic margins and in marginal seas and which go by the name of tidal-streams are to be regarded, again fundamentally, as being brought about by the intervention of one or more of the factors detailed below. At any rate, the important feature of both tides and tidal streams, although perhaps in lesser degree as regards the latter, is the diurnal, semi-diurnal, or other short-term periodicity which marks their incidence. Drift-bottles, as at present constructed, are not suited to the evaluation of this primary characteristic of tidal phenomena. This, indeed, is demonstrated by certain of the present records referring to the year 1910 and to the region of the Firth of Forth estuary. Doubtless because they involve only inshore and estuarine waters, where tidal influences greatly predominate as a rule, these records do not conform to an /

an interpretation similar to and agreeing with that evolved from the analysis of contemporary results embracing more open-sea areas, even although these areas are immediately adjacent to the inshore waters in question.

There is, however, a certain periodicity, referring in the first instance to velocity, which is revealed by the foregoing analyses of drift-bottle records pertaining to the Northern and Middle North Sea principally, but one which, along with other aspects of the results set forth in this thesis, demonstrates the essential non-tidal character of the movement which is measured by the agents in question and to which the name surface drift has been applied. As will be indicated in the following, this periodicity is no doubt directly connected with a certain recurring phenomenon in the hydrography of the areas cited.

With regard to definitions of surface drift similar to the second of those given above, namely, such as seek to ally the conception of surface drift with the translation of a given mass of water from one region to another, a serious difficulty, apparently irreconcilable with this notion, soon arises when the physical properties of the sea water over the extensive area embraced by most drift-bottle records is taken into account. Only a limited knowledge of these properties, with reference to the surface waters of the North Sea and contiguous regions, is sufficient to refute the idea that the surrounding water into which a drift-bottle is initially dropped, remains in direct contact, or even closely associated with the drifter from beginning to end of its sea career. So that, although a definition of this sort no doubt meets the case up to a point, it cannot be altogether true and is therefore not wholly satis-:factory as a definition.

In short, it appears that drift-bottles and similar bodies measure a transference of energy which may or may not coincide with the material translation of a part, or parts, of the medium itself. The experiments are no less important on that account. Until, however, the intricacies of the various factors - winds, tides, internal friction, or viscosity, den-:sity distribution, the rotation of the earth, land contours, bottom configurations, etc. - which, _a priori_, are associated with movements in the sea, are somewhat better understood, a more comprehensive, even if more theoretical definition seems desirable. Accordingly, for his own guidance in these and cognate investigations, the writer has formulated the following:-

'The surface drift in the sea may be defined meantime as the horizontal component of the resultant effect of all forces which impart, or tend to impart, motion to bodies which are freely suspended and totally immersed in the uppermost layer of water.'

In/

In the light of this definition the cartographical analyses given in the foregoing pages have been performed, that is, without special regard, except in stated instances and for particular reasons, to any one of the above-mentioned factors affecting water movements in the areas investigated.

II.

DRIFT-BOTTLE DATA.

Drift-Periods.

Their Significance and Classification.

As previously pointed out, the statistical treatment of the data which forms the first part of this thesis and which yields important information of further consequence, is, for that reason, very largely of the nature of an introductory to the more exacting investigation of Part II. The latter, that is, the cartographical analysis, may be said to consist essentially of a reasoned and practical inquiry into the histories of all recovered drift-bottles. The method of this inquiry commences from a close study of the dates and positions of liberation and recovery of drifters and especially of the intervals which elapsed between the two events in question.

Those intervals, in days, between dates of liberation and recovery, are called <u>drift-periods</u>. The term is not adopted without due regard having been paid to its literal significance in conjunction with the circumstance that many drifters undoubtedly remain undiscovered upon beaches for unknown lengths of time. This aspect of surface drift-bottle results has, in fact, in former investigations of this kind, been given what now appears to be undue prominence in the interpretation of results, having been held to be mainly responsible for the great variations which are evident among the so-called drift-periods. It should be mentioned, however, that the experiments now under consideration were conducted on a much more extensive scale than had hitherto, or has since been attempted in the North Sea and neighbouring regions, thus giving sufficient scope for the establishment, by deduction from the results obtained, of certain fundamentally important conclusions. One of these concerns the reliability of the intervals between the dates of liberation and recovery

of/

of drifters as true measures of the actual times spent at sea. In order to discuss this point further and more fully, it is necessary to digress at this stage.

The above-mentioned intensive study of the present records leads to the recognition of three classes of drift periods - short, long, and extremely long drift-periods. From the point of view of the absolute magnitudes of these quantities, the division into three groups is by no means rigid and is certainly not uniform throughout the complete range of the experiments. The three classes, in fact, are more or less indistinct, one from another, although, of course, they are relative. The same relativity, however, holds only for a given experiment, or for a series of experiments. The classification of a drift-period depends upon three major considerations; first, its relationship to the other drift-periods belonging to the same experiment, or series of experiments; second, the extent of the sea-area involved, or which can be assumed, tentatively, to have been involved, until the cartographical analysis decides the matter, and third, the season or seasons of the year embraced by the drift-period. For instance, a short-period return from, say, an experiment launched in open-sea waters, could obviously be classed as a long-period record where only coastal, or even landward areas are concerned and conversely. Again, for a specified region, a short-period record which embraces only one, or at most between two and three consecutive seasons, might fall to be included in a higher category if the opposite season, or seasons, are involved and vice versa.

Long Drift-Periods.

In the records presently under discussion, relatively long-period returns are in the vast majority. They are, indeed, so numerous and persistent and, moreover, do not come from any given locality without exception, while, at the same time, short-period returns related thereto in one way or another occur with sufficient frequency, that there is in consequence, ample justification for a doubt as to the significance of the 'lying-upon-the-beach' hypothesis. In short, as one outcome of the foregoing cartographical analysis, taken as a whole, it can confidently be laid down that these problematical times spent upon beaches are, almost in every case, but insignificant fractions of the entire periods between the dates of liberation and recovery and may therefore be neglected in the first study of the latter intervals. That is to say, the so-called drift-periods are primarily to be regarded as such in the literal sense, namely, as true measures of the times spent by drifters in/

in coursing through, or in, the surface waters of the sea. Obviously, therefore, as one result of these pre-war Scottish experiments, a much less restricted and, at the same time, more detailed interpretation of surface drift-bottle data is now rendered possible. The above conclusion, however, does not imply, in any very great degree, a lesser necessity for the prosecution of similar experiments on a similarly wide and inten:sive scale, in order that a multiplicity of comparable records may ensue.

While, therefore, the magnitudes of long drift-periods are comparatively seldom to be taken as denoting lengthy intervals of time passed upon shores prior to the actual discovery of the bottles concerned, there yet remains to be explained the great variations which, as a rule, are evident among these magnitudes. A point of signal importance in this connection is that, for a particular series of strandings along a limited stretch of coast-line, this variation among the drift-periods is not always totally irregular. There is frequently to be observed, in the magnitudes of these quantities, distinct indication of the bøttles having been cast ashore more or less in batches, with appreciable intervals between successive groups of strandings. Further, these intervals are sometimes found to be of almost equal duration. In other words, such records afford strong evidence of periodicity in the incidence of strandings and the fact of its occurrence can be taken as ruling out any question of the incidence of discovery as distinct from that of actual strandings, in these particular cases at least. The amplitude of the period is not always the same, but varies according to the sea-area involved and sometimes, for a given area, according to the season. Moreover, the periodicity does not appear to be directly connected with any known periodicity associated with tides. In fact, there would seem to be no other alternative than that this phenomenon should be ascribed to some more or less systematic influence affecting the careers of drifters while these are still at sea.

The most promising line of investigation, in pursuance of this matter, is that in relation to the phenomenon of surface water movements which go by the name of swirls, or eddies. These complications appear to function as closed gyratory systems and are either roughly circular, or almost elliptical in plan. Con:sidered in relation to the column of water over which they function, each of these surface water complexes probably constitutes but the upper end of a vortex, involving perhaps the entire water column, or only part of it. At any rate, from the point of view of the surface hydrodynamics of the North Sea area, the conception of/

of swirls may be said to have been introduced by Fulton in 1897 as a result of his drift-bottle experiments of that year and the year previous in the Moray Firth area, where he suggested at least the occasional operation of a small anti-:cyclonic eddy. Since then the idea has developed, until, prior to the publication of the papers comprising this thesis, the German investigator, Böhnecke, in 1922, published a paper in which no fewer than seven of these systems are enumerated and discussed. Not all of them are constant, either in time, or position, nor do they all gyrate in the same sense. They are referred to individually in the introduction to Part I of this thesis and several of them form the subject of substantial parts of the thesis itself.

For the investigation in hand, namely, the effect which one or another of these complications may have upon the courses of drifters, the records of the first experiments dealt with cartographically in the foregoing memoirs - i.e. the two first experiments of April 1910 - in association with Böhnecke's North-East Dogger Bank Eddy, furnish a singularly appropriate material. From the cartographical analysis of these results a relationship is established between the periodicity which is more or less clearly discernible along the drift-periods concerned and a certain characteristic of the above eddy which is revealed for the first time in these papers. It is deduced, in fact, that the amplitude of the period (20 days) which marks the incidence of strandings (in this case on the north-west coast of Denmark) furnishes also a measure of the time occupied by a drifter in making a complete circuit of the North-East Dogger Bank Swirl just within its periphery. This period of time it is proposed to call the Period of Circuit of the complex. The longer drift-periods of the series investigated signify the accomplishment of two or more circuits of the system, performed in the same manner, i.e. immediately within the boundary of the eddy, by the drifters concerned. This matter will be further discussed when some of the other eddies, with their Periods of Circuit, where these have been estimated, have been treated.

S h o r t D r i f t - P e r i o d s.

In the above discussion relative to the frequency of long-period returns it is indicated that, in the records under review, the class of short drift-periods is not insignificantly small. Formerly - again, no doubt, by reason of the restrict-:ions of the data - there has been a tendency merely to mention those instances of apparently extraordinarily fast-moving bottles; to regard them, in fact, as of the nature of 'freak' cases, arising perhaps from faulty construction or preparation of the drifters themselves, or from some temporary derangement of the surface drift of too infrequent occurrence to be resognised as a/

a normal episode. But, at the outset of the present investig-:ations, and in like manner as the long drift-periods, by their very persistence, conveyed an idea of some underlying significance, so too did the frequency of short-period records throughout the entire range of the experiments call for a closer scrutiny of these particular records in relation to the remainder before relegating the former to, at best, a secondary position. The outcome of this examination was to concede to these results, or at least to a number of them, an altogether new and indeed front-rank importance. Their frequency is sufficient to allay the suspicion of faulty construction or preparation and, moreover, their distribution in time and with respect to geographical areas discredits the notion that abnormal circumstances (of weather, is implied) can have been the underlying cause of every such record. This being so, there can be no legitimate object-:ion, in most cases, to the assumption that these results yield first-hand information as to the direction and also the velocity of the surface drift throughout the intervals covered by their drift-periods and, in the first instance, with reference to the area lying between the positions of liberation and recovery. That is to say, in the interpretation of records of this description, it can be taken, as a first approximation at all events, that direct, or fairly direct routes were accomplished by the drift-bottles. Charting these routes on a large-scale chart clearly provides a means of obtaining estimates of the directions of the drift and of its average velocities throughout the periods involved, and upon these unique results may be based the analysis of the longer-period returns which are associated in one way or another with them. Association may consist either in a common point, or more or less restriction region, of liberation, or in a similar liaison between places of recovery; or again, the calendar times of either of these events (liber-:ation or recovery) may connect a number of results. This is essentially the method which has been devised by the writer and applied to the present investigation.

Recalling that the characteristics of the surface drift which it is desired to evaluate are its direction and its velocity, both of which doubtless vary to some extent and from time to time, perhaps even within a fairly short interval, it may be questioned whether the analysis of long-period recoveries on the basis of a short-period return is altogether permissible for the reason indicated, namely, the liability to variation on the part of one or other, or both, of the above characteristics. The analytical results obtained by the application of the method to the examination of the data for 1910 in particular, provides the/

the answer to this question. As will be indicated below, a modification of the method was necessary to the satisfactory interpretation of the 1911 material, but, fundamentally, the method was the same. The results for both years show that the direction and the velocity of the surface drift both vary throughout any one year, but the variation in either case is not sufficiently rapid to vitiate entirely the above-mentioned analysis of long-period recoveries which can reasonably be associated with a short-period return. In this, the chief characteristics of the surface drift appear to comply, more or less, with what may be considered as a fairly general rule, or principle, connected with certain natural phenomena in the sea. The rule, or principle, is stated on page 34 of the third paper of the thesis and is as follows:-

"In sea regions possessing oceanic characteristics, such as, for instance, the Northern North Sea basin, no event in which time is an essential factor occurs with a marked suddenness approaching instantaneity."

III.

THE CARTOGRAPHICAL ANALYSIS.

Preliminary Conditions.

The practical application of the above method of cartographical analysis of drift-bottle records is governed by certain very simple conditions, so simple, in fact, that they appear in the light of axioms. They have not, however, been observed in the past by all investigators. These conditions are set forth in the intro:duction to Part II, Section 1 of the thesis, but, as they are neither numerous nor lengthy, they may be repeated here. Firstly, it cannot be held to be generally true, as has been stated by Nielsen,* that the several members of a group of drifters despatched simultaneously from a given point will immediately separate and set off upon widely divergent routes. Rather it is likely that such a group of drifters will at once set off all in the same mean direction and only gradually fall apart, if at all, as they pro:ceed. This under most circumstances. Liberations effected at, or near, the junction of two distinct currents may give rise to rapid separation, but such instances are doubtless rather the exception than the rule when experiments are conducted on the lines of those now dealt with.

Again,/

* See footnote, Part II, Section 1, page 4.

Again, in tracing curves to represent the courses of contemp-:orarily drifting bottles, every care is taken to avoid the acute intersection of any two curves over open-sea areas, as this would imply the untenable hypothesis of superficial cross-drifts at one and the same time in a restricted sea-area. In short, the fundamental rule in all such work, namely, that of consistency, must be maintained as rigidly as possible, in the present case, consistency in the directions of the curves and in the velocities they represent. For reasons of economy, of course, one chart must suffice for a number of curves and it sometimes inevitably happens that two curves cross each other sharply. In all such cases it is essential to show, by measurement and calculation from the data of velocities and calendar dates, that the inter-:section does not actually represent contemporaneous events.

