DEPARTMENT OF THE NAVAL SERVICE

CANADIAN FISHERIES EXPEDITION, 1914-1915

nvestigations in the Gulf of St. Lawrence and Atlantic Waters of Canada

UNDER THE DIRECTION OF

DR. JOHAN HJORT,
Head of the Expedition
Director of Fisheries for Norway.

OTTAWA
J. DE LABROQUERIE TACHÉ
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LIST OF ERRATA TO BE NOTED BY THE READER.

P. 28, Fig. 20. *Merluccius* not *Merlucius*.

P. 30, Fig. 21. *Mallotus* not *Malotus*.

P. 32, Fig. 22. *Mallotus* not *Malotus*.

P. 118, Fig. 29. The second figure 6 at the bottom of the figure should be 8.

Coloured Plate 1 (Sandström's Report). 83 not 33 between 67 and 31 NE. of Station VIII.

" " 2 (Sandström's Report). The figure 4 below V is reversed in error.

" " 3 (Sandström's Report). In the explanation X — XX should be XIII — XX, and the small triangular area close to 65 should be yellow not white. Also the figures 82-88 should be 83-89 and 79-81 consecutively.

" " 4 (Sandström's Report). Omit minus sign (—) in legend. It should be <O°C not <— 0°C.

" " 4 (Sandström's Report). The triangular space with V in the centre should be white, not coloured red.

" " 5 (Sandström's Report). Midway between XVIII and XIX the figures should be 89 not 79.

DEPARTMENT OF THE NAVAL SERVICE.

CANADIAN FISHERIES EXPEDITION, 1914-1915, IN THE GULF OF ST. LAWRENCE AND ATLANTIC WATERS OF CANADA,

Under the Direction of Dr. Johan Hjort, Director of Fisheries for Norway.

Scientific results embodied in nine memoirs as follows:—

Johan Hjort: Introduction to the Canadian Fisheries Expedition, 1914-1915.

Alf. Dannevig: Canadian Fish-Eggs and Larvæ.

Einar Lea: Age and Growth of the Herring in Canadian Waters.

A. G. Huntsman: Growth of the Young Herring (so-called sardines) of the Bay of Fundy.

Arthur Willey: Report on the Copepoda obtained in the Gulf of St. Lawrence and adjacent waters, 1915.

J. W. Sandström: The Hydrodynamics of the Canadian Atlantic Waters.

Paul Bjerkan: Results of the Hydrographical Observations made by Dr. Johan Hjort in the Canadian Atlantic Waters during the year 1915.

A. G. Huntsman: Some Quantitative and Qualitative Plankton Studies of the Eastern Canadian Plankton.

1. Introduction.
2. Quantity of Plankton.
3. A Special Study of the Canadian Chætognaths, their Distribution, etc., in the Waters of the Eastern Coast of Canada.

H. H. Gran: Quantitative Investigations as to Phytoplankton and Pelagic Protozoa in the Gulf of St. Lawrence and outside the same.

PREFACE.

By Professor Edward E. Prince, LL.D., *Dominion Commissioner of Fisheries and Chairman of the Biological Board of Canada.*

The series of reports on the results of the Canadian Fisheries Expedition, 1914-15, with the important introductory memoir by Dr. Hjort, Director of Fisheries under the Government of Norway, and head of the expedition, are weighty contributions to our knowledge of fish-life in the sea. They inform us, also, as to the complex conditions of marine life generally in our Atlantic waters, and a few preliminary words seem necessary in explanation of the origin, character, and scope of the expedition. About ten years ago the Biological Board of Canada, of which I am chairman, decided to ask Dr. Hjort if he could take charge of a comprehensive fishery investigation in Canadian waters on the lines of the researches which, under his direction, had proved so beneficial to the fisheries of Norway. In spite of the fact that the great cod and other fisheries off our Atlantic coast had been carried on for centuries, it was felt that there were doubtless hidden possibilities of development and expansion that awaited only a basis of accurate knowledge to turn them to account. Certain urgent problems affecting the herring resources of the gulf of St. Lawrence and the Atlantic coast adjacent seemed to call for adequate scientific investigation. After some correspondence with Dr. Hjort, carried on by myself and by Professor McBride (then of McGill University, and a member of the Biological Board), the matter was allowed to remain in abeyance. Dr. Hjort could not at that time visit Canada, though he suggested the name of an able young Norwegian scientist who might undertake the work. The proposal was revived by the Biological Board five years ago, with the result that after much correspondence, Dr. Hjort came to Canada, and arrangements for the expedition were completed in Ottawa, after conferences between the Deputy Minister (Mr. Desbarats), the Biological Board, and Dr. Hjort.

As the expenditure involved in carrying out a well-planned deep-sea investigation was too considerable to be readily met by the Biological Board, the Deputy Minister of the Naval Service cordially agreed to an arrangement whereby the department would provide the amount necessary. Dr. Hjort and I met in conference a number of times and, as a result, a plan of work was outlined, which is summarized in the Introductory Report. The plan embraced the necessary physical, hydrographical, chemical, and biological researches, including collection of water samples, etc., and the determination of the plankton collections, distribution and varied abundance of the young fry, as well as the eggs of the cod, haddock, flat-fishes, and other species, in addition to the thorough study of the varieties, distribution, migrations, and breeding of the herring. The survey, in short, was to be as complete as possible in order to afford a basis for the future development of the fishing industries.

Eight years ago Dr. Hjort had carried on investigations in Newfoundland waters, in conjunction with the late Sir John Murray, on the well-known cruise of the Norwegian Government steamer *Michael Sars*. The Canadian investigations now planned would, it was thought, advance some aspects of the important results achieved by Dr. Hjort and Sir John Murray. They certainly show, as demonstrated in the Preliminary Report on the "Natural History of the Herring, 1914," by Dr. Hjort, published by the Naval Service Department in 1915, in what a unique degree the Atlantic waters of Canada, especially the gulf of St. Lawrence, a thorough scientific investigation can aid in the solution of important fishery problems so exhaustively studied in Norway. These problems centre round the relation between the distribution and life-cycles of fishes, and other organisms, and the prevailing environments obtaining in successive seasons of the year, the physical, chemical, biological, and other conditions, which so profoundly affect animal and plant life in the sea.

Dr. Hjort has succinctly summarized in his Introductory Report his own main results, and the results obtained by the scientific staff working under him, in connection with the expedition.

The herring resources of the Atlantic coastal waters of Canada and of the gulf of St. Lawrence offer a field for enormous commercial development, and Dr. Hjort gave primary attention to the study of the Canadian herring.

As the Preliminary Report on the various types of Canadian herring described by Dr. Hjort was published three years ago, it is not necessary to repeat its main points here, and Mr. Einar Lea's further and more elaborate detailed results must be studied in his report now presented; but it may be pointed out that, on the whole, four very different groups of herring may be distinguished, viz.:—

(1) The Newfoundland type (with the remarkable exception of the St. George Bay herring), which grows slowly during the first summer, but from the third summer on grows at a rapid rate. The samples studied ranged from four to twenty years in age, and the age-group of 1904 was dominant, recalling Dr. Hjort's discovery of a dominant age-group in Norway—a single year-class maintaining a dominant position in successive season's catches for several years. The typical Newfoundland herring in growth and age composition of the schools form a group distinct and apart, as demonstrated by all the samples studied.

(2) The second type are formed by the herring off cape Gaspé, Magdalen islands, and Northumberland straits, roughly embracing the west and northwest waters of the gulf of St. Lawrence, which grow rapidly during the first summer, and slowly in later years, and are thus smaller later on than Newfoundland herring of the same age. The 1903 and 1907 year-classes dominated.

(3) A third type from the Cape Breton (Atlantic) coast, from North Sydney south, which have a moderate first-summer's growth, but a more rapid growth from the third summer on. The divergent type from bay St. George, Newfoundland, belongs to this group. The dominant age-group is that of 1903.

(4) A fourth type from Chedabucto bay and southwest along the Nova Scotia shore, which grows well during the whole of its first five or six years, and outdistances all the other types of herring. The 1911 year-class was found to prevail, while in the large, older herring from Nova Scotia, the 1908 year-class dominated, and in the Halifax and Lockport samples the 1908, 1910, and 1911 year-classes were best represented.

Mr. Einar Lea makes the important observation in his report that the samples of herring which resembled each other in age-composition, also exhibited great resemblance as regards growth, hence the types signalized would appear to be valid and unquestionable, though more extended researches are urgent to fully confirm these results.

The special investigations upon the herring yielded conclusions so interesting that it seemed necessary to extend the studies in hand to other species, and to elucidate faunistic conditions generally in all the Gulf and Atlantic waters embraced in the scheme.

Problems as to the influence of the earth's rotation, the effects of the annual melting of the great fields of ice, the features of temperature, salinity, specific gravity, etc., of the sea water, and other matters vital to the vertebrate and invertebrate life, and especially fish-life, off our Atlantic coast, were included.

Professor Gran's masterly plankton studies show that in the gulf of St. Lawrence there is a plentitude of minute floating plants of northern types, whose development each season appears to be annually much later than in the northern European waters. The prevalence of an Arctic temperature for so large a part of the year is the explanation.

On the spawning, the eggs, and the young stages of food- and other fishes, important observations were made. Mr. Dannevig's report on the material obtained is exceedingly interesting. Thirty-six species were determined, which belong to twenty families, the cod being most important, and its eggs and larvae occurred during a long period, May to August. Haddock were more rare, one egg only being secured in the gulf of St. Lawrence. Nor were mackerel egg numerous, while very few flat-fish eggs, or young, were found, excepting the Canadian Plaice.

The eggs and young of fishes and other animal forms constitute an important part of the plankton, but the scarcity of these eggs and young is a striking feature. Over the northern portions of the gulf, there occurred, in May and June, eggs of cod and other gadoids, also flatfishes, and in a marked degree the eggs of the Canadian plaice (*Hippoglossoides,* or *Drepanopsetta*), with a few larval fish of Arctic types such as the northern wolf-fish (*Anarrichas latifrons*), capelin (*Mallotus*), and others. Mackerel eggs were taken in Cabot straits, and considerable quantities of Norway haddock or rose fish (*Sebastes*) over the deep (Laurentian) channel leading from the gulf into the open ocean. Expectations of greater quantities of floating fish eggs, in the later summer cruises, were disappointed. Cod eggs occurred, and a very small number of young fish, while northern forms such as *Mallotus*, the capelin, occurred, and the more southerly types such as mackerel and *Sebastes*, as before. Outside of the gulf, cod eggs were scanty, but the whiting (*Merluccius*), sometimes called hake, were plentiful. For this scarcity of eggs and young fry the usual explanation (as in European waters) is that they are swept in vast quantities from the spawning and hatching grounds, and may be scattered over vast distances outside the gulf of St. Lawrence. There is no reason to suppose that after the huge schools of parent cod have cast their eggs into the waters inside the gulf, they perish, although the temperature may be as low as the freezing point, or lower, 31° to 32°F. (—1·5 to 0°C.). In Europe, floating eggs such as those of the cod rarely occur in water under 35° or 36° F., but the fishing experiments in the gulf of St. Lawrence showed cod to be abundant in the vast cold water layers immediately above the bottom, and the eggs are deposited under these frigid conditions, and undergo their early stages of development there. It is truly a remarkable result of Dr. Hjort's Canadian researches to find (as he states), "cod spawning on the floor of the banks in water of absolutely Arctic temperature," while at the surface, immediately overhead, more southern forms, such as the mackerel, also spawn.

Dr. Huntsman's interesting quantitative and qualitative plankton research confirms the observations, made during the expedition, that the minute floating life in the Canadian Atlantic waters is more abundant in colder water and where the water is deep, while on the whole, these myriads of small living organisms are at a deeper level during the day than during the night.

Professor Willey and Dr. Huntsman made a study of special plankton groups, the former reporting on the Copepods, the latter on the Chaetognaths, and their reports demonstrate a remarkable agreement between distribution and the various water layers so exhaustively treated by Mr. Sandström in his elaborate report on the hydrodynamics of the waters investigated, and by Mr. Paul Bjerkan in his very thorough hydrographic investigations, including the distribution of temperature and salinity. The former reports on the phyics of the sea—too technical and detailed to summarize, but the presence of a great cold intermediate layer is a striking feature, and due, as pointed out in the report, to ice melting in the gulf or even in the more northerly Arctic areas, probably as distant as Greenland. The earth's rotation causes it to tend to the east, or right, and forces it out via cape North into the open ocean.

The salinity features of the gulf and coastal waters, as determined by Mr. Bjerkan, are of peculiar interest. The outflow of relatively fresh water from the superficial layers in the gulf is more marked in summer than in spring, and one of its effects is to force seawards, the superficial bank water of higher salinity, 32 to 33, this influence being noted to a depth of 25 m., but the salter water, deeper down, forces the bank water back, especially in the Labrador channel (at depths of 75 to 100 m.), where also the Atlantic water of high salinity, 35°, penetrates farther in towards the channel in the spring at a depth of 100 to 200 m. As to temperature, the surface of the gulf is warmer in summer than in spring, owing to the (fresher) coastal water and the Gulf Stream. In the straits of Northumberland it is as high as 18·5° C. (about 65° F.), while the lowest record is 11·65° C. close up to the north shore. In the inner parts of the gulf at 10 m. depth the temperature ranges about 10° C., but in the outer parts at 20 m. an extremely low temperature prevails at 50 to 80 m., especially in the northern parts. There must be a constant inflow of frigid Arctic water through the deeper parts of Belle Isle straits, as the cold water layers are more extended in summer than in spring, though this cold influence appears, off the Newfoundland banks, to decrease in summer. The influence of the Labrador current and the Gulf Stream introduces many complications, as Mr. Bjerkan shows, and the water-masses of continental origin, of low salinity, add to the complexity, both superficial and at greater depths. The effects potently influence the breeding, hatching, and larval development of important food-fishes, and throw light on the migrations and the distribution of the schools of adult-fish on which our great Atlantic fishing industries depend.

CONTENTS.

INTRODUCTION TO THE CANADIAN FISHERIES EXPEDITION, 1914-15.

By Johan Hjort,

Director of Fisheries for Norway, and Head of the Expedition.

(With Five Figures.)

In the course of my researches in North European waters, it has frequently occurred to me that many problems of long standing in the sphere of fishery and marine investigation might perhaps best be solved by making a comparison between the two separate areas of sea which contain the same forms of animal life, viz., the waters of northern Europe, and the range of sea from the coast of Labrador and Canada to that of Maine.

In 1910, I was invited by Sir John Murray, himself Canadian-born, to make a cruise on board the ss. *Michael Sars*, belonging to the Norwegian Fisheries Department, the voyage in question extending over the greater part of the northern Atlantic. Here, naturally enough, the same idea once more asserted itself, and we both felt that it would be desirable to undertake, at any rate, some slight preliminary investigations in the Canadian waters, and there make test of the same methods of research as have been developed, during the course of the past generation, in the fishery investigations of northern Europe, and the International Council for the Exploration of the Sea.

As mentioned in my account of this voyage[1] it was also our desire "to set our course from the Azores to the Bermudas, and thence on to Boston, finishing with a series of short zig-zag sections between the land and the edge of the coast-banks, till we reached Newfoundland. We should in that case have been able to study the remarkable transition that occurs on passing from the almost tropical conditions of the Sargasso sea to those of the icy Labrador stream, which creeps southward along the Labrador coast from Baffin's bay to Newfoundland, and even farther south. The short time at our disposal made this impossible, and we were compelled to cross from the Azores to the nearest coaling station, namely, Newfoundland, and then make for home."

On the way from the Sargasso sea to Newfoundland, however, we had occasion, after all, to make certain observations, the results of which still further convinced me of the great and peculiar interest attaching to such a comparison as that mentioned. Indeed, this last cruise in itself sufficed to show in what unique degree the waters off the coasts of Canada and Newfoundland were suited to the study of those very problems which have ranked foremost in the Scandinavian marine researches of the past generation, to wit, the relation between the distribution and life-cycle of the organisms, on the one hand, and the prevalent physical conditions in the sea on the other.

On this cruise, from the Sargasso sea to the Newfoundland waters, we encountered the sharpest and most remarkable transitions between warmer and colder water layers, and in the closest connection therewith, a constantly coinciding occurrence of plant and animal communities, which were now of tropical, now of distinctly northern boreal character. It was these observations of ours which furnished me with the leading principles on which the investigations described in the following pages were subsequently based. And as, moreover, these earliest discoveries of ours afford a kind of

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[1] Sir John Murray and Johan Hjort: The Depths of the Ocean. Macmillan, London, 1912. Chapter III, pages 99 and following.

rough introductory survey of those Canadian waters which I was later able to study in closer detail, it may perhaps not be out of place to give some of the leading features here.

Fig. 1 shows a temperature and salinity section from the Sargasso sea to Newfoundland. "At stations 64 and 65[1] we see the vast layer, with a salinity of over 35 per thousand and high temperature down to considerable depths, the same as found by us over the whole distance from away beyond the Canary islands.

"On our way north from station 64 on 28th June we saw patches of Sargasso weed all the morning, and numbers of flying fish, about 10 centimetres long, started up in front of our bows. This led us to believe that we should capture the same forms as before, when we lowered our pelagic appliances in the evening at station 66. Great was our astonishment, therefore, to discover next morning on hauling in our appliances that the catches mainly consisted of true "boreal" plankton, that is to say, animal forms which we were accustomed to get in the so-called extension of the

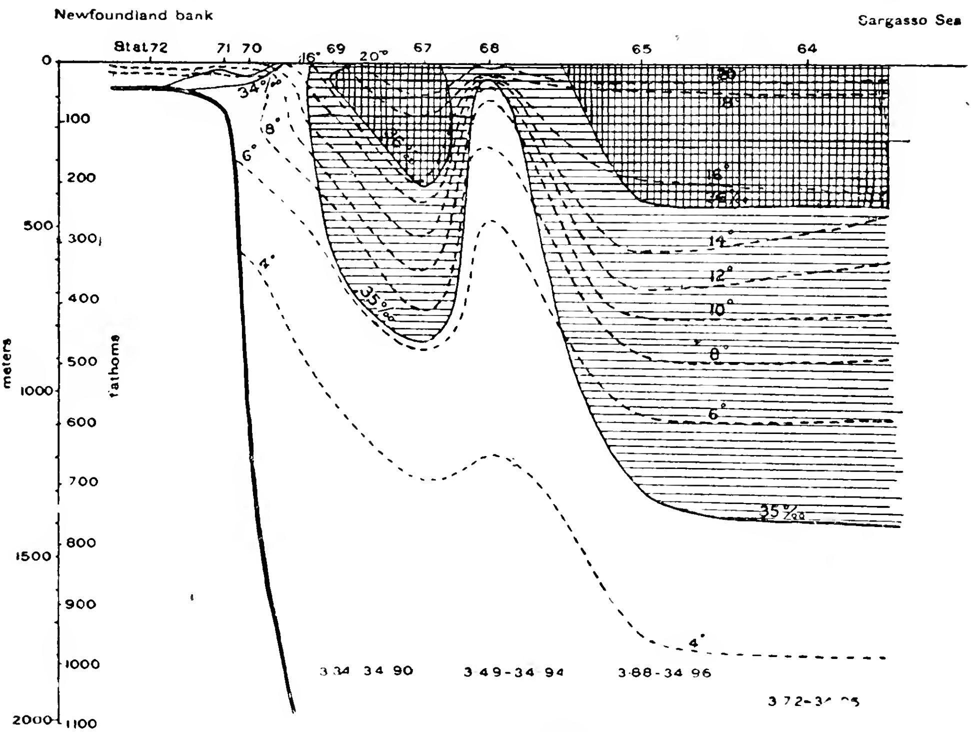

Fig. 1. Hydrographical Section from the Sargasso Sea to the Newfoundland Bank.

Gulf Stream in the Norwegian sea right up to the very shores of Sitsbergen. There was the amphipod *Euthemisto*, the copepod *Euchaeta*, and "whale's food" (the pteropod *Clione limacina*), large quantities of which are met with from time to time in the waters between Spitsbergen and the north of Norway. This last is not an "arctic" form, that is, it is not associated with polar water in the Norwegian sea, but on the contrary is found in Atlantic water to the south of Iceland, according to Danish observations. It seems, however, to be associated with the northern portion of the Atlantic and the Atlantic water that enters the Norwegian sea. These animal forms were entirely absent during the whole of our cruise from the Canary islands to station 64, so that their occurrence at station 66, where lower temperatures were recorded at no great depth beneath the surface, is very significant.

[1] *Loc. cit.*

"We fancied now that we had said farewell to the Sargasso sea and its interesting animal life, but at stations 67 and 69, in close accordance with the hydrographical conditions depicted in fig. 93 (fig. 1), we came once more across more southerly forms. In the upper layers there were the same young fish, many of them with stalk-eyes, and Leptocephali, while flying fish, Sargasso weed, and the familiar Sargasso animals were all once more in evidence.

"We found a large cluster of eggs, weighing approximately a kilo., drifting about at station 69, belonging to the common angler-fish (*Lophius piscatorius*), the development of which was studied by Alexander Agassiz; we hatched out the eggs and obtained the stages depicted by him. Angler-fish only inhabit the coast banks, so that our find of slightly developed eggs, that could not have been drifting many days, indicated that we were now in the neighbourhood of the American coast bank.

"In deep water we found once more at stations 67 and 69 the deep-sea animals of the Sargasso sea, that is to say, all the black fishes and red crustaceans which we have so often mentioned already. There were not merely the commonest kinds of small fish, but also large ones (such as three examples of *Gastrostomus*), and fishes which are caught in other oceans (*Aceratias*, *Serrivomer*). . . .

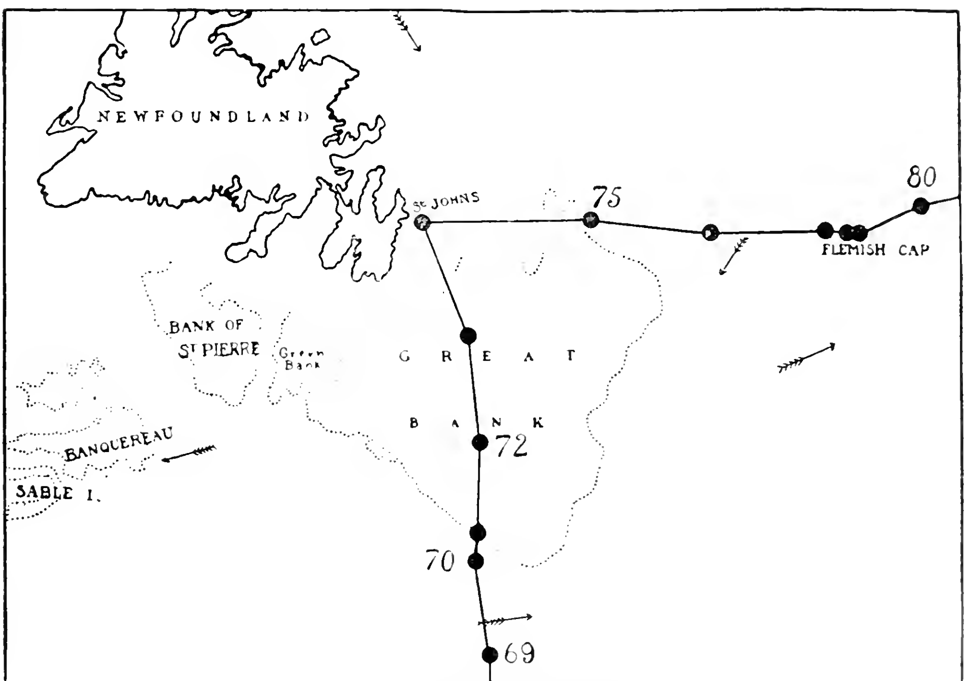

Fig. 2. "Michael Sars" Stations 69 to 80.

"At station 70, on the edge of the coast bank, where the depth was 1,100 metres, we discovered that we had for the second time left purely oceanic conditions behind, and once more the true boreal plankton appeared in the surface layers. There was the little copepod *Calanus finmarchicus*, the commonest crustacean in the Norwegian sea, and we also now met with *Euthemisto*, *Nyctiphanes*, *Krohnia hamata*, *Limacina helicina*[1] and *Clione limacina*, all species that are regarded as specially characteristic of the Norwegian sea. Still in the deep water from 350 metres down to 1,100 metres we continued to get the familiar pelagic deep-sea fish *Cyclothone signata* and *C*

[1] *Limacina* was taken in numbers by Haeckel and Murray off Scourie in Scotland.

microdon, as well as the medusa *Atolla* and other forms; so that the area of distribution of these animals extends from Africa to North America, that is to say, in all the water from one continental slope to the other."

"The coast bank itself (fig. 94 [2]) offered us a totally different field for study, which no doubt would have proved very interesting, but unfortunately our time was too short to attempt systematic researches; we had to steam for our coaling station, contenting ourselves with one or two shallow stations on the way.

"Fig. 95 (3) shows the hydrographical conditions from our last true oceanic station (69) to a station (74) just off St. Johns. It is extraordinary what a sudden change there is from the warm salt oceanic water to the cold coast water. The curves of temperature and salinity between stations 69 and 70 go down straight like a wall—the well-known "cold wall" of oceanographers. Over the bank there is a surface layer, about 40 metres in depth, with a temperature of over 6°C., similar to what we get in the boreal portion of the Norwegian sea along the coast of Norway. Below that, however, the temperatures are under 2°C., and even as low as − 1·5°C., that is to say,

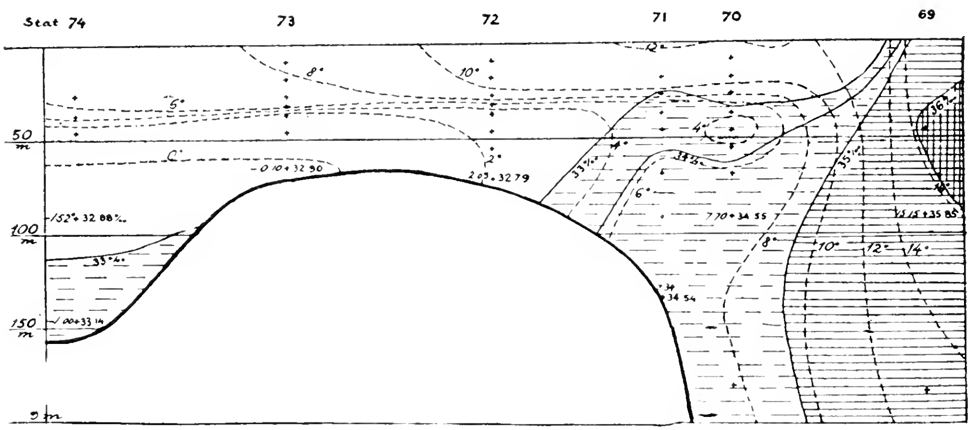

Fig. 3. Hydrographical Section across the Great Newfoundland Bank.

the water may be as cold as what Nansen found near the North Pole. Probably at no other part of the globe are there such peculiar temperature conditions—conditions comparable with those in the Arctic regions, though the latitude is the same as that of Paris. It would have been an agreeable task to trace these conditions by following up the currents and animal life, both northwards and southwards. Still, even our random investigations furnished interesting results. Thus we discovered that from station 70 to St. Johns there was the same northerly plankton already mentioned, and an examination of the young fish showed that they accorded with what had previously been found by Norwegian naturalists off the coast of Norway, and by the Danes south of Iceland.

"On the outer side of the coast bank, at station 71, we met with larvæ of red-fish (*Sebastes*). At station 72 there were cod-eggs and numbers of little cod-fry, besides fully developed eggs of haddock (*Gadus æglefinus*) and haddock larvæ, 3½ millimetres in length and upwards, and also young fish of the boreal long rough dab (*Drepanopsetta*). At station 73 we came across eggs of this dab (besides a number of eggs that we have not yet determined), and the shallow-water form *Ammodytes*. At station 74 there were neither eggs nor young fish.

"Similar catches are taken off the coasts of Norway and Iceland; near and just beyond the continental edge there are larvæ of red-fish, and on the bank, in 30 or 40 fathoms of water, there are larvæ and eggs of cod and haddock. It was interesting to find the eggs and larvæ of these fish at station 72, where the bottom-temperature was between 2°C. and 4·6°C., whereas nearer land, where the bottom-temperature was 0°C, or even less, they were absent."[1]

In 1915, I had the honour of being invited by the Biological Board of Canada to make a stay of some months' duration in that country in order to study the Atlantic herring fisheries of Canada; an invitation which I was extremely happy to accept. I could not, of course, hope to accomplish very much in so short a time, especially as I had no prospect of being able to procure the necessary means for practical research work at sea. The investigations of recent years, however, with regard to the growth of various species of fish—and particularly of the herring—had shown that it was possible, by studying the growth of the fish and age composition of the stock, as expressed in the annual rings of the scales, to form a remarkably close estimate, not only of the biology of the separate species, but also of the conditions in the sea wherein they occurred. It seemed to me, therefore, worth while to see whether such investigations, albeit here necessarily of an occasional and by no means final character, might not open up fresh points of view, and lead to further and more detailed study in the same field.

The main objects of such scale investigations should then, it seemed to me, be formulated as follows:—

1. Do the herring that visit the Atlantic coast of Canada all belong to a single race or type, or is it possible to distinguish several races in these waters?

2. Does the rate of growth vary according to the conditions of the waters along the coast? Can types of different growth be distinguished and defined?

3. Is the renewal of the stock of herring of a constant character, or are there the same great fluctuations in the stock, *i. e.*, in the number of individuals in the different year-classes, as in European waters?[2]

The first two problems, or groups of problems, are of course identical with the problems of the distribution and migrations of the herring. If the Atlantic stock of herring can be shown to belong to several different races, then of course the area of distribution and migration of each race or type may be defined by a study of samples of herring taken from different localities along the whole coast.

The third problem is of the greatest importance for any elucidation of the old riddle—the fluctuations in the yield of the fisheries—this being to a very great extent dependent upon the fluctuations in the number of herrings living in the sea at the time.

On arriving at Halifax, therefore, in October, 1914, I first of all endeavoured to organize a collection of material. I had no other means at my disposal than such as could be contained in the not very extensive luggage of an ordinary traveller, and it was thus useless to think of anything beyond samples drawn from the catches brought in by the fishermen themselves. In other words, my material would have to consist of salted herrings purchased from various localities. Thanks to the very kind assistance afforded me by the Biological Board, especially by the Dominion Commissioner of Fisheries, Prof. E. E. Prince, and by Prof. A. B. Macallum, Secretary-Treasurer of the Biological Board, who endeavoured by every means in their power to facilitate my researches, I succeeded in obtaining samples from various parts of the gulf of St. Lawrence, and from Newfoundland. It was necessary, however, to form some idea as to the representative value of the samples thus obtained, and with this end in view I made a journey along the coast, in the autumn of 1915, and over to Newfoundland, visiting the fishing stations, and taking every opportunity of ascertaining, by conversation with the fishermen, what kind of implements were employed for the capture of herring, and what experience the fishermen themselves had acquired as to the occurrence of the fish. In some places, I was able myself to study the fishing in progress, and examine the implements used. The fishermen everywhere, almost

[1] *Loc. cit.* p. 106, and following.

[2] See my paper: Fluctuations in the Great Fisheries of Northern Europe. Rapports et Procès-Verbaux, Vol. XX, Copenhagen, 1914.

without exception, use gill-nets with a certain fixed size of mesh ($2\frac{1}{2}$ to $2\frac{3}{4}$ inches). The nets are placed along the sea-bottom on the coast or in the bays or inlets along the shore. At no point is fishing carried on far out from the coast in deep water, or on the surface (by drift-nets or by purse-seines).

As pointed out in a preliminary report of my journey[1] "this particular method of fishing" naturally "has great disadvantages for the study of the life-history of the herring. The big meshes of the fishermen's nets can procure samples of the large mature herring only, and it is further quite uncertain whether the samples are in any way representative of even the mature shoals or not. It may be that the fishermen, through a long experience of fishing in these waters, have been able to adopt a size of mesh which takes practically all the sizes of mature herring visiting the coast, but only by means of experiments, carried out with gear taking all the sizes probably occurring, can this question be satisfactorily answered."

In the course of the winter 1914-15, I had now occasion to study the samples collected, primarily with a view to ascertaining how far it might be possible, with such material, to arrive at an understanding of, at any rate, some points in the natural history of the herring. The biological laboratory at the University of Toronto afforded me excellent facilities for this work, and it was there that I carried out the investigations referred to in my preliminary report above referred to.[2]

As will be seen from this, the samples collected distinctly showed that there are on the coasts of Canada types of herring differing widely one from another. The scales were eminently suited for investigation purposes in the case of all samples from the northern parts of the waters concerned, as, for instance, those from Newfoundland and gulf of St. Lawrence (e.g. Magdalen islands), whereas the samples from the west coast of Nova Scotia were far more difficult to deal with.

It was very interesting, at the outset, to find that samples from so small and restricted an area as the gulf of St. Lawrence should present such clear and definite differences in the manner of growth as those here found. The herring from the west coast of Newfoundland, for instance, were distinguished by a poor growth during the first years, and a long continued later growth, while those from the waters around Prince Edward island and the Magdalen islands showed considerable growth for the first years, followd by a more rapid decline in the annual increment. This difference was, moreover, strongly supported by the results arrived at on studying the age composition of the samples. The Newfoundland samples, both those from the autumn of 1914 and those from the spring of 1915, all showed a distinctly marked abundance of fish from the year-class 1904, whereas in the samples from the southern parts, a very different composition was apparent.

Some preliminary investigations as to the "racial" characters of the herring (number of vertebræ, keel-scales, etc.) revealed a state of things such as, in European waters, has only been observed in the Baltic and the White seas; that is, from enclosed waters with a very low winter temperature and low salinities. These racial investigations likewise tended to support the view obtained by growth investigations and study of the age composition, to wit, that real differences were discernible.

I had now succeeded in making clear, even with the primitive methods here employed, that the herring from the coastal waters of Canada differed widely as between one part and another of the region concerned. This result in itself must be regarded as of great importance, since it threw light upon the area of distribution (migration) of the herring, and paved the way for closer investigations in the future.

It seemed to me, therefore, desirable to endeavour to carry out more comprehensive investigations on a larger scale, throughout the whole of the waters in question,

[1] Investigations into the Natural History of the Herring in the Atlantic Waters of Canada, 1914. Supplement to the fifth annual Report of the Department of the Naval Service for the fiscal year ending March 31, 1915, Ottawa, 1915.

[2] *Loc. cit.*

and instead of restricting the work to a single species, and a single method of operation, to employ, as far as possible, most of the methods which have been developed in fishery investigations of recent years.

This proposal was most kindly received, by the Biological Board, in the first instance, and subsequently also by the Department of Naval Service, in particular by the Deputy Minister, Mr. G. J. Desbarats, himself keenly interested in scientific research. I therefore conferred with the Dominion Commissioner of Fisheries, Prof. E. E. Prince, and drew up, in collaboration with him, a programme of work. The idea was to collect, by short cruises made with vessels belonging to the Canadian Government, a quantity of material such as would serve to elucidate both the conditions with regard to marine currents, and the character of the fauna in the sea from Newfoundland to Halifax, and in the gulf of St. Lawrence itself.

There being no vessel in Canada specially built and equipped for fishery investigations, and the general tonnage available being much in demand for other purposes, it was necessary to confine operations to the carrying out of very simple investigations, comprising short cruises at times previously determined, and along certain definite routes. It was evident, moreover, that only the simpler forms of implements and apparatus could be used; for the hydrographical work, for instance, water bottles and thermometers, and for the fishery work, silk nets for studying the distribution of fish eggs and plankton. I considered it highly desirable to cover the same routes at least twice; once in the spring, at the time when the most important species of fish would presumably be spawning, and once later on in the summer, when we might hope to procure fish larvæ in the more easily recognizable stages.

Apart from the work on these routes, it seemed to me that we should also endeavour to carry out fishing experiments with a small steam drifter, the *No. 33*, belonging to the Government, and which had previously been employed for practical experiments. I hoped thus to obtain samples of another and more valuable sort than those taken from the fishermen's hauls, and also to ascertain whether herring could be taken with drift nets of different sizes, especially in the gulf of St. Lawrence.

The plan thus formed was most cordially and liberally adopted by the authorities concerned, and in the spring of 1915 we set to work getting together the requisite implements and apparatus. I was here fortunate in being able to procure the assistance of two of my former colleagues, Capt. Thor Iversen and Mr. Paul Bjerkan, with whom I had worked together for years past, and who now found time to come over for some months in 1915 and help in the work. With their aid, the following instruments and apparatus were collected.

(*a*) *For the hydrographical work:*

Six Nansen water bottles, made in Norway.

Ten Richter reversing thermometers from Schmidt and Vossberg, calibrated to 0·1° Centigrade, delivered by the International Hydrographical Laboratory at Copenhagen, which also provided us with two hand-winches, with wire and reels taking about 500 metres of wire of about 4 millimetres diameter. A meter wheel of the usual pattern for oceanographical research was used for determining the depths. Several water bottles could be used at the same time.

(*b*) *For the biological work:*

A large number of *Michael Sars* plankton nets of 1-meter diameter, and of the type found most suitable by the Norwegian Fishery Investigations. A description of this form of net will be found on p. 46 of my account of the cruise of the *Michael Sars* in the Atlantic in 1910[1]. Several of the nets were also furnished with closing mechanism, according to the model described by Nansen.

[1] "Depths of the Ocean."

(c) *For use on board the fishing steamer No. 33:*

A number of drift nets with different widths of mesh, with cable and buoys. A number of cod lines and other implements for capture of cod and other fish, as also a small shore seine.

At the commencement of May, 1915, I made a reconnoitering tour to Prince Edward island, together with my friend, Prof. Arthur Willey, of McGill University, Montreal, who, to my great satisfaction, had agreed to take part in the expedition. On our arrival there, on the first of May, the sea all around the island was still full of ice as far as one could see, and it was stated that the pack ice lay north of the island and round the Magdalen islands. This state of things lasted all through the week, until the 8th of May. We learned that the ice had set southward over toward Prince Edward island from the northern parts of the gulf of St. Lawrence. Northumberland strait and the Pictou coast were also blocked by ice, even the steamer connection having been stopped. The C.G.S. *Princess* twice attempted to force a passage through the ice in order to take Professor Willey and myself out on a preliminary survey cruise. At last she reached Charlottetown, and we started on the 10th of May for the Magdalen islands. We succeeded in taking some few stations, which gave some interesting material for the study of temperature conditions and the incipient development of the plankton, but the cruise was unfortunately interrupted, as the commander of the vessel, Mr. Wakeham, was taken very seriously ill, and had to be brought home.

By the middle of May a sudden change took place in the state of the ice. About the 20th of that month, the Halifax newspapers stated that the ice had been driven by northwesterly winds towards the Gut of Canso, and about the 25th, the remainder had either melted, or been carried out of the gulf. This state of things was generally regarded as unusual. Both on land and at sea the general opinion was that the ice should have been gone six weeks before. As it was, the delay produced its effect upon the fishing industry; the herring fishery round the Magdalen island was a failure, and the herrings taken came unusually late.

After this preliminary survey of the ground, a definite plan was drawn up for the work, the Canadian Government placing at our disposal the two cruisers *Princess* and *Acadia*, and the fishing steamer *No. 33*. The *Princess*, now under the command of Capt. J. Chalifour, vice Commander Wakeham deceased, was to make two cruises in the gulf of St. Lawrence: the first in June and the second in August.

The *Acadia*, under Commander F. Andersen, was to make two cruises, between the south coast of Newfoundland and Halifax, as nearly as possible coincident with the cruises of the *Princess*.

The No. 33, under Capt. Thor Iversen, was to carry out fishing experiments in the gulf of St. Lawrence, and, in addition, to make occasional hydrographical observations and collections of plankton. At Souris, P.E.I., a temporary laboratory was established, where the material from the cruises could be collected and subjected to a preliminary examination.

The scientific work on board the two cruisers was carried out by myself, with the assistance of Prof. Arthur Willey, Dr. A. G. Huntsman (University of Toronto), Curator of the Atlantic Biological Station of Canada, and, for a shorter period, of Mr. Nightingale of the United States Bureau of Fisheries.

All members of the expedition worked at the laboratory at Souris between cruises, and Mr. Paul Bjerkan, with Prof. James W. Mavor, now of Union College, Schenectady, U.S.A., were occupied there throughout.

The first voyage was made by the C.G.S. *Acadia*, which cruised from the 29th of May to the 4th of June from Halifax over the continental edge towards Newfoundland and the entrance to the gulf of St. Lawrence. In the course of this cruise, thirty-six stations were taken (*Acadia* stations 1-36).

From the 9th to the 15th of June, the *Princess* made her first cruise in the gulf, in the course of which twenty-three stations were taken (*Princess* stations 3-26).

These two cruises are charted in fig. 4, which thus represents the first investigations made in spring or early summer.

From the 21st to the 29th of July, the C.G.S. *Acadia* made her second cruise in the waters off the coasts of Nova Scotia and Newfoundland. This gave the *Acadia* stations 37-91.

Immediately after this, the C.G.S. *Princess* made her second cruise, from the 3rd to the 12th of August, in the gulf of St. Lawrence, with stations 27-50.

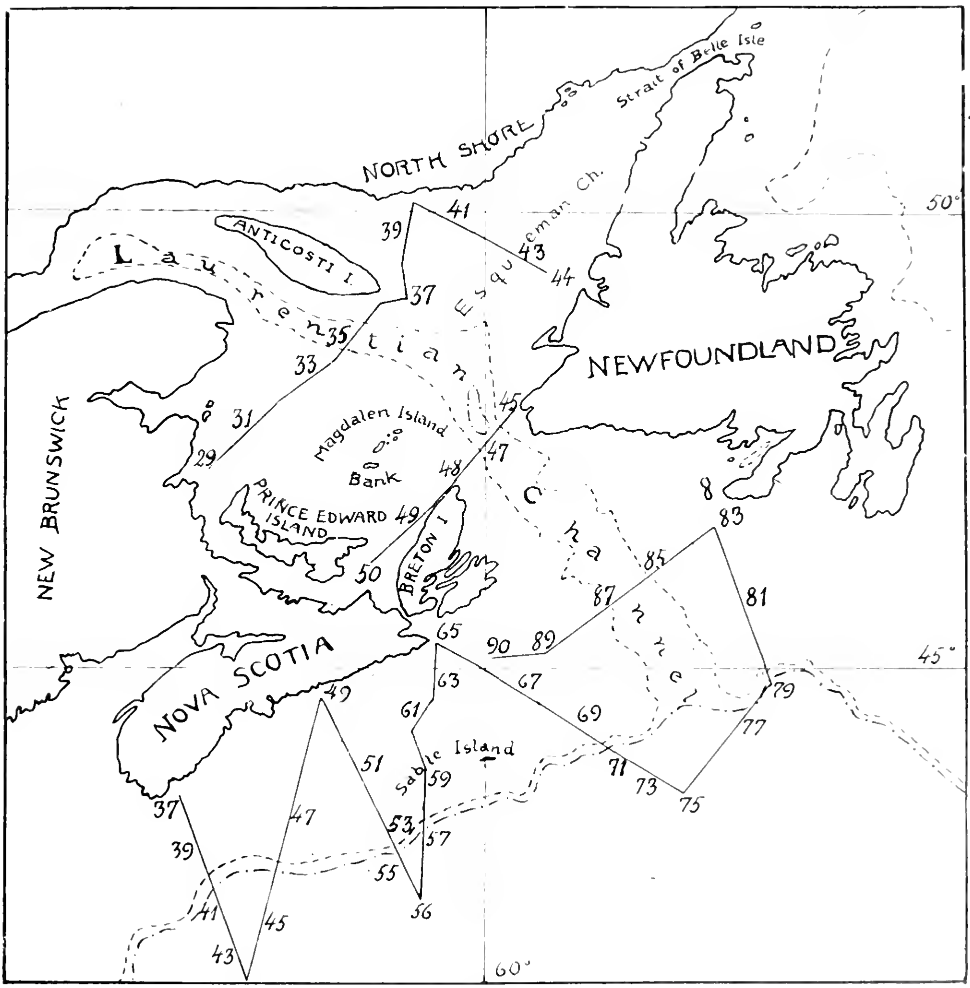

Fig. 4.

These two cruises are charted on fig. 5, which thus shows the investigations of the late summer period.

Throughout the whole of this time, the *No. 33* was working in the gulf of St. Lawrence, and collected there a considerable quantity of material.

Subsequently, also, it was found highly desirable to procure hydrographical observations from a later season of the year, and it was therefore a source of great satisfaction to me when Commander F. Andersen, who had taken the keenest interest in the investigations carried out on board, undertook to make a cruise off the coast of Nova Scotia later in the year. This was effected in November, the voyage occupying the time from the 14th to the 22nd of that month. The route followed will be found charted on fig. 8, p. 374.

These cruises yielded altogether a very large amount of material, the treatment of which naturally called for the services of several experts. Needless to say, I had looked forward to taking part in this work myself, but as it turned out I was pre-

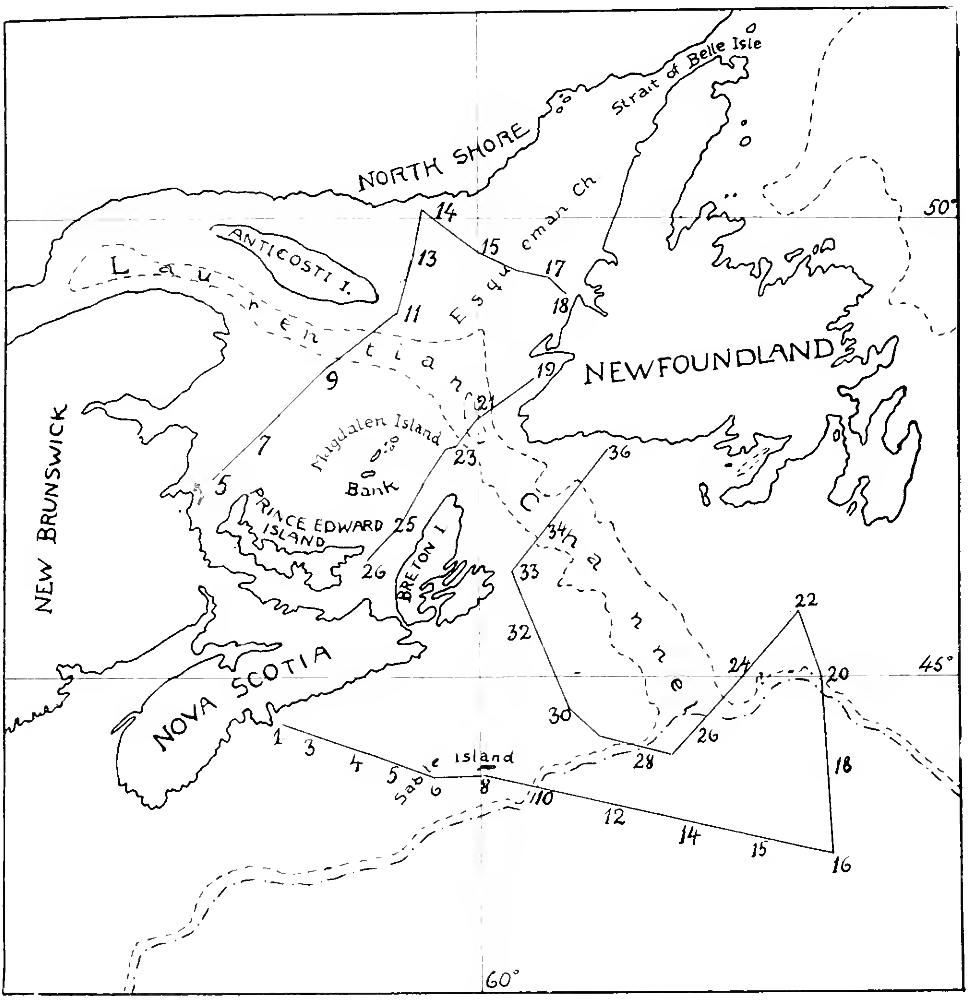

Fig. 5.

vented from so doing, as on my return to Norway in September, 1915, I found myself compelled to devote my whole time and energy thenceforward to the handling of important questions in connection with the Norwegian fishing industry, which in the autumn of that year was in a critical state. Under these circumstances, it was a great satisfaction to me to know that the material was to be dealt with by pre-eminently competent hands. A complete and exhaustive treatment of the whole of the material collected would, of course, be out of the question here, but the papers included in the present volume will yet suffice to give a survey of the most important results attained. The reader will here find:—

The hydrographical material dealt with in two separate papers. Mr. Paul Bjerkan gives (pp. 349-403) a survey of the distribution of salinity, temperature, and density in the waters covered by all cruises.

Then, on the basis of the data furnished by Mr. Bjerkan, Mr. J. W. Sandström has (pp. 221-341) subjected the entire question of dynamic conditions in the Canadian waters to a thorough and most valuable investigation.

The great mass of the plankton material could not, of course, be dealt with exhaustively here; to do so would, at any rate, have required a far longer time than that which has actually elapsed since its collection. It is the more fortunate, then, that Dr. A. G. Huntsman, in addition to his record of the hauls made (pp. 405-420) has found time and occasion to give an interesting example showing the occurrence of a single animal group in the material (Chætognaths: pp. 421-485). We have, furthermore, an extremely valuable contribution by Professor Willey, on the important group of the copepods, the distribution of which is here dealt with by a method now applied for the first time (pp. 173-220). On most of the cruises, in addition to the net hauls, water samples were preserved for subsequent study of the pelagic plants, which are dealt with by H. H. Gran, according to methods developed by himself. Professor Gran's paper will be found on pp. 489-495.

Under the heading of plankton, also, we must of course reckon the pelagic fish eggs, which form the most important group of all from a fishery point of view. These are dealt with by Mr. Alf. Dannevig, and the distribution of these forms in the Canadian waters is here described for the first time.

Of the considerable material dealing with the biology of the fishes concerned, we have up to the present only been able to complete the report concerning the growth and age of the herring, composition of the stocks, migrations, etc. Mr. Einar Lea has in his paper (pp. 75-164) not only treated the whole of the available material—and this far more exhaustively than could be done in my preliminary report above mentioned—but has also furnished a general introduction to the methodical aspects of herring investigations on the whole, and to the study of the problems which can now be dealt with thereby. Mr. Lea's paper, like that of Mr. Sandström, will be found to afford a guide to the study of these questions applicable in itself to far more than the restricted and particular sphere embraced by the actual investigations concerned in each case.

A contribution to the study of the younger year-classes of herring from the southern part of the Canadian waters, the Bay of Fundy, is given by Dr. A. G. Huntsman (pp. 165-171).

I venture to hope that the work thus produced may, albeit by no means exhaustive or altogether comprehensive in itself, yet serve in principle and by example to pave the way for further research, and awaken new interest in the study of these Canadian waters, which offer such remarkable and valuable features for investigation. I trust, also, that the scheme of work laid down, and the nature of the material thereby procured, for which I am of course responsible, may prove to be justified by the results attained. It might seem tempting in various ways to endeavour to collect the various separate investigations here given into a single whole. I have refrained, however, from any attempt at so doing, partly because it is perhaps too early as yet to think of this, and partly also because I myself would infinitely rather that the reader should have the advantage of consulting the excellent reports themselves, not a mere extract of the same.

On the other hand, it will doubtless be advisable to give here, in the form of introductory remarks, some general idea of the principles followed throughout the cruise, with some reference, also, to the experience gained in the course of the actual work on board, which will best explain the particular manner in which the researches were carried out.

THE HYDROGRAPHICAL INVESTIGATIONS.

A description of the submarine physiography of the Canadian waters has been given by J. W. Spencer (see chapter IX of Sub-oceanic Physiography of the North Atlantic Ocean, by E. Hull, London, 1912, and Bull. Geol. Soc. Amer. vol. XIV, 1903, p. 207), of which a brief summary is given by Dr. Huntsman (p. 479 and following pages) which latter I will draw upon here, as it affords an excellent introductory view of the waters investigated.

As will be seen from Mr. Sandström's chart (pl. 1), the continuation of the St. Lawrence river forms "the submerged Laurentian valley cutting across the middle of the St. Lawrence gulf, and passing through Cabot strait and between St. Pierre bank and Banquereau. We have referred to this as the Laurentian channel. Another channel, the Cansan, cuts through between Sable Island bank and Banquereau. Farther to the south is the Fundian channel, passing out from the Bay of Fundy and through the gulf of Maine. These three channels delimit two portions of the continental shelf off Nova Scotia. That to the north, between the Laurentian and Cansan channels, includes the Banquereau, Misaine, and Cansan banks, and may be called the Breton portion of the shelf, or the Breton bank, since it lies off Cape Breton island. The southern part lies between the Cansan and Fundian channels, and includes La Have and Sable Island banks. It may be called the Scotian bank, since it lies against the main portion of the province of Nova Scotia.

"In the St. Lawrence gulf we have, to the north of Anticosti island, the Anticostian channel, and running north towards the straits of Belle Isle, the Esquimau channel. To the south of the Laurentian channel, in the gulf, is an extensive submarine plateau, with, for the most part, less than 30 fathoms of water covering it. Cropping up from it are the Magdalen islands and Prince Edward island . . . . We have referred to it as the Lower Gulf region. It might be called the Magdalen bay."

Prior to the cruises described in this volume there existed a series of excellent hydrographical investigations carried out by Dr. W. Bell Dawson, published in the reports of the Tidal and Current Survey of Canada for the years 1894 to 1913. Dr. Dawson made determinations of specific gravity (density), and also some temperature measurements. He has described the current of fresher (lighter) water layers which spreads from the St. Lawrence river along the Gaspé coast and out over the Magdalen bay, as above defined. This current, called the Gaspé current, runs farther out along the south side of Cabot strait as a Cape Breton current.[1]

From the sea outside another current makes its way into the gulf along the north side of Cabot strait off cape Ray, spreading out along the north side of the gulf. Outside the gulf, the water was far less known. As pointed out by Dr. Huntsman, there was known to exist "a slight westward tendency on the southern coast of Newfoundland, and a southwestward drift along the outer coast of Nova Scotia."

In the gulf of Maine, on the other hand, the currents have been more thoroughly investigated: there are, as we know, the excellent investigations of many years carried out by Dr. H. B. Bigelow in these waters. Before commencing the present researches, as also during the progress of the same, and afterwards, I had frequent opportunities of discussing with Dr. Bigelow himself, the questions involved, and I may say that the present work has greatly profited thereby.

The first cruise made in connection with the present investigations was, as mentioned above, that of the C.G.S. *Acadia*, from the 29th of May to the 4th of June, 1915. The vessel started from Halifax, the primary object being to take a section of the westerly drift off the east coast of Nova Scotia, and determine the volume of the mixed layers between the coast and the warmer water of the open ocean. The reader will best be able to follow the course of this cruise by referring to Sandströms figs. on

[1] For a closer study of the hydrographical features in detail, it will be better to consult Mr. Bjerkan's sections and tables (pp. 379-403).

pls. 2, 4, and 6, where the sections of the spring hydrographical cruises are drawn *in situ*. On examination of these, it will be seen that the first observations immediately revealed the existence of a distinctly marked light coastal layer with low temperature. At the outermost station (section V, 16) the warm and salt ocean water was encountered. In the course of the cruise two pronounced temperature minima (below 0° C) were met with, one off Halifax and one off the Continental Shelf. In the latter case, the temperature at 75 m. depth reached the extremely low figure of −1·7° C. (Acadia station 12).

It was obvious, of course, that the former of these two minima must be due to a cold (and fresher) current from the gulf of St. Lawrence, while the other would presumably be the last outpost of the cold Labrador current, already encountered by the *Michael Sars* in 1910, and here shown in the section, fig. 1, as mentioned in the foregoing.

It therefore seemed to me imperative to shape a course up towards the banks south of Newfoundland, in order to rediscover this water layer, if possible. This we succeeded in doing (see Sandström's pl. 4, sections VI and VII, stations 21-25), finding the sea floor on the banks covered with a cold layer, the temperatures going right down to −1·4° C (station 24), or about the same figure as found by the *Michael Sars* in July, 1910, off St. John's Newfoundland.

This point being thus disposed of, the sections VIII and IX were then taken, with a view to obtaining good sections both of the water pouring into and out of Cabot strait, and of the connection between the outward current from the gulf of St. Lawrence and the westerly drift off Halifax. Sandström's pl. 4 shows at a glance how the temperatures alone suffice to reveal the connection between the cold water layers from the gulf round cape Breton and along the coast of Nova Scotia. Furthermore, we notice the inflow from the Newfoundland area into the gulf, along the north side of Cabot strait; and finally, the sections also indicate the connection between the cold Labrador water and the temperature minimum off the Continental Shelf on the outer side of the Sable Island bank.

From the 9th to the 15th June, or only five days after the conclusion of the *Acadia's* cruise, the C.G.S. *Princess* set out to continue the investigations in the gulf of St. Lawrence. Here, two large sections were made across the well-known Gaspe current, as also one section from the north coast of the gulf to Bay of Islands. Pl. 4 shows distinctly the fresher surface layers in Magdalen bay, and along the north coast, while the eastern part of the gulf has a higher salinity at the surface. It is interesting to follow the high salinity from the open sea all through the Laurentian channel in towards the mouth of the St. Lawrence river. The temperatures (Sandström's pl. 6) show that the lower figures, under 0° C. represent a great intermediate layer covering the chief banks in Magdalen bay, off the north coast, and off the western shores of Newfoundland. These points are of the highest importance to the study of all biological questions.

These cruises had thus showed that it was possible to obtain good sections of the principal currents, and the plan here followed was therefore, in essentials, taken as a basis for the later summer cruises.

A similar rapid survey of these is best obtained by referring to Sandström's pls. 3, 5, and 7, and comparing the same with those for the previous cruises (pls. 2, 4, and 6).

It will soon be apparent that the quantity of fresh water has now considerably increased, especially on the Gaspé coast, and in the mixed layers, which are essentially fresher even far out at sea. A comparison of the two plates 6 and 7 very clearly shows the same thing. On the other hand, the saltest water which lies deeper down seems to have risen considerably, a feature which calls to mind the fundamental investigations of Patterson and Ekman in the Skagerak on the European side, resembling in many respects these Canadian waters. The figures for temperature naturally exhibit a marked increase on the surface, and a reduction in the thickness of the cold intermediate layer. Even in the first half of August, however, considerable areas on the banks in the gulf of St. Lawrence were found to be covered with water colder than 0° C.

As will be seen from these brief remarks, we had now succeeded in procuring a material which enabled us to measure the thickness of the various water layers by sections taken transversely to their direction of movement, and this in the shortest possible time. We had furthermore been able to repeat such investigations at a later period. This furnished us with the basis for a theoretical treatment of the material, and an analysis of the influence exerted by the various factors: the earth's rotation, melting of the ice, specific gravity, temperature, etc. In Mr. Bjerkan's paper, the reader will find all the precise data concerning the values for salinity, temperature, and density. And Mr. Sandström has endeavoured, on a wide scale, to give a thorough analysis of the causes conducive to the circulation of the water as a whole, and its dynamics generally. This is, as far as my experience goes, the most thorough treatment of these questions which has yet appeared.

We are now brought face to face with a great number of most interesting problems for future hydrographical investigations.

In the first place, it would be well to ascertain what fluctuations may occur from the conditions found to prevail in 1915. What variation can take place, for instance, in the amount of fresh water discharged by the St. Lawrence river, in the Gaspé current, in the interchange of water between the gulf of St. Lawrence and the area outside, in the great cold intermediate water layer, in the Labrador current, and in the distance of the warm ocean water from the costal banks? All these questions will naturally be of the highest importance in the study of biological problems, chiefly, perhaps, the varying distribution of the cold water layers. A particularly interesting feature is the remarkable wedge of the very coldest salt water off the Continental Shelf (*Acadia* station 12). Can this current penetrate still further southward in the spring, and can this be the great cause of the death of multitudes of fish, occasionally observed in the sea off the east coast of America? Bearing in mind the state of things in the North-European waters, as revealed more especially by the Swedish investigations, there is good reason to believe that the fluctuations in the Canadian waters will likewise prove to be of very considerable extent.

Sandström's investigations revealed various possibilities for a further comprehension of hydrodynamics in the sea. I would here more particularly call attention to his suggestions as to the study of submarine waves, where fresher layers encounter the mighty wall of the saltest Atlantic water, or in the intermediate layers in the gulf of St. Lawrence, or in the current movements of the deeper layers, as, for instance, those in the Laurentian channel.

PLANKTON INVESTIGATIONS.

The scientific, and particularly the quantitative study of plankton in the sea has long been a subject of discussion giving rise to widely divergent views. Hensen and his followers have emphatically maintained that only quantitative investigations could lead to results of any scientific value, and that the methods developed by Hensen himself afforded satisfactory means of ascertaining the quantitative occurrence not only of separate species, but also of the total plankton in a column of water corresponding to the range filtered by the Hensen net from bottom to surface. Other investigators, again, were indisposed to bind themselves to such methods of research, or to accept the given formulation of the problem. It has been pointed out, for instance, that the method in question was not altogether satisfactory in itself, as the nets did not by any means take the entire plankton content—i.e., all the forms represented—in the column of water through which they were drawn. And it has also been demonstrated beyond question that many forms passed through the nets, while the larger ones managed to avoid them. Moreover, it has been maintained that both the term "plankton," and the idea of a vertical haul were calculated to obscure the true nature of the proposition. The conception of vertical hauls through the whole column of sea water, under one square meter of surface, is undoubtedly derived from the simpler process of soil valuation on land, but the knowledge gained as to the circulation of sea water, with its surface, intermediate, and bottom currents, and the highly fluctuating velocity of the same, militates very strongly against the acceptance of the vertical haul as a universal means of estimating quantitatively the production of floating organisms in a given area.

