Physical and Biological Conditions in the North Sea.

By

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SUMMARY.

In my report, in the preceding number of this Journal, on my observations in the North Sea, I referred briefly to the problem of the relation between the physical and biological conditions. This problem will afford scope for investigation for some time to come, and the purpose of the present article is to discuss and compare some of the most recent additions to our knowledge of the matter. The paper by Mr. H. N. Dickson, to which I referred in my previous report, was published in the *Geographical Journal* last March, under the title of "The Movements of the Surface Waters of the North Sea," and in the *Scottish Geographical Journal*, in 1894, was published a series of papers by Professor Pettersson on "Swedish Hydrographic Research in

the Baltic and the North Seas." Professor Heincke has discussed the fish fauna of Heligoland, its composition and sources, in an interesting paper in the series issued under the title of "Wissenschaftliche Meeresuntersuchungen," by the staff of the Biological Station at Heligoland, in association with the Commission for the Investigation of the German Seas, at Kiel. Professor Heincke's paper is contained in Bnd. I., Hft. 1 of this series (1894), and in the same volume are a number of papers dealing on similar lines with other divisions of the marine fauna of the Heligoland Bight.

It will be most convenient and logical to start the present discussion with a consideration of the results of Professor Pettersson's work. He found that the Skagerack and Cattegat were filled with layers of water distinguished from one another by differences of salinity, and that the lower layers entered the channel as under-currents, and could be recognised at the surface somewhere in the North Sea.

The different waters he distinguishes are the following:

1. Ocean-water of 35 per thousand salinity or more.

2. Water of from 34 to 35 per thousand salinity. On account of its extension over a great part of the North Sea, this is called North Sea water.

3. Water whose salinity is 32 to 34 per thousand. This forms a broad edging along the coasts of Holland, Germany, Denmark, and Norway, and is named by Pettersson "bank-water." I shall prefer to distinguish it for the present purpose as coast water.

4. Water from 30 to 32 per thousand salinity, or less, belonging to the outflowing stream from the Baltic.

The numbers of course signify the parts of salt by weight in a thousand parts of the water.

Now, the oceanic water fills the central part of the North Sea as far as the Dogger Bank from bottom to surface. Towards the east it does not reach to the surface, but fills the bottom of the deep channel which extends along the Norwegian coast and into the Skagerack.

The North Sea water is found in the North Sea south-east and west of the Dogger Bank, and along the coasts on each side of the North Atlantic Ocean. In the Skagerack it lies over the oceanic water, and is not found at the surface, except in a band along the north coast of Denmark. The North Sea water flows into the Skagerack principally in spring and summer.

The coast water flows into the Skagerack most abundantly in autumn and winter, when it reaches a considerable thickness, and predominates at the surface in the central part of the channel. In summer time the quantity of this water present is very much reduced. It is then displaced by Baltic water.

The cause of the difference in the amount of the influx cannot be other than the periodic variation in the outflow from the Baltic. When the Baltic outflow decreases, coast water flows into the Skagerack, where it is found as a thick and relatively warm surface layer in the coldest months of the year. When the outflow of Baltic water increases in spring and summer, the coast water is swept out of the Skagerack again, and at the same time the deeper waters begin to flow in and swell in volume. Professor Pettersson attributes the latter inflow to a reaction upon the deeper strata in the North Sea, due to the energy stored up in the waters of the Baltic, but I must confess that for my comprehension these expressions require further explanation. The annual variation in the Skagerack affects the water to a depth of about 50 fathoms.

The temperature of the North Sea water varies inversely with that of the season; it is the coldest water of the Skagerack in summer, and the warmest in winter.

The North Sea water varies much in the amount of dissolved oxygen which it contains; in July, 1890, it was very deficient in oxygen, while in September, 1893, it was supersaturated with that gas, a condition which has only been found to occur in surface waters from high latitudes.

The North Sea water begins to flow into the Skagerack in May, and its entrance coincides with the commencement of the mackerel fishery on the Swedish coast. There seems to be a certain connection between the expansion of the volume of 34 per cent. water in the Skagerack, and the appearance of the mackerel and gar-fish.

The temperature of the coast water, on the other hand, and still more of the Baltic water, varies with that of the season.

The coast water may flow into the Skagerack from two directions, namely, either from the south along the coasts of Denmark and Germany, or from the north along the coast of Norway. This is important, because there are reasons for believing that the coast water has two periods of influx. The first influx occurs in August and September, and is due to the influence of westerly gales. At this time of the year warm water, whose temperature reaches 15° or 16° C., and whose salinity is 32 to 33 per cent., sets in along the north-west coast of Jutland. It fills the central part of the Cattegat from top to bottom as far to the south as a point between Trindelen and Anhalt, and then dips under the Baltic water.

In early autumn the herring fishery, with floating nets, in the Cattegat and south Skagerack, coincides with this influx of coast water. In a subsequent part of his paper, Pettersson points out that Möbius and Heincke, in their memoir on the Fishes of the Baltic,

state that there are 32 species, of which specimens occur in the Western Baltic occasionally, and are not resident there. These fish are immigrants, and 18 of the species are southern forms—that is, forms whose range extends from the Mediterranean to the British Islands, but not to the Arctic Circle, while of the remaining 14 species, 10 are northern forms—that is, species which are abundant within the Arctic Circle, but do not occur in the Mediterranean. The occurrence of the southern forms in the Baltic takes place chiefly in September and October, and, therefore, coincides with the inflow of the southern coast water. The species in question are:—

Labrax lupus, the Bass; *Sciaena aquila*; *Mullus surmuletus*, the Red Mullet; *Brama Rayi*, Ray's Bream; *Thynnus vulgaris*, the Common Tunny; *Xiphias gladius*, the Sword-fish; *Trigla hirundo*, the Tub, or Latchet; *Mugil chelo*, the Grey Mullet; *Labrus maculatus*, the Spotted Wrasse; *Crenilabrus melops*; *Gadus minutus*, the Poor Cod; *Merluccius vulgaris*, the Hake; *Solea vulgaris*, the Common Sole; *Orthagoriscus mola*, the Sun-fish; *Engraulis encrasicholus*, the Anchovy; *Conger vulgaris*, the Conger; *Carcharias glaucus*; *Trygon pastinaca*.

Now, we cannot consider the herring as a southern fish. It is very improbable that herrings enter the North Sea from the English Channel: on the contrary, the evidence points the other way—namely, to the conclusion that the North Sea herrings come from the north; and the association of herrings with southern coast water is a fact which requires further examination. Pettersson does not discuss the difficulty.

In January, February, and March, the coldest season of the year, there is an influx of water of the same salinity as that previously mentioned—namely 32 to 33 per cent., but of a temperature of only 4° to 5° C., which evidently comes from the north along the Norwegian coast. In 1893 this northern coast water was entering the Skagerack in November, and it was found to contain a very characteristic Plankton, or assemblage of minute swimming forms, entirely different from that of the adjacent water of the Baltic current. The latter consisted chiefly of vegetable organisms, such as Diatoms, Cilio-flagellates, etc., intermixed with Copepods, such as *Centropages hamatus*, which occur also in the Cattegat and Baltic up to the Aland Islands, at the entrance of the Gulf of Bothnia.

In the northern coast water, on the contrary, vegetable Plankton was scarce, and the animals were of Arctic or North Atlantic origin, which never appear in the Skagerack during summer, *e.g.*:—

Euphausia inermis (Kröyer) (*Schizopod*); *Hyperoche Kröyeri* (Bovallius) (*Amphipod*); *Parathemisto oblivia* (Kröyer) (*Amphipod*); *Diphyes truncata* (M. Sars) (*Siphonophore*).

The first-mentioned is known to be the principal food of the great whale, *Balenoptera Sibbaldii*, and is most abundant between Varanger Fjord and the Lofoten Islands. The herring fishery was then going on in the neighbourhood of Lysekil. Only 33 per cent. of the herrings caught had any food in their stomachs, and it consisted of 15 forms of animal Plankton, of which the remains of *Limacina balea* was the most remarkable. This Pteropod frequents chiefly the North Atlantic and Arctic Ocean, and occasionally appears on the west coast of Norway, where it is greedily devoured by herrings. As not a single specimen of the species was found in the waters of the Skagerack in November, the shells of the *Limacina* in the stomachs of the herring must have been a remnant of the food swallowed by the fishes outside the Skagerack. The winter herring are caught in water of the kind denoted here as northern coast water, and disappear with it.