M e t h o d.

With due observance of the foregoing conditions and on the basis of a number of unique results which could be relied upon to give more or less precise information concerning the direct-:ion and the velocity of the surface drift over a given area and for a particular period, the cartographical analysis of the 1910 data was performed, with the results set forth in the second paper of this thesis. For convenience and in order to conduct the analysis according to some definite plan, the material pertaining to the liberations of a calendar month was devoted a single large-scale chart in the first instance, the scope of the experiments for the entire year being statistically represented on a blank area-chart (Figure 2). All of these diagrams appear on a greatly reduced scale in the paper cited. In one case, where, at the dictates of economy, the necessary reduction would have rendered the resulting diagram almost unread-:able, the chart has been represented in four sections (Figure 9). As far as possible the chronological sequence of these monthly analyses is preserved, but where the logic of the argument appears to demand it, this rule is not strictly adhered to.

Directional consistency among the routes estimated in respect of returned bottles is clearly shown on the several charts and to a degree which has not hitherto been achieved. The test of consistency is, of course, to be applied first of all to each chart independently. The 1910 data, however, are particularly fortunate in that they include a number of records which estab-:lish a direct connection between the experimental results for one month and those for another. This connection is, or can be, demonstrated cartographically. For instance, the experiments of the month of April 1910 are connected with those of the following month by two sea recoveries, one from each month's liberations. Similarly, in virtue of a common class of recovery resulting therefrom, the May liberations can be associated cartographically/

cartographically with those of September and, likewise, the September results are historically related to those of December 1910. Other instances occur and are dealt with in course of the analysis. Hence, as regards the direction, or the directions of the surface drift over the regions surveyed, as it were, in the year 1910, consistency is maintained throughout the period embraced by the experiments, namely, from April to December.

Consistency in relation to the velocity of the drift is not, however, from the nature of the concept, so readily demonstrated practically, although, of necessity, a consideration of velocities also enters into the question of the association of one month's experiments with those of another.

One result of the method of analysis applied to the 1910 data is to divide the records for that year into a number of groups. Each group corresponds, approximately, with the series of liberations carried out in a calendar month and is centred round a short-period return. Consistency among velocities is accordingly confined, at first, to each of these several groups independently and is implicit in the various more or less intimate relationships which have been shown to exist among the individual members of a group comprising, for the most part, long-period returns, when the latter are analysed on the basis of a short-period record furnishing the necessary vector denoting velocity.

The writer has, however, devised a practical method of test-:ing the over-all consistency of velocities which are estimated, or deduced, from the experimental data for a whole year. This is by means of a time-velocity diagram on rectangular co-ordinates, the axes of reference being, on the one hand, calendar dates and, on the other, absolute values of velocity. The test, which is fully described below and which was devised as the outcome of an extended study of the 1910 analysis and its results, was not originally applied to the 1910 data as a test of the consistency of velocities, but its introduction arose from a necessary modification of the method of analysis, as applied to the 1910 material, when the 1911 records became the subject of study.

As already pointed out, the fundamental basis of the carto-:graphical method outlined above is the short-period return which can be relied upon to yield a reasonably accurate estimate of the direction and velocity of the surface drift for a given region and for a particular period. It is to be observed, in parenthesis, that, by reason of circumstances of time and place, not all relatively short-period returns can be accepted as furnishing the desired information with the requisite accuracy. In a preliminary survey of the 1911 records, the occurrence of suitable short-period returns was found to be so infrequent that a satisfactory interpretation/

interpretation of the remainder of the results could not be founded upon them and, although certain resemblances to the 1910 material were apparent, these were insufficient to justify the initial assumption of wider analogies between the events of the two years, which, had it been permissible, would have facilitated the analysis of the 1911 data. Accordingly, the method of analysis, as applied to the 1910 results, was carefully revised and eventually modified in a manner to meet the difficulty of the 1911 analysis. This modification, however, entails a more exacting examination of each individual record and, consequently, of all records of the year. It is, in fact, a much more rigorous form of analysis which, on that account, will doubtless hold for future investigations of a similar nature, no matter how plentiful are the data. It consists, as already mentioned, in the construction of a time-velocity curve, the construction, or rather, as will be explained later, the <u>verification</u> of the curve proceeding along with the cartographical analysis of the main body of the data.

Among the 1910 records, as before indicated, unique instances of recovery are sufficiently plentiful to subserve the cartograph-:ical interpretation of all results of any significance which accrued from the year's liberations. Going further into the matter of velocities, however, it was soon clear from a study of their distribution in time that a selection of these unique results could, with the aid of certain simple assumptions, be made to form the cardinal points of a time-velocity diagram on rectangular co-ordinates as above described. The selection of unique records was confined to those which involved no repeated retrogression in the routes estimated for the bottles concerned and which in other ways could be considered as normal. The assumptions upon which the construction of a curve from those instances was based, are as follows:-

1. From the standpoint of their drift-velocities the selected instances are accepted as representative of the Northern and Middle North Sea as a whole.

2. In each case the mean velocity covering the interval of the drift-period is regarded as being equivalent to the actual velocity of the drift on the mid-date of the drift-period.

The unique time-velocity/for 1910 are given in Table XXVIII and the curve derived from them on the basis of the foregoing assump-:tions, on Figure 19. It is not, of course, claimed that the same assumptions in respect of the longer-period 1910 records - namely, such as are for the most part gathered together in tables and in groups centred round a short-period record - would, with the same velocities as are used to interpret the records in this thesis, result in the plotting of these records exactly on the velocity-curve of Figure 19. Some would doubtless lie considerably away from the curve in so far as their analytical results only approximate to/

to those of the short-period records upon which they are based. But it is claimed that the revision of these analyses on the lines suggested below, that is, with a view to making all velocities fit a smooth time-velocity curve, would entail adjust-:ments - in the tabular information, the lengths of the curves on the charts, or even in the velocity-curve itself - which would be of small moment beside the larger and more important results which have accrued from the analyses as carried out in these pages. No doubt, many of these adjustments would (as, indeed, can be gathered from the 1911 analysis which was conducted on the new plan) lead to still closer agreements among the individual records than those which have been demonstrated. For instance, contemporary curves on several of the charts would be more nearly coincident and in those tables which concern eddy movements, the periods which denote intervals passed by drifters in those systems, would approach uniformity as regards their deviation from a common factor, or a simple multiple of this factor. Such adjustments, however, while they would strengthen the case for the broader issues which have been derived from the analysis as performed, would make little if any difference to those issues themselves.

On the other hand, regarded as a means of testing the con-:sistency obtaining among numerous estimates of velocity which range over the months and seasons of a year and which on that account are liable to show an appreciable amount of variation, the time-velocity curve constitutes a valuable check upon the results of analysis. With the curves upon charts conforming to the rule of directional consistency and, at the same time, all velocities fitting closely to a time-velocity curve, there can be little room for doubt as to the inherent truth of an inter-:pretation of surface drift-bottle records on these premises.

The velocity-curve, however, as suggested above, can be made to serve a double purpose in the investigation of drift-bottle results, particularly in cases where short-period returns are relatively scarce. Provided, initially, that the data are sufficiently numerous there would appear to be no valid reason why the assumptions underlying the time-velocity curve for 1910 should not be considered in the light of principles, to govern, not only the construction of such a curve for any year, but the cartographical analysis of the surface drift-bottle records pertaining to a year's liberations, in the North Sea at any rate, except perhaps that further assumptions of a wider nature would thereby be entailed. First of all, there would be the tacit understanding that in any one year surface drift conditions are such as to render possible the construction of a time-velocity curve, not necessarily of the same shape as that referring to 1910, but of the same characteristic smoothness. In other words, the possibility of totally irregular surface drift conditions in any one year, or for a considerable portion of a year, or again, over an appreciable extent of the area involved, is disregarded/

disregarded by the above change of viewpoint. Secondly, granting the possibility of such a curve, the question arises as to whether all, or even the majority of the year's drift-bottle results ought to be expected to fit it, at least approximately.

With regard to the first-mentioned assumption we may, in answer, refer again to the general rule of evolutionary, as opposed to more or less instantaneous change in those natural phenomena of the sea in which the time-factor is inextricably involved. By the same principle, and for the reason (already argued) that the problem-:atical times spent by the vast majority of drifters in other ways than floating in the sea are negligible in relation to the times thus spent, there can be no case for records which do not fit a time-velocity curve of the above description, save that, in some way, or for some reason which does not affect the present investig-:ation, they are anomalous. A final and, indeed, conclusive answer to this question of the majority of drift-bottle records conforming to a time-velocity curve, is given by the 1911 analysis in which the proposed scheme was put into effective operation and every record of any significance examined according to the principles already enunciated. Only in a few instances do records fail to come into alignment, so to speak, with the majority and, in the writer's opinion, it is in those instances, after all else in the way of explanation has been tried, that the 'lying-upon-the-beach' hypo-:thesis may legitimately be invoked; that is to say, only in the last resort.

The actual practice of this improved method of investigation consists, first, in plotting on the co-ordinate diagram the few short-period records (only five in number in the case of the 1911 data) which can reasonably be accepted as fairly accurate indices of events during the short intervals involved. The smooth curve traced through the points so derived is then employed as a basis for the interpretation of the remainder of the records, keeping in mind the fundamental rule of consistency in relation to the directions of curves entered upon charts and representing the routes estimated in respect of the drifters concerned. That is to say, with refer-:ence to the velocity-curve, the reverse operation to that used in the case of the short-period returns, is put into effect in the investigation of the longer-period recoveries. For the latter, the velocity-curve, as constructed from the short-period records, supplies the vectors from which the lengths of the routes can be calculated and the problem now is to enter these routes on the charts in such a way as to obey the rule of directional consistency and, at the same time, to account for the full times denoted by the drift-periods.

In the majority of cases these conditions cannot be satisfied by postulating what may be called continuously progressive courses, involving no delay for any length of time in a given area. The variation in the magnitudes of the routes, as calculated from the drift-periods and the data of the velocity-curve, as well as, sometimes,/

sometimes, the magnitudes themselves, often clearly indicate complication in the routes followed. Traces of systematic hindrance to the drifters while they are still at sea, may, or may not, be discernible among the quantities denoting the lengths of the routes. Nevertheless, these complications are, in the first instance, to be put down to eddy influence and an attempt is made to 'place' these eddies and to estimate the times which have been passed under their dominant influence. This may be accomplished in one or another of three ways.

In areas where eddies of approximately known size and shape are believed to function and when it is clear that those parts of the entire routes which fall within the system concerned constitute major portions of the drifters' sea-passages, or, better perhaps, where it is recognised that the area covered by an eddy system is large in comparison with the total area involved by the experimental results under consideration, the suggested complications in the courses of the drifters may be investigated cartographically by introducing a loop in a position more or less tangential to the 'straight' portions, as it were, of the several routes. By the above premises as to the extent of the eddy area relative to the whole and if all the bottles in question are obviously to be taken as having entered the eddy, these routes will have at least a common point, if not a common section. Moreover, the paths of the drifters within the system can be regarded as having been coincident, more or less, according to one of the early findings from the cartographical analysis of the 1910 data to the effect that, within an eddy movement, drifters apparently circulate round the periphery of the complex. A single loop, therefore, of such linear dimensions that its accomplishment as a course, perhaps once, or a number of times, by the drifters concerned, will account for the residual times not occupied in traversing the above-mentioned 'straight' portions, should, for demonstrative purposes, serve all records. The so-called 'straight' sections of bottle courses signify what has been termed continuous progress from one point to another, namely, from liberation-station to stranding-place. Eddy circuits are of the nature of hindrance, or definite delays to this progress.

By the above method of analysis and in order, indeed, to gauge the accuracy of its results, besides the rule of directional consistency as applied to the portions of the routes outwith the eddy, the various times spent within the system ought to show some simple relationship one to another. Otherwise an analysis on/

on these lines is practically ineffective. It may happen, however, that no permissible adjustment of curves or velocities will result in the establishment of a relationship among the intervals passed entirely under eddy influence. The records pertaining to the liberations at Stations Nos. 8, 9 and 10, of July 1911, are a case in point. Here, where two distinct eddy systems approached each other and finally coalesced during the period covered by these experimental results, the only method of analysis is to lay down each and every route according to the magnitudes calculated from the drift-periods in conjunction with the velocity-curve, with particular attention to the time-factor in its relation to the directional consistency of the courses so constructed.

The third method involves a narrower and more detailed examination of the records, although on the same lines as before. Its operation is advisable when the area occupied by the single eddy which affects the routes of a number of drifters is very small in comparison with the entire area covered by the drifters from beginning to end of their sea careers.

Taking a number of results, either all belonging to the same (simultaneous) group of liberations, or to a series of liberations from a number of points, but which can all be regarded as having been influenced by the same eddy system, the routes estimated as a first approximation for the drifters in question are each divided into two portions, (i) from the point of liberation to the point of entry into the eddy and (ii) from the point of exit from the system to the stranding-place. It can generally be assumed for the purposes of analysis that all points of entry into and departure from an eddy are coincident. Both sections of all routes must, individually, satisfy the requirements of the velocity-curve, calculating forward from the dates of liberation in the case of the initial sections of the routes and estimating backwards, as it were, from the recovery-dates in respect of the final stages. In other words, each course from the liberation-station to the point of entry into the eddy must be accomplished in a certain interval and at an average velocity for that interval which is equivalent to the actual velocity represented on the velocity-curve for the mid-date of the interval. In the same way the final sections of all routes must be referred to the appropriate points of the vel-:ocity-curve depending upon the recovery-dates in conjunction with the distances to be covered between the eddy and the stranding-places.

In addition, of course, the rule of directional consistency is to be observed, especially with reference to the earlier stages of the drifters' courses. These earlier portions are, as/

as a rule, very nearly contemporary. Obviously, in view of the different lengths of time which may be passed under eddy influence, escapes therefrom may seem to pursue more or less widely divergent routes according as conditions in the vicinity of the complex may have altered during the times in question.

two By the above means new dates are obtained in respect of each record, namely, the dates of entry into and escape from the swirl and the difference, in days, between these dates furnishes a measure of the time spent in the complex. Again, for the number of records involved and before these analytical results can be accepted with confidence as indicative of the actual state of affairs in relation to the surface drift, these eddy-times, or residual periods as they are called in this thesis, ought to bear some simple relationship to one another.