For the present, then, as long as we still lack a clear and indisputable analysis of the great group of problems actually involved by the questions raised, and have yet to find satisfactory methods of research for approaching the same, it would surely seem far better to content ourselves with studying the geographical (qualitative and quantitative) occurrence of certain definite forms, applying in each particular case the methods best suited thereto. This view has previously been advanced by the present writer [1] and by Prof. H. H. Gran. We pointed out that a quantitative estimate of the plankton in a water layer should at any rate be based upon a combination of samples drawn from horizontal layers which must themselves be defined as closely as possible, and their physical and chemical conditions investigated at the same time. In the case of the animal forms, several methods have been tried in connection with such horizontal hauls. From time to time, there have been constructed more or less adequate plankton nets, which could be opened and closed at certain depths, and indicate what water they had fished, but the methods hitherto employed can hardly be said to fulfil the claims of absolute accuracy in these respects. My own personal view has always been, that it is unjustifiable to attempt a task which the methods of work available do not suffice to accomplish, and that it is therefore better to recognize the restrictions imposed by the fact, and aim advisedly at results which shall be approximately valid for certain selected forms. On the *Michael Sars* expedition in 1910, I found it most practical, and therefore most effective, in the case of the fishes, to tow nets through the water at different depths, and then endeavour to ascertain the catch made at a given depth by statistic treatment of the yield. (*Vide* "Depths of the Ocean," pp. 615-617.)

Only in the case of the vegetable plankton have we an altogether satisfactory method of work, viz., that of H. H. Gran. Professor Gran was able to show, that by preserving water samples (with Flemming's liquid) and subsequently centrifuging them, we can obtain material sufficient for quantitative determination of the entire vegetable plankton in the sample. Gran has by this means, as we know, succeeded in obtaining the first real view of the true plant production of the sea,[2] his experiments being carried out in European waters (the Skagerak) which in so many respects resemble the Canadian. At most of our stations, plankton samples were collected according to Professor Gran's method, and the material is dealt with by Gran in his paper here given (p. 489.)

The paper in question throws light upon some extremely important sides of the natural history of plankton. As will be apparent from the work itself, the Canadian plankton reveals marked resemblances to that of the European waters. It differs, however, in the common occurrence of typical arctic forms, corresponding of course, to the very low temperatures prevailing in the gulf of St. Lawrence during winter in all the upper water layers, and in summer throughout the great intermediate layers. A point of great importance for all conditions of growth in the Canadian waters is the fact demonstrated by Gran, that the development takes place much later in the year there than in the waters of northern Europe. This naturally agrees with the fact that the gulf of St. Lawrence was full of ice until nearly the middle of May—and it is interesting to note, in this respect, that while the growth of the herring in the far more north-

[1] See, for instance, "Depths of the Ocean," pp. 771-785.
[2] H. H. Gran. The Plankton Production of the North European Waters in the spring, 1912. Bulletin Planktonique pour l'année 1912 publié par le bureau du Conseil Permanent International pour l'exploration de la mer. Copenhague, 1915.

erly Norwegian waters commences in April, that of the herring in the gulf of St. Lawrence does not begin until June; in the case of a single sample, indeed, not until July. In Lea's paper, also, pp. 158-159, it is pointed out that a similar late growth is known from the Baltic, near the coast of Finland—a further example of the similarity between conditions in the gulf of St. Lawrence and those of European bays.

In considering the collection of animal plankton, there are certain points which should be borne in mind.

For carrying out the cruises above mentioned, I could only reckon on having the two vessels, *Princess* and *Acadia* at my disposal for about a month, or, to be precise, for thirty-three days in all. In order to cover, within this short period, a sufficiently large expanse of water to give a real survey, it was necessary to arrange beforehand for the quickest possible method of work, making only a short stay, for instance, at each station. This was the more imperative, since the frequently boisterous or foggy weather compelled us to allow a margin for delay, though, as it turned out, we met with no serious difficulties in this respect.

Moreover, the two vessels, not being built specially for the purpose, could naturally not offer ideal facilities for plankton work. The *Michael Sars,* as described in the "Depths of the Ocean," lies low in the water, and can be easily manœuvred against the wind, so as to keep the line of a net vertical in the water; our vessels here, on the other hand, with their higher freeboard, could only take their stations by lying transversely to the direction of the wind, which often rendered it difficult to get vertical hauls.

Owing to these circumstances, the hauls made are by no means all that could be desired, especially from the point of view of the Hensen school. The critical remarks proffered by Dr. Huntsman in his notes on the list of hauls in the present volume (pp. 407-420) are therefore entirely justified from this point of view, and the quantitative figures for volume are really only of value to a limited degree—more limited, in the present case, than such figures otherwise would be in themselves. They are given here, nevertheless—albeit, as mentioned, with all reserve—because, to those who are themselves acquainted with the fluctuating quantity and quality of plankton generally, they will be of interest as affording some idea of the order of magnitude in the present samples. And in connection with subsequent collections, taken for instance at other seasons and in other years, as also for further treatment of the material, the figures in question will doubtless be of some importance after all. They also serve to indicate approximately the extent of the collections from which the different groups of material treated separately in the special sections were drawn.

In the case of larger, rarer, and more conspicuous forms, such as fish eggs, fish larvæ, Chætognaths, treated in the present volume, we endeavoured as far as possible to count, treat, and examine *all individuals in the samples.* In such treatment it is always more or less interesting to note the size of the samples, and the depth in which the numbers of individuals found were obtained. For forms of less frequent occurrence, also, the quantitative approximation is perhaps also satisfactory, but gives, of course no information as to the interesting question of the precise depth at which the individuals concerned actually were taken.

The study of fish eggs and fish larvæ gave rise, during the progress of the cruises themselves, to a series of most interesting and important questions.

On the first cruise of the *Princess* in the gulf of St. Lawrence, (May 29 to June 4), we encountered a characteristic occurrence of eggs of Gadoid species, in particular of the cod proper, and of the flatfish *Drepanopsetta* (*Hippoglossoides*) all over the banks, i.e., in what we have called Magdalen bay, at Anticosti, along the north shore, and off the west coast of Newfoundland. Besides these greatly predominating species, we found on the banks only eggs and a few larvæ of arctic species (*Anarrhichas latifrons, Mallotus villosus, Icelus,* and *Agonus decagonus.* At the southernmost stations, we found at Cabot strait the first mackerel eggs, and above the deep Laurentian channel—and nowhere else—considerable quantities of *Sebastes.*

These finds led me to expect that we should, on the later summer cruise, encounter quantities of larvæ of the species in question. To my surprise, however, this cruise likewise yielded hardly anything beyond cod eggs and *only a very few larvæ indeed.* A characteristic feature, also, was the fact that we found arctic forms (*Mallotus*) in the northern part of the gulf; eggs and larvæ of southern forms (*Ctenolabrus*, mackerel) in the southern part, with *Sebastes*, as before, sharply limited to the waters immediately above the Laurentian channel.

Outside the gulf we found, on both cruises of the *Acadia*, a scanty occurrence of cod eggs. Beyond this, I will here only mention a considerable occurrence of *Merluccius* in this water, and Scopelids out on the edge; these last affording sufficient testimony that the investigations had covered the whole breadth of the coastal zone.

The most remarkable point in connection with these hauls was the extreme paucity of the older egg stages, and of all larval forms. It was therefore necessary first of all to study the ratio between eggs and larvæ in our present material, and to compare the same with what was known from other waters in this respect. Mr. Dannevig's paper gives a critical treatment of this question, and it will be noted, that, as he expresses it (p. 44) "the gulf of St. Lawrence is considerably behind the other localities with respect to the occurrence of later stages, both in the case of the earlier investigation and those made subsequently (*Princess I*, *Princess II*, and *No. 33*). The ova have evidently a far poorer chance of being developed and hatched than in other places." The few experimental hauls made by the *No. 33*, and the information gleaned from fishermen in conversation also confirmed the view that in the gulf of St. Lawrence, very few young fish of any species are known to occur at all. The question is, of course, of vital importance for the study of the stock of fish in the water. How, then, are we to explain the facts as they appear?

The results of the European fishery investigations lead apparently to the conclusion that all boreal forms of food fish are restricted to water with positive temperature, rarely occurring, indeed, in water under 2° C. In the Arctic ocean, the Greenland sea, and the deepest part of the Norwegian sea, where the temperature varies from 0° to – 1·5° C, only arctic forms of fish are found: here, however, in the gulf of St. Lawrence and on the Newfoundland banks, we encountered masses of cod eggs floating in and immediately above thick water layers colder than 0°, even below —1° C. Our fishing experiments, with hand lines, for instance, had showed beyond any possibility of doubt that the cod themselves really were to be found in this cold layer, which immediately covers the sea floor, while this water contained the very youngest stages of spawned eggs, but hardly any of the older stages at all. Were we then to suppose that these millions of fish were here spawning under conditions which doomed their milliards of eggs to destruction? Naturally, the question could not be answered by means of such investigations as those upon which we were then engaged: to do so would have required a vessel, say like the *Michael Sars*, able to devote itself entirely throughout a whole season to all kinds of work in the water concerned. Hatching and cultivation experiments would be necessary, as also intensive experimental fishing for young stages, etc. Failing all this, and wishing to throw some light upon the problem, if possible, I applied to Prof. August Krogh and Dr. A. C. Johansen, of Copenhagen, with a request that they would institute experiments in order to ascertain whether cod eggs from Danish waters could be satisfactorily spawned and hatched out in water of such low temperature. The results of the experiments made by these two gentlemen are quoted in Mr. Dannevig's paper, and it will be seen that they give no grounds for supposing that the temperature alone should offer any hindrance to the development of the eggs.

Again, it might be supposed that the cod eggs were carried out from the gulf, *en masse*, as is known to be the case in European waters, where they are transported by the movement of the water to a great distance from the spawning grounds. The hydrographical papers in the present volume, as also Dr. Huntsman's plankton report, contain numerous facts pointing very markedly in this direction. It is impossible, however, from the present investigations, to come to any final decision here, but the work done has certainly raised questions of the greatest importance for future Canadian fishery investigations.

These waters are, of course, extremely interesting from the most general biological point of view. We find here, in one and the same area, and with only a water layer of a score of fathoms between, cod spawning on the floor of the banks, in water of absolutely arctic temperature, while at the surface, directly above, spawn southern forms such as the mackerel, which have possibly migrated from the water layers just off the Continental Shelf where the last remains of the Sargasso weed are still to be found. And a single haul at the surface will be seen to contain pelagic eggs of both these species of fish.

Of the remaining plankton, only two groups have been dealt with up to the present, viz., the Chaetognaths, by Dr. A. G. Huntsman, and the Copepods, by Prof. Arthur Willey. These two studies afford, however, in themselves, excellent examples of what plankton investigations can yield in the way of results, and of the methods which must doubtless best be employed until better implements are available for quantitative study. Of the comparatively large and not so very numerous Chaetognaths, Huntsman has given estimates for the total number of individuals in the samples. In the case of the small and numerous Copepods, this was impossible, and the method here adopted was therefore to determine, from a small selected sample, the percentage of composition represented by the separate species. In the case of some few more important forms (especially *Calanus finmarchicus*), Willey has given also the percentages of the various principal stages of development in the sample.

Thus the two papers illustrate the occurrence of various biological types, viz., those pertaining to the oceanic water of the Atlantic, those of the colder boreal water layers, and finally those of the fresher coastal layers. And a study of these plankton reports, compared with those of the hydrographical work, will give an idea of the marked agreement between the distribution of the animal forms concerned and that of the various water layers.

The results of the fishery investigations proper, i.e., investigations as to the actual life and occurrence of the fish themselves, cannot yet be given in their entirety, as the treatment of part of the material is not yet concluded. Up to the present, we have only Mr. Einar Lea's description of all the herring samples; this section is, however, after all, the most important part of the work from a biological point of view, and the primary object of the expedition is thereby attained.

Mr. Lea has in his paper given a thorough explanation of the methods employed in age and growth determinations, based on examination of the scales, and the work will therefore, it is hoped, prove useful in future Canadian fishery investigations.

For the rest, I would merely point out that Mr. Lea's careful researches have satisfactorily demonstrated what the results of my preliminary investigations had already indicated, viz., that there are in the Canadian waters *distinct types of herring*, excellently characterized by their *manner of growth* and the *difference in age composition*. His thorough treatment of the material likewise shows that the various areas exhibit the same peculiarity as has been found so markedly apparent in several European (and especially Norwegian) waters, to wit, the pronounced fluctuation in the increment of young individuals from year to year, whereby the age composition of the stock reveals an enormous predominance of some few extremely rich year-classes, while others hardly contribute in any appreciable degree to the numerical value of the whole. The conclusions here arrived at, regarded together with the like results which are becoming, apparently, more and more common in various spheres of biological research, force us to admit that hitherto prevalent views not only on leading fishery questions, but also of general biological problems as to the maintenance of species, and all that is comprised in the old Malthusian ideas, will need to be essentially revised.

CANADIAN FISHERIES' EXPEDITION, 1914-15

BIOLOGY OF ATLANTIC WATERS OF CANADA

CANADIAN FISH-EGGS AND LARVÆ

BY

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CANADIAN FISH-EGGS AND LARVÆ

I. INTRODUCTION.

When Dr. Hjort invited me to undertake the work of dealing with his valuable material of fish eggs and young from the Canadian waters, I was fully aware of the many difficulties which the task would involve. The determination of ova and young from a quarter of the globe where many species of fish exist, whose young stages have not been described, is naturally no easy matter, more especially when only preserved material is available, and it will, as a rule, be obvious from the outset that complete success must be out of the question. The object of the Canadian investigations was, however, principally to ascertain the biological conditions under which the most important species of fish lived and multiplied, so that possible errors in the determination of some few of the less frequently occurring species would be of minor importance. In view of this fact, and with the promise of every assistance from Dr. Hjort and Magister Koefoed, I undertook the task, all difficulties notwithstanding.

As to how far the determination of species has been successful, it is naturally impossible to say at present; future investigations of the same waters will, in all essentials, make this clear. I have thought it proper, however, here to make a few introductory observations as to certain particular difficulties which may be imagined as having given rise to erroneous determinations.

The transatlantic literature on the subject being somewhat scanty, I have had recourse more especially to descriptions of European species, and it might therefore seem not unlikely that related western forms could have become confused with or mistaken for these; but regarding the young of species found on both sides of the Atlantic, however, and where good descriptions of the young stages are available, this source of error does not apply.

A considerable number of forms have been drawn with great accuracy by Mr. Rasmussen, these including both species previously described and drawn, and also other lesser-known species. I have not thought it advisable to give any description of such forms on the basis of the preserved material, more especially since this would lie outside the scope of the present work.

As regards the determination of the ova, this is naturally more or less uncertain, since the eggs of many species are indistinguishable one from another until the embryos are well developed. In some few cases, on the other hand, the ova may be accurately determined from the time of spawning. It will, moreover, be justifiable to presuppose relation between ova of like appearance in one and the same sample, where some are newly spawned and others with the embryo sufficiently developed to permit of certain determination.

The present material of ova and young was collected by means of a silk net (1m. diameter) and preserved in 4 per cent formol. The duration of the surface hauls varied somewhat, as a rule between ten and fifteen minutes; the depths, as stated for the vertical hauls, are also in some cases only approximately correct, owing to difficulties in the working of the net.

Similarly, the records as to quantity should not be taken too strictly, these being for like reasons only approximate figures. The proportional quantitative values, however, as between eggs at different stages of development, may be taken as fairly reliable.

The material was collected in the course of five different cruises, of which two made on board of C.G.S. *Acadia* covered a zigzag course between the southern point of Nova Scotia and Newfoundland, the first extending from May 29 to June 4, the second from July 21 to July 29.

In the gulf of St. Lawrence, two cruises were made with the C.G.S. *Princess* from June 9 to June 15 and August 3 to August 12; here also, the SS. *N° 33*, in addition to its ordinary fishery operations, collected a number of samples during the period from June 1 to August 18.

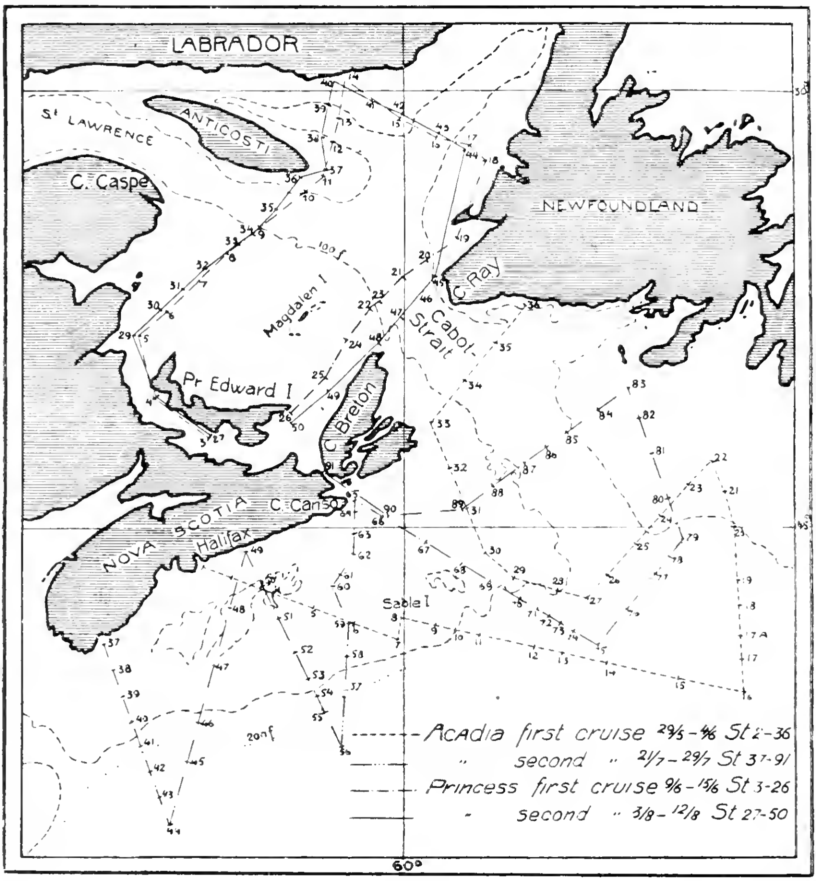


Fig. 1.

Before proceeding to the treatment of the material, I should mention that a quantity of ova and young had already been determined by Dr. Hjort in Canada, while Mr. Koefoed also has kindly determined a number of Atlantic fish, and has further assisted me in doubtful cases with other forms.

II. THE MATERIAL COLLECTED.

In the plankton samples, ova and young of thirty-six species of fish have been determined, representing twenty families in all.

The species will be dealt with in the following pages in systematic order, having regard to their occurrence within the area investigated, their geographical distribution generally, and certain features in their biology and reproduction.

1 *FAM. LABRIDÆ.*

Ctenolabrus adspersus (Walbaum).

(Plate II, Figs. 1 and 2; Table IIa.)

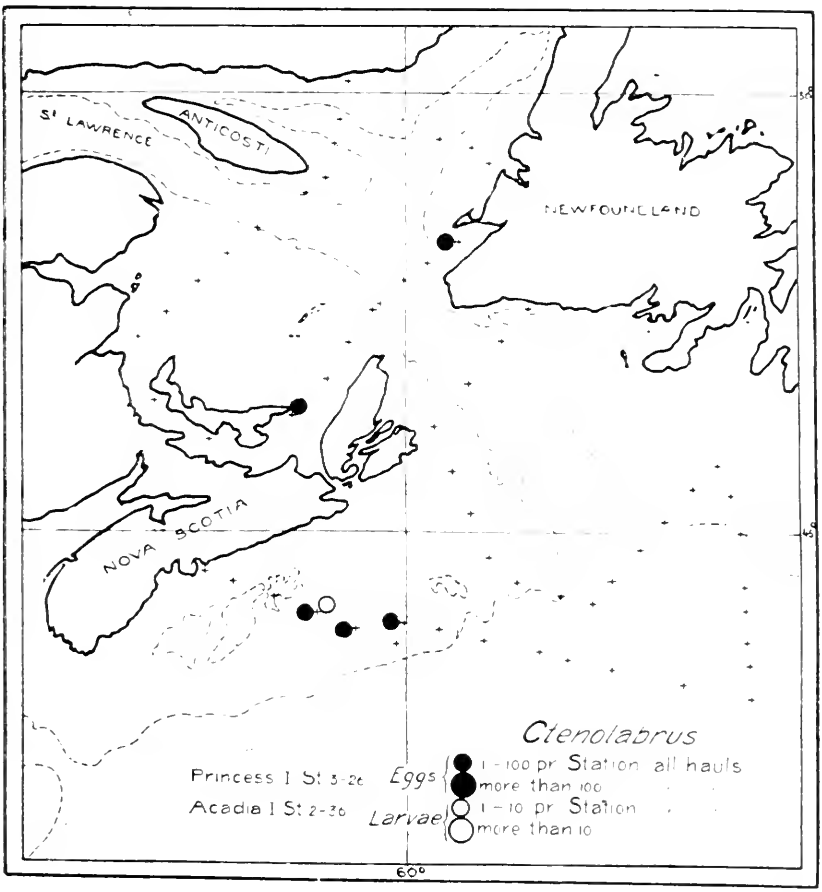
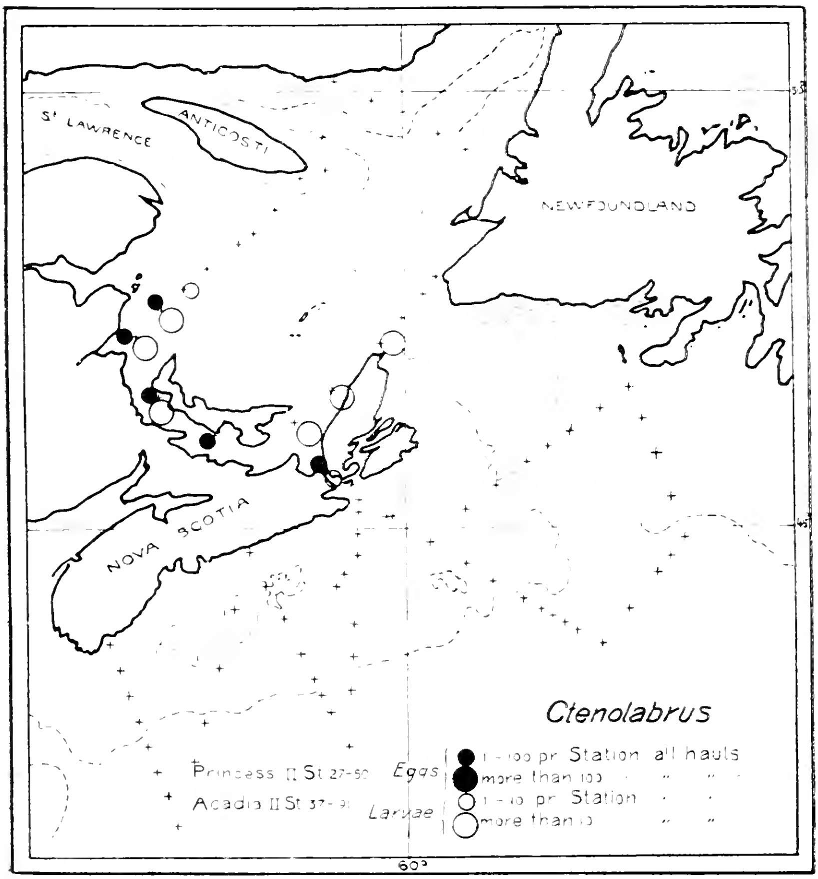


Fig. 2



Sᵗ LAWRENCE
ANTICOSTI
NEWFOUNDLAND
NOVA SCOTIA
Ctenolabrus
Princess II St 27-50
Acadia II St 37-91
Eggs
Larvae
1 - 100 pr Station all hauls
more than 100 " " "
1 - 10 pr Station " "
more than 10 " "
60°

Fig. 3.

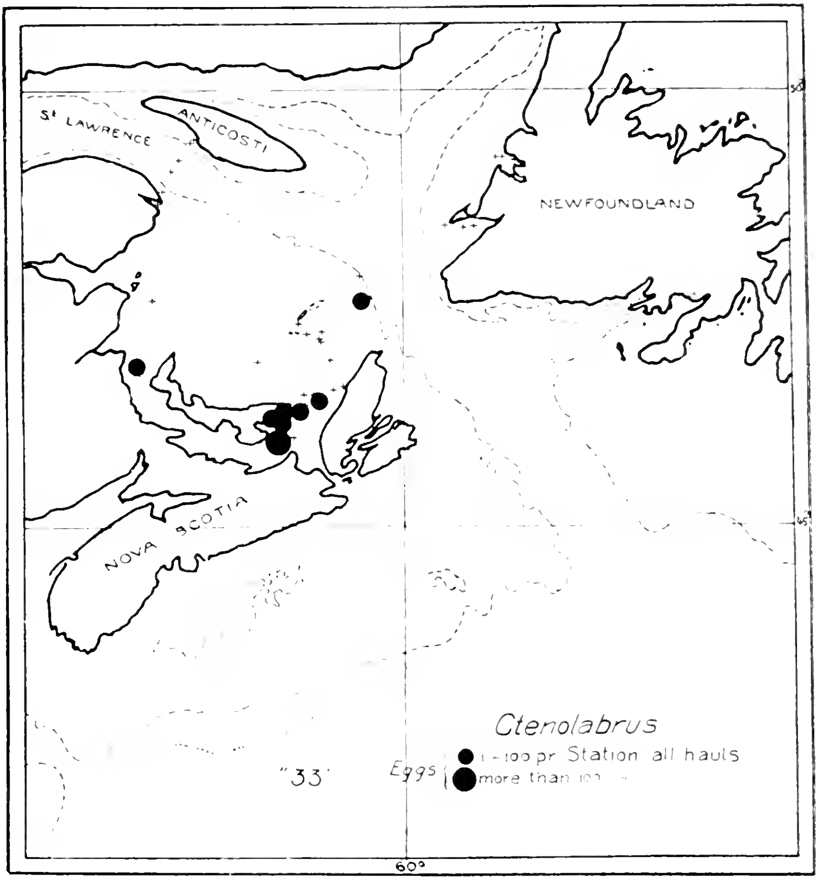


Fig. 4.

The young stages of this species have been shown by Agassiz (On the Young Stages of some Osseous Fishes, Part III, *Ctenolabrus coeruleus* DeKay, pl. XIII, and XIV). I have not, however, been able to identify the species with certainty from these drawings, but as the larvæ agree very well with the young stages of the related European form *Labrus rupestris*, I have had no hesitation in ascribing the Canadian material to *Ctenolabrus adspersus*.* According to Professor Ehrenbaum's "Nordisches Plankton," the larvæ of *Tautoga onitis* are very similar to those of this species, but as *Tautoga* is a southern form, there can hardly be any question of confusion with the present species.

As will be seen from the illustrations, the Canadian form differs from the European in having a very distinct massing of pigment at the posterior basis of the dorsal fin.

The diameter of the ova is the same in both species, viz., 0·8—0·9 mm.

The distribution of *Ctenolabrus adspersus* ranges from Labrador to Sandy Hook (Jordan and Evermann); it is a distinctly coastal form, especially affecting rocky bottom. *Ctenolabrus adspersus* is summer-spawning; on the first cruise of the *Princess* (June 9 to June 15) but not more than twenty-one eggs of this species were taken. On the second cruise (August 3 to August 12), on the other hand, numerous larvæ were found, and only very few eggs, most of those found being in a very advanced stage of development.

* *Tautogolabrus adsperus* Walbaum.

As will be seen from the chart, ova and young were only found at the stations nearest the coast, especially in the gulf of St. Lawrence along Prince Edward Island and Cape Breton.

The material of this species from the *Acadia* amounts to some few eggs and young taken at Sable island and farther in near the Gut of Canso.

The size of the young varied between 3 and 9 mm.; (see also tables).

2. *FAM. CARANGIDÆ.*

Capros aper (Lacépède).

Of this species, only one specimen (total length 6 mm.) was taken, this being from the *Acadia,* Station 44, where it was brought up in a vertical haul from 150-0 m.[1] Although Jordan and Evermann do not mention this species as occurring in American waters, I have been obliged to ascribe this specimen to the species in question. *C. aper* is also found, by the way, in the eastern Atlantic right up to the coasts of England, and it also penetrates into the Mediterranean.

3. *FAM. SCOMBRIDÆ.*

Scomber scombrus (Linnæus).

(Plate I, Fig. 3; Table IIb.)

Of this species, quite a considerable quantity both of ova and young were collected, especially by *No. 33,* and on the second cruise of the *Princess.*

Jordan and Evermann give the distribution of the mackerel along the American coast as from Labrador to cape Hatteras, and it is therefore remarkable that its ova and young should here have been found almost exclusively in the southern portion of the gulf of St. Lawrence. The cruises of the *Acadia* furnished but three eggs from stations outside Nova Scotia, and neither the *Princess* nor *No. 33* found ova or young of mackerel in the northern part of the gulf.

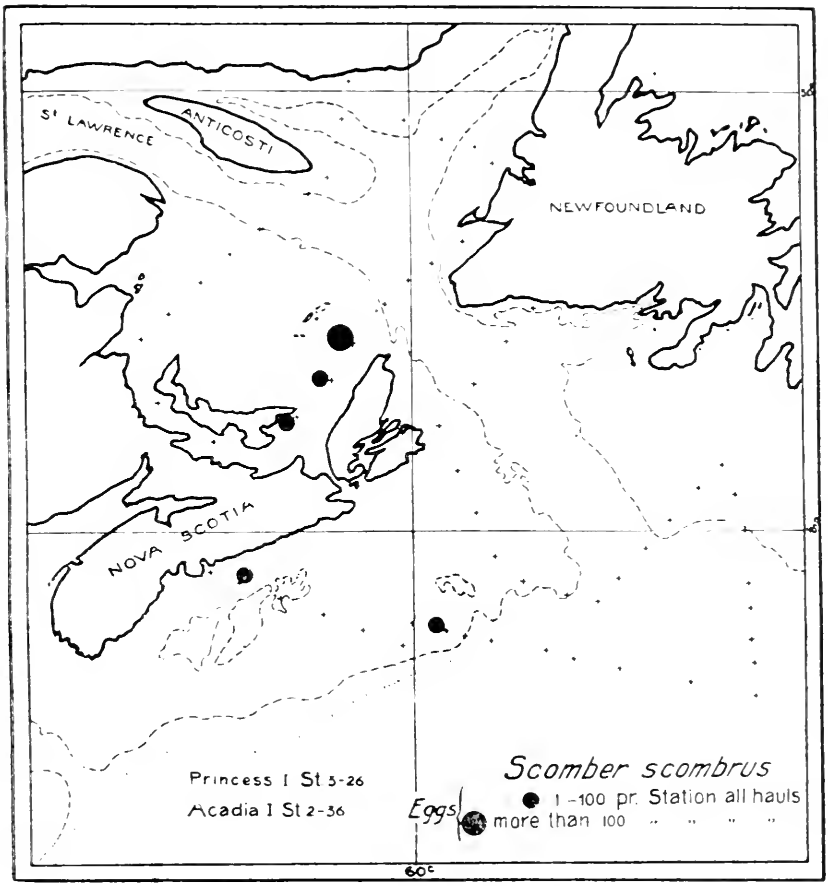
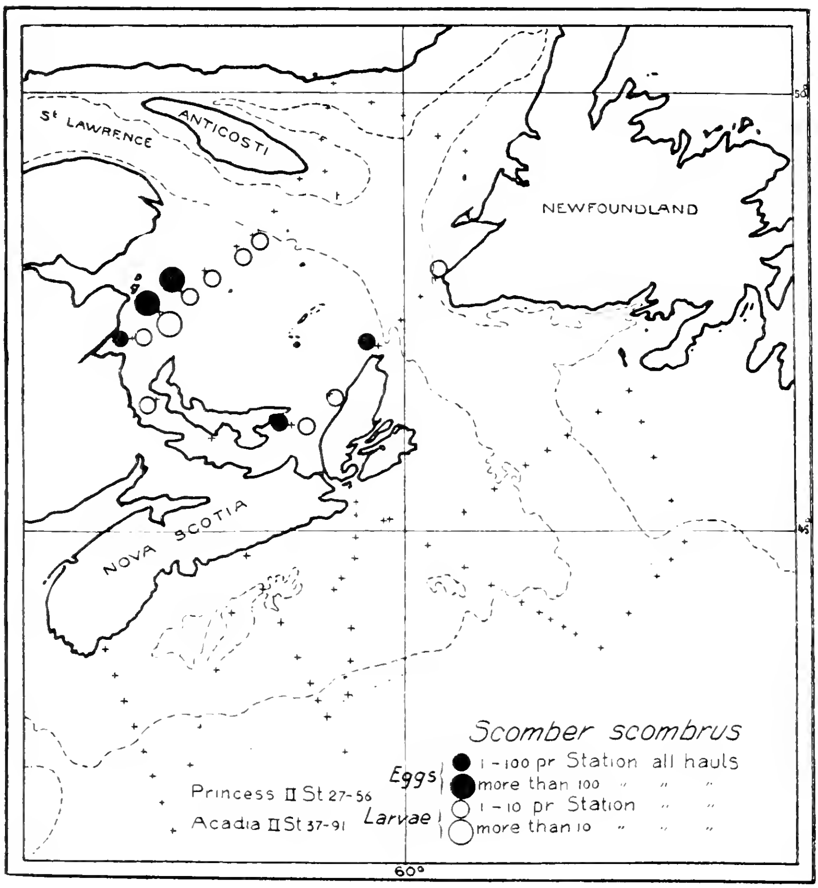

St LAWRENCE
ANTICOSTI
NEWFOUNDLAND
NOVA SCOTIA
Princess I St 5-26
Acadia I St 2-36
Scomber scombrus
Eggs
1-100 pr. Station all hauls
more than 100 " " " "
60°

Fig. 5.



St LAWRENCE
ANTICOSTI
NEWFOUNDLAND
NOVA SCOTIA
Scomber scombrus
Eggs
Larvae
1 - 100 pr Station all hauls
more than 100 " " "
1 - 10 pr Station " "
more than 10 " " "
Princess II St 27-56
Acadia II St 37-91
60°

Fig. 6.

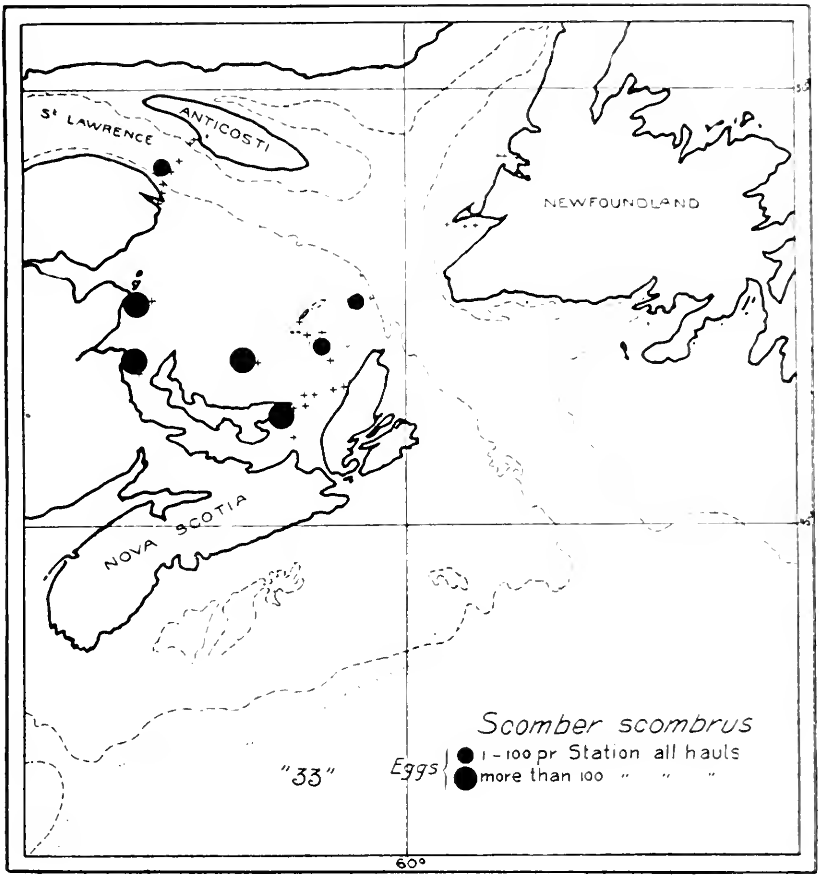


Fig. 7.

It would seem that the mackerel here when spawning keep to the shallower waters in towards Prince Edward Island. It is also interesting to note that while the first stations on the first cruise of the *Princess* inside and west of Prince Edward Island furnished purely arctic species, the hauls made a week later, on the eastern side of the island, brought up the first mackerel eggs.

The mackerel's spawning season appears to extend over a considerable period, from middle of June (first cruise of the *Princess*) to some way on in August.

The size of the mackerel ova will be seen from the table; it will be noted that the diameter varies greatly, a phenomenon which is also well-known in European waters.

MM.	*Princess.* Station 26.	*Princess.* Station 30.	*Princess.* Station 31.	"33." Station 29.
1·00	....	....	23	
1·05	....	9	47	
1·10	....	16	34	1
1·15	1	1	1	4
1·20	8	....	....	12
1·25	11	....	....	8
1·30	5	....	....	

The diameter of the oil globules was about 0·03 mm.

Mackerel larvæ were taken only during the second cruise of the *Princess*, for the most part from Prince Edward Island, and out towards the edge, where stations 28 to 34 gave 40 larvæ between 3 and 8 mm.

In addition, a single larva of 9 mm. was taken at station 45, this being the only mackerel larva found on the north side of Cabot strait. At Stations 49 and 50—between Prince Edward Island and Cape Breton—six larvæ ranging from 4 to 6 mm. were found.

4. *FAM. PEDICULATI.*

Lophius piscatorius (Linnæus).

Of this species, only a single specimen, of 11 mm., was found (*Acadia*, station 47). *L. piscatorius* has a very wide distribution on both sides of the Atlantic; according to Jordan and Evermann, it ranges from Nova Scotia as far as the Barbadoes; only in deep water, however, is it found so far south.

5. *FAM. SCORPAENIDÆ.*

Sebastes marinus (Linnæus).

(Plate I, Figs. 4, 5, 6, 7; Table IIc.)

Young of *Sebastes* were found in all the deeper parts of the areas investigated, save at the outermost stations of the *Acadia*.

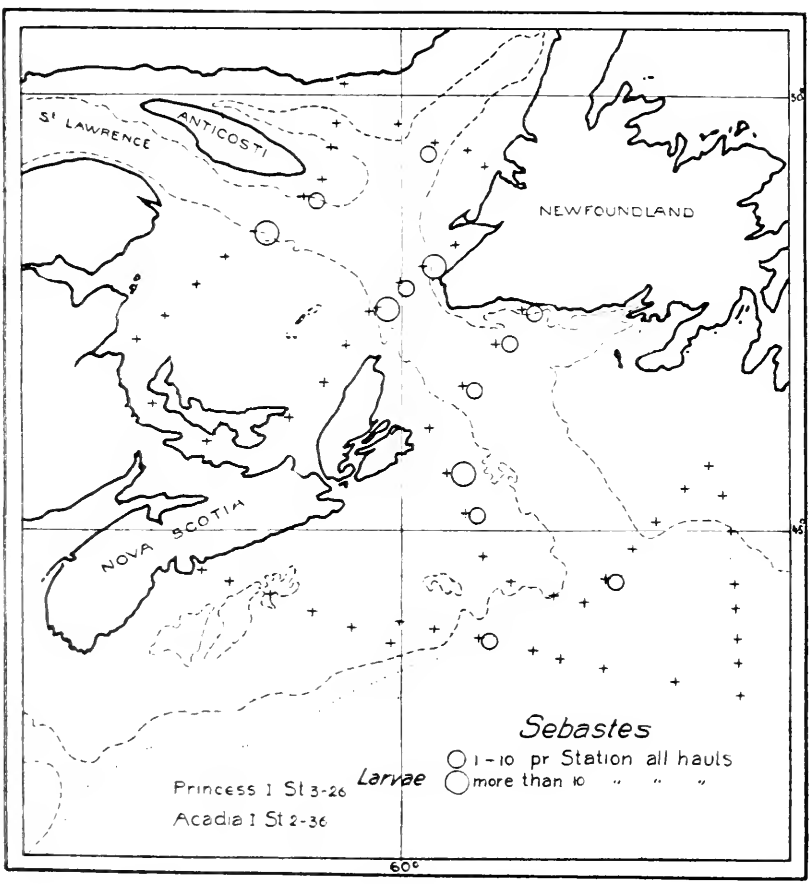


Fig. 8.

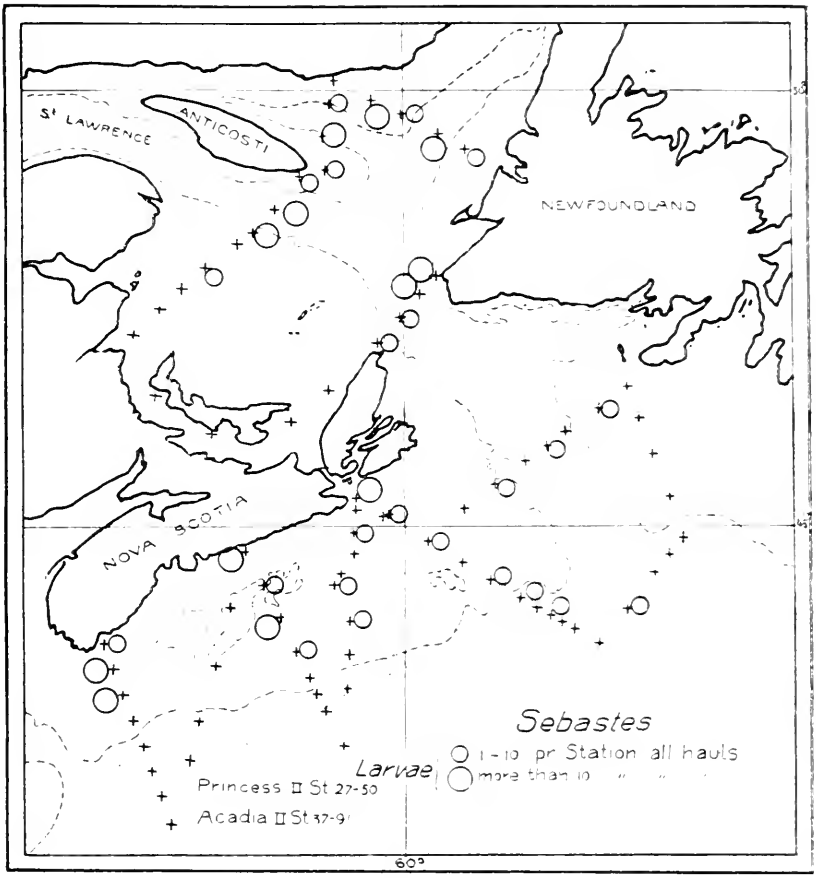

ST LAWRENCE
ANTICOSTI
NEWFOUNDLAND
NOVA SCOTIA
Sebastes
Larvae
1 - 10 pr Station all hauls
more than 10 " "
Princess II St 27-50
Acadia II St 37-91
60°

Fig. 9.

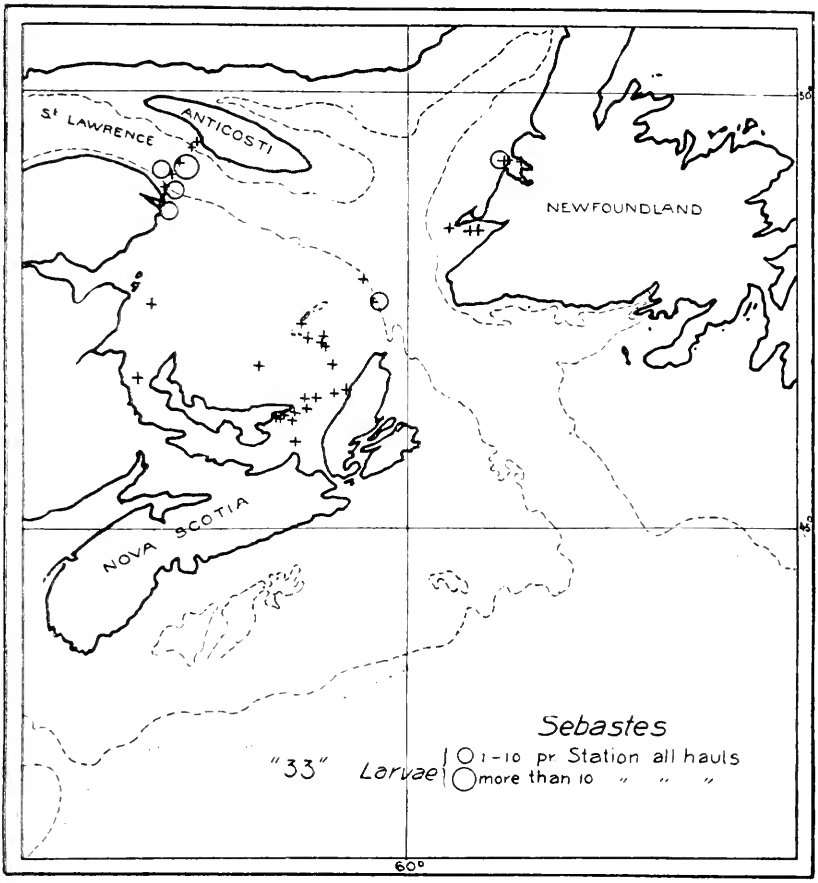


Fig. 10.

It would appear to be most numerous above the deep channel south of Anticosti; the *No. 33* took here 325 young in a single haul. On the slope towards Newfoundland also, it is numerous. (*Princess* station 45.)

On the second cruise of the *Acadia*, also, by the way, it was found in remarkable quantities on the banks off Nova Scotia: this fact may be ascribed to the existence of large depressions in the banks, or possibly to the nature of the currents.

Sebastes marinus is found throughout the northern seas between America and Europe, both on the slopes of the banks and pelagically above the greater ocean depths. Jordan and Evermann note it as occurring on the American side from Greenland along the coast as far as midway off New Jersey; from Maine and farther south, however, in deep water only.

These writers affirm that Goode and Bean found spawning *Sebastes* late in the summer off the coasts of New England, at a depth of 100 to 180 fathoms and state that there is no "reason to believe that the young rise to the surface."

According to Dr. Bigelow, adult *Sebastes* are also found in quite shallow water (about 10 fathoms) in the gulf of Maine—a very remarkable phenomenon, since *Sebastes* is otherwise both south of this (Jordan and Evermann) and farther north, chiefly encountered at medium depths.

6. *FAM. COTTIDÆ.*

Cottus scorpius (Linnaeus).
Cottus bubalis (Euphrasen).
Icelus bicornis (Reinhardt).

Three species belonging to this family are represented in the material, numbering six specimens in all, these being taken, without exception, from the waters near Prince Edward island and Magdalen island.

C. scorpius, No. 33, station 14, one specimen of 10 mm.; station 17, one of 11 mm. This species is found on both sides of the Atlantic, and extends some considerable distance to the northward, as far as Spitzbergen.

According to Jordan and Evermann, it occurs to the southward along the coast as far as Eastport, Maine. In the European waters, *C. scorpius* deposits its egg capsules in midwinter, and the young are subsequently encountered as plankton in the spring. It is noted, however, that in this species, internal fertilization may take place, and that the ova may therefore be in a far advanced stage of development before being spawned; this occurs especially in the northerly waters.

C. bubalis (Euph.) Two specimens from *No. 33*, station 17—both of 6 mm.—agree very well with the larvæ of *C. bubalis*, and have been ascribed to this species, although Jordan and Evermann regard it as doubtful whether *C. bubalis* occurs on the western side of the Atlantic.

Icelus bicornis (Reinhardt) was taken at *Princess* station 7 (14 mm.) and another of 10 mm. at *No. 33* station 15.

This species is an arctic circumpolar form, penetrating, however, southward along the east coast of America as far as cape Cod. Both the specimens here taken were found in comparatively shallow water.

7. *FAM. AGONIDÆ.*

Agonus decagonus (Schneider).

One specimen of 24 mm. was taken by the *Princess* at station 7, and strangely enough, at the surface. *A. decagonus* is otherwise found for the most part at some considerable depth, down to a couple of hundred fathoms, and in very cold water about 0° C. As to its propagation, little is known.

Aspidophoroides monopterygius (Bloch).

One specimen of 15 mm. taken by the *No. 33* at station 21 (C. Gaspé) should probably be referred to this species. In point of habitus, it is very like *Agonus decagonus,* but differs from this in having but one dorsal fin. On the other hand, it has very spinous scales, and differs in this from *A. monopterygius*; possibly, however, this may be a larval character.

8. *FAM. BLENNIIDÆ.*

Chirolophis sp.

(Plate II, Fig. 8; Table IId.)

Two species belonging to the family Blenniidæ were found, of which the one could not be determined with certainty.

This was found (no less than sixty-three specimens) throughout the whole of the gulf St. Lawrence, and out towards the Newfoundland banks. The number of vertebræ, about 13 + 42 or a total of about 55, agrees very well with that of *Chirolophis galerita* (L.) Walb. It differs slightly, however, from this in the shape of the head and intestines, while the pigmentation appears to be of more or less the same character.

It was taken in sizes ranging from 8 to 13 mm. and was most numerous during the time extending to July 15.

Stichæus punctatus (Fabricius).

(Plate II, Fig. 9.)

Of this species, two specimens measuring 30 and 40 mm., respectively, were taken. *Stichæus punctatus* is an arctic fish; it is recorded as penetrating as far southward as Newfoundland. The specimens in question were taken at the surface, station 89 (*Acadia*) i.e., down towards Nova Scotia.

9. *FAM. CRYPTACANTHODIDÆ.*

Cryptacanthodes maculatus (Storer).

(Plate II, Fig. 10.)

This species was taken in a vertical haul (80 to 0 m.) at the *Princess* station 8. Only one specimen, of 38 mm. Found from Labrador to Long Island sound—but not common. (Jordan and Evermann.)

10. *FAM. ANARRHICHADIDÆ.*

Anarrhichas latifrons (*Steenstrup*).

Two specimens of *A. latifrons* were taken, one of 21 mm. in a surface haul (*Princess* station 3) and one of 25 mm. in a vertical haul 125 to 25 m. (*Acadia* station 35). These were so far developed as to be distinguishable by the position of the vomerine teeth. An arctic fish, extending southward along the east coast of America to Banquereau.

11. *FAM. CALLIONYMIDÆ.*

Callionymus sp.

A fish larva of 6 mm. taken in a vertical haul 150 to 0 m. *Acadia* station 44, strongly resembles the European *Callionymus* species, but lacks the notochord otherwise so prominent in these species. The formation of the fin rays, however, was so far advanced that possibly the notochord may have been reduced.

12. *FAM. CYCLOPTERIDÆ.*

Liparis sp.
Liparis major (Gill).

(Table IIe.)

Of the Liparidæ taken, three specimens from *No. 33* station 57 were ascribed to *Liparis major* (*vide* Jordan and Evermann). They had a total length of 25 to 30 mm., but were not in good preservation, and the determination is therefore somewhat uncertain. *L. major* is an arctic fish, extending from the White sea to Greenland, but, has, according to Jordan and Evermann, not been encountered on the coast of America.

The remaining Liparidæ it was found impossible to determine as to species; in all, sixteen were taken on all cruises.

13. *FAM. PLEURONECTIDÆ.*

Pleuronectidæ do not occur in any great number in the material, with the exception of *Drepanopsetta.*. There are, however, on the coasts of America, many species of flounder whose eggs and larval stages have not been described, that on this point, more especially as regards the ova, errors may have occurred in the determination.

The larvae recorded under the different species are so like the European that, as a rule, there was no difficulty in deciding; several species, moreover, have been figured. If we consider, however, the insignificant number of unknown flounder larvae (of which part could not be determined owing to accidents in the preservation) it would hardly seem likely that any great number of unknown eggs would be liable to confusion with other species. Of unknown Pleuronectidæ the following were taken:—

		Length.
Acadia station 4, 150—0 m 1	Pleuronectes?	5 mm.
" " 38, 100—0 m 1	"	6 "
No. "33" station 39, vertical 1	"	4 "
No. "33" station 49, vertical 6	"	6-7-6-7-6-7 "

To these should be added one specimen of 4 mm. length from the *Princess* station 48; probably belonging to the genus *Bothus*.

P. limanda (?) L.

A quantity of ova of this species was found on the first and second cruises of the *Acadia* (above the banks off Nova Scotia and Newfoundland).

	At Surface.	In Vertical Hauls.
Station 29	5 eggs.	5
" 30	3 "	8
" 36	1 "	
" 61	5 "	
" 62	43 "	
" 80	2 "	
" 82	....	

The diameter of the eggs was about 0·9 mm. and the embryos revealed typical Pleuronectid characters, though none were so far advanced as to permit of their being ascribed with certainty to *P. limanda;* they undoubtedly belong, however, to a closely related form.

According to Jordan and Evermann, this species also is stated as apparently not found off the coasts of North America.

P. microcephalus (Donovan)=*Microstomuskitt* (Walbaum).

At *Acadia* station 84, a larva of 6 mm., taken in a surface haul, must be referred to this species.

P. (*Glyptocephalus*) *cynoglossus* L.

(Plate II, Fig. 11.)

Of this species, the following specimens were taken:—

Princess station 34—Oblique: 1: ca. 6 mm.
" " 49—Surface: 2: 8-10 mm.
" " 50—40-0: 1: 7 mm.
Acadia " 83—Surface: 4: 6-8 mm.

There were thus taken eight larvae in all, but eggs of this species were not found; these probably did occur in the samples, but must then in some way have been overlooked. *P. cynoglossus* spawns in European waters from May to September; the ova have a diameter of 1·07 to 1·25 mm., and are otherwise distinguishable by their slightly striped structure.

P. cynoglossus belongs to the North Atlantic; on the American side it extends as far as cape Cod: lives in comparatively deep water, preferably with sandy bottom.

Ancylopsetta (*Notosema* sp.)

(Plate II, Fig. 12.)

A specimen of 7 mm. from *Acadia* station 44 (surface). Belongs to the warm seas.

Drepanopsetta (Hippoglossoides) platessoides (Fabricius).

(Plate II, Figs. 13, 14, 15; Table IIf.)

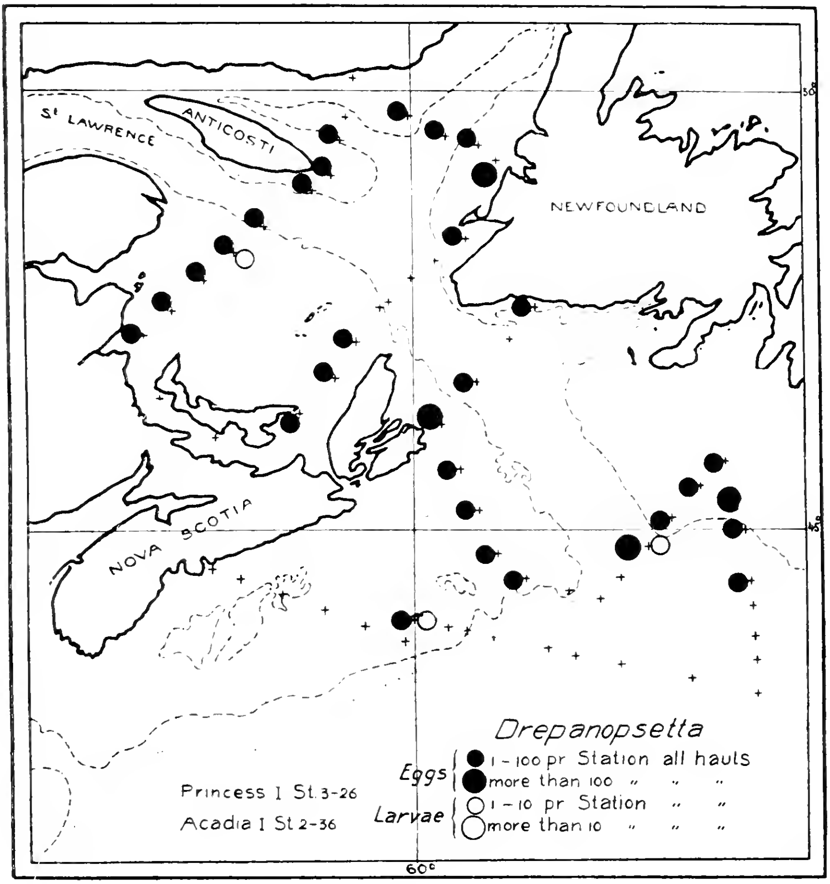


Fig. 11.

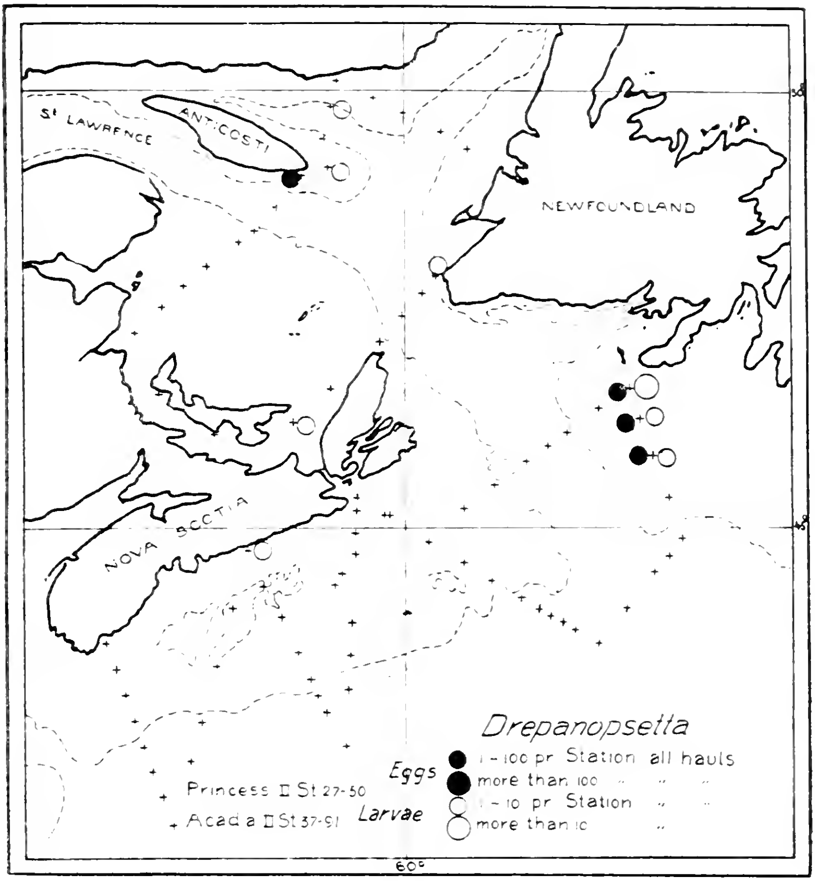

ANTICOSTI
St LAWRENCE
NEWFOUNDLAND
NOVA SCOTIA
Drepanopsetta
Eggs
1 - 100 pr Station all hauls
more than 100
Larvae
1 - 10 pr Station
more than 10
Princess II St 27-50
Acadia II St 37-91
60°

Fig. 12

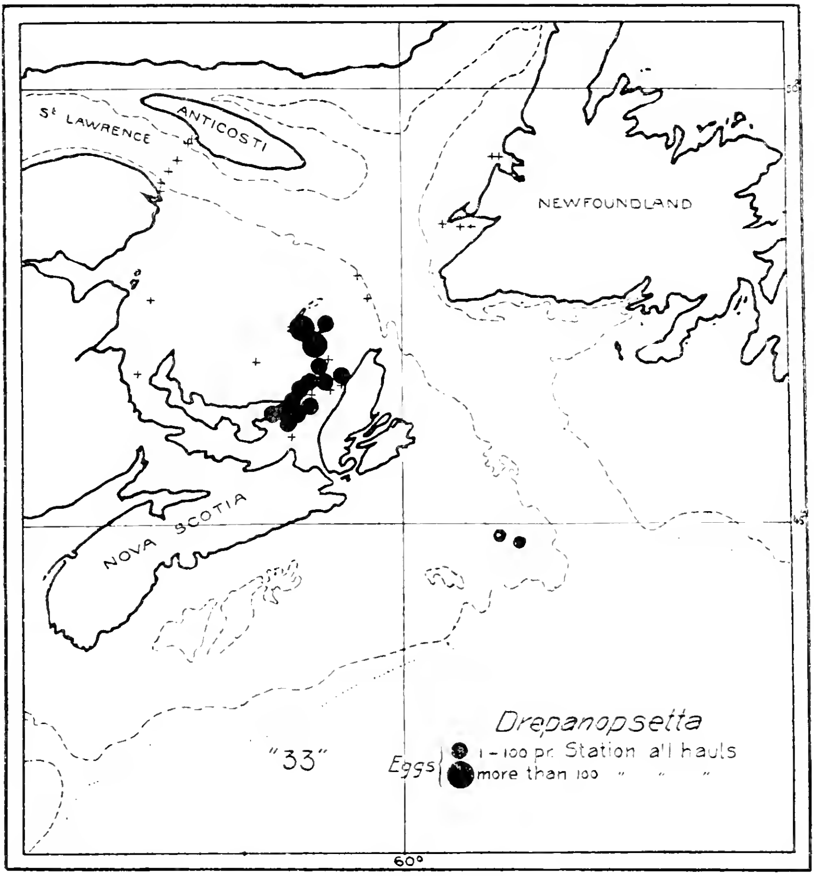


Fig. 13.

Eggs and larvæ of *Drepanopsetta* have a wide distribution, especially over the banks. The ova are very often found together with cod eggs, and were especially numerous on the first cruises.