The northern species of fish mentioned by Möbius and Heincke as occurring occasionally in the Baltic are :—*Liparis Montagui*, Montague's Sucker; *Anarrhichas lupus*, the Cat-fish; *Stichaeus Islandicus*; *Gadus pollachius*, the Pollack; *Hippoglossus vulgaris*, the Halibut; *Pleuronectes cynoglossus*, the Witch; *Gadus virens*, the Coal-fish; *Lota molva*, the Ling; *Raia radiata*.

According to Pettersson these northern fishes are only found in the Western Baltic in the early part of the year, that is to say, chiefly in January, February, and March, during the time when, as he has proved, there is an inflow of coast water of a temperature of 4° to 6° C. along the south coast of Norway into the Skagerack and Cattegat.

Having analysed with so much success the composition of the waters entering and leaving the Baltic, Professor Pettersson and the Swedish hydrographers associated with him, conceived the project of extending the application of their methods to the whole of the North Sea, in order to distinguish the different waters entering and leaving that basin, and to trace them to their sources. Proposals were accordingly made to the governments of other countries bordering the North Sea, that they should take part in an international co-operative hydrographic survey. On behalf of Britain the Scottish Fishery Board undertook to survey the region to the north and east of Scotland. In accordance with the plans arranged, H.M.S. *Jackal* was employed in the work, and Mr. H. N. Dickson, F.R.S.E., was entrusted with its execution. Four expeditions to the northern entrances to the North Sea were made—in August and November, 1893, and in February and May, 1894. The results of the observations are recorded in detail in the Twelfth Report of the Scottish Fishery Board; and in *Natural Science* for January, 1895, Mr. Dickson published an article in which he discussed the probable influence of the movements of water which had been ascertained to

occur, on the migrations and distribution of fishes, and consequently on fisheries.

Mr. Dickson regards the subject in a manner which seems to me peculiar; and while his work in the physical department is well known to be in all respects admirable and sound, I am obliged to express some disagreement with the argument he employs concerning the biological questions. He urges that we cannot discover direct hard and fast relations between the temperature or the salinity or the density of sea-water, and the constant or periodic occurrence of certain animals (*e.g.*, fishes) in particular localities. Yet we have to discover some reason for the fact that the appearance of certain fishes and other marine animals has been frequently observed to be associated with a periodical change in the temperature or salinity of the water. Mr. Dickson says that the peculiarities of temperature or salinity are certainly too slight to seriously affect animal life. But he points out that it is just these two physical elements upon which the oceanographer relies in tracing the circulation of waters, and in identifying the sources from which they are derived.

He proceeds to lay stress upon the alleged fact that Pettersson and his colleagues have collected a mass of evidence shewing that the migrations of herring and mackerel, and other variations in the distribution of not only fishes, but Plankton, are dependent on the amount of oxygen present in the sea-water. The amount of oxygen dissolved in the water depends solely on the temperature and atmospheric pressure to which it was exposed when at the surface. The lower layers of water, in enclosed areas, are accordingly liable to become deficient in oxygen, and fresh supplies must be obtained by mixture with water from the ocean, if animal life is to remain healthy and abundant.

Now, after careful study of Pettersson's papers in the *Scottish Geographical Magazine*, I cannot perceive that they exactly correspond to Mr. Dickson's description. According to Pettersson, the advent of the mackerel corresponds to the influx of North Sea water in May and the following summer period. During winter the amount of North Sea water present in the Skagerack decreases, and that which remains becomes deficient in oxygen. But it is scarcely possible to hold that the deficiency of oxygen in this layer of water alone causes the mackerel to leave. For in the first place mackerel swim very near the surface, and are therefore not, in all probability, contained in the North Sea water at all, but in the overlying Baltic water, which in summer flows out through the Skagerack in considerable quantity. Then, again, the herring enter the Skagerack, according to Pettersson, in autumn and winter, with the influx of coast-water from the north.

If it were a mere question of oxygen, there would be no reason why the mackerel should migrate to the Swedish coast in summer, and the herring in winter. Moreover, the coast-water flows in at the surface, and displaces the Baltic current in winter, and so far from being richer in oxygen, contains less of that element than the surface water of the Baltic. In a foot-note on the latter, Pettersson states:—

"This singular fact that the waters of the Baltic upper layers may occasionally be supersaturated with oxygen like Arctic water, is worthy of attention. I have discussed this phenomenon with the eminent specialist on diatoms, Professor Cleve of Upsala. We both arrived at the conclusion that supersaturation with oxygen, as well as deficiency of oxygen, is probably due to the influence of organic life. The predominance of vegetable Plankton, which is characteristic of Arctic as well as of Baltic water, may cause the former, the respiration of animals and of animal Plankton the latter phenomenon.

"Be this as it may, it is certainly a fact to be borne in mind by biologists, that the conditions of organic life are very different in the Baltic and in the North Sea, on account of the relatively high amount of dissolved oxygen in the upper layers of the Baltic. Owing to the low salinity, the perfect aeration of the water down to a considerable depth, and the low temperature at which their water is saturated with air in winter, the upper layers of the Baltic contain about 30 per cent. more oxygen than the waters of the North Sea."

In view of the above statement, it can scarcely be maintained that the visits of migratory fish, like herring and mackerel, to the mouth of the Baltic, are to be attributed to the abundance of oxygen present in the sea-water which flows into the entrance of that sea at certain seasons of the year.

What Pettersson does prove with regard to the herring is, that its presence on the west coast of Sweden depends on the presence of water having certain qualities, and derived from a certain source. In the fifth of his series of papers, in the *Scottish Geographical Journal* for 1894, there is a special discussion of the changes in the water on the west coast of Sweden, and their effect upon the herring fishery. In 1877, after an absence of seventy years, herring again appeared on the Swedish coast. It appears to be a historical fact that, time after time, herring have entirely deserted this coast, have remained absent for a period of about seventy years, and have then resumed their annual migration to the region, giving rise to a valuable and important fishery. The cause of this regular irregularity does not concern us here, nor is it discussed by Pettersson; we are considering merely Pettersson's conclusions concerning the changes in the water which determine the arrival and departure of the herring on the coast during the period

when it pays its annual visit. In the middle of December, 1878, before the herring had appeared, the salt-water of 34 per cent. salinity (North Sea water) reached to within fifteen or twenty fathoms of the surface, and filled the deep channels of the coast. The surface water overlying this consisted of layers of 32 and 33 per cent. salinity, evidently the remnant from the inflow of coast-water in autumn; the temperature of this was 8° to 9° C.

In the latter part of December stormy weather occurred, and a new influx of coast water took place, of the same salinity, but with a temperature of only 4° to 6° C. The last influx of this water occurred on the 28th and 29th December, and simultaneously the herring fishery began on the coast to the east of Wäderö Islands. In the middle of January the fishery began to decline at the same place, the cause of which was as follows: On the 11th and 12th January the wind, which had been blowing from the N.E., began to blow from S. and S.E., in consequence the fresher and colder water belonging to the Baltic stream began to flow northwards along the Swedish coast, and as the Baltic water displaced the coast water the herring disappeared. There can be no suggestion here of a superiority in the supply of oxygen in the coast water. Both the water with which the herring came, and that which drove them away, were surface waters, and both well supplied with oxygen, especially the latter. The difference between the two consisted chiefly of salinity and temperature, and the effect upon the fish may have been due rather to the movement of the water than to its qualities.

On the other hand, it is perfectly correct that Pettersson has discussed in considerable detail the absence of oxygen in the bottom water contained in deep depressions separated by higher ground from similar depths in the neighbourhood. In such cases the water contained in the depression is salter, and therefore heavier than the overlying water, and remains undisturbed and unaffected by the movements of the lighter and fresher water passing over it. When deprived of the dissolved oxygen which it contains, the bottom water, being cut off from contact with the air, can obtain no new supplies, except what it takes up by diffusion from the layers of water above it, and that is scarcely any. The oxygen originally contained in it is constantly being abstracted by the respiration of the animals that live in it, and by algae also in the absence of light, so that if undisturbed for a long time water in an isolated depression becomes almost entirely destitute of oxygen, and, therefore, incapable of supporting animal life. Pettersson states that these are the conditions to which the deep basins of the fjords on the west coast of Sweden are subjected, because the bottom of the fjords is much higher and nearer

the surface of the water at the entrances than at the inner parts, so that below a certain depth the water in the fjords is cut off from communication with the water in the open sea. The Gullmar Fjord is described as a typical example. The depth of water on the Swedish coast bank, *i.e.*, from the shore of the mainland as far as the outermost rocks and shoals, does not usually exceed 15 fathoms. But corresponding to each fjord, leading from its entrance towards the S.W. there is a deeper channel, cut off from the deep inner basin of the fjord by the ridge across its mouth.