While the majority of drift-bottle results are generally found to conform to one or another of the above methods of procedure there occur a few records which cannot be analysed with great precision. These are cases for which it cannot be definitely known whether two or more distinct eddy systems played a part in the histories of the drifters concerned, although it can generally be told which eddies were probably involved.

It is evident, then, that for the majority of surface drift-bottle records pertaining to the regions with which we are immediately concerned, a number of effective checks can be brought to bear upon their cartographical analysis, sufficient, in fact, to ensure a reasonably accurate interpretation of these records, for, in addition to the observational check of directional consistency on the various charts, the criterion of consistency of velocities in the form of a time-velocity curve and, where eddy systems intervene, the above conditinn as to the relationships among numerous periods passed under their dominant influence for the time being, the copious overlapping of numerous drift-periods, when considered from the point of view of the calendar intervals they embrace, leads, in effect, to the repeated verification of the velocity-curve itself, even while it is being used as a basis of investigation. In other words and to summarise the foregoing arguments in a single sen-:tence, the aims of a cartographical analysis of surface drift-bottle records pertaining to the Northern and Middle North Sea should be, to obtain simultaneously, (i) directional consistency in the routes estimated and entered upon charts, (ii) consistency among all velocities by ensuring that all really significant records fit a smooth time-velocity curve and (iii) precise relationships among the more or less contemp-:orary intervals spent by numbers of drifters in the same eddy system.

IV.

THE ANALYTICAL RESULTS.

Attention may now be given to the results which have accrued from an investigation conducted on the above lines.

At the outset it is of signal importance to note that, as revealed by the drift-bottle experiments of 1910 and 1911, the broad features of the surface drift in the Northern and Middle areas of the North Sea were essentially the same in both years, for this fact at once bespeaks the wider applicability of these results than as pertaining, exclusively, to the two years in question. It is perhaps premature to cite the findings which are the outcome of the foregoing analyses, as of the nature of a generalcase, but, having been demonstrated for each of two successive years, it is to be expected that the same, or very similar conditinns will be met with again in other years, and it may even be permissible to refer to these conditions as comprising a surface current system in the areas concerned.

The broad similarity between conditions in 1910 and 1911 rests, of course, in the direction, or directions of the surface drift and in its velocity throughout each year, that is, in the characteristics which it was the aim of the experiments to measure. Each of these characteristics will be treated singly.

Direction of the Drift.

As regards direction, perhaps the most outstanding revel-:ation of the present analyses is that of the extraordinary complexity of the surface drift movements in the areas surveyed. Except in the current charts published along with Böhnecke's paper (1)* in 1922 - and these are on such a small scale that their utility is thereby seriously limited - this complexity has not hitherto been fully appreciated. That it should be demonstrable by means of drift-bottles is a point in favour of these agents as important instruments of research in connect-:ion with surface current systems.

Another striking feature of these analytical results is con-:tained in the strong suggestion that, in certain regions at least of the Northern North Sea area, the surface drift apparently coincides with, and is indistinguishable from stream-currents in the surface of the sea. The idea that there are streams in the sea, or in the ocean, is not new, having been introduced,/

*Numbers in brackets refer to the List of Publications in Part I, page 30.

introduced, so far as the writer is aware, by Maury* towards the middle of last century in his Chapter upon the Gulf Stream. As a concept of wider applicability the idea has since been more or less discredited by oceanographers generally. The results of the present investigations, however, would appear to revive the concept in relation to the surface water movements of the Faroe-Shetland Channel and the North Sea.

As its title implies the chief concern, from a geographical point of view, of the present thesis is the Northern and Middle area of the North Sea considered as a whole. The thesis, however, deals also with the southern reaches of the Norwegian Sea, between the parallels of 61° and 62°N. latitude and with the region to the west of the Orkney and Shetland Islands which is generally referred to as the Faroe-Shetland Channel area. It was anticipated from the beginning, by reason of the then existing knowledge of the physical characteristics of the sea waters to be found within this extended area that a proper under:standing of the surface hydrodynamics of the northern parts of the North Sea could only be achieved by investigating also the relationships which were obviously suggested to obtain between one region and another. It is in this light that the results of the drift-bottle experiments begun to the north and west of the Northern North Sea proper are to be regarded, although some significant results in respect of those external regions them:selves are forthcoming from these same experiments. These results are considered before passing to the main question of their connection, or connections, with the North Sea surface water circulation.

Although, over the whole extent of the Faroe-Shetland Channel, the surface drift has a marked easterly component, which is most pronounced in mid-Channel, certain evidence goes to show that the entire area may be looked upon as comprising a northern and a southern region. On the eastern side of the area the line of division between the two regions lies approximately along the latitude of 59°45'N. Westward of about longitude 4°W. the division-line probably becomes less distinct and curves slowly to the northward.

This demarcation of the area into northern and southern regions appears to be effected by a stream-current which flows eastward along the above parallel, at least for some distance. The stream-current itself may arise solely as a stream-current emanating from the north-eastern part of the Atlantic Ocean, or as the result of two distinct currents converging upon each other./

* Maury, M.F.: "The Physical Geography of the Sea." New York, 1855.

other, as suggested by the stream-lines on Figure 16, for instance. At any rate, the impulse derived from the area to the immediate west of the Outer Hebrides apparently did not, either in 1910 or in 1911, carry drifters from that region farther north than the above latitude and, likewise, no drifter set afloat in the neighbourhood of the Faroe Islands seems to have crossed this latitude on the west side at all events of the Orkney-Shetland group.

In the northern region of the Channel two eddy systems may be found to function. The first, an anticyclonic circulation, encloses the group of the Faroe Islands and has not hitherto been cited. Its existence, however, can readily be accounted for by a consideration of the surface currents prevailing over the deep-sea regions surrounding the submarine plateau which supports these islands. To the west, the Atlantic influence pushes northward and on the north a branch of the East Icelandic Polar Current passes south-eastward on the borders, and forming part of, the general cyclonic circulation of the Norwegian Sea. The effect of the rotation of the Earth - sometimes referred to as the Coriolian force - upon both of these currents, is to induce deflection towards the right. The Faroe Islands them-:selves and doubtless the plateau upon which they rest, counteract this tendency on the part of the Atlantic current, although, before it reaches the Faroe group, there is evidence to show that part of it does, in fact, deviate eastwards between the Faroe Bank and the Faroe Islands. This is indicated on Figures 15 and 16.

On the other hand, the easterly-flowing current to the north of Faroe experiences no such obstacle to its deflection south-:wards on the east side of the islands. Hence, all that requires to be postulated to complete the circuit of these islands is a connection between the northerly directed current on the west side and the southerly drift on the east. That a connection does exist, upon occasions at least, is clearly shown by certain unique results of the drift-bottle experiments launched in the eastern and southern vicinity of Faroe in the month of May 1910.

The second eddy operative in the northern region of the Channel is a cyclonic system lying midway, practically, between Shetland and Faroe. Its existence has previously been noticed by other investigators and it is engendered no doubt by the above-mentioned southerly-flowing current on the east side of Faroe in conjunction with the principal Faroe-Shetland Channel current, which in this region flows in a north to north-easterly direction along and off the western shores of Shetland.

No more precise information concerning the above circulations can be obtained from the data so far examined, first of all on account/

account of their insufficiency and secondly, because of the uncertainty as to whether the relevant records may, or may not embrace other complications of a similar kind. The first circumstance, in fact, applies to the material for the whole of the Faroe-Shetland Channel area, the above remarks referring mainly, although probably not exclusively, to summer months.

In the opposite corner of the area to that occupied by the Faroe Islands, namely, about the Orkney group, yet another eddy gyration is revealed on more than one occasion by the present material. This system, like the Faroe complex, encloses the Orkney Islands within an anticyclonic current, the genesis of which is a branch from the afore-mentioned stream which heads eastward along the latitude of 59°45'N. The branch flows south-eastward between Fair Isle and Orkney and finally southward along the eastern shores of the latter islands, showing a tendency, however, to push westwards through the various passages between the islands. This westward tendency appears to be most effective through the Pentland Firth, thus completing the circulation round the group of islands, for the drift on the west side of Orkney is northerly in the main. The evidence for this gyration shows it to be operative in summer and autumn months if conditions permit. An influence from the east and south, however, which will be mentioned later, may break the circulation of waters around Orkney.

Mention is made above of 'the principal Faroe-Shetland Channel current.' For the purposes of this thesis, this current may be considered as originating in the north-eastern Atlantic Ocean. It is to be regarded essentially as a stream-current composed of warm, highly saline water. Probably at some distance before it reaches the Wyville-Thomson submarine ridge the current divides, part flowing over the ridge into the Faroe-Shetland Channel and part continuing on a more northerly route, to pass on the west side of Faroe. As already mentioned, the latter, or again only part of it, deviates eastward between Faroe Bank and Faroe itself and so into the Faroe-Shetland Channel in a south-easterly direction. This direction is maintained for some distance, being aided in this respect by the influence which proceeds from a southerly-flowing current along the east side of Faroe, which current gradually deflects eastward. About mid-Channel and approximately on latitude 59°45'N., the main Atlantic current crossing the Wyville-Thomson Ridge converges with the stream from the Faroe to Faroe Bank region and holds the course of the whole for some distance almost due east. Shortly, however, this main stream begins to turn north-eastwards again to flow on the west side of Shetland, but leaving a branch still heading eastward. This branch again divides into two streams, one of which gives rise to the Orkney circuit already mentioned. The complementary branch, as it were, makes for the opening between Shetland and Fair Isle, through which it may pass/

pass into the north-western area of the North Sea. Surface drift-bottle results, however, do not make this point very clear. What is clear is that the said stream, on the surface at all events, sometimes finds its progress into the North Sea barred by a current flowing practically normal to its own direction. This matter, which is of great importance, not only from a fisheries point of view, but in any question concerning the water economy of the North Sea as a whole, will be dealt with again later. In relation to the current system of the Faroe-Shetland Channel, however, the consequence of this closure of the North Sea to the influence which emanates from the west is that the stream in question turns sharply to the left and flows northward along the west coasts of Shetland.

Associated with the foregoing circumstance, is the almost indisputable fact that, in greater or less degree according to the time of year, the surface water circulation of the Northern and Middle North Sea area receives its ~~greatest~~ main impulse from the north through the wider opening between Shetland and Norway, that is, more or less immediately from the southern reaches of the Norwegian Sea, the conventional northerly limit of the North Sea being taken as defined by the 61st parallel.

The Atlantic current, as it streams through the Faroe-Shetland Channel off the western shores of Shetland, goes to meet the somewhat opposing influence of the Norwegian Sea cyclonic circulation, to the north of the Shetland Islands. Moreover, being a deep current, it is influenced also by the contour of the Continental Shelf as defined by the 100-fathom bathymetric contour. Both influences, north of Shetland, have the same tendency and, in addition, the rotation of the earth promotes the deflection of the current towards the east. Thereafter conditions are similar to those obtaining in mid-Faroe-Shetland Channel. The easterly trend prevails for some 60 to 80 miles, but gives way, once again, to a north-easterly course directed towards, and ultimately parallel to, the Norwegian coast. Again, however, as this change takes place, an offshoot from the easterly stream continues the course approximately along the latitude of 62°N. and as far at least as longitude 2°E. About this meridian, which marks the locus of a sudden change in the contour of the Continental Shelf, the Atlantic offshoot also changes direction rather sharply, almost in fact to a right-about. From east it turns south-east, south and, as it crosses latitude 61°N., south-west. Gradually, however, it swings back again as it advances into the Northern North Sea until it flows practically due south along the prime meridian between latitudes 59° and 60°N. This, according to the surface drift-bottle results which form the subject of the thesis, is the movement from which the major circulation/

circulation of the surface waters in the areas concerned, may be said to commence and again, according to the cartographical interpretation of these same results, it is in the nature of a stream movement, to begin with, at all events.

The view expressed in the preceding paragraph as to the immediate source of the main impulse behind the surface water movements of the Northern North Sea area, although it has previously been cited by at least one authority, is not that which has generally been held in recent years by those who are perhaps most interested from a scientific standpoint.

In the chart published by Fulton(3b) in 1897 as a result of his drift experiments of that period, the impetus of the general cyclonic system which is the basis of surface water movements over almost the entire area of the North Sea north of latitude 54°N. is definitely represented as being derived immediately from the Faroe-Shetland Channel area through the openings between Shetland and the mainland of Scotland and, except for the remarks of one authority in relation to a particular year, the same idea has repeatedly been conveyed by interpretations of observatinnal data of the temperature and salinity of the sea waters in and between the two regions, until, even so late as 1922, Böhnecke, in his several surface-current charts, depicts a like state of affairs in the main. In the same year, however, the British Admiralty published a chart (No. 327) of the "General Drift of the Surface Water in the neighbourhood of the British Islands and in the North Sea," on which it is indicated that some influence to the latter area proceeds from the Faroe-Shetland Channel by way of the north of the Shetland Islands, but the impression given is distinctly that of a minor influence by this route as opposed to what appears to be the more direct connection through the passages between Scotland and Shetland.

With reference, however, to the year 1902, which witnessed the beginning of co-operative effort in the study of marine problems by the countries bordering upon the North Sea mainly, Helland-Hansen (10), from his examination of temperature and salinity data pertaining to this year, deduced that the principal current-connection between the Faroe-Shetland Channel and the Northern North Sea lay through the southern reaches of the Norwegian Sea, that is, by way of the north of Shetland. At the same time he sounded a warning, to the effect that the argument of currents from temperatures and salinities is a process requiring extreme caution. In both respects the present analysis of drift-bottle data yields strong support to Helland-Hansen's remarks, first as regards the route by which the Faroe-Shetland Channel influence reaches the North Sea and second, as to the danger of over-emphasising the indications as to currents afforded by temperature and salinity measurements. Almost of necessity, the/

the stations at which physical observations are taken on a cruise are, most times, no less than twenty to thirty miles apart and, provided the writer's suggestions regarding stream-currents are substantially true, there is no doubt that such widely set observation-stations will often miss the significance of, say, two similar sets of surface observations which may lie one on either side of a stream-current comprising water of higher, or lower, physical characteristics. The writer has recently had the opportunity of conducting a short series of these physical observations on a more intensive scale in the north-western area of the North Sea, taking stations at intervals of only ten miles along a line of about eighty miles. The results of this cruise have not yet been studied in detail, but their first indications are definitely in support of the above arguments with reference to stream-currents and the significance of small but essential differences in the physical properties of sea water at near neighbouring stations within a given area.