June 9 to June 15, *Princess*	I	gave 609	eggs	+ 5 larvæ.
August 3 to August 12, *Princess*	II	" 1	"	+ 7 "
May 29 to June 4, *Acadia*	I	" 1,089	"	+ 7 "
July 21 to July 29, *Acadia*	II	" 35	"	+ 28 "

To these should be added the hauls made by the *No. 33*, which contain ova of *Drepanopsetta* in considerable quantities until July 10. The spawning time must thus be regarded as over by middle of July, which is somewhat late in comparison with the European waters. (In the North sea, spawning taken place from January to May.) The ova of *Drepanopsetta* are very easily distinguishable by the large perivitelline cavity, and by their considerable size.

Measurements from the *No. 33* station 16 give the following numbers of eggs for each size (diameter in mm.):—

2·1 mm.	1
2·2 "	3
2·3 "	10
2·4 "	4
2·5 "	7

As will be seen from the above, the diameter varies up to 4·10 mm.

Larvae of *Drepanopsetta* were found especially on the cruises of the *Acadia* and *Princess* in July-August; they occur but sparsely, save at stations 81 and 83 (Newfoundland banks), where they were more numerous. The length of the larvae varied between 5 and 20 mm.

Distinction is made between two forms of *Drepanopsetta*; *D. platessoides*, the more arctic, which also extends down along the coast of America, and *D. limandoides*, the European form.

Drepanopsetta lives preferably on sandy bottom, on the banks, but can also, at certain times of the year, move down into the deep water of the channels, where it then lives on soft bottom.

14. *FAM. GADIDÆ.*

Gadus æglefinus (Linnæus).

Gadus callarias (Linnæus).

Onos sp.

Onos cimbrius (Linnæus).

Merluccius merluccius (Linnæus).

(Plate III, Figs. 16 to 22; Table II*g* to II*i*.)

The gadoids play the most important part in the material collected; ova and young of this family were found in all the areas examined and on all the cruises made. On consulting the chart, however, it will at once be noticed that the different species have each their own area of distribution, and only occasionally overlap.

The ova of cod and haddock cannot be distinguished one from another with full certainty in the earlier stages. True, those of the haddock are, as a rule, some tenths of a millimetre larger than those of the cod, but both species vary so greatly as to overlap in this respect. I have, however, always counted such eggs as could be determined with certainty (i.e. those with developed embryo) in each sample, on the basis of which it is justifiable to reckon the proportion between the two species, also as regards the earlier stages, at any rate with a considerable degree of exactitude.

DIAMETERS in millimetres for Eggs belonging to the genus Gadus, from different Canadian localities.

—	May 30.		June 9.	June 11.	June 15.	August 4.		August 5.
	"Acadia" Sta. 6.		"33" Sta. 10.	"Princess" Sta. 10.	"Princess" Sta. 26.	"Princess" Sta. 31.		"Princess" Sta. 36.
	Gadus sp.	**G. æglefinus*	*Gadus sp.*	*Gadus sp.*	*Gadus sp.*	*Gadus sp.*	**G. callarias*	*Gadus sp.*
mm.								
1.15	......	......	......	......	......	1	......	1
1.20	1	......	1	......	1	4	......	2
1.25	14	......	4	4	......	35	4	21
1.30	23	6	7	6	10	43	5	27
1.35	38	6	10	7	9	44	4	18
1.40	33	15	2	6	5	41	......	9
1.45	8	1	1	2	......	6	......	......
1.50	4	......	......	......	......	1	......	......

* With diagnostic pigmentation of the species.

As will be seen from the table, the ova of cod and haddock have a diameter of 1·15 to 1·50 mm.; a number of safely determinable cod eggs 1·25 to 1·35, and haddock eggs 1·30 to 1·45 mm.

With regard to the pigmentation, the larvæ of cod should most properly be taken as belonging to the type described by Schmidt from the southern part of the North sea; it may perhaps be designed as a warm-water type, with extremely faint pigment. *Vide* fig. 17, and, for comparison, also fig. 16, which shows a more northerly type. As no larva of this type was available suitable for illustration purposes in the material, one from Norway has here been used.

On looking through the tables, we find a single haddock egg in the gulf of St. Lawrence, and no haddock larvæ; the material from here can therefore, practically speaking, be taken as belonging to *Gadus callarias*.

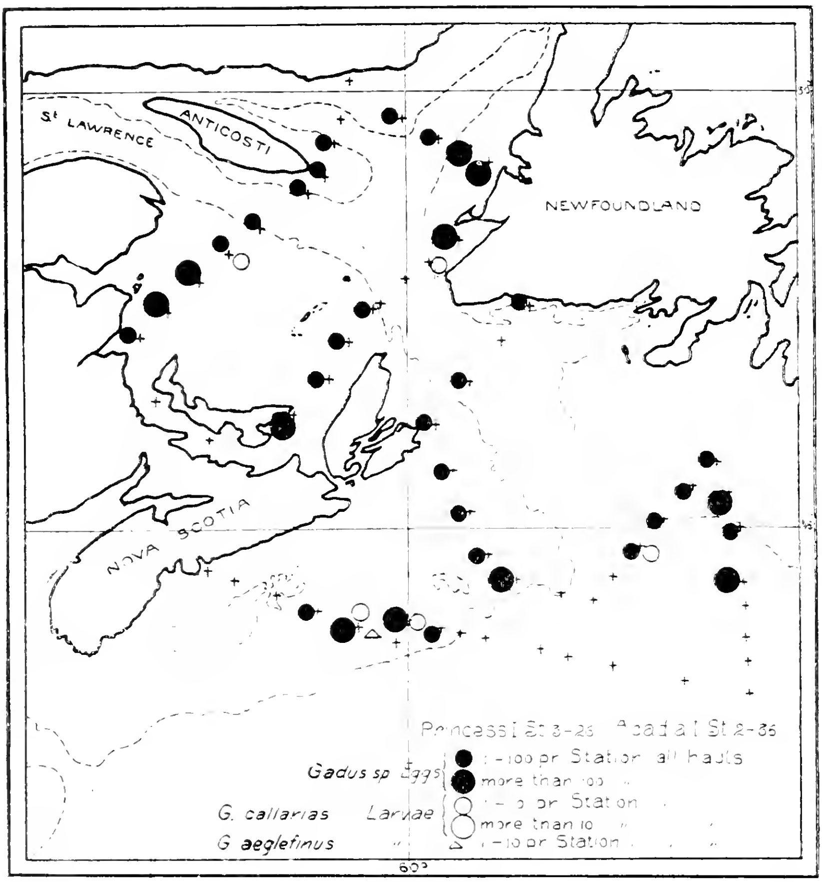
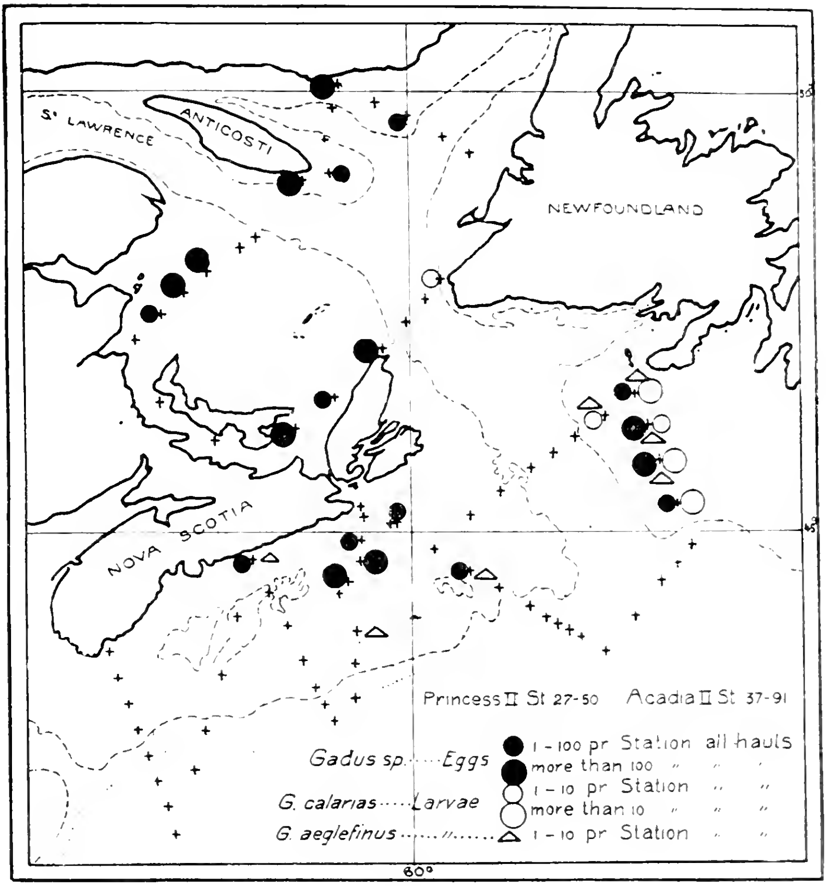


Fig. 14



St LAWRENCE
ANTICOSTI
NEWFOUNDLAND
NOVA SCOTIA
50°
45°
60°
Princess II St 27-50 Acadia II St 37-91
Gadus sp. ····· Eggs
1 - 100 pr Station all hauls
more than 100
G. calarias ····· Larvae
1 - 10 pr Station
more than 10
G. aeglefinus ········ ········
1 - 10 pr Station

Fig. 15.

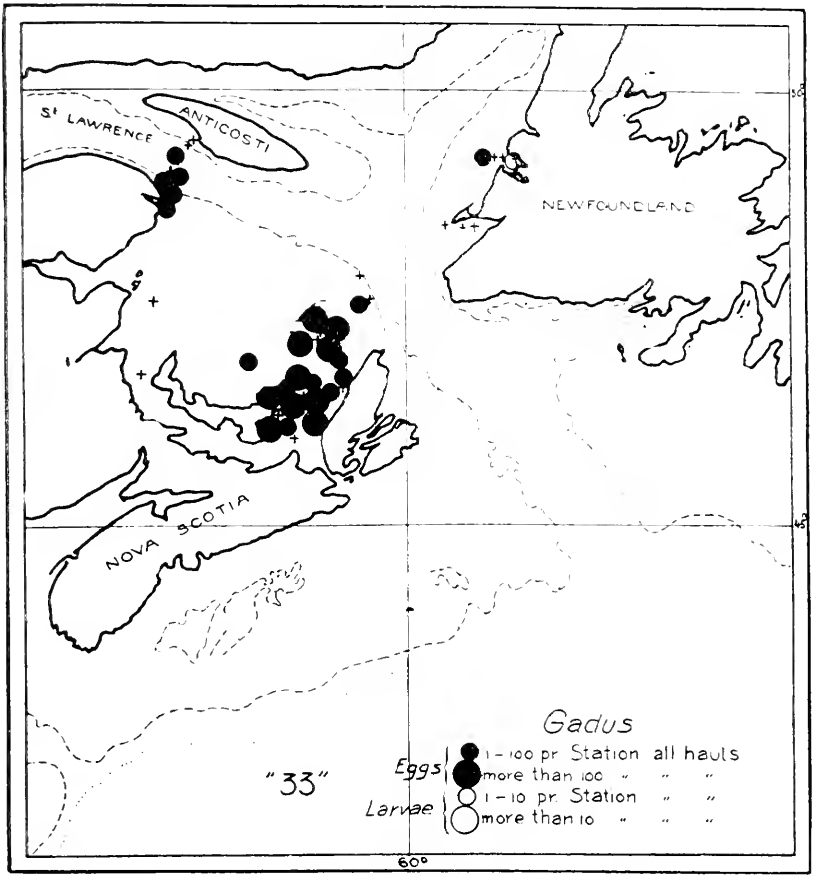


Fig. 16.

Only on the cruises of the *Acadia* arose any risk of confusion with haddock, and here, more especially in the case of the southerly stations, where examples of haddock ova were in the majority.

The charts show very distinctly the distribution of the cod eggs. We find them always over the banks, and as a rule in greatest numbers where the banks shelve down, but never distributed over great depths.

Cod larvae occur very sparsely; only on the Newfoundland banks have we at Station 83 a fairly good yield of 216, the sizes here varying between 3 and 10 mm. and ranging for the greater part between 4 and 6 mm., i.e., comparatively newly emerged fry.

Haddock larvae were found only on the cruises of the *Acadia*, especially the second, off Nova Scotia and on the Newfoundland banks. They are very few in number; only sixteen for both cruises together. The size varied between 3 and 15 mm.

Cod and haddock have, as we know, a very wide area of distribution in the northern hemisphere. The haddock ranges from the bay of Biscay as far as Spitzbergen; on the American side, where, by the way, it is not so numerous, down to cape Hatteras.

In European waters, the haddock spawn from January to June.

The cod has more or less the same distribution as the haddock, penetrating, however, also down into the Pacific. It spawns at the same time. Spawning has, moreover, been recorded in August on a single bank of the North sea. The spawning takes place for the most part on the banks, where the temperature keeps at about 4° C., and it is generally supposed that the cod, for this reason, move down from the Polar seas to the southward, in order to spawn on the Norwegian coastal banks about Lofoten, which are washed by the temperate waters of the Gulf Steam. Cod held in captivity seldom spawn in water below 2° C.

The spawning in Canadian waters evidently extends over a very long period. On the first cruises of the *Acadia* and *Princess*, May 29 to June 16, free larvae of cod were found, while on the last cruises, July 21 to August 12, ova were still obtained in early stages. This is doubtless due to the extraordinary conditions of temperature in these waters.

Of the *Onus* eggs and larvae, most no doubt, belong to *O. cimbrius*, Plate III, figs. 21 to 22, but as pigmentation, especially of the larvae, varies somewhat, I could not feel certain that all belonged to this species. A number of *Onos* eggs from the *Acadia* captures certainly belong to another species.

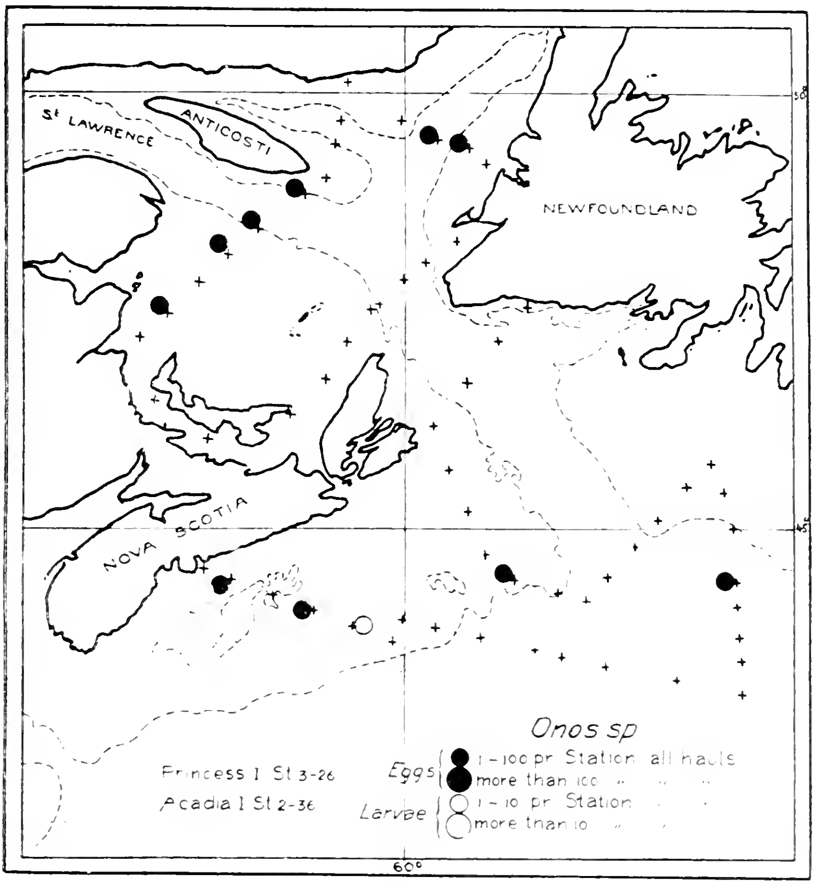


Fig. 17.

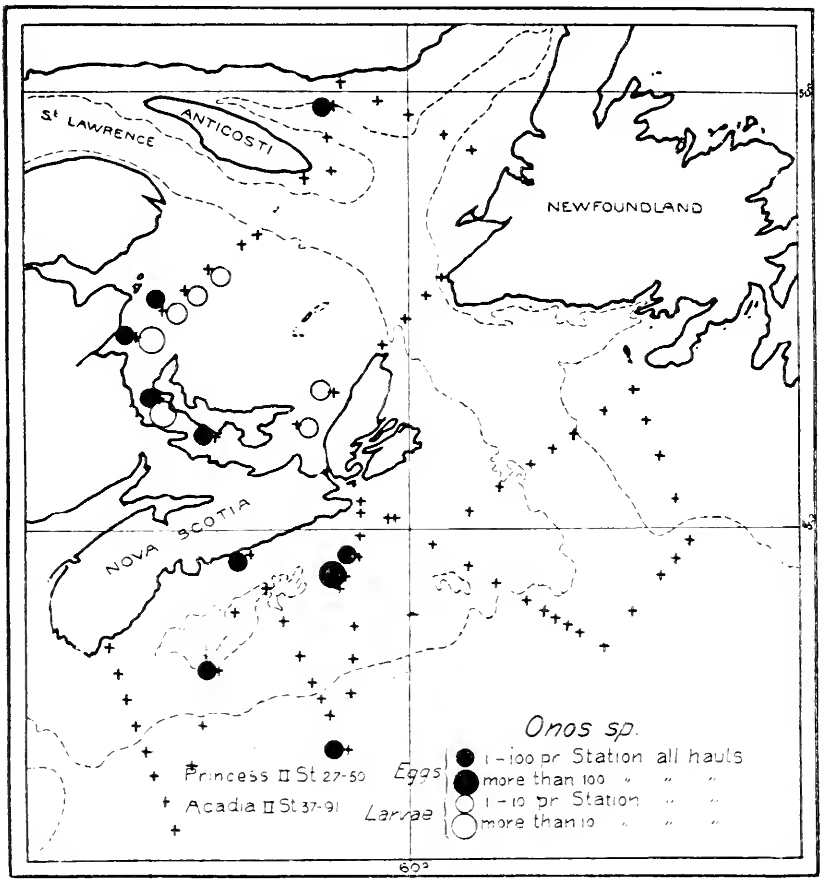

St LAWRENCE
ANTICOSTI
NEWFOUNDLAND
NOVA SCOTIA
Onos sp.
Eggs
1-100 pr Station all hauls
more than 100 " " "
Larvae
1-10 pr Station " "
more than 10 " " "
Princess II St 27-50
Acadia II St 37-91
60°

Fig. 18.

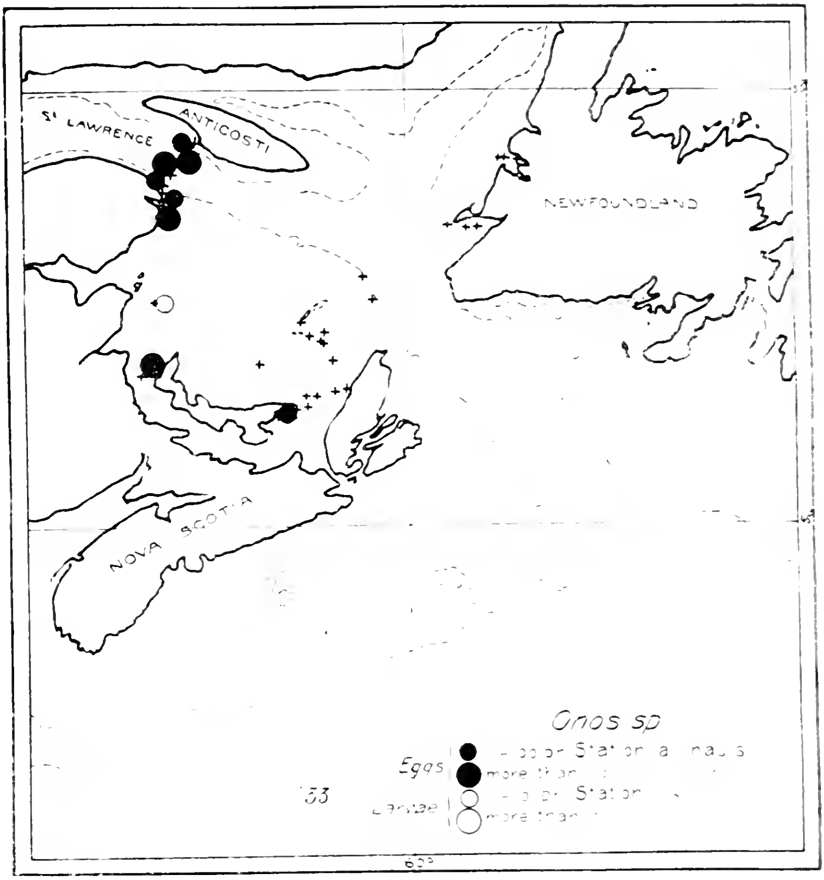


Fig. 19.

The diameter of the eggs is between 0·8 and 0·9 mm. as regards those from the gulf of St. Lawrence. At the *Acadia* Station 47, however, the diameter was 0·70 to 0·75 mm.

Onos cimbrius is widely distributed both in European and American waters. It does not, however, penetrate so far to the northward as the cod; lives mainly on soft bottom in fairly deep water, near the coast. It spawns more especially in May (Europe).

As regards its distribution in the gulf of St. Lawrence we notice that it is especially numerous about Prince Edward Island and towards Anticosti; always close to land or above the more shallow banks.

Ova of *Merluccius* were found in considerable quantities on the second cruise of the *Acadia*, especially above the banks off Nova Scotia.

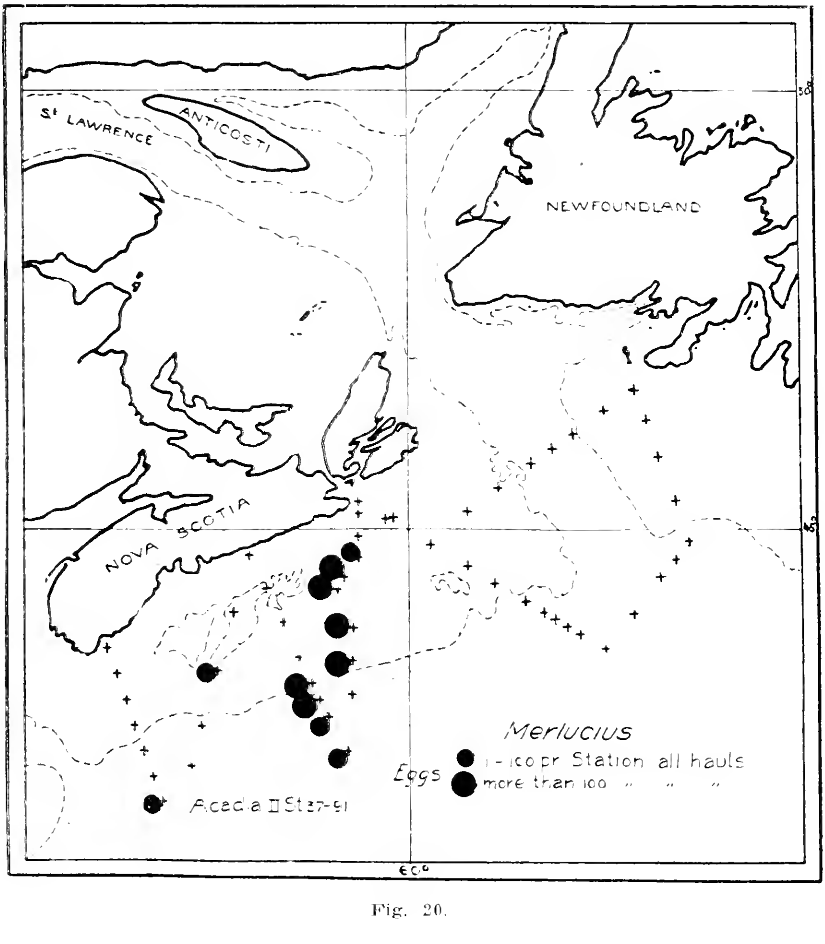

St LAWRENCE
ANTICOSTI
NEWFOUNDLAND
NOVA SCOTIA
Merlucius
Eggs
1 – 100 pr Station all hauls
more than 100 " " "
Acadia II St 37-91
60°

Fig. 20.

A number of measurements made give the following results:—

0·90 mm.	6 eggs.
0·95 "	28 "
1·00 "	5 "

Merluccius merluccius is not noted in Jordan and Evermann's "Fishes of North America." The ova, however, certainly agree very well with the European form. Larvæ of this species were not found, but some few eggs in a fairly advanced state of development.

Of the American forms, *M. bilinearis* (Mitchill) is the species most closely resembling the European, and the ova should probably be ascribed to this species.

In European waters, *Merluccius* is of very common occurrence in the Mediterranean and off the coasts of England; it extends, however, up as far as Norway and Iceland.

In the Mediterranean, it spawns in the spring months; in the more northerly waters, during summer.

15. *FAM. AMMODYTIDÆ.*

Ammodytes tobianus (Linnæus).

(Plate III, Figs. 23 and 24; Table IIj.)

A. tobianus was found in greatest numbers on the first cruise of the *Acadia*, eighty-nine specimens being secured.

The second cruise of the *Acadia*, the cruise of *No. 33*, and the first cruise of the *Princess*, furnished together only thirteen specimens; the second cruise of the *Princess*, none.

It would seem to be found especially above the banks, but has also occasionally been encountered over the deep channels, and closer in to land. The length varies from 7 to 25 mm. the different sizes apparently occurring together.

A. tobianus has a wide European area of distribution, extending from Spain to Finmarken, the White sea, Iceland, and Greenland.

It is probably identical with *A. americanus*, DeKay, which species, according to Jordan and Evermann, ranges from Newfoundland to cape Hatteras.

The European form spawns in the autumn at about 20 metres depth, where the ova are attached to grains of sand.

The eggs may be hatched during the course of the winter; not until spring, however, are the larvae found in any considerable numbers among the plankton, where they are then often encountered in enormous quantities.

16. *FAM. TETRAGONURIDÆ.*

Tetragonurus cuvieri (Risso).

(Plate III, Fig. 25.)

One specimen of this Atlantic species, measuring 76 mm. was taken at *Acadia* station 56; (210 to 140 fathoms).

T. cuvieri is especially numerous in the Mediterranean and adjacent portions of the Atlantic; according to Jordan and Evermann, it has only once previously been taken off the coast of America. It keeps chiefly to deep water, feeds on medusæ, and its flesh is said to be highly poisonous.

17. *FAM. GASTEROSTEIDÆ.*

Gasterosteus aculeatus (Linnæus).
= *G. bispinosus* (Walbaum).

The three specimens of this species taken would seem to be full-grown, living pelagically in the neighbourhood of land.

Their total length was 65, 44, and 38 mm. they were taken in surface hauls, at *Princess* stations 28 and 29, and *No. 33* station 13.

G. aculeatus has an extraordinarily wide area of distribution in the northern hemisphere, and is found down along the coast of America as far as New York. It also penetrates up into the rivers.

18. *FAM. SALMONIDÆ.*

Mallotus villosus (Müller).

(Plate III, Figs. 26 and 27; Table II k.)

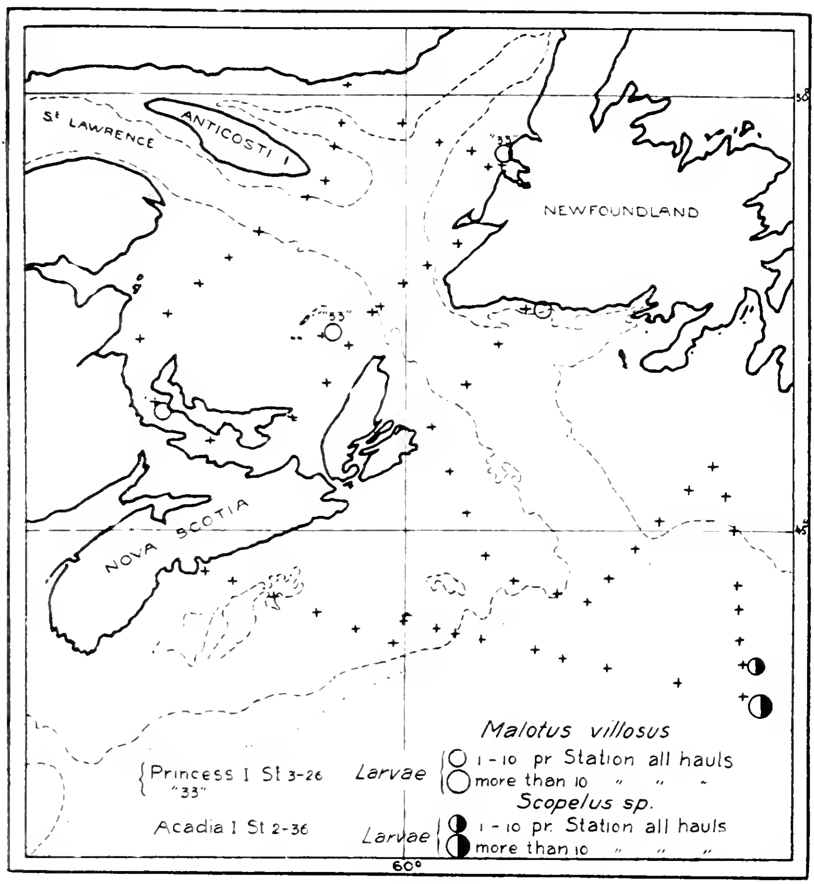


Fig. 21.

This arctic circumpolar species often occurs in great numbers down towards Finmarken and Newfoundland. In North America waters it is found as far down as cape Cod.

In Norwegian waters, it spawns along the coast from April to June, depositing its eggs in great quantities, chiefly on sandy bottom, at depths to about 100 metres.

The newly emerged larva is about 7 mm. long. Of *M. villosus*, a considerable number were collected, especially around the coasts of Newfoundland; it occurs more sparsely out towards Labrador and down in the direction of Prince Edward Island.

The size of the larvæ varies between 7 and 42 mm., the great majority, however, being between 10 and 20 mm.

19. *FAM. STOMIATIDÆ.*

Stomias boa (Risso).
Cyclothone sp.

Stomias boa (one specimen of 30 mm. taken at the surface, *Acadia* station 40) is a cosmopolite, belonging to the warm seas of the world.

Of *Cyclothone*, five specimens were taken, ranging from 7 to 16 mm.; these were not determined as to species.

Two specimens from the surface, 8 to 16 mm. *Acadia* station 16.

Three specimens, vertical haul, 200 to 0, 7-8 and 10 mm., *Acadia* station 16.

The genus *Cyclothone* comprises several bathypelagic species from various warm and temperate seas of the world.

20. *FAM. SCOPELIDÆ.*

Scopelus sp.
Omosudius elongatus (A. Brauer).
Myctophum glaciale (Reinhardt).
M. benoiti (Cocco).
M. punctatum (Rafinesque).
M. humboldti (Risso).

(TABLE II 1)

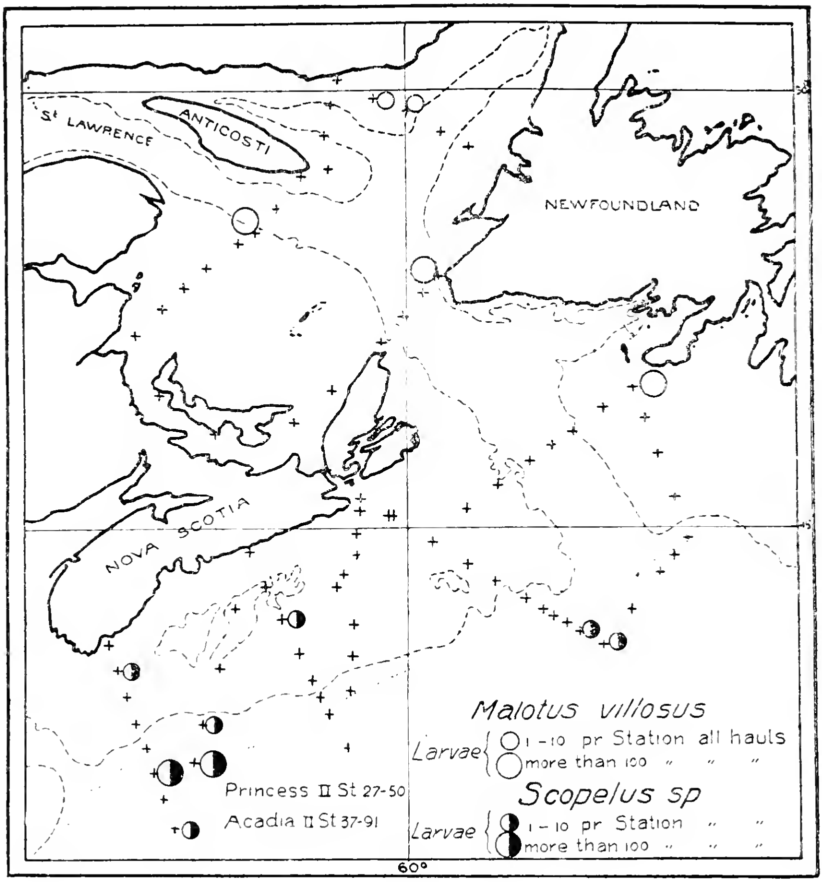


Fig. 22.

A large number of *Scopelidæ* were taken at the outermost *Acadia* stations. It was found impossible to determine species in the majority of examples, the preservation being frequently imperfect. *Omosudis elongatus* was taken at three of the *Acadia* stations.

Station 16	200—0 m.	2 species 25 to 36 mm.
" 57	150—50 fms.	1 species 105 mm.
" 75	180—0 fms.	1 species 45 mm.

This species belongs to the warmer portions of the Atlantic and Pacific.

M. glaciale (one specimen of 15 mm. from *Acadia* station 45, 150 to 0 m.) This species is of common occurrence on the east coast of America, but is also found throught the whole of the North Atlantic. Also taken off the coast of Greenland.

M. benoiti, one specimen, 15 mm., from *Acadia* station 16 (surface haul). Belongs chiefly to the warm Atlantic waters; also penetrating into the Mediterranean.

M. punctatum, one specimen, 23 mm., from *Acadia* station 16, 200—0 m.

This species has frequently been taken up towards Newfoundland. (A. Brauer.)

M. humboldti, one specimen, 31 mm., from *Acadia* station 11 (surface haul). Found in all warm seas

III. DISTRIBUTION OF EGGS AND YOUNG IN THE WATERS INVESTIGATED.

It is a well-known fact that certain species have their more or less definite spawning grounds, or, at any rate, are to be found during the spawning season, at places where certain physical conditions prevail, these conditions being, presumably, such as are best adapted to the propagation of the species in question.

When spawning, our most important food fish assemble upon grounds of restricted area, where they can naturally be taken in the greatest number; it is therefore of considerable importance, for the fisheries, to ascertain the position and extent of such grounds. This may be done by making experimental hauls to secure the spawning fish, or, far more easily, by plankton hauls, from the results of which it will be seen where the newly spawned eggs and young are to be found, whence we can determine the locality of the spawning grounds. This latter method has been largely employed in the international investigations in European waters, and has led to the charting of the spawning grounds of the different species.

If we now consider the results of the various cruises in Canadian waters, it will soon be seen that the eggs and young of each species have one or more principal areas of distribution, diminishing in frequency to either side of such area; further, that certain species generally occur together, others again being invariably found apart.

This distribution is dependent upon the different circumstances under which the fish spawn, and we shall see that each species is always encountered under certain conditions, wherefore a certain degree of regularity may be shown to exist in their occurrence. The eggs and young of littoral fish are found close to land, or over the shallow banks; the banks have their own particular young-fish fauna, and the deeper parts, again, theirs. To these must be added a fourth group, to wit, that of the pelagic species, such as the mackerel; in the case of these, the question of depth is less important, and their eggs may therefore be found scattered throughout all areas, where they may be taken together with the ova of the three first groups. An interesting phenomenon, however, is the fact that both eggs and young of practically all our principal species of fish have a pelagic stage, during which they are to be found near the surface, without regard to whether they were spawned there or at greater depths. In the case of most species, both eggs and young are so balanced as to float in ordinary sea-water, and when spawned deep down will, owing to their own buoyancy, rise to the surface, where their development then proceeds. The young will thereafter, as their growth advances, again move down to greater depths, or in towards land, passing from a pelagic habit of life to a more or less pronounced bottom stage.

A. The Gulf of St. Lawrence.

The various cruises furnish a number of instances showing how the character of the fauna changes as we pass from the vicinity of the coast outwards, or from colder to warmer waters, and *vice versa*.

As already mentioned, the gulf St. Lawrence was investigated by the *Princess*, June 9 to June 15 and August 3 to August 12, with some occasional work done by the *No. 33* from June 1 to August 18; this latter cruise may be disregarded in the present chapter, both on account of the length of time covered, and also because the voyage was not planned according to the special lines of our present purpose. The route followed on such cruises is, it should be noted, of great importance both for the investigation of the different localities, and also for the collective survey of the waters as a whole.

The cruises of the *Princess* (*vide* chart, p. 4) both proceeded from Prince Edward Island over to the eastern point of Anticosti, continuing up to Labrador, and thence eastward to Newfoundland, then following the coast southward, past Cape Breton, and back to Prince Edward Island. Glancing now at the hauls made at the different stations, we find close to land (Stations 3 and 4) very few larvæ; only one or two specimens of the arctic species *Anarrhichas latifrons* and *Mallotus villosus*; moving out over the banks, we encounter *Drepanopsetta* and *Gadus callarias,* with some few ova of *Onos cimbrius*, besides some arctic fish, viz., *Icelus bicornis* and *Agonus decagonus*. At station 9, near the edge, *G. callarias* and *Drepanopsetta* are again less numerous; we find, however, instead, the young of *Sebastes marinus.* Stations 10, 11 and 12 above banks east of Anticosti reveal once more a true bank fauna, *Drepanopsetta* and *G. callarias.*

Stations 13 and 14, up towards Labrador, furnished but a poor yield; the stations nearer Newfoundland, however, are again seen to be rich in eggs of *Drepanopsetta* and *G. callarias,* with some few Sebastes in the vicinity of the deeper channels. Here, on the slope towards Newfoundland, lie the richest stations of the whole cruise; stations 17 and 18, for instance, furnished each over 1,000 cod eggs in surface hauls alone, besides a considerable number of *Drepanopsetta* ova. Moving southward along the coast, the hauls are still rich as regards these species, and at station 19, close in to land, we encounter, for the first time, ova of the southerly form *Ctenolabrus adspersus.* Above the deep channel in Cabot Strait, *Sebastes* predominated. Not until station 24 is reached do we again meet with the banks fauna, *G. callarias* and *Drepanopsetta,* which are thenceforward of common occurrence throughout the remainder of the cruise back to Prince Edward Island. The last stations, south of Cabot strait, also furnished quite a respectable yield of newly-spawned mackerel eggs, which was not a little surprising in view of the fact that the hauls made but a few days previously on the opposite side of Prince Edward Island had yielded nothing but more or less arctic species.

The August cruise of the *Princess* (*vide* chart, p. 4) covered, roughly speaking, the same ground as the first. Close in to land, the yield consisted mainly of eggs and young of *Onos* and *Ctenolabrus,* until we reach the banks, when cod and mackerel make their appearance. These latter increased in numbers as the outward voyage proceeded, the *Onos* and *Ctenolabrus* gradually disappearing. Above the deep channel, *Sebastes* predominates; some few mackerel larvæ were also found. On the Anticosti bank, we find cod eggs once more, and the same alternation of cod above the banks, *Sebastes* over the channels, is continued all the rest of the way to Newfoundland, and thence southward to Prince Edward Island. Station 45, however, near the southwest point of Newfoundland, also furnished a rich yield of the arctic species *Mallotus villosus*, evidently indicating the existence of a cold current near at hand; on the southern side of Cabot strait, however, eggs of mackerel and *Ctenolabrus* were again encountered.

As will be seen from the foregoing, the gulf of St. Lawrence may be divided up into several zones, each with its own characteristic young-fish fauna. In the first place, a line drawn from Cabot strait to Anticosti will form the northern limit of occurence for the southern forms found in the gulf, such as mackerel, *Onos* and *Ctenolabrus*. Only at one or two of the more southerly stations situated near the coast of Newfoundland were some few specimens of these species found.

Northern species, however, may also be found south of this line, occurring more particularly in the southwestern portion of the gulf, west of the Magdalen islands. For the rest, the character of the young fauna varies with the depth; we find *Ctenolabrus* and *Onos* near land, and close to quite shallow banks, the bank forms consisting fo *G. callarias* and *Drepanopsetta*, while above the deep channels *Sebastes* is found. The mackerel, again, is encountered throughout all areas, subject to the restriction noted above.

B. The waters outside Nova Scotia and the Newfoundland Banks.

The cruises of the *Acadia* (*vide* chart, p. 4) reveal a similar grouping of the different species, according to depth, distance from land, and geographical position.

On the May cruise, the stations from Halifax out over the banks past Sable island yielded eggs of cod and haddock, several species of flounder, *Ammodytes*, and a very small number of *Ctenolabrus* above the shallower grounds near Sable island. Outside the banks we find *Sebastes*, but farther out again the yield becomes extremely poor until the outermost station (station 16), where a number of pelagic Atlantic forms were found. On reaching the Newfoundland banks, we find once more cod, *Drepanopsetta* and *Ammodytes*; above the deeper portions towards Cape Breton and Cabot strait, *Sebastes* is of more or less frequent occurrence.

The second cruise of the *Acadia* shows small yields at the start, off the southern point of Nova Scotia; strangely enough, however, we here find *Sebastes* at comparatively slight depths. This is probably connected with the fact that *Sebastes* in these southern waters (Bay of Fundy and New England waters) spawns in more or less shallow water. On the slopes, where the depth increases, we find numerous eggs of *Merluccius;* farther out, the Scopelidæ play a more prominent part. Ova of cod and haddock are now but sparsely found at all stations outside Nova Scotia; on the Newfoundland banks, however, they are once more encountered in great numbers, stations 81 to 83 being particularly rich. Eggs of *Drepanopsetta* also are fairly numerous here, while the arctic capelin bears witness to the vicinity of the polar current. From the banks over to Cape Breton, *Sebastes* is again more frequently found, *Onos* (hardly however, *Onos cimbrius*) only in very small quantities, *Ctenolabrus* only at station 91, quite close to land. We see, then, that in this area, likewise, distinction may be made between several different kinds of fauna. Up towards Newfoundland, we have—according to European terms—eggs and young of boreo-arctic fish, on the banks off Nova Scotia a boreal bank fauna, while out over the great depths, especially to the southward, the Atlantic species predominate.

On comparing the stock of young in these two areas; the gulf, and the waters outside Nova Scotia, we find that the gulf should most properly be regarded as a coastal water, where littoral and coastal forms are found in great numbers; we find the usual high degree of variation in temperature between summer and winter, with corresponding variation in the fauna between northern and southern forms; purely Atlantic species, however, do not appear in the hauls.

An interesting feature, by the way, is the fact that the mackerel is not represented at all in the *Acadia* material (but few eggs on the first cruise); while the greater portion of the *Ammodytes* taken during the investigations was furnished by the *Acadia*. It is remarkable also, that none of the cruises furnished a single herring larva, despite the fact that the herring occurs in nearly every part of the areas investigated.

IV. BIOLOGICAL CONDITIONS.

Modern marine research has shown us that life in the sea is to a high degree dependant upon hydrographical conditions: current, temperature, and salinity. We should, therefore, in seeking to explain the peculiar phenomena encountered with regard to the propagation of the fish in Canadian waters, base such endeavours upon the hydrographical data furnished by the expedition. These are, however, not yet compiled, in order and completeness, and we must for the present content ourselves with recalling the more prominent features. It will be obvious from the outset that an area subjected to such markedly contrasted influences as those of the Labrador current and the Gulf Stream must present many remarkable features both as regards fauna and biology, and it is only by bearing in mind the peculiar hydrographical conditions that we can explain the otherwise surprising data furnished by the Canadian Hydrographical Expedition with regard to the propagation of the most important species. On comparing the Canadian with the European waters in this respect, several peculiarities will at once be noticed, especially the pronounced transposition and extension of the spawning season, which here takes place in the case of several species, among those pre-eminently which on the eastern side of the Atlantic are counted as spring-spawners. A prominent example is that of the cod (in addition to haddock and *Drepanopsetta*) which spawns in considerable numbers in the gulf of St. Lawrence right on into the month of August, whereas in the Norwegian waters, its spawning is over in May. As a consequence of this, we may, in the gulf of St. Lawrence, find one and the same plankton haul to contain both newly-spawned cod eggs and newly-hatched mackerel young.

That cod and mackerel should find suitable spawning conditions in the same water and at the same time is remarkable indeed; in European waters, the spawning of these two species differs widely, both as regards time and place. What is more, it is only exceptionally that the mackerel come so far north as to touch the principal spawning grounds of the cod at all. The explanation may not unnaturally be imagined to lie in the abrupt changes of temperature encountered in the Canadian waters. The same natural conditions which cause Atlantic warm-water forms to meet, off the coasts of Newfoundland, with representatives of the arctic fauna, might well account for the fact that in the gulf of St. Lawrence, the cod of the far north are able to live and propagate there simultaneously with the more southerly mackerel. If we take a temperature series from the surface downwards in the gulf of St. Lawrence during summer, we find, within a vertical range of less than 100 metres, a difference in temperature equivalent to that encountered outside Newfoundland by sailing from the Gulf Stream over into the Labrador current, while on the eastern side of the Atlantic, such difference will involve a distance as from the North Sea to Spitzbergen.

In the gulf St. Lawrence, then, we find the different water layers varying so greatly in temperature as to afford favourable conditions both for cod and mackerel. That both species should live in the same stratum there is no reason to believe; on the contrary, it must be presumed either that the fish are themselves able to seek out the more suitable water layers, and avoid those less favourable, or that they are, owing to certain biological features, more or less passively led to frequent such strata as are by nature best adapted to their needs.

It is a well-known fact that certain species of fish, such as cod, herring, and mackerel, vary their habitat according to the temperature of the water. Cod and herring may at times move in shallow, at others in deeper, water, and in the southern Norwegian waters the mackerel seems rarely to move in towards the coast until the surface temperature is at about 10° C., a fact so generally recognized that some of the drift-net fishermen even carry a thermometer in order to make sure of not laying out their nets in a cold current.

Among the biological features which might be thought to act in this direction, we should first of all remember that the cod is a bottom fish, belonging essentially to the strata nearest the sea floor, where its food is found, and where its spawning takes place. The mackerel, on the other hand, is a pelagic species, frequenting—at any rate during the spawning season—the upper-water layers. Indeed, until the roe is spent, the mackerel hardly seems able to penetrate down beyond some 20 metres depth.

On glancing at a temperature series from the *Princess* station 30, where ova of cod and mackerel were found in one and the same sample, the phenomenon will easily be explained.

0 m	t = 16·1°	σ_t = 20·27
10 "	15·7°	20·33
25 "	10·5°	21·97
40 "	7·9°	22·99
50 "	5·65°	23·97
60 "	0·45°	25·40

If we now apply to these figures what we know of the biology of the cod and mackerel, it will be justifiable to conclude that the mackerel keep to the upper layers—down to about 25 m.—where the temperature is favourable to its needs, while the cod seek the lower strata, finding there more suitable conditions in this respect.

The yield of cod and mackerel eggs at this station gives the following numbers:—

	Cod.	Mackerel.
At surface	3 eggs.	172 eggs, 14 larvæ.
" 30-0 metres	12 "	8 " 3 "
" 60-0 "	25 "	1 "

Mackerel eggs and young are by far most numerous at the surface (in the horizontal hauls) the cod eggs, on the other hand, being found in greatest numbers farther down (vertical hauls). Naturally, however, this cannot be taken as indicating that the mackerel eggs were spawned near the surface, and the cod eggs lower down. The vertical position of fish ova in the layers is determined by the specific gravity of the former as compared with that of the water, and they will, under normal conditions, be found in water of specific gravity equal to their own. The specific gravity of ova, however, is not a constant magnitude; that of cod eggs, for instance, which normally varies but very slightly, may be affected by a low degree of salinity in the water, which has the effect of gradually reducing the weight of the eggs. If exposed to strong sunlight, again, or to comparatively high temperature, they will sink, even in water of high salinity; and the same applies to newly hatched young. This last is a very well-known phenomenon in marine hatcheries; I am, however, unable to give any definite figures, having had no opportunity this season of making experiments in this direction.

The specific gravity—and variation of same—in cod eggs at Flödevigen will be seen from the following experiments (Dahl & Dannevig; Undersökelser over nytten av Torskutlækningi Östlandske fjorde, Bil. I, p. 28).

The roe and young were placed in three separate receptacles in order to determine their approximate specific gravity.

I. Sp. gr. 1·019 at + 5·4° (sp. gr. *in situ*, 1·01796).
Ova, about one-third floating, others suspended, the remainder at the bottom.
Young, most at bottom, some suspended and at surface.

II. Sp. gr. 1·020 at + 5·4° (sp. gr. *in situ*, 1·01897).
Ova, more than half floating, the remainder at the bottom or suspended.
Young, about half floating, the rest at bottom or in suspension.

III. Sp. gr. 1·022 at + 5·4° (sp. gr. *in situ*, 1·020965).
Ova, practically all floating.
Young, practically all floating.

Station 30, above-mentioned, the specific gravity of the water near the surface oscillates about the value for specific gravity of cod eggs as noted in Norway; we might therefore have expected to find a greater number of ova at the surface. That this was not the case should possibly be ascribed to the influence of the high temperatures there prevailing.

We find, then, that the simultaneous spawning of cod and mackerel in one and the same water may be explained as due to conditions of temperature. And consequently, we cannot, in Canadian waters, distinguish between winter and spring-spawning fish, as is generally done in Europe; if any such biological distinction is to be made, it must be based upon the limits of temperature between which spawning takes place, a method which would of course be equally justifiable on the eastern side of the Atlantic.

The question arises, however, whether the temperature of the water really does exert such influence upon the spawning of the fish; whether other causes might not be imagined, and the explanation above suggested be found insufficient.

In this connection, it will be natural to recall the annual periodicity in the development of the sexual organs, which might be supposed to proceed independently of all external factors. It has, however, repeatedly been found, by investigation in other spheres, that where regularity of the seasonally varying physical conditions in animals or plants ceases, the annual period disappears, or becomes irregular and indistinct.

The influence of temperature upon the daily intensity of the spawning may easily be observed in a hatchery, at any rate where a spawning basin is employed. Also the degree to which spawning depends upon temperature is in particular most easily noticeable where the latter factor ranges beween 0° and + 5°, to a lesser extent when between + 5° and + 10°. Other influences may make themselves felt, as for instance of the amount and more or less regular distribution of the food, the fish spawning largely when well fed. This may, however, possibly be due to purely physical conditions, at any rate, as long as the amount of food consumed is sufficient for nourishment, as the expansion of the stomach will exert a pressure upon the ovaries. Furthermore, the salinity of the water may be supposed to have some effect though this will scarcely be of any importance as long as the variation involved is not too great.

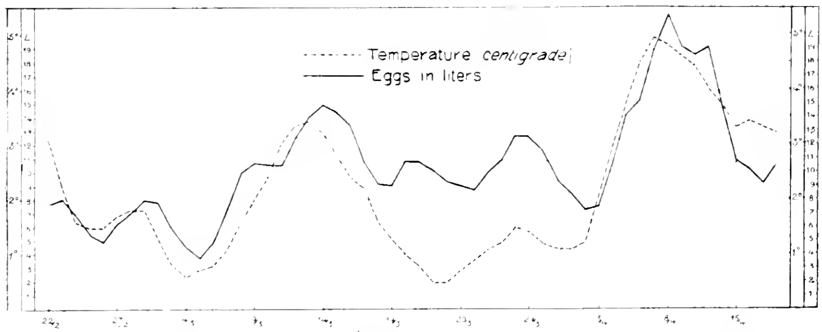


Fig. 23.

The curves here shown are based upon daily observations at the hatchery of Flödevigen during the spring of 1909, and indicate the fluctuations in temperature and spawning throughout the essential part of the spawning time. In order to present the clearest possible survey, I have here marked off, not the daily values, which vary considerably, but a mean value calculated each day from the observations of that date plus those of the two previous and the two subsequent days, i.e. a movable mean extending over five days.

V.—Possibilities of development, and relative frequency of the different stages.

In the foregoing chapters, we have dealt with the spawning of the different species in relation to depth, temperature and season. It now remains to consider how the development of the eggs in the separate species takes place, and what chances there are for their being hatched.

From the figures in table II, we obtain the following numbers of eggs and larvæ for the six most commonly occurring species:—

	Ova.	Larvæ.
Ctenolabrus	434	318
Scomber	5,575	47
Drepanopsetta	2,369	47
Gadus callarias and G. æglefinus	15,988	293
Onos	2,975	92
Merluccius	8,821	0

It will be seen that the gadoids here predominate, and among these, as we have already seen, the cod is of most frequent occurrence. Ova of *Merluccius* are also very numerous, but the material of these is of a somewhat casual character, being derived from only a few stations, where they must, however, have been present in great numbers.

The proportion between ova and young varies greatly: in the case of *Ctenolabrus*, we have nearly as many larvæ as eggs while of *Merluccius*, on the other hand, only eggs were found.

Such a table cannot, however, be used without reserve as a means of calculating the percentage hatched for the different species; the period of time required for development of the ova will need to be taken into consideration, as also the age of the young when captured. With most species it is true these points are insufficiently known, but in the case of the cod we have knowledge sufficient for a satisfactory discussion of the question despite the difficulties involved in following the development of ova under natural conditions.

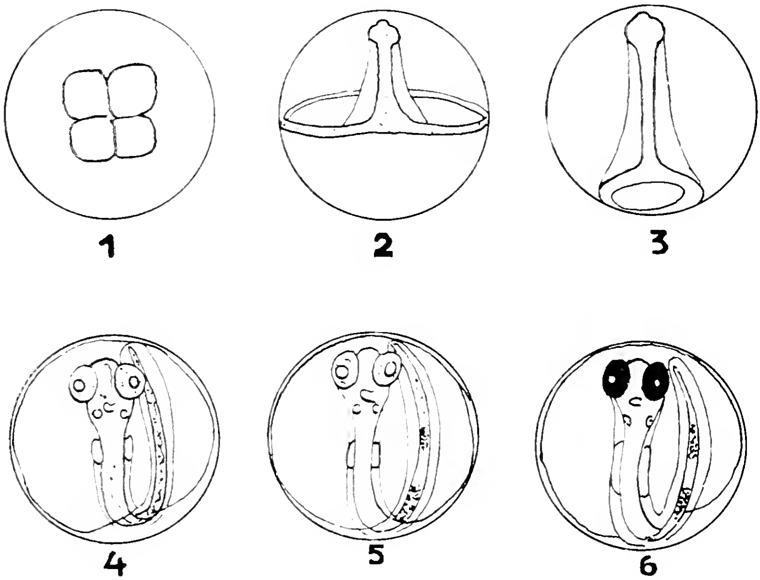
We know, of course, that the destruction of cod eggs and of the early stages of young must be enormous; were this not so, the sea would soon become over-populated with cod. As to the particular stage of development at which the germ is specially liable to destruction, however, we know, unfortunately, all too little.

Professor Apstein has, in his work entitled "Die Verbreiting der pelagischen Fischeier und Larven in der Beltsee und den angrenzenden Meeresteilen," 1908-09, dealt with these questions, and calculated that 72 cod eggs are required to produce one larva. This applies, of course, only to the waters investigated by him, and similarly, here only for a single year.

THE CANADIAN WATERS.

During the actual collection of the material, Dr. Hjort already noticed that there was a very great majority of newly spawned eggs, the later stages of development, and the larvæ, being far more rare. This was especially noticeable on the cruises of the *Princess*. Wishing to go closely into this question, I have, in determining the ova, noted throughout the number of eggs belonging to earlier and later stages; in the smaller samples all the ova were examined, in the case of the larger, only a representative portion was measured off and investigated, the figures thus obtained being then utilized for calculation of values for the whole.

In order to keep the work within a reasonable scope, distinction has here been made between three stages only; the first being the "germinative disc" stage, before the formation of the embryo (figs. 1-2), the second from the early pigmented embryo to well-developed pigmentation (figs. 3-4), and the third with pigmentation characteristic of the species (figs. 5-6). These stages correspond to Apstein's figs. 1-9, 10-18 and 19-22, from which these text figures have been taken.



EMBRYONIC DEVELOPMENT OF EGG OF COD.

This system of division is based on no other principle than that of obtaining, as easily as possible, a survey of the numerical values at the different stages, these last being so selected as to be distinguishable with no great difficulty when slightly magnified, and without regard to whether one stage may be of longer duration than another.

Apstein's tables show, for instance, that my "germinative disc" stage embraces 31 per cent of the total period of development in the ovum; stage II, 46 per cent, and stage III, only 23 per cent.

Taking the material consisting of cod eggs from the cruises of the *Princess* we find, for all hauls made, the following figures:—

	First cruise.	Second cruise.
Stage I	4,315	1,391
" II	799	340
" III	13	33
Larvae	6	6

We find then, on both cruises, an overwhelming majority of ova in the early stages. How is this to be explained? Is it to be taken as entirely due to mortality or destruction by some means, or do other factors here exert their influence, rendering the immediate impression produced by the above incorrect?

As we shall see, a table of this sort should be treated with the greatest caution. The proportion between the different stages is not only dependent, for instance, upon mortality, but also to a high degree upon the time at which the investigations were made: in addition to which, we have also to consider the position of the stations in relation to the spawning grounds.

When the investigations are carried out early in the spawning season, then naturally there will be a very high percentage of newly-spawned ova, and no late stages. Investigations later in the season, on the other hand, will give the opposite result.

A few rich hauls made on the exact spot where spawning takes place will give a different result to that obtained from hauls made out over the greater depths where the fish do not spawn; the few eggs, found outside the banks, will have been carried thither by the current, and the longer they have been adrift since leaving the spawning grounds, the farther will their development have advanced. On the spawning grounds, therefore, we must expect to find newly-spawned eggs in the majority; outside these localities, the later stages will predominate.

The investigations in the gulf of St. Lawrence are, however, to a very great extent free from these sources of error. It will be seen from the table that the spawning was in full progress during the first cruise of the *Princess* in June, and that so few late stages were found, may be explained as due to the fact of the hauls in question being made comparatively early in the season. On the August cruise of the *Princess*, however, this objection is no longer valid; the number of ova has greatly decreased, the season being now nearing its close, and a far greater quantity of eggs in the later stages might have been expected.

On going through the tables for the cruises of the *Princess* it will further be noticed that the proportion between newly-spawned ova and those in the later stages is approximately the same at all stations, only exceptionally do we find the later stages in the majority. No single station is so rich in newly-spawned ova as to exert a dominant influence upon the result as a whole, and there is thus no reason to question the representative value of the material on this head.

As regards the number of larvæ, this will always be subject to considerable error, as the larvæ are more or less endowed with power of motion, rendering capture more difficult, in addition to which, their age is often difficult to determine. Comparison between ova and young will therefore be subject to greater uncertainty than that between ova at different stages.

One thing we can, however, state with certainty: that the number of larvæ taken in the gulf of St. Lawrence was remarkably small.

In the case of the *Acadia*, the proportion between the different stages is somewhat better; here, however, we must consider cod and haddock together as one, these two species being indistinguishable one from another in the early stages of the ova.

—		Acadia I.		Acadia II.	
Stage I		1717		307	
Stage II		2183		197	
Stage III	cod	64	= 142	43	= 72
	haddock	78		29	
Larvæ	cod	4	= 5	260	= 275
	haddock	1		15	

For these cruises, the results are as might have been expected, the May cruise showing a comparatively large number early stages, with some advanced and a few larvæ, while that of July has many later stages and still more larvæ.

Before proceeding to consider the possible explanation of this great difference between the occurrence of early and later stages in the gulf of St. Lawrence, it may be of interest to compare the conditions in Canadian waters with those observed on the principal spawning grounds of the cod in European waters, viz.:—

LOFOTEN.

The material upon which the following discussion will be based consists of but a few samples from the otherwise extensive mass of material collected by Dr. Hjort during the winter and spring of 1913, the remainder having not yet been completely depth with as regards the stage of development of the ova. (*Vide* also Johan Hjort: Fluctuations in the great Fisheries of Northern Europe.)

These investigations, besides rendering possible a comparison between the wastage per cent in the two waters, further afford an excellent illustration of what has been mentioned in the foregoing as regards the extent to which the respective numerical value of the different stages depends on time and place of sampling.[1]

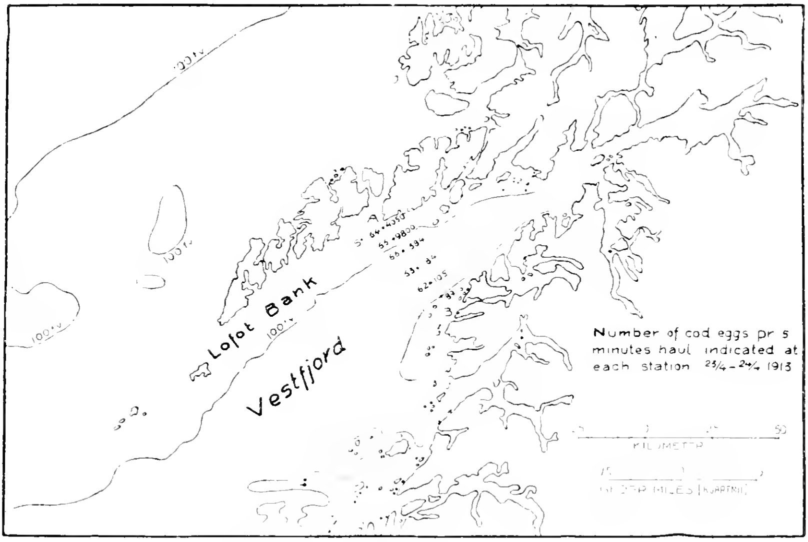


Fig. 25.