In summer the ocean water and the North Sea water in the Skagerack extend from the bottom nearer to the surface than in winter, and above the North Sea water lies the Baltic water, which flows out most abundantly in summer. On the declivity of the coast the layer of Baltic or fresh water is deeper than in the central part of the Skagerack. In consequence of these facts the ocean water never enters the Gullmar Fjord, because its level never reaches to within 20 fathoms of the surface on the coast declivity, and that is the depth of the ridge at the entrance of the fjord. The North Sea water, however, whose salinity is 34 per 1000, enters the fjord occasionally, or periodically, and it is water of this salinity which fills the inner basin of the fjord. Waters of 33 per 1000 and less flow into or out of the fjord from the surface to the depth of 20 fathoms at all seasons of the year.

It was found that the bottom water of the Gullmar Fjord in February, 1890, was extremely deficient in oxygen, that it was cut off from communication with water of the same salinity outside, which contained plenty of oxygen. In June, 1890, the level of the North Sea water outside the fjord rose to less than 20 fathoms from the surface, flowed over the ridge, and displaced or mixed with the stagnant water already there. This did not happen again until 1893.

The Gullmar Fjord is noted for the fishery for cod and John Dory in its deep water, a fishery which takes place in winter, but not every winter. In the winter of 1889–90 this fishing was very poor, and had been so for some previous years. In the winter of 1890–91 it was very successful. The inference suggested is that the entrance of these fish into the Gullmar Fjord is dependent upon the entrance of North Sea water in summer, which does not always occur. When it does not occur, even if the fish should enter the fjord by swimming over the bar at the entrance, the bottom water of the fjord would be nearly or quite uninhabitable for them on account of the small supply of oxygen it contains. Pettersson expressly points out that he does not consider the herring fishery in the fjord to be affected by this change in the bottom water, but believes it to be dependent upon the inflow of

coast water at the surface, in the manner which has already been described.

The general results of Mr. Dickson's own investigations of the conditions and movements of the sea-water to the north of Scotland were as follows. Between the Faröe and Shetland Islands and the submarine elevations of which they are the highest points, is a narrow submarine valley extending from the deep basin of the Norwegian Sea. This valley is separated at its south-western end from the deep basin of the Atlantic by the Wyville Thomson ridge, which is only 300 fathoms from the surface of the sea. Over this ridge the water of the Atlantic flows throughout the year towards the north-east, its movement being caused by the cyclonic winds in winter and by the greater warmth and consequent higher level of the Atlantic water in summer as compared with the Norwegian Sea. The Atlantic water flowing over the ridge sucks up the cold water from beneath, and mixes with it. Owing to its greater saltness the Atlantic water thus cooled sinks and loses its velocity. The influence of the earth's rotation deflects the current to the right, and thus in summer a mass of Atlantic water tends to collect on the north-western and northern edge of the North Sea bank. At all seasons this water enters with the tides between the Orkneys and Shetlands, but in winter, westerly winds drive it towards the east, and none passes down the east coast of Britain. But in summer, when the winds are light, and the surface layers of the North Sea are warmer and lighter, the Atlantic water mixes with the cold bottom water of the North Sea, and finds its way along the east coast of Scotland. The causes by which, according to Mr. Dickson's explanation, this is accomplished, I do not profess to fully understand. The explanation given is that the Atlantic water collected at the edge of the North Sea bank mixes with the cold bottom water already there, and increases its salinity but reduces its specific gravity by warming it. At a certain stage of mixture the temperature and salinities of the two waters combine to form an axis of maximum specific gravity. This axis, which probably runs N.E. from Shetland at the end of May or in June, turns slowly toward a N. to S. direction and moves eastward. As it retreats, Atlantic water is gradually admitted round the north end of the Shetlands, passes down the east side of the islands, joins the tidal stream at the south end, and guided by the axis of heavy water, is distributed along the east coast of Scotland probably during July and August.

In his essay in *Natural Science*, Dickson states that it is in the oceanic or Atlantic water, thus admitted in summer down the east coast of Scotland, that the summer and autumn herring fishery takes place, and remarks that whether this fresh supply of oceanic water really does contain a markedly greater amount of oxygen than the

water it replaces can only be ascertained by actual analysis (which was not carried out), and that the further question, whether the herring comes with this water or to it, must be settled by zoologists.

In his paper on "The Movements of the Surface Waters of the North Sea," published in the *Geographical Journal* for March, 1896, Mr. Dickson tells us that in the International Hydrographic Survey, in 1893 and 1894, Denmark, Sweden, Germany, Scotland, and Norway took part. The plan was to obtain simultaneous observations in different parts at times arranged beforehand. In May, 1893, Danish and Swedish ships were at work; in August and November, 1893, and February and May, 1894, ships from the Kiel Commission and the Fishery Board for Scotland co-operated; while a Norwegian vessel also made observations in the latter periods. Mr. Dickson gives a summary of all the observations so far as they refer to the surface waters, combining with them observations made on merchant vessels, obtained from Professor Pettersson and from the Meteorological Office in London.

In his preliminary remarks Mr. Dickson points out a fact which, obvious enough in itself, is of great importance, namely, that the original sources of the water in the North Sea are the oceanic waters entering from the north and north-west, and, to some extent also, from the Straits of Dover, and land waters entering from the Baltic and the rivers. The other waters, distinguished and appropriately named by Pettersson, are due to mixture of these two. In a large and deep basin the fresher water would overlie the ocean water, and mixture would take place slowly; but in a shallow basin like the North Sea the influences of wind and tide penetrate to the bottom, and mixture sometimes takes place with great vigour and rapidity, so that North Sea water (34 to 35 per thousand) sometimes occupies almost the entire basin. The varying temperatures of the seasons and the force of winds are very important local influences governing the distribution of the different waters.

Descriptions are then given of the distribution of the various waters as distinguished by Pettersson in May, August, and November, 1893, and in February and May, 1894. The distribution is well shown on the series of coloured maps, one showing the salinities, the other the temperatures of the surface waters. Perhaps the most important point to notice at the different periods is the distribution of oceanic water, which enters from the north southwards, and from the Straits of Dover northwards, but the temperatures are also, in relation to the distribution of fishes and other animals, of great importance.

At the beginning of May, 1893, oceanic water covers a small area well to the north and north-east, forming a central tongue terminating

opposite the entrance of the Baltic, and an isolated patch between East Anglia and the Dutch coast. The rest of the North Sea is covered by North Sea water, except a narrow edging along the continental coast extending some distance into the Skagerack; this is coast water. The isothermals, or lines of equal temperature of the surface water, are interesting at this period. At the western entrance of the English Channel we have 12° C., which diminishes as we pass up the Channel, but the limit of 9° C. passes from the islands outside the Zuyder Zee to a point on the English coast about Flamborough Head. North of this we have only 8° and then 7°, a band of the latter extending from about Aberdeen to the Baltic and along the Norwegian coast, while north-west of this we have again 8° and 9°. Along the whole of the western coast of the British Islands, the Atlantic temperature is 9° and 10°. The influence of this distribution of temperature alone, on the distribution of southern species of animals, cannot, I think, be over-rated, as will be seen below when the distribution of animals is considered. The distribution of animals is not discussed at all by Dickson in the paper with which we are now dealing.

In August, 1893, the northern tongue of oceanic water is broader and extends further southward, reaching to the edge of the Dogger Bank, while in the south a tongue from the Straits of Dover extends to the latitude of Lowestoft. The band of coast water along the German and Danish coasts is somewhat broader, but it does not extend into the Skagerack; we now see the Baltic current or stream flowing out in full force, extending northwards along the Norwegian coast in a broad band. This Baltic water is now, owing the influence of the sun on the land, of higher temperature than any other part of the surface of the North Sea, except two isolated patches near the British coasts. The whole of the North Sea (surface) is now as warm as the Atlantic water on the west coasts of the British Islands. Both in the North Sea and on the west coasts, the temperatures diminish from south to north from 18° to 13° C., but a narrow tongue of colder temperature extends southward, so as to include the Orkney and Shetland Islands and part of the Moray Firth.

In November, 1893, the northern tongue of oceanic water is broader, but does not extend further south; the southern tongue extends a little beyond the Texel. The outflow of the Baltic stream has ceased, and coast water is seen in the map extending along the south-west coast of Norway and entering the Skagerack, in the manner previously described by Pettersson.