Seeking for the probable cause, or causes, of such a pronounced deflection of the stream-current which penetrates the North Sea from the Norwegian Sea, we are reminded, first, of the effect which may be produced by the rotation of the Earth and secondly, of the influence due to the contour of the sea bottom in this region. Ekman*, who has studied this problem of movements in the sea from a mathematical standpoint, has propounded a theorem which states that a current flowing from a deeper to shallower region will, in the Northern Hemisphere, tend to swerve to the right and, conversely, a current from a shallower to a deeper region will have a left-hand tendency in the Northern Hemisphere. Clearly, the circumstances of the former statement may be taken as a further contributory cause of the phenomenon under discussion. The analysis of the drift-bottle records themselves, however, bring to light a third and by no means the least inducement towards the above deflection.

The cartographical interpretation of the experimental records for 1910 and 1911 places beyond a doubt a matter, which, although, long suspected and, in fact, diagrammatically represented on one or two current charts since the end of last century, is for the first time dealt with in more or less precise fashion in these pages. This concerns the surface hydrodynamics of the northern part of the North Sea which, apparently, is dominated largely by a huge cyclonic system functioning in the form of a closed eddy and occupying almost the entire deep-sea area between Scotland and Norway north of about latitude 57°30'N. The Great Northern North Sea Eddy is the name which is proposed for this gyration, shortened,/

* See footnote, Part II, Section 1, page 36.

shortened, when repeated reference is necessary, to the Great Eddy. Its maximum limits as a closed system would appear to be defined, approximately, by latitudes 61°15'N. and 57°30'N. on north and south and by longitudes 0° and 4° E. on west and east respectively. That is to say, it is practically elliptical in plan, the major axis of the ellipse sometimes coinciding with the meridian of 2°E. and sometimes, as in 1911 when the system appears also to have been of smaller superficial dimen-:sions than in 1910, inclined at an angle of about 30° to this meridian, so as to lie almost in the line of the compass directions, NNW - SSE.

It is not surprising that the existence of such a system as this in the area cited has previously been suggested, somewhat tentatively perhaps. Its counterpart, as it were, in the bottom water layers of the area was demonstrated by Brown (6) from his work upon <u>bottom</u> drift-bottle experiments in the years 1906, 1907, 1910 and 1911. But, quite apart from drift-bottle investigations, the Great Eddy is a simple deduction from the long existing knowledge of a southerly-flowing current on the west side of the area concerned and a northerly current along the Norwegian side, constituting, as it were, a hydro-couple, the arm of which lies approximately along the latitude of 59°20'N.

Further evidence from drift-bottle work towards the estab-:lishment of the Great Eddy is contained in the results of a few experiments launched by Fulton in the year 1903. This evidence, although not conclusive in itself, augments that obtained from the 1910 and 1911 material where the latter happens to be weakest, although it is by no means weak when all relevant circumstances of the data are taken into account. In the autumn of 1903, however, Fulton liberated batches of drift-bottles at points 115, 130, 164, 185 and 190 miles distant from Aberdeen along a line running in the direction of E. by N. from that port, that is, in an area and at a season of the year which were not too well served by the 1910 and 1911 experiments. To quote Fulton's own words on the results of these 1903 liber-:ations, "The earliest (bottles) to be returned were those of the third and fifth lots and they came, unexpectedly, from the Shetland Islands." Taken in conjunction with the numerous like records which accrued from the liberations of May and September, 1910 and May 1911, in the regions immediately to the north-east, north, north-west, west and south-west of the area estimated to be covered as a rule by the Great Eddy, these records furnish almost irrefragable evidence from which to conclude, as a normal feature of the Northern North Sea surface water circulation, just this huge gyratory movement. The following more recent record, which also, as it were, fills in a blank in the 1910-1911 data, is strikingly in accord, not merely/

merely with the conception of the Great Eddy as a closed entity, but with the manner in which, as will be explained later, this and other like systems exert and appear to maintain their influence for definite periods upon floating bodies. On 1st August 1931 a drift-bottle was picked up <u>from the surface of the sea</u> at the position:- latitude 60°18'N., longitude 3°15'E., which point is only some five or six miles southward of the spot at which, along with nine others, the bottle was set adrift twenty-nine days beforehand.

The northerly limit of the Great Eddy, then, is generally on, or a few miles beyond the 61st parallel and practically on longitude 2°E. and the system is cyclonic in character. It is, therefore, not difficult to imagine what will be the effect of the gyration upon the drift-stream seeking entry into the North Sea about this region. The results presently under review show that the Great Eddy plays a large part in the deflection of the stream from a due southerly course to a south-westerly one as it crosses latitude 61°N. The same influence, acting in opposition to the strong easterly drift towards the region in question from the area northward of Shetland, restricts the stream within narrow limits as it is about to enter the Northern North Sea.

Before passing from the consideration of the Great Eddy it is convenient to notice, at this stage, certain differences which are apparent between its characteristics in 1910 and those of the following year. Of course, it is to be remembered that the earlier analysis was performed somewhat less rigidly than the other, especially with regard to velocities, but it is practically certain that this circumstance does not entirely account for the differences in question. In the first place the 1911 complex, while still elliptical in plan, appears to have been much smaller, superficially, than it was in the previous year and, secondly, the 1910 examination gives no indication of the seasonal translation of the entity which is revealed by the 1911 analysis. This translation may have an important significance which will be touched upon later. A third difference has already been mentioned, namely, the inclination of the major axis of the ellipse defining the boundary of the eddy in 1911 to the meridian of 2°E., with which the like dimension of the 1910 complex apparently coincided.

As already pointed out, the Atlantic offshoot which enters the Northern North Sea across the 61st parallel of latitude and a little to the west of longitude 2°E., does so approximately in a south-westerly direction, but gradually deviates southward again as it advances farther into the area. At the same time there is evidence of a gradual tendency towards a westward lateral expansion on the surface of the stream at all events, its eastern margin continuing to form the western boundary of the Great/

Great Eddy for a considerable distance. Under these circum-:stances the characteristics of the movement as a stream-current become somewhat modified. For the purposes, however, of a clearer interpretation of results and not entirely without the support of certain suggestions borne by the carto-:graphical analyses themselves, the idea of the surface drift being largely comprised of stream movements along fairly definite tracks may still be utilised as a means towards this end.

About the latitude of 58°30'N., or perhaps a little before this, the main southerly-flowing stream can be looked upon as splitting up into a number of streams which, sooner or later, become almost independent of one another. Between a pair of streams the direction of the surface drift is intermediate between the directions of the streams themselves.

The eastmost stream, then, continues to define the con-:tour of the Great Eddy south-eastward and, more or less rapidly, through eastward on or about latitude 57°30'N. to north-east and, later, north. Next to this there are indic-:ations of a stream which, although still influenced to some extent by the Great Eddy, gradually sheers off from this system and makes, first of all, in the direction of the entrance to the Skagerak across the area between latitudes 56°30'N. and 57°30'N. Towards the eastern side of this area, however, the underlying cyclonic character of the entire Northern and Middle North Sea drift introduces a northerly component into the direction of this stream which may deflect northwards along the Norwegian coast before it enters properly into the Skagerak, or it may flow into the periphery of a small eddy situated south-west of Lindesnaes - Böhnecke's Lindesnaes Eddy, from which the efflux is northward along the Norwegian coast in the current emanating from the Baltic area and hugging the Norwegian shores of the Skagerak as it emerges into the North Sea.

A third sub-division, as it were, of the main southerly stream on the western side of the Northern North Sea also deviates eastward across the Middle North Sea area, but less rapidly than the previous stream. The individuality of this third stream is partly lost in the North-East Dogger Bank Swirl, situated as a rule and as its name applies, on the north-east end of the Dogger Bank, or somewhere between this region and the Little Fisher Bank on latitude 57°N. The normal efflux from this eddy would appear to take place about its southern limit and carry north-eastwards towards Hanstholm on the north-west corner of Jutland, thence into the Skagerak along its southern shore.

Here,/

Here, in parenthesis, it may be mentioned that, upon occasions, conditions may be such as to cause the Lindesnaes and North-East Dogger Eddies to approach each other and finally to coalesce, forming a single resultant system inter-:mediate in character between those of its components. A remarkable feature of the 1911 analysis is the cartographical estimation of almost the precise date upon which this coales-:cence took place in the summer of that year. In 1910 a similar event is not registered, but between spring and autumn months there is evidence to show that the North-East Dogger Bank Eddy was translated from a position over the Little Fisher Bank to a more southerly or south-westerly region, nearer to the Tail End of the Dogger Bank.

Still further to the west of the last-mentioned branch-stream which apparently feeds the North-East Dogger Bank Eddy, the drift holds still longer in a southerly direction before tending eastwards, until, before the easterly component has had time to become really effective, another eddy complication intervenes. This is the South-West Dogger Bank Eddy whose southerly limit would appear to lie over the Outer, or Great Silver Pit, on latitude 54°N. Floating objects which escape from this complex may either be carried north-eastwards towards and into the North-East Dogger Swirl, or more definitely east-:ward towards the coast of Schleswig-Holstein, which again, under circumstances which seem to be closely associated with meteorological phenomena, is in a sense 'protected' by a closed cyclonic circulation of surface waters.

Probably by reason of the irregular contour of the east coast of Scotland and the north-eastern English counties, from about Flamborough Head to the northmost point of Shetland, as well as the nature of the bottom within thirty to forty miles of the land, surface drift conditions on the western margins of the areas under consideration are more complicated than those obtaining in more open-sea regions. On this western margin the distinction between the Northern and Middle Areas of the North Sea may at times be quite marked.

As it pushes southward along the prime meridian, the main-stream on its western fringe shows a tendency to make for the Moray Firth. The tendency may develop so far, and then, to the north-east of Kinnaird Head, recover again, this stream passing southward into the Middle Area and, on its western fringe, into the periphery of an eddy which usually functions off the Scottish coast between the latitudes of Fife Ness and Aberdeen. The "Mid-East Scottish Coast Eddy", as it is called in the present thesis, is usually elliptical in plan, but circumstances may arise, as in certain months of 1911, which cause the swirl to assume a shape more nearly circular than elliptical./

elliptical. It generally operates in the area westward of longitude 1°W. but here again, conditions to the northward of latitude $57^{\circ}30'$N. are often the predisposing cause of an expansion of the system seawards. Meteorological conditions too, particularly strong or persistent south-easterly winds, may break the systematic circulation of surface waters in this area. Escape from the complex takes place, as a rule, along its eastern boundary and the main tendency is for drifters so expelled to make more or less gradually, according to circumstances, for some point on the neighbouring coast-line. This point may be anywhere between Fife Ness and about Whitby on the Yorkshire coast. There is evidence, however, of a tendency for objects to be cast ashore on definite short stretches of the coast between these places. Concentrations of drift-bottle strandings often occur between Dunbar and St. Abbs Head, in the vicinity of Holy Island and along the Yorkshire coast for about fifteen miles eastward of the mouth of the River Tees. The manner of approach towards these stranding-places generally gives clear indication of a narrow current proceeding northwards along the above mentioned coastline and it sometimes appears as if this current were but a part of a large anticyclonic circulation of which the Mid-East Scottish Coast Eddy may be regarded as the nucleus.

On the other hand, the above-mentioned tendency of the western border of the main Northern North Sea drift-stream to enter the Moray Firth may become an accomplished fact, as in the early summer of 1910. This completed deviation towards the west appears to take place on or about latitude 58°N. and between longitudes 1° and 2°W. and it may last for a considerable period, to be reckoned in weeks. The branch-stream which so deviates into the inner Moray Firth flows into the periphery of the small eddy suggested by Fulton to function in these waters and abundantly proved by the present analyses. The continuance of the westward movement is the cause suggested by the writer for the inauguration of a narrow current northwards from the area of the Moray Firth Eddy and passing along and off the eastern shores of Orkney, past Fair Isle and on to Shetland. It is more than probable that this current passes up the eastern side of Shetland, although, on approaching the southern extremity of the Shetland peninsula, a lesser part of it may flow along the western shores of these islands.

The results of these conditions in the north-western area of the North Sea, when they occur, are doubtless of far-reaching importance, for the time being at least. Considered as a whole the effect is to render the area in question almost self-contained, being enclosed, practically, in an anticyclonic system of surface drift. The current forming the western boundary of the system shuts off at least the superficial connection between the Faroe-Shetland Channel region and the North Sea by way of the passages southward of Shetland to the mainland of Scotland and, as demonstrated/

demonstrated by the 1910 analysis, this 'closure' may continue for an interval of more than six weeks in mid-summer. It will be the purpose of further investigation to ascertain whether this effect is merely on the surface, to a depth of only six or eight inches (the length of a drift-bottle) or extends apprec-:iably below what may be regarded as essentially the surface film of water. The knowledge is obviously a sine qua non in the consideration of an important aspect of the hydrography of the North Sea as a whole, namely, that of the water economy of the entire area.

The above circumstances relative to the establishment, temporary at all events, of a self-contained region embracing the whole of the north-western area of the North Sea, probably do not arise all at once. There are indications, for instance, that the stream-current issuing from the north-west corner of the Moray Firth may not, at first, reach Shetland before turning eastward and then southward in the opposite arm of the final composite system. This appears to occur in the eastern vicinity of Fair Isle, that is, about latitude 59°30'N. Again, the southerly-flowing, main current from Norwegian Sea latitudes may throw off a branch westwards about latitude 59°N. and this branch soon turns northward to proceed towards Shetland. In the area between latitudes 59° and 59°30'N. a small eddy may ensue from a combination of these circumstances.

When the system above-described is in operation over the north-western area of the North Sea the momentum of the drift passing southward into the region off the mid-east Scottish coast is probably less than at other times. As a result, the Mid-East Scottish Coast Eddy may expand considerably towards the east, as already mentioned and as demonstrated by the analysis of records belonging to the experiments of the month of June 1910.