By way of illustrating these conditions under varying circumstances, I have chosen a section across the Vestfjord, as marked on the chart, and as the surface hauls (1 m. net, 5 min.) give the greatest amount of material, I have employed these only.

Six stations are noted on the chart, all from April 23 to April 24, 1913, the total number of cod eggs per 5 mins. surface haul being appended in each case. It will be noticed that station 65, on the edge, has a pronounced maximum, with 9,800 eggs in a single haul, after which the number rapidly decreases to either side, as we leave the spot where the principal spawning presumably took place. During the actual investigations it was frequently noted that the greatest numbers of eggs were taken on the fishing grounds themselves, where the fish were most densely congregated. The number diminishes gradually right over towards station 61, on reaching which we again find ourselves near the edge. Here we might thus again have expected to find a maximum; as a matter of fact, however, there was evidently very little spawning, if any, on these grounds. The banks here, by the way, are of very restricted extent, the bottom sloping abruptly down from land to a great depth.

With regard to the proportion between the different stages at each of these stations, we find the following figures (per cent):—

	Station 64.	Station 65.	Station 66.	Station 63.	Station 62.	Station 61.
I..	25	63	32	30	40	28
II..	55	30	53	57	30	46
III..	20	7	15	13	30	26

From this it will be seen that the earliest egg stages are found in the highest proportion at the very places where the total number was greatest; the more advanced

[1] The investigations extended throughout the whole of the spawning season, comprising also both the bank grounds and the greater depths. The same places were, moreover, investigated several times during the season, partly with the closing net, and partly with an ordinary surface net.

stages, on the other hand, being of great relative frequency as the distance from the spawning grounds increases.

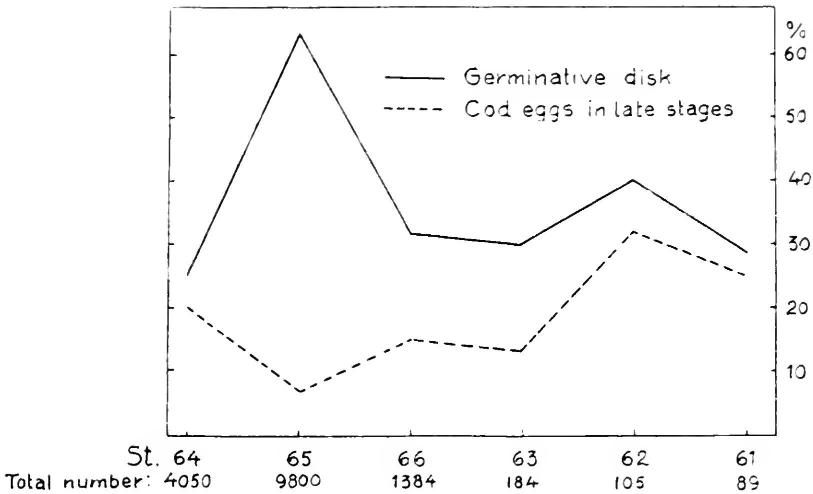


Fig. 26.

Station 62 differs slightly from the remainder, inasmuch as we here find a greater number of newly spawned eggs than was to be expected. Evidently, the current must have brought down the newly spawned eggs from the banks southwest of the station. The current at this spot can at times be very strong, and in this very direction. The numbers, however, both at stations 62 and 61, are not sufficiently great to furnish an exact picture of the stock there.

The curve for the later stages (III) shows throughout what might theoretically have been expected, the later stages themselves being proportionately fewest where most eggs were found. The curve rises as we move away from the spawning banks, as far as station 62, falling again over towards the land, thus indicating that we are once more approaching grounds where, in some slight degree, spawning takes place.

As we have seen, the proportion between the different stages varies greatly at different places, even for samples taken on one and the same day; the variation is, however, sufficiently regular to permit of our forming some opinion as to the cause. The example here shown is taken from a locality where the contrast is marked; great quantities of cod spawning within a restricted area, close to the very deep water where cod never spawn, but in which a certain quantity of eggs may be found, having been carried thither by the current. A different state of things would necessarily be encountered where the spawning takes place sparsely over areas of wide extent, especially if forming part of a restricted region of sea; at such places, there would never be the great difference between the relative frequency of the stages at the various stations.

Stations 64-65 and 66 were also previously investigated, viz.: 25/2-12/3 and 29/3. Not until the last-mentioned date however, were cod eggs found in great numbers; the principal spawning was then just commencing. At these three stations (30-31-32) (29/3) we find the following yield for the different stages (here stated in %).

	No.	I	II	III
Station 30 (=Station 64)........	23,600	93%	7%	0
Station 31 (=Station 65)........	19,400	50%	50%	0
Station 32 (=Station 66)........	2,340	25%	75%	0

The principal spawning this time takes place farther in on the banks; we find, however, again the same feature as before noted; where the eggs are found in greatest numbers, there also the number of those newly-spawned is at a maximum, its minimum falling there where the yield as a whole is poorest. We notice, moreover, that advanced stages are not yet present in the samples, this being doubtless due to the fact that the season is only just commencing.

If we now consider the results from Canada in conjunction with this sample from the Lofoten material, we obtain a table for comparison of the stages of development in the eggs from the different waters.

	Lofoten		Acadia I		Princess I		Acadia II		Princess II		"33"	
	29/3	23-24/3										
	Surface	Surface.	Surface	Vertical.	Surface	Vertical	Surface.	Vertical.	Surface	Vertical.	Surface.	Vertical.
Stage I............	62%	48%	43%	35%	84%	86%	52%	68%	64%	84%	95%	83%
Stage II..........	38%	40%	55%	49%	16%	13%	35%	29%	32%	15%	5%	14%
Stage III.........	0%	12%	2%	16%	0%	1%	13%	3%	4%	1%	0%	3%

From this it will be seen that the gulf of St. Lawrence is considerably behind the other localities with respect to the occurrence of later stages, both in the case of the earlier investigation and those made subsequently (*Princess I, Princess II,* and *No. 33*). The ova have here evidently a far poorer chance of being developed and hatched than in the other places; in the gulf of St. Lawrence the eggs must—at any rate occasionally—be liable to a high degree of mortality, either due to the hydrographical conditions or to their being preyed upon with unusual intensity.

The task of solving this question must be left to future investigations; I may, however, in conclusion, set forth such material as we have available for the consideration of what factors should be regarded as detrimental to the development of cod eggs and the growth of the young.

VI.—Influence of Temperature and Salinity upon the Development of Eggs and Growth of the Young.

In order to ascertain what effect the low bottom temperatures might possibly have upon the development of the ova in the gulf of St. Lawrence, Dr. Hjort approached Dr. Johansen and Dr. Krogh, of Copenhagen, who had previously at the Zoo-physiological Laboratory there, carried out a whole series of experiments with hatching of eggs at constant temperatures, with the request that they would repeat their investigations having the special object at present in view.

We are aware that cod in the gulf of St. Lawrence spawn near the bottom, i.e. in water frequently below 0°; the inherent upward tendency of the ova then lifts them to the water layers above, where they develop at considerably higher temperatures.

Dr. Johansen and Dr. Krogh then commenced experiments with fertilization of ova at low temperatures, from 0° to ÷ 2° C., the eggs being thereafter either maintained at various low temperatures or gradually transferred to warmer water, up to 6.6° C.

According to Dr. Johansen, the results showed:—

1. That fertilization can take place at a temperature between ÷0·6° and ÷2°C.

2. That full development can be obtained by ova fertilized at such temperature and thereafter exposed for nine days to a temperature between ÷ 0·7° C. and ÷ 1·4, mean value ÷ 1°, and afterwards transferred to warmer water (e.g. 0° to 3·3° C.)

3. That full development can be attained by ova fertilized at 0° C. and constantly kept in water at that temperature.

The mortality observed in the course of these experiments was considerable; as, however, these were carried out under conditions which in several respects must be less favourable than those prevailing in the sea, we should not, as Dr. Johansen also points out, attach too much weight to this. Even at the most favourable temperatures, the mortality was, in the apparatus employed by Dr. Johansen and Dr. Krogh, still considerable.

Dr. Johansen's experiments show, however, that the low temperature at the bottom in the gulf of St. Lawrence where the cod are to be found during spawning time, cannot be regarded as a general hindrance to the development and hatching of the ova.

With regard to the influence of high temperatures upon the development of the ova, we may refer to the experiments previously made by Johansen and Krogh (The Influence of Temperature and certain other Factors upon the Rate of Development of the Eggs of Fishes; Publications de Circonstance No. 68). These show that cod eggs may be hatched in water up to 12° C. H. C. Dannevig (late Director of Fisheries for Australia) has even hatched them in water at 14° C, (Scottish Fishery Board, 13th Report for 1894.)

At Flödevigen, where several hundred million cod eggs are annually hatched, low temperatures (down to 0° C.; the lowest figure at which we have worked) never seem to have any detrimental effect; the most favourable temperature would seem to be about 3°-5° C., while temperatures up to 8° or 10° occasion a higher degree of mortality. As the quantity of ova in the apparatus is very great, the direct cause of such mortality might possibly be lack of oxygen, or poisoning, despite the fact that the water is constantly renewed.

That the young can thrive at considerably higher temperatures in a greater mass of water is shown by an experiment which I made in the culture basin at Flödevigen during May and June, 1909. The basin is situated in the open air; it measures 34 by 22 by 5 m. and is used in the hatching operations as a water reservoir for the apparatus. It is supplied with sea water by means of a steam pump, and in order that the water may be constantly renewed, as well as for other reasons, the water for the hatching apparatus is always drawn from here.

On the 25th of May, when the hatching experiments were brought to a close, and the circulation of the water consequently ceased, about 100,000 young cod, from one to two days old, were liberated in the basin. The eggs from which these young were hatched had been spawned at about 7° C., and the development had taken place in the course of about nine days at temperatures between 7·6° and 9·5° C. At the time of liberation, the water in the basin at 3 m. depth had a specific gravity of 1·026 at 9·5° C. The young could now be seen every day in the water, at first near the surface, and later swimming for the most part in great shoals in the intermediate water layers.

On the 16th of June, I noted in my journal that up to fifty young could be counted at one time. On that day also, feeding was commenced with finely chopped *Mytilus edulis*. The water in the basin, by the way, was extremely rich in plankton, especially larvæ of molluscs and crustaceans, which, with some few copepods, made up the stomach contents in such of the young fish as were examined. On the same day, the water in the basin had reached a temperature of 20° C. at the surface, with a maximum, at 1 m. of 21·4° C., and a bottom temperature of 21·1° C.

On the 18th of June, eight fish were taken up and measured; they showed the following lengths: 25, 25, 27, 24, 24, 23, 23, 22 mm. The fish were by this time moving nearer the bottom.

The weather now set in colder for a time, with cloudy sky, and the temperature of the water sank somewhat. On the morning of the 21st, the surface showed 18·9° C.; maximum of 19·5° at 2 m. On that day, fresh sea water was pumped in (temperature 8·3° C.) and in the evening, after the surface water had been drawn off, and replaced by a new supply, the surface temperature was 19·4°, this being the maximum, while at 3·4m. a minimum of 15·7° C. was recorded.

On the 29th June, pumping was renewed, but as the young were considerably fewer, (and always at the bottom), the experiment was brought to a close. The temperature of the air had, during the last part of the time, been very high, with sunshine and slight wind.

This experiment shows therefore that the young can thrive—and even grow very rapidly—at temperatures up to 20°. The increment of growth from May 25, when the length was 3 to 4 mm. until June 18, amounts to about 20 mm. or about 0·8 mm. per day.

From the measurements available for growth of young in a free state, the latter would seem to grow less rapidly, presumably about 0·5 mm. per day.

Among other causes which might be imagined as affecting the development of ova, we may reckon the salinity of the water.

If cod spawn in water of lower salinity than that which corresponds to the specific gravity of the eggs, then these latter will necessarily sink to the bottom and be destroyed. And again, if eggs should by any means be transferred from water of their own specific gravity to considerably fresher water, the mortality here likewise would be very great.

As an illustration of the manner in which fresh water can affect the ova, the following data from an experiment which I carried out in March, 1909, at the hatchery may be quoted.

About twelve hours after fertilization, eggs were distributed in four glasses containing water of different specific gravity, and at approximately the same temperature. The glasses were placed in a cold room—temperature of air about 0° C. The water was not changed, only aerated from time to time with a large pipette.

The cleavage and the development generally were observed under the microscope. After the lapse of twenty hours some samples were taken and transferred to fresh sea water in order to ascertain whether the development could there proceed normally.

In the case of sample IV, this was repeatedly done.

The result of the experiment will be seen from the following table:—

1909.	Number of hours.	I Sp. Gr. 1·0247 T. 2·2°C.	II Sp. Gr. 1·020 T. 2·0 C.	III Sp. Gr. 1·015 T. 1·8	IV Sp. Gr. 1·010 T. 1·6
March 19, 2 p.m.	0	....	....	....	....
" 7 p.m.	5	All alive........	All alive.	All alive........	All alive. ..
" 10 p.m..	8	"	"	"	" ......
March 20, 10 a.m.. ..	20	" ...	"	"	Development often abnormal
" 21, 10 a.m.	44	"	"	"	Some dead.
" 23, 4 p.m......	98	"	"	"	More dead.
" 24, 10 a.m.......	116	"	"	"	Few alive.

A similar experiment with newly hatched young in water of:—

I..................................	Sp. gr.	1·0242	at	T = 2·0°C.
II..................................	"	1·020	"	2·2 "
III..................................	"	1·015	"	2·5 "
IV..................................	"	1·010	"	2·5 "
V..................................	"	1·008	"	2·7 "

gave the following results:—

I. All the young suspended; after the lapse of an hour some few at the bottom, after four hours the majority near bottom, but all living. After the lapse of 103 hours, some few were dead, but the remainder stood out well until the experiment was concluded after 148 hours.

II. All on the bottom by the end of an hour, some endeavouring to rise. Same course as previous sample, only slight mortality after eighty hours, until about half died by the end of 142 hours.

III. Some few suspended after a quarter of an hour, but at the end of an hour all at the bottom. Some few died after the lapse of fourty-six hours, mortality then increasing rapidly until all were dead by the end of 138 hours.

IV. All on the bottom after a quarter of an hour, some trying to work upwards. Some few died after four hours, more after twelve hours, the remainder with irregular pulsation of the heart. After thirty hours, many dead, and by the end of fifty-two hours from the commencement, none were left alive.

V. Some few died in the course of the first seven hours, and all within thirty-four hours from the start.

From the result of these experiments we may be justified in supposing that a stay of any duration in brackish water will be detrimental to eggs and young; this will, however, only occur under quite peculiar conditions, and can be of no importance with regard to the open sea.

Other factors which might be supposed to have some effect upon the development of the ova are: lack of fertilization, action of bacteria, and internal causes (natural death).

Prof. Apstein has, in his investigations in the Belt Sea and the western Baltic, shown that considerable quantities of dead—or as he considers, unfertilized—ova occur in the plankton samples. In his work above quoted, "Die Verbreitung der pelagischen Fischeier und Larven in der Beltsee und den angrenzenden Meeresteilen 1908-09," we find the following table for dead ova (p. 231):—

Per cent dead.	Pleuronectes platessa.	Pl. flesus.	Pl. limanda.	Gadus callarias.	Clupea sprattus.
Vertical	35	21·9	27·7	11·3	31·7
Surface	38·5	41	3·7	29	49·6
Deep water	20·6	19·8	17·5	12·7	30·3
Mean	28·4	20·9	20·4	12·8	31·9
Dead	1/4	1/5	1/5	1/8	1/3

These figures, however, appear abnormally high, for it must be remembered that dead ova—at any rate those of cod and plaice—are only exceptionally found suspended in the water, sinking otherwise very soon to the bottom, they would consequently only appear in plankton samples by mere accident. Unfertilized cod eggs may remain suspended for about two days; those of the plaice somewhat longer.

As to how far unfertilized or dead eggs appear in the samples from the Canadian waters, I am unable to say on the basis of the preserved material; the question would have to be dealt with by means of fresh plankton samples.

That cod eggs should be subject to "natural death" in any considerable degree is hardly probable; if such were the case, the mortality figures at the hatchery would be far higher than they are.

When working under normal conditions, solely with a view of obtaining the greatest possible amount of living young, and without regard to what quantity may be lost, the mortality percentage at Flödevigen amounts annually to something like 12 per cent for the entire period of hatching, including unfertilized eggs.

The figures for the three last years are as follows:—

	Per cent.
1912	12·5
1913	13·8
1914	11·0

These percentages are calculated from very large quantities, in 1913 for instance, 1,222 litres, about 550 millions of eggs, and they do not vary greatly from year to year. When much brackish water occurs on the coast, the mortality may increase considerably; this is, however, rarely of long duration. Similarly, if the weather for any length of time is dark and cloudy, the eggs may become entirely overgrown with bacteria, from which, however, they may be freed by being placed in a bath with water of high salinity. As to the degree of influence exerted by these bacteria (*Leptothrix?*) in a natural state I can say nothing from experience; possibly the conditions at the hatchery may be especially favourable to them.

As regards the growing up of the young, we have here to consider another factor, viz., that of nourishment. That this is of great importance to the growth of the young is certain, and possibly the most critical period of all in this respect is the time when the young first commence to take food; they do not live long without nourishment after the yolk-sac has been consumed.

In the spring of 1914, a number of newly hatched young were placed under observation at Flödevigen for the purpose of ascertaining when they commenced to take food, and what such then consisted of. The investigations were carried out by Prof. H. H. Gran, and led to the result that the young did not take any food until the yolk-sac had been absorbed, and that on commencing to feed, they appeared from the first to prefer animal matter, such as mollusc larvæ, nauplii, etc., seeming, strangely enough, to despise the innumerable diatom forms which are likewise present in the water.

Such food as was pumped in with the sea water was alone available to the young fish; but as the greater part of the plankton was retained in the apparatus, the nutritive matter was fairly concentrated there.

As to the influence exerted by conditions of nourishment upon the growing of the young in a natural state, this question has not yet been investigated, and it will probably form one of the earliest subjects for future fishery investigations.

It is, we may say, of prime importance in every way to ascertain what factor or factors normally hinder the germs of our most important fish in their development, to discover at what stage the destruction occurs, and by what means it takes place.

This will have to be done by investigation of the propagation of fish in the sea, and by experiments and artificial culture, both branches of the work proceeding in conjunction.

It is from such a point of view that I have in the foregoing pages endeavoured to treat the material of fish eggs and young collected by the Canadian expedition. Unfortunately, however, we still know far too little of these questions, and my work can therefore only be regarded as furnishing, in this respect, a preliminary survey of the complicated, yet highly interesting, conditions which prevail on the Atlantic coast of Canada.

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TABLE Ia.*

"Acadia" 1	Date.	Mallotus villosus.	Anarrhichas latifrons.	Chirolophis sp.	Drepanopsetta platessoides		Onos sp.		Pleuronectes sp.	Pl. limanda	Gadus sp.	G. callarias.	G. aeglefinus.	Liparis, sp.	Sebastes marinus.	Ammodytes tobianus	Ctenolabrus adspersus		Scomber scombrus		Myctophum, sp.	Scopelus sp.	Cyclothone, sp.	Omosudis elongatus
					Egg.		Egg.				Egg						Egg		Egg					
Station 2—	May 29																							
20-0																								
50-25																								
Station 3—	"																							
Surface							1									2			2					
30-0																								
100-50																								
Station 4—	"																							
30-0																								
80-40																2								
150-0									1							3								
Station 5—	May 30																							
Surface							3				65					1	1							
60-0											13					1	2	1						
Station 6—	"																							
Surface											1359	1					1							
40-0								1			223		1				3							
** Station 7—																								
Surface																								
Station 8—	"																							
Surface					6						295						1							
Vertical						3					56	2		1		7								
Station 9—	"																							
Surface											1													
25-0											2								1					
Station 10	"																							
Surface																								
Station 11—	"																							
Surface															10						1			
70-0																								
Station 12—	May 31																							
Surface																								
100-0																								
Station 13—	"																							
70-0																								
Station 14—	"																							
Surface																								
200																								
Station 15—	"																							
Surface																								
100-0																								
Station 16—	June 1																							
Surface																					1	5	2	
200-0																					1	13	3	2
Station 17—	"																							
Surface																								
200-0																						3		
Station 18—	"																							
Surface																								
Station 19—	"																							
Surface					2		1				134					5								
Station 20	June 2.																							
Surface					7						81													
Station 21	"																							
Surface					615						1334					4								
Station 22—	"																							
Surface					3						72					2								
Station 23	"																							
Surface				1	16						61													
70-0					5						1					9								
Station 24—	"																							
Surface					17						4			1		17								
100-0					3											3								
Station 25—	"																							
Surface					132						39													
120-0					12	4						1				8								
Station 26—	"																							
Surface																3								
100-0															3	1								
Station 27	June 3																							
Surface																								
Station 28	"																							
Surface																								
100-25																								
Station 29—	"																							
Surface					18		1			5	84													
55-0					3					5	21													
Station 30	"																							
Surface					24					3	66													
Vertical					7					8	9													
Station 31—																								
Surface					23						19													
Vertical															1	2								
Station 32—	"																							
Surface					33						1				43	7								
100-25					3						1				5									
Station 33	June 4																							
Surface					112						51													
Station 34—	"																							
Surface				5	26						22				1									
100-0															3	6								
Station 35—	"																							
Surface				2											1									
125-25			1												7									
Station 36—	"																							
Surface		1			22					1	28				1	5								
100-15																1								
		1	1	8	1089	7	6	1	1	22	4042	4	1	2	75	89	8	1	3		3	21	5	2

* The columns give the number of larvae when not otherwise stated. Depth is in metres except Acadia Sta. 44-91.

** Sample in bad condition.

TABLE Ib.

"Princess" I.	Date.	Mallotus villosus	Agonus decagonus.	Icelus bicornis	Anarrhichas latifrons	Cryptacanthodes maculatus	Chirolophis sp.	Drepanopsetta platessoides		Onos sp.	Gadus sp.	G. callarias.	G. aeglefinus.	Liparis sp.	Sebastes marinus.	Ammodytes tobianus	Ctenolabrus adspersus	Scomber scombrus
								Egg		Egg	Egg						Egg	Egg
Station 3—	June 9																	
Surface					1													
20-0																		
Station 4—	June 9																	
Oblique		1																
Station 5—	June 10																	
Surface																		
30-0								1			2							
Station 6	June 10																	
Surface								4		1	233							
60-0											24							
Station 7	June 10																	
Surface			1	1				7			700							
80-0								3			55							
Station 8	June 10																	
Surface								5	5		79	2						
40-0								4		1	21							
80-0						1												
Station 9	June 11																	
Surface										10	1				1	1		
80-0											1				17			
100-0								1			3				17			
Station 10—	June 11																	
Surface								18		5	93				1			
100-0											3							
Station 11	June 11																	
Surface							16	18			32							
50-0								2			8							
Station 12—	June 11																	
Surface								3			10							
100-0											7							
Station 13—	June 11																	
100-0							2											
Station 14—	June 11																	
Surface														1				
35-0																		
Station 15—	June 12																	
Surface								47			24					2		
80-0								3			11							
Station 16—	June 12																	
Surface								5		1	51					1		
100-0											3				7			
Station 17—	June 12																	
Surface								9			1124							
100-0								1		2	127							
Seation 18	June 12																	
Surface							3	369			1162							
50-0								2			34							
Station 19—	June 13																	
Surface								45			890						20	
80-0								5			50							
Station 20—	June 13																	
Surface												4			4			
100-0															33			
Station 21	June 13																	
100-0															10			
Station 22—	June 13																	
50-0											1							
Station 23	June 13																	
100-0															18			
Station 24—	June 15																	
Surface							1	27			60							162
30-0								10			9			1				27
Station 25	June 15																	
Surface							2	1			58							21
60-0								2			16							15
60-25											17							8
Station 26—	June 15																	
Surface								7			175						1	80
40-0								10			43							5
		1	5	1	1	1	24	609	5	20	5127	6		2	108	4	21	318

TABLE 16

Station	Date	Ova	Gadus sp.	Pleuronectes sp.	Liparis sp.	Sebastes marinus	Merluccius bilinearis	Tetragonurus	Scopelus sp.	Remarks
Station 49— Surface, 70-0 fms., 70-0 fms.	July [illegible]	10	9			11, 15				
Station 50— Surface, 50-0 fms., 80-0, 30-30	July 23					1				
Station 51— Surface, 70-0 fms., 70-30	July 23					10, 3			1	
Station 52— Surface, 50-0 fms.	July 24					3				
Station 53— Surface, 50-0 fms.	July 24						3000, 1500			
Station 54— Surface, 70-0 fms., 150-0 fms.	July 24						188			
Station 55— Surface, 50-0 fms., 150-0 fms.	July 24						2			
Station 56— 140-0 fms., 210-140 fms.	July 24	1					1	1		
Station 57— Surface, 50-0 fms., 150-50	July 24								1	
Station 58— Surface, 30-0 fms., 80-0, 100-30	July 24						205, 22, 21, 1			
Station 59— Surface, 25-0 fms.	July 25			1		1	1600, 2000			
Station 60— Surface, 50-0 fms.	July 25					5	485			
Station 61— Surface	July 25	1.35[illegible]	111		5		370			
Station 62— Surface, 50-0 fms.	July 27	8	121		4		10			
Station 63— Surface, 50-0 fms.	July 2[illegible]		1			10				
Station 64	July 2[illegible]									
Station 65— Surface, 70-0 fms., 60-0	July 2[illegible]					2, 11, 1				
Station 66— Surface, 30-0 fms., 20-0 fms.	July 27		1							
[illegible]	[illegible]									N. plankton samples
[illegible]	[illegible]									N. [illegible]
Station 90— [illegible]	July 29									
Total		45 28 201	576 200	1	4 1	229	1882	1	168	

[illegible]

TABLE Id.

"Princess" II	Date.	Mallotus villosus	Drepanopsetta platessoides		Onos sp.		Gadus sp.	G. callarias	G. aeglefinus	Pl. cynoglossus		Liparis sp.	Sebastes marinus	Gasterosteus aculeatus	Ctenolabrus adspersus		Scomber scombrus		Bothinae
			Egg		Egg		Egg			Egg.					Egg.		Egg		
Station 27—	August 3																		
Surface					8										17				
20-0					3										26				
Station 28—	August 3																		
Surface					23									1	11	2			
20-0					3	35									4	53		1	
20-0																			
Station 29—	August 4																		
Surface					11	25								1	8	33	5		
20-0						8										5		1	
Station 30—	August 4																		
Surface					2	5	3								1	23	172	14	
30-0						1	12									1	8	3	
60-0							25										1		
Station 31—	August 4																		
Surface							200										105		
30-0							46										2		
60-0							61										2		
Oblique						3	84									2	11	6	
Station 32—	August 4																		
Oblique							135											5	
30-0						1	51												
80-0							574						1						
Station 33—	August 4																		
Oblique																		2	
30-0																			
80-0																		7	
Station 34—	August 5																		
Oblique		12									1		19						
30-0																			
130-0		3											2					1	
Station 35—	August 5																		
Oblique													14						
30-0																			
130-0																			
Station 36—	August 5																		
Oblique			1				79					1	8						
60-0							25												
Station 37—	August 5																		
Oblique							84												
30-0				1									1						
80-0							12												
Station 38	August 5																		
Oblique													5						
40-0													1						
130-0													5						
Station 39—	August 5																		
Surface																			
Oblique				1									2						
40-0					1														
130-0													2						
Station 40	August 5																		
Oblique							102												
40-0							8												
70-0							7												
Station 41—	August 6																		
Oblique													27						
30-0		1											1						
130-0													8						
Station 42—	August 6																		
Oblique							1												
30-0		1					2												
100-0													1						
Station 43	August 6																		
Oblique													17						
30-0													3						
30-0																			
130-0													4						
130-0																			
Station 44—	August 6																		
30-0																			
130-0													2						
Station 45—	August 12																		
Surface		75						4					38						
Oblique		265		2				2					20					1	
30-0		30											12						
130-0		30											8						
Station 46—	August 12																		
Surface													8						
30-0													1						
130-0													4						
Station 47	August 12																		
Surface													3						
30-0																			
130-0													2						
130-0																			
Station 48	August 12																		
Surface							147						1			75	1		
30-0							5												
130-0							10												
Station 49—	August 12																		
Surface						1					2					54		2	
30-0						1													
70-0							10												
Station 50—	August 12																		
Surface				2		4	131					1				50	1		
40-0				1		3					1	1				18		4	
40-0																			
		417	1	7	51	87	1764	6			4	3	220	2	66	316	308	47	1

TABLE Ie.

Steam Drifter "N. 33"	Date	Mallotus villosus	Aspidophoroides monopterygius	Icelus bicornis	Cottus scorpius	Cottus tubalis	Chirolophus sp.	Drepanopsetta platessoides	Onos sp.		Gadus sp.	G. callarias.	Pleuronectes sp.	Liparis sp.	Sebastes marinus.	Gasterosteus aculeatus.	Ammodytes tobianus.	Ctenolabrus adspersus.	Scomber scombrus.
	Year							Egg	Egg		Egg		Egg					Egg	Egg
Station 3	June 1																		
Horiz. 0-2																			
15-20								9											
Station 4—	June 2																		
Horiz. 0-2								16			60								
Station 5—	June 3																		
Surface								3			4							127	
Station 6—	June 8																		
Surface								9			1703							82	
Station 7	June 9																		
Surface								7			600							29	
Station 8	June 9																		
Surface								2			150							5	
Station 9—	June 9																		
Surface								16			100								
Station 10—	June 9																		
Surface								3			154							1	
10-0											11								
25-10								1			3								
35-25											48								
Station 11—	June 9																		
Surface				....				2			150								
Station 12—	June 9																		
Surface								10			31								
Station 13—	June 9.																		
Surface								1			9					1			
Station 14—	June 10																		
Surface					1			8			87						2		
Station 15—	June 10																		
Surface				1			6	350			520								
Station 16	June 10																		
Surface							1	130			150								
Station 17—	June 10.																		
Surface		3			1	2	3	80			130			1			4		
Station 19—	June 24																		
Surface									1800		90				2				
Station 21—	June 25																		
Surface			1						6		26						2		
Station 22—	June 25																		
Surface							2		40		60				1				
Station 23—	June 25																		
Surface									420						5				6
Station 25—	June 26																		
Surface									25										
Station 26—	June 26																		
Surface									100						325				
Horiz. 15-30m									110		4								
Station 29—	June 30																		
Surface										4									3800
Station 35—	July 7																		
Horiz. 6-15m									192									12	525
Station 36	July 8																		
Horiz. 8-20											27								436
Station 39	July 13																		
Vertical 40-10											110							20	100
(50 fs + ?							18		1		12		1	2				20	6
Station 40—	July 13																		
Station 48—	July 26																		
Surface											2				3			1	4
Station 49	July 27																		
Surface ?											212								49
Vertical ?							1						6						
Station 54—	Aug. 7																		
Station 57—	9																		
107 fms. ?												1		3					
Station 58—	Aug. 10																		
Surface ?		3									26				1				
Station 59—	Aug. 10																		
Station 64	12																		
Station 67	17																		
Station 68	17																		
Station 69	18																		
Station 70	18																		
		6	1	1	2	2	31	635	2694	4	4479	1	7	6	337	1	8	207	4946

TABLE II.—Summary of the six most common species of fish. (All the cruises included.)

—	Surface.			Vertical hauls.*		
	Germinative disk.	Pigmented embryo.	Larvæ.	Germinative disk.	Pigmented embryo.	Larvæ.
Ctenolabrus	245	61	237	70	74	81
Scomber	2178	2231	16	774	392	31
Drepanopsetta	1118	1160	30	46	45	17
Gadus	10167	3528	276	1773	520	17
Onos	1323	1328	39	208	116	53
Merluccius	4496	773	....	3252	300	..
	19527	9081	598	6123	14	199

* Here also included some deep horizontal towings by ss. No. 33.

TABLE II a (1).—Egg and Larvæ *Ctenolabrus adspersus.*

—	Date.	Surface.			Vertical hauls.		
		Germinative disk.	Pigmented embryo.	Larvæ.	Germinative disk.	Pigmented embryo.	Larvæ.
"Acadia" I Station 5-8..	May 29 to June 4..	1	2	....	5	....	1
"Princess" I Station 19-26	June 9 to June 15.	6	15	....	....	....	.....
Acadia" II Station 91...	July 21 to July 29.	....	....	....	21	37	1
'Princess" II Station 27-50	Aug. 3 to Aug. 12.	4	33	237	18	11	79
"No. 33" Station 5-48.	June 1 to Aug. 18.	234	11	....	26	26	.....
		245	61	237	70	74	81

TABLE II a (2).—Egg and larvæ, *Ctenolabrus adspersus.*

—	Surface.			Vertical hauls.		
	Germinative disk.	Pigmented embryo.	Larvæ.	Germinative disk.	Pigmented embryo.	Larvæ.
"Acadia" I.						
Station 5	......	1	......	2	......	1
" 6	1	......	......	3	......	......
" 8	......	1	......	......	......	......
	1	2	......	5	......	1
"Princess" I.						
Station 19	5	15	......	......	......	......
" 26	1	......	......	......	......	......
	6	15	......	......	......	......
"Acadia" II.						
Station 91	......	......	......	21	37	1
"Princess" II.						
Station 27	3	14	......	17	8	......
" 28	1	10	2	1	3	53
" 29	......	8	33	......	......	5
" 30	......	1	23	......	......	1
" 31	......	......	......	......	......	2
" 48	......	......	75	......	......	......
" 49	......	......	54	......	......	......
" 50	......	......	50	......	......	18
	4	33	237	18	11	79
				Vertical and deep horizontal.		
No. "33"—						
Station 5	125	2	......	......	......	......
" 6	80	2	......	......	......	......
" 7	26	3	......	......	......	......
" 8	3	2	......	......	......	......
" 10	......	1	......	......	......	......
" 35	......	......	......	12	......	......
" 39	......	......	......	14	26	......
" 48	......	1	......	......	......	......
	234	11	......	26	26	

TABLE II a (3).—Larvæ, *Ctenolabrus adspersus.*

—	Length in mm.															
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	More than 17.
"Acadia" I Station 5	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...
"Acadia" II Station 91	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
"Princess" II Station 28	...	...	55	...	...	...	...	...	...	...	...	...	...	...	...	...	...
" 29	...	...	38	...	...	...	...	...	...	...	...	...	...	...	...	...	...
" 30	...	...	24	...	...	...	...	...	...	...	...	...	...	...	...	...	...
" 31	...	...	...	1	1	...	...	...	...	...	...	...	...	...	...	...	...
" 48	...	...	...	...	75	...	...	...	...	...	...	...	...	...	...	...	...
" 49	...	...	...	...	54	...	...	...	...	...	...	...	...	...	...	...	...
" 50	...	...	...	...	68	...	...	...	...	...	...	...	...	...	...	...	...

TABLE II b (1).—Egg and Larvæ, *Scomber scombrus.*

—	Date.	Surface.			Vertical hauls.		
		Germinative disk.	Pigmented embryo.	Larvæ.	Germinative disk.	Pigmented embryo.	Larvæ.
"Acadia" I Station 3-9	May 29 to June 4	3	...	...	...	...	...
"Princess" I Station 24-26	June 9 to June 16	263	...	...	55	...	...
"Princess" II Station 28-50	Aug. 8 to Aug. 12	80	204	16	10	14	31
"33" Station 23-49	June 1 to Aug. 18	1,832	2,027	...	709	378	...
		2,178	2,231	16	774	392	31

TABLE II b (2).—Egg and Larvæ, *Scomber scombrus*.

—	Surface.			Vertical haul.		
	Germinative disk.	Pigmented embryo.	Larvæ.	Germinative disk.	Pigmented embryo.	Larvæ.
"Acadia" I.—						
Station 3	2					
" 9	1 (?)					
	3					
"Princess" I.—						
Station 24	162	...	...	27		
" 25	21	...	...	23		
" 26	80	...	...	5		
	263	...	...	55		
'Princess" II.—						
Station 28	...	...	...	...	...	1
" 29	2	3	...	...	...	1
" 30	1	171	14	...	9	3
" 31	75	30	...	10	5	6
" 32	...	...	...	...	...	5
" 33	...	...	...	...	...	9
" 34	...	...	...	...	...	1
" 45	...	...	...	...	...	1
" 48	1					
" 49	...	...	2			
" 50	1	...	...	...	...	4
	80	204	16	10	14	31
No. "33"—						
Station 23	3	3				
" 29	1,800	2,000				
" 35	...	...	...	525		
" 36	...	...	...	144	312	
" 39	...	...	...	40	66	
" 48	4					
" 49	25	24				
	1,832	2,027	...	709	378	

TABLE II b (3).—Larvæ, *Scomber scombrus.*

—	Length in m.m.															
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	More than 17.
Princess II.—																	
Station 28	....	...	..	...	1	....	..	....	...	....	....	....	....	....	...	...	....
" 29	...	..	...	1	...	....	....	....	...	....	....	....	....	....	...	...	....
" 30	..	1	8	3	3	1	1	....	...	....	....	....	....	....	...	...	....
" 31	....	...	2	...	4	....	.	....	...	....	....	....	....	....	...	...	....
" 32	....	...	3	..	2	....	....	....	...	....	....	....	....	....	...	...	....
" 33	..	....	2	5	1	1	...	....	...	....	....	..	....	....	...	...	.. ....
" 34	..	....	...	.....	1	...	...	..	...	...	....	....	....	....	...	...	....
" 45	...	..	....	...	...	....	....	1	....	...	...	...	...	....	...	...	.. ....
" 49	....	....	..	..	2	....	....	..	...	...	....	....	....	....	...	...	....
" 50	....	...	2	2	...	...	....	....	...	..	..	....	....	...	...	...	.. . .

TABLE II c (1).—*Sebastes marinus.*

—	Date.	Surface. Larvæ.	Vertical Hauls. Larvæ.
"Acadia" I— Station 11-36	May 29 to June 4	56 (56)	19 (19)
"Princess" I— Station 9-23	June 9 to June 15	6 (6)	102 (93)
"Acadia" II— Station 37—90	July 21 to July 29	73 (73)	155 (155)
"Princess" II— Station 32-48	Aug. 3 to Aug. 12	50 (50)	170 (165)
No. "33"— Station 19-58	June 1 to Aug. 18	337 (37)	
		522 (222)	446 (432)

() Numbers measured.

TABLE II c (2).—*Sebastes marinus.*

	Surface.		Vertical hauls.	
	Total number.	Midle length.	Total number.	Midle length.
"Acadia" I—				
Station 11	10	7·8		
" 26	...	...	3	8.0
" 31	...	...	1	8·0
" 32	43	8·7	5	8·0
" 34	1	8·0	3	7·3
" 35	1	8·0	7	8·0
" 36	1	7·0		
	56	...	19	
"Princess" I—				
Station 9	1	8·0	34 (25)	8·3
" 10	1	9·0		
" 16	...	...	7 (7)	8.3
" 20	4	7·8	33 (33)	8·4
" 21	...	...	10 (10)	8·1
" 23	...	...	18 (18)	8·1
	6	...	102 (93)	
"Acadia" II—				
Station 37	7	7·4		
" 38	2	6·5	52	7·3
" 39	...	...	22	7·5
" 49	...	...	29	7·9
" 50	1	9·0		
" 51	40	7·6	3	8·7
" 52	...	...	3	7.0
" 59	...	...	1	8·0
" 60	...	...	3	6·7
" 63	...	...	10	6·4
" 65	2	6·5	15	6·5
" 67	...	...	9	5·3
" 69	...	...	1	8·0
" 70	1	7·0		
" 72	5	7·6		
" 76	5	8·2		
" 84	...	...	2	7.5
" 86	...	...	4	10·5
" 88	9	6·3	1	8·0
" 90	1	8·0		
	73	...	155	
"Princess" II—				
Station 32	...	...	1 (1)	9·0
" 34	...	...	21 (21)	9·6
" 35	...	...	14 (14)	11·7
" 36	...	...	8 (8)	8.8
" 37	...	...	1 (1)	9·0
" 38	...	...	11 (6)	7·0
" 39	...	...	4 (4)	8·0
" 41	...	...	36 (36)	10·0
" 42	...	...	1 (1)	10·0
" 43	...	...	24 (24)	10·3
" 44	...	...	2 (2)	8·5
" 45	38	8·9	40 (40)	8·7
" 46	8	9·6	5 (5)	7·8
" 47	3	13·3	2 (2)	12·0
" 48	1	8·0		
	50	...	170 (165)	
No. "33"—				
Station 19	2 (2)	7·0	...	...
" 22	1 (1)	8·0	...	...
" 23	5 (5)	8·0	...	...
" 26	325 (25)	8·0	...	...
" 48	3 (3)	9·7	...	...
" 58	1 (1)	8·0	...	...
	337 (37)			

TABLE II d.—*Chirolophis* sp.

—	Surface.		Vertical.	
	Total number.	Length in mm.	Total number.	Length in mm.
"Acadia I"—				
Station 23	1	10		
" 34	5	ca. 10		
" 35	2	ca. 10		
	8			
"Princess" I—				
Station 11	16	ca. 12		
" 13			2	10-11
" 18	3	8-10		
" 24	1	10		
" 25	2	ca. 8		
	22		2	
No. "33"—				
Station 15	6	ca. 12		
" 16	1	12		
" 17	3	11-13		
" 22	2	ca. 8		
" 39			18	8-10
" 49			1	ca. 12
	12		19	

TABLE II e.—*Liparis* sp.

—	Surface.		Vertical hauls.	
	Total number.	Length in mm.	Total number.	Length in mm.
"Acadia" I—				
Station 8			1	3
" 24	1	4		
	1		1	
"Princess" I—				
Station 14	1	5		
" 24			1	5
"Acadia" II—				
Station 81	6	4-7		
"Princess" II—				
Station 36			1	9
" 50	1	10	1	8
	1		2	
No. "33"—				
Station 17	1	4		
" 39			2	4-3
" 57			3	25-30
			5	

TABLE II f (1).—Egg and Larvæ, *Drepanopsetta platessoides.*

—	Date.	Surface.			Vertical hauls.		
		Germinative disk.	Pigmented embryo.	Larvæ.	Germinative disk.	Pigmented embryo.	Larvæ.
"Acadia" I Station 8-36.	May 29 to June 4..	322	734		10	23	7
"Princess" I Station 3-26.	June 6 to June 15	260	305	5	29	15	
"Acadia" II Station 49-83.	July 21 to July 29.	7	25	23		3	5
"Princess" II Station 36-50	Aug. 3 to Aug. 12.			2		1	5
"33" Station 3-17.	June 1 to Aug. 18.	529	96		7	3	
		1118	1160	30	46	45	17

TABLE II f (2).—Egg and Larvæ, *Drepanopsetta platessoides.*

—	Surface.			Vertical haul.		
	Germinative disk.	Pigmented embryo.	Larvæ.	Germinative disk.	Pigmented embryo.	Larvæ.
"Acadia" I						
Station 8..		6				3
" 19..	2					
" 20..	2	5				
" 21..	200	415				
" 22..	1	2				
" 23..	3	13		1	4	
" 24..	6	11		2	1	
" 25..	18	114			12	4
" 29..	2	16			3	
" 30..	7	17		7		
" 31..	18	5				
" 32..		33			3	
" 33..	57	55				
" 34..	2	24				
" 36..	4	18				
	322	734		10	23	7
"Princess" I						
Station 5..					1	
" 6..	3	1				
" 7..		7		1	2	
" 8..	3	2	5	3	1	
" 9..					1	
" 10..	3	15				
" 11..	11	7		2		
" 12..	2	1				
" 15..	22	25		3		
" 16..		5				
" 17..		9		1		
" 18..	189	180		2		
" 19..	20	25		3	2	
" 24..	6	21		4	6	
" 25..		1		1	1	
" 26..	1	6		9	1	
	260	305	5	29	15	

TABLE II f (2).—Egg and Larvæ, *Drepanopsetta platessoides*—Con.

—	Surface.			Vertical haul.		
	Germinative disk.	Pigmented embryo.	Larvæ.	Germinative disk.	Pigmented embryo.	Larvæ.
"Acadia" II						
Station 49..	....	....	....	....	....	1
" 81..	1	3	7	....	1	
" 82..	2	9	....	....	2	3
" 83..	4	13	16	....	....	1
	7	25	23	....	3	5
"Princess" II						
Station 36..	....	....	....	....	1	
" 37..	....	....	....	....	....	1
" 39	....	....	....	....	....	1
" 45..	....	....	....	....	....	2
" 50..	....	....	2	....	....	1
	....	....	2	....	1	5
No. "33"						
Station 3..	....	....	....	6	3	
" 4..	2	8	....	....	....	
" 5..	2	1	....	....	....	
" 6..	9	....	....	....	....	
" 7..	7	....	....	....	....	
" 8..	2	....	....	....	....	
" 9..	9	1	....	....	....	
" 10..	1	2	....	1	....	
" 11..	1	1	....	....	....	
" 12 .	10	....	....	....	....	
" 13..	....	1	....	....	....	
" 14..	8	....	....	....	....	
" 15..	310	40	....	....	....	
" 16..	95	35	....	....	....	
" 17..	73	7	....	....	....	
	529	96	....	7	3	

TABLE II f (3).—Larvæ, *Drepanopsetta platessoides*.

—	Length in mm.																
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	More than 17.
"Acadia" I—																	
Station 8....	....	...	...		2	....	....	...	...	.	....	....	....	....	....	....	
" 25....	....	....	..	2	1	1	....	....	...	...	..	...	....	....	....	...	
"Acadia" II—																	
Station 49....	....	....	....	....	...	....	....	....	..	...	1	..	...	...	....	...	
" 81....	....	...	....	...	6	..	....	....	...	...	.	1	...	...	....	..	
" 82....	....	....	....	....	....	3	...	....	.	...	..	...	....	...	....	...	
" 83....	....	....	....	....	...	...	...	...	1	7	....	...	...	...	....	...	
"Princess" I—																	
Station 8....	....	..	...	...	6	....	....	....	....	....	....	....	....	...	...	..	
"Princess" II—																	
Station 37....	....	...	....	....	....	...	....	....	....	....	....	....	...	...	....	1	
" 39....	....	....	....	....	1	....	....	....	...	...	....	....	....	....	....	....	
" 45....	...	...	....	....	..	....	....	...	..	....	....	...	....	....	....	....	2 (20 mm.)
" 50....	....	....	....	2	...	....	....	...	1	....	....	...	....	....	...	..	

TABLE II g (1).—Egg and Larvæ, *Gadus* sp.

—	Date	Surface.						Vertical hauls.					
		Egg.				Larvæ.		Egg.				Larvæ.	
		Germinative disk.	Pigmented embryo.	*Gadus callarias.*	*Gadus æglefinus.*	*Gadus callarias.*	*Gadus æglefinus.*	Germinative disk.	Pigmented embryo.	*Gadus callarias.*	*Gadus æglefinus.*	*Gadus callarias.*	*Gadus æglefinus.*
"Acadia" I— Station 5-36..	May 29 to June 4...	1601	2025	59	31	1	...	116	158	5	47	3	1
"Princess" I— Station 3-26..	June 9 to June 15...	3940	743	9	.....	6	...	375	56	3	1	....	....
"Acadia" II— Station 49-84..	July 21 to July 29...	284	187	43	28	250	14	23	10	...	1	10	1
"Princess" II— Station 27-50..	Aug. 3 to Aug. 12...	310	152	19	.....	4	....	1081	188	14	...	2	....
"33"— Station 4-58..	June 1 to Aug. 18...	4032	232	..	..	1	...	178	31	6	...	...	...
		10167	3339	130	59	262	14	1773	443	28	49	15	2

TABLE II g (2).—Egg and Larvæ, *Gadus* sp.

—	Surface. Egg. Germinative disk.	Surface. Egg. Pigmented embryo.	Surface. Egg. G. callarias.	Surface. Egg. G. aeglefinus.	Surface. Larvæ. G. callarias.	Surface. Larvæ. G. aeglefinus.	Vertical hauls. Egg. Germinative disk.	Vertical hauls. Egg. Pigmented embryo.	Vertical hauls. Egg. G. callarias.	Vertical hauls. Egg. G. aeglefinus.	Vertical hauls. Larvæ. G. callarias.	Vertical hauls. Larvæ. G. aeglefinus.
"Acadia" I.—												
Station 5	61	4	....	....	....	....	12	....	....	1		
" 6	94	1,250	....	15	1	....	66	117	....	40	....	1
" 7	ca. 100 damaged eggs, probably haddock.											
" 8	146	137	1	11	.	....	23	24	3	6	2	
" 9	1	....	....	....	....	....	1	1				
" 19	55	76	....	3								
" 20	47	32	....	2								
" 21	850	440	44									
" 22	70	1	1									
" 23	60	1	....	....	..	....	....	1				
" 24	4											
" 25	20	13	6	....	....	....	....	....	....	....	1	
" 29	36	42	6	....	..	..	7	12	2			
" 30	60	5	1	....	....	....	7	2				
" 31	19											
" 32	....	1	....	....	....	....	....	1				
" 33	32	19										
" 34	20	2										
" 36	26	2										
	1,601	2,025	59	31	1	....	116	158	5	47	3	1
"Princess" I.—No. 33.—												
Station 4	60											
" 5	4											
" 6	1,700	3										
" 7	600											
" 8	150											
" 9	100											
" 10	153	1	....	....	.	..	60	2				
" 11	150											
" 12	30	1										
" 13	7	2										
" 14	83	4										
" 15	500	20										
" 16	115	35										
" 17	124	6										
" 19	73	17										
" 21	21	5										
" 22	33	27										
" 26	...	....	....	....	....	....	1	3				
" 36	....	....	....	....	....	....	9	13	5			
" 39	....	....	....	....	....	....	108	13	1			
" 48	2											
" 49	116	96										
" 57	....	....	....	....	1							
" 58	11	15										
	4,032	232	...	....	1	..	178	31	6			
"Acadia" II.—												
Station 49	4	....	5	...	....	3						
" 59	....	....	....	....	..	....	....	....	....	....	....	1
" 61	90	20	1									
" 62	105	14	2									
" 63	1											
" 66	....	....	....	....	....	....	....	1				
" 68	....	....	....	....	....	1	11	1				
" 80	6	13	3	.	12							
" 81	37	65	11	11	20	6	9	3	...	1		
" 82	40	71	13	17	3	1	3	5				
" 83	1	4	8	.	206	1	.	....	....	..	10	
" 84	...	....	.	.	9	2						
	284	187	43	28	250	14	23	10	...	1	10	1

TABLE II g (2).—Egg and Larvæ, *Gadus* sp.—*Con.*

—	Surface.						Vertical hauls.					
	Egg.				Larvæ.		Egg.				Larvæ.	
	Germinative disk.	Pigmented embryo.	G. callarias.	G. aeglefinus.	G. callarias.	G. aeglefinus.	Germinative disk.	Pigmented embryo.	G. callarias.	G. aeglefinus.	G. callarias.	G. aeglefinus.
"Princess" II.—												
Station 30	1	2	....	....	....	....	24	11	2			
" 31	148	45	7	....	....	....	124	17				
" 32	....	....	....	....	....	....	687	71	2			
" 36	....	....	....	....	....	....	88	12	4			
" 37	....	....	....	....	....	....	41	52	3			
" 40	....	....	....	....	....	....	104	13				
" 42	....	....	....	....	....	....	2	1				
" 45	....	....	....	....	4	....	....	....	....	....	2	
" 48	48	89	10	....	....	....	2	10	3			
" 49	....	....	....	....	....	....	9	1				
" 50	113	16	2									
	310	152	19	....	4	....	1,081	188	14	....	2	
"Princess" I.—												
Station 5	....	....	....	....	....	....	1	....	1			
" 6	206	26	1	....	....	....	22	2				
" 7	618	82	....	....	....	....	48	7				
" 8	69	10	....	....	2	....	19	2				
" 9	....	1	....	....	....	....	1	3				
" 10	49	44	....	....	....	....	2	1				
" 11	29	3	....	....	....	....	8					
" 12	9	1	....	....	....	....	5	2				
" 15	5	18	1	....	....	....	4	5	1	1		
" 16	34	15	2	....	....	....	1	2				
" 17	1,076	54	....	....	....	....	114	12	1			
" 18	855	307	....	....	....	....	29	5				
" 19	750	135	5	....	....	....	47	3				
" 20	....	....	....	....	4							
" 22	....	....	....	....	....	....	1					
" 24	51	9	....	....	....	....	4	5				
" 25	37	21	....	....	....	....	30	3				
" 26	158	17	....	....	....	....	39	4				
	3,940	743	9	....	6	....	375	56	3	1		

TABLE II g (3).—Larvæ, *Gadus callarias.*

—	Length in mm.																
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	15	17	More than 17
"Acadia" I—																	
Station 6	....	1	..	....	....	....	....	....	....	..	....	....	....	....	....	..	......
" 8	....	..	....	1	1	....	....	....	....	....	....	....	....	....	....	..	.....
" 25	....	..	..	1	....	..	....	....	....	....	....	....	....	....	....	..	....
"Princess" I—																	
Station 8	....	....	....	2	....	....	....	....	....	....	....	....	....	....	....	..	..
" 20	....	..	....	2	....	1	....	....	...	1	..	..	....	....	....	....	..
"Acadia" II—																	
Station 80	....	4	....	3	4	1	....	....	....	....	....	....	....	....	....	....	....
" 81	....	....	....	....	20	..	....	....	....	....	....	....	....	....	....	..	....
" 82	....	..	2	..	1	....	....	..	.	....	....	....	....	....	....	....	....
" 83	....	....	....	....	..	216	....	....	..	....	....	....	....	....	....	....	....
" 84	....	..	....	....	9	....	....	....	..	....	..	..	....	....	....	....	....
"Princess" II—																	
Station 45	....	..	....	....	....	....	1	1	1	1	2	....	....	....	....	....	....
"33"—																	
Station 57	....	....	....	....	..	....	..	....	....	..	....	....	....	....	....	..	1 (21 mm)

TABLE II g (4).—Larvæ, *G. aeglefinus.*

—	Length in mm.																
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	More than 17
"Acadia" I—																	
Station 6	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Acadia" II—																	
Station 49	....	....	....	....	....	....	..	....	....	....	....	....	1	2	....	..	..
" 59	....	....	....	....	....	1	....	..	....	....	....	....	..	..	....	....	....
" 68	..	....	....	....	....	....	..	....	....	..	1	....	..	....	....	..	....
" 81	....	....	3	3	..	....	....	....	....	....	..	....	....	....	....	....	....
" 82	....	..	1	....	....	....	..	....	....	....	....	..	....	..	....	..	....
" 83	....	....	1	..	....	....	....	....	....	....	....	....	....	....	....	..	....
" 84	....	....	....	2	....	....	..	....	..	....	....	....	....	..	....	..	....

TABLE II h (1).—Egg and Larvæ, *Onos.*

—	Date.	Surface.			Vertical hauls.		
		Germinative disk.	Pigmented embryo.	Larvæ.	Germinative disk.	Pigmented embryo.	Larvæ.
"Acadia" 7—							
Station 3-29	May 29 to June 4	5	1	......	......	......	1
"Princess" I—							
Station 6-17	June 9 to June 15	15	2	......	1	2	
"Acadia" II							
Station 47-62	July 21 to July 29	158	35	......	11		
"Princess" II—							
Station 27-50	Aug. 3 to Aug. 12	23	21	35	2	5	52
"33"—							
Station 19-39	June 1 to Aug. 18	1122	1269	4	194	109	
		1323	1328	39	208	116	53

TABLE II h (2).—Egg and Larvæ. *Onos.*

—	Surface, Germinative disk.	Surface, Pigmented embryo.	Surface, Larvæ.	Vertical hauls. Germinative disk.	Vertical hauls. Pigmented embryo.	Vertical hauls. Larvæ.
"Acadia" I—						
Station 3	1					
" 5	3					
" 6	.....	.....	.....	.....	.....	1
" 19	1					
" 29	.....	1				
	5	1	.....	.....	.....	1
"Princess" I—						
Station 6		1				
" 8					1	
" 9	10					
" 10	4	1				
" 16	1					
" 18	.....	.....	.....	1	1	
	15	2	.....	1	2	
"Acadia" II—						
Station 47	20	20	.....	10		
" 49	10					
" 56	.....	.....	.....	1		
" 61	120	15				
" 62	8					
	158	35	.....	11		
"Princess" II—						
Station 27	4	4	.....	1	2	
" 28	15	8	.....	1	2	35
" 29	4	7	25	.....	.....	8
" 30	.....	2	5	.....	.....	1
" 31	.....	.....	.....	.....	.....	3
" 32	.....	.....	.....	.....	.....	1
" 39	.....	.....	.....	.....	1	
" 49	.....	.....	1	.....	.....	1
" 50	.....	.....	4	.....	.....	3
	23	21	35	2	5	52
No. "33"—						
Station 19	800	1000				
" 21	3	3				
" 22	9	31				
" 23	220	200				
" 25	15	10				
" 26	75	25	.....	110		
" 29	.....	.....	4			
" 35	.....	.....	.....	84	108	
" 39	.....	.....	.....	.....	1	
	1122	1269	4	194	109	

TABLE II h (3).—Larvæ, *Onos*.

—	Length in mm.																
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	More than 17.
"Acadia" I—																	
Station 6	....	1	..	....	....	....	....	....	....	....	....	....	....	....	....	....	....
"Princess" II—																	
Station 28	....	3	5	....	....	....	....	....	....	....	....	....	....	....	....	....	....
" 29	....	3	3	....	....	....	....	....	....	....	....	....	....	....	....	....	....
" 30	....	6	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
" 31	....	....	3	....	....	....	....	....	....	....	....	....	....	....	....	....	....
" 32	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....
" 49	....	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....
" 50	....	....	7	....	....	....	....	....	....	....	....	....	....	....	....	....	....
No. "33"—																	
Station 29	....	....	4	....	....	....	....	....	....	....	....	....	....	....	....	....	....

TABLE II i.—Egg and Larvæ, *Merluccius merluccius*.

—	Surface.			Vertical haul		
	Germinative disk.	Pigmented embryo.	Larvæ.	Germinative disk.	Pigmented embryo.	Larvæ.
'Acadia" II—						
Station 44	2					
" 47	7	....	....	1		
" 53	2650	350	....	1400	100	
" 54	176	12				
" 55	1	1				
" 56	....	....	....	1		
" 58	200	5	....	50		
" 59	750	250	....	1800	200	
" 60	400	85				
" 61	300	70				
" 62	10					
	4496	773	....	3252	300	

TABLE II j.—*Ammodytes tobianus.*

	Surface.		Vertical hauls.	
	Total number.	Length in mm.	Total number.	Length in mm.
"Acadia" I—				
Station 3	2			
" 4	.....	.....	5	ca 15
" 5	1	ca 25	1	ca 15
" 8	.....	.....	7	15-22
" 19	5	15-20		
" 21	4	ca 15		
" 22	2	12-15		
" 23	.....	.....	9	6-10
" 24	17	10-18	3	8-14
" 25	.....	.....	8	10-13
" 26	3	10-15	1	10
" 31	.....	.....	2	12-20
" 32	7	8-22		
" 34	.....	.....	6	ca 15
" 36	5	12-17	1	12
	46	.....	43	
"Princess" I—				
Station 9	1	15		
" 15	2	7-7		
" 16	1	18		
	4			
"Acadia" II—				
Station 82	1	15	1	16
" 83	3	12-20		
	4	.....	1	
No. "33"—				
Station 14	2	10-20		
" 17	4	ca 8		
" 21	2	12-13		
	8			

TABLE II k.—*Mallotus villosus.*

	Surface.		Vertical hauls.	
	Total number.	Length in mm.	Total number.	Length in mm.
"Acadia" I—				
Station 36	1	42		
"Princess" I—				
Station 4			1	15
"Acadia" II—				
Station 83	12	10-15	1	12
"Princess" II—				
Station 34			15	22
" 41			1	16
" 42			1	12
" 45	ca 75	7-25	ca 325	7-25
	ca 75		ca 342	
No. "33"—				
Station 17	3			
" 58	3	ca 8		
	6			

TABLE II l.—*Scopelus* sp.

"Acadia" I—				
Station 16	5	8-11	13	7-14
" 17			3	6-10
"Acadia" II—				
Station 38			1	7
" 42	37	6-9	1	8
" 44	4	14-16		
" 45	2	5-6	9	6-16
" 46	1	8		
" 51	1	6		
" 74	5	6-12		
" 75	1	9	6	8-21
	56		33	

EXPLANATION OF PLATES

PLATE I.

FIG. 1. *Ctenolabrus adspersus*, 4·2 mm., *Princess* Station, 50 (surface).
" 2. *Ctenolabrus adspersus*, 8 mm., *Princess* Station, 50 (surface).
" 3. *Scomber scombrus*, 6·2 mm., *Princess* Station, 33 (obl. haul).
" 4. *Sebastes marinus*, 5·6 mm., Kristianiafjorden July 1913 (taken from the adult fish).
" 5. *a* and *b*, *Sebastes marinus* 8 mm., No. "33" Station, 26.
" 6. *a* and *b*. *Sebastes marinus*, 10·4 mm., *Princess* Station, 46 (surface).
" 7. *Sebastes marinus*, 20 mm., *Princess* Station 41 (30-0).

PLATE II.