The temperature of the surface water is now lowest in a band along the coast of Holland, Germany, and Denmark, corresponding closely with the extent of the coast water, where it is 8°. This same temperature

extends from the coast of Norway to the east coast of Scotland, and the Orkneys and Shetlands. The rest of the North Sea is 9° and 10° C., becoming warmer towards the English Channel, at the western entrance of which we have 11° to 13°. On the west coasts of the British Islands the temperature is 9° and 10°, as in the south-western part of the North Sea. Mr. Dickson observes that the low temperature on the east coast of Scotland at this period corresponds to the up-welling of bottom water which has been observed there.

In February, 1894, we find that the northern and southern tongues of oceanic water have met and joined, so that there is a broad central region of this water extending completely through the North Sea. North Sea water occupies a narrow strip on each side, and extends in a narrow tongue into the Skagerack. Coast water is seen on the south coast of Norway, extending into the Skagerack as far as the Skaw, and as usual in a narrow band along the east coast of the North Sea.

Surface temperature is now at its lowest for the year. From the east coast of the North Sea nearly to the middle it is only 4° C., this temperature extending all over the Heligoland Bight. Over the whole of the western part of the North Sea the temperature is only 5° and 6° C. On the west coast of the British Islands we have temperatures of 7° and 8°, including the western entrance of the English Channel, but 9° and 10° are found not far to the westward in the Atlantic.

The yearly cycle has now been completed, but we have also observations and charts for May, 1894, and these show that the conditions of May, 1893, are not exactly repeated. It would naturally be expected that the same conditions do not recur exactly at the same period every year, if ever, though there must be a general similarity in successive years. In May, 1894, the data are incomplete, but they show that oceanic water extended throughout the central part of the North Sea, as in the preceding February, with a narrow band of North Sea water on each side. The temperatures are more similar to those of May, 1893, but are rather higher, that of 8° C. extending over nearly the whole of the northern part of the North Sea, while, as in the earlier period, the temperature of 9° extends on the west coast of our islands beyond the north of Scotland.

Professor Pettersson has also mapped the distribution of surface salinity over the greater part of the North Sea at the end of November, 1894, and the middle of February, 1895. In November, 1894, the total area occupied by oceanic water was but small, and the Baltic outflow, instead of being cut off, as at this time in 1893, extended far to the northward. Absence of winds may account for the weakness of the oceanic streams, and the greater strength of the Baltic stream is ascribed to the mildness of the season.

Mr. Dickson adds a discussion of the forces at work in producing the observed conditions and changes, taking separately the local forces in the North Sea and the external. He finds that the chief influence at work locally is the wind. His conclusions are that the existence of a continuous strip of oceanic water along the central axis of the North Sea, is due to westerly and south-westerly winds strengthening the oceanic current. Strong northerly winds tend to broaden the northern area of oceanic water, and to blunt its extremity, and also have the effect of sending coast water southwards along the west coast of Norway: it is probable that this is the cause of the inflow of coast water into the Skagerack. Calm weather favours the spread of North Sea water over a great part of the North Sea, while easterly and south-easterly winds spread the fresher waters of the east side of the sea over the surface.

With regard to the inflowing or oceanic waters, as they are all of about the same salinity, Mr. Dickson infers their movements from the different temperatures. He finds that the Atlantic streams are on the whole strongest in summer, but the cold streams moving southwards from the eastern coasts of Iceland and Greenland are also strongest in summer. It is a mixture of the two which takes place in the Faröe-Shetland Channel, and this mixture is driven into the North Sea in the manner already mentioned.

I do not think that, for my present purpose, it would be of much advantage to give a more detailed account of Mr. Dickson's discussion of the physical conditions. He does not enter upon their relation to the migrations and distribution of fish, and it seems to me that, with respect to this relation, the changes and distribution of actual temperature and salinity in detail are of more importance than the forces by which these changes are caused. The points of view of the physicist and the biologist are different. The former is chiefly interested in tracing the causes of the observed movements of waters, regarding temperature and salinity rather as qualities by which the different currents are to be identified. The biologist's business, on the other hand, is to ascertain how the degrees of temperature and salinity affect the migrations and distribution of different species of fish. It must be understood, therefore, that in this paper I have, to a large extent, expressed conclusions of my own concerning the relation of the observations published by the physicists to those made by zoologists.

We have then to consider more particularly what is known concerning the actual distribution of fishes and other animals in the North Sea, and the waters communicating with it. With regard to two well-defined portions of the regions, namely, the Baltic and the Heligoland Bight, the facts have been collected and analysed in a very interesting manner by the German naturalists associated with the Kiel Commission, and the

Biological Station on Heligoland. The fish of the Baltic have been considered by Möbius and Heincke in a paper* which has already been cited, while Fr. Heincke alone has treated the fishes of the Heligoland Bight in a similar manner.† Papers on the other animals of these districts are also contained in the publications of the same institutions. For the rest of the region I have to rely on various ichthyological works, and on my own experience.

The peculiarity in the general distribution of fishes in the North Sea is that southern species are found along its eastern side, and at its northern as well as its southern entrance, but are absent on its western shores, and in its central and western portion. The reason of this, as Heincke points out, is that there are two routes by which southern species can enter the North Sea, namely, that of the Gulf Stream—the drift of Atlantic surface water which bathes all the western coasts of the British Isles, flows past the Shetlands to the coast of Norway, and sends a twig into the Baltic; and secondly, the route which leads from the English Channel, a slow stream of southern warmer water passing along the Dutch and other continental coasts.

Southern Species entering the North Sea from the South.

In discussing distribution it is necessary to distinguish between littoral species, which inhabit the zone of sea-weeds, surface species, which feed and swim in the open water, and bottom species, which feed on the bottom; Heincke uses for the latter two divisions the terms aperticolous and fundicolous. He also distinguishes three divisions according to the frequency of their occurrence, namely, common resident species, rarer resident species, and occasional immigrants. We do not know with sufficient completeness the seasonal movements of the majority of fishes in a particular locality, but there is evidence to show that the aperticolous species are most migratory, the fundicolous less so, and the littoral species least of all. It is fairly certain that aperticolous southern species enter the North Sea from the Straits of Dover only in summer, and that they retire in winter. The aperticolous southern forms found in the Heligoland Bight are *Scomber scomber*, the Mackerel; *Caranx trachurus*, the Scad; *Belone vulgaris*, the Gar-fish; *Merluccius vulgaris*, the Hake; *Thynnus vulgaris*, the Tunny; *Engraulis encrasicholus*, the Anchovy.

* Fische der Ostsee. *Vierter Bericht der Commission zur Untersuchung der deutschen Meere*, 1883.

† *Wissenschaftliche Meeresuntersuchungen herausgegeben von der Kommission zur Untersuchung der deutschen Meere, und der Biologischen Anstalt auf Helgoland, Neue Folge, Erste Band, Heft* 1, 1894.

Heincke places the mackerel among the common resident forms, and in general only considers the comparative abundance and rarity of the forms, while I am endeavouring to trace the relation between the temporary and permanent presence of certain species on the one hand, and temporary and permanent physical conditions on the other. The anchovy, according to Heincke, has not been yet found at Heligoland, but we know that it is abundant in summer in the Zuyder Zee, and Ehrenbaum found its pelagic ova further to the east near the Island of Nordeney.

We must remember that these forms might reach the Heligoland Bight from the north, since all of them occur in the Skagerack and Western Baltic. It is probable that the hake does come from this direction, as it is a deep-water fish, and has scarcely ever been taken in the shallow part of the North Sea south of the Texel; it is not mentioned in Van Beneden's "Fishes of the Coast of Belgium."* It is not common in the Heligoland Bight, being placed by Heincke among the rarer residents. The tunny is still more rare, and is classed by Heincke as an occasional visitor. It probably comes both from the south and the north, as it has been occasionally taken on the coast of Kent and of Norfolk. But on the whole, as it is an oceanic fish, it is more likely to reach Heligoland from the north. The other four species are more important, because they visit the region in question in greater numbers, and they undoubtedly come from the south through the Straits of Dover, appearing regularly every summer in the narrow southern part of the North Sea between the coasts of Holland and Belgium and the English coasts, as well as on the south coast of England. The anchovy, however, is practically absent from the English side north of Kent.

All these four species are so scarce as to be practically absent along the east coast of England, but become somewhat more abundant towards the north along the east coast of Scotland, owing clearly to their incursion from the north.