These, then, are the main features of the surface drift in the Northern and Middle North Sea areas particularly, as ascer-:tained from the cartographical analysis of the drift-bottle records for 1910 and 1911. Most of these features, it may be allowed to state, are obviously corroborated, in greater or less degree, by more recent experimental results, which, however, remain to be subjected to a more critical analysis. All of them are more or less subject to variation in any one year and from one year to another and these facts render their representation on a single chart almost impracticable from the standpoints (i) of the synchronisation of events over such an extensive area and (ii) of the acceptance of such a representation as in the nature of a general case. Indeed, with reference to the latter condition, not only do certain of Fulton's drift-bottle results pertaining to the years 1895-1897, preclude the affirmation of a universally general case meantime, but the statistical analysis which forms the first part of the present thesis gives strong indication/

indication that surface drift conditions in the year 1913 were so different from those obtaining in the three years immediately preceding as perhaps to constitute a radically different current system in respect of that year. Never-:theless, as previously remarked, having been demonstrated for each of two successive years, it is only to be expected that, in the nature of things and in the main, the surface drift conditions of 1910 and 1911 will be registered again in other years. In this belief and with no pretensions towards either the synchronism of events between one region and another, or to the universal application of such a current picture irrespective of season or even year, the out-:standing issues of the foregoing analyses are depicted on the chart at the end of this chapter.* The arrows on the chart have no relation to the velocity of the drift, being concerned with direction only. The heavier arrows are designed to represent the essential stream-line movements of the drift, the lesser arrows merely filling in the blank spaces between these lines, with due heed, of course, to the indications of the various parts of the cartographical analysis.

Taking the 1910 and 1911 results as a whole there is one observation which should be made in regard to their relation-:ship to those of former investigations in the same areas approximately. On Fulton's well-known drift-chart, published along with his paper of 1897, the southerly limit of the cyclonic system of surface drift characteristic of the major part of the North Sea is given as the chain of islands off the coast of Holland. The present analysis places this limit no farther south than about latitude 54°N., below which relatively few bottles from the 1910-1914 experiments stranded, in contra-:distinction, to some extent, to Fulton's results which include an appreciably greater proportion of these returns.

Before disposing thus of the matter of the direction, or directions, of the surface drift in the Northern and Middle North Sea areas, further brief consideration may be given to the eddy systems which form such a significant part of these non-tidal surface movements.

In respect of four of the half-dozen or so of these eddy systems which, either permanently, or from time to time, char-:acterise the surface water circulation of the above areas, in open-sea as well as in landward and coastal regions, it has been possible from the drift-bottle data referring to the years 1910 and 1911 to derive quantities which it is proposed meantime to call Periods of Circuit and which represent, first of all, the times required by drifters to make single complete circuits of the eddies concerned. For instance, for the North-East Dogger Bank Eddy the Period of Circuit appears generally to be about 20 days, for the Lindesnaes Eddy, approximately 16 days, and when/

* In pocket of cover.

when these two systems join forces, as it were, by coales-:cence, as above explained, the Period of Circuit of the resultant system, in 1911 at least, was in the neighbourhood of 27 days. The Mid-East Scottish Coast Eddy may be characterised by Periods of Circuit of 7, 10 or more days according to circumstances, while the Moray Firth Eddy, appar-:ently, is more constant in its operation with a Period of Circuit of about 7 days. These circuits, several of which may be registered in succession by a single drift-bottle within a given system, appears to be accomplished by the drifters cruising round, but immediately within, the peripheries of the eddies, whether these be in the form of circles or ellipses. To begin with it is not to be suggested that these eddies, where they occur, or appear to occur, in the same or near neighbouring areas, bear any close relationship to the amphi-dromic points of the North Sea tidal system, for, in the first place, eddies have been shown to exist where no such points are known to occur and secondly, whatever movements may take place around amphidromic tidal points will doubtless be character-:ised by periodicities, the amplitude, or amplitudes of which are, primarily, of a different order to the quantities denoting the Periods of Circuit of the eddies concerned. Nor is it the present purpose to discuss the theoretical significance of Periods of Circuit themselves. But the fact, hitherto unrecog-:nised, that such quantities can be estimated from drift-bottle data, when these are subjected to precise cartographical analysis, raises questions as to the physical manner in which eddies react upon floating bodies, for they would seem to be more or less commensurable physical entities and not just totally irregular movements in the nature of clashes, as it were, between opposing forces, or currents. It has already been suggested that these superficial eddies may form the upper ends of vortices which involve at least a part of the column of water below the surface, but this aspect of the problem does not really concern the present thesis which deals only with surface move-:ments.

First of all it is to be noted that drifters which are liberated within the compass of a closed eddy movement gradually work their way outwards from the centre towards the periphery of the system, which seems to argue in respect of these surface complications a characteristic centrifugal force. At the same time we have drifters entering eddies from the outside, as it were, either on account of the propulsive force exerted by the drift in their neighbourhood, or by attraction from the peri-:pheries of the eddies themselves. In view of the above-mentioned centrifugal effect these drifters from outside must, so long as they continue to be dominated exclusively by eddy movements, tend to revolve in close proximity to their perimeters. Furthermore, the fact that drifters may remain for considerable periods/

periods under the dominance of an eddy, argues, first, that the centrifugal force of the system is probably weak and second, that it just balances, around the periphery, whatever force is instrumental in bringing floating bodies within the eddy's region of influence.

Escape from the dominance of an eddy may then be conditioned by a temporary adjustment, or re-adjustment, of this balance. It does not necessarily follow from certain of the cartographical analyses given in these pages that this adjustment of the balance between internal and external forces about an eddy system should occur periodically in the neighbourhood of a fixed point on its periphery, although this may be what is implied by the assumption which is sometimes introduced in order to facilitate the analysis, namely, that, for this purpose, all points of entry into and emergence from an eddy may be considered as having been coincident. On the other hand it is not altogether out of the question that this assumption, where it is introduced, may represent, fairly nearly, the actual state of affairs and in this connection the concept of stream-currents in relation to the surface drift of the North Sea receives a measure of support. The North-East Dogger Bank Eddy may be taken as an example.

By reason of the circumstance that, on escaping from this cyclonic system, drifters which are estimated to have been involved in it for a time seldom appear to be directed at once in any but an easterly to a north-easterly course, it is legitimate to argue that, as a general rule, escape from the dominating influence of the system is effected in the vicinity of the southmost point of its boundary. There is also some indication from the cartographical analysis of the appropriate material that definite entry into the system takes place about the same region. It would seem, therefore, as if the above-mentioned balance of external and internal forces were relatively unstable along a small arc of the southern periphery of the swirl and this instability may reasonably be considered as arising from the action and reaction of a stream-current flowing more or less tangentially to the eddy boundary at its southern limit. In the case under discussion part of this stream-current can be looked upon as feeding the eddy complication and part, probably the greater part, as passing on with some slight alteration in its direction due to the temporary influence of the eddy at the point or arc of contact.

Among the analytical results contained in the memoirs of the present thesis there is sufficient evidence to justify the extension of the above ideas to other eddies, including those which function within an elliptical boundary. Of the latter the Mid-East Scottish Coast Eddy is a case in point. Fed, as it were, by a drift-stream from the north on its north-eastern periphery it is from this same section of the eddy boundary that the majority of drifters affected by the gyration seem finally to emerge from it to proceed southwards, at least for some distance./

distance, in the main body of the feeder-stream which continues on its course with only a temporary deviation in direction, to be attributed to eddy influence. Similarly, entry into and emergence from the Great Northern North Sea Eddy seems most often to be effected around its north-western boundary along which passes the Atlantic Stream as it penetrates the Northern North Sea area.

Velocity of the Drift.

The second of the two chief characteristics of the surface drift in the Northern and Middle North Sea, upon which the drift-bottle experiments of 1910 and 1911 were designed to yield information of value to marine biological research is that of the velocity of the movement, but, before entering upon a discussion, from the point of view of velocities, of the results achieved by the present investigation, brief allusion to the position prior to the publication of the foregoing reports will form a fitting introduction to these results.

Fulton, in 1897, as a result of his drift-bottle experiments in many of the regions with which we are again concerned, found that, on the average, the rate of the surface drift could be put down at from two to three miles per day. Greater velocities were registered in a few instances, but were considered to be due to the more or less temporary effects of strong or persistent winds from particular mean directions and, therefore, to be of the nature of anomalies from the standpoint of the general applicability of the results. Vectors of very much the same order were the major outcome of Carruther's examination of drift-bottle material in respect of the years 1920 and 1921, bearing upon surface drift conditions in the Southern North Sea, that is, principally below latitude 54°N. This authority also makes mention of a number of instances of apparently greater velocity, but in neither case were these records made the subject of particular investigation, being incorporated with extreme records of the opposite nature and with intermediate results in order to estimate what may be called, in one sense or another, 'mean' or 'average' conditions.

Having made a study of the relevant publications dealing with the subject and the areas presently under discussion, the writer, for reasons which are stated in the introduction to the first paper of the thesis, came to the conclusion that the initial step towards the establishment of an almost universally applicable surface current picture - provided that were found to be possible in the end - should be the extraction in detail of all available information in respect of each of a number of years. This of course applies equally to the direction of the drift as to its velocity, for the apparent variations in both characteristics during any one year and/or from one year to another, seemed, at times, to be so great that the practicability of devising a general or 'mean' case of sufficient accuracy to subserve marine biological research in connection with fisheries (which, of course, was/

was originally the main aim of these drift-bottle experiments) was seriously in question. Böhnecke's several surface current charts may be cited in illustration of what is meant.

To return, however, to the matter of velocities, brief mention may be made of certain precision-apparatus, known as current meters, by means of which directions as well as the velocities of horizontal sea movements have been estimated in the North Sea and neighbouring areas. There are several types of these instruments, but all the better known ones are more or less alike in principle. Each houses a compass and for this reason it is not possible to use the apparatus for accurate surface drift measurements except under conditions which, in the open-sea at any rate, are rarely met with nowadays. Nevertheless, their results in relation to depths of about ten metres might be compared with surface measurements from other sources were it not that, in regard to velocities in particular, these results are so extremely variable among themselves as to afford little or no ground for effective comparison except in isolated instances. The method, in fact, would appear to be at once too fine and not fine enough; too fine in that these instruments register, or appear to register, overmuch detail at a given spot and not fine enough, since, to effect numerous more or less simultaneous observations over a wide area, in order as far as possible to comply with the conditions of synchronism, is well nigh impracticable.

Another source from which velocities have been derived, although not in relation to the North Sea, but in respect of the Faroe-Shetland Channel area, is by means of hydrodynamical computation from the observational data of temperatures and salinities, according to a formula worked out by V. Bjerknes and his collaborators.* Vectors ranging from about six to eight miles per day in autumn or winter to a maximum of from twelve to sixteen miles per day in spring or early summer have thus been calculated with reference to the surface of the Faroe-Shetland Channel current flowing practically north-eastwards to the west of Shetland and from which, as already indicated, the main North Sea cyclonic system may be regarded as deriving its initial impulse. For this reason, the discrepancy between these magnitudes and the 'average' vectors estimated from drift-bottle records in respect of the North Sea surface drift would seem to demand further investigation. This, in fact, was a subsidiary aim of the cartographical analyses of the 1910-1911 material and was partly responsible for the fuller exploitation of the short-period return with its implication of relatively rapid motion on the part of the drifter and hence of the surface current or currents in the areas traversed.

That a closer connection can be established between the velocities registered by drift-bottles in the Northern and Middle North Sea and those which have repeatedly been calculated in respect/

* V. Bjerknes: "Dynamic Meteorology and Hydrography." Carnegie Institute of Washington, 1910 and 1911.

respect of what may be termed the 'parent' area of the Faroe-Shetland Channel, is amply demonstrated by the velocity-curves of Figures 19 and 32 in the present thesis. The velocities there represented range from five to nearly thirteen miles per day. Moreover, the variation in velocity is shown to correspond very closely with the seasons. This circumstance denotes not only an advance in our knowledge of surface drift phenomena in the areas investigated, but, in relation to velocities at any rate, effectively disposes of the 'average' idea by placing our understanding of these magnitudes, particularly of their variations, upon a more or less precise foundation.

There is still a sense, however, in which even the above-mentioned velocity-curves represent only mean conditions. Referring again to the matter of stream-currents and if this conception has any foundation in fact, it is more than likely that, in the central line of such a stream, the velocity will be slightly greater than to right and left, enhancing thus any tendency which may arise from this or other causes towards the deviation from the main stream of its outer margins. The following quotation from Fulton gives point to this argument.

"It also appears that the speed is, as a rule, greatest at some distance from the coast of Scotland and the north of England; that it diminishes quite near the coast and likewise at a considerable distance, say 50 or 60 miles, from it."

It is still more probable, if not, indeed, almost certain, that, contemporaneously, the velocity of the drift will vary somewhat from one region to another within the wider areas dealt with. Neither of these variations, however, if they actually exist, appear to be so significant as to affect, materially, the cartographical analysis of drift-bottle records on the lines laid down in this thesis, as evidenced by the fact that a smooth curve results from the assumption that the vector deduced in respect of a small but essential part of the entire area may be taken as representative of conditions in any other part, or indeed, in the whole area.

The most conspicuous feature of the velocity-curves for 1910 and 1911 obviously lies in their marked similarity of form. Both show a maximum of approximately the same magnitude and, although the 1911 curve stops short of a minimum, there is evidence pointing to the circumstance that, had the data been sufficient to cover the period involved, practically the same minimum of about five miles per day would have been recorded towards the end of that year as in the corresponding period of 1910. This broad similarity between the two velocity-curves still further bespeaks the wider applicability of these 1910-1911 surface drift results and the fact that the two curves are, primarily, of the same shape or form, showing maxima and minima at or near the same seasons of the year, strongly suggests that the events or conditions which give rise to their con-:struction are more or less periodic in character. This point will/

will be further discussed in the sequel.

As indicated above it is estimated that the respective minima on the two velocity-curves in question occurred about the same time of the year. The same is not true of the maxima. In 1911 this condition was reached practically two months in advance of the time of the corresponding phase of the 1910 surface drift velocity. There is no doubt that this difference has a wider significance which also will be commented upon below.