FIG. 8. *Chirolophis ?*, 11 mm., *Princess* Station 13 (100-0).
" 9. *Stichæus punctatus*, 30 mm., *Acadia* Station, 89 (surface).
" 10. *Cryptacanthodes maculatus*, 38 mm., *Princess* Station, 8 (80-0)
" 11. *Pleuronectes cynoglossus*, 16 mm., details lost.
" 12. *Ancylopsetta* sp., 7 mm., *Acadia* Station, 44 (surface).
" 13. *Drepanopsetta platessoides*, *Acadia* Station, 25 (120-0).
" 14. *Drepanopsetta platessoides*, 7 mm., *Acadia* Station, 82 (30-0 fms).
" 15. *Drepanopsetta platessoides*, 13 mm., *Acadia* Station, 81 (surface).

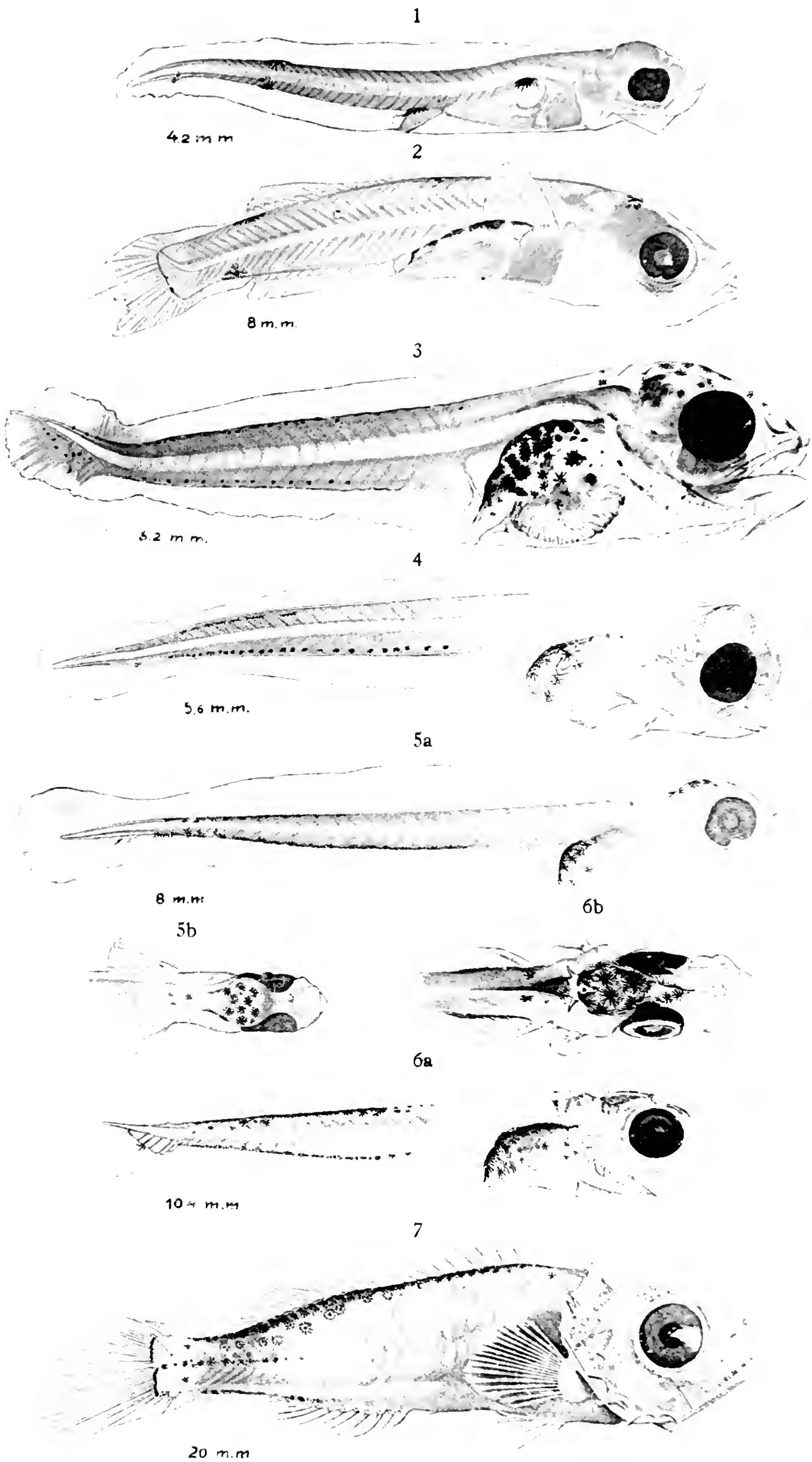
PLATE III.

FIG. 16. *Gadus callarias*, 3·8 mm., The Flodevig Sea Fish Hatchery.
" 17. *Gadus callarias*, 4·5 mm., *Acadia* Station, 8 (vertical).
" 18. *Gadus callarias*, 11 mm., *Princess* Station, 20 (surface).
" 19. *Gadus aeglefinus*, 3·7 mm., *Acadia Station*, 81 (surface).
" 20. *Gadus aeglefinus*, 7 mm., *Acadia* Station, 59 (25-0 fms.)
" 21. *Onos cimbrius* (?), 4·4 m., *Princess* Station, 50 (40-0).
" 22. *Onos cimbrius* (?), 4·6 mm., *Princess* Station, 31 (oblique).
" 23. *Ammodytes tobianus*, 7·2 mm., *Acadia* Station, 23 (70-0).
" 24. *Ammodytes tobianus*, ca., 15 m., *Acadia* Station, 82 (30-0 fms.)
" 25. *Tetragonurus cuvieri*, 76 mm., *Acadia* Station, 56 (210-140 fms.)
" 26. *Mallotus villosus*, 8 mm., *Princess* Station, 45 (oblique).
" 27. *Mallotus villosus*, 19 mm., *Princess* Station, 45 (130-0).

The figures, except those of macroscopical fishes, are drawn from specimens imbedded in glycerine-gelatine, transferred directly from formaline 4 per cent without being cleared or stained. The originals of figs. 3, 4, and 16, however, are borax-stained specimens mounted in Canada balsam.

All drawings from original material by Mr. Thorolv Rasmussen, draughtsman to the Fishery Board of Norway.

All depths in meters, when not otherwise stated.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6b
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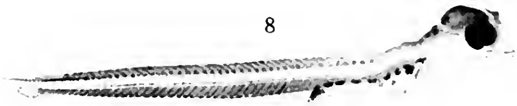


11 m.m.

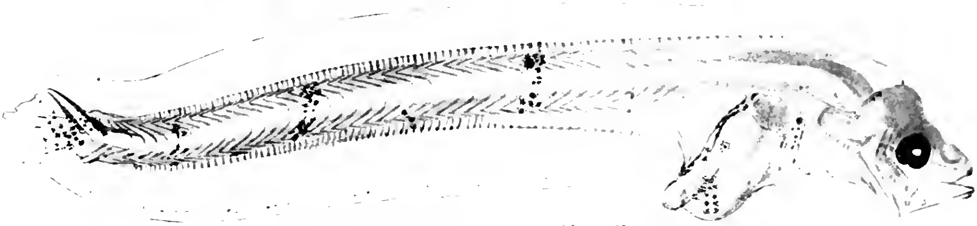
9

30 m m.

10

38 m m

11



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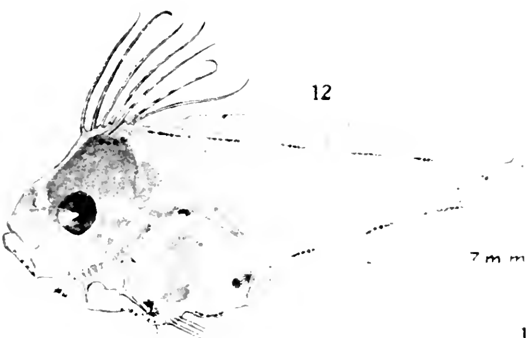

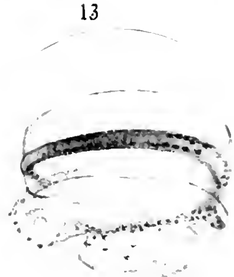

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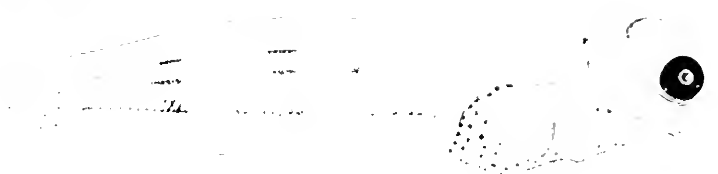

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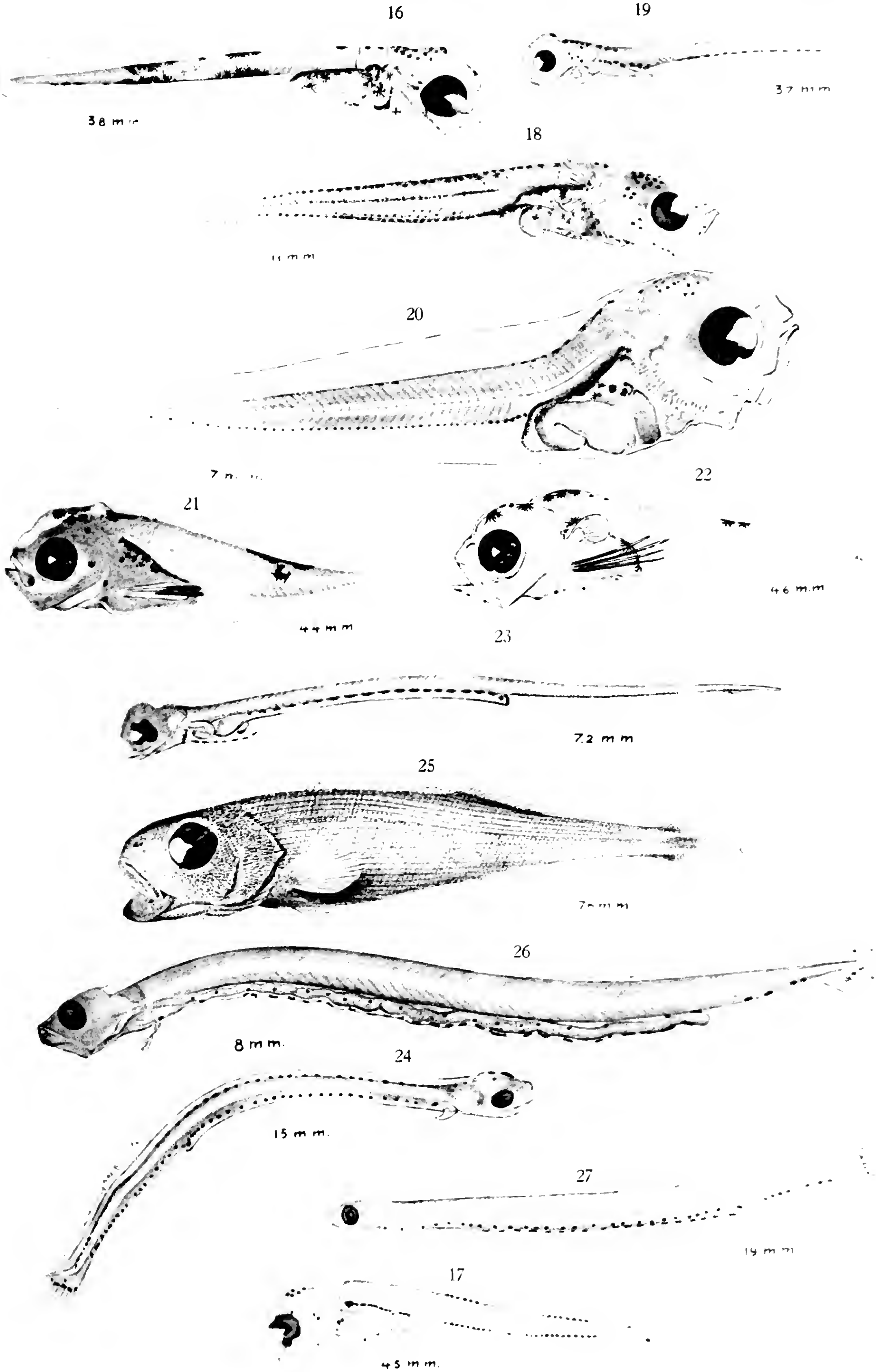
16
19
18
20
21
22
23
7.2 mm
25
26
8 mm.
24
15 mm.
27
17

CANADIAN FISHERIES' EXPEDITION, 1914-15

BIOLOGY OF ATLANTIC WATERS OF CANADA

REPORT ON "AGE AND GROWTH OF THE HERRING IN CANADIAN WATERS"

BY

EINAR LEA,

Bergen, Norway

AGE AND GROWTH OF HERRING IN CANADIAN WATERS
BY EINAR LEA, BERGEN, NORWAY.

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PLATE II.

Fig. 2. Herring scale on light background: the winter rings appear brighter than the the summer zones. ×14. (LEA phot.)

PLATE III.

Fig. 3. Left half: Impression in a collodion film of surface of portion of a herring scale. Right half: Same portion of the actual scale itself. ×15.

Fig. 4. Scale split, the detached part showing a contour similar to that of the whole scale; pattern formed by fibrils on the surface of distension. ×9. (LEA phot.)

PLATE IV.

Fig. 6. Part of herring scale, the outer covering removed, showing margins of fibrillar plates with alternating tangential and radial course of the fibrils. ×75. (LEA phot.)

Fig. 8. Part of cross-section through a herring scale, stained with thionine. ×380. (LEA phot.)

Fig. 13. Effect of silver impregnation acting from the outer surface of a scale. ×170. (LEA phot.)

PLATE V.

Fig. 14. Total views of a herring scale, impregnated with silver, demonstrating the inner system of annual zones. Oblique illumination. ×13.

Fig. 15. Half of a scale with normal structure. ×17.

Fig. 16. Half of a scale with abnormal structure from the same herring as the scale shown in Fig. 15. ×17. (LEA phot.)

PLATE VI.

Fig. 17. Part of an abnormal scale, the outer covering layer of which is removed, showing irregular course of fibrils. ×107. Compare with fig. 6, Plate IV.

Fig. 18. a. b. c. d. The appearance of scales situated near an a normal one. Central portion of four scales shown, taken in successive order from a lateral scale-row:

a. Ninth scale in the row being normal,

b. Tenth scale in the row being slightly modified,

c. Eleventh scale, being greatly modified,

d. Twelfth scale is abnormal. The next scales in the row (on the other side of the abnormal one) show similar features.

Fig. 23. Part of a scale, showing faint concentric shadows, caused by the inner fibrillar plates (corresponding to Fig. 14, Plate V). ×9. (LEA phot.)

Plate VII.

Fig. 19. Herring scale from northernmost Norway, end of April, showing the commencement of a new summer's growth. ×19. (Lea phot.)

FIGURES IN THE TEXT:

Fig. 5. *a.* and *b.* Showing pattern formed by fibrils in the inner surface of small (young) herring's scale.
c. Pattern *a* superposed over pattern *b*. Diagrammatic.

Fig. 7. Herring scale in section. Highly diagrammatic.

Fig. 9. Edge of a herring scale in section, indicating true proportions.

Fig. 10. More central portion of a herring scale in section, showing the appearance of a radial furrow: true proportions.

Fig. 11. Part of a section of a herring scale, the position of two winter rings indicated. True proportions.

Fig. 12. Effect of silver impregnation of the inner surface of a scale, the course of the fibrils being indicated by small dark spindle-shaped particles. Diagrammatic.

Fig. 20. Showing average increase of the last (new) summer belt during the summer of 1910 on the scales of young fish caught near Bergen.

Fig. 21. Composition in point of age of the stock of Norwegian mature herring, during a series of years as shown by the samples investigated. (From Hjort.)

Fig. 22. *a.* Shows a scale with normal arrangement of winter rings.
b. Shows a scale with abnormal arrangement of winter rings, the distance between second and third rings being small.

Fig. 24. Marking off the growth of scale on a paper slip.

Fig. 25. Multiplying the distances marked off on the paper slips by help of a triangle with a moveable side.

Fig. 26. Composition in point of age of all the seine samples of mature Norwegian herring, spring of 1916.

Fig. 27. Frequency curves for growth-dimension l_2 in Norwegian herring of the year group 1904, during a series of years.

Fig. 28. Chart showing localities mentioned in the following: the black numbered dots show the positions of the stations of "Steam Drifter No. 33," during summer 1915.

Fig. 29. Age composition of five samples from various places in Northumberland Strait, spring of 1914 and 1915, each sample kept separate: the individuals arranged according to age.

Fig. 30. Composition in point of year-groups of five samples from various places in Northumberland Strait, spring of 1914 and 1915; samples from each season taken together.

Fig. 31. Age-composition in two samples from Magdalen Islands, spring of 1914 and 1915.

Fig. 32. Age composition in samples from the coast of Newfoundland, spring 1914

REPORT ON "AGE AND GROWTH OF THE HERRING IN CANADIAN WATERS."

I.—INTRODUCTION.

Dr. Johan Hjort has requested me to work up the material of scale samples and observations bearing on the biology of the herring, collected in Canadian waters during the Dominion Government expedition, 1914 and 1915. The points especially taken into consideration when collecting the material—and which naturally also furnish the main problems to be dealt with in the present work—have been formulated by Dr. Hjort, in his preliminary report (VI) as follows:—

> 1. Do the herring that visit the Atlantic coast of Canada all belong to a single race or type, or is it possible to distinguish several races in these waters?
> 2. Does the rate of growth vary (according to the conditions of the waters along the coast)? Can types of different growth be distinguished and defined?
> 3. Is the renewal of the stock of herring of a constant character, or are there the same great fluctuations in the stock (in the number of individuals belonging to the different year-classes) as in European waters?

A small portion of the material collected consists of biometrical observations, i. e., determinations of number of vertebræ, number of fin rays, and number of keel scales, these being characters which, as Heincke has shown, may serve as a basis for morphological distinctions between different tribes or races of herring. The greater part of the material consists of observations as to length, weight, sex, state of sexual organs, and fat, accompanied by scale samples serving for determinations as to age and growth.

The material embraces a considerable geographical area, including, as it does, samples from southern waters of Canada (including a series from Gloucester, Mass., U.S.A.), Bay of Fundy, Nova Scotia, Cape Breton island, Newfoundland, Magdalen islands, Northumberland strait and as far north as the Gaspé waters. In some of these localities, moreover, the collection of material extended over several seasons, and there are also various samples taken with different fishing implements.

The results arrived at on examination of this material will be described in the following pages. From the nature of the material itself, the greatest weight will necessarily be attached to the discussion of that portion which deals with the age and growth of the fish, as indicated by the state of the scales. A brief preliminary description and explanation will therefore be given as to the methods employed in scale investigations, with observations as to the practicability of the method for dealing with the herring in transatlantic waters.

II.—METHODS OF AGE DETERMINATION AND GROWTH MEASUREMENT IN HERRING.

It was early discovered that the bony parts of fish were built up in layers, resembling the annual rings visible in the trunk of a tree, and as far back as the eighteenth century, the suggestion was advanced that it might prove possible, by counting these layers, to arrive at the age of the specimen. This theory was formulated in 1759 by a Swede, Pastor Hederstrom, in the following manner: "Anyone taking the trouble to examine a vertebra from a boiled fish, will observe certain rings thereon. And as many rings as there may be, so many years will be the age of the fish."

This suggestion, however, was afterwards lost sight of, and it was not until about 1900 that the skeletal parts of fish were called into requisition for the purpose of age determinations. The same observation was then revived by two scientists, Hoffbauer (VIII) and Reibisch (XIII) and the question has since been further dealt with by many others.[1].

It has been found that the different bony parts are not all equally well suited for the purpose of age determinations; in the case of the plaice, for instance, the scales are difficult to deal with from this point of view, being small, and with indistinct ring formation. In this species, the otoliths and the opercular bones furnish the best means of ascertaining the age. In the case of the herring, the opposite has been found to be the case, the otoliths are here small, and awkward in shape, whereas the scales are large, easily collected, and distinctly ringed. Although the otoliths and vertebræ of the herring can be, and have been, used for age determination, the scales offer so many advantages that there can, in my opinion, be no question as to choice. In the following pages, the structure of these scales will be briefly described, with special reference to the pattern of the annual rings. A résumé will likewise be given of the exact facts adducible in proof that the ring formation actually does consist of annual rings, and that the scales may therefore be employed for the purpose of age determination. Finally, mention will be made of the methods of preparation and investigation which the writer's experience has shown to be most convenient.

III.—STRUCTURE OF HERRING SCALES.

On examining a number of herring scales, it will be found that these are thin, pliable plates, differing both in size and shape according to the position on the body of the fish. The scales from the forepart of the body are larger than those from the caudal region, and those on the back smaller than those situate farther down, near the lateral line, etc. The shape, or outer contour, differs between scales set, for instance, immediately behind the gill cover and those farther back. Most scales are, however, more or less, of the shape, shown in fig. 1, which is reproduced from a photograph of a scale taken from near the lateral line, almost straight above the pectoral fin. A feature common to almost all scales is the fact that the anterior portion, which lies embedded in the scale pocket, presents an entirely different appearance to that of the posterior portion. The former is of even contour, and appears to be finely striped, whereas the latter has a fringed contour, and lacks the fine striped pattern. The two portions are divided by a line, termed the basal line (*b—b* in plate I, fig. 1). The stripes of the anterior portion appear to fall into two distinct systems, with a zigzag boundary between, this being as a rule almost perpendicular to the basal line (*z—c* in plate I, fig. 1). At the point of intersection between this zigzag line and the basal line lies the centre of the scale (*c*); this is in most cases distinctly marked, but may scarcely be seen on this figure. In addition to the fine stripes, a number of very pronounced lines are seen running from the margin some distance in (*r*); these are called the radial lines, from the fact that in the scales of many species of fish, the corresponding lines radiate out from the centre of the scale. In plate I, fig. 1 will be seen eight dark narrow lines, arranged concentrically about the middle of the

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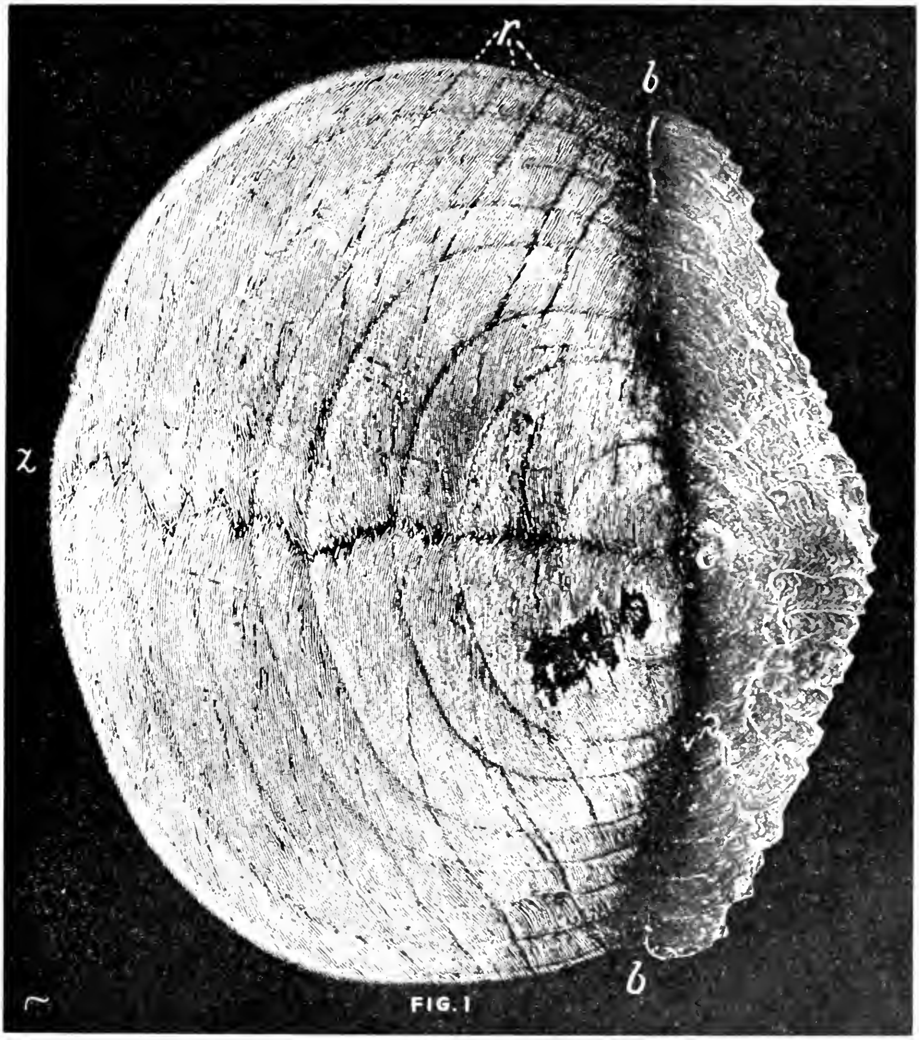
[1] A list of the most important works on this subject will be found in *Dahl* (I) The assessment of age and growth in fish, Intern. Revue d. gesamt. Hydrobiologie u. Hydrographie 1909, Bd. 11.

scale; these divide the striped portion of the scale into nine zones, each having the outline of a horseshoe; in plate I, fig. 1 these appear lighter than the narrow lines. By altering the light in which they are viewed, these broad zones can be made to appear darker than the narrow lines (plate II, fig. 2). These latter are the winter rings of the scale, and the broader zones representing summer growth; it is by counting these that the age of the fish is determined, and by measuring the distance between them, it is possible to calculate the growth.

PLATE I



It is an easy matter to show that all the details above referred to pertain to the outer surface of the scale, i. e., that surface of the scale which faces outward when the scale itself is in its normal position on the body. The optical effect is a result of reflection and refraction in this external surface. The demonstration may most easily be made by producing an impression of the outer surface of the scale in a transparent plastic mass, as, for instance, collodium solution. The scale is glued to a glass plate, with its inner side next the glass, a small quantity of collodium is poured over the whole, and the glass set aside in a slanting position, to dry. After a short time, when still soft, the collodium may be removed in the shape of a thin film, in which will be found an impress of the surface of the scale. Plate III, fig. 3, shows

PLATE II.

FIG. 2

a photographic reproduction of a part of such an impression, together with the corresponding part of a photograph of the scale itself. All details are distinctly visible in the plastic impression. From this experiment we may with perfect certainty conclude that the picture presented to the eye when observing a herring scale through a low-power lens, is nothing but the play of light on the surface of the scale, which is thus found to be moulded in delicate and detailed relief. The visible winter rings and summer zones, like the fine stripes, the basal line, and the centrepoint, all belong solely to the surface of the scale.

The inner structure of the scale thus plays no part in the formation of the picture presented by the visible system of annual rings. It is possible, however, by particular means, to bring out another system of annual rings, located in close relation to those of the outer surface, yet altogether different from these. In order to comprehend the genesis of this inner system, it will be necessary to have some idea as to the internal structure of the scale as a whole. This may be arrived at by various

PLATE III.

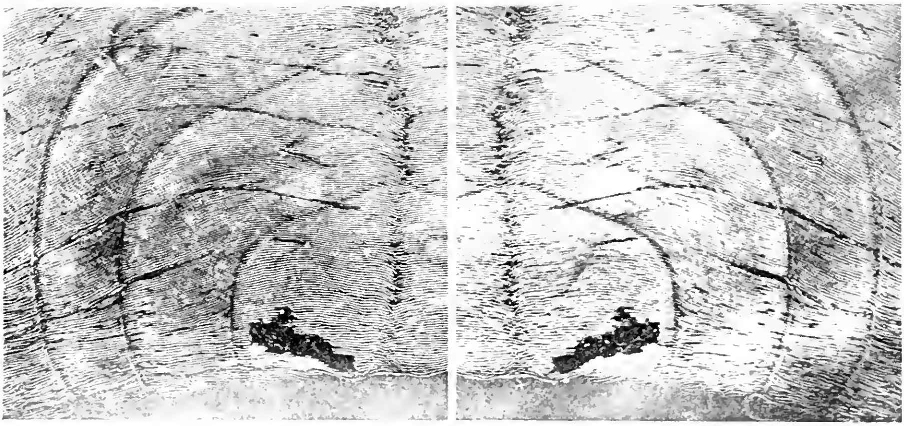


FIG. 3

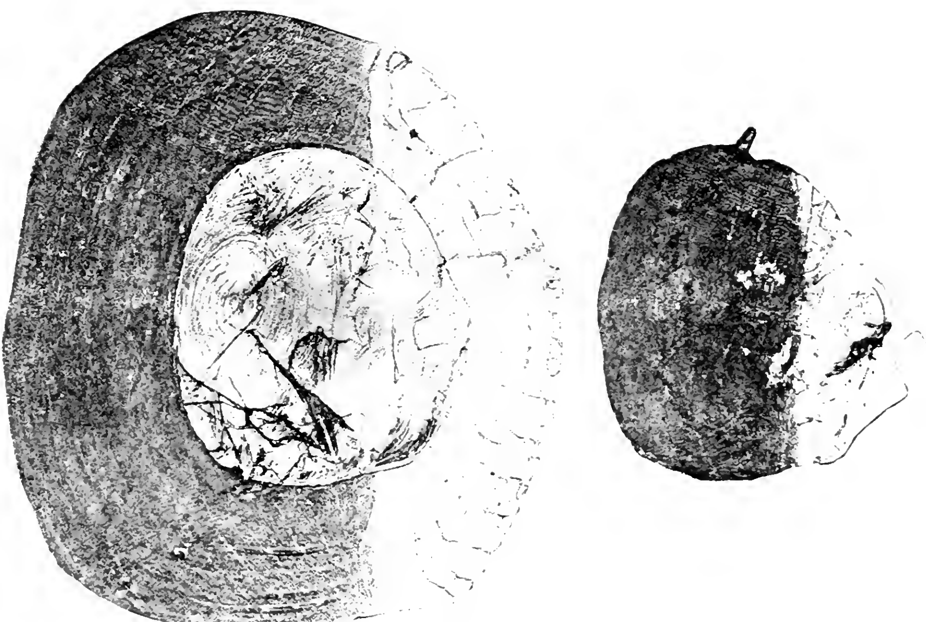


FIG. 4

simple methods, the results of which will be found to agree with those obtained by more complicated experimental processes.

With the aid of a needle and tweezers, a herring scale may be split up into several thin plates, all exhibiting a contour identical in form with that of the scale itself. The scale can only be thus split by inserting the point of the needle in the outer surface, and the size of the flakes thrown off will depend upon whether the cleavage is commenced near the edge of the scale or farther in towards the centre. By commencing near the margin, two large plates will be obtained, starting from a point farther it will give one large and one small. Plate III, fig. 4 shows the two portions of a scale thus split. The central portion here thrown off presents the appearance of a small scale, with the margin somewhat torn, the remainder, constituting the larger part, exhibits a transparent " sore " in its central portion corresponding to the smaller flake detached. From such experiments it may be seen that the scale is built up of thin plates, similarly formed, each somewhat smaller than the next. The layers must have been deposited in order of size, forming something approaching a very low cone, the base of which is represented by the inner surface of the scale, and the apex by the centre. The exact number of layers of which a scale is composed cannot be determined by mechanical means, as it is impossible to say whether each flake detached comprises but a single layer, or is itself composed of several adhering together.

In a scale thus split, the surface exposed reveals a kind of pattern formed by fine fibrils curving in arcs and whorls (*vide* plate III, fig. 4.) In most cases it will be found that the fibrils nearest the edge of the exposed portion run parallel with the same, while those farther in, on the anterior part, form a kind of elliptical figure, and those in rear, on the posterior part (viewing the scale as in its normal position on the body) form irregular whorls. From the pictures thus presented, which are almost always to be found in such exposed portions where flakes have been detached, it might well seem that the fibrils in each elementary plate were arranged in this manner, with tangential marginal fibrils. This is, however, not the case, for on studying the arrangement of the fibrils in scale preparations obtained by other methods one may sometimes find the pattern above described, and in other cases patterns of altogether different character.

The inner side of the scale is formed by a fibrillar plate, and, with a fairly strong lens, the fibrils in this may easily be seen, especially if the scales are first

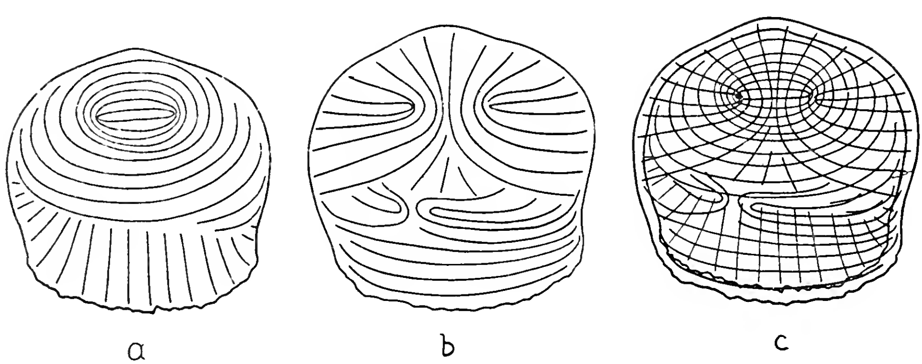


Fig. 5.

treated with nitric acid, and, in mounting, placed with the outer side down in a drop of glycerine, leaving the inner side upwards, exposed to the air. On examining a number of such preparations, not a few will be found in which the fibrils, instead of running tangentially to the edge of the scale, fall perpendicularly to this, at any rate along the greater part of the margin. In the case of large scales, the fibrils form a highly complicated pattern farther in towards the centre. With small scales thus prepared the patterns formed by the fibrils may be divided into two types, schematically shown in fig. 5, *a* and *b*. The one of these types is characterized by a more or less elliptical figure, and by the fact that the marginal fibrils run tangentially, the other by a hyperbolar figure and radial marginal fibrils. There is thus no doubt that in addition to elementary plates with tangential marginal fibrils, there must also be others with radial fibrils, and the fact that these latter are rarely if ever found in the exposed surface of a split scale must be due to the method employed. It is also obvious, that a needle, thrust in with the point directed towards the centre, will find no hold until it comes into contact with transverse fibrils, i. e. until it reaches a plate with tangential fibrils.

The scale may thus be considered as a greatly flattened cone composed of fibrillary plates, of which some have tangential fibrils, others radial. This cone is evidently covered entirely by a non-fibrillary layer, on the upper side of which, however, is found finely marked relief which gives the scales its characteristic appearance. If this covering layer could be removed, the margin of each fibrillary plate would then be visible, since each plate is larger than the next. A method by which large portions at least of the covering layer can be removed is as follows: A drop of fish glue is placed upon an object glass, and a scale set thereon, with the outer side downwards in the glue, leaving, however, a small corner of the scale free, just large enough to afford a hold for the tweezers. As soon as the glue has dried the scale is damped very slightly with an almost dry brush, the free corner is then grasped with the tweezers, and the scale torn away. If the operator is fortunate, the covering layer of the scale will then be found adhering to the glue on the glass, and the part detached by the tweezers may be mounted for observation. Plate IV, fig. 6 gives a photographic reproduction of part of such a preparation. The curved boundary lines of the elementary plates are distinctly visible, and it will also be seen that plates with tangential fibrils alternate with those having the fibrils radially arranged.

It will be easily understood that the arrangement of the fibrils in the elementary plates as here described imparts to the scale a high degree of firmness in all directions, the fibrils in one lamella will, roughly speaking, form a considerable angle with those of the two adjacent, so that the scale may, in a way, be compared with the composite wooden plates which are made by gluing several thin sheets together, with the grain of each perpendicular to that of the two adjacent. Fig. 5 *c* gives, purely schematically, the arrangement of the fibrils in two plates, one with radial, the other with tangential fibrils, showing the manner in which the direction of the fibrils in the one lies transversely to that of those in the other, when two such plates are placed in juxtaposition.

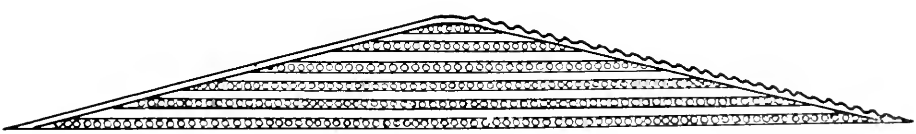


Fig. 7.

Judging from what we have hitherto learned, the transverse section of a scale should present more or less the appearance shown in fig. 7. This is also, roughly speaking, found to be case. The upper covering layer can be distinctly seen when the section is stained with thionine, as shown in fig. 8, the layer in question then assuming

FIG. 6

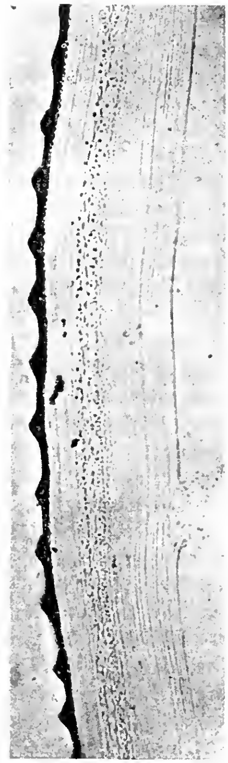


FIG. 8

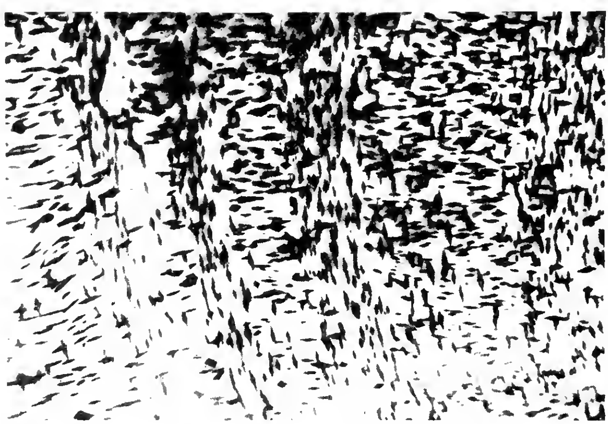


FIG. 13

an intense blue colour, while all the remainder is unaffected.[1] Sections show that this upper covering layer is of almost equal thickness at the edge and near the centre of the scale, and evidently does not grow thicker; it is thus easy to understand that the winter rings, for instance, upon the surface of this layer, continue equally distinct many years after formation, in contrast to what is found be to the case with otoliths, where the earliest annual rings become entirely concealed, and are only discernible after the otolith has been ground down so as to expose its inner structure.

An examination of sections also reveals a number of breaks in the upper layer; these will be found to be the so-called radial furrows (*vide* plate I, fig. 1), which run like channels in the surface layer. Finally, it will be seen that the exterior covering layer extends out beyond the edge of the fibrillar plates and forms by itself, independently of these, the margin of the scale. The winter rings are not particularly conspicuous in a section; despite the most careful orientation by means of the fine ridges on the surface, it has not been found possible to discern any conspicuous peculiarity in those parts of the outer layer where the winter rings lie. It is noticeable that the ridges, which resemble the teeth of a saw, are set somewhat irregularly; possibly, also, the outer layer itself is slightly thinner in the inner than on the outer side of the point where a winter ring is situated. These features are, however, so inconspicuous, that without exact orientation it would be impossible to demonstrate where the winter rings actually lie in a section. Figs. 9 to 11 give diagrams of various details from sections of herring scales.

Fig. 9.

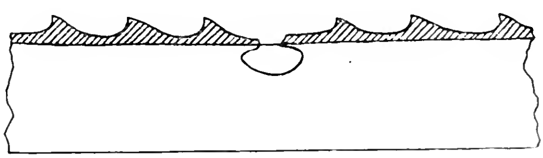


Fig. 10.

Fig. 11.

Below the outer covering layer may be seen, viewing the scale in section, a thicker stratum, divided into zones of varying appearance. If the section be embedded in a medium of low refraction, it may be distinctly seen that the fibrils in some of the zones have been cut transversely across, whereas other zones are clearer, with less apparent structure, suggesting that the fibrils here are not transversely severed. This layer formation may be strikingly shown by placing the sections in polarized light, when, in certain positions, a series of bright bands, with darker zones between, will be apparent. It will then be distinctly seen that the thickness of the lamellæ varies, and,

[1] This staining did not succeed, when the scales cut had been treated with acids in order to remove inorganic matter. I have, by microchemical reactions, satisfied myself of the fact that practically all inorganic matter (principally phosphate of lime) is in the herring scales deposited in the outer covering layer, while the fibrillar plates are devoid of it. I suspect that the differential staining is due to the presence of metallic salts in the one layer only, the salts acting, as it were, as a mordant.

as will shortly be shown, this is, in all probability, to be regarded as in connection with the fact that the lamellæ themselves form a system of annual rings, which may be rendered discernible by preparing the scales in a special manner. If we take, for instance, fresh herring scales, treated, however, with nitric acid, and impregnate them with bichromate of potassium, thereafter placing them in a solution of nitrate of silver, a dark precipitate of some silver compound will be formed between the fibrils. This precipitate is not amorphous, but is deposited in small spindle-shaped particles, each with its axis in the direction of the fibrils, so that a preparation of this kind distinctly shows the course of the fibrils themselves just as the course of currents is shown on nautical maps. As the impregnation takes place only, or mainly, in those layers which lie nearest the surface of the scale, it is possible, by gluing the scale to be impregnated, on to a glass plate, to exclude one of its two surfaces from the action of the silver solution and thus to impregnate either the innermost lamellæ alone, or only that portion of each, which lies immediately adjacent to the outer layer of the scale. The operator can thus obtain at will either views as in fig. 12, giving

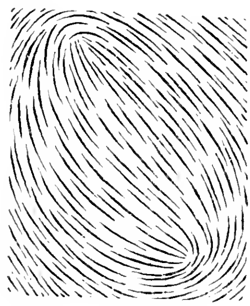


Fig. 12.

schematically a portion of the innermost lamellæ, or as in plate IV, fig. 13, showing a portion of a scale impregnated from the outer side. This latter shows, in another manner, the same feature as seen in plate IV, fig. 6, while the former corresponds to plate III, fig. 4.

On examining a scale thus impregnated, with a low-power lens and in oblique light, the small spindle shaped bodies will not be discernible. They produce, however, by reflection an effect as shown in plate V, fig. 14. In this manner, an excellent view is obtained as to the extent of the elementary lamellæ, and it is at once strikingly noticeable that the breadth of the zones exhibits an irregular progression, broader belts suddenly appearing after a series of narrow zones. Closer comparison reveals the fact that the transition from narrow to broader zones takes place just where the surface of the scale shows a winter ring. Thus the elementary plates are seen to form their own system of annual rings, corresponding to that of the surface layer, but otherwise differing greatly from this, and more resembling that found in the scales of many salmonoids and gadoids, etc., where the winter rings are not so sharply marked, but a gradual transition from summer to winter is seen.

The foregoing description as to structure of the scales does not apply to all the scales found on the body of a herring. On looking through a collection of herring scales, some will be found to differ from the rest, being most easily distinguishable from these by the fact that the zigzag boundary line between the two systems of stripes (*vide* plate I, fig. 1) does not reach right down to the basal line, and that the stripes in a more or less considerable central portion of the scale form irregular patterns, in contrast to what is normally the case. Winter rings, again, are invariably lacking in this abnormal central portion, although present outside it, excepting, of course, cases

FIG. 14

FIG. 15

FIG. 16

where the entire surface of the scale is abnormal and no winter rings are to be seen. Plate V, figs. 15 and 16 give photographic reproductions of the central portions in a

PLATE VI.

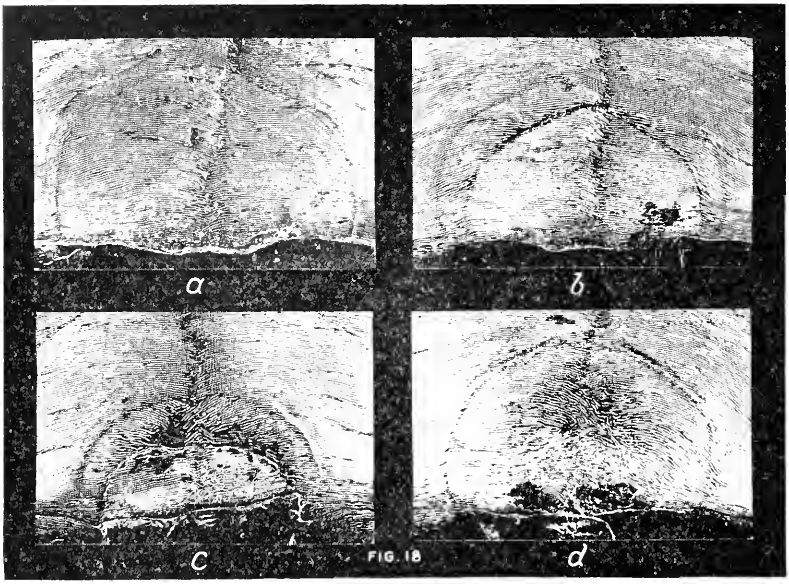


FIG. 18

FIG. 17

FIG. 23

normal and an abnormal scale from the same fish. The occurrence of these abnormal scales is highly irregular; on one specimen, numbers may be found, while in another, long and careful search will be required to discover a single one. It is further remarkable, that in one and the same specimen may be found scales where the abnormal central portion is quite small, and others in which a large portion, or the entire surface, is of abnormal appearance.

The same confusion noticed in the relief of the outer surface is likewise encountered in the inner structure of such abnormal scales. It will be found impossible to split them, for instance, as long as the needle point is introduced within the abnormal central part, and if the covering layer be removed, we do not find the regular alternation of radial fibrillar zones with those having tangential fibrils; on the contrary, the fibrils will be seen to intertwine, forming patterns similar to that shown in plate VI, fig. 17. If such abnormal scales be treated with silver solution as described before, it will be noticed that the division into zones, which otherwise makes itself so distinctly apparent during this process, is not discernible within a central portion corresponding to the visibly abnormal portion of the surface layer.

The most probable explanation as to the origin of these abnormal scales would seem to be as follows. The scale originally set in the scale pocket where now the abnormal one is found, must on some occasion have fallen out, this taking place at a time when the original scale was of a size corresponding to the abnormal portion of its successor. Within a short time after the loss of the original scale, a new scale (the abnormal portion) grows out, and then, having filled the vacant place, the scale proceeds to grow normal wise.

Closer investigations of the scales of a herring, with this question in view, will soon reveal the fact that the scales immediately adjacent to an abnormal scale are, as a rule, themselves abnormal, forming together a group. And outside these again, or rather round about them, may frequently be found scales presenting another form of abnormal structure than the first mentioned, the central portion corresponding to the abnormal centre in the first being here either dislocated in relation to the peripheral part, or at least separated from this by a line concentric with the periphery, and more or less distinctly marked. Outside these scales lie the wholly normal scales, so that transition stages are seen to lie between the two extremes. In order to make this clear, a group of entirely abnormal scales was sought for on the body of a herring, and all the scales surrounding this group were then picked off and prepared, careful note being kept as to their respective positions. Plate VI, figs. 18*a* to *d* are from photographs showing the central portions in a horizontal series of these scales, the first giving a view of the last normal scale before the abnormal formation begins, and the last illustration being that of the first abnormal scale. This series of views, and similar series which I have had no difficulty in finding, distinctly suggest that the abnormal scales are nothing but supplementary growths intended to replace scales previously lost by accident. The scales immediately adjacent have become slightly displaced from their natural position in the scale pockets, as shown by the fact that the central portion forms, as it were, a scale upon the scale. It will also be seen that the transition forms may well give rise to erroneous determinations of age, the boundary line between the central portion and the periphery frequently bearing more or less resemblance to a winter ring. This will be further referred to later on.

IV.—THE SCALES AS AN INDICATION OF AGE. SOURCES OF ERROR IN AGE-DETERMINATION.

We have no experimental proof of the fact that the so-called winter rings on the scales of the herring actually are annual rings, i. e., that one such winter ring is formed each year. On the other hand, statistical observations point so emphatically to the correctness of this supposition, that it will hardly seem possible to otherwise explain the regularity revealed by the observations. The observations in question deal primarily with the Norwegian stock of herring, which have been under consideration in this respect for several years. The proofs thus furnished can, strictly speaking, only be regarded as entirely applicable to the stock in question, and it is of course perfectly justifiable to demand that in dealing with other races of herring, similar data should be sought for before assuming that the conclusions arrived at are equally valid for these. As we shall see later on, the Canadian material, like the Norwegian, does in fact point to the same conclusion, that the winter rings really are an indica-

PLATE VII.

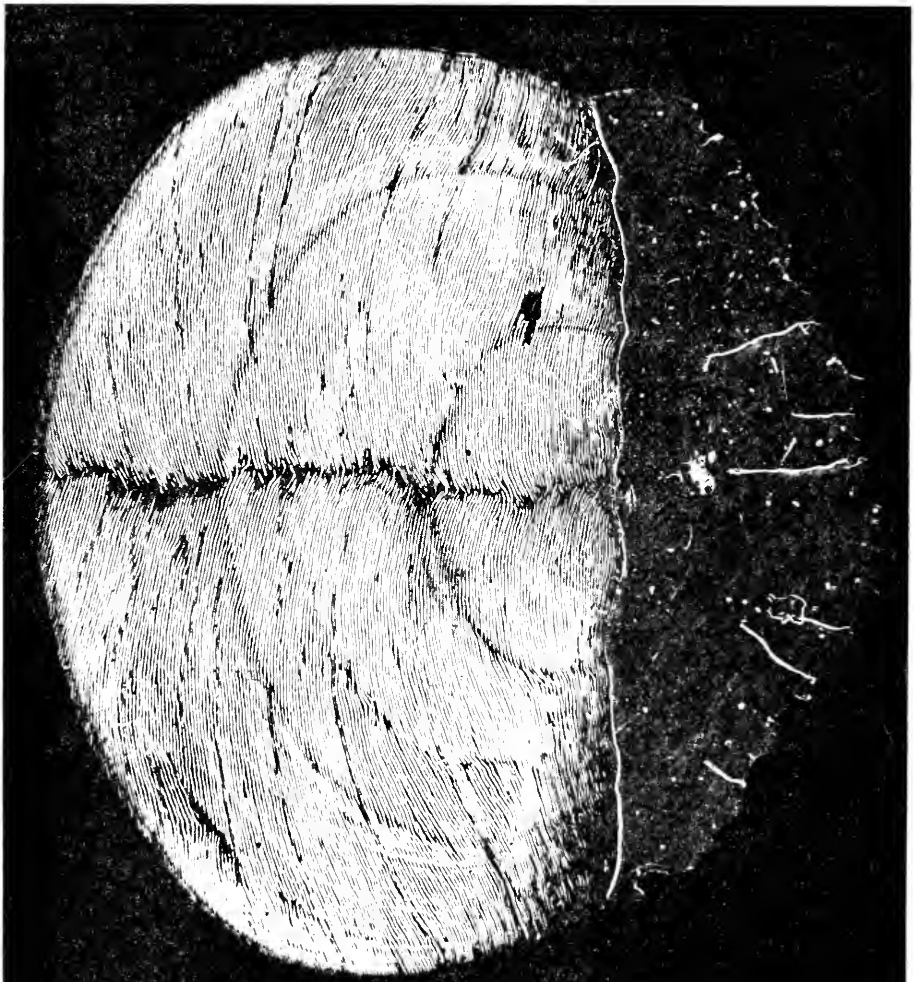


FIG. 19

tion of the age of the fish. At present it will suffice to mention, as briefly as possible, the manner in which the observations were carried out in the case of the Norwegian herring; it should be noted, however, that corresponding features have been observed in the case of other stocks of herring, e. g., those of the Færoes.

In the course of the year 1910, the young herring which were continually taken in the neighbourhood of Bergen were subjected to observation (*vide* Lea, X). It was then found that the outermost summer zone on the scales, which in May was extremely narrow, grew broader and broader as the summer progressed, until September, when a period of stagnation set in. Supplementary investigations have shown that at some time or another during the months of March or April, small herring are found, some of which have only broad summer zones (one or two), while others have either a broad inner zone and a very narrow outer one, or two broad ones innermost, and one very narrow beyond (*vide* plate VII, fig. 19). Fig. 20 shows schematically the manner in which the annual rigs were seen to appear at different times of the year. Observations extending over several years have shown that the small herring taken near Bergen only exhibit this narrow outer summer zone in the spring, and that the outer summer zone is in autumn invariably found to be broad.

Continuous observations of this nature will be analogous to the observation of herring kept in tanks, with periodic examination of the scales. If an experiment of

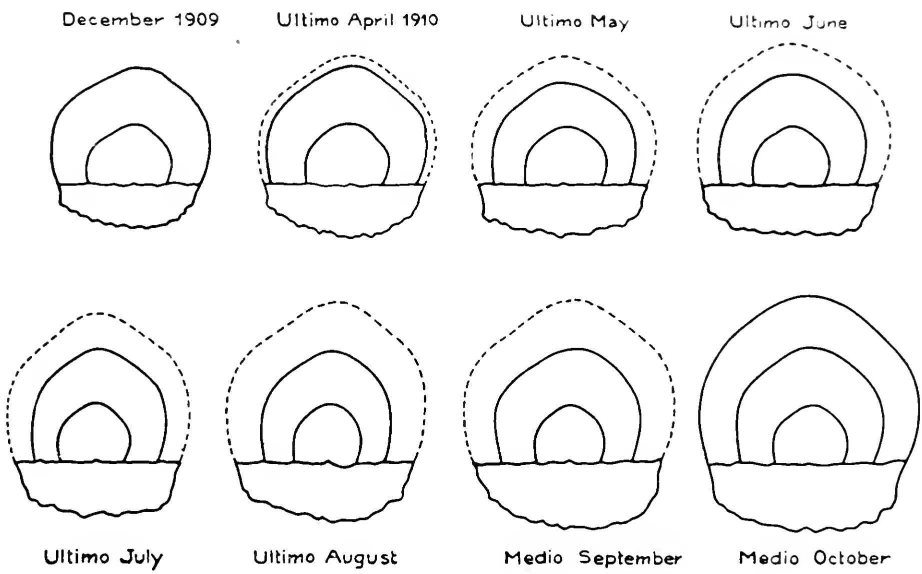


Fig. 20.

this kind, with herrings in tanks, were found to give the same results, we should then certainly be justified in concluding that the summer zones of the scales were formed and developed during the period, April to September, and that the winter rings in consequence represent the time from October to March. In the present instance, this absolute certainty is not attained, since the observations with captured herring naturally to do not represent different states of the same fish at different times.

During a period of years, from 1907 to 1916, samples of so-called spring herring were collected, these being the fish which early in the spring move in towards the west coast of Norway to spawn. Scales of each fish in the samples collected were examined, and the herring grouped according to the number of rings on the scales. It was then found that for the greater part of the period embraced, a remarkable regularity prevailed, as indicated by fig. 21. This has been lent from Hjort (V) and shows the percentage of fish (in the samples investigated) falling to each group according to the number of rings. It will be seen that in 1908, there were many with 4 rings; in 1909, 5; in 1910, 6; and so on until 1914. The investigations of 1915 and 1916 revealed the presence of a large number of herring with eleven and twelve rings, respectively. This regularity, which, by the way, is also encountered in samples of another "kind" of Norwegian herring, the so-called large herring, can hardly be explained save by the supposition that a certain year-class of herring have throughout the whole of the time from 1908 been more numerously represented in the stock than others, and that as time went on, and the fish grew older, one ring was formed on the scales for each successive year.

These observations exhibit great similarity to the results in the following experiment, which may be easily carried out with fresh-water fish: A number of fish are caught, all those with a certain number of rings on the scales sorted out and liberated in a pond where no fish of the same species are found. A year later they are recaptured, scale samples taken and examined, to ascertain whether the scales now exhibit one ring more than at time of liberation. They are then again set free, to be taken up once more a year after for renewed examination. The investigations actually made

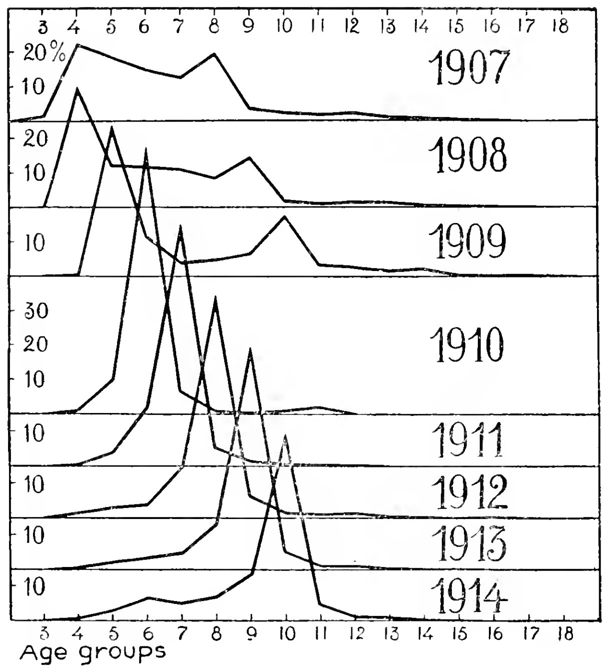


Fig. 21.

lack the absolute certainly as proof which such a test experiment would have; on the other hand, the length of the period here embraced, and the absolute uniformity of the results from all samples, are points of no little weight. Throughout the whole of the time from April, 1908, to February, 1916, not a single sample was found to furnish any exception to the general regularity. Not until February, 1916, was a sample brought in which lacked the 12-ringed fish present in such great numbers in the remaining twenty-four samples from the winter in question. This single instance, however, does not impair the proof-value of the material as a whole, for the regularity observed can naturally not be expected to continue indefinitely. On the contrary, it would be natural to expect that the character of the stock in this respect will in a short time exhibit noticeable change.

The samples of grown Norwegian herring, from the year 1910, inclusive, contain a considerable quantity of specimens exhibiting a remarkable arrangement of the winter rings. As a general rule, the distance between the rings decreases from the innermost outwards to the margin of the scale, as shown in fig. 22 *a*; in the specimens here in question, however, the arrangement was similar to that shown in fig. 22 *b*, where, as will be seen, the third summer zone is narrower than the fourth, reckoning from the centre outwards. In 1910, this peculiar feature was especially marked

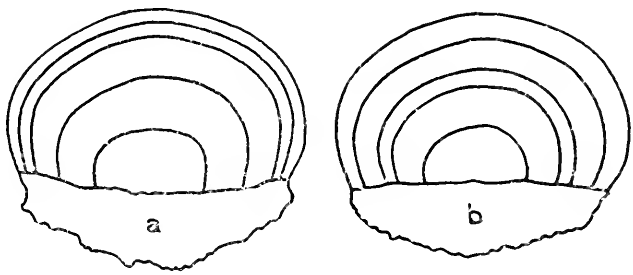


Fig. 22.

among the 6-ringed fish; in the following year, it was chiefly apparent in the scales of the 7-ringed specimens; and so onwards. The table prepared shows how these particular fish keep together in one group, with a gradual progression of the group as a whole towards the right of the table.[a]

TABLE 1.—Distribution of herring with abnormal arrangement of rings on the scales. Material from grown Norwegian herring, seine caught.

Year.	Total number of individuals with abnormal arrangement.	Percent of individuals in the different ring-classes.											
		4 ringed.	5 ringed.	6 ringed.	7 ringed.	8 ringed.	9 ringed.	10 ringed.	11 ringed.	12 ringed.	13 ringed.	14 ringed.	15 ringed.
1910	134	......	2·2	**91·0**	4·5	.	0·7	0·7	0·7	....	....	.....	....
1911.....	372	...	1·1	4·8	**86·3**	4·6	1·3	1·1	0·5	0·3	....	.....	......
1912.....	322	.....	2·5	1·2	4·3	**84·5**	3·4	0·3	....	0·9	1·9	0·9	.....
1913	217	0·9	0·9	2·3	1·4	3·7	**86·7**	2·3	0·5	0·9	...	.....	0·5
1914	518	1·9	3·1	1·9	2·1	2·7	5·4	**79·2**	2·1	0·6	0·6	0·4	....
1915 . .	1291	0·2	23·8	2·8	3·3	1·8	0·7	3·6	**61·5**	1·4	0·6	0·3	0·1

These observations may best be compared with an experiment which has already been carried out in the case of the cod (Winge, XIV). The fish, when caught, are marked with numbered labels, scale samples taken and the marked specimens liberated, care being taken to select only fish of unimpaired vitality. After the lapse of some time, some of them are recaptured, and the scales examined, to see whether new annual rings have appeared in number corresponding with the lapse of time between first examination and recapture. Instead of the artificial mark affixed we have here the peculiar arrangement of the rings as the distinguishing feature of a group whose scales in a given year (1910) numbered six rings in all. It is hardly likely that an approximately equal percentage of this group would then, in 1911, be found among the 7-ringed fish, in 1912 among those with eight rings, and so on, up to to the 12-ringed in 1916, if it were not that a new ring made its appearance each year.

Scales having the appearance shown in fig. 22 *b* were not found, or found in but minimal quantities, among the samples of mature fish until 1910. On the other hand, in 1907-09, these were the more numerous among the samples of immature herring from the north of Norway, and as might be expected (in view of the fact that the samples consist of autumn-caught fish) they are found in 1907 only among the herring with four summer belts; in the following year, 1908, they appear in large numbers (95 per cent)[1] among the fish with five summer belts, and in 1909 among those with six (79 per cent). In the autumn of 1910, only a very few fish with seven summer belts were found (seventy-eight in all, out of 1614 specimens examined). Of these, however, fifty-five had scales of abnormal appearance, and these fifty-five specimens amount, after all, to 40 per cent of the total found.

Consideration of fig. 21 and table 1, leads us directly to the question of possible error in counting the rings of the scale. What would be the results, for instance, if, owing to various difficulties, the investigator were unable to note with certainty the number of rings on a considerable proportion of the scales? Would such inaccuracy by any means be able to account for a final result revealing so distinctly marked a regularity as that here found in the case of the Norwegian herring?