Although more complete observations are required concerning the time at which these fish are present in the southern and eastern part of the North Sea, we have evidence that they occur there only in summer and autumn, and disappear in winter. Mackerel fishing at Lowestoft begins at the beginning of May, and lasts till the end of June, and there is a second or autumn fishery in September and October. It is difficult to understand why these fish are not present in the same neighbourhood in July and August. Van Beneden states that the scad appears regularly on the coast of Belgium towards the end of April, before the arrival of the mackerel. The gar-fish occurs

* *Mémoires de l'Acad. Roy. de Belgique.* Tom. *XXXVIII.*

at the same time as the mackerel: in the Schelde it is taken with the anchovies in May and June; I have seen it at Brightlingsea in the same two months, and I also saw several specimens brought in with the mackerel at Lowestoft on October 12. The saury-pike (*Scombresox saurus*) has habits similar to the gar-pike, but occurs only occasionally, apparently not every year. Van Beneden states that he saw a shoal swim ashore near Ostend. The anchovy fishery in the Zuyder Zee and the Schelde takes place principally in June and July, although young specimens are found there for some time afterwards. They appear to depart entirely before the end of October.

There can be little doubt, I think, that the annual incursion of these migratory fishes into the North Sea along the continental coast depends primarily on temperature. In the regions we are considering the depth is less than 20 fathoms, and there can be little question of difference between bottom and surface temperature. In February, which is the month in which the water is coldest, as we have seen the west side of the North Sea is at 6°, the east side, east of the Texel, 4° to 5°. We may consider that this is cold enough to drive out mackerel and the other species mentioned. At this time the limit of 9° C. lies to the west of the western entrance of the Channel. Mackerel in January and February are caught in the western part of the Channel as far east as Start Point. In May the limit of 8° has advanced eastwards and runs across the North Sea from the southern part of Denmark to the Firth of Forth. In August temperatures above 13° prevail over the whole of the North Sea, and in November we find the cold again advancing from north to south and from east to west.

These surface temperatures do not, however, explain the absence of the fish in question from the coast of Britain in summer. The restriction of the fish to the continental coast may be due to two causes: firstly, a movement of water in that direction; secondly, the extension of the deeper portion of the North Sea along the east coast of Britain. The salinity of the water has little to do with the matter. We have seen that in 1894 the oceanic water was more extended in February than at any other time of the year. Concerning the question of an inflow of water from the Straits of Dover, this distribution of surface salinities does not indicate that it is greater in summer than in winter. The report of an expedition for physical investigation, to which no reference has yet been made, namely, that of the *Pomerania* in 1872, does mention that the outflow of the warmer water from the southern area of the North Sea was traced as a current which flowed along the coasts of Schleswig-Holstein and Jutland to the Skagerack. This was in summer, but it seems to me that the surface salinities indicate that this current is due rather to the greater outflow of fresh water from the

continental rivers, than to a greater flow of salt water from the Straits of Dover. At any rate, so far as I understand it, the physical evidence does not show that there is an inflow of Channel or Atlantic water corresponding to the immigration of southern aperticolous fish, while the higher temperature which does correspond to that immigration appears to be caused by the warming of the land and shallow water by the summer sun.

On the other hand, the *Pomerania* observations actually prove that in the deeper north-western depression the bottom water was frequently below 8° C., and that the passage of this cold water southwards was arrested by the Dogger Bank. I think it would be more correct to say that the boundary of this cold water to the south and east is the 25 fathom line. It is reasonable to infer that although the temperature at the actual surface in summer on the north-east coast of England is by no means low enough to account for the absence of mackerel, anchovy, etc., yet the influence of the cold water below is sufficient to restrict these southern species to the region south and east of the 25 fathom line.

We proceed next to the consideration of the southern species of fundicolous or bottom fishes in the Heligoland Bight and southern area of the North Sea. The list of these is rather a long one. The commonest of them are: *Rhombus maximus*, the Turbot; *Rhombus laevis*, the Brill; *Solea vulgaris*, the Sole; *Solea lutea*, the Solenette; *Trigla gurnardus*, the Grey Gurnard; *Trachinus draco*, the Greater Weever; *Trachinus vipera*, the Lesser Weever.

Less abundant are: *Trigla hirundo*, the Tub or Latchet; *Trigla cuculus*, the Red Gurnard; *Mullus barbatus*, the Red Mullet; *Callionymus lyra*, the Dragonet; *Arnoglossus laterna*, the Scaldfish; *Galeus vulgaris*, the Tope.

Heincke does not mention *Trachinus vipera* among the fishes of Heligoland. In the voyage of the *John Bull* off Amrum in June, I saw nothing of either species of weever, but both were very common on the Brown Ridges off the Dutch coast in September.

Heincke believes *Trigla cuculus* to be absent, but I saw specimens, identified with certainty, taken frequently in the trawl in my voyages both north of Heligoland and on the Brown Ridges.

As occasional immigrants the following species occur: *Labrax lupus*, the Bass; *Zeus faber*, the John Dory: *Gadus luscus*, the Pout or Bib; *Motella tricirrata*, the Three-Bearded Rockling; *Conger vulgaris*, the Conger; *Mustelus vulgaris*, the Smooth Hound; *Scyllium canicula*, the Small Spotted Dog-fish; *Trygon pastinaca*, the Sting Ray.

To the fundicolous forms may be added *Amphioxus lanceolatus*, which burrows in the sea-bottom, and is common near the Horn Reef.

How far the movements of these fundicolous species are influenced by the seasons we have very little evidence to show.

I think that it will be found that the occasional immigrants are usually taken in the area in summer, *i.e.*, during the period when the water is warm. I obtained a specimen of *Mustelus vulgaris* off Lowestoft on September 18th. The grey gurnard is not such a distinctly southern form as the latchet, nor is the red, *Trigla cuculus*. On board the steam-trawler *Lucania*, to the south of the Horn Reef in May, no latchets were taken, while northern forms, such as haddock, were abundant, and one halibut was taken. Grey gurnard were plentiful. Latchets were plentiful off Amrum in June, and on the Brown Ridges in September.

It will be found that the abundance of these forms in the Heligoland Bight is in proportion to the degree of their restriction to a southern habitat. The turbot, brill, and sole are fairly common along the north-east coast of England, while turbot and brill extend along the east coast of Scotland, accompanied by *Trigla cuculus*. As for the weevers, I do not think they are rightly said by Heincke to be common in the neighbourhood of Heligoland, as I did not meet with them there, nor at Grimsby, and although McIntosh records them as not uncommon at St. Andrew's, this may mean merely that a few specimens are seen every year. They were certainly abundant on the Brown Ridges in September.

It is well known that in hard winters soles are caught by the trawlers principally in the deeper depressions in the North Sea, especially in the Great Silver Pit south of the Dogger Bank. The latter is an isolated depression, and being cut off from the influence of the water in the deep valley along the north-east coast of Britain, probably contains warmer water than that valley in winter. The physical condition of such depressions in winter does not appear to have been examined, but the fact that soles collect in the Great Silver Pit in winter indicates that the species we are considering are affected by the fall in the temperature of the shallow eastern and southern waters in the coldest months of the year. At present I have no further knowledge of the relative abundance of the southern fundicolous species in the southern area and the Heligoland Bight from December to April.

The third class of southern species in the same region comprises the littoral species, which live principally among the sea-weeds of the littoral zones, and belong chiefly to the families of wrasses, pipe-fishes, gobies, etc. The commonest of these at Heligoland are: *Gobius minutus*, the Sand Goby; *Nerophis aequoreus*, the Snake Pipe-fish; *Ctenolabrus rupestris*, the Goldsinny. Less abundant are: *Syngnathus acus*, the

Common Pipe-fish; *Siphonostoma typhle*, the Broad-nosed Pipe-fish; and still rarer, *Labrus mixtus*, the Striped Wrasse. To these may be added *Mugil chelo*, the Thick-lipped Grey Mullet, which haunts the shore, but is an active wandering fish, not restricted in its movements like the others.

Heincke does not mention *Labrus maculatus*, the Spotted Wrasse, which, having a much more extended range than *Labrus mixtus*, is more likely to occur at Heligoland than the latter. Possibly this is a mistake, and *maculatus* should be substituted for *mixtus* in the above list. *Labrus maculatus* has certainly been taken at Yarmouth and Lowestoft, and occurs all along the east coast of Britain, while *mixtus* has scarcely ever been taken there.

It is not likely that any of these species, except the grey mullet, make long journeys at different seasons; they are in all probability resident where they are found in the region considered. They are southern species, which are able to bear the winter cold: Heincke states that they are driven in the cold months of the year from the inter-tidal zone into somewhat deeper water.