In both years the approaches towards maximum velocities appear to have been very similar, for although, in this respect, it is the 1910 curve which literally falls short, as it were, there is sufficient indication from that part of the curve which is shown that the rise towards the maximum in that year was almost, if not quite, as steep as it was nearly a year later. In other words, the circumstance represented by this portion of each curve is that, in the early part of the year, the velocity of the surface drift in the Northern and Middle North Sea is rapidly accelerated. Maximum velocity, when once it is attained and as is naturally to be expected perhaps, may continue to hold for an interval of two or three weeks. Thereafter, a more or less gradual retardation of velocity towards a minimum takes place.. Apparently, this retardation was more gradual in 1911 than in 1910, for a month or two at least, being, in fact almost imperceptible throughout the month of September. Once again, in conjunction with other important findings from the 1911 cartographical analysis, this may have an important bearing upon related hydrographic and perhaps meteorological phenomena, the fuller discussion of which will form a fitting conclusion to this chapter.

GENERAL OBSERVATIONS.

The fundamental significance of hydrography, from the biological standpoint, rests in the importance of environmental factors in the study of marine life. Primarily, this calls for a knowledge of the chemical composition of sea-water and of the physical conditions and processes to be met with in the sea; in other words, a knowledge of the physico-chemical nature of the medium in which marine plants and animals live. It was soon perceived, however, that the results of investigations directed towards this end could be rendered of more far-reaching service to/

to fisheries research by, at least, conjoint practical inquiry into the question of water movements or currents in the sea. On logical grounds a case might even be argued for the precur:sory acquisition of information on the latter subject, for, in the words of a modern authority, it would seem that "the foundation of a true knowledge of the seas is a knowledge of the (its) movements."

Of the movements which take place in the medium of the sea, embracing probably all combinations and modifications of movements which are either purely horizontal or purely vertical in character, those approximating more or less nearly to the former category are, without a doubt, the major movements and, consequently, are those of most immediate practical importance. Again, in relation to horizontal movements, the surface currents in the sea are obviously the first which should be considered, if for no other reason than that they are most accessible to some practical form of measurement.

The primary significance of surface currents, from our point of view, lies in their transporting power, not necessarily of masses of sea-water of definite physical characteristics, although this also enters largely into the problem for solution and is the next question to be attacked, but, first of all, in relation to objects which are suspended and immersed in the surface waters of the sea. The most obvious and most direct method of approach towards this particular problem would therefore seem to be by means of such specially-prepared agents as drift-bottles, upon which, as a practical proposition, the nearest approach to direct and continuous observation over somewhat lengthy intervals of time, can be made. The knowledge to be derived from drift-bottle experiments, subject to certain conditions as to their prosecution over wide areas, may therefore be regarded as fundamental to the science of hydrography itself.

In the body of the thesis an attempt is made, by the critical analysis of drift-bottle records, to answer the questions of what <u>are</u> the movements which take place in the surface waters of the Northern and Middle North Sea principally and of their resultant effects, in a horizontal direction, upon inanimate objects and so, presumably, upon living organisms, with no motive power of their own, which may be suspended in these waters, and, although the results obtained are to be regarded meantime as referring only to the surface layer of the sea areas concerned, to a depth of six or eight inches, their significance in other directions involving somewhat greater depths, may be considered, in particular their significance in relation to the translation of masses of sea water possessing definite physical characteristics.

The North Sea as a whole receives its supply of water from two main sources, first, from the north-eastern Atlantic Ocean by way/

way of the north of Scotland and, to a much lesser extent, through the Straits of Dover and second, from the Baltic area, with which may be included, as of similar significance, the rivers flowing into the North Sea. The characteristics of the waters so derived are the high salt-content and, usually, the relatively high temperature of the Atlantic water and the almost extreme freshness and, to begin with, low temperature, of the Baltic and river outlets. Water of intermediate physical properties fills a large part of the North Sea and is known as North Sea water.

The most important contribution, from a fisheries point of view, to the water economy of the Northern North Sea is the Atlantic influx from the north. This invasion has been the subject of much study, despite which a certain amount of confusion still holds in regard to the various aspects of the problem.

Atlantic water is continuously pushing its way southward into the Northern North Sea; always by way of the Shetland-Norway opening, but probably not without intermission, at least, through the Shetland-Scotland passages, as hitherto believed. This, of course, is a deduction from the present work.

The Volume of Atlantic water to be found in the Northern North Sea at a given time varies throughout the year and from one year to another. Within the period of a calendar year this volume appears generally to be greatest in autumn, or towards the end of the year and least, some six months correspondingly earlier, although the degree of variation in this respect may, in a particular year, be very great.

Again, what has been called the intensity of the Atlantic inflow also varies throughout a yearly period and, to a less extent doubtless, from one year to another. It is in the confusion of the two ideas of 'volume' and 'intensity' that much of the difficulty arises in the endeavour to understand the sequence of hydrographic events in the areas concerned, for the intensity of the Atlantic 'invasion' would appear generally to be greatest when the volume occupied by the water itself in the Northern North Sea is least and vice versa, or approximately so.

It would be better perhaps to substitute the composite name of momentum for that of intensity, for then, in considering the 'intensity' of flow, there are two factors, mass and velocity, which must, simultaneously, be taken into account and, on this basis, the present drift-bottle results, in conjunction with the above findings from the study of physical observations, would seem to offer an explanation of the apparent anomaly between the corresponding phases of the momentum and the capacity or cubic content of the Atlantic incursion into the Northern North Sea.

Of/

Of course, for lack of precise measurements the following explanation can only be regarded meantime as a working hypo-:thesis. As such, however, it places the problem upon a more or less definite footing, to be investigated further on the lines suggested by existing information regarding the physical and dynamical characters of the waters to be found in the North Sea and contiguous regions.

It has been demonstrated that the velocity of the surface drift, which also has been considered to comprise a number of stream-currents, reaches a maximum in spring or early summer and a minimum in winter. If we take this to apply to the Atlantic stream-current which flows for a short distance east-:ward, to the north and east of Shetland, and from which is derived the branch-stream turning more or less abruptly south-:ward into the Northern North Sea, it seems that, by reason of this abrupt deviation, the <u>mass</u> (or volume) of the water composing the branch-stream will tend to be least when the velocity of the main-stream is greatest and <u>vice versa</u>. Hence the conditions outlined above in respect of the Atlantic influence in and upon the Northern North Sea area would probably follow as a natural consequence from these circumstances, the greater <u>volume</u> of water in the area being due to the 'overweight', as it were, of the mass factor in the momentum, while greater <u>intensity</u> of flow signifies greater velocity in relation to a small mass. It may be the business of future research to push this idea still further back, as it were, and seek to establish at least a qualitative relationship between current events in the north-eastern Atlantic Ocean and - through the Faroe-Shetland Channel - contemporaneous, or perhaps somewhat later hydrodynamical conditions in the North Sea.

In connection with the above aspect of the hydrography of the areas with which we are immediately concerned and upon which the present drift-bottle results appear to have a most signific-:ant bearing, it may be mentioned that, in the separate study of the relevant physical data, to which allusion is made in the Foreword to this thesis, a prominent feature of these investig-:ations with reference to the southern reaches of the Norwegian Sea between latitudes 61° and 62°N. and from about longitude 2° to 4°E., is the crowding together on the surface of this region, of both isotherms and isohalines. Moreover, the direction of these curves is approximately N - S, which would hardly be the case if the currents within the area were essentially eastward in direction as propounded on several occasions by Robertson(11) in his interpretations of temperature and salinity measurements. Similar correspondence in respect of other regions are to be traced between surface drift phenomena, as revealed by the charts in the foregoing papers, and similar cartographical representations of the surface distribution of isothermal, isohaline and iso-:pycnic conditions. From this circumstance, referring only to direction,/

direction, it may be reasonable to anticipate a yet fuller knowledge, not only of the surface current systems in the areas investigated, but of the horizontal motions which take place below the surface at intermediate depths to the bottom and concerning which little of a precise nature is now known, mainly on account of the practical difficulties to be overcome.

Another important aspect of the present drift-bottle results, in association with the information to be derived from the observ-:ational data of temperatures and salinities, extends this anticipation to include also the velocities of sub-surface currents. As explained earlier in this chapter, surface drift velocities have been calculated in respect of the Faroe-Shetland Channel current by hydrodynamical computation and, with these results, the comparable vectors obtained from drift-bottle analyses have been shown to agree very closely. This fact is of prime importance, for the hydrodynamical method does not of itself yield absolute values of velocity. Only where the velocity at a given depth may be taken as zero, or where the velocity at any depth is otherwise known, can the relative values given by calculation according to the circulation theory and formula of Bjerknes, be converted into absolute values. A 'zero' layer, such as must exist in the Faroe-Shetland Channel where the upper water layers move northwards and the bottom waters towards the south, is not known on the North Sea plateau, nor, by any other sufficiently reliable means, has there been obtained so far an absolute vector in relation to a specific depth, so that, meantime, only relative values of velocity can be derived from Bjerknes' theory in relat-:ion to the North Sea. But the important point is this. If, in respect of regions where they can be compared, the drift-bottle vectors are found to agree with those derived by the above means, that is, from quite another source, it is only another step to convert the relative hydrodynamical values into absolute quan-:tities and so apply the theory to an investigation of horizontal water movements in the intermediate and bottom layers of the North Sea.

In dealing with the incursion of Atlantic water into the Northern North Sea it is mentioned that, while this occurs with greatest momentum in spring or early summer as a rule, thereafter gradually falling off towards minimum momentum in autumn or winter, more or less substantial variations from these so-called normal conditions are liable to take place in a particular year. For instance, in the year 1905 it is estimated that, in addition to the usual spring 'advance' of Atlantic water into the area, a secondary strong pulsation from the same source occurred in the month of October. Some indication of very similar circum-:stances is given by the drift-bottle analyses of 1911, on the assumption, for which there seems to be adequate justification, that the velocity-curve, in general, may be taken also as a register of events in relation to this Atlantic influence. Notice has/

has already been taken of the different positions occupied by the Great Eddy throughout the year 1911; first, at the end of February, it operated in a southerly position, then, three months later, it was found more to the northward and three months after that again, that is, at the end of August approximately, the system had apparently reverted to its position of February. It is suggested that these circumstances also have a direct connection with the pulsation of Atlantic water from the north into the North Sea. On the basis of the foregoing assumption, the velocity-curve for 1911 shows that from the beginning of the year until the middle of March the momentum of the Atlantic inflow increased rapidly, which may be taken as the cause of the Great Eddy being in a southerly position about that period. Likewise, its migration northward between the months of March and May inclusive was probably conditioned by the fact of diminishing resistance from the north, in the form of a gradual diminution in the momentum of the Atlantic impulse. By the same sort of argument its reversion to a southerly position towards the end of August can be read as implying increased momentum on the part of the Atlantic stream issuing immediately from the southern latitudes of the Norwegian Sea. On the lines of the above assumption it does not appear from the velocity-curve that this increase of momentum was, in the main, due to an increase in velocity, but the 'flatness' of the curve representing the months of August and September, practically, may indeed signify the attainment of a minimum and a small secondary maximum in the interval, the amplitude of this deviation from the conditions represented by the curve as given being of too small moment to be measurable by the drift-bottle analysis.

Probably connected with the above translations of the Great Eddy of 1911 are the corresponding changes which apparently affected North-East Dogger Bank and Lindesnaes Swirls in the summer of that year. From a southerly position we find the original North-East Dogger complex moving slowly northwards prior to the beginning of August 1911, at which period its proximity to the Lindesnaes Eddy resulted in the coalescence of these two systems. Immediately thereafter the resultant eddy commenced a southerly migration which seems to have ceased about the end of August.

Again regarding the velocity-curve as an index of events connected with the Atlantic influence upon the Northern North Sea area the appreciably different times of occurrence of maximum velocity in the surface drift of 1910 and 1911 may be taken to represent an equal difference in the times of occurrence of maximum momentum in the Atlantic inflow as between the two years in question. This and kindred matters doubtless have an underlying significance in relation to questions concerned with the Northern North Sea fisheries, the vagaries of which from year to year present many formidable problems for solution.

In/

In conclusion, brief reference may be made to the still wider significance which these drift-bottle experiments may possess in association with the other aspects of the hydro-:graphy of the areas involved. This concerns their probable repercussions upon that branch of meteorological science which is devoted to the forecasting of weather. From the point of view of the hydrographer, the connection between the two sciences of meteorology and hydrography by this avenue is dis-:cussed broadly in the second appendix to the present thesis. The following observations are in the nature of an illustration of the ideas contained in this appendix.

In the first quarter of the year 1911, besides a concen-:tration of drift-bottle strandings on Skagerak shores, which is not an extraordinary feature of Scottish drift-bottle results, there was registered a similar concentration of recoveries on the west coast of Schleswig-Holstein, between the mouth of the River Elbe, Germany, and Blaavandshuk, Denmark. Among the records extending over a long period of years, it is observed that bulk strandings on this southerly stretch of the eastern North Sea seaboard is a somewhat unusual occurrence. Moreover, these 1911 recoveries were of bottles which had been adrift for lengthy periods, wherefore their chances of earlier strand-:ing, here or elsewhere, must be considered as having been relatively great.

In the same interval (the first quarter of 1911), according to the velocity-curve the acceleration of velocity was extremely rapid and we have already associated this phenomenon with the incursion of warm, salt Atlantic water into the Northern North Sea with its resultant effect, from the point of view of its momentum, upon the Northern and Middle North Sea surface water circulation. For the present it is the temperature of this water which concerns us, as an index of the amount of heat which is transported into the area. The ratio of the heat capacities of sea water and of air is such that the liberations of a small amount of heat into the atmosphere from the sea doubtless has a very marked effect upon the temperature of the atmosphere and so upon weather conditions over at least near neighbouring lands. It may be that this meteorological effect is not regis-:tered until after a lapse of some weeks from the entry of the warm sea water into the area. At any rate, in relation to the above facts concerning the drift-bottle records of that year and the hydrographic conditions with which they are probably associated, it is significant that the 'summer' of 1911, in north-western Europe, was a remarkably fine one. Again, although the last quarter of the year was notable for storms and heavy rains, the latter, however, occurring mostly in the night-time, the season/

season was marked by unusual warmth for the time of year. This may have been more or less the direct outcome of the above-suggested secondary pulsation of Atlantic water which appears to have taken place about the month of August 1911. There are thus good grounds for an opinion that, through the science of hydrography, by the intensive investigation of currents in all their aspects, may come the long-desired power of being able to anticipate the duration and intensity of the seasons and, with this power, the benefits which would thereby accrue to mankind, in agriculture to begin with probably, and also in trade and industry, need only to be mentioned to be appreciated.