It is no difficult matter to see that erroneous age determinations will tend to produce an age curve which, where it should exhibit marked differences in the number of individuals in the various groups, assumes, instead, a more even contour, with less pronounced contrast and more gradual transition between the age-groups. The groups most numerously represented will give off a greater number of individuals to the groups adjacent than they receive from these.

The experience gained in the course of the investigations with Norwegian herring tends to show that the probability of error is greater when dealing with older fish than with young specimens, and further, that the error more frequently falls to the one side, thus placing the fish in a younger year-class than that to which it actually belongs. And finally, it has been found that the majority of such errors are uniform in degree, the fish being reckoned as one year younger than is actually the case.

The effect of errors of this nature and degree will then be that, where a certain sample contains one dominant age-group, the predominance of the group in question will appear less than it should, and the younger group next following be credited with greater number of individuals than is its due. We are consequently led to the conclusion that the figures arrived at in the case of a dominant group are minimal values, i. e., that the diagram shown in fig. 21, for instance, would have presented essentially the same features, but in an even more marked degree, if all the determinations of age on which it is based had been correct.

That errors and uncertainty are unavoidable in investigations of this kind will be admitted by all who have had any experience of such work. The material may be handled with the highest possible degree of care and attention, so as to warrant the hope that a repetition of the determinations must give exactly the same results, yet on going through the whole once more, discrepancies will nevertheless be found. As a matter of fact, we are hardly justified in using the term "age-determination" when dealing with scales; "estimate" would be more correct, for there will always be found, whatever may be the material under consideration, a greater or less number of individuals whose scales must be classed as doubtful, and where the decision must be based more or less upon personal judgment.

In this respect, the herring from different localities will be found to vary, and it is therefore impossible to formulate any generally valid rule as to how great the probability of error will be. And, indeed, any such estimate would always be a matter of difficulty. Repetition, of course, affords a certain guide in this respect, and this method has also frequently been employed, with satisfactory results, in dealing with the Norwegian herring. Another method is to examine the actual results arrived at in the investigation of a certain stock. It would be altogether unreasonable to suppose, for instance, that the age determination in the case of the Norwegian herring

[1] Excluding all fish with less than four summer belts.

could ever have been brought to exhibit peculiarities so marked, if the number of erroneous determinations, a neutralizing influence, had been considerable. As will be shown later on, the Canadian material furnishes several excellent instances of consistency in the results arrived at. For the present, it will suffice to point out that the material from the Canadian investigations presents, in the case of some localities, no particular points of difficulty, whereas samples taken elsewhere have included fish with scales by no means easy to decipher. On the whole it may be said that the Newfoundland material from the gulf of St. Lawrence is to be regarded as well suited for the purpose of age determinations, whereas some part of that from the open coast presents many difficulties. It is of great importance, however, in such investigations, to familiarize oneself, by long-continued observation, with the peculiarities of the particular herrings to be dealt with. Valuable aid is also furnished where opportunity occurs of following the progress of a single age-group from year to year. There is probably no single circumstance which has so largely contributed to the firmness of conviction, now prevailing among Norwegian investigators, than the fact of their having been in a fortunate position to watch the growth of a single rich year-class throughout an extended period of time.

The greater or less probability of error, or uncertainty, may depend upon various factors. The sources of error may be divided into two categories:—

1. Circumstances of a purely technical nature. The technical methods employed in dealing with the material are of considerable importance, and will therefore be described at greater length later on.

2. Conditions independent of the technical treatment, i. e., such as will make themselves apparent even when the most adequate technical methods are employed. In this case, it is generally a question of fish whose scales have the winter rings indistinctly marked, or which exhibit fainter intermediate markings between those normally legible, or again, as with older specimens, the outermost rings so close together as to render them difficult to distinguish.

Where the winter rings are not sharply defined, they frequently present the appearance of several very thin lines, one outside the other, in the form of a faint band. Such double or manifold rings would seem to be of most frequent occurrence among those earliest formed; a type of scale very commonly met with is that where the outermost rings are rather clearly marked and easily distinguishable, while the inner one, and possibly the next few, will be vague and double. How far this may be connected with the spawning, as tending to render the rings more sharply defined, cannot be stated with certainty, but it is not unlikely that such is the case.

The fainter rings occasionally found between the true ones have been termed by Dahl (I) "secondary rings", and are so distinguished in the present report, albeit the term might well be taken to embrace various kinds of rings. I was at first of the opinion that the position of all kinds of these "secondary rings" varied from scale to scale, and that their disturbing influence might therefore be eliminated by examining a sufficiently large number of scales from each fish. Objections to this have, however, been raised by Hellevaara (IV), who considers that secondary rings may be found, the position of which corresponds on the different scales of a fish—being, however, in some scales almost indistinguishable.

As to the origin of the secondary rings, nothing can be said with certainty. The dislocated scales described on p. 93 show, however, that a slight shifting of the scale from its normal position may occasion the formation of secondary rings. In other cases, faint shadows, produced by the inner fibrillar plates, may be seen. Plate VI, fig. 23, reproduces a photograph of a scale exhibiting such shadows. Where the winter rings are faint or doubled, it may be conceived that these shadows may become of some importance as sources of errors.

With regard to the close-set outer rings in older fish, there is little to be said, save that as the rings lie closer and closer with increasing age, we have here a limit to the possibility of approximately certain estimates of age. In the Canadian material, some herrings were found which must certainly have been older than any which I have examined among those from European waters, their age being over 20 years. Where a definite age is assigned to them in the tables, this must expressly be noted as approximate; in cases of this sort accurate determination is out of the question.

Finally, mention should be made of a particular source of error which needs to be guarded against by special precautions.

In a sample of herring collected just at the time when the fish are developing the first stages of a new summer zone on the scales, some specimens of a certain year-class may be found where this has already visibly commenced, whereas others of the same group have not yet reached so far. If, then, the rings be counted quite schematically, and the observations recorded accordingly, the results will be that fish which have already commenced their summer growth will appear a year older than those which, albeit somewhat behindhand in this respect, are in reality contemporary with the former, and the greatest confusion will ensue.

In many cases, e. g., in dealing with young herring, the change is more or less conspicuous and the error may be avoided: as in such specimens, a narrow summer zone is visible outside a broader one, or several such. It is a different matter, however, when the fish are older, and have already one or more narrow zones near the margin of the scale. A new narrow zone on such a scale does not occasion any conspicuous and easily distinguishable alteration. In this latter case, it is difficult to say what precautions should be taken unless it be to avoid collecting samples during this transition period, or, possibly better, to supplement such samples by others taken before and after. The grown Norwegian herring, it may be noted, are not regularly fished for during the transition period.

V. THE SCALE OF THE HERRING AS AN INDICATION OF GROWTH. SOURCES OF ERROR.

If, in addition to counting the winter rings on the scales, we measure the distance between them, these measurements will enable us to calculate how each fish has grown from year to year. This, of course, presupposes that the growth of the scale takes place at a rate simply proportionate to the rate of growth of the fish. Judging from the investigations already made (*vide* Lea IX), the scales from various parts of the body differ somewhat in this respect. On the whole, however, we may say that such proportion does exist.

It has been found, however, that in dealing with the material obtained from such measurements of growth, the values arrived at in the case of young fish appear to be higher than the corresponding figures for the older groups (*vide* Lea XI and Lee XII), so that possibly there may be a systematic error in the growth measurements.

This is, in my opinion, only true to a certain extent. Moreover, some part of the apparently systematic error will, as a matter of fact, be found to arise from other causes, to wit, as the results of a biological process. Nevertheless, we may, in practice, until these problems are fully solved, do well to handle our material as if there were a systematic error, of the nature shown in the following table:—

TABLE 2.—Showing the decrease with increasing age of the corresponding calculated average values for the yearly increment in length. (Table reprinted from Lea (V) tab. 7.)

Year of capture.	Age.	No. of samples.	No. of individuals.	t_1	t_2	t_3	t_4	t_5	t_6	t_7
1907	$3\frac{1}{2}$	2	69	7·2	5·8	4·8	4·7*	......	..	......
1908	$4\frac{1}{2}$	1	58	7·1	5·2	3·7	4·2	3·9*	..	
1909	$5\frac{1}{2}$	3	331	7·1	5·0	3·5	3·9	3·4	3·2*	
1910	$6\frac{1}{2}$	6	78	6·9	5·1	3·5	3·9	2·9	2·8	2·5*

* Denote incompleted increments.

In the table above, t_1 indicates increment of length during first summer of life, t_2 the corresponding increment for second summer, etc. It will be noticed that the figures in the vertical columns exhibit decreasing values, and that a growth curve drawn on the basis of the figures for fish at $3\frac{1}{2}$ years would differ from one based on the values for fish $6\frac{1}{2}$ years old. This feature, which is very frequently encountered, may render immediate comparison between the growth values for young fish and those for older specimens precarious; therefore, where possible, samples of herrings of more or less equal age should be compared.

As regards the degree of accuracy obtainable in such individual measurements of growth, this is fairly high, and it is always possible, where greater accuracy is needed, to measure several scales from the same fish and take their average. This branch of the question need not therefore be further dealt with here. It should, however, be noted that all the sources of error which make themselves apparent in age determinations also apply to measurements of growth. If a ring be overlooked, then two years growth will be taken together as that of one, and the growth of the succeeding years will be erroneously reckoned, etc. If, on the other hand, a secondary ring be mistaken as a true one, the year's growth will be divided into two, and that of the following years again incorrectly recorded.

Save in the case of particularly difficult scales, however, errors of this nature will rarely occur in the values for growth during the first few years.

VI. AGE DETERMINATION AND GROWTH MEASUREMENT IN PRACTICE.

Where the winter rings are distinctly marked, and the fish young, it is of little importance from what part of the body the scales are selected; in the reverse case, however, this may be of the utmost importance. In all the scales of a herring the winter rings are by no means equally distinct. Where possible, therefore, the scales where these are most pronounced should always be chosen, i. e., the large scales from the middle forepart of the body.

VII. PREPARATION OF SCALES FOR PRESERVATION.

In the earlier years of the Norwegian investigations, the herring scales were scraped from the body with a knife, and placed in small envelopes, where they gradually dried. Before being used, they were soaked in a soap solution to which glycerine was added, which afforded a good enough means of cleansing them. This is a practicable method, and even presents certain advantages, when working on the fishing grounds, or on board a vessel under unfavourable conditions. Of late years, another method has been employed; three scales are plucked out with a pair of tweezers, cleaned while still fresh, then dipped in clean water, and laid in their wet state on an object glass, upon which have been placed three small drops of white of egg and glycerine (half and half), one little drop to each scale. Care must be taken that the scale lies with its inner side against the glass. When the water has evaporated, the scales will be found adhering firmly to the glass, and a permanent preparation is thus obtained. Notes as to length, weight, etc., may be made on the glass itself with water-proof ink (india ink to which is added some water-glass).

A third method of extreme simplicity is merely to take a single scale from each fish, and place it in a tube of water, to be mounted later. Tubes are kept for each length-group, or for each length-group and either sex, and the scales are then placed each in the tube assigned to its particular length and sex. Each scale in a given tube thus represents a fish of a certain sex and length and may afterwards be mounted on glass slides. By this means, a large sample of herring specimens may be dealt with in a very short time; it involves, however, the necessity of dispensing with data as to weight, state of development of genital organs, etc., besides lacking the indubitable advantage conferred by having several scales from the same fish. The advantage of the method lies in the fact that it enables the operator to procure a large quantity of material for age determinations in a short space of time, and that it may be employed even under the most unfavourable conditions. Moreover, where no examination of the specimens is made as to sex, the fish are entirely unharmed.

Microscopical examination.—As we have seen in the description given in the foregoing of the structure of herring scales, the impression of the winter rings is produced by reflection and refraction of light in the outer surface of the scale. In accordance with this, it has been found that no colouring, or similar process, will serve to render the rings more distinct than they naturally appear. The most that can be done is to alter the conditions of reflection and refraction by embedding the scale in a more or less highly refracting medium, experience having shown that this does render the winter rings more easily discernible. For examination of herring scales, a medium with not too great power of refraction has been found most useful, water with a little glycerine, or alcohol (90 per cent) is good, the latter being preferable when the scales have been mounted with the white of egg and glycerine, as aqueous liquids tend to loosen the mounted scales.

In observing scales through the microscope, a suitable attachment should be used, preferably an objective so arranged that the power can be altered at will. Leitz' objective 1*a* and Reichert's objective 1*b* are both very convenient, as with these the power may be continuously changed within certain limits.

In age determinations, it is best to remove the condenser from the microscope, and leave the lighting to the plane mirror alone. It is rarely possible to obtain suitable lighting of the entire scale simultaneously, and the mirror must therefore be frequently moved. The rings are best seen in slightly oblique light, when they show up darker than the summer zones (*vide* plate I, fig. 1).

In counting the winter rings, the operator should make it a rule to commence at the margin of the scale and work inwards towards the centre, i. e., first counting the rings which are most difficult to distinguish.

Where several scales have been preserved from each specimen, it is well to make a preliminary glance at all those which are ready prepared, and choose the one in which the rings appear most distinct. When the rings on this have been counted, another scale may be taken as a check, to see if the same number and arrangement of the rings is also found there.

Instead of counting the rings on the scales, it is possible, by means of a drawing mirror, to outline them on paper and count them afterwards. Such a method presents several advantages also as regards the actual determinations of age, and it is a question whether the method should not be adopted in most cases. It is best to use a drawing mirror with a series of smoked glasses for regulating the light. In order to render the picture of the scales as distinct as possible, a background of black paper should be laid on the table to the right of the microscope. It will not be necessary to draw the entire contour of the winter rings; all that is needed is to mark the position of each ring along the edge of strip of a card, as shown in fig. 24. The card

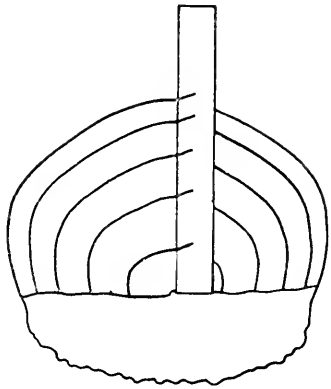


Fig. 24.

is laid on the table beside the microscope in such a manner that, to the eye, viewing both card and scale in the mirror, the corner of the card falls exactly upon the centre of the scale, the corresponding long side of the strip lying almost at right angles to the basal line. If then each winter ring, and the margin of the scale, be marked off along the edge of the card, a graph is obtained, presenting a magnified picture of the growth of the scale. Multiplying all these dimensions by a factor which renders the distance from the corner of the card to the mark for the edge of the scale equal to the length of the fish—this can be easily done graphically as shown in fig. 25—we have

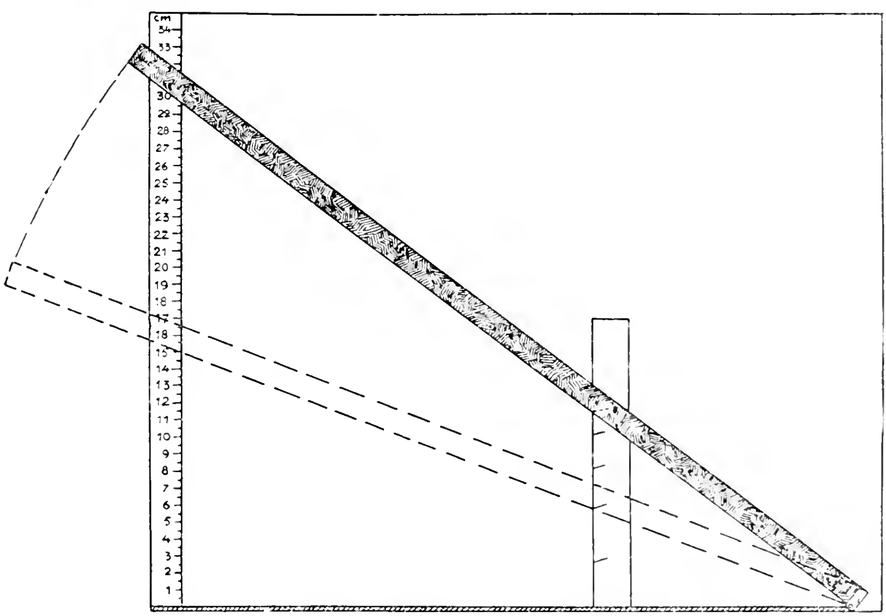


Fig. 25

the length of the fish at the times the different winter rings were formed. This entirely graphical method of measuring the growth of each individual specimen will naturally not give such accurate figures as those obtained by the more exact, but less rapid, methods of measurement and calculation; both the use of the mirror and the subsequent graphical multiplication involve the occurrence of errors which can of course, be diminished by the application of more exact methods. For most purposes, however, the method will be found sufficiently accurate.

VIII. DEFINITIONS AND ABBREVIATIONS ADOPTED.

Various expressions and signs employed in the following pages will need to be defined.

1. *Age.*—Age is expressed by the number of annual rings which have been found on the scales of the specimen in question, the relation of time of capture to season of birth being, however, here taken into consideration whenever possible. Thus a herring taken at Newfoundland in the spring will, if its scales show, say, ten summer belts be reckoned as 10 years old, whereas one from the same place, but taken in the autumn, and with ten summer belts, will be regarded as about 9½ years old, having regard to the spawning season at Newfoundland.

2. *Age-group.*—In assigning a specimen, say, to age-group 10, this is to be understood as meaning that its scales showed ten summer belts, ignoring the fact, when nothing is stated, as to whether it was taken in early spring or late autumn. The term is therefore used without regard to season of birth or time of commencing new summer growth.

3. *Year-group.*—When a fish is assigned, say, to year-group 1910, this means, that the specimen in question probably formed its first summer belt in that year. For all fish spawned in the spring, the date of the year-group will be identical with that of the year of birth; in the case of those spawned later, however, towards the autumn, it will remain open as to whether or not they formed any summer belt during the remainder of the year in which born. Fish taken during the period of transition to new summer growth may be difficult to class correctly in their proper year-group, and personal judgment will here be brought into play (*vide* p. 113).

4. *Growth-dimensions.*—On the basis of growth measurements, we obtain for each specimen figures indicating its calculated length at the time of forming first winter ring. This calculated first winter length is noted as l_1, while similarly, the calculated lengths or time of formation of second, third, and subsequent winter rings, will be designated by l_2, l, etc. Subtracting l_1 from l_2, we obtain the calculated increment of growth during the time falling between the formation of the first and second winter rings, this increment being denoted by t_2, and similarly, $t_3 = l_3 - l_2$ $t_4 = l_4 \div l_3$, etc.

5. *Length.*—By the length of a herring is understood the distance from the point of the snout to midway between the extreme points of the tail-fin when naturally extended. The length may be measured in millimetres or centimetres, and a fish is assigned to its nearest length-group; thus all fish, between the limits 29·5 and 30·5 cm. length, will belong to the 30 cm. group.

IX. COLLECTING OF MATERIAL.

The methods of individual age-determination and growth-measurement naturally suggest themselves as aids to the statistical investigation of the biology of the herring. If, however, they are to be used for this purpose, it will be necessary to formulate problems suitable for treatment by statistical methods of work, and to procure adequate observation material for statistical investigations. The question as to what problems can be dealt with will largely depend upon the possibilities of obtaining material for observation, in which respect, different waters will be found to vary, as we have here to reckon both with the technical features (implements used, intensity of the fishery, etc.) and also with natural conditions, which are not everywhere alike. In the case of each area investigated, therefore, it will be necessary to test the possibilities and limitations of the methods, i. e., to gain experience by actual application of the methods on the spot, and to utilize the results obtained by the work in determining the possibilities of continued operations, and in drawing up plans for the same. On the other hand, such determination will naturally be facilitated when it is possible to compare the results of preliminary investigations in a new area with the experience furnished by similar work elsewhere, which renders it easier, for instance, to distinguish between generalities and specific local features. In the following pages, therefore, an attempt will be made to sum up conclusions as to the possibilities for obtaining material of a typical and representative character acquired during the Norwegian herring investigations, which have now continued over a period of ten years.

First, as regards the age composition of the Norwegian herring stock, the investigations distinctly show that the stock in question does not appear as an even mixture of every possible age-group; on the contrary, it is seen to be divided up into several more or less markedly separated groups. These groups correspond in some degree to the various "sorts" of herring, as known and distinguished by the fishermen, and the appearance of the various groups at different places and times gives rise to various kinds of herring fisheries. The most distinctly defined group is that containing the mature fish, known by the fishermen as "large herring" when taken before spawning, and "spring herring" when captured on the spawning grounds and ready to deposit their spawn. Another group is the "fat herring," which may be characterized as herrings of moderate size still immature, and of excellent quality, whence the name. A third group is that of the "small herring," i.e., small, young, immature fish, of poorer quality than the fat herring. The habitat and migration of the various groups are evidently different. The spring herring, for instance, crowd in to the west coast in enormous numbers during the first months of the year. The fishermen have a characteristic name for these close-packed shoals; they call them "sildebjerg"=a "bjerg" or mountain of herring. It is a rare thing to find a young, immature fish among these masses of mature, "full" herring. And on the other hand, fish with genital products already developed are rarely found among the fat herring taken in the northern Norwegian waters during autumn.

The individuals in a year-class move up, so to speak, from group to group as time goes on, and as their development proceeds. The movement, however, does not take place simultaneously in all individuals, so that a particular year-class may become divided up, and fish of the same age will be thus encountered at different places and times, in association with those of various other ages. The Norwegian herring material offers several instances of this spreading of a year-class over different groups. In 1908, 1909, and 1910, fish of the 1904 year-class were found both among the mature, full, herring on the west coast, and among the immature fish in the northern waters, *vide* Hjort (V) and Lea (XI). The investigations upon immature herring, in 1915, showed that a distinct age-group occurred within a restricted area, and at the same time, associated partly with younger, partly with older, but still immature fish. This feature will be seen illustrated in table 3.

It is apparent from table 3, that the fish $2\frac{1}{2}$ years old are in two samples associated with almost exclusively older fish (one year older) whereas in the two others, they are found in company with others, almost without exception younger (one year younger). In the one case, they make up about two-thirds of the total number in the sample; in the other, less than a third.

The recognition of this important phenomenon leads us to the conclusion that an investigation of the age-distribution in a herring stock should include a study of the different groups, and that the interchange between them should be most attentively observed. One of these groups, that comprising the mature fish, has been under observation for ten years in Norway. The experience gained during the course of the work distinctly points to the possibility of following the age-composition, and its variations, within this group. These investigations have, in methodical respects especially, furnished interesting results; a brief description and discussion will therefore here be given of the material collected for the study of this age-composition and renewal of the mature group.

During the first years, from 1907 to 1913, only a small number of samples, from two to four, of the true full herring were collected annually, with, in addition, one to three samples of the so-called large herring, i. e., mature fish with genital products large but firm, which we now know to be very closely related to the actual spawning herring. Despite the small number of samples, and of specimens investigated, the samples were found to agree so closely one with another, and the features observable with regard to age-composition so marked as to convince the investigators at work on the material that even these few samples, and this small number of specimens, might yet be taken as representative, so far related to a certain very important point in the distribution of year-classes in the group of mature Norwegian herring. The main point in question was the fact that the year-class 1904 exhibited a marked numerical superiority over all others.

This year-class made its first appearance in any great number in a sample from April, 1908. It was thereafter found, in every single sample investigated during the years in question, to be enormously superior in numbers to all other year-classes. The striking contrast between the numbers of this one year-class and those of the many others, and the fact that this contrast was maintained for several years, served largely to confirm the conviction in the minds of the investigators. In order to give the surest possible foundation for the observations, a larger number of samples was collected during the following years, from 1914 to 1916. The analysis of this material confirmed most emphatically the presumption already arrived at, the year-class 1904, despite its continually increasing age, being still found to occupy a dominant position. One sample from the southern verge of the spawning grounds (Kristiansand, February, 1914) contained, besides the 1914 year-class, another numerically strong age-group, that of 1908 (*vide* Hjort V), but as this peculiarity was not observed in subsequent samples from either the same area or elsewhere it was presumed that the sample in question only represented a slight local disturbance occasioned by the immigration of a new year-class, which supposition was later confirmed. The winter season 1914-15 passed, and still the 1904 year-class, with its now 11-year-old fish, was seen to predominate. The first samples then investigated, however, already indicated that the 1910 year-class would now come to occupy a distinctive position, being more numerously represented than the adjacent classes, albeit far from equal in this respect to the old 1904 class. At first, also, there was but a slight degree of uniformity between the different samples as to the numerical value of this new year-class. Not until the commencement of March, 1915, was it seen to be evident beyond question that this year-class was decidedly richer than its older neighbour 1909, and in the two last samples of the season, it even rivalled 1904, the last but one containing 48 per cent 1910 and 25 per cent 1904, the figures for the last sample being 33 per cent and 38 per cent, respectively.

With these results in mind, the following season would appear to be doubly interesting; in the first place there was the question, would the 1904 year-class, now no less than 12 years old, continue to assert itself as heretofore; and, secondly, would the new year-class, maintain the same distinctive position as in the two last samples from 1915, or fail to maintain it as had been seen in the case of the 1908 sample from

Kristiansand. The first nineteen samples of large herring, in the winter of 1915-16, presented the same appearance as noted so many times before, the year-class 1904 being still predominant, and that of 1910 represented by only a few specimens. The twentieth sample, however, the first of the true spring herring, was a great surprise, as it contained one single specimen only of the 1904 year-class, and was otherwise composed mainly of young fish, 6, 5 and 4 years old, i.e., the year classes 1910 (with 26 per cent), 1911 (18 per cent), and 1912 (43 per cent). Here, then, was the 1910 year-class, but associated with two younger ones, of which the class 1912 especially was present in force. The following spring herring samples (from February, 1916) reverted once to the old style of composition, with 40 to 50 per cent 1904, but in March this is gradually changed, and we have first the 1910 year-class, and later the 1912 class, accompanied by the less numerously represented intermediate year-class 1911. Fig. 26 shows the entire series of age-analyses for seine-caught spring herring, the previous series of drift-net-caught large herring samples is here omitted for want of space, but may be supplied by imagining the nineteen earlier samples of fairly the same character as Nos. 2 to 4 in the figure.

A glance at the figure will show that the group of mature fish must have undergone a thorough change during the course of the season. At the commencement, there were evidently two very different sub-groups (represented by samples 1 and 2-4). As the season goes on, however, these intermingle, so that the curves for age-distribution exhibit a highly peculiar appearance. Altogether, the different samples agree very well one with another, and this despite the fact that the situation this year was highly variable, and not, as hitherto, practically stationary.

The entire material of mature Norwegian herring, it will doubtless be admitted distinctly indicates as possible the statistical recording of age-distribution and its variations in this group of the stock. The results arrived at in methodical respects from analysis of this material is, that the year-classes which have passed over into the group in question become so thoroughly mixed that it is possible, even with relatively few and small samples, to keep trace of the condition, when the same is, as during the years 1910-13, mainly stationary. During periods where marked alterations take place, as in 1908, 1914, 1915, and 1916, the number of samples will need to be greater, in order to furnish a view of the actual changes occurring. Thus, in 1916, no single sample can be taken as representative of the conditions, and erroneous conclusions would certainly have resulted had not several samples been available from various parts of the season, and different fishing grounds.

It is interesting, from a methodical point of view, to consider somewhat more closely samples from those periods when new year-classes began to make their appearance. We have here, first of all, the immigration of the 1904 year-class, in 1908; then that of the 1908 class in 1914; the 1910 class in 1915; and finally, the year-classes 1910-12 in 1916.

The 1904 year-class was first observed among the mature fish in 1907, but only in very small numbers; in 1908, it is found in the first sample from February, although not numerously represented; in the next and last sample from this season, however, it makes up 65 per cent. In the sample from 1909, it amounts to about 40 per cent, i. e. a decrease in the proportion. This rule, a rise of the percentage to a maximum, followed by a fall, applies to all cases where investigation has been made. The 1908 year-class appeared on the south coast at first in great numbers, later on in the same year the percentage was lower. The 1910 year-class reaches a maximum in the penultimate sample from 1915, with 48 per cent, in the last sample from that year percentage is only 33 per cent. The immigration of a new year-class, and the intermingling of the same with the older components of the stock, evidently takes some time, and would appear to commence with the entrance of the immigrants in a body, which wedges itself into the stock already on the grounds within a restricted portion of the same. The absence of the 1910 year-class during a great part of the fishing season

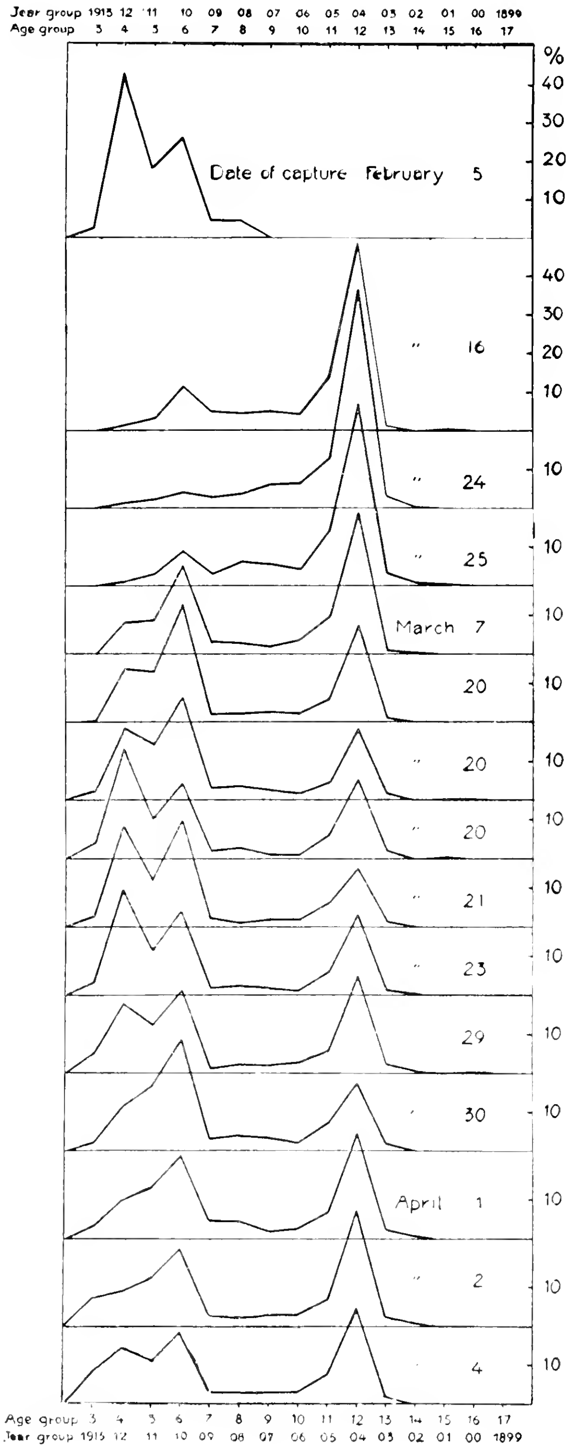

Jear group 1915 12 '11 10 09 08 07 06 05 04 03 02 01 00 1899
Age group 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
%
40
30
20
10
Date of capture February 5
" 16
" 24
" 25
March 7
20
" 20
" 20
" 21
" 23
29
30
April 1
" 2
4
Age group 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Jear group 1915 12 11 10 09 08 07 06 05 04 03 02 01 00 1899

Fig. 26.

1915-16 also seems to suggest that the process of mixing is gradual and may require some time, in other words, the group comprising the mature fish can at certain periods be more or less heterogeneously composed, as was the case to a very high degree in 1916.

Investigations as to age among the Norwegian herring have been carried out under favourable conditions, inasmuch as it has been possible to obtain samples not biassed owing to the methods of capture employed. Obviously, when gill-nets are used, some doubt may easily arise as to whether the age-distribution, apparent in a sample, may be more or less a result of the selective effect of the net itself, and a sample of such netted herring cannot be credited *a priori* with the same representative value as one taken with the fine-meshed seine. It was therefore fortunate for the Norwegian investigations that the herring fishery of Norway happens to a great extent to be carried on by seine (shore and purse-seines), and these more reliable seine samples furnished a starting point from which to investigate those taken in other nets.

The best means of carrying out such investigations would probably be to set nets of different mesh out in a standing seine. This would furnish excellent material for the purpose. Unfortunately no such experiments have hitherto been carried out, and for the present, all we can do is to utilize the material available, and compare seine samples with net samples taken at approximately the same place and time. In so doing, however, we have to reckon with a disturbing factor, to wit, a certain relation existing between time and place of capture, on the one hand, and implement on the other. Thus drift-nets are employed for the capture of herring out at sea, and especially early in the season; the whole of the "large herring" fishery is carried on with drift nets. The shore seine, on the other hand, can only be used when the fish come close in to land. Stake nets, again, are fixed on the bottom, while the purse-seine is worked near the surface. The Norwegian material includes a number of paired samples more or less satisfying the above requirements. These are set out in pairs in table 4 so as to permit of comparison between the age-composition in the samples.

TABLE 4.—Comparison between samples from seine and net-hauls. Each net sample compared with the seine sample nearest adjacent in point of time and place.

Locality.	Date.	Gear.	Age—Group.												
			4	5	6	7	8	9	10	11	12	13	14	15	16
Svinöhavet	Mar. 5, 1914	Net	0·9	2·3	2·3	4·6	5·6	13·9	56·9	4·2	2·8	3·7	1·9	0·9	...
Gurskö	" 26, 1914	Seine	1·1	...	2·2	7·7	8·4	19·4	51·6	5·5	1·8	1·5	0·4	0·4	...
Karmsund	Feb. 19, 1914	"	...	3·1	5·5	6·2	10·0	16·6	50·8	3·9	1·4	1·8	...	0·7	...
Rövær	" 13, 1914	Net	...	1·9	3·7	3·0	5·0	12·4	62·1	7·1	1·6	1·9	0·5	0·7	...
"	" 19, 1914	"	0·3	2·5	3·9	5·4	5·4	14·7	60·5	3·4	1·7	0·8	1·1	0·3	...
Karmsund	" 19, 1914	Seine	1·5	1·5	3·5	4·0	5·4	11·4	60·7	6·0	1·5	2·5	0·5	1·5	..
Skudenes	" 18, 1915	Net	...	2·0	4·1	8·2	5·4	8·2	17·0	53·1	1·4	...	...	...	0·7
Inside Skudenes	" 22, 1915	Seine	...	2·5	5·1	8·0	4·7	5·9	8·9	61·5	1·3	0·8	0·8	0·4	...

The general impression given by the table is that the columns of net-sample figures resemble very closely those for the seine-caught fish, such discrepancies as occur being small and without apparent regularity. Particularly interesting are the columns for the samples for Karmsund and Rövaer, where the two seine samples are from hauls made on the same day and quite close together. The impression, furnished by such paired comparisons between seine and net samples, leads us to the conclusion that the age-composition of mature Norwegian herring has been very much the same in the netted samples as in those taken with the seine. The same result is arrived at if we consider the material as a whole, the whole of the netted material tending in the same direction as that furnished by the seines. And bearing in mind the fact that the samples as a rule include more than ten age-groups, this result cannot but be said to be surprising. It might easily be imagined, for instance, that the difference in size between the younger and the older fish would be so considerable as to involve a degree of net selection far from negligible, the smallest and largest specimens avoiding capture, whereby the net samples would be seriously biassed. That this proved not to be the case, with the Norwegian samples of mature herring, is due to an important biological phenomenon, which we shall now have occasion to examine more closely, in considering the question of how best to procure representative material for the study of growth.

As already mentioned, the individuals in a year-class may fall into several sub-groups, appearing in company with older or younger fish. This subdivision of a year-class does not appear as merely accidental, but seems on the contrary to be regulated in a definite manner according to the stage of development at which the fish have arrived. This is, of course, natural enough in cases where some individuals of a year-class attain maturity and are ready to spawn, while others are still immature. Nothing could be more reasonable than to suppose that the mature fish should part company with those of their contemporaries that have not reached that stage, and move off by themselves to the spawning grounds. The year-class is thus divided up and dissociated according to the degree of maturity of the genital products. We now find, however, that the mature individuals in a year-class thus divided are of larger—often considerably larger—size than those still immature. There exists a positive correlation between degree of maturity and size. The year-class thus divided according to degree of maturity will therefore also be found dissociated according to size, the larger specimens of such a year-class will be found associated with older, mature fish, the smaller with younger, immature companions.

This being ascertained, the question then arises as to whether the attainment of maturity should be regarded as the only phases of development accompanied by such dissociation in point of size among the individuals of a year-class.

TABLE 3.—Age distribution (showing percentage) in four samples of immature herring from northern Norway, autumn 1915. Group 3 ($2\frac{3}{4}$ years old fish) are in two samples found in association with older herring, and in two samples with younger herring.

Number.	Locality and Date.	Number of individuals in sample.	Per cent belonging to different Age-Classes.			
			group 2	group 3.	group 4.	group 5.
			%	%	%	%
1	Kvæfjord, Oct. 15, 1915....	169	0·6	74·0	24·9	0·6
2	Gröttavær, Oct. 20, 1915.....	194	2·6	63·9	32·0	1·5
3	Ibestad, Nov. 7, 1915	259	88·0	12·0	....	....
4	Kvæfjord, Nov. 11, 1915............	265	68·3	31·3	0·4	....

The answer here must be that the dissociation already mentioned (*vide table 3*) is also regulated according to size; we find, for instance, that the average length of the $2\frac{1}{2}$-year-old fish (group 3 in table 3) is considerably greater in the two first samples, where this age-group was associated with older fish, than in the two last, where it was found in company with younger fish (22·1, 22·6, 17·0 and 18·3 cm., respectively). The four samples in the table are from hauls made within a restricted area, the greatest distance between places of capture being about 40 km. and within a short space of time, viz., from 15th October to 11th November. An even more striking example of this size-regulated dissociation, among immature fish, is furnished by two samples from hauls made at an interval of eight days and 21 km. apart. Table 5 shows the age-distribution in these two samples, and the difference between the average sizes of the year-class 1913.

TABLE 5.—Showing difference in average size of herring belonging to the same year-group (1913) in two samples. In one sample the herring considered were found associated with younger herring, in the other with older herring.

Locality and date.	No. of individ. in sample.	Percentual age composition.				Average length of group 1913.
		Year gr. 1914.	Year gr. 1913.	Year gr. 1912.	Year gr. 1911.	
Bergsvaag, Trondenes, Sept. 10 .	254	89·0	11·0	......	......	16·5 cm.
Tennvik, Sept. 18.......	177	0·6	63·3	35·6	0·6	22·7 "

Finally, it should be mentioned, that mature, full specimens of the same year-class were also found among the spring herring in the spring of 1916, the average size of these was 25·8 cm., or considerably in excess of that found in any sample of immature herring, where the maximal average size was 22·7 cm. Neither the difference in size nor in degree of maturity, can easily be explained as a result of growth in the period between late autumn 1915 and the spring of 1916, the discrepancy being too great, the time too short, and the season, as has been shown by experience, being a period of stagnation. It is therefore most reasonable to suppose that the said year-class was dissociated into at least three groups, one consisting of small fish, associated with younger ones; another of large, but immature individuals associated with their seniors; and finally one comprising those of large size and completed maturity, associated with the adults.

The remaining two important year-classes in the material, viz., those of 1914 and 1912, do not exhibit fluctuations so violent as in that of 1913; there is, however, also here a suggestion of dissociation according to size, wherefore it would be well to reckon with the possibility that a year-class may become dissociated and grouped according to size of individuals throughout the entire period of growth until full maturity is attained.

What takes place after this time, when all surviving individuals of the year-class have reached maturity, cannot be stated with certainty as yet; there is, however, reason to believe that the process of maturing should be regarded as a phase of development which, when completed, leads the separate components of a divided year-class to reassemble, i. e., that the sub-groups formed by the varying rate of development will, after maturity and subsequent spawning, reconsolidate into a whole.

At any rate, it would seem, from the results of the Norwegian growth investigations, that the components of the rich year-class 1904—which, from its numerical importance and peculiarities of growth, furnishes excellent material for a study of this question—did reassemble after their separation during the process of attaining maturity, and were later found mingled and collectively in the samples of mature fish. The observations made from year to year present, when seen together, the picture of a process terminating in a fairly stable mixture of the heterogeneous elements which compose the year-class in question. This is especially noticeable in the case of that growth-dimension which exhibits the greatest and most peculiar variation, viz., the increment for the third year of life (t_3). Fig. 27 shows curves of frequency for this dimension, the observations of each year being noted separately, and subdivided into

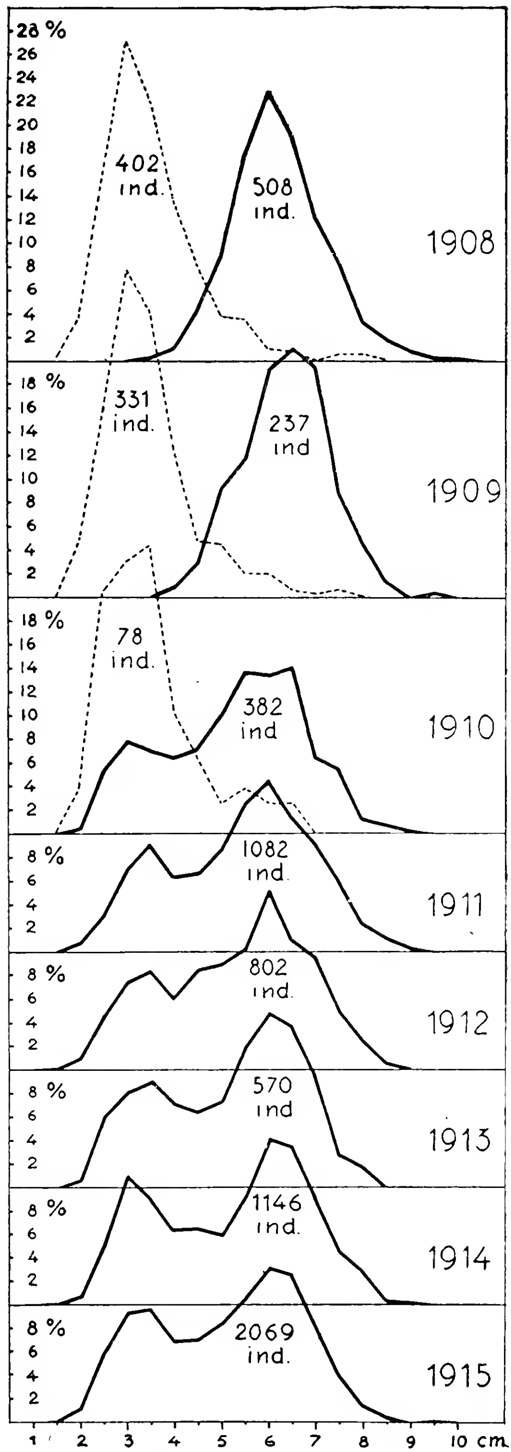


Fig. 27. ——— Mature herring. . .... Immature herring.

two categories, the one embracing a sample from the spawning grounds taken during the spawning season (the spring fishery of the west coast) and the other including immature fat herring taken in autumn on the north coast of Norway.

It will be noticed that the individuals found among the grown fish in 1908 have a considerably greater t_3 than the autumn-caught immature fish from the north, a similar difference is also observable in 1909. In 1910, however, the curve for the mature fish exhibits a different course, and is here distinctly bimodal; during the autumn of the same year, only a few specimens of this year-class were found among the immature fish, and the following year none. After 1910, the curve maintains its peculiar form, with the two modes, the position of which, as will be seen, corresponds to the two modes in the two pairs of curves for 1908 and 1909.

Similar conditions will be found to apply in the case of the remaining growth dimensions (t_1 t_2 t_4 t_5) save that the original difference between the two categories is not so great as to produce a final bimodal curve, but only a compound curve.

From the foregoing, it will be seen that the biological process which is termed the dissociation of year-classes is a phenomenon which must be taken into consideration in statistical investigations of the growth (and age) of herring. The phenomenon itself would seem, as far as can be judged up to the present, to be of considerable dimensions, and to be closely related to other phenomena such as maturation, migration, accumulation of fat, etc. It is therefore, in my opinion, worthy of closer study, in the prosecution of which growth measurements may be of assistance, in view of the relation between dissociation and size (growth).

In the case of investigations dealing with the problem of growth during different years, or in different waters, the phenomenon will appear as a complication, a new and variable factor. It will therefore be necessary, in such investigations, to procure material, the elements of which are as far as possible comparable. And as circumstances are, the best material would be that consisting of older fish, as offering greater facilities for the procuring of representative samples.

With regard to the question as to number and size of the samples, it will be seen from the foregoing that various points need to be taken into consideration here. The number of samples, and their size (i. e., the number of individuals contained) must be determined according to the peculiarities of the stock to be dealt with, or of the water under investigation, or of the problems which it is desired to solve. In the case of the immature Norwegian herring, for instance, where, as we have seen, the year-classes occur in several combinations, and dissociated according to size, a large number of samples will be necessary; owing to the small number of year-classes represented, however the samples need not be particularly large. The mature Norwegian herring, on the other hand, in 1914 might, as we are now able to see, have been dealt with through fewer samples than were collected, owing to a comparative stability in the distribution of the year-classes with a single dominant group, which marked this year, as compared with the variability of the situation in 1916, where several new year-classes cropped up.

A water area containing several different tribes of herring will in particular require a larger number of samples than one where simpler conditions prevail.

In dealing with problems which demand that the values operated with (e. g., the mean values for growth dimensions) shall be accurate, i. e., with the smallest possible degree of accidental error, it may be necessary to make the sample larger.

It is impossible to lay down any definite rule or system for determining this question, as the circumstances to be considered vary from place to place and from time to time. In most cases, however, we may say that given a certain number of specimens to be examined, there will be more chance of obtaining the best material when these are distributed among a larger number of smaller samples, then if they are massed in one or a few large ones. In the Norwegian investigations among the grown herring, the material was at first collected by taking a few samples each year, each sample containing a relatively large number of specimens. As the work went on, however, it was found desirable to collect the material on a more extensive basis, with more samples, distributed as widely as possible throughout the area and the season embraced by the fishery. This involved an alteration of the methods employed, and a number of the samples thus collected were now subjected to a simpler process of examination (*vide* p. 133) in addition to which the question as to possibility of reducing the number of specimens in each sample was considered and tested. With this new method, which was tried and adopted in 1914, it was found that for the object in view, and under the conditions then prevailing among the stock, comparatively small samples might well be used. An average of some 200 specimens per sample was seen to be sufficient, and it was also realized that the advantage gained by operating with larger samples would be altogether disproportionate to the extra work involved, as the discrepancies between the samples could not be essentially minimized thereby, and may be due to other causes than fluctuations of sampling.

It should be emphatically pointed out, however, that the prevailing situation was exceptionally favourable for the work of age investigations, the contrast between the one enormously rich year-class 1904, and all the others, being so great that the curves for age distribution would maintain their characteristic appearance even with considerable errors of sampling. In other words, the age composition was so characteristic, that it was advantageous to work with small samples, and consequently greater accidental fluctuations, as this rendered it possible to deal with a greater total number of samples.

In cases where the age distribution is less characteristic, e. g., where several successive year-classes are more or less equally strong, accidental fluctuations of samples may impair the agreement between the samples, or at any rate, render it less obvious. In such cases, therefore, it may be desirable to reduce the extent of the fluctuations of sampling by increasing the number of specimens in each sample. It was in anticipation of such a possible change in the situation that the number of specimens per sample was increased to about 400 in the case of the Norwegian spring herring investigations in 1916.

The situation prevailing during the past few years among the Norwegian spring herring has not been quite so favourable for growth investigation; when so great a percentage of the specimens examined is derived from a single year-class, the result is an almost superfluous quantity of material confined to the group in question, with a corresponding reduction in the amount for growth observations for the many other year-classes represented. Under these circumstances, it would require a disproportionate amount of work to procure material in which every single year-class should be represented by the full number of specimens desirable for growth investigations.

B. SPECIAL.

THE CANADIAN MATERIAL.

X. Description and preliminary grouping of the Canadian material.

The chart, fig. 28, on page 117 will serve to locate the samples placed at my disposal and dealt with in this chapter. The material comprises a large number of samples from an area embracing the Atlantic coast of Canada, the gulf of St. Lawrence, and the coast of Newfoundland.

The comparatively large number of samples, and their distribution throughout different seasons, counterbalances, at any rate in the case of certain waters, the disadvantage arising from the fact that the number of individuals in each sample is, as a rule, but small. It will, however, probably be desirable in the case of future investigations, to secure larger samples, as the stock in these waters has been found to include an unusually large number of age-groups. Nowhere have fish of so great age been found in such considerable numbers as here.

By far the greater portion of the samples originates from catches made with implements, viz., gill-nets, which cannot be regarded as particularly suitable for the purpose of obtaining representative material. As mentioned in the foregoing, samples of netted herring must necessarily be less reliable than samples taken with non-selective implements, especially where no opportunity occurs of making comparison, as in Norway, with samples of the latter sort. Some doubt may therefore arise as to whether the younger and smaller fish are represented in their due proportion in the samples. There are, however, as will subsequently be shown, certain peculiarities in connection both with age-distribution and growth, which cannot be explained as merely resulting from the selective effect of the nets.

In addition to the samples of grown herring from various places and taken at various times, we have also a number of samples of young, immature fish, drawn partly from catches made by steam drifter *No. 33* with the drift-net, during the summer of 1915, and partly also from trap-catches. The importance of these samples of immature herring lies not so much in their representative value, which may be open to considerable doubt, not only on account of the method of capture, but also because the experience gained in the course of the Norwegian investigations has shown that some caution is necessary when dealing with samples of quite young herring. They form, however, a valuable supplement to the material of grown fish, as furnishing an aid to to the determination of the time when summer growth begins, and also because it has been found that these young fish exhibit growth variations for the different waters exactly similar to those noted in the case of the grown individuals. These young samples, therefore, add to the value of the remaining material, and give the results a more general character.

From the very first, on going through the scale-samples it was strikingly evident that the material must embrace several different, in some cases strikingly different, "sorts" of grown herring. The difference between fish from the different localities made itself apparent partly in the more or less distinct marking of the annual rings on the scales, rendering number and distance more or less easy to read, partly in the fact that the dominant age-groups (year-classes) differed in samples from different localities, and finally, in the different character of the growth, as indicated by the scales. It therefore seemed natural, after this first survey, to make a preliminary division of the material according to locality. This gave four groups of samples, as follows:—

1. Samples from the waters about Prince Edward Island, i. e., west and south of a line drawn from cape North, Cape Breton, to the eastern point of Prince Edward island, and thence on to cape Gaspé in the province of Quebec.

2. Samples from the waters about Magdalen islands.

3. Samples from the coast of Newfoundland (all from the west coast, excepting one from White bay).

4. Samples from the Atlantic side of Cape Breton island, Grand Narrows, Ardoise, coast of Nova Scotia, Bay of Fundy, and from Gloucester, Mass.

The following pages will be devoted to a description of the results obtained from age-determinations and growth measurements, arranged on the basis of the above group-division. The first question to be dealt with will be, how far fluctuations occur in the relative numerical value of the year-classes, and if such occur, whether they become apparent in the same manner throughout the entire area embraced by the samples, or whether they vary in the different waters. Thereafter, the growth in the various localities will be discussed. And finally, by summing up the information obtained from the study of the age and growth, and discussion of the material available as to number of vertebræ, etc., an attempt will be made to deal with the question as to the possible existence of different races or tribes of herring in the Canadian waters.

XI.—AGE.

a. The waters about Prince Edward Island.

From these waters we have five samples of grown fish, taken by gill-net at different places in Northumberland strait; two of these are from May, 1914; the remaining three from May, 1915. In addition to these, there are also two samples of herring caught in traps in the neighbourhood of Souris during the summer of 1915, and eight samples from drift-net catches made during the cruises of the drifter *No. 33* at various places in the gulf, in June and July, 1915. The chart, fig. 28, shows the localities.

The trap-and drift-net catches contain a quantity of young specimens, and on examining scales from these we find as will subsequently be shown, that the summer growth for 1915 commenced some time in June in the case of the young fish, probably during the second half of the month. It will therefore be reasonable to suppose that the older and grown specimens in the samples from May had then not yet commenced their new summer growth, and that, consequently, the last summer zone in the scales would represent the growth of the fish during the summer of the year previous to capture.

The other samples, containing older fish, date from the time between the end of June and the end of July. With regard to these therefore, we cannot be so sure as to whether summer growth has commenced, or if so, whether it has commenced in all cases. Some doubt arises in assigning the fish to definite year-classes (*vide* p. 119), in addition to which the length of drift-net used by *No. 33* was composed of greatly varying widths of mesh, and thus rather calculated to take herring of all sizes than to take them in the natural proportion between the different size-groups. The value, therefore, of the samples in studying the proportions of the different year-classes is somewhat difficult to determine, and the samples of grown fish from Northumberland strait have consequently been kept apart from the rest. Fig. 29 shows the percentual age-distribution in these five samples.

It will immediately be noticed that the implements have here succeeded in capturing fish of most widely differing age, from specimens 4 years old to individuals of (apparently) some 20 years, a circumstance resembling that noted in the case of the drift-net hauls of Norwegian grown herring, but in the present instance perhaps even more marked. And although we here lack such means of gauging the value of the samples as is afforded by comparison with samples taken with non-selective implements, yet the circumstance in question gives us further grounds for hoping that the fish of medium age at any rate have been taken in something like their natural proportion. This presumption is further confirmed on examination and comparison of the curves for the different samples. Here, as will be seen, the different age-groups are represented in by no means equal numbers, and what is more, the samples themselves agree in this respect to a degree which, considering the small number of specimens and the large numbers of age-groups, may be taken as very satisfactory.

Fig. 28.

The curves being age-curves, there is, of course, transposition from 1914 to 1915 of the two characteristic modes; in 1914 there are comparatively many fish aged 7 and 11 years, in 1915 many of 8 and 12 years old, whereas the age-groups 6, 8, 9 and 10 in 1914, and 7, 9, 10 and 11 in 1915 contain relatively few specimens.

In the case of the younger fish, we do not find the same agreement in the different samples. It must in all probability be taken as due to accident that we find, for these ages also, an almost perfect agreement when we take the two 1914 samples together as one, and compare the resulting age-curve for the whole with that for the three 1915 samples together. This is shown in fig. 30, where the grouping is arranged according to year-classes, and not in order of age.

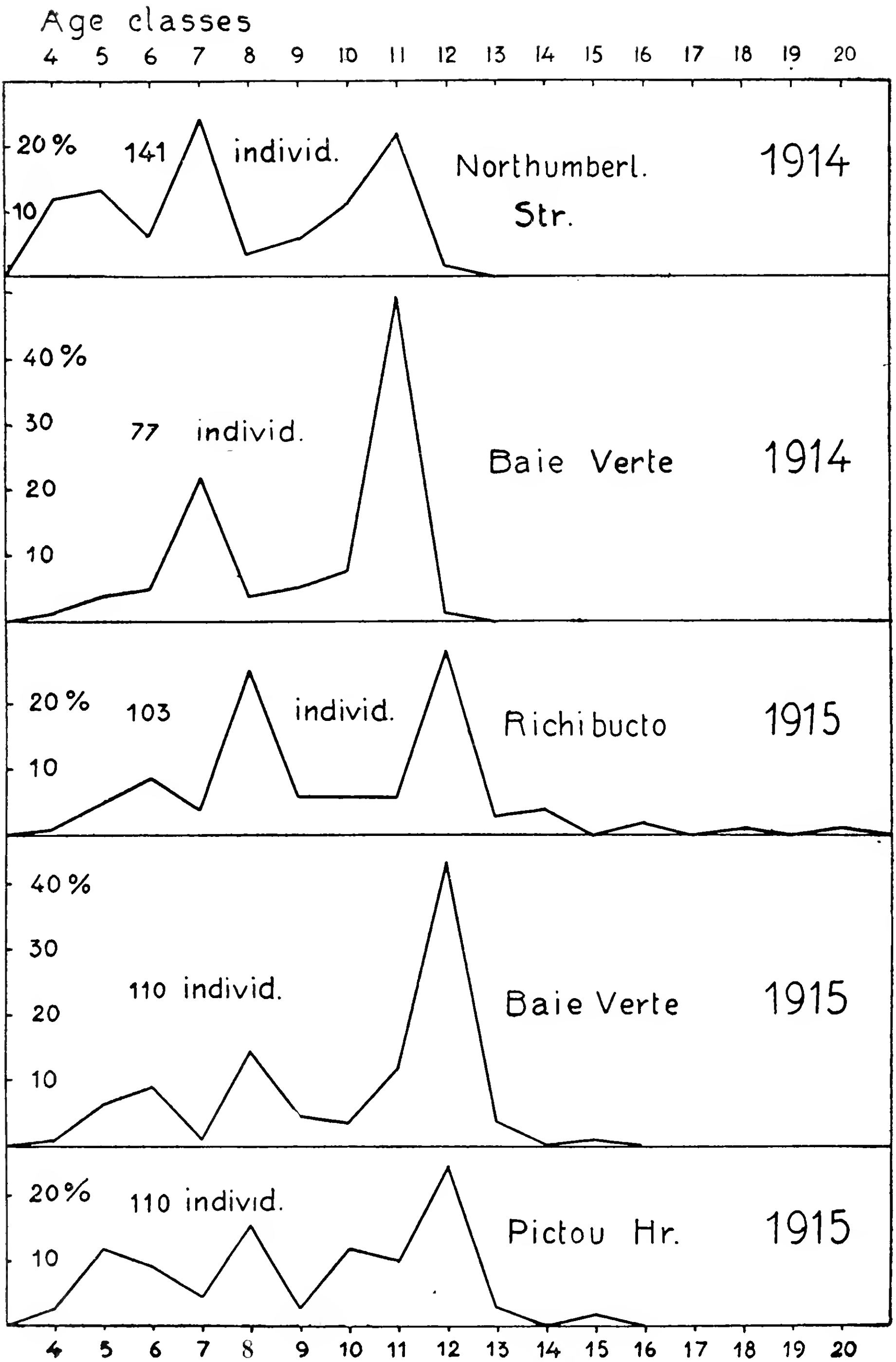

Age classes
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
20 %
10
141 individ.
Northumberl. Str.
1914
40 %
30
20
10
77 individ.
Baie Verte
1914
20 %
10
103 individ.
Richibucto
1915
40 %
30
20
10
110 individ.
Baie Verte
1915
20 %
10
110 individ.
Pictou Hr.
1915
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Fig. 29.

It will be seen that the year-classes 1903 and 1907 were considerably more numerously represented in the samples than the other year-classes, and especially characteristic is the difference between the "good" year-classes 1907 and 1903, on the one hand, and the three intermediate years 1904, 1905, and 1906. The older year-classes are represented by few specimens, whereas the younger ones, as mentioned, vary from one sample to another.

The small number of specimens and of samples, and the nature of the implement of capture, are points which diminish the representative value of the material. On the other hand, the marked degree of similarity between the samples, the characteristic transposition of the modes of the curves for 1914-15, and not least, the peculiar course of the curves themselves, are features which must be taken as favouring the supposition that the peculiarities noticeable in the material actually reflect typical conditions. A bimodal or multimodal age curve will probably, as a rule, arise not on account of, but despite the selective effect of the implement of capture.

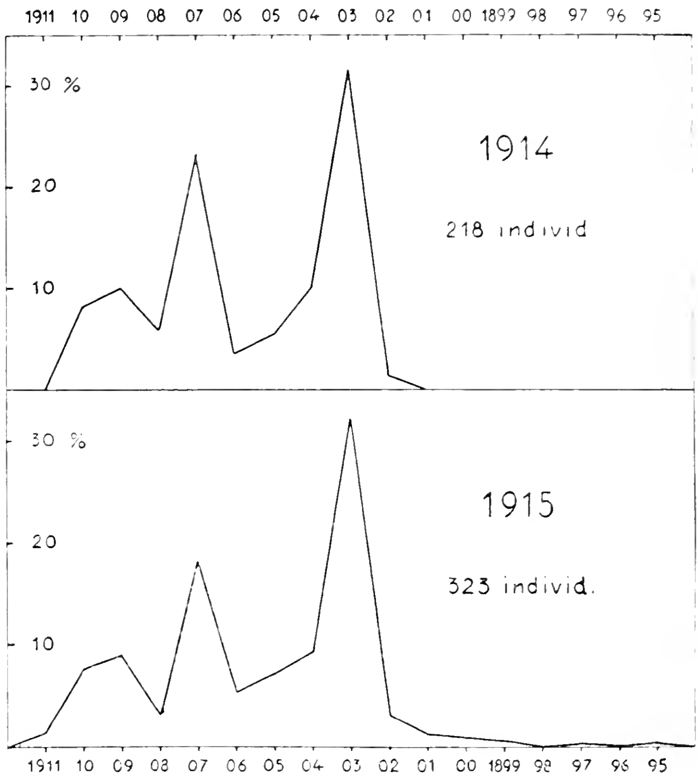


Fig. 30.

We cannot, however, take it for granted that net samples, even though exhibiting variations in the relative strength of the year-classes, present these variations in their correct numerical proportion. If we cannot be sure that the nets have taken the younger year-classes (1911-1910-1909) in their due proportion, neither can we be certain that the two strong year-classes are correctly represented in this respect, the nets might well be supposed to have retained a relatively greater number of the one group than of the other, owing to the difference in size. This question could be decided by continued investigations, or by procuring material from hauls made with non-selective implements. A slight step in this direction may be made by considering the samples taken during the cruise of *No. 33* and the samples from Souris. Most of the samples contain many young and immature fish, but, in five, some old fish were found, viz., in the samples from stations 27, 28-29, and 42, and also in one of the trap samples from Souris. The three first stations are situated between the western side of Prince Edward Island and the Gaspé coast, while station 42 lies north of cape George (*vide* chart, fig. 28).