My conclusions concerning southern species entering the North Sea from the south, are as follows:—

(1) The area in which the more characteristic southern species, such as mackerel and *Trigla hirundo* are found, is bounded by a line drawn from the north coast of Norfolk in a north-easterly direction to the 20 fathom line, and following the latter limit to the Horn Reef.

(2) Certain southern aperticolous species visit this area only in summer, from May to October, and certain fundicolous species are found there at the same time, but how far the latter are absent in winter is not known.

(3) The immigration of these southern forms at this period of the year appears to be determined by the higher temperature due to the season, not by an inflow of water taking place only at that season. The uniform shallowness of the water is, however, an important factor, on the one hand causing a great difference between summer and winter temperatures, and, on the other, protecting the area in summer from the influence of the cold water in the deeper part of the North Sea, to the north and west.

Southern Species Entering at the North.

We next proceed to study the distribution and migrations of southern species in the northern part of the North Sea. In a previous part of this paper, I have already given a list of 18 species of southern forms, which according to Möbius and Heincke are occasionally taken in the

Western Baltic. But it will be more instructive now to take the species of the southern area in the divisions already distinguished, and note which occur in the Western Baltic and which do not, and what others occur in addition. This analysis has been made by Heincke. Of the aperticolous southern species of the southern area of the North Sea, all occur also in the Western Baltic. The mackerel, scad, and gar-fish occur in some numbers, and are classed by Möbius and Heincke as constant rarer residents, but are really summer immigrants making their appearance in May, and absent after October or November. The hake is a rare visitor, and has only been occasionally taken on the east coast of Schleswig-Holstein in November and December. The tunny and anchovy are also but occasional immigrants, which have been occasionally taken in autumn.

Of fundicolous forms, the following, according to Heincke, do not occur in the Western Baltic: *Zeus faber*, the Dory; *Callionymus lyra*, the Dragonet; *Gadus luscus*, the Pout; *Motella tricirrata*, the Three-bearded Rockling: *Solea lutea*, the Solenette; *Arnoglossus laterna*, the Scald-fish; *Galeus vulgaris*, the Tope; *Mustelus vulgaris*, the Smooth Hound; *Scyllium canicula*, the Small Spotted Dog-fish; *Amphioxus lanceolatus*, the Lancelet.

All these species have, however, been found in more or less abundance on the west and south coasts of Norway, with the exception of two, *Solea lutea*, and *Mustelus vulgaris*. The latter has been taken at the Shetlands and Orkneys. Of littoral species only two, *Nerophis aequoreus* and *Labrus mixtus*, are stated by Heincke to occur at Heligoland and not in the Western Baltic, but these again are fairly common on the south and west coasts of Norway, as far to the north as Tromsö.

On the other hand, the following southern species occur in the Western Baltic, which are not found in the Heligoland Bight or the southern part of the North Sea:—

APERTICOLOUS: *Sciaena aquila; Xiphias gladius; Orthagoriscus mola; Carcharias glaucus.*

FUNDICOLOUS: *Brama Rayi* (deep sea); *Gadus minutus; Raja fullonica.*

LITTORAL: *Gobius niger; Labrus maculatus; Crenilabrus melops; Nerophis ophidion.*

In addition to these a large number of southern species have been taken more or less frequently on the west coast of Norway. Of pelagic or aperticolous forms, Collett *(Norges Fiske*, 1875*)* gives *Lampris luna; Antennarius marmoratus; Argyropelecus Olfersii; Exocoetus volitans; Alopecias vulpes; Scopelus caninianus; Scombresox saurus.*

These southern aperticolous forms found on the coast of Norway, and not in the southern part of the North Sea, are oceanic species which live

in the warmer parts of the Atlantic far from the coasts. The warm surface drift of the Gulf Stream carries them occasionally to the south-west coast of Norway, as also to the west coasts of the British Islands, but they do not penetrate through the English Channel and are, therefore, not seen in the southern part of the North Sea. They appear to be usually taken on the Norwegian coast in summer.

Certain deep-sea species extend from the Mediterranean to the coast of Norway, such as *Argentina sphyraena*, but most of these have a very wide range, and need not be considered in relation to the present subject.

The southern character of the fish found on the south-west coast of Norway is strikingly exhibited by the numerous species of *Scombridae*, *Percidae*, *Sparidae*, and *Labridae*, which are found there. Besides those which have been mentioned as occurring in the Western Baltic, we have of shallow-water forms:—*Pagellus centrodontus*; *Cantharus lineatus*; *Polyprion cernium*; *Acantholabrus exoletus*; *Acantholabrus couchii*; *Pristiurus melanostomus*; *Spinax niger* (deep sea); *Lamna cornubica*: *Nerophis lumbriciformis*.

In considering the relation of the occurrence of these southern forms on the south-west coast of Norway to physical conditions, we have to remember that a narrow channel over 200 fathoms in depth runs along that coast at no great distance from the shore, and that even the 100 fathom line does not go further north than the latitude of the north coast of Scotland. The warm Gulf Stream is only a surface layer, and beneath it is colder water. A large number of the southern species have only been occasionally taken on the Norwegian coast, and then chiefly in summer and autumn. They are probably to be regarded as isolated stragglers, which have been partly tempted onwards by the warmth of the water, partly carried by the surface drift. More detailed information concerning the permanence or periodicity of the occurrence of these species on this coast is required. The information available in Smith's recent edition of Fries and Ekström's *Scandinavian Fishes*, I have not yet had time to study thoroughly, as it is only given in separate statements under each species. It would appear, however, that a considerable number of littoral southern species are resident all the year, and it is to be noted that the surface temperature on the coast of Norway, to the north of 60° N. L., does not fall in February below 6°, while in the Heligoland Bight it is between 4° and 5° C. in that month.

It has been shown by the physical observations previously reviewed that in summer a strong surface outflow from the Baltic northwards along the Norwegian coast takes place, while in winter this is entirely cut off. This water flowing out in summer is at a high temperature,

being warmed by the sun. It is therefore as warm as the Gulf Stream surface water from the Atlantic, and it seems to me that this fact is the chief condition determining the annual arrival of mackerel, gar-fish, scad, and anchovy on the south-west coast of Norway, and at the entrance of the Baltic.

The southern forms which have been mentioned occur also to some extent along the east coast of Scotland, but more commonly towards the north. It is therefore evident that they come round the northern end of Britain, and travel southwards. Here, again, detailed information as to the duration of their stay is at present deficient. It is stated that mackerel do not appear at the Orkneys till July, and in the Moray Firth are most abundant in August. The gar-fish, skip-jack, scad, and anchovy are all also recorded as occurring in the Moray Firth and on the east coast of Scotland, the three former as far south as St. Andrew's and the Firth of Forth. Others of the southern species which have been mentioned also are taken as isolated individuals, or in small numbers, as far south as St. Andrew's, and only in summer and autumn. *Trigla hirundo*, for instance, has been once taken at St. Andrew's, while *Pagellus centrodontus* is said to be not uncommon there. *Zeus faber*, the dory, is rare in that locality. *Labrus maculatus* occurs, and the only other wrasse is *Crenilabrus melops*, which is rare. The southern forms are scarcest or altogether absent between the Firth of Forth and the Wash.

Distribution of Northern Species.

The northern species, that is, species whose range extends beyond the Arctic circle but not into the Mediterranean, which occur in the Western Baltic, are chiefly littoral species, or fundicolous species, inhabiting moderate depths. The herring is the chief exception, being almost the only aperticolous species in the list. The species, as given by Möbius and Heincke, are: *Cottus scorpius, Cyclopterus lumpus, Centronotus gunnellus, Zoarces viviparus, Spinachia vulgaris, Gadus morrhua, Gadus aeglefinus, Gadus merlangus, Ammodytes tobianus, Pleuronectes platessa, Pleuronectes limanda, Pleuronectes microcephalus, Hippoglossoides limandoides, Clupea harengus.* Less abundant are: *Cottis bubalis, Agonus cataphractus, Liparis vulgaris, Gadus pollachius, Lota molva, Motella cimbria.* The occasional immigrants are: *Anarrhichas lupus, Gadus virens, Pleuronectes cynoglossus, Hippoglossus vulgaris, Liparis Montagui, Stichaeus islandicus (Lumpenus lampetraeformis), Brosmius brosme, Raia radiata.*

As we have seen, Pettersson points out that these northern immigrants are taken in the Baltic early in the year, from February to April, at which season the Baltic outflow has ceased, the force of the

Gulf Stream is diminished, and an influx of cold water 4° to 5° C. takes place into the Baltic, from the north along the Norwegian coast.