- -

A final word as to the future conduct of surface drift-bottle experiments. It is mentioned in the introduction to Part I of this thesis and also in Appendix I that the desiderata for the most satisfactory outcome of the drift-bottle method of investigation must be, regularity and continuity of liberation-operations, rather over a wide field than from one or two selected points. While these conditions have, since 1920, been observed to some extent and, moreover, should continue yet to be observed for some time to come, there are more or less definite indications from the results set forth in these papers that some relaxation of the above conditions will doubtless be permissible when much of the information already to hand is more firmly established. This means that the continuance, for a period of years, of intensive and widespread liberations will almost certainly lead to the revelation of 'key' regions, within which surface drift conditions at a given time will have important later consequences in another, or other, regions. Thus, from a knowledge of events in one of these so-called key areas, events further afield may be more or less anticipated. At present it may be laid down that a good working programme of liberations extending over a year in the areas concerned in the present investigation would be to commence operations early in the year on a line between the Butt of Lewis and Faroe Bank, thereafter proceeding north-eastwards on lines transverse to the direction of the Faroe-Shetland Channel, until a line from the northmost point of Shetland to the northern part of Faroe is accomplished. Thence, from the area north of Scotland, lines of stations should be thrown out north-eastward from these islands, working round to eastward and so, as the seasons advance, down into the North Sea on lines approximately parallel to the latitudes and extending, as far as possible, the whole width of the area.

* * * *

A P P E N D I X I.

THE DRIFT-BOTTLE METHOD

AS A MEANS OF DETERMINING SURFACE CURRENT SYSTEMS.

By

JOHN B. TAIT, B.Sc.

Paper communicated by Dr J. N. Carruthers, D.Sc. (Ministry of Agriculture and Fisheries, Lowestoft) at a meeting of the Northern North Sea Committee of the International Council for the Exploration of the Sea. Copenhagen, 29th May, 1930.

THE DRIFT-BOTTLE METHOD

AS A MEANS OF DETERMINING SURFACE CURRENT SYSTEMS.

Despite the fact that there is more than one method by which currents in the sea may be investigated, existing knowledge of the general water movements within the Northern North Sea, which has more or less open communication with oceanic waters, is remarkably indefinite and uncertain. To some extent, this is due to shortcomings in the methods themselves, most of which are either lacking in some important particular or demand adherence to such rigid rules and conditions as seriously to hamper practical operations. Weather, of course, governs in greater or less degree, the application of all methods depending upon means of observation.

There is, however, one method, so far most successfully applied to the problem of surface currents, which is not so restricted in many ways as those involving precision apparatus of various kinds. I refer to the drift-bottle method which has been employed by Scotland for many years and which has already yielded satisfactory results with distinct promise of better.

As to cost, this method compares most favourably with any other so far employed. Weather conditions obviously impede its initial prosecution less than is the case with any operations necessitating the laying-to of the ship, and there is the additional advantage that drift-bottles will ride through rough weather and perhaps tell us something of its effects upon the sea. The method is not an absolute one such as that of current-meter observations purports to be. Nevertheless, in comparison with this method, there are one or two points on which advantage can be claimed.

An important desideratum is the synchronisation of observations over an extensive area. The achievement of this objective by current-meters is exceedingly remote. On the other hand it can definitely be claimed that, with fairly intensive and continuous liberation of drift-bottles over widespread areas, the approach towards synchronism will be surprisingly near.

In a given time obviously more 'ground' can be covered in the launching of the drift-bottle method than is possible even in the collection of temperature and salinity data, which also, by hydrodynamical computation, furnish a means of determining currents, not only on the surface, but at intermediate depths and along the bottom. The values so obtained, however, are only/

are only relative. Nevertheless, if in respect of surface currents alone, these two methods be worked together and one is found to corroborate the other, it must be conceded that a step forward will have been taken. Corroboration has indeed been obtained in connection with Scottish experiments in the Faroe-Shetland Channel. A means of determining, not only surface currents, but those beneath, may thus be in sight.

An apparent disadvantage of the drift-bottle method, compared with certain others, is the period which must elapse between the execution of the initial work and the attainment of a current picture. The results which have accrued from such experiments carried out by Scotland in pre-War years strongly indicate that this drawback will become gradually less as the experiments are continued, for the establishment, by this means, of prevailing current systemsover a wide area seems likely to lead to the revelation of portions of this area within which alterations in the direction and strength of a current will have wider significance. It should be sufficient, therefore, when this is possible, to 'tap' those 'key' areas. In this way too the objective of synchronism may be still more nearly approached.

In effect, a powerful objection to the drift-bottle method has been the belief that the only reliable information to be gained from these experiments is a knowledge of the positions of liberation and recovery of drifters. The implication is that the times which elapse between the dates of these events is of relatively little value, the magnitudes of these periods, in a large number of cases, pointing, it is thought, to the fact of the drifters having stranded considerably before actual discovery was made. On the contrary, the Scottish experiments show that the'drift-periods' of returned bottles, collectively in the first instance and then individually, are <u>the</u> important factors in an analysis of the data. Furthermore, the problematical times spent upon beaches are, in the majority of cases, negligible in comparison with the entire drift-periods, the incomparably greater magnitudes of these quantities being due to certain unique phenomena of surface water movement, notably swirls or eddies. By a judicious plan of liberation these complications in the surface current system may be'placed' with a fair degree of precision.

These are the main points in a case for the adoption of this simple and by no means costly method of attacking/

of attacking the complex problems of ocean currents. The conditions for the most satisfactory outcome of the method are, regularity and continuity of operations from numerous widely-scattered points rather than from only a few selected stations.

* * * * *

A P P E N D I X II.

VIIe CONGRÈS INTERNATIONAL D'AQUICULTURE
ET DE PÊCHE
(PARIS 1931)

The Liaison between the Sciences of Oceanography and Meteorology

by John B. TAIT. B. Sc.

ORLEANS
SOCIÉTÉ NOUVELLE DE L'IMPRIMERIE DU LOIRET
RUE DU BOURDON-BLANC, 37-39

1931

VII[e] CONGRÈS INTERNATIONAL D'AQUICULTURE
ET DE PÊCHE
(PARIS 1931)

Groupe I
Section 2

QUESTION N° 5

Liaison des Sciences océanographiques et météorologiques

The Liaison between the sciences of oceanography and meteorology

by John B. TAIT, B. Sc.

In the words of Beaugé (1). « C'est un truisme que de poser en principe les réactions réciproques de l'air et des océans. » The highly commendable work of Maury (2) in the middle of last century was founded upon this belief. In addition to reciprocal reactions it is only to be expected, on account of the fluidity of the two media, that there should exist a parallelism between the physical phenomena, both static and kinetic, occurring within the atmosphere and the hydrosphere. The following discussion is mainly concerned with relationships of the former category, namely, such as establish a connection between the sciences of oceanography and meteorology in their practical aspects.

Hitherto, that branch of oceanography embracing the study of the physical characteristics and processes pertaining to the sea, namely, the science of hydrography, or as some prefer to call it,

(1) Commandant BEAUGÉ. — « Contribution à l'étude des relations de la Météorologie et de l'Océanographie ». Bulletin de la Société d'Océanographie de France, 11e année, nos 58 et 59, 1931.

(2) M. E. MAURY. — « The Physical Geography of the Sea », 1855.

hydrology, has had in greatest measure for its immediate object the elucidation of cognate biological problems of the hydrosphere. From a humanistic point of view these investigations have been intimately associated with questions of signal importance to the fishing industry. There are, however, other directions in which hydrology will almost certainly develop and these, while they have not been entirely overlooked, have not so far received the attention they merit, largely on account of the obstacles to be overcome.

On the land, the analogue of the fisherman is the farmer, one of whose chief, one might almost say, vital concerns is the weather, especially the anticipation of weather. At its present stage of development the range of fairly accurate weather-forecasting, generally from one to three days, is only of limited value to the agriculturalist, viewing his occupation as an annual cycle of events. In some respects these short-period forecasts, demanding from the landworker an additional knowledge of local idiosyncrasies of weather, are, by comparison, of greater import to the fisherman on account of his mobility.

At the other extreme in this branch of meteorological science are the investigations, based on the period law, relative to climatological cycles of numbers of years. For instance the annual incidence of rainfall at various places on the earth's surface and observed over a long period of years suggests a periodical recurrence of similar conditions, once in eleven years as regards India and once in nineteen years in Australia and South Africa. Furthermore, the recognised periodicity of eleven years in the frequency of sunspots has formed the basis of numerous researches aiming at the correlation of the more outstanding features of weather with this solar phenomenon. These results, however, even were they more definitely conclusive, would still be of uncertain aid in the essentially practical matters of land-productivity, at the root of which is ever the question of a good or a bad season forthcoming.

The mere mention of the possibility of a seasonal forecast of weather conditions is sufficient to convey an idea of the inestimable benefits which would thereby accrue to agriculture and other pursuits which are dependent upon factors of climatic variation, not only as between one season and another, but relative to the incidence and duration of a particular season While it is not the purpose of the present paper to claim that this end can be at once achieved from a study of hydrology, there can be no question that a more intimate knowledge than at present prevails concerning the seas and their ways is essential to a fuller understanding of atmospheric phenomena and will furnish a step towards that much-desired end, the anticipation of the seasons.

The problem is highly complicated, no doubt, and is beset with practical difficulties attendant upon the long and arduous labour of collecting the requisite data, arduous because of its routine and, at the same time, meticulous character. In addition, of course, work to be performed at sea is contingent upon weather conditions to a much greater extent than similar work on land.

Nevertheless it is well to note, as having a significant bearing upon this matter of long-period weather-forecasting, that some pioneering work of a promising nature has already been accomplished, pointing the way to further researches. Scandinavian and German scientists (1, 2 and 3) have demonstrated the existence of broad correlations between *the temperature of the sea* during a particular epoch and subsequent agricultural events in the countries of northern Europe. That these relationships have been established through the connection which evidently exists betwen the temperature of the sea on the one hand and the temperature of the air on the other, is not altogether surprising, for, from a consideration of the physical properties of the two media, it is clear that the sea must exercise an enormous influence upon atmospheric temperature, in illustration of which may be cited the following.

The ratio of the heat capacities of sea and air is such that if the temperature of a cubic metre of sea-water containing 35 parts by weight of salt is lowered 1°C. by loss of heat to the superincumbent atmosphere, the loss to the sea is sufficient to *raise* by 1°C. the temperature of 3000 cubic metres of air.

In this matter of sea-temperatures, then, there doubtless lies the crux of many meteorological phenomena contributing towards the incidence and what might be called the « intensity » of the seasons. Stated simply, the problem consists in the measurement of the heat exchange between the hydrosphere and the atmosphere. To complicate matters there enter firstly the questions of evaporation and

---

(1) B. Helland-Hansen and F. Nansen. — « Die jährlichen Schwankungen der Wassermassen im norwegischen Nordmeer in ihrer Beziehung zu den Schwankungen der meteorologischen Verhaltnisse der Ernteerträge und der Fischereiergebnisse in Norwegen ». International Revue der gesamten Hydrobiologie und Hydrographi. Band II. Leipzig, 1909.

(2) W. Meinhardus. — « Ueber einige meteorologische Beziehungen zwischen dem Nordatlantischen Ozean und Europa im Winterhalbjahr ». Meteorologische Zeitschrift, March 1898.

(3) O. Pettersson. — « Ueber die Beziehungen zwischen hydrographischen und meteorologischen Phänomenen ». Meteorologische Zeitschrift. August 1896.

condensation, the effects of which might readily be submitted to measurement were the media static, but the movements which are constantly taking place in sea and air introduce further complexities of no mean order.

From the hydrological standpoint an attack upon the present problem might well commence from this angle of water movements which are now known only on very broad and general lines and mostly appertaining to horizontal motions. Although perhaps of smaller magnitudes on the whole than the vast oceanic translatory movements, vertical currents in the sea, particularly in the neighbourhood of continents, call for serious consideration in the matter under discussion at the moment. The prime significance of horizontal movements in relation most of all to temperate regions lies in the circumstance that the heat conveyed there by oceanic currents is derived essentially from the absorption of solar radiation in tropical latitudes. The contingency of vertical movements also comes into play where the warm uppermost current, by reason of its salt content, is denser than the sea water through which and over which it passes. To give further point to the argument we shall consider the water of the North Sea which, in virtue of its more or less open communication with oceanic regions, constitutes a very favourable area for the development of hydrological theory in association with meteorology.

Since the year 1902, when fishery investigations were put upon an international footing, much work has been done on the subject of the physical properties of the waters comprising the North Sea and adjacent areas, particularly as regards the relationships between those areas and the North Atlantic Ocean. It is now known that water of oceanic origin, recognised by its high salinity and high temperature, penetrates the North Sea from the south through the Straits of Dover and from the north between Scotland and Norway. The latter inflow is of the greater strength and volume and appears to be continuous throughout the year, except under very abnormal circumstances. But the *momentum* of the current carrying this warm and salt water into the area is subject to more or less seasonal fluctuation, the strongest flow taking place as a rule between the months of March and May and the weakest impulse occurring towards the end of the year. In one or two years, however, marked departures from the general or « average » rule have been experienced. The incursion of what is known as Atlantic water may be extraordinarily weak or extraordinarily strong in any one year. At other times, within the space of three consecutive seasons, two distinct propulsions may be recorded.

These hydrological events, besides having their effects upon the fauna of the North Sea, undoubtedly influence in marked degree the climate of northern Europe, as instanced in fact by the work of the afore-mentioned authorities. Meinardus, for example, formulated two groups of conditions which are invariably associated. A weak Atlantic circulation between the months of August and February corresponds with a low air temperature over middle Europe from February to April and bad wheat and rye crops in west Europe and north Germany. Conditions the reverse of these also appear to hold good. That is to say, good cereal crops follow from a high air temperature over middle Europe between the months of February and April and this in turn is evidently connected with a strong pulsation of water from the Atlantic in the previous six months. It seems pertinent therefore to investigate further these interesting associations with a view to their formulation on a quantitative basis.