TABLE 6.—Age distribution in three drift-net samples taken off the Gaspé coast (stations 27-29), one trap sample from Souris, P.E.I., and one drift-net sample from west of Port Hood, Cape Breton (station 42), June, 1915.

Locality and Date.	Number of individ.	Age-groups—Year-groups.										
		3	4	5	6	7	8	9	10	11	12	More.
		1912	1911	1910	1909	1908	1907	1906	1905	1904	1903	
Station 27, 48° 21′ N., 63° 57′ W., June 28-29.	82	1·2	13·4	15·9	9·8	8.5	13·4	3·7	4·9	6·1	23·2	
Station 28, 47° 56′ N., 63° 27′ W., June 29-30.	30	3·3	40·0	6·7	6·7	3·3	3 3	....	6·7	10·0	16·7	3 3
Station 29, 47° 34′ N., 64° 12′ W., June 30-July 1.	95	3·2	68·4	12·6	3 2	3 2	5 3	2·1	....	...	2·1	
Souris, June 7	117	25·6	36·8	15·4	6·0	0·5	6 0	1·7	4·3	2·6	0·8	
Station 42, 46° 0′ N., 61° 56′ W., June 15-16.	133	0·7	64·7	21·1	3·8	7·8	1·5	...	0·7	....	....	

Table 6 shows the percentual distribution of year-classes in these samples. As already mentioned, there may be some difficulty in determining whether new summer growth has commenced in the case of the older fish. In these samples the scales of some of the younger specimens distinctly show an incipient new growth, whereas in others, judging from the breadth of the last summer zone, it would seem that the new summer growth had not yet commenced. This being the case with the younger fish, one would hardly expect the scales of the older fish to exhibit any commencement of new summer growth, and, as a matter of fact, the last summer zone on these old scales was found to be of about the same breadth as the previous one.

The age-tables have therefore been drawn up accordingly, and the column farthest to the left thus includes specimens, some of which exhibit the number of summer zones indicated in the heading, and others an additional narrow zone beyond this. In by far the greater number of the older specimens (from group 7 and upwards) the last summer zone on the scales is taken as representing the summer of 1914. This method of arrangement should, as regards all that is here essential, be correct enough, albeit some doubt may exist in the case of fish of a medium age.

It will be seen from the table that the fish assigned to the 1903 year-class are relatively numerous, especially in the samples from station 27; in three of the samples, the specimens assigned to 1907 are relatively numerous (stations 27-29, and the samples from Souris). The sample from station 42, on the other hand, exhibits no resemblance to the five gill-net samples from Northumberland strait; this sample we shall later on have occasion to consider in another connection, and it is merely mentioned here in order to note its difference from the samples from Northumberland strait.

All samples from these waters point, when taken together, to the correctness of the supposition that the 1903 and 1907 year-classes were present in greater numbers than the intermediate year-classes of 1908, 1909, and 1910.

With regard to the younger fish, it is not so easy to arrive at definite conclusions on the basis of the material available; it is always, moreover, a far more difficult task to ascertain the relative strength of the different year-classes among immature herring.

Nevertheless, a glance at tables 6 and 7 will immediately reveal the fact that only a few specimens of the year 1912 year-class were taken, whereas the 1911 and 1913 year-classes were particularly well represented.

TABLE 7.—Showing age distribution in samples where young and immature fish predominate.

Locality and date.	No. of indvd.	Age-groups. — Year-groups.					
		2	3	4	5	6	More.
		1914.	1913.	1912.	1911.	1910.	
Station 33, 48° 13′ N. 63° 58′ W. July 5-6.	38	....	78·9	18·4	....	....	2·7
" 31, 47° 52′ N. 63° 57′ W. " 1-2.	73	....	52·0	8·2	30·1	5·5	4·1
" 34, 47° 13′ N. 64° 21′ W. " 6-7.	47	....	83·0	17·0			
" 35, 46° 51′ N. 64° 25′ W. " 7-8.	47	....	100·0				
Souris " 11.	33	....	42·4	57·6			
Station 53, 45° 46′ N. 62° 23′ W. " 30-31.	32	37·5	3·1	21·9	9·4	28·1	

b. The waters about Magdalen Islands.

From this area, we have a gill-net sample taken in May, 1914, one from May, 1915, and further a very small sample (which is of no value in this connection), with finally, one from a drift-net haul made by *No. 33* about end of July, 1915 (station 49). It will be as well to deal with this last sample first, as an examination of the scales here shows that the younger fish (4- and 5-year-olds) therein contained, had doubtless commenced a new summer's growth but had made only very slight progress therewith the new summer zone appearing in most cases as a very narrow belt outside the broader zones for the previous years. This would seem to indicate that the summer growth in these waters begins late, as is also the case farther to the west and south. In the case of the two samples from May, 1914, and 1915, therefore, we may take it that the last summer zone on the scales represents the summer previous to the year of capture. For the older fish, however, in the July sample mentioned, it will be a matter of doubt whether these have commenced their new summer growth or not. In table 8, therefore, only the two youngest age-groups have been assigned to year-classes, the headings for the older groups indicating only the number of rings on the scales.

TABLE 8.—Age distribution in samples from station 49, 70 specimens. Year-class noted only for the youngest fish.

Age-groups — Year-groups.									
5	6	7	8	9	10	11	12	13	14
1911.	1910.	1909.	1908.						
21·4	14·3	7·1	37·1	2·9	2·9	2·9	7·1	5·7	1·4

It will be seen from the table that a considerable number of specimens belonged to the 1911 and 1910 year-classes, and many fish occured with eight rings on the scales, with finally a more indistinct accumulation of individuals in groups 12 and 13.

If we now turn to the two samples from May, 1914 and 1915, we find, as shown in fig. 31 that one from 1914 contained many 11-year-old fish, while in 1915 there were many of 12-years-old. The 1903 year-class that is to say is relatively numerous in both samples. In the 1915 sample, moreover, there were many specimens of the 1911 and 1910 year-classes, a feature common to this sample and that from station 42, and as regards the 1911 year-class, also to the several of the samples from the waters between cape Gaspé and Prince Edward Island. On the other hand, in these two

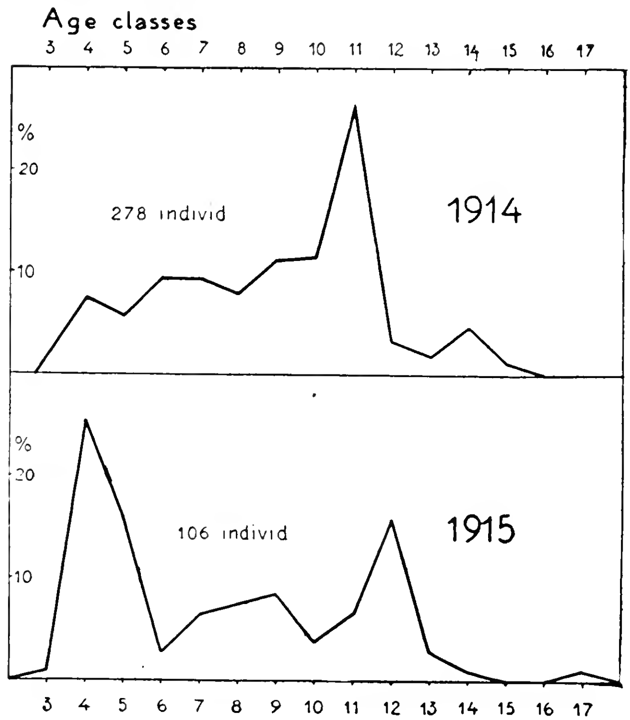


Fig. 31.

samples from the Magdalen islands, we do not find that quantity of fish belonging to the 1907 year-group which was so characteristic of the samples from Northumberland strait. What signifiance should be attached to this point of difference it is impossible to say until further material is available; one thing, however, is certain; the samples from the Magdalen islands exhibit no small likeness to those from Northumberland strait and from off the Gaspé coast.

It is therefore open to doubt whether the division here made is in accordance with the actual conditions, which question will be discussed when the growth investigations have been dealt with, and in connection with the treatment of racial characters (number of vertebræ, etc.)

c. The Newfoundland waters.

The material from these waters comprises five samples from the spring of 1914, four from the autumn of the same year, and three from the spring of 1915, making twelve samples in all, of grown fish, all caught with the gill-net. In addition to these, there is also a sample of quite young herring from the cruise of the steamer *No. 33* in the summer of 1915; this sample however, isolated as it is, will be of no importance as regards the questions here dealt with. The samples are all from the west coast, with the exception of one from White bay.

Figs 32, 33 and 34, present, in graphical form, the results of the age determinations, the material being here divided into three groups, according to season.

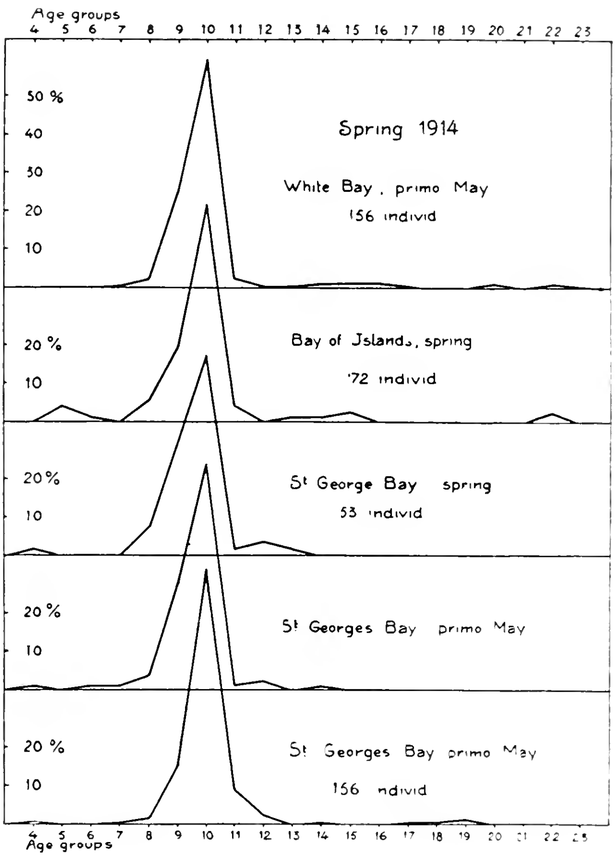


Fig. 32.

The Newfoundland samples, like those from the Magdalen island and Northumberland strait, include a considerable number of age-groups, the age of the specimens varying from 4 to over 20 years. Only very few of these groups, however, are at all numerously represented; in all the samples save one, the fish are found for the greater part massed in a particular group, to wit, group 10 in the spring samples from 1914, and group 11 in the later ones. Taking it for granted that summer growth in these waters, as in those farther to the south in the Gulf, has not commenced by May, then the age-group 10 will in the spring of 1914 answer to the year-class 1904, and similarly presupposing that the new growth commences some time during the summer, then age-group 11 in the autumn samples from 1914, and those from the spring of 1915 will be likewise equivalent to year-class 1904. All the samples, with the single exception named, thus bear witness to a state of things similar to that noted in the case of the Norwegian stock, i. e., a single year-class taking up a dominant position, which is maintained for several seasons. Fig. 35 shows the distribution of the year-classes during these three seasons, as revealed in the samples, the single divergent sample from 1915 is here omitted, but will be referred to later on, as it is of considerable interest. We have noticed, in the three foregoing figures, that no essential difference was

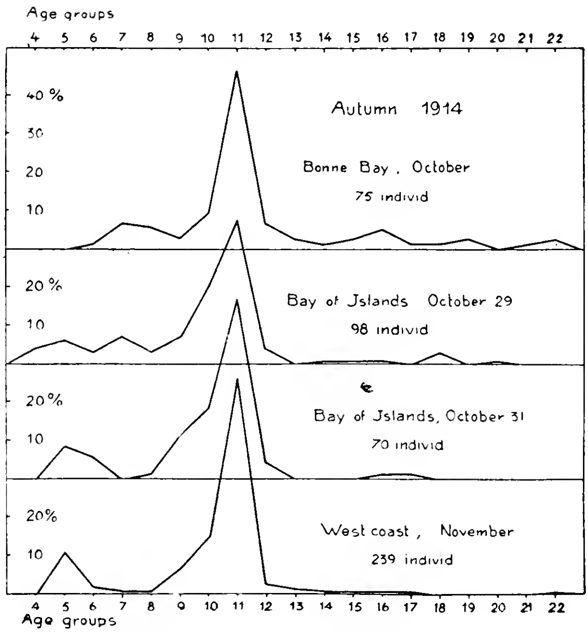


Fig. 33.

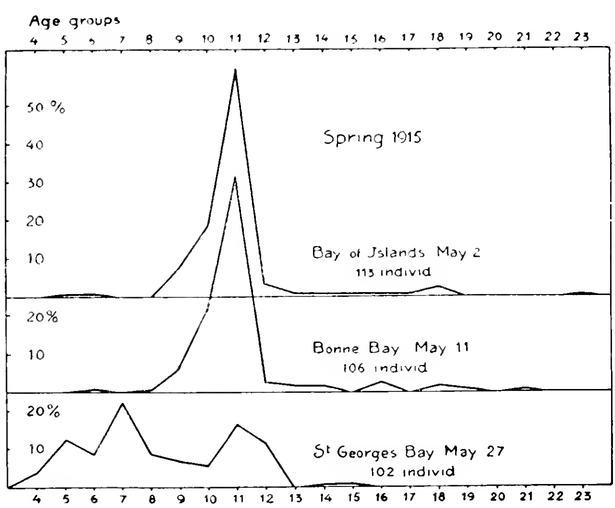


Fig. 34.

apparent between the samples from different localities. Here again, in the present case, the samples from the three seasons are seen to differ but very slightly one from another, save perhaps for the fact that the autumn samples seem to include a greater number of young fish than those from the spring. The difference, however, is by no means considerable, and it is possible, moreover, that the part of the curve indicating the numerical value of the young fish may in reality be not altogether accurate, owing to the nature of the implements employed. As a matter of fact, therefore, nothing definite can be said as to the relative frequency of the young fish here.

The age-groups in the samples have, as already indicated, been carried over into year-classes; this is analytically supported by consideration of the age-curves resulting from the spring samples from 1914 and the autumn samples of the year, with the similarity between these latter and those from the spring of 1915, distinctly pointing to the fact that the new summer growth must have commenced some time after the month of May. The strong contrast between of 1914 and groups 11 and 12 in the

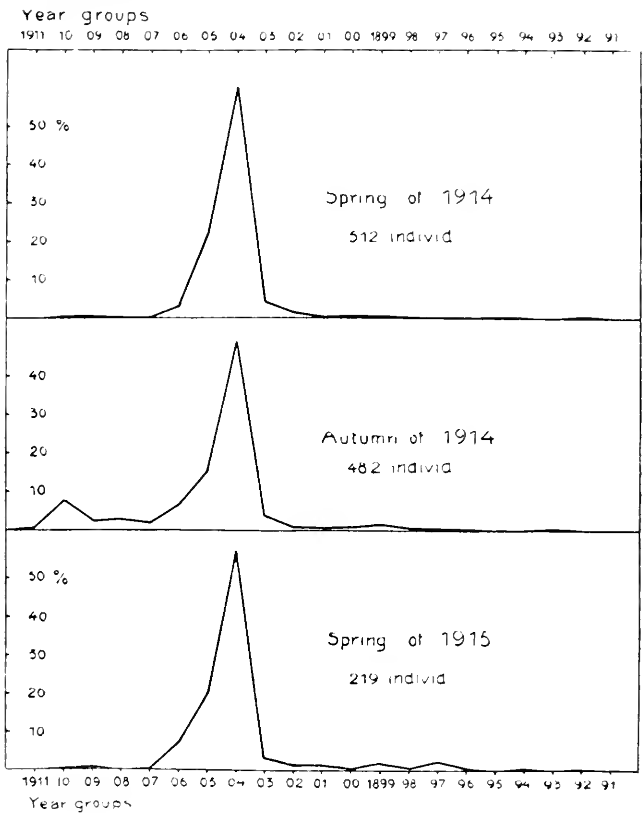


Fig. 35.

spring of 1915 suggests that the summer growth has not made itself apparent on the scales at that time of the year. Had such been the case, the contrast would certainly have been effaced by the division of each year-class into two age-groups, according as they had or had not commenced their new summer growth. The divergent sample might possibly to some extent be explained by supposing that some of the individuals therein contained had commenced new summer growth; the sample in question was also taken late in May. But as will later be shown, it is more likely that it represents another group of herring than those in the remaining samples. This sample apart, the material presents an appearance totally different from that furnished by the samples from Magdalen islands and Northumberland strait; moreover, as we shall now have occasion to show, it differs likewise in point of age distribution from that collected on the Atlantic coast.

d. From Cape North southwards along the Atlantic coast of Canada.

The material from these waters embraces seven samples of mature herring, and four of immature fish, covering a range from Sydney, Cape Breton, to Gloucester, Mass. In going through the scale preparations from these samples, it was strikingly noticeable that the scales were considerably more difficult to read than those of the specimens from the gulf of St. Lawrence. The first and second winter rings were often found to be faint, thus rendering less distinct the contrast between the true winter rings and the secondary rings, which latter were of frequent occurrence in these scales. The rings beyond these may be said to be fairly distinct, but the outermost ones, on old scales, were again difficult to discern owing to the fact that the fine ridges on the surface of the scales were often irregularly developed, a symptom of senility in herrings. Another feature, which will be more important in connection with the growth investigations, was the frequent irregularity in the proportion between longitudinal and lateral growth of the scales. I have made no measurements in this respect, but it could often be seen that the scales had during the last few years grown more in breath than in length, thus rendering the distance between the winter rings relatively greater, at the two sides of the scale, than in the anterior portion.

The pecularities here noted in the scales of herring from these Atlantic waters tend to give the investigator an impression that the fish in question must have lived and grown up under conditions widely different from those which obtain among the herring in the gulf of St. Lawrence; true it is no easy matter to tabulate and systematize such features, as distinctness of winter rings or frequency of secondary rings, the appearance actually presented is, however, none the less remarkable on examination of the scales. In estimates (and growth measurements) this means increased labour, and greater uncertainty in the results obtained.

With regard to these difficulties, there appears to be some difference between the samples from the northern parts of the waters in question, and those from Nova Scotia, the scales of herring from the more southerly localities being less easy to read than the others. The material is too limited, however, to permit of any definite statement in this respect, as much depends upon the quality of the scale preparations.

The difficulties are most felt in dealing with older fish, for the younger specimens, up to 8 years old, it may safely be said, that a fairly accurate age determination can be arrived at, with continued investigations, also, and by great care to make the scale preparations as perfect as possible, a similar degree of accuracy may be attained in the case of the older fish. Fortunately as matters stand, the material from Nova Scotia includes only one sample with many old fish; in the others, young specimens predominate.

As regards the northern samples (North Sydney, Main-a-Dieu and Grand Narrows) we have the further disadvantage that they were taken during May and June, i. e., at a time when the herring in these waters may be expected to be commencing their summer growth. And, as we here lack the support afforded by study of the quite young fish, and as the samples themselves do not form any series in point of time, it is difficult to assign the specimens to definite year-classes. In table 9, therefore, where the results of age-determinations for these three northern samples are shown, the specimens have only been arranged in the age-group, or as one might say, "summer-zone groups". As far as it is possible to judge, however, the great majority of the specimens in these samples have not yet begun their summer growth.

TABLE 9.—Showing age distribution in samples from Cape Breton, north side. New growth probably not commenced, so that group 4 should correspond to year-class 1910, in the 1914 sample, and to year-class 1911 in the samples from 1915.

Lo ty and date.	Number of individuals.	Age-groups.									
		4	5	6	7	8	9	10	11	12	More.
Main-à-Dieu, May 1914..............	54	1·9	9·3	3·7	11·1	7·4	7·4	14·8	31·5	7·4	4·6
North Sydney, June 3, 1915..........	98	5·1	12·2	6·1	24·5	10·2	8·2	1·0	17·3	12·2	2·0
Grand Narrows, June 2, 1915........	88	18·2	27·3	9·1	4·5	10·2	10·2	3·4	12·5	2·3	2·2

The sample from Main-a-Dieu, 1914, and that from North Sydney, 1915, have this point in common, that groups 10 and 11 in 1914 and groups 11 and 12 in 1915 contain a relatively large number of specimens. These should presumably be the 1904 and 1903 year-classes. The similarity is not, it is true, either here or elsewhere, remarkably great, but we have to consider the small number of individuals in the one sample. The sample from Grand Narrows has, like that taken at the same time from North Sydney, a large number of fish with five rings, but differs not a little from this: there is, however, here again some massing of the 11 and 12 group fish.

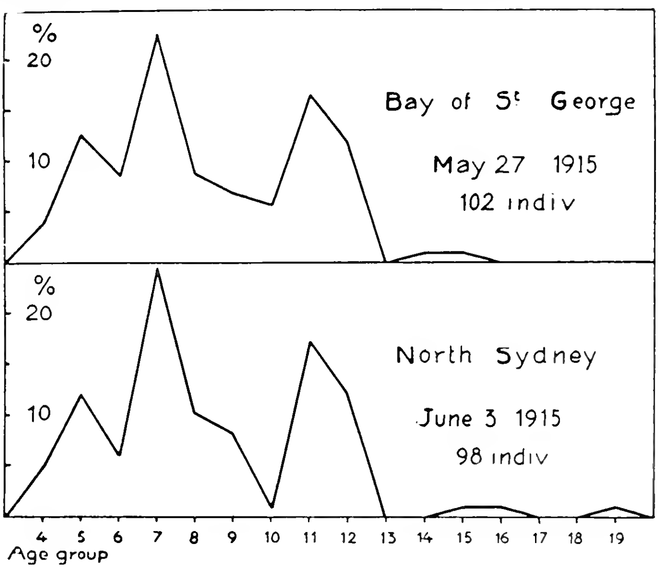


Fig. 36.

On the other hand, if we compare the sample from North Sydney with the one divergent sample from the Newfoundland area, taken a week earlier, we find the most perfect agreement. The curves for these two samples will be seen in fig. 36. The striking agreement between these two samples, on the one hand, and the exceptional position occupied by the Newfoundland sample among the remainder from that area, on the other, greatly tend to support the presumption that these two samples represent one and the same group of herring, in which the age-composition is widely different from that of the Newfoundland fish. The two samples in question will therefore be more closely compared in the chapter on growth.

From West Ardoise, farther to the south, we have two samples, both from 1914, one, however taken in July, and the other in August. In these the scales may pretty safely be said to exhibit new, and in some cases, fairly advanced summer growth. It is therefore possible to group the fish in year-classes, as has been done in table 10.

TABLE 10—Age distribution in two samples from West Ardoise, Cape Breton. July and August 1914. Mature and ripening herring.

Locality and date	Number of individuals.	Year-groups and Age-groups.										
		1912	1911	1910	1909	1908	1907	1906	1905	1904	1903	
		3	4	5	6	7	8	9	10	11	12	More.
West Ardoise, July 1914	104	....	60·6	7·7	1·9	6·7	3·8	2·9	6·7	5·8	1·0	2·9
" Aug. 10, 1914....	125	1·6	42·4	19·2	2 4	21·6	2·4	4·0	1·6	3 2	1·6	

It will be noticed that the samples include a considerable number of year-classes, the younger fish, however, predominating. The 1911 year-class in particular is distinguished by its high numerical value in both samples. In the one from August, the 1908 year-class is also fairly strongly represented, and the same is the case, albeit to a lesser degree, in the July sample. In the former also the 1910 year-class is likewise good. The older fish are too poorly represented to permit of any decision in their case.

The curves for these two 1914 samples, and in particular that for the two together, exhibit strong resemblance to the curve for a divergent sample from the area first

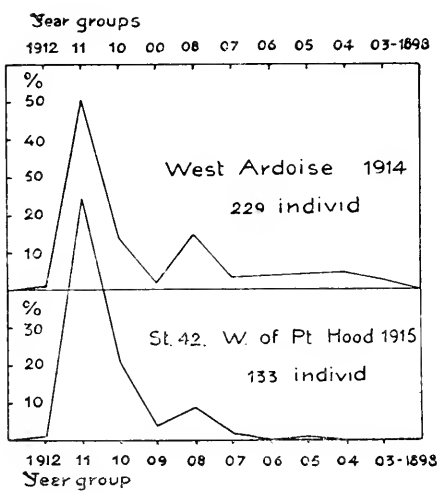


Fig. 37.

described, viz., that from station 42 (west of Port Hood and north of cape George) taken July, 1915. The likeness will be seen from fig. 37. As in the case of the divergent sample from Newfoundland, it must be left for future investigations to study this question more closely.

The next sample in the series is one from the Atlantic coast of Nova Scotia, taken in August, 1915. This sample has been dealt with by Dr. Hjort in his preliminary report. On comparing Dr. Hjort's and my results in the case of this sample, it was found that we agree as regards the young fish, but not in respect of the older ones, Dr. Hjort having on the whole counted fewer rings on the scales of old fish than I.

TABLE 11.—Sample of large and old herring from Nova Scotia, August, 1914, presenting difficulties as regards age determination. The table shows the results arrived at by Dr. Hjort after his preliminary examination, compared with the results of Lea's two analyses

—	Age-groups.							
	5	6	7	8	9	10	11	More.
Hjort's analysis, 135 individ	3·0	5·9	16·3	11·1	31·1	17·8	11·9	3·0
Lea's analysis in. I, 139 "	1·4	2·2	16·6	2·9	15·8	15·8	26·6	19·4
" " II, 138 "	1·5	1·5	15.9	4·4	10·1	15·9	30·5	20·3

These different results may be compared in table 11, which further shows that my first estimates, when compared with an analysis subsequently made, likewise reveal some discrepancy in the case of the older fish. The scale preparation for this sample not being perfect, and the difficulty in the case of older fish being, as already mentioned, considerable, all that can be said as to this sample is that there were a large number of old fish and that age-group 7 (year-class 1908) is well represented as compared with the neighbouring groups.

TABLE 12.—Age distribution in a sample of immature herring from Halifax, N.S., and a sample of mature and ripe herring from Lockeport, N.S. Autumn, 1914.

Locality and date.	No. of individuals.	Year-classes and age-classes.										
		1912.	1911.	1910.	1909.	1908.	1907.	1906	1905	1904	1903	
		3	4	5	6	7	8	9	10	11	12	More.
Halifax, N.S., Oct. 14, 1914..	82	9·8	84·2	6·1	....	....	....	....	....	....	....	....
Lockeport, N.S., Nov. 1914..	269	0·4	48·3	27·9	3·3	6·3	1·5	1·1	2·2	4·5	1·9	2·6

Besides this sample we have also one from Lockeport, Nova Scotia, taken in November, 1914, consisting of mature fish, and another from Halifax, October 1914, with immature fish. Table 12 shows the age distribution in these samples. The sample of mature herring shows an unmistakable likeness to those from Ardoise, its best year-classes being 1911, 1910, and 1908. In the sample of immature fish, the 1911 year-class is very numerously represented.

The two samples of small herring from the Bay of Fundy and Gloucester, Mass., present no features of interest in this connection: they contain quite young herrings with one to three summer belts on their scales.

Taking a general survey of all samples from the Atlantic coast, we find, it is true, a somewhat complicated picture with much varied detail, nevertheless, one cannot fail to see that these samples reveal certain definite features upon which to base a further grouping of the material. Save for the samples from Grand Narrows, which owing to the isolated locality of capture, situated so to speak, in the middle of Cape Breton Island, must be considered apart, the samples may naturally be divided, according to the age-analyses, into two groups, one embracing those from Main-à-Dieu and North Sydney, the other those from West Ardoise and Nova Scotia. The best sample in the northern group bears, as we have seen, a strong resemblance to the single divergent sample from Newfoundland, while the southern samples again exhibit features in common with a similarly exceptional sample from station 42, west of Cape Breton island. In the northern group we find, presuming that summer growth had not commenced in the beginning of June, the year-classes 1910, 1908, 1904 and 1903 as most numerously represented, in the southern, the 1911 year-class especially, with, to a lesser degree, those of 1910 and 1908, predominating among the younger fish, while in the case of the older ones, the uncertainty of the age-determination renders it impossible to say definitely which year-classes are here the richest.

e. *Comparison of the different areas.*

In the foregoing, an attempt has been made to describe the age distribution in the samples from the different areas, on the basis of a preliminary group arrangement. And it was found that samples from different waters may differ altogether in point of age composition, while those from one and the same locality exhibit a high degree of similarity. Particularly striking is the likeness observable between most of the samples from the Newfoundland coast, as also between those from Northumberland strait. Having now compared the separate samples and noted the points of resemblance for the different areas, with due reference to such exceptions as occur, it may finally be of interest to draw up as far as possible, a brief survey of the entire area embraced, on the basis of the details furnished by analysis of the age distribution.

Fig. 38 shows the age distribution for a number of samples from different waters, chosen from among the 1914 and 1915 samples. The principles upon which such selection has been based will be found justified by the foregoing.

The figure shows, in its own way, how thoroughly unlike the samples from different waters proved. Especially characteristic is the difference between the Newfoundland samples, on the one hand, and those from the southern parts of the gulf on the other. The samples from the Atlantic coast, however, also exhibit a marked dissimilarity to the southern gulf samples and also to those from Newfoundland.

On comparing the two parts of the figure, we find, feature for feature, a considerable likeness between them. Particularly marked is the resemblance between the Newfoundland samples in the two years and those from Northumberland strait.

Having regard to the nature and quantity of the material, it must be admitted that the analyses distinctly suggest the existence of several types of age composition in the waters investigated, and it would also seem that in arranging the samples according to age composition, we shall simultaneously have arranged them, roughly speaking, according to locality of capture, i.e., that the samples from one and the same locality exhibit similarity of age composition. That we can speak of such a thing as a "type of age composition" is due to the fact that in a sample from a certain water, certain year-classes are found to be more numerously represented than the remainder, all year-classes present are not equally rich, and the curves for these fluctuations thus acquire a typical appearance.

These differences in the samples from the various waters give rise to the supposition that the area investigated may include several races or tribes of herring, each for the present with its own characteristic age composition. Judging from the age curves, it might possibly be advisable in the investigations by means of growth measurements, to start from the hypothesis here indicated by the arrangement of fig. 38.

1. That the Newfoundland herring form a tribe apart, represented throughout the present material in all samples, save the single exception.

2. That the exception in question, the sample from St. George's Bay, and the samples from Main-à-Dieu and North Sydney, represent another.

3. That the samples from Magdalen islands and Northumberland strait, and off cape Gaspé, represent a third.

4. That the samples from West Ardoise and Nova Scotia, together with the exceptional sample from the mouth of St. George's bay (station 42, west side of Cape Breton island), represent a fourth.

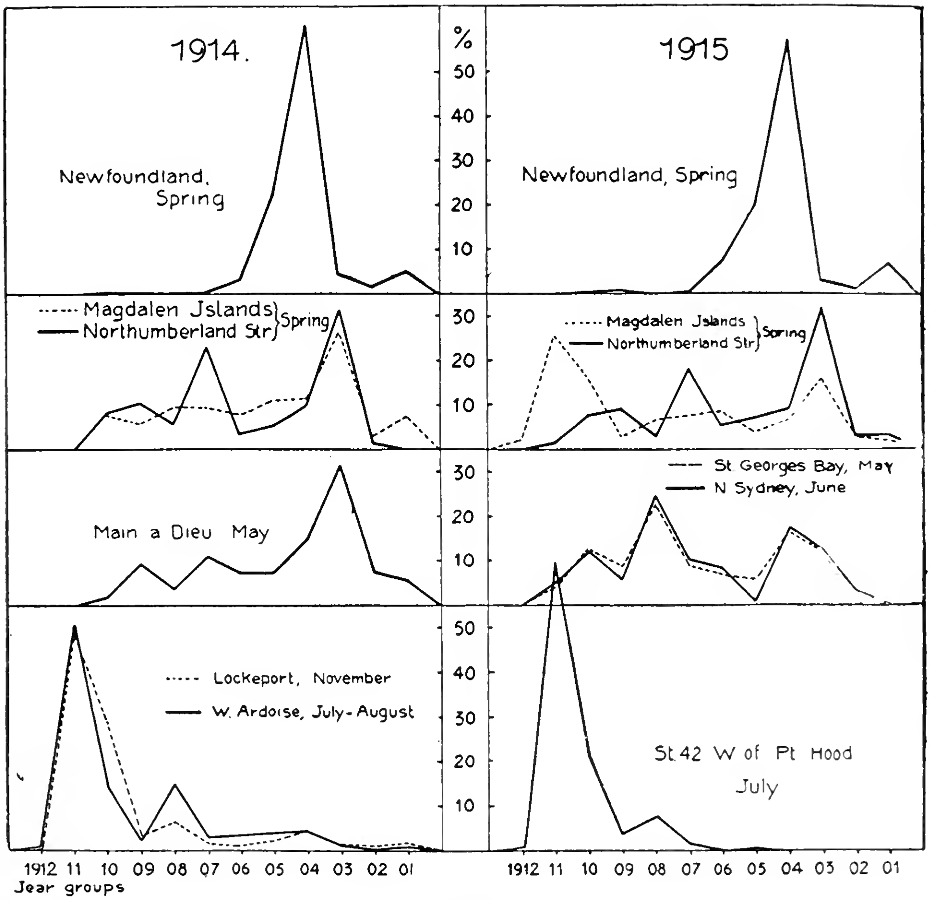


Fig. 38.

In the following pages, the observations as to growth of the herring will be subjected to analysis, on the basis of the grouping above given. This should, however, as in the case of the first rough arrangement, only be regarded as preliminary, and intended but to serve present needs.

XII.—GROWTH.

COMPARISON OF GROWTH IN SAMPLES OF SIMILAR AGE COMPOSITION.

A number of samples were taken from the material available, for further treatment with regard to growth. In making this selection, several points were taken into consideration. In the first place, it was desirable to include samples from as many areas possible. In addition to which, it would naturally be interesting to investigate in this respect such samples as might be said to occupy a peculiar position in the material, e.g., the one exceptional sample from Newfoundland. It was necessary, moreover, to select those offering the best scale material, the quality of this being of more importance in growth measurements than in age determinations. And finally, it was recognized that the growth material should include, as far as possible, material illustrative of the manner in which growth proceeds during the different seasons of the year. With regard to this seasonal growth of the herring, there is but little information to be gleaned from the present material, some facts may, however, be brought to light by examination of the samples containing young fish.

The nature and quantity of the material will to a certain extent determine what problems may be taken up for consideration in these growth investigations: it is undoubtedly best suited for a study of the growth in the different waters. This problem, then, will receive the greatest share of attention in the following examination, and we shall, bearing in mind the results of the investigations as to age composition, endeavour to arrive at a solution of the following questions:—

1. Are those samples which have been found to be of uniform character, as regards age composition, likewise uniform or similar with respect to growth of the individuals; and
2. Are those samples or groups of the same, which differ in respect of age-composition from the remainder, likewise different from these in point of individual growth?

The two questions taken as one may be formulated thus: Can the grouping according to similarity and dissimilarity of age-composition, as drawn up in the foregoing chapter, be further supported and rendered more distinct by consideration of the growth of the fish?

In making comparisions of this nature, it would of course be an advantage to have an opportunity of examining one or more year-classes common to all samples. This will be done when we come to compare samples of like character as regards age-composition; having regard, however, to the great differences in this respect which exist between the samples from the different waters, a very extensive mass of material, with very large samples, would have been necessary in order to ensure that each sample contained a sufficient number of the particular year-classes. In the material as it stands, we find, for instance, that a year-class which is well represented in the samples from Northumberland strait (the 1903 year-class) appears but very poorly so in the Newfoundland samples. By proceeding according to this method, we should, in comparing two samples from different localities in many, or possibly most cases, actually be comparing, pairs of values of which one only could be taken as accurate, having been based on a great number of single observations, while the other would be subject to a higher degree of error, being based on only a few observations. The error in a difference between two values depends upon the separate errors in the two values themselves, and will always be greater than the larger of these, with the method referred to; therefore many comparisons would infallibly give unreliable results from a statistical point of view. In the following comparisons, the greatest importance is attached to the investigation of those year-classes which are best represented, and for which we have the most accurate average figures, care being taken, however, throughout to make sure that these good year-classes do not differ essentially with regard to growth from the inferior ones. We thus avoid the necessity of making lengthy calculation for the inferior year-classes, and obtain at the same time some idea as to how far the growth of the good year-classes is representative of the sample (or samples, or water).

In the case of two equally strong year-classes the older will generally be employed, as, in the case of the younger fish, a greater allowance will have to be made for the effects of the dissociation previously mentioned. And in comparing young fish, therefore, the rule as to taking fish of equal age will have to be more strictly observed.

In making these comparisons, the average values (A) only, have in some cases been used. In cases requiring closer analysis, however, the standard errors (e) have been calculated from the standard deviation (δ) according to the formula $e = \frac{\delta}{\sqrt{n}}$, where n is the number of variates. In testing the difference between two averages, the standard error (d) of this difference calculated according to the formula $d^2 = e^2_1 + e^2_2$ where e_1 and e_2 are the respective standard errors of the two averages. The standard error of the difference compared with the difference itself (D) will then serve to indicate what value should be attached to the difference; if the difference be great in proportion to its error then it will in all probability be significant, i.e., not due to fluctuations of sampling, and *vice versa.*

This calculation of the standard errors in the averages has been carried out for the growth dimensions t_1—t_5; for t_6—t_{10} the method employed was, save in such cases where averages only were compared, as follows: When the analysis of and examination of the averages for the remaining dimensions indicates similarity between a number of samples, then one of these is selected, and the standard deviation for the dimensions t_6—t_{10} calculated for that sample. Presuming then that the standard deviations for the other samples will be more or less equal to these, the standard errors for all samples may be calculated from the standard deviations for the one. I have tested this method, and convinced myself that the presumption is correct, and the consequent simplification of the calculations thus justifiable.

In all mathematical comparisons, the calculated increment of growth (t) has been employed, and not the calculated length (l), the former is, as far as I can see, easier to deal with than the length; for reasons of economy also it was found necessary to restrict the work to the consideration of one of these dimensions. In the following comparisons of the results, on the other hand, the calculated lengths have been used, as being more immediately legible (the length of a herring can be seen, whereas one can only form an idea as to its growth or increment).

1. *Samples from Newfoundland.*—The age investigations led to the results that all samples of grown fish from the coast of Newfoundland, with a single exception, were characterized by the marked superiority of the 1904 year-class. The single exception (sample from St. Georges bay, May 27, 1915, exhibit remarkable likeness to a sample from North Sydney, and will therefore be taken together with this.

Table 13 shows the averages for all increments of the year-class 1904, and the standard errors of the averages for dimensions t_1—t_5 all each single one of the nine samples selected for growth measurements; the lowest series in the table further shows the total averages with corresponding standard errors, arrived at by taking all specimens of the said year-class (in the nine samples) together as a single larger sample.

TABLE 13.—Showing averages (A) and standard errors of the averages (e) for growth dimensions t_1—t_{11} for the year class 1904 in the different samples from the coast of Newfoundland ("A" and "e" expressed in centimetres).

Sample No.	Locality and Date.	No. of individ.	t_1		t_2		t_3		t_4		t_5	t_6		t_7	t_8	t_9	t_{10}	t_{11}
			A	e	A	e	A	e	A	e	A	e	A	A	A	A	A	A
1	White Bay, early May, 1914........	93	5·62	0·12	6·98	0·12	5·69	0·09	3·16	0·07	2·80	0·05	2·48	1·80	1·13	0·66	0·55	
2	Bay of Islands, spring, 1914	41	6·08	0·27	6·95	0·13	5·43	0·15	3·37	0·09	2·75	0·08	2·11	1·55	1·06	0·85	0·64	
3	St. George's Bay, early May, 1914....	104	6·92	0·18	7·01	0·10	5·17	0·10	3·21	0·06	2·57	0·06	1·96	1·31	1·06	0·97	0·73	
4	Bonne Bay, October, 1914	35	6·88	0·45	7·42	0·23	5·58	0·20	3·31	0·12	2·56	0·13	2·13	1·40	1·05	0·83	0·68	0·57
5	Bay of Islands, October 29, 1914....	37	6·41	0·58	7·17	0·18	5·67	0·14	3·44	0·12	2·91	0·12	2·24	1·50	1·15	1·00	0·78	0·62
6	" " " 31, 1914.....	33	6·03	0·24	7·46	0·28	5·39	0·22	3·39	0·12	2·77	0·13	1·89	1·37	1·06	0·93	0·90	0·68
7	West Coast, November, 1914.	135	5·79	0·13	6·70	0·10	5·27	0·07	3·31	0·06	2·71	0·06	1·93	1·33	1·03	0·92	0·73	0·62
8	Bonne Bay, May 11, 1915............	60	6·04	0·21	7·00	0·13	5·59	0·10	3·33	0·07	2·82	0·09	2·12	1·52	1·12	0·91	0·75	0.62
9	Bay of Islands, May 2, 1915..........	68	5·96	0·17	6·98	0·14	5·44	0·11	3·42	0·09	2·88	0·08	2·20	1·55	1·15	0·88	0·74	0·54
	Total.	606	6·14	0·07	6·98	0·05	5·43	0·4	3·30	0·3	2·74	0·03	2·11	1·47	1·08	0·88	0·71	0·61

By a study of this table, and comparison of the averages with due regard to their errors, it will be seen that all the samples are very much alike. Among features especially characteristic may be noted, that t_1 is on an average less than t_2 and that average values of less than 1 cm. are not reached until t_9; further, that t_3 is more than half as great as t_1.

Some variation is, however, noticeable between the separate samples. It is found that several of the largest samples exhibit the greatest difference, and it will therefore be desirable to inquire how far any degree of regularity can be discerned in the variation, and whether it is so considerable as to suggest the probability of its being due to other causes than fluctuations of sampling. In order to ascertain this, the samples were first divided into three season-groups, one comprising the samples from the spring of 1914, another those from the autumn of the same year, and a third those from the spring of 1915. Table 14 shows the seasonal averages with corresponding standard errors .

TABLE 14.—The samples from Newfoundland arranged according to season of capture. Table showing averages and errors for growth dimensions t_1-t_{10} for year class 1904, all samples from each season being taken together.

Season.	No. of individ.	t_1		t_2		t_3		t_4		t_5		t_6	t_7	t_8	t_9	t_{10}
		A	e	A	e	A	e	A	e	A	e	A	A	A	A	A
1914, Spring............	238	6 26	0·11	6·99	0·07	5·42	0·06	3·21	0·04	2·69	0 04	2·19	1·54	1·08	0·83	0 64
1914, Autumn..........	240	6·08	0·12	6 98	0·08	5 39	0·06	3 34	0·04	2·74	0·05	2·00	1·37	1·06	0·92	0·75
1915, Spring...... ...	128	6·00	0·13	6·99	0·09	5·51	0·08	3·38	0·06	2·8.	0·06	2·16	1·54	1·14	0·89	0 74
Total.....	606	6·14	0 07	6·98	0·05	5 43	0·04	3·30	0·03	2·74	0·03	2·11	1·47	1·08	0·88	0·71

It is not easy to discover any essential difference between the seasons here; t_1 falls a little, t_2 shows no change, t_3 is likewise unchanged, t_4 and t_5 rise slightly, while t_6, t_7 and t_8 are lowest in the autumn. All these differences are, however, insignificant and lie within the limits allowable for fluctuations of sampling. Also each seasonal group presents the same total view of the growth, as seen in each separate sample or in all samples taken as one.

A somewhat similar result is arrived at by arranging the samples according to locality, as in table 15.

TABLE 15.—Newfoundland samples arranged according to locality of capture. Table showing averages for growth-dimensions t_1—t_{10} for year class 1904, all samples from each locality being taken together.

Locality.	No. of individ.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}
White Bay........... ...	93	5·62	6·98	5·69	3·16	2·80	2·48	1·80	1·13	0·66	0·55
Bonne Bay	95	6·35	7·15	5·58	3 32	2·72	2·12	1·47	1·09	0·88	0·72
Bay of Islands	179	6·09	7·04	5·48	3·41	2·84	2·13	1·51	1·11	0·91	0·76
St. George's Bay.....	104	6·92	7·01	5·17	3·21	2 57	1·96	1·31	1·06	0·97	0·73

In this case, the differences are much more conspicuous. The growth dimension t_1 is lowest for White bay, and highest for St. George's bay, the reverse being the case with t_3, while the dimensions t_5—t_8 are lowest for St. George's bay.

Judging from these averages, there might possibly be some slight difference between the most northerly locality and that farthest to the south.

In order to test the value of the differences thus found between the various samples, all possible differences between growth dimensions of the same character were first ascertained, the nine samples giving thirty-six differences for each dimension, making 180 in all for the five first dimensions.

For each of these differences (D), the corresponding standard error (d) was then calculated, and the fraction D/d formed. This fraction, which expresses the difference in units of its error may serve as a kind of indicator for the importance of the difference. Where the value of the fraction is small, there is but little probability that the difference is due to other causes than accidental fluctuations, and *vice versa,* and in particular, where its value exceeds certain limits, the probability becomes an empiric certainty that the difference is not merely due to fluctuations of sampling.

Table 16 shows the manner in which the various values of the fraction D/d arrange themselves, first for each separate growth dimension, and finally for all together. It will be noticed that in 91 of the 180 cases, the fraction is less than 1, in 154 less than 2, and in 171 less than 3. Only in 9 out of 180 cases is the fraction over 3, i.e., in these cases the difference is more than three times as great as the error. In the last column will be found figures showing the arrangement which should have resulted had all samples been drawn from an entirely uniform stock and subject only to fluctuations of sampling.

TABLE 16.—Showing distribution of values of $\frac{D}{d}$ for all possible comparisons between the nine samples from Newfoundland. (Year class 1904, t_1—t_5).

Values of $\frac{D}{d}$ between:	t_1.	t_2.	t_3.	t_4.	t_5.	Total.	Theoret.
0 and 1	18	18	18	21	16	91	123
1 " 2	11	14	11	13	14	63	49
2 " 3	3	4	3	2	5	17	8
3 " 4	2	......	2	......	1	5	......
4 " 5	......	......	2	......	......	2	......
More than 5	2	......	......	......	......	2	......
	36	36	36	36	36	......	......

A comparison of these theoretic values with the figures actually found, inclines us to suppose that the nine cases where the value of $\frac{D}{d}$ exceeds three are probably significant. And on examining these nine differences, it will be seen that they are due to peculiarities in the sample from White Bay and in that from St. George's bay, only in one instance is there a difference noted where neither of these samples is included, i.e., between samples 7 and 8 for the growth-dimensions t_5. The small t_1 and the large t_3 in the White Bay sample, with the large t_1 the small t_3 and t_5 in that from St. George's bay, give rise to the differences. It would thus seem that the dissimilarity noticed in table 15, as between these two extreme samples, is significant. It is impossible to say with certainty what importance should be attached to these differences, as several possible explanations may be given. As far as I can see, the most reasonable supposition would seem to be that the sample from St. George's bay is not quite "pure," i.e., that it consists of a majority of individuals, belonging to the same growth type as that of the remaining samples, mixed up with a minority of another type. From the nature of the dissimilarity noted, the growth of this second type should be characterized by a large t_1 and smaller t_3 t_5 t_6 and t_7.

On the whole, however, the samples are as nearly as possible equal in regard to growth of the 1904 year-class, as they were also found to be nearly equal in respect of age composition.

The question now arises, whether the picture of growth presented by the 1904 year-class can be taken as representative for the remaining year-classes, and especially for that of 1903. In order to investigate this point, table 17 has been drawn up, showing the growth of the 1904 year class compared with that of the year classes 1903, 1905, and 1906, as also with all older fish taken together and all younger ones together.

TABLE 17.—Averages for year class 1904 compared with those for other year-classes in the samples from Newfoundland. Averages based upon all nine samples.

Year class.	No. of individuals.	t_1.	t_2.	t_3.	t_4.	t_5.	t_6.	t_7.	t_8.	t_9.	t_{10}.	t_{11}.
1911 - 1906.	149	6·36	7·90	5·17	3·13	2·10	1·51	1·26	1·08	0·83	..	....
1905 ...	198	6·52	7·07	5·43	3·36	2·74	2·17	1·51	1·16	0·82	0·69	..
1904. ...	606	6·14	6·98	5·43	3·30	2·74	2·11	1·47	1·08	0·88	0·71	0·61
1903.....	45	6·67	7·47	5·17	3·24	2·54	2·00	1·45	1·14	0·91	0·75	...
1902 - 1891... ..	84	6·88	7·81	4·72	3·47	2·55	1·69	1·37	1·09	0·86	0·72	0·61

It will be seen from the table that the important features are common to the older fish. The younger ones, and also, to some extent, the 1906 year-class, exhibit greater deviation, a phenomenon also noted in the great majority of other herring samples (*vide* p. 144.). It is impossible to say whether this dissimilarity in the younger fish, in the present instance, is due to selective effect of the implements used, to the dissociation of year-classes, or to intermingling with fish of different growth. Probably each of these features is to some extent responsible. It is at any rate evident that the 1904 year-class does not differ essentially, in point of growth, from the older fish. Also that the small t_1, at least, is probably characteristic for the herring taken on the coast of Newfoundland as shown by table 18, the growth of quite young fish from western bay of Port au Port, August 16-17, 1915. The 1914 year-class, which is well represented, and that of 1913, which furnished eleven specimens, show exactly similar values for t_1 and t_2 to those of the old fish; the 1910 year-class is represented by only two specimens, so that the figures for this are practically valueless, and are only included as a matter of form.

TABLE 18.—Growth of small, immature herring caught by drift nets in West Bay of Port au Port, Aug. 1915.

Year class	Age group.	No. of individuals.	t_1.	t_2.	t_3.	t_4.	t_5.	t_6.
1914	2	101	6·36	7·26				
1913	3	11	6·80	7·60	4·24			
1910	6	2	7·45	6·55	7·45	4·20	2·80	1·05

2. *Samples from the Magdalen islands.*—The 1903 year-class is the best common year-class among the older fish in the Magdalen islands two samples, taken in spring 1914 and 1915. In the one sample, there were seventy-four of this year class, in the other unfortunately but seventeen.

Table 19 shows the average values for the different increments (t) of this year-class in the two samples. In the 1914 sample, t_1 and t_2 are less than in that from 1915, whereas t_3—t_5 are greater. The remaining growth dimensions are practically alike in both samples.

TABLE—19.—Showing averages (A) and standard errors (e) for growth dimensions t_1—t_{12} for the year class 1903 in two samples from Magdalen Islands, spring of 1914 and 1915.

Locality and Date.	No. of individuals.	t_1		t_2		t_3		t_4		t_5		t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}
		A	e	A	e	A	e	A	e	A	e	A	A	A	A	A	A	A
Magdalen Islands, May, 1911.	74	10·11	0·19	7·14	0·16	4·69	0·12	2·88	0·07	1·54	0·05	1·01	0·78	0·66	0·67	0·74	0·74	......
" medio, May, 1915	17	10·85	0·36	7·77	0·32	4·34	0·16	2·70	0·15	1·40	0·12	1·03	0·76	0·69	0·65	0·72	0·82	0·79
Total	91	10·25	0·17	7·26	0·14	4·62	0·10	2·85	0·66	1·52	0·05	1·01	0·78	0·66	0·66	0·73	0·76	0·79

The standard errors of the averages for dimensions t_1—t_5 have been calculated for each sample separately and for both taken together. With the aid of these, it has been possible to estimate the importance to be attached to the differences. It was found that all the differences were between once and twice as large as the corresponding error, and they can thus hardly be considered as noteworthy. And as the remaining growth dimensions have also been seen to exhibit no difference, the two samples should be regarded as equal, so far as concerns the growth of the 1903 year-class. Characteristic features common to both samples are: t_1 is large, distinctly greater that t_2; average values of less than 1 cm. are reached as early as t_7; and finally, t_8 and t_9 are less than the following dimensions, t_{10} and t_{11}.

If we now turn to the remaining year-classes in these samples, we find, as will be seen from table 20, entirely analogous conditions, all year-classes exhibit an unmistakable likeness in respect of growth. There is the great t_1 and the low values for t_7 and onwards, and even so slight a detail as the fact that the last year's growth is somewhat greater than that of the few years immediately preceding, is met with now and again. As regards the 1904 year-class especially, which it would seem desirable to compare with the same year-class in the samples from Newfoundland, we find that it forms no exception, save perhaps that the characteristic features are possibly even more marked.

TABLE 20.—Averages for year class 1903 compared with those for other year classes in the samples from Magdalen Islands.

Year class.	No. of individuals.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}
1910	21	11·2	8·8	4·7	2·6	...	...	...	...	...	...	...	...
1909	16	11·9	8·4	3·9	2·8	1·8	...	...	...	...	...	...	...
1908	26	10·3	9·5	4·3	2·4	1·8	1·3	...	...	...	...	...	...
1907	26	10·1	9·3	3·9	2·6	1·7	1·4	1·0		...	...	...	...
1906	22	11·2	8·7	4·3	2·0	1·3	1·0	1·0	0·9	...	...	...	...
1905	31	11·3	8·6	3·9	2·3	1·3	1·0	0·8	0·9	0·8	...	...	...
1904	32	10·8	7·5	4·2	2·7	1·4	1·0	0·8	0·7	0·8	0·8	...	...
1903	91	10·3	7·3	4·6	2·9	1·5	1·0	0·8	0·7	0·7	0·7	0·8	0·8
1902	9	11·3	8·0	4·0	2·4	1·4	1·1	0·7	0·7	0·6	0·6	0·5	0·5
1901	5	11·2	8·9	3·9	2·5	1·4	1·1	0·7	0·6	0·5	0·4	0·4	0·4
1900	13	10·8	7·9	4·2	2·8	1·5	1·1	0·9	0·7	0·5	0·5	0·4	0·3

We find then, for these two samples also, that the growth of the fish is alike in both; and that 1903 year-class may be taken as representative for the remainder, at any rate for the older fish.

3. *Samples from Northumberland Strait.*—In the five samples of grown fish from this area, 1903 is the best common year-class among the older fish, and 1907 among those of medium age. These two year-classes were therefore subjected to closer examination. Tables 21 and 22 show the averages and standard errors for these year-classes, in each of the five samples.

TABLE 21.—Showing averages (A) and standard errors (e) growth dimensions t_1—t_{12} for year class 1903 in five samples from Northumberland Strait, 1914-1915.

Sample No.	Locality and Date.	No. of individuals	t_1		t_2		t_3		t_4		t_5		t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}
			A	e	A	e	A	e	A	e	A	e	A	A	A	A	A	A	A
10	Northumberland Strait, May, 1914	31	10·38	0·22	6·41	0·20	4·85	0·17	2·87	0·11	1·45	0·06	1·02	0·77	0·73	0·70	0·66	0·65	
11	Baie Verte, N.B., May 11, 1914	38	9·80	0·21	6·43	0·19	4·80	0·15	2·79	0·11	1·57	0·08	1·03	0·77	0·69	0·69	0·76	0·70	
12	Pictou Harb., N.S., May 8, 1915	27	10·59	0·30	6·47	0·27	4·75	0·20	2·95	0·13	1·59	0·07	1·11	0·87	0·81	0·76	0·65	0·78	0·87
13	Richibucto, N.B., May 19, 1915	29	10·06	0·33	6·80	0·20	5·09	0·16	3·10	0·11	1·54	0·07	1·13	0·86	0·64	0·66	0·75	0·84	0·90
14	Baie Verte, N.B., May 22, 1915	48	10·19	0·19	6·26	0·17	5·13	0·14	3·15	0·10	1·70	0·08	1·17	0·80	0·71	0·69	0·75	0·77	0·73
	Total	173	10·18	0·11	6·45	0·09	4·94	0·07	2·98	0·05	1·58	0·04	1·08	0·81	0·72	0·70	0·72	0·75	0·81

TABLE 22.—Showing averages for growth dimensions t_1—t_7 for the year class 1907 in five samples from Northumberland Strait, 1914-1915. At the foot, total averages and their standard errors.

Locality and Date.	No. of individuals.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8
Northd. Strait, May 1914	34	9·74	9·06	3·88	2·49	1·57	1·43	1·04	
Baie Verte, May 11, 1914	17	10·52	8·45	3·92	2·54	1·56	1·42	1·01	
Pictou Harbour, May 8, 1915	17	11·71	8·23	3·84	2·35	1·69	1·30	1·15	1·14
Richibucto, May 19, 1915	26	10·74	8·68	4·20	2·44	1·57	1·40	1·20	1·24
Baie Verte, May 22, 1915	16	10·09	9·12	4·12	2·74	1·56	1·39	1·18	1·18
Averages for the two samples from 1914 together.		10·00	8·85	3·89	2·50	1·57	1·43	1·03	
Standard errors " " " 1914	"	0·21	0·12	0·08	0·07	0·06			
Averages for the three samples from 1915	"	10·84	8·67	4·07	2·50	1·60	1·37	1·18	1·19
Standard errors " " " 1915	"	0·23	0·14	0·10	0·06	0·04			
Total averages..		10·45	8·76	3·99	2·50	1·59	1·39	1·11	1·19

It will be seen from the tables that there is certainly a considerable degree of similarity between all the samples; there are, however, also differences which seem, despite the small number of specimens, to be by no means negligible. Thus, sample 11 differs in its small t_1 in the 1903 year-class, and Northd. Strait sample in the same manner as regards the 1907 year-class. In order to test the value of these deviations, the method adopted in the case of the Newfoundland samples was also applied here, all possible differences (D) between samples two and two were taken (for growth dimensions of like character) and the corresponding standard errors of the differences (d) formed; and finally, the fraction $\frac{D}{d}$ obtained. It was then found, as will be seen from table 23 that the value of $\frac{D}{d}$ in one case out of fifty, is greater than three. This single difference, of considerable magnitude in proportion to its error, occurs between samples and for the growth dimension t_1. Save for this single instance, all the differences are relatively small, being here, as in the Newfoundland samples, in the majority of cases less than twice their error.

TABLE 23.—Showing distribution of values of $\frac{D}{d}$ for all possible comparisons between the five samples from Northumberland Strait. (Year class 1903, t_1—t_5).

Values of $\frac{D}{d}$ between	t_1	t_2	t_3	t_4	t_5	Total.
0 and 1	5	7	4	5	3	24
1 and 2	4	2	6	4	6	22
2 and 3	1	1	....	1	1	3
More than 3.. ..	6					1
	10	10	10	10	10	50

As the remaining growth dimensions likewise show considerable similarity between the various samples, we must conclude that there is no essential difference, as far as the good year-classes are concerned. With regard to the remainder, these show, as will be seen from table 24, considerable resemblance to the two more closely examined. These last may therefore be taken as representative of the samples when comparing them with samples from other waters. This will accordingly be done, the 1903 year-class being used in cases where it is desirable to have older fish, and 1907 where younger are preferable for purposes of comparison.

TABLE 24.—Averages for year classes 1903 and 1907 compared with those for other year classes in the five samples from Northumberland Strait.

Year class.	Number of individuals.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}
1911	5	12·6	8·9	4·1	2·8									
1910	43	12·8	7·7	4·7	2·3	1·8								
1909	51	12·9	7·3	3·9	2·9	1·8	1·6							
1908	23	11·3	8·4	4·1	2·6	1·7	1·3	1·4						
1907	110	10·5	8·8	5·8	2·5	1·6	1·4	1·1	1·2					
1906	25	11·1	7·6	4·5	2·6	1·5	1·1	1·0	1·0	1·1				
1905	35	12·3	6·9	4·2	2·6	1·3	1·0	0·8	0·9	0·8	0·9			
1904	52	10·4	6·7	4·8	3·0	1·6	1·1	0·9	0·9	0·8	0·8	0·8		
1903	173	10·2	6·5	4·9	3·0	1·6	1·1	0·8	0·7	0·7	0·7	0·8	0·8	
1902	13	11·2	7·0	4·6	2·8	1·6	1·0	0·8	0·6	0·5	0·5	0·6	0·6	0·6

If we are to characterize the growth of the individuals in these samples, we can only repeat what has been said in the case of those from the Magdalen islands; the similarity existing between these two waters, in respect of age composition, is supplemented by the resemblance noticeable in the growth of the fish. We shall later on examine the question as to whether there is any essential difference between these waters as regards growth.

It may not be out of place here to mention the samples containing very young fish. Some of these are from the waters about Prince Edward Island and the Gaspé coast, others from the neighbourhood of Souris and cape George. Table 25 shows the average value for these samples.

TABLE 25.—Showing averages for growth dimensions t_1—t_4 for young herring in the waters around Prince Edward Island. Values with an asterisk are incomplete.

Locality and date.	Year group.	Number of individuals.	t_1	t_2	t_3	t_4
Station 33, 48° 13′ N., 63° 58′ W., July 5-6, 1915	1913	31	10·6	7·9	1·4*	
	1912	6	7·9	7·9	5·5	1·0*
Station 35, 46° 48′ N., 64° 32′ W., July 7, 1915	1913	47	10·2	7·1	1·8*	
Souris, July 14, 1915	1913	14	11·3	8·2	1·0*	
	1912	19	10·2	8·8	4·9	1·0*
Station 53, 45° 46′ N., 62° 23′ W., July 30-31, 1915	1914	12	11·1	3·9*		
	1912	7	11·5	8·0	4·5	1·9*

It should be borne in mind that the last growth dimension in most of these samples is incomplete, and cannot therefore be compared with the same in the older fish. The table shows that these young fish also are characterised by a high value for t_1, exactly the reverse of what was the case with the young fish from Port au Port (taken, it is important to note, with the same set of gear as the present samples from the Gaspé coast). As regards the differences apparent between the different samples, and between the different year-classes, it should be remembered that both dissociation of year-classes and net-selection must doubtless have had some effect. Making allowance for these considerations, the resemblance between the samples is marked.

In view of the great similarity between the samples of grown fish from Magdalen islands and Northumberland strait, it would be of little use to go into the question as to how far the present samples of young fish more resemble those from the former or those from the latter waters: they may fairly be said to exhibit a considerable likeness to both.

4. *Samples from North Sydney compared with the highly exceptional sample from St. Georges bay, Newfoundland.*—As repeatedly mentioned already, one of the samples from the Newfoundland coast differed greatly from all the rest in point of age-composition, while exhibiting, on the other hand, a very strong resemblance to a sample taken at the same time from North Sydney. It will now be well to compare these two samples from the point of view of individual growth.

There is no age group which is particularly well represented in these two samples, group 7 (=year-class 1908 if, as would seem to be the case, new summer growth had not commenced at time of capture) is the best, and comprises 23 specimens in the North Sydney sample, and 25 in the other. After these, come age groups 11 and 12 (presumably corresponding to year-classes 1904 and 1903). In the following comparative tables, where the errors of averages have been called into requisition, age-group 7 is taken separately, groups 11 and 12 being combined into a single group, in order to furnish a reasonable number.

Table 26 shows averages for group 7 in the two samples, in addition to which, the standard errors of the averages and the values of the fraction $\frac{D}{d}$ are also noted.

TABLE 26.—Showing averages for growth dimensions t_1-t_5 for the divergent sample from St. Georges Bay and for sample from North Sydney. (Year class 1908, presumably). At foot the differences and values of fraction $\frac{D}{d}$.

Sample.	t_1	t_2	t_3	t_4	t_5
N. Sydney	10·40	9·65	4·16	2·64	1·79
St. George's Bay	10·28	9·43	4·28	2·79	1·89
Difference (D)	0·12	0·22	0·12	0·15	0·10
$\frac{D}{d}$	0·29	0·51	0·52	0·79	0·83

It will be noticed that this age group exhibits the most perfect uniformity as regards growth, and in no single instance, among those investigated, does the difference between two averages equal the magnitude of their errors.

Very similar results are arrived at in the case of groups 11 and 12. Table 27 shows these two groups compared in the same manner as with group 7.

TABLE 27.—Showing averages for growth dimensions t_1—t_8 for the divergent sample from St. George's Bay, and for sample from North Sydney. (Year class 1903 and 1904 presumably). At foot the differences and values of fraction $\frac{D}{d}$.

Sample.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8
N. Sydney	10·90	8·18	4·32	2·41	1·61	1·14	0·77	0·78
St. George's Bay	10·93	8·09	4·36	2·65	1·58	1·20	0·94	0·82
Difference (D)	0·03	0·09	0·04	0·24	0·03	0·06	0·17	0·04
$\frac{D}{d}$	0·07	0·26	0·15	1·41	0·19	0·46	2·12	0·57

Here again the resemblance between the two samples is striking, while the differences are insignificant. Only in two instances does the value of the fraction $\frac{D}{d}$ exceed 1, which differences, however, also lie well within the limits for fluctuations of sampling.

Table 28 shows these two samples compared with regard to the remaining age groups.

TABLE 28.—Comparison of the divergent sample from St. George's Bay with the sample from North Sydney by help of averages for all year-classes presenting a reasonable number of specimens.

Year group.	Sample.	No. of individuals.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}
1911	St. George's Bay	4	11·7	10·6	4·8	3·2								
	North Sydney	5	11·6	8·2	5·2	3·0								
1910	St. George's Bay	13	12·7	8·4	4·6	2·5	1·8							
	North Sydney	12	13·0	8·0	4·5	2·6	1·6							
1909	St. George's Bay	9	12·1	8·5	4·1	2·9	1·7	1·4						
	North Sydney	6	11·0	9·1	4·2	3·0	1·6	1·4						
1908	St. George's Bay	23	10·2	9·4	4·3	2·8	1·9	1·3	1·2					
	North Sydney	25	10·4	9·6	4·2	2·6	1·8	1·3	1·2					
1907	St. George's Bay	9	11·3	8·9	4·4	2·3	1·6	1·4	1·1	1·1				
	North Sydney	9	11·1	8·8	3·4	2·5	1·7	1·6	1·1	1·0				
1906	St. George's Bay	7	10·9	8·5	4·4	2·0	1.6	1·1	1·3	0·9	0·8			
	North Sydney	8	11·9	8·5	4·3	2·3	1·4	1·1	1·1	0·8	0·8			
1905	St. George's Bay	6	12·1	7·9	3·7	2·0	1·4	0·9	1·0	0·8	0·8	0·7		
	North Sydney	1	11·4	8·8	5·4	2·7	1·8	1·3	0·8	0·7	0·6	0·5		
1904	St. George's Bay	17	10·7	8·0	4·6	2·5	1·7	1·3	0·9	0·8	0·9	0·8	0·7	
	North Sydney	17	11·1	8·3	4·5	2·2	1·7	1·1	0·8	0·8	0·9	0·8	0·7	
1903	St. George's Bay	12	11·3	8·2	4·0	2·8	1·4	1·1	0·9	0·8	0·8	0·7	0·7	0·5
	North Sydney	12	10·6	8·0	4·4	2·6	1·5	1·1	0·8	0·7	0·7	0·7	0·7	0·6

This table strongly confirms the impression furnished by the previous ones, of similarity between the two samples. We may safely say that the resemblance is no less marked as regards growth of the individuals than it was seen to be in respect of age composition.

Comparison of samples from West Ardoise, Lockeport, and west of Port Hood (station 42).

Only young fish of the 1911 year-class are here numerous in all four samples, the calculations as to errors of averages and comparison, on the basis of the same, have therefore been restricted to this group.

Table 29 shows the averages for this year-class together with the corresponding standard errors.

TABLE 29.—Averages (A) and standard errors (e) for the year-class 1911 in three samples from the Atlantic coast and one from west of Port Hood.

Locality and Date.	No. of individuals.	t_1		t_2		t_3		t_4	
		A	e	A	e	A	e	A	e
W. Ardoise, July, 1914	63	12·44	0·21	8·12	0·11	4·82	0·14	2·07*	0·06
" August, 1914	25	12·99	0·34	8·72	0·28	4·43	0·20	1·45*	0·09
Lockeport, November, 1914	57	12·14	0·24	7·76	0·14	4·85	0·16	2·20*	0·07
W. of P. Hood, July, 1915	86	12.68	0·21	8·44	0·12	5·12	0·10	3·38	0·09

Only the dimensions t_1—t_3 will be of interest in this connection, as t_4 is incomplete in the samples from 1914.

A test calculation of the fraction $\frac{D}{d}$ gave three differences of eighteen, which were over three times as great as the corresponding standard errors. It was the sample from Lockeport which differed in respect of t_2 from the West Ardoise (August) sample and from station 42, while station 42 again differed in respect of t_1 from the West Ardoise (August) sample. In the remaining fifteen cases, the differences were less than three times their standard error,

5 differences being less than				once,
11	"	"	"	twice,
15	"	"	"	three times,
18	"	"	"	four times,

the corresponding error.

The similarity between the various samples is thus on the whole good, albeit less so that in the cases previously dealt with. It should, however, be borne in mind that the comparisons in this case are made with young fish, where the dissociation of year-classes will be more likely to make itself felt.

Of other year-classes which might be selected for comparison between one sample and another, that of 1910 is the best; the number of specimens is here, however, so small, that it would not be worth while to make calculations of the standard errors. Table 30 shows the averages for this year-class.

TABLE 30.—Averages for the year class 1910 in the four samples mentioned in table 29.

Locality and Date.	No. of in-divid.	t_1	t_2	t_3	t_4	t_5
W. Ardoise, July, 1914	8	12·26	8·06	5·95	2·69	1·41*
" August, 1914	12	12·30	7·87	5·38	2·89	1·14*
Lockeport, November, 1914	18	9·82	8·83	5·48	2·59	1·44*
W. of Pt. Hood, July, 1915	28	11·94	7·85	5·89	2·95	2·61

Save for the incomplete dimension t_5 these samples agree, well enough, as will be seen, always bearing in mind the small number of individuals dealt with. Only the sample from Lockeport differs in respect of the small t_1. The interesting sample from station 42 (west of Port Hood) does not appear to differ in any essential degree from the remaining samples.

Finally, table 31 shows comparison for the 1908 year-class.

TABLE 31.—Averages for the year class 1908 in the four samples mentioned in table 29.

Locality and Date.	No. of individ	t_1	t_2	t_3	t_4	t_5	t_6	t_7
W. Ardoise, July, 1914	7	11·6	8·3	4·5	3·2	2·0	1·4	0·9*
" August, 1914.	7	10·6	7·7	4·6	3·8	2·6	1·6	0·7*
Lockeport, November, 1914	6	11·3	7·1	5·3	3·8	1·8	1·0	0·6*
W. of Pt. Hood, July 1915	10	11·6	7·6	5·1	3·5	2·1	1·6	1·2

Taking into consideration the extremely small number of observations in each sample, the resemblance here again is noteworthy. With regard to this year class also, the sample from station 42 differs in no way from the remainder.

All things considered, these samples must be said to be fairly uniform with regard to growth, and even with the points of difference noted, each separate sample yet presents a type of growth unlike those hitherto observed, and characterized by the high values of all growth dimensions investigated. The same impression is obtained if we collect the really old fish from all samples and consider their growth as it will appear in some tables subsequently.

The type of growth may be characterized as approaching, with regard to t_1 the samples from the southern part of the gulf, while as regards the remaining dimensions, it more resembles the Newfoundland samples. This will be further discussed in the following section.

5. *Samples differing in point of age composition.*—It will be seen from the foregoing, that samples resembling one another in point of age composition likewise exhibit resemblance as regards growth. This double likeness is very marked between all samples from Newfoundland save for the single exception, the sample from St. George's bay; strikingly so between this and the one from North Sydney; good between the two from the Magdalen islands and the five from Northumberland strait; and still good, albeit less conspicuous, between the samples from West Ardoise, Lockeport, and west of Port Hood.

Hitherto, our comparisons have been made between samples which, from their age composition, appeared at first sight as belonging to the same group or tribe, or whatever it may be termed. We may now proceed to make comparisons between the different groups of samples into which the material was provisionally divided.

The object of this is twofold. In the first place, to carry the analysis of the growth observations a step further, and endeavour to ascertain whether any of the groups set up in the preliminary arrangement can be taken together. This possibility will more especially require investigation in the case of the samples from Magdalen islands and Northumberland strait, the two groups which bear an evident likeness one to the other in point of age composition, and growth. With the sample from North Sydney also (and its companion from St. George's bay) it will be desirable to look into the question of how far combination should be made, for instance, with the sample from West Ardoise and Lockeport, i.e., whether the former may be taken as representing the older fish in the group from which are derived those younger specimens composing the latter; the latter having but recently attained maturity, and having not yet attached themselves to the shoals of the elders. And in the second place, it will be necessary to examine the various groups of samples together, and thus, by pointing out the differences existing in point of growth, to show up more clearly the resemblances already found. Further, to describe the types of growth as far as can be done upon the basis of the results obtained from the previous analysis.

In this further analysis, which will to a certain extent take the form of an analysis of growth in the different waters, we shall first of all make comparison of the total averages for growth dimensions as calculated on the basis of several similar samples, and in addition, examine the differences between pairs of single samples, each from its own groups of similar material. This latter method of comparison is more especially intended to show the manner in which examinations of single samples here leads to the same results as obtained by taking several together. A demonstration for instance, of the marked and uniform differences between any of the nine Newfoundland samples and any other, will, by a further test, afford further justification for our regarding these nine samples as representing a distinct growth type. And in a similar manner, the correctness of the remaining group divisions will be tested.

For the sake of convenience, the nine similar samples from Newfoundland will first be compared with the remainder, then those from the Magdalen islands will be taken, and in like manner compared with the rest, and so on. The comparisons will be illustrated by means of curves for growth and increment.

The nine similar samples from Newfoundland will now be compared with the remaining material.

6. *Comparison with the samples from Magdalen Islands.*—The following table 32 shows total averages for the nine samples from Newfoundland, taken together; for the two Magdalen Islands samples taken together; the differences between growth dimensions of the same character with the corresponding standard error, and the fraction $\frac{D}{d}$.

TABLE 32.—Growth of Newfoundland herring compared with that of herring from Magdalen Islands by help of total averages for year-class 1904 and 1903 respectively.

Area of samples.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}
Newfoundland	6·14	6·98	5·43	3·30	2·74	2·11	1·47	1·08	0·88	0·71
Magdalen Islands	10·25	7·26	4·62	2·85	1·52	1·04	0·78	0·66	0·66	0·73
Difference (D)	4·11	0·28	0·81	0·45	1·22	1·07	0·69	0·42	0·22	0·02
$\frac{D}{\text{Standard error of difference}} = \frac{D}{d}$	22·8	1·9	7·4	6·4	20·3	26·8	17·3	21·0	11·0	1·0

It will be noticed that all differences except t_2 and t_{10} must be regarded as significant, being greater than seven times their error. Judging from the values of the fraction $\frac{D}{d}$ the growth dimensions t_1, t_5, t_6, t_7, and t_8 would seem to differ most in the two sets of samples, t_1 being greatest in the sample from the Magdalen islands, the remaining dimensions being the smallest. On comparing each of the two samples from Magdalen islands with each of the nine samples from Newfoundland, exactly similar results were obtained, even in the case of the 1915 sample from the former locality, where the number of specimens was so very small (seventeen). This will be seen from the following table, showing the value of the fraction $\frac{D}{d}$ for each growth dimension up to t_8, all values exceeding four, however, being for the sake of convenience placed in one group.

TABLE 33.—Showing distribution of the values of $\frac{D}{d}$ arising by comparison of either of the samples from Magdalen Islands with either of the samples from Newfoundland.

Value of $\frac{D}{d}$ between.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	Total.
0 and 1	......	10	......	......	......	......	......	......	10
1 " 2	......	3	......	......	......	......	......	......	3
2 " 3	......	5	1	2	......	......	......	......	8
3 " 4	......	......	4	10	......	......	......	......	14
4 and more.	18	......	13	6	18	18	18	18	109
	18	18	18	18	18	18	18	18	144

It will be seen that save for t_2 all the growth dimensions exhibit distinct differences between the Newfoundland samples on the one hand, and those from the Magdalen islands on the other; most of the differences, moreover, are of a very considerable magnitude in proportion to their errors, and the impression produced by this table is thus totally different from that given by table 16 (p. 136), showing the internal differences exhibited by the Newfoundland samples when compared one with another.

Comparison with the sample from Northumberland strait. Table 34 corresponds to table 32 and shows the total averages of the Newfoundland samples compared with total averages for the samples from Northumberland strait.

TABLE 34.—Growth of Newfoundland herring compared with that of herring from Northumberland Strait by help of total averages for year-classes 1904 and 1903 respectively.

Area of samples.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}
Newfoundland..........	6·14	6·98	5·43	3·30	2·74	2·11	1·47	1·08	0·88	0·71
Northumberland strait..........	10·18	6·45	4·94	2·98	1·58	1·08	0·81	0·72	0·70	0·72
Difference (D)..........	4·04	0·53	0·49	0·32	1·16	1·03	0·66	0·36	0·18	0·01
$\frac{D}{\text{Standard error of difference}} = \frac{D}{d}$ ..	31·1	5·3	6·1	5·3	23·2	46·9	30·0	25·7	8·2	0·7

The table here shows that the Newfoundland samples, when compared with those from Northumberland strait, differ from these in very much the same way as they were seen to do from the Magdalen islands samples, the difference for t_2 however, is greater, and must be considered as significant. In view of the great differences apparent, I have not considered it necessary to show comparison between the separate samples; such a table would, roughly speaking, be merely a repetition of table 33.

7. *Comparison with exceptional sample from St. George's Bay.*—Table 35 shows the total averages of the nine similar samples from Newfoundland compared with the corresponding averages for the exceptional sample, the 1904 and 1903 classes being taken together in the latter.

TABLE 35.—Growth of Newfoundland herring compared with that of the herrings of the divergent sample from St. George's Bay by help of total averages for year-class 1904, in Newfoundland samples, and those for year-classes 1904-1903 in the divergent sample.

Sample.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8
Newfoundland (nine samples)	6·14	6·98	5·43	3·30	2·74	2·11	1·47	1·08
St. George's Bay..........	10·93	8·09	4·36	2·65	1·58	1·20	0·94	0·82
Difference (D)..........	4·79	1·11	1·07	0·65	1·16	0·91	0·53	0·26
$\frac{D}{d}$	14·5	4·5	5·6	5·9	14·5	10·1	8·7	5·2

The table shows the great differences between the exceptional sample and the remaining ones from Newfoundland; these differences are indeed so marked as to be distinctly apparent even when making comparison with the few (seventeen) specimens of the 1904 year-class contained in the former sample as shown in table 36.

TABLE 36.—Growth of Newfoundland herring compared with that of the herrings in the divergent sample from St. George's Bay, by help of averages for the year-class 1904.

Sample.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8
Newfoundland (nine samples)...	6·14	6·95	5·13	3·30	2·74	2·11	1·47	1·08
St. George's Bay	10·68	8·06	4·62	2·50	1·62	1·25	0·95	0·84
Difference (D)	4·54	1·08	0·81	0·80	1·12	0·86	0·52	0·24
$\frac{D}{d}$	9·1	3·3	3·2	2·7	14·0	7·2	6·5	3·4

There can thus be no doubt that the exceptional sample differs strongly both with regard to age composition and growth, from the remaining Newfoundland samples. The difference in growth is again of a similar character to that noted between the Newfoundland samples and those from the Magdalen islands, the greatest differences are found in the growth dimensions t_1, t_5, t_6 and t_7. Here, likewise, t_1 is greater in the exceptional sample, while the other dimensions are smaller.

Table 37 shows the exceptional sample compared with each of the remaining Newfoundland samples separately; the order of magnitude of the fraction $\frac{D}{d}$ being given for the differences between the five first growth dimensions.

TABLE 37.—Distribution of values of fraction $\frac{D}{d}$ arising by comparison between the divergent sample from St. George's Bay and each of the nine other samples from Newfoundland.

Value of fraction $\frac{D}{d}$ between:	t_1	t_2	t_3	t_4	t_5	Total.
0 and 1..........	......	......	......	......	......	......
1 " 2...........	......	1	......	......	......	1
2 " 3...........	......	1	......	......	......	1
3 " 4...........	......	2	2	1	......	5
4 " 16..........	9	5	7	8	9	38

It will be seen that the exceptional sample differs strongly from each one of the remainder.

8. *Comparison with the sample from North Sydney.*—In view of the great resemblance which exists between the sample from North Sydney and the exceptional sample from St. George's bay, it might appear superfluous to make any further comparison between the former and the Newfoundland samples. For the sake of completeness, however, this has been done in table 38, and we find that the Newfoundland samples differ from this sample exactly as they were seen to do from the exceptional sample from St. George's bay.

TABLE 38.—Growth of Newfoundland herring compared with that of the herring in the sample from North Sydney by help of total averages for year-class 1904 in the case of Newfoundland herring, averages for the year-classes 1904 and 1903 taken together in the other case.

Sample.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8
Newfoundland	6·14	6·98	5·43	3·30	2·74	2·11	1·47	1·08
North Sydney	10·90	8·18	4·32	2·41	1·61	1·14	0·77	0·78
Difference (D)	4·76	1·20	1·11	0·89	1·13	0·97	0·70	0·30
$\frac{D}{\text{Standard error of difference}} = \frac{D}{d}$	14·0	4·8	6·2	6·8	8·1	10·8	14·0	6·0

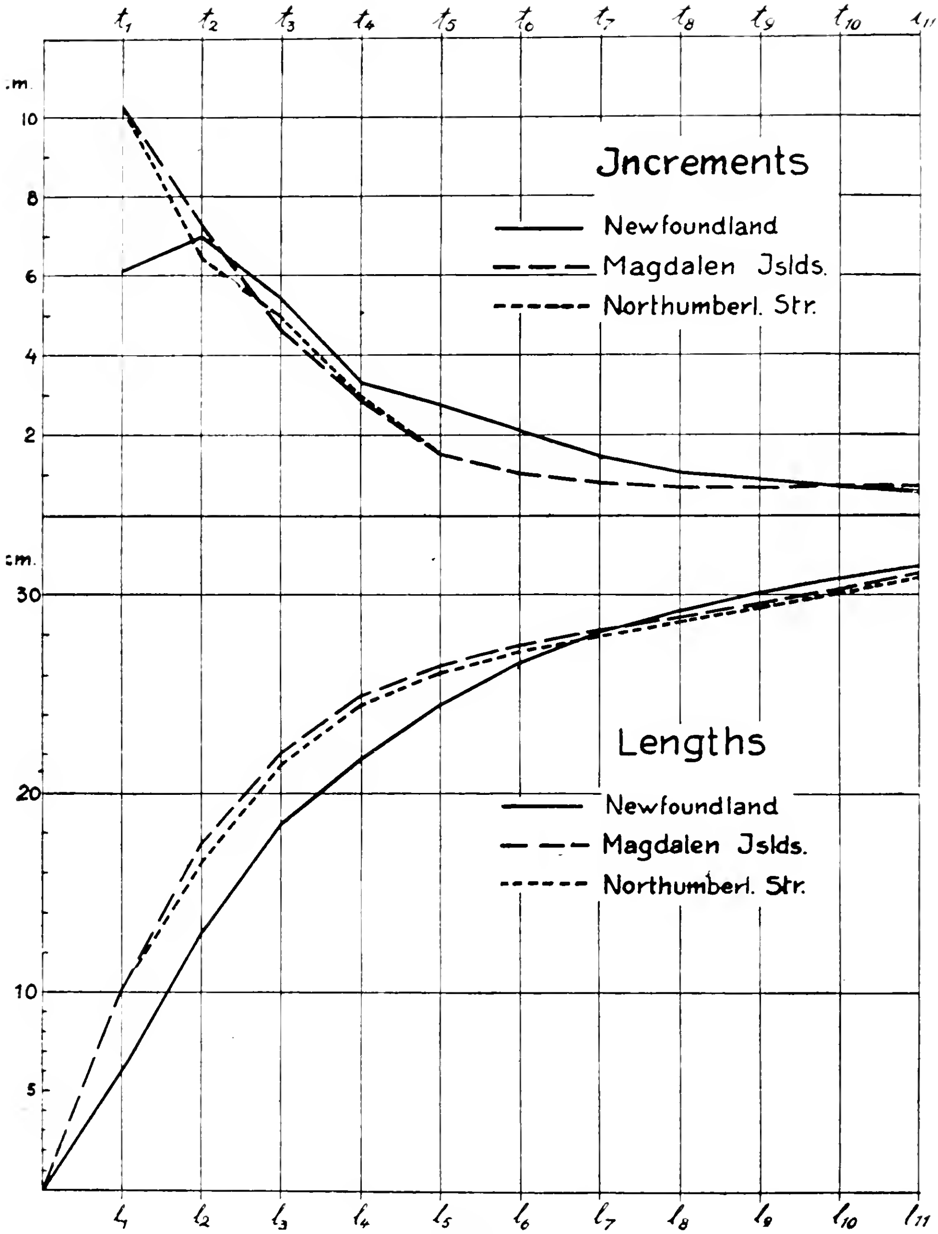
9. *Comparison with old fish from West Ardoise, West of Port Hood, and Lockeport.*—In order to procure material for comparison of the Newfoundland herring with fish of old age from the Atlantic coast, it was necessary to collect older specimens from the different samples. Taking all those of the 1904 and 1903 year-classes together we have a total of thirty-four fish, one of which is from the sample taken at station 42, west of Port Hood. Averages and standard errors for these thirty-four specimens have been calculated, and comparison made accordingly, with the results shown in table 39.

TABLE 39.—Growth of Newfoundland herring (year-class 1904) compared with that of herring from Nova Scotia (year-class 1904 and 1903 together).

Locality.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8
Newfoundland	6·14	6·99	5·43	3·30	2·74	2·11	1·47	1·08
Nova Scotia	11·24	7·76	4·97	3·04	2·05	1·36	1·11	0·87
Difference (D)	5·10	0·77	0·46	0·26	0·69	0·75	0·36	0·21
$\frac{D}{d}$	15·5	3·1	2·1	1·7	5·8	12·5	7·2	5·2

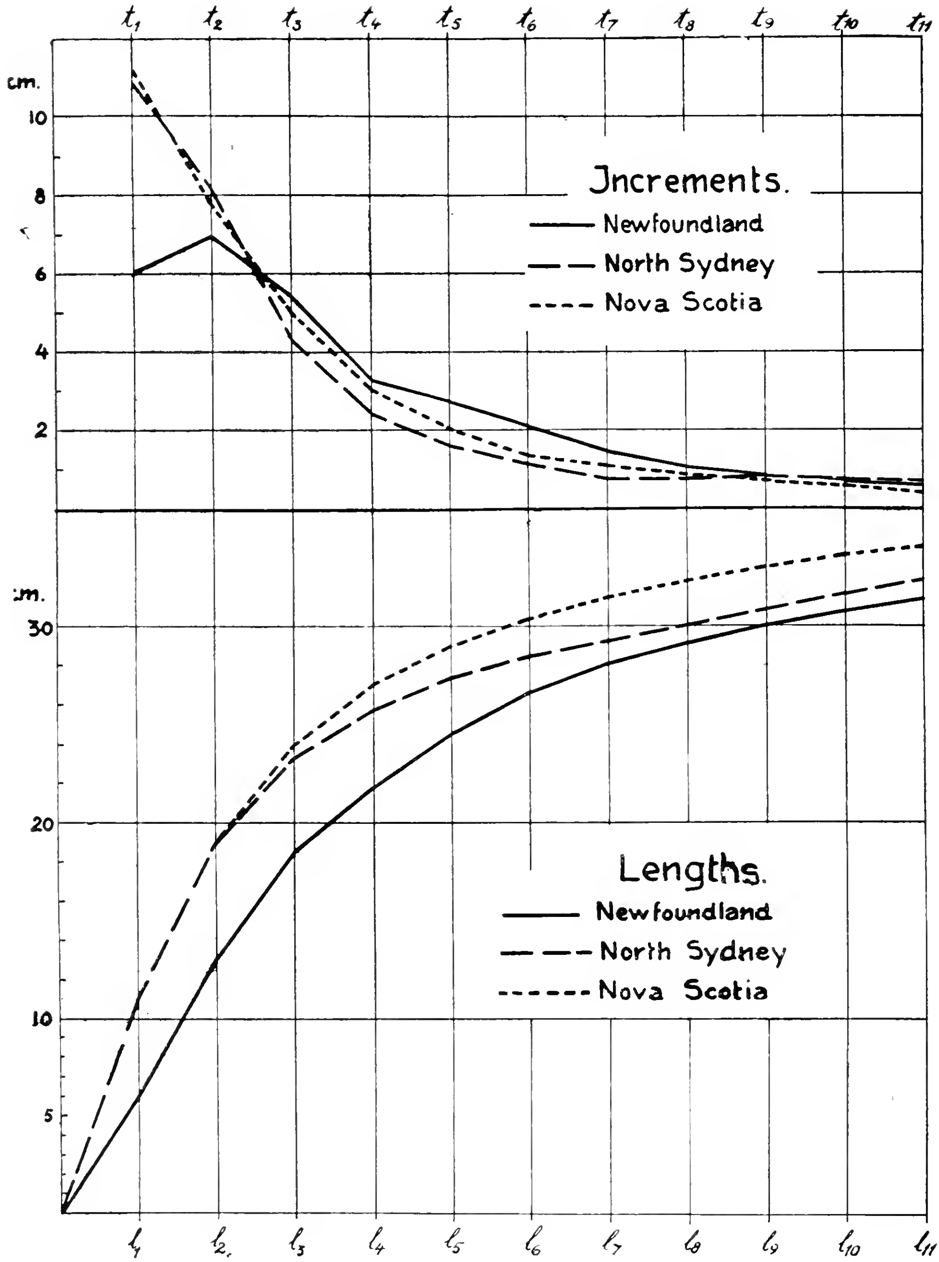
There is here, as will be seen, a very marked difference in growth between the Newfoundland fish and those from the southern portions of the Canadian Atlantic coast. The differences here again are most distinctly apparent in the growth dimensions t_1 and t_5—t_8 and resemble those found in the case of the sample from North Sydney, t_1 and t_2 being greatest in the fish from the Atlantic coast, the remaining dimensions less.

10. *Graphical illustrations of the results obtained.*—Figs. 40 and 41 show, in graphical form, the results of comparison between the growth of the Newfoundland herring and the growth of those in the remaining samples. In order to avoid a figure complicated with too many curves, we have here shown, in fig. 40, the growth of the Newfoundland herring compared with that of those in the samples from the gulf of St. Lawrence (Magdalen islands and Northumberland strait) and in fig. 41 with that of the Atlantic fish (North Sydney and southern samples). The upper portion of each figure presents in graphical form the data already utilized, i.e., the average calculated increments, while the lower portion showing ordinary growth curves, gives the actual length of the herring at the time of the formation of each winter ring on the scales.



Jncrements
Newfoundland
Magdalen Jslds.
Northumberl. Str.
Lengths
Newfoundland
Magdalen Jslds.
Northumberl. Str.

Fig. 46.



cm.
10
8
6
4
2
cm.
30
20
10
5
Jncrements.
Newfoundland
North Sydney
Nova Scotia
Lengths.
Newfoundland
North Sydney
Nova Scotia

Fig. 41.

The curves for increment need no further comment, the differences between the Newfoundland samples and the remainder having been sufficiently indicated in the foregoing. The length curves show how the Newfoundland herring, starting modestly enough, ends, owing to the favourable growth of the later years, with an average length greater even than that of the fish from the Magdalen islands and Northumberland strait (fig. 40). Fig. 41 shows that the somewhat slower growth of the Newfoundland fish during the first two years enables the Atlantic herring, and, to a lesser degree, also those from North Sydney, to maintain a part of the distance gained during the first years, albeit the differences become more and more reduced with increasing age.

11. *Samples from Magdalen islands compared with the remainder.*—The samples from Magdalen islands have already been compared with those from Newfoundland, and were found to differ greatly from these with regard to growth. It now remains to compare them with the samples from Northumberland strait, North Sydney (including the exceptional sample from St. George's bay) and with the Atlantic herring.

Table 40 shows the samples from Magdalen islands compared with those from Northumberland strait, by means of total averages for the 1903 year-class in both waters. The table is arranged in exactly the same manner as table 32.

TABLE 40.—Growth of herring from Magdalen Islands and Northumberland Strait compared by help of total averages for the year-class 1903.

Locality.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}
Magdalen Islands	10·25	7·26	4·62	2·85	1·52	1·04	0·78	0·66	0·66	0·73
Northumberland Strait	10·18	6·45	4·94	2·98	1·58	1·08	0·81	0·72	0·70	0·72
Difference (D)	0·07	0·81	0·32	0·13	0·06	0·04	0·03	0·06	0·04	0·01
$\frac{D}{d}$	0·35	4·77	2·67	1·62	1·00	1·33	1·00	3·00	1·33	0·50

It will be seen that the growth dimension t_2 is the only one exhibiting a difference which can really be called significant. Possibly t_3 and t_4 also differ: otherwise the differences are unimportant in proportion to their errors. In order to test the one really serious difference, the two samples from the Magdalen islands were compared with each of the five from Northumberland strait, as regards the first five growth dimensions. Table 41 shows the values of $\frac{D}{d}$ here found.

TABLE 41.—Distribution of values of fraction $\frac{D}{d}$ arising by comparison between each of the samples from Magdalen Islands and Northumberland Strait (year-class 1903).

Values of fraction $\frac{D}{d}$ between:	t_1	t_2	t_3	t_4	t_5	Total
0 and 1	4	......	3	5	4	16
1 " 2	5	1	1	2	5	14
2 " 3.	1	4	4	3	1	13
3 " 4.	......	3	2	......	......	5
More than 4	......	2	......	......	......	2
Sum	10	0	10	10	19	50

It will be noticed that the differences for t_2 are greater than three times their error in five out of ten cases and exceed twice the error in nine, whence it would seem likely that the figures express a real difference between the two sets of samples. The difference cannot, however, be called great, as presented in these comparisons.

Comparison with the sample from North Sydney, and with the exceptional sample from St. Georges bay. Table 42 shows the total averages for the samples from Magdalen islands compared with the averages for the above-mentioned samples, which, in contrast to those from the Northumberland strait, both exhibit a greater t_2 than the Magdalen islands samples. Otherwise, there is a not inconsiderable degree of similarity in regard to growth.

TABLE 42.—Growth of herring from Magdalen Islands and North Sydney and St. Georges Bay divergent sample compared. (Year-classes 1903 for Magdalen Island, 1903+1904 for the other localities compared.)

Locality.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8
Magdalen Islands	10·25	7·26	4·62	2·85	1·52	1·04	0·78	0·66
St. George	10·93	8·09	4·36	2·65	1·58	1·20	0·94	0·82
Difference = (D)	0·68	0·83	0·26	0·20	0·06	0·16	0·16	0·16
$\frac{D}{\text{Standard error of difference}} = \frac{(D)}{(d)}$	1·9	3·0	1·2	1·5	0·7	1·8	2.3	3·2
North Sydney	10·90	8·18	4·32	2·41	1·61	1·14	0·77	0·78
Difference = (D)	0·65	0·92	0·30	0·44	0·09	0·10	0·01	0·12
$\frac{D}{\text{Standard error of difference}} = \frac{(D)}{(d)}$	1·8	3·3	1·4	3·1	0·6	1·1	0·2	2·4

The comparison with the older fish from the Atlantic coast is interesting. Table 43 shows the samples from Magdalen islands compared with the thirty-four specimens of the 1904-03 year-classes representing the samples from West Ardoise and Lockeport.

TABLE 43.—Growth of herring from Magdalen Islands (year-class 1903) and Nova Scotia herring (year-class 1903+1904).

Locality.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8
Magdalen Islands	10·25	7·26	4·62	2·85	1·52	1·04	0·78	0·66
Nova Scotia	11·24	7·76	4·97	3·04	2·05	1·36	1·11	0·87
Difference (D)	0·99	0·50	0·35	0·19	0·53	0·32	0·33	0·21
$\frac{D}{d}$	2·75	1·79	1·46	1·19	4·08	4·57	5·50	5·25

The differences here are more marked than those found in the previous comparisons, four out of the eight amounting to over four times their respective errors. Bearing in mind, moreover, the fact that all average values are higher in the case of the Atlantic fish than the corresponding values for the Magdalen islands samples, it will be realized that the difference in growth is here by no means inconsiderable.

12. *Graphical illustration of the results obtained.*—Curves for the samples from Magdalen islands and Northumberland strait have already been shown together in one of the previous figures, it has therefore sufficed to give the curves for Magdalen islands, North Sydney and the Atlantic coast (fig. 42).

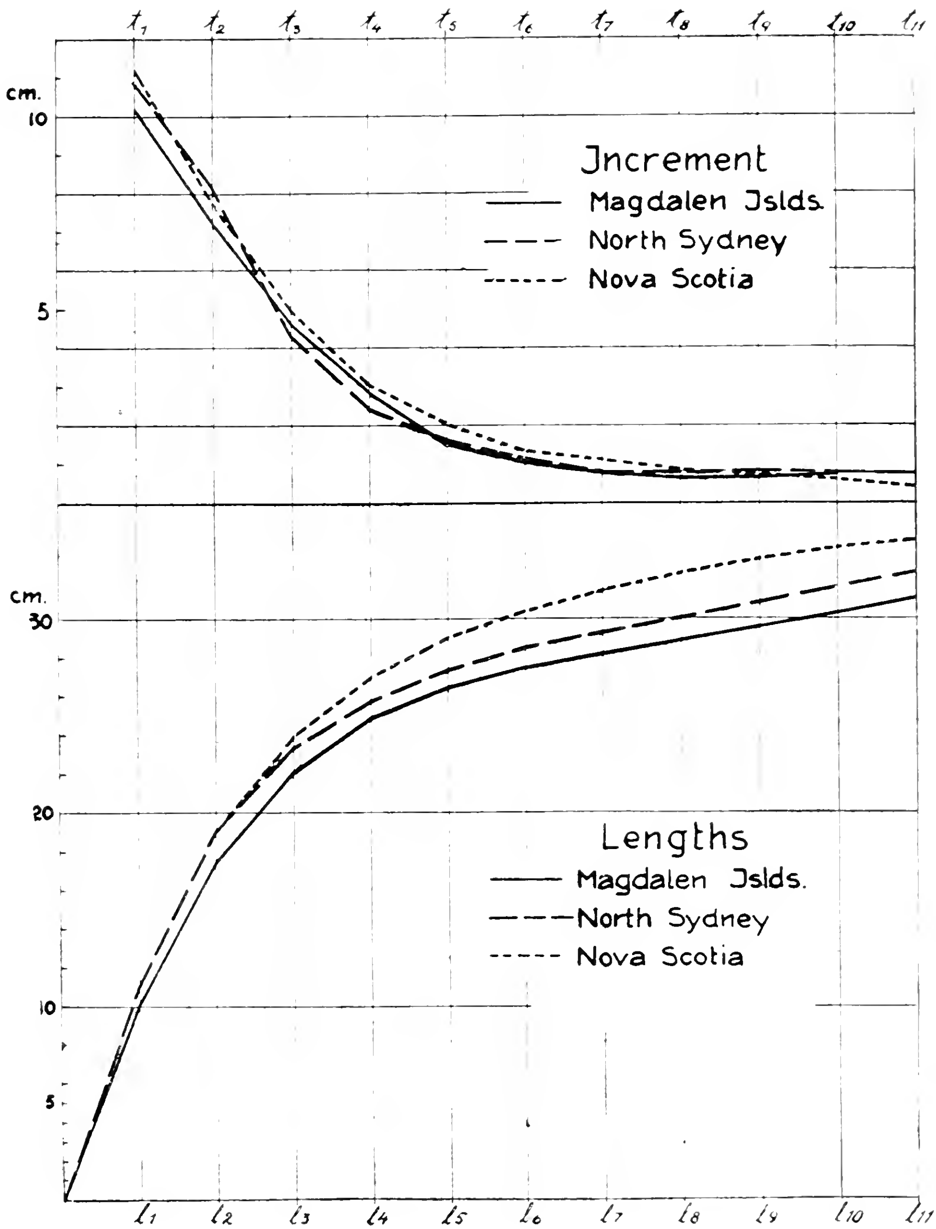


Fig. 42.

It will be seen from this figure and the foregoing remarks, that the growth of the Magdalen islands fish differs distinctly from that of the Atlantic herring farther south, while exhibiting a considerable resemblance to that of the fish from Northumberland strait, on the one hand, and North Sydney on the other. Fig. 42 shows that the growth of the Magdalen Island herring may be more or less aptly characterized as something midway between that of the Northumberland Strait and that of the North Sydney fish.

13. *Samples from Northumberland strait, North Sydney, and the Atlantic coast compared.*—Of the comparisons which still remain to be made, that of the Atlantic fish (West Ardoise and Lockeport) with the herring from North Sydney, is the most interesting. We can judge from the foregoing that the rest of the comparisons will turn out much as with the samples from the Magdalen islands, only with differences more strongly marked. Table 44 shows, that such is the case.

TABLE 44.—Growth of herring from Northumberland Strait (year-class 1903) compared first with herring from North Sydney (year-class 1903+1904), then with herring from Nova Scotia (year-class 1903+1904).

Locality.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8
Northumberland Strait	10·18	6·45	4·94	2·98	1·58	1·08	0·81	0·72
North Sydney	10·90	8·18	4·32	2·41	1·61	1·14	0·77	0·78
Difference (D)	0·72	1·73	0·62	0·57	0·03	0·06	0·04	0·06
$\frac{D}{d}$	2·06	6·65	3·26	4·07	0·20	0·67	0·80	1·20
Nova Scotia	11·24	7·76	4·97	3·04	2·05	1·36	1·11	0·87
Difference (D)	1·06	1·31	0·03	0·06	0·47	0·28	0·30	0·15
$\frac{D}{d}$	3·1	5·0	0·1	0·4	3·6	4·7	6·0	3·7

Unfortunately, the observations available for comparison of the herring from North Sydney with those from more southerly Atlantic waters are rather few. We have therefore here taken, in addition to the 1904-03 year-class, also the younger fish of 1908, there being at any rate some of these in the samples from both waters.

Table 45 shows the comparison for fish of 1904-03.

TABLE 45.—Growth of herring from Nova Scotia compared with that of herring from North Sydney. (Year-classes 1903+1904 in both cases.)

Locality.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8
Nova Scotia	11·24	7·76	4·97	3·04	2·05	1·36	1·11	0·87
North Sydney	10·90	8·18	4·32	2·41	1·61	1·14	0·77	0·78
Difference (D)	0·34	0·42	0·65	0·63	0·44	0·22	0·34	0·09
$\frac{D}{d}$	0·74	1·24	2·3	3·2	2·4	2·00	4·9	1·5

All averages save for t_2 are greater in the case of the Atlantic fish. Only in two instances however, is the difference greater than three times its error.

Table 46 shows the comparison for the 1908 year-class; here also we find one or two marked differences, while the averages for all dimensions, save t_2 are again greatest in the case of the Atlantic fish. The unanimous testimony afforded by these comparisons between the different age groups is, in my opinion, sufficient evidence of a real difference in growth between the fish from North Sydney and those in the more southerly samples. This difference is perhaps more pronounced when we look at the calculated lengths, instead of the calculated increments, as the differences for dimensions t_2—t_5 small, it is true, yet tending in the same direction, are then added together.

TABLE 46.—Growth of herring from North Sydney and Nova Scotia compared. (Year-class 1908.)

Locality.	t_1	t_2	t_3	t_4	t_5	t_6
North Sydney	10·46	9·65	4·16	2·64	1·79	1·30
Nova Scotia	11·16	7·72	4·78	3·57	2·16	1·37
Difference (D)	0·76	1·93	0·62	0·93	0·37	0·07
$\frac{D}{d}$	1·65	4·28	2·58	3·21	2·18	0·64

14. *Summary.*—On glancing through the comparisons made in the last two sections, we are led to the following conclusions: Samples resembling one another in point of age-composition also exhibit great resemblance as regards growth.

The samples from Magdalen islands, Northumberland strait and North Sydney (with the exceptional sample from St. Georges bay) exhibit a type of growth which may to a certain extent be characterized as markedly distinct from the Newfoundland type, while differing also to a lesser degree, albeit still pronouncedly, from that noted among the herring from West Ardoise and Nova Scotia, which appear to form in this respect a group apart

The growth of the Newfoundland herring is characterized by a modest commencement in the first summer, proceeding well, however, from the third summer onwards. The herring from the gulf of St. Lawrence have a good first summer's growth, but owing to the slower growth in their later years do not, when older, exhibit the same average length as fish of the same age from Newfoundland and other waters. The herring from North Sydney show good growth for the first two years; comparatively poor, however, later on; nevertheless, they exhibit, on reaching a considerable age, a very respectable average length, inferior only to that of the herring from the southern Atlantic waters. These last may be said to grow well for the first five or six years, whereby they outdistance the fish from other localities.

XIII. APPENDIX. OBSERVATIONS AS TO SEASONAL GROWTH IN YOUNG HERRING.

Some samples of young herring in the material collected afford some evidence as to the manner in which the summer growth proceeds in the different Atlantic waters. This, taken together with what we have learned regarding the growth of the older fish, furnishes some rough idea, as to the main features of seasonal growth in Canadian waters, though a complete survey is not at present feasible.

The sample of small herring from Port au Port, mentioned on p. 137, seems to show that most of the summer growth in that area has taken place before the middle of August. Fig. 43 shows the observations taken together, with curves indicated for seasonal growth during the second and third summers, as far as can be calculated from the scanty data available.

The samples of young fish from the waters between the Gaspé coast and Prince Edward Island exhibit a growth similar to that of the adult fish from Magdalen islands and Northumberland strait albeit it does not seem possible to class them definitely with either of these two groups.

Fig. 44 shows the observations obtained from these samples, arranged in the same manner as in fig. 43.

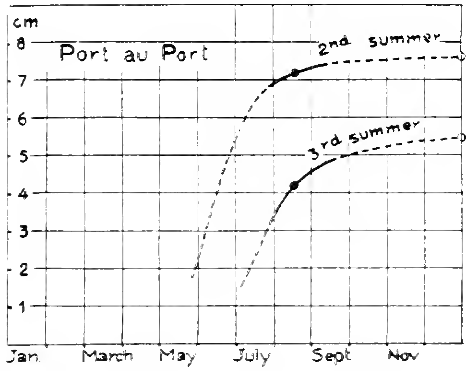


Fig. 43.

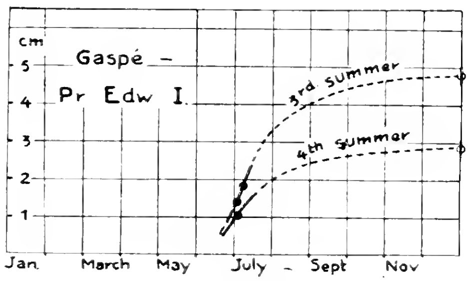


Fig. 44

Finally, a couple of trap samples, from Souris, Prince Edward Island, and a drift-net haul from the vicinity of cape George (station 53) include some young fish, the seasonal growth of which is indicated in fig. 45.

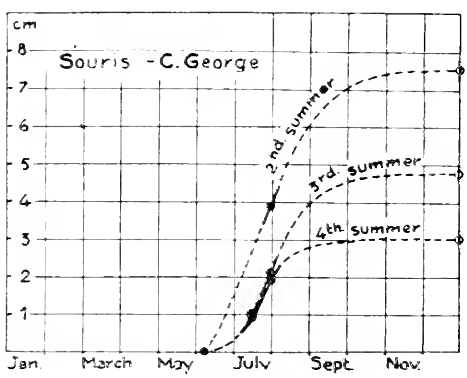


Fig. 45

These later samples give a more definite idea as to the time when summer growth of the younger herring in these waters begins, as in one of the samples (early June) the fish had not yet commenced their growth, while the remaining samples revealed a distinct new summer belt on the scales.

An interesting feature in connection with these fish is the fact that the summer growth commences so late. Off the coast of Norway, the new summer growth commences in April; but far up in the Baltic, near the coast of Finland, similar conditions are observed. Hellevaara (IV) who has investigated the herring of these waters, observes in this connection: "Not until the 27th of June did I observe that the scales had begun to grow on the young fish 1 or 2 years old; but not on those which had reached maturity."

XIV. RESULTS OF AGE AND GROWTH STUDIES, VIEWED IN THE LIGHT OF OBSERVATIONS AS TO RACIAL CHARACTERS.

In the foregoing I have endeavoured, by analysis of the age determinations and growth measurements made, to arrive at a satisfactory solution of some of those problems which group themselves about the two more comprehensive questions, as to the numerical proportions of the different year-classes, and the growth of the fish in different waters. It became very soon apparent, during these studies, that the area, within which the samples analysed were collected, presented contrasts often most pronounced, and it would therefore be natural to consider both age and growth observations against the background, so to speak, of the third problem, viz., whether several more or less distinctly different races of herring could be shown to exist within the area investigated.

We may therefore, in conclusion, glance at this question, while considering the observations as to racial characters, and discussing the possibility of employing growth observations as a means of distinguishing races.

The results of the age and growth studies bearing on this problem may be briefly summed up as follows: The different waters exhibit different conditions with regard to the age-composition in the samples and the growth of the fish.

In seeking for the cause of the differences observed between samples from different waters, and of the resemblance between those from the same locality, we are naturally led to the supposition that several local tribes or races of herring must exist, each having its own particular area of distribution. Without such hypothesis, it would appear difficult to understand how the different waters could differ so remarkably with regard to age and growth of the fish, as seen, for instance, in the marked dissimilarity between the herring of the Magdalen islands and those taken off the coast of Newfoundland, despite the short distance—but a few days' swim—between the two localities. By presupposing the existence of such local races, we are at least able to accept without surprise the fact that such differences do exist, albeit we can, from our present slight knowledge of the subject, form but vague and uncertain ideas as to how the differences in question may have arisen.

It would therefore be must useful, if other methods of investigation could be brought to bear upon the problem as to existence of local races in these waters. One in particular immediately suggests itself, to wit, that formulated by Heincke for the very purpose of studying the racial distribution of the herring, by arithmetical description of the morphological features.

As mentioned in the introduction, countings of vertebræ, fin-rays, and keel-scales were carried out with a number of herring from different waters, at the time the material was collected. These observations should, however, as Dr. Hjort has pointed out in his preliminary report, only be regarded as of a tentative character, the samples in question being few and small. Hence, I can, as a matter of fact, add but little to what Dr. Hjort has already stated with regard to these observations; nevertheless, it may yet be of interest to consider them here in connection with what has been set forth in the foregoing pages respecting age and growth.

The features noted were as follows: Total number of vertebræ (Vert. T.); numerical order of first vertebra with closed hæmal arch (Vert. H.); number of fin-rays in dorsal (Dors.); and in anal fin (An.); and number of keeled scales between the ventral fin and the anus (K.).

I have worked out the standard error of the averages for each of these characters in the several samples, and found that the resulting error of the differences in all cases may, without risk of serious inaccuracy, be taken as about 0.17, the actual figures being sometimes slightly higher, sometimes a little lower than this value. In making comparison between two averages, then, a value of at least 0·5, or thereabouts, will be required before the differences can with any great degree of probability be regarded as statistically significant, i.e., due to other causes than accidental fluctuation. Where the differences of several averages tend in the same direction, smaller values may naturally be taken as significant.

In the autumn of 1915, however, I made an observation which seems to suggest that it may, in certain cases, be necessary to demand a higher order of magnitude in the differences between two averages before deducing therefrom the existence of variety in race. And as this particular feature has not, as far as I am aware, been touched upon before, I have thought it advisable to mention it here.

While investigating the number of vertebræ in a sample of young herring from the north of Norway, in the autumn of 1915, I found that the fish of about 1⅝ years old (numbering forty-nine in all) averaged 57·37 vertebræ, while those of about 2⅝ years (241 specimens) showed an average of 57·72. The difference between the two age groups in this respect was 0·35 ± 0·11 giving 0·9995 for the probability that it was not due to accidental fluctuations of sampling. It would thus seem that variation may occur in the number of vertebræ of the different year-classes (year-class variation as opposed to age variation). In samples where a large majority is furnished by a single year-class, therefore, such year-class variation may possibly affect the results to a certain degree, while on the other hand, this is hardly likely to be the case in samples consisting of several year-classes, all more or less equally represented. As samples of young herring are particularly liable to exhibit such majority of a single year-class, it will be prudent to regard them as less truly representative of the race to which they belong.

Table 47 shows the average values for the seven samples examined as to number of vertebræ, etc. The values are here carried to the first decimal point, a value of about 0·5 being, as we have seen, required to make the difference statistically significant. There are one or two slight discrepancies between this table and the corresponding one in Dr. Hjort's preliminary report. One of these (West Ardoise, number of vertebræ) is due to the omission there of an extreme variate which has been included here; another owing to a slight error in the arrangement of the variates; the remainder to the loss of some of the sheets on which the figures had been noted; none are however, of any grave importance.

TABLE 47.—Racial characters. Averages for samples from different localities.

Locality and Date.	Characteristics.	Dors.	An.	K.	Vert. H.	Vert. T.
Newfoundland, west coast, Autumn '14	Old, mature, developing sex. org.	20·0	17·9	12·6	25·0	56·8
Magdalen Islands, May 1914	Old, mature, ripe	18·3	16·6	12·5	25·4	56·5
Northumberland Strait, May 21, 1914	Old, mature, ripe	18·3	16·7	12·5	25·2	56·3
W. Ardoise, Aug. 10, 1914	Younger, mature, ripening	18·5	17·3	12·9	25·4	56·5
Lockeport, Nov. 1914	Younger, mature, ripe?	20·3	18·5	12·9	25·2	56·5
Bay of Fundy, Nov., 1914	Young, immature	18·7	17·6	14·1	25·0	56·5
Gloucester, Mass. Nov. 1914	Young, immature	19·9	18·1	13·2	24·9	56·7

From the figures here shown, it would certainly seem very likely that the method in question might serve to define the differences between the herring from different parts of the Canadian waters. Thus the sample from Newfoundland, for instance, differs distinctly from the Magdalen islands and Northumberland strait samples as regards the number of rays in the dorsal fin, which character likewise seems to indicate a difference between the herring of the Magdalen Islands and Northumberland strait on the one hand, and those of the Atlantic coast on the other. This character also, therefore, might possibly prove of importance if the error of the averages were reduced by increasing the number of specimens in the samples. Somewhat the same applies, indeed, to the number of vertebrae; the present samples are too limited to reveal any absolutely indubitable difference in this character.

On comparing the figures for the sample from Northumberland strait with those of the one from Magdalen islands, no essential difference is apparent, and one is reminded of the great resemblance in point of growth exhibited by the samples from these waters, with the good 1903 year-class common to both. It would be interesting to investigate the localities in question more closely, with the aid of more extensive material, in order to determine, if possible, whether the differences in growth and in age-composition found, warrant our considering the herring of these two waters as separate groups.

The sample from West Ardoise differs strongly from that taken at Lockeport, by the smaller number of rays in the dorsal and anal fins. The differences are so great that it seems almost certain they cannot be accidental. Here again is a point which might well be investigated further with a larger amount of material. Possibly the results might then lead to a definite distinction between several forms of herring along the Atlantic coast, based on the study of morphological characters and growth measurements. In our present investigations, the paucity of material rendered it impossible, as already mentioned to demonstrate with certainty the existence of any difference in point of growth between the herring of Lockeport and those of West Ardoise. In further investigations it would also be well to include samples from the north side of Cape Breton island, in order to determine the character of these fish more accurately than it has here been possible to do; the same applies to the waters between Port Hood, Souris, and cape George, as well as the more southerly parts of the Atlantic waters of Canada.

One special subject for growth investigations which, owing to the favourable conditions in these waters, have every chance of success, is the distribution of the herring in the gulf of St. Lawrence, studied by means of quite small samples of old fish, examined as to growth. The very remarkable difference in growth between the herring from the southern portions of the gulf, and those from the coast of Newfoundland renders it, as far as I can see, an easy task to determine, even with small samples, whether the fish in question can be said to belong to one or the other growth type. Such identifications of the herring could be carried out in a manner similar to the method of Heincke for the identification of herring by means of morphological characters. Heincke's method may be briefly described as follows: It is desired to ascertain whether a given specimen, of which certain characters have been determined by count and measurement, more resembles in such respects the one or the other of two races in which these same characters are known (average and variation). The first step is to ascertain in what degree the specimen differs, as regards each separate character, from the average values for same in the one race, the difference in each case being expressed in units of the respective standard deviations. The differences thus obtained are then squared and added together. Similarly, the deviations of the specimen from the average of the other race is then determined, the differences here being expressed in units of the respective standard deviations for the race in question. The specimen then differs in the lessor degree—i.e., resembles more—the race for which the resulting sum of the squares of the differences is the less. Table 48 shows the order of the calculations. The example here used was a fish from one of the Newfoundland samples, belonging to the 1904 year-class; the values for the different increments (t) for the specimen in question are shown in the first column of the table. The second column gives the corresponding average values for all Newfoundland fish investigated; the third the deviation of the specimen from these averages; the fourth, the standard deviations for these averages in question; the fifth, deviations of the specimen divided by the respective standard deviations (i.e., deviations of the specimen expressed in units of the corresponding standard deviations); the sixth, these deviations squared; and finally, the sum of these squares is shown at the foot. The second half of the table is drawn up in a manner exactly corresponding to this, the specimen being here compared with the averages for the 1903 year-class from the Magdalen islands. The resulting sums of the squares are, it will be noticed, highly dissimilar; that for the comparison with the Magdalen islands averages being more than ten times the figures resulting from comparison with the averages for the fish to which the specimen actually belonged.

It will be interesting to refer to table 48 showing the method of comparison between growth values for a single herring and the corresponding average figures for the herring of two different waters, according to the principle of "least squares."

TABLE 48.—Example showing the growth of a single herring compared with average growth of the herring from Magdalen Islands and Newfoundland by the method of least squares.

—	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}
Individual herring, to be tested...	7·1	7·0	5·1	3·1	3·0	1·7	1·1	1·0	1·1	0·8
Average from Newfoundland samples	6·1	7·0	5·4	3·3	2·7	2·1	1·5	1·1	0·9	0·7
Deviations from Newfoundland averages δ........	1·0	0·0	0·3	0·2	0·3	0·4	0·4	0·1	0·2	0·1
Standard deviations for Newfoundland samples σ........	1·69	1·13	0·95	0·67	0·65	0·57	0·47	0·31	0·29	0·25
$\frac{\delta}{\sigma}$ Newfoundland....	0·59	0·00	0·32	0·30	0·46	0·70	0·85	0·32	0·69	0·40
$\left(\frac{\delta}{\sigma}\right)^2$	0·35	0·00	0·10	0·09	0·21	0·49	0·72	0·10	0·48	0·16
Averages for Magdelen Islands samples........	10·3	7·3	4·6	2·9	1·5	1·0	0·8	0·7	0·7	0·7
Deviations from Magdalen Islands averages δ........	3·2	0·3	0·5	0·2	1·5	0·7	0·3	0·3	0·4	0·1
Standard deviations for Magdalen Islands samples σ	1·63	1·38	0·98	0·59	0·46	0·28	0·24	0·20	0·22	0·21
$\frac{\delta}{\sigma}$	1·96	0·22	0·51	0·34	3·26	2·50	1·25	1·50	1·82	0·48
$\left(\frac{\delta}{\sigma}\right)^2$	3·84	0·05	0·26	0·12	10·63	6·25	1·56	2·25	3·31	0·23

Resulting sum of $\left(\frac{\delta}{\sigma}\right)^2$: For comparison with Newfoundland averages 2·7.

Resulting sum of $\left(\frac{\delta}{\sigma}\right)^2$: For comparison with Magdalen Islands averages 28·5.

The specimen here dealt with was one of twenty others selected for examination by this method. Ten of these were taken from one of the Magdalen islands samples among the 1903 year-class, the requisite standard deviations for this year-class having been previously computed; the remaining ten were selected from fish of the 1904 year-class in one of the Newfoundland samples. In order to ensure the obtaining of an absolutely independent selection, the task of choosing out specimens was delegated to another party, who simply noted down twenty of the numbers which had been assigned in the tables to the fish of the mentioned year-classes in the two samples. The sample from Newfoundland was, moreover, the one with averages differing most from the total average for all Newfoundland samples, the deviation tending in the direction of the averages for the Magdalen islands. It may therefore be admitted that the results obtained will not present any unjustifiably favourable view of the possibilities inherent in such comparison. It was found that in seventeen out of twenty instances the sum of the squares was the less in comparison with the averages for those fish to which the specimen in question belong. The reverse was found in the case of one specimen from the Magdalen islands, and two from Newfoundland, these differing more from the averages of the fish whence they were taken. This result seems to suggest that it should be possible, by means of the figures obtained from growth measurements, to determine, in many cases at least, whether an old fish taken in the gulf of St. Lawrence belongs in point of growth to the type found off the Magdalen islands, or to that found in the Newfoundland waters. In order to obtain the best results, good averages would be required, i.e., it would be necessary to examine large samples, taken during the spawning season, and on the actual spawning grounds, such choice of time and place being the best means of procuring "pure" samples, without admixture of foreign elements. The comparison should be made not as has here been done with averages for different classes (Magdalen islands 1903 and Newfoundland 1904) but with averages for the same year-classes in samples from the different spawning grounds.

As to how far any similar individual distinction may properly be made with regard to the herring in other Canadian waters, we cannot at present decide anything with certainty, the material from the Atlantic areas being insufficient. Most probably, however, we should in the majority of cases be able to determine whether a herring taken between Cape Breton and Newfoundland should be regarded as a Newfoundland herring in the strict sense, or not, always provided that the investigations are so continued as to furnish a sufficient quantity of material for computing the averages (with standard deviations).

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CANADIAN FISHERIES EXPEDITION, 1914-1915

BIOLOGY OF ATLANTIC WATERS OF CANADA

GROWTH OF THE YOUNG HERRING (SO-CALLED SARDINES) OF THE BAY OF FUNDY

A PRELIMINARY REPORT

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In the spring of 1915 Dr. Hjort proposed in connection with the extended investigations in 1914-15 that I study the young of the herring (*Clupea harengus*) or "sardines" of the Bay of Fundy to determine if possible how large they were during the first winter, and the amount of growth during the year. The numerous Canadian weirs that are fished throughout the greater part of the year to supply the sardine factories chiefly in Maine were practically certain to furnish an abundance of material.

Owing to the work that was being prosecuted in the gulf of St. Lawrence it was not possible for me to examine the material in the fresh state except at the beginning and end of the season. It was necessary to rely upon salted material.

The material has been collected in large part by the engineer of the Biological Station at St. Andrews, Mr. A. E. Calder. When circumstances permitted, he collected samples weekly. The material has proved to be far from complete enough to settle the points in question. This is particularly the case with regard to the smaller fish, popularly known as "brit," which are for the most part too small to be satisfactorily taken by the nets used in seining the weirs. Not only will they pass through the nets in seining, but when present in quantity they will not be taken out, being too small for canning. Although there are many gaps in the material, the results are not without interest.

It appeared desirable to use the scale method of determining the age and the yearly amount of growth; but the material presented such great difficulties owing to the indistinctness of the winter rings that this was abandoned and the method of measurement, instituted by Petersen, alone was used.

The samples were measured on one of the usual boards, divided into centimetres, with the divisions at the half centimetres so that in each case the measurement was to the nearest centimetre. This gave centimetre groups for statistical treatment. To facilitate accurate determination of the length, the measuring board was marked on either side of the mid-line with a series of parallel diagonal lines, making an angle of 40 degrees with the mid-line. By aligning the margins of the tail with these it was possible to spread the tail to an arbitrary, constant angle of 80 degrees