Five of these occasional immigrants are absent from the Heligoland region, namely, *Liparis Montagui, Stichaeus islandicus, Brosmius brosme, Pleuronectes cynoglossus*, and *Raia radiata*. These are also wanting in the southern shallower part of the North Sea, that is to say, south of the 20 fathom line, except *Liparis Montagui*, which, according to Day, occurs at the mouth of the Thames and on the south coast of England. These five are the most especially northern of the above list, and are true Arctic species. *Liparis Montagui* is common along the east coast of Scotland and north-east coast of England. Of *Stichaeus islandicus*, only one or two specimens have been taken occasionally in the north-western part of the North Sea, once in 40 fathoms off St. Abb's Head, once in February, 1894, off the mouth of the Firth of Forth, and two specimens in July, 1892, 240 miles E. ½ N. from Spurn Head. *Brosmius brosme*, the tusk or torsk, is abundant from Spitzbergen to the Shetlands, but further south becomes scarcer: it has only been occasionally taken off the Yorkshire coast. *Pleuronectes cynoglossus*, the witch, is abundant on the Great Fisher Bank, and may be said to be limited in the North Sea by the 30 fathom line. *Raia radiata* has a similar distribution, not being found south of Yorkshire.

Two species found in the Heligoland region have not been taken in the Baltic, namely, *Carelophus ascanii*, of the blenny family, and the rockling, *Motella mustela*. The former is common on the north-western coast of Norway, and occurs rarely on the east coast of Britain as far south as Yorkshire. *Motella mustela* extends southwards throughout the southern area of the North Sea, and occurs also on the south coast of England.

The other three occasional immigrants into the Western Baltic, namely, the cat-fish, the coal-fish, and the halibut, occur along the east coast of Britain as far to the south as the 30 fathom line, but not south of it.

Hippoglossoides limandoides, the long rough dab, is resident in the Baltic, and also in the north part of the North Sea, north of the 30 fathom line, but is absent from the Heligoland region, and from the shallow southern area.

The other species mentioned in the above list, although not entirely absent from the southern area and the eastern slope of the North Sea, become much scarcer there, as will be seen from the observations in these areas recorded in the two previous numbers of this Journal. The lemon dab *(Pleuronectes microcephalus)* is found more plentifully along the English coast in the southern area, *i.e.*, along the line of deeper water. *Lepidorhombus megastoma*, the megrim, is a northern form, not

mentioned in the above list because not occurring in the Baltic. It is common in the northern part of the North Sea, in the deeper water, and also at Iceland, and at depths over 30 fathoms on the south-west coast of England.

In the northern region the species most abundant in individuals are haddocks, whiting, cod, plaice, dabs, lemon dabs, witches, long rough dabs, megrims, cat-fishes, ling, while on the southern ground the only northern species which are abundant are whiting, plaice, and dabs.

In this discussion I have omitted all mention of a number of species, such as *Raia clavata*, the thornback ray; *Raia batis*, the skate; *Lophius piscatorius*, the angler; which are classed by Heincke and Möbius as of indefinite distribution, because they either extend both to the Arctic Ocean and the Mediterranean, or to neither.

In the further consideration of the distribution of northern species, three subjects may be taken separately: (1) the general physical conditions, (2) the migrations of the herring, (3) the difference in the size of fish of the same species in different parts of its habitat.

(1) *The general physical conditions.* In general terms, the physical fact which determines the distribution of northern species of fish in the North Sea, is that deep water in open communication with the Arctic Ocean extends along the east coast of Britain towards the coast of Norfolk. If we look at the contour lines of the sea-bottom, we see that the 100 fathom line passes round the north of the Shetlands and bends round to the south, parallel to the Norwegian coast and at no great distance from it. The 50 fathom line passes down the east side of the Shetlands, Orkneys, and the east coast of Britain to the latitude of the Farn Islands, and runs north again along the west side of the Great Fisher Bank, to the edge of the Norwegian depression. The 40 fathom line runs further south off the east coast of England, and to the west of the Dogger Bank and Great Fisher Bank. The 30 fathom line runs outside the Dogger Bank, and the whole of the Fisher Bank is more than 30 fathoms in depth. But the 20 fathom line isolates the Dogger Bank, and leaves a valley between it and the slope of the mainland. To the south of this valley the 20 fathom line runs across the North Sea from Flamborough Head to the continental slope.

Apart from movement of the water, this depression must contain at the bottom water which is continuous with the cold bottom water of the Arctic Ocean, and which cannot be much affected or raised in temperature by the warm current of the Gulf Stream, both because that is a current of surface water, and because it flows past the north of Britain to the Norwegian coast. We see thus that the roads of the northern forms and southern forms actually cross one another to the east of the Shetlands and Orkneys, the southern species travelling in the warm

surface water of the Atlantic to the south-west coast of Norway, the northern species moving at the bottom down the western side of the North Sea.

The observations of the *Pomerania* expedition previously mentioned, show that in summer, in the deep depression, the temperature at the bottom was not higher than 8° C., while at the surface it was 12° to 14° C. At the western side of the southern area the temperature at the bottom was somewhat lower than at the surface, but not on the eastern side. This is attributed to an inflow of cold water from the north. It seems to me that it is with regard to this question of the flow of the cold bottom water at different times of the year, that further information from the physicists is most required. We know that northern forms, such as haddock and lemon dabs, extend down the east coast of England as far as the Thames, in greater numbers than on the continental side, and we know that there are isolated depressions over 20 fathoms in depth along this side, which are wanting on the continental side. But it would be interesting to know further to what extent the cold water makes its way southward beyond the latitude of the Wash, and what is the cause of its movement?

Reference has already been made to Dickson's account of the entrance of oceanic water down the east coast of Britain from the north, and his opinion that the important property of this water is, that it contains more oxygen than the bottom water of the deeper part of the North Sea, which it replaces. In his interpretation of the observations, Dickson has laid chief stress on the introduction of *Atlantic* water into the west side of the North Sea at the bottom, and says little of the temperature of the introduced water. Apparently the reason of this is, that the Atlantic water was originally surface water, and was presumably saturated with oxygen. Now, the question of the oxygen in the bottom water introduced, or in that which it displaces, has not been directly investigated. It seems to me that it is very desirable that Mr. Dickson and the other physicists who are studying the phenomena in question, should consider the movements of the water in relation to the contrasted distribution of northern and southern fish, of which I have in this paper attempted to trace the main features. The herring is a northern species, abundant in the Norwegian Sea, and its incursions into the North Sea must, I think, depend, like the presence of the other northern species characteristic of the north-western part of that sea, on the introduction not of Atlantic water, but of cold water from the Norwegian Sea. It seems to me the question is one rather of temperature than of oxygen. In Dickson's conclusions it is noteworthy that the introduced water is a mixture of Atlantic water and water from the Norwegian Sea, and to me the latter constituent and its low temperature appear to be the more

important factors. In any case it is important that Dickson concludes from his observations that cold bottom water does flow from the north down the north-western depression of the North Sea, and this fact corresponds to the prevalence of northern species of fish in that depression and the east coast of Britain.

(2) *The migrations of the herring.* Turning more particularly to this difficult subject, I cannot profess, with the data at present available, to give a complete explanation of these migrations. I propose merely to point out some of the more obvious relations, in the hope that my remarks may be of some use in directing attention to the conditions which have to be investigated.

On the east coast of Scotland, it appears at first sight that the summer herring arrive and are present when the water is warmest. In the northern part, for instance in the Moray Firth, the chief fishing is in July and August. Further south it gets later, taking place in August and September, while at Lowestoft it lasts from October to the beginning of December. There is a mackerel fishing at Lowestoft in September and October, so that during October, as I know from personal observation, both mackerel and herrings are being landed in numbers at the same time. But it must be remembered that the mackerel are going away to the south, and herrings are arriving from the north, and also that mackerel usually swim near the surface, and herring near the bottom, or at some distance below the surface. It is probable that at this time when the herrings visit the neighbourhood of the Norfolk and Suffolk coasts, the bottom water is colder than it has been during the preceding summer, in consequence of the inflow of bottom water from the north. This does not explain why the herrings are absent in January, February, and March. But the herrings come to spawn, and there is some evidence that they retire northwards into deep water to feed. All that I would suggest is, that we do not know that the bottom water, where the summer herring spawn, is at its warmest when the spawning takes place off Lowestoft, although, according to Dickson, the mixed Atlantic water which makes its way down the east coast of Scotland in summer is warmer than the water it displaces. The warmth of the inflowing water, however, is not very great, its temperature is not above 9° C. We have seen that, according to the observations of the *Pomerania*, the temperature at the bottom in the northern part of the North Sea in summer is frequently below 8° C., and we do not know what the winter temperature is. The hypothesis that the arrival of herrings is connected with a greater supply of oxygen, seems to be inconsistent with the fact that there is at all times of the year such an abundance of bottom fish (haddock, plaice, cod, etc.) in the places where the summer herring fishery is carried on.

We have seen that Pettersson traces a distinct connection between the herring fishery in the Skagerack and Cattegat, and the inflow of coast water. But there appear to be two periods of inflow, one from the south of warm water 15° C. to 16° C. in temperature in August and September, and one from the north of cold water 4° to 5° C. in January, February, and March. Herring fishery is associated with both of these, but principally, it would appear, with the northern water, which contained northern forms of plankton. It is well known that there are winter spawning herring in various localities, which must be considered to be races quite independent of the summer spawners. With regard to the relation of the fish to temperature, it is suggestive that on the south-west coast of England, in the neighbourhood of Plymouth, there are no herrings in summer or autumn, but only from about the end of November till the end of February, that is at the time when the water is coldest.

Dr. John Murray considers that there is evidence that the herrings of Loch Fyne and the Firth of Clyde reside there permanently, and do not merely make periodical visits, and believes that they feed chiefly in the deep depressions near the bottom. Whether these are the herrings which spawn on the Ballantrae Banks in early spring, we cannot definitely decide at present. But enough has been said to show that the introduction of Atlantic water with a greater supply of oxygen is not a sufficient explanation of the annual migration of summer herrings into the North Sea, and that probably some important and interesting discoveries have yet to be made concerning the relation between the food, breeding, and movements of herrings, and the temperature of the water in which they are found at different seasons.

(3) *Different sizes of fish of the same species at different parts of its habitat.* Mr. Holt's observations, together with my own, as published in previous numbers of this Journal, have shown the different sizes of plaice in (1) the northern and western part of the North Sea (2), on the south coast of Iceland (3), in the southern shallow part of the North Sea and in the English Channel. In the two latter cases the difference has been precisely exhibited in the lengths of the smallest mature and largest immature specimens. This is probably the best method of testing the matter, for the average size of mature specimens as a standard is liable to the objection that it depends on the extent to which older and larger fish are captured. Mr. Holt's observations in the Journal, and Petersen's* in the Annual Report of the Danish Biological Station, refer to small races of plaice in the Baltic. There are three points to be taken into consideration in relation to these

* Dr. C. G. Joh. Petersen, the Danish biologist, is not to be confounded with Prof. Pettersson, the Swedish hydrographer.

size-varieties or geographical races: (1) that their occurrence in the plaice is only one instance among a number, several other northern species, *e.g.*, the Greenland bullhead, *Cottus greenlandicus*, and the so-called Norway haddock, *Sebastes norvegicus*, being very much larger on more northern coasts than on British coasts or on the south coast of Norway; (2) the question whether definite structural peculiarities are present, as well as mere size, to distinguish the geographical forms from one another; (3) the question whether the differences are hereditary, each race breeding and transmitting its peculiarities independently, or whether the fish are the offspring of parents from other areas, and owe their peculiarities merely to the conditions under which they have lived and grown.

With regard to the first point, we cannot say that the existence of geographical races differing in size is peculiar to northern forms, although it is to these that my attention has been principally directed. It is probable enough that any wide-spread species may be found to show the same state of things. At a certain part of its habitat it appears that a species attains its greatest development, because there the conditions, whatever they may be, are most favourable to it, and at regions lying near the limits of its range it is less favourably circumstanced, and is found in smaller numbers and of smaller size. In Greenland it is stated that the short-spined bullhead attains to six feet in length, although it is the same species as the *Cottus scorpius* occurring on the east coast of Britain, where it never exceeds a length of fifteen inches. It is very difficult to decide what are the favourable and unfavourable conditions which cause the differences in size in such cases, and the investigation of these conditions would be both important and interesting. With regard to the plaice and other northern species, it might be supposed that a higher temperature was the chief unfavourable condition, and it may probably enough be one of them. We know that the water of the Channel is warmer than the bottom water of the northern part of the North Sea, and this higher temperature extends for great part of the year to the southern narrower area of the North Sea. But on the other hand, the Baltic, which contains plaice of small adult size, is colder, except perhaps in the height of summer, than the North Sea. Here it might be supposed that the lower salinity was an unfavourable condition, but this would not apply to the English Channel. It is possible that the amount of available food, the extent of suitable ground, and the competition of other species, have more influence on the size and general development of a particular species than purely physical conditions such as salinity and temperature.

With regard to the second point, it is found in many cases that

minute structural peculiarities do co-exist in geographical races together with limits of size. Such races, therefore, must be regarded as incipient species; they only differ from species in the minuteness of the structural peculiarities and in the absence of definite limits between one race and another, a continuous transition from one to the other being observed in individuals and in intermediate areas. The study of such geographical varieties is therefore philosophically important, since in these cases we have actually the origin of species before our eyes.

Mr. Holt has previously written in this Journal concerning the ciliation of the scales in the males of the dwarf variety of plaice in the Baltic, and mentioned that these plaice have been stated to have a smaller number of dorsal and ventral fin-rays. Dr. Heincke had suggested that the Heligoland plaice were smaller than those of the western side of the North Sea, and probably formed a local variety. Dr. Georg Duncker, at Heincke's request, has investigated,* by the method applied by the latter to races of the herring, the distinguishing characters of local varieties of the plaice. He examined separately specimens from Greifswald, Kiel, the Cattegat, all localities in the Baltic, and from the neighbourhood of Heligoland. It appears from Duncker's results that ciliation restricted to the middle rays of the dorsal and oval fins is more common than a greater extension of the condition. It was more developed in specimens from Kiel and the neighbourhood than in those from the Cattegat, and in specimens from Heligoland was found on the body in two males out of 35, on the fins alone in 18 out of 35. But unfortunately no examination was made of specimens from other parts of the North Sea, and therefore it remains an open question whether the plaice of the Heligoland Bight have the special characters of a local race. Only a small number of specimens altogether were examined by Duncker. It will be remembered that my own examination of the size of mature specimens went to prove that the plaice of the Heligoland region were not smaller at maturity than those of the north-western part of the North Sea. The examination of specimens from the different regions of the North Sea, for the purpose of ascertaining whether constant structural differences can be found distinguishing the local forms, is yet to be carried out.

With regard to the third point, whether the peculiarities of local races are hereditary, or are acquired by the individual in consequence of the conditions under which it has lived and grown, to decide upon this, it would be necessary to know in each case how far interchange of

* Variation und Verwandtschaft von *Pleuronectes flesus L.* und *Pl. platessa L.*: *Wissenschaftliche Meeresuntersuchungen. Neue Folge, Erster Band, Heft 2, 1896.* (See this Journal, vol. iv. p. 293.)

individuals takes place between different areas, or whether the individuals of a region are the offspring of parents which lived in the same region. At present it is difficult to give answers to these questions. The English Channel is so extensive that we can confidently conclude that the plaice found there are the offspring of parents that also lived there. But we cannot be certain that the eggs of plaice which spawn between Lowestoft and the Dutch coast are not carried by the currents to some distant region, most probably to the Heligoland Bight, where they would develop into plaice of larger size at maturity. Similarly we cannot be certain that young plaice on the German coast near Heligoland are the offspring of parents which themselves grew up on that coast. To obtain evidence on these matters we must trace with more certainty the movements of the adult fish, and the course which the eggs are compelled to take by the currents. Something has been done in this way by the hydrographers, and by Dr. Fulton in his experiments with floating bottles, and the results indicate that the plaice of the Heligoland Bight are largely derived from spawn shed in the central part of the North Sea. In the Western Baltic the plaice have marked characteristics, distinguishing them even from those of the Cattegat, especially in the small size at which they are mature. Yet according to Petersen, young plaice, in the first summer after their development from the egg, are not found in the Baltic east of Zealand, Moen, and Falster at all, but enter it from the Cattegat when a year old. At the same time, Petersen finds indications that the mature fish in the Baltic emigrate through the Great Belt and spawn in the Cattegat, so that the dwarf plaice of the Baltic, with all their peculiarities, might be the offspring of parents which lived in the Baltic.