The first point at issue is the water economy of the region in question namely, the North Sea and its contiguous areas. In the south, that is between England and France, experiments to this end are being carried out at the instigation of Carruthers who has already published some results of his investigations (1). The northern entrances to the North Sea present a more difficult problem. Knudsen (2) and Gehrke (3) have made observations and calculations upon the amount and characteristics of the water entering the North Sea between Scotland and Norway in the course of a year. Apparently the annual increment of waters to the North Sea by way of the north and south channels respectively is in the ratio of ten to one. In view, however, of certain results which have been obtained by the present writer (4) in regard to the surface currents functioning in the northern pas-

---

(1) J. N. Carruthers. — « The Flow of Water through the Straits of Dover as gauged by continuous current-meter observations at the Varne Lightvessel (50°56'N. 1°17'E.) ». Part I. Ministry of Agriculture and Fisheries. Fishery Investigations. Series II, Vol. IX, N° 1.

(2) M. Knudsen. — « Some Remarks about the Currents in the North Sea and Adjacent Waters ». Conseil International pour l'Exploration de la Mer. Publications de circonstance, N° 39, 1907.

(3) J. Gehrke. — « Mean Velocity of the Atlantic Currents running north of Scotland and through the English Channel ». *Ibid.*, N° 40, 1907.

(4) J. B. Tait. — « The Surface Water Drift in the Northern and Middle Areas of the North Sea and in the Faroe-Shetland Channel ». Fishery Board for Scotland. Fish. Sci. Invest. 1930, nos II and IV.

sages giving access to the North Sea (from the Faroe-Shetland Channel on the north-west and from the southern reaches of the Norwegian Sea on the extreme north) the results obtained by Knudsen and by Gehrke may require to be modified in some respects.

Another significant source of recruitment to the waters of the North Sea, especially to the topmost layers, is the Baltic area, from which, again more or less at periodic intervals and by way of the Skagerak, a strong current of relatively *fresh* water emerges, to spread sometimes far westwards on the surface of the sea. By reason of its freshness this water absorbs and again loses heat much more rapidly than is the case with the salter water of Atlantic origin. Of smaller magnitude, but similar in effect to the Baltic outflow, is the output of river water to the sea, giving rise at least to a coastal zone where temperatures fluctuate more markedly than in open sea areas.

The question of the escape of waters from the area under survey does not appear to have received the same attention, yet the matter is naturally of some importance to the point at issue, namely the water economy of the North Sea. It is known that in a narrow belt adjacent to the Norwegian coast large volumes of water are constantly leaving the area, but so far as the writer is aware the ratio of this efflux to the total annual increment has not been calculated.

To the ultimate purpose of the establishment of a connection between the amount of heat in the sea and the amount present at some later time in the atmosphere it is most desirable that the above facts should be known in greater detail than merely as average yearly values. By a combination of the methods employed by the above investigators, that is, by means of current meter observations, temperature and salinity data, from which densities and thence under certain conditions currents may be calculated, and finally by the agency of drift-bottles, it should be possible to assess at these gateways to the North Sea the quantities and the physical characteristics of the water entering and leaving the area from time to time. Similar material, principally temperature and salinity data, collected at fairly regular intervals from numerous stations widespread over the area, will afford information relative to the rate of dissipation of the store of heat carried into the region by way of the channels above-mentioned. In conjunction with meteorological observations of air temperature, pressure, wind and humidity the directions in which this dissipation takes place may be investigated. Systematic research on these lines ought to reveal certain « key » factors from which subsequent effects, hydrological and meteorological, may be computed.

To sum up these arguments in a brief sentence one might venture the opinion that continued progress in the study of hydrology, while furthering the interests of the fishing industry, will at the same time have its repercussions on other human occupations through the medium of long-range weather-forecasting. As already remarked much has been done in the way of the acquisition of data. A great deal more however remains to be accomplished in this direction and on an organised principle. The magnitude of the task is such as calls for international co-operation. At the same time the benefits which are visualised from a successful outcome of the work are unquestionably international in character.

RÉSUMÉ

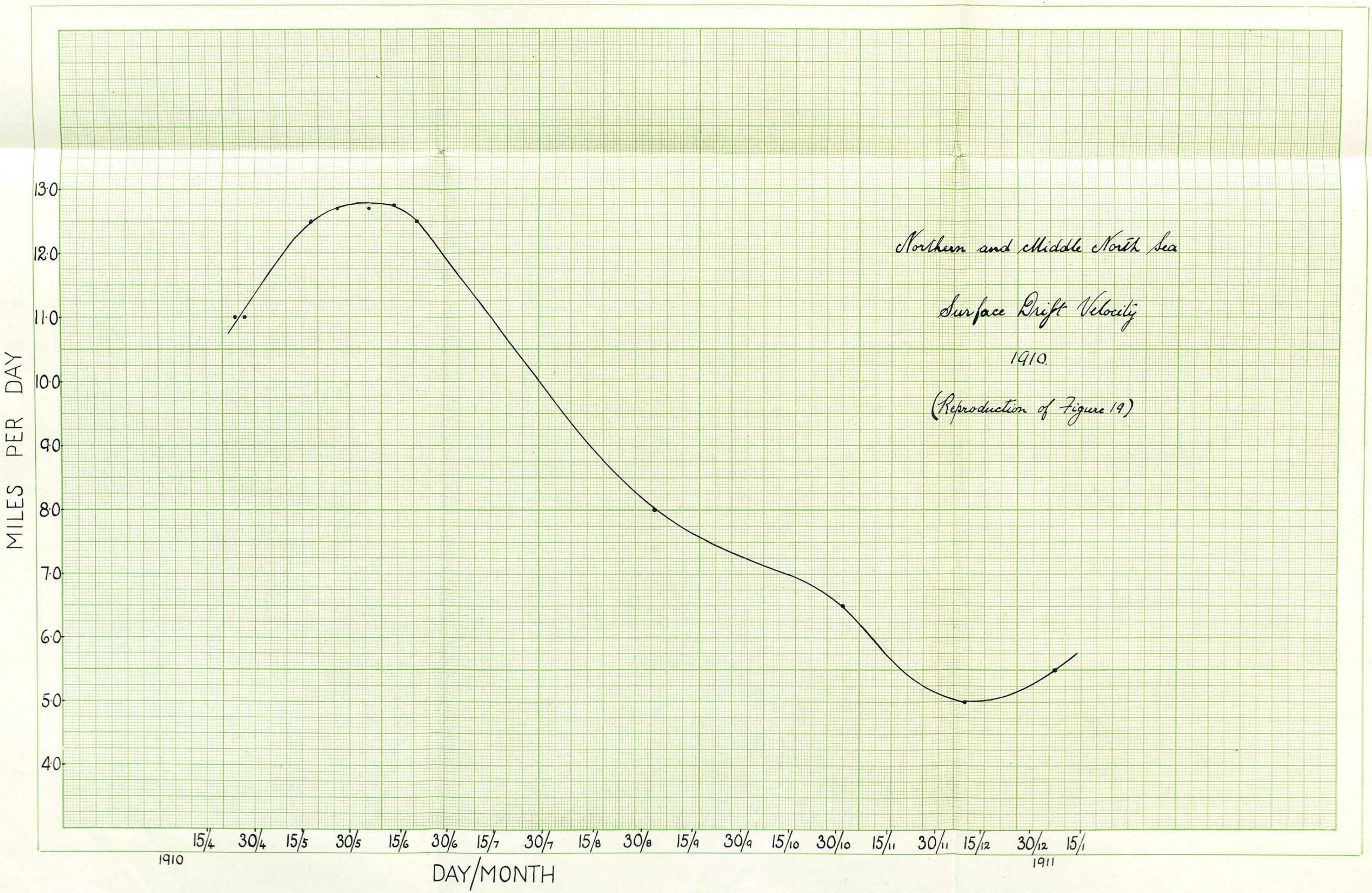
L'auteur montre combien une connaissance approfondie des conditions physiques des mers serait utile pour la prévision des caractéristiques des saisons ; problème des plus compliqués, mais en faveur duquel les données acquises dès maintenant sont très encourageantes.

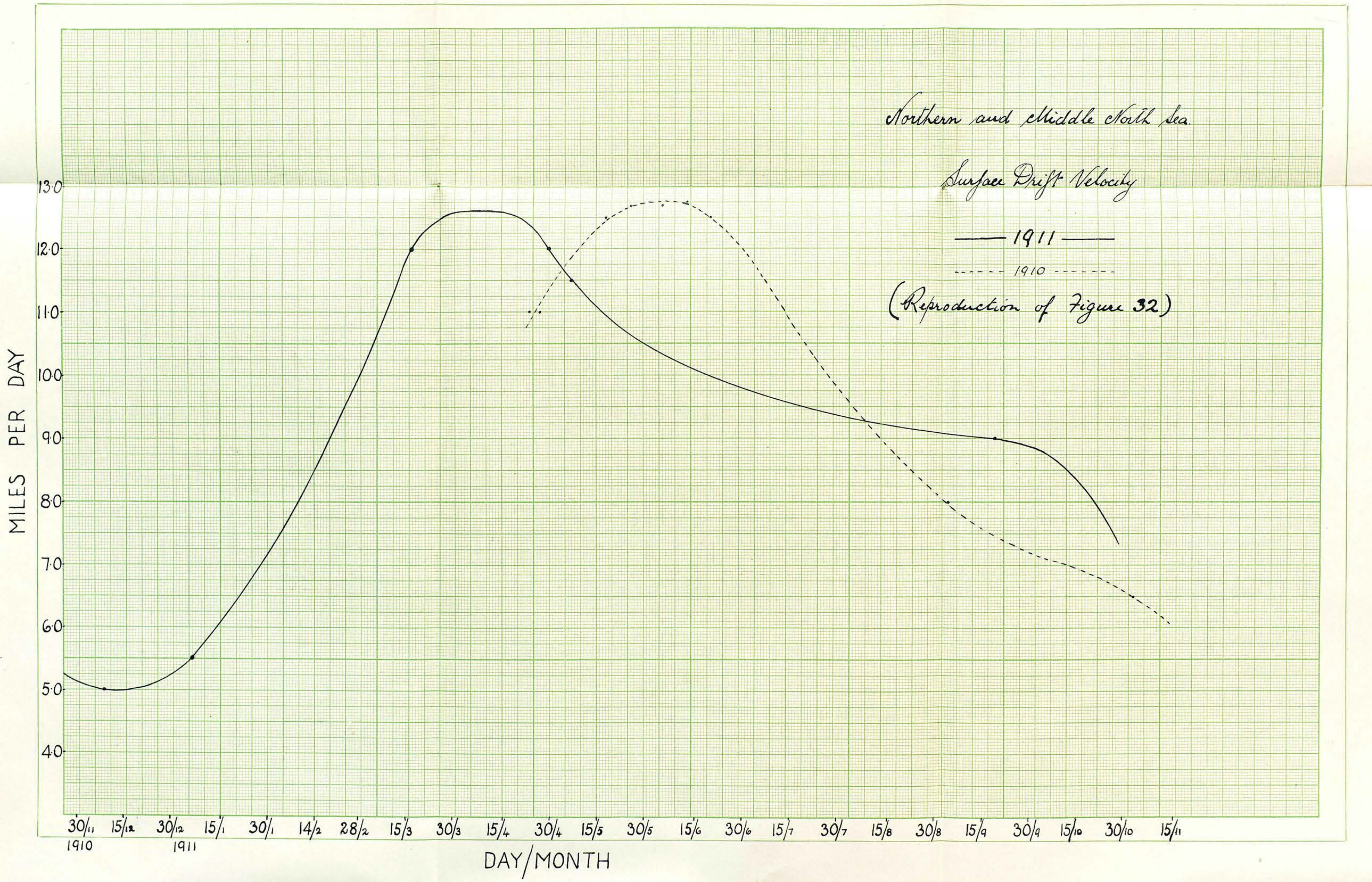
La température de la mer à une époque particulière montre une relation certaine avec les événements agriculturaux de divers pays du Nord de l'Europe, la connexion entre la température de la mer et celle de l'air étant évidente ; car si la température d'un mètre cube d'eau de mer, de 35 pour mille de salinité, est abaissée de 1° par déperdition de chaleur dans l'atmosphère au-dessus, cette perte est suffisante pour élever de 1° la température de 3.000 mètres cubes d'air.

Depuis 1902, date à laquelle les investigations concernant les pêches ont été entreprises de façon internationale, des travaux importants ont été faits sur les propriétés physiques des eaux de la mer du Nord en rapport avec celles de l'Atlantique Nord. Les variations dans l'apport des eaux atlantiques ont non seulement une influence marquée sur la faune de la mer du Nord, mais aussi sur les conditions climatiques de l'Europe septentrionale. Par exemple, une faible circulation atlantique entre les mois d'Août et de Février correspond avec une basse température au-dessus de l'Europe centrale entre Février et Avril et de mauvaises récoltes de blé et de

seigle dans l'Europe occidentale et en Allemagne du Nord. Les conditions contraires se trouvent aussi valables : les bonnes récoltes de céréales, conséquences d'une température élevée en Europe centrale de Février à Avril, suivent à leur tour un afflux important d'eaux atlantiques dans les six mois précédents. On voit combien il serait intéressant de poursuivre de telles recherches en vue d'établir des bases, en quelque sorte quantitatives.

L'importance de ces travaux montre la nécessité d'une coopération internationale, car les avantages qui en résulteront seront aussi de caractère international.


Northern and Middle North Sea
Surface Drift Velocity
1910.
(Reproduction of Figure 19)
MILES PER DAY
13·0
12·0
11·0
10·0
9·0
8·0
7·0
6·0
5·0
4·0
15/4
30/4
15/5
30/5
15/6
30/6
15/7
30/7
15/8
30/8
15/9
30/9
15/10
30/10
15/11
30/11
15/12
30/12
15/1
1910
1911
DAY/MONTH



Northern and Middle North Sea.
Surface Drift Velocity
1911
1910
(Reproduction of Figure 32)
MILES PER DAY
13·0
12·0
11·0
10·0
9·0
8·0
7·0
6·0
5·0
4·0
30/11 1910
15/12
30/12 1911
15/1
30/1
14/2
28/2
15/3
30/3
15/4
30/4
15/5
30/5
15/6
30/6
15/7
30/7
15/8
30/8
15/9
30/9
15/10
30/10
15/11
DAY/MONTH

No. A. 208/F.G.
Ordnance Survey 1925.
250/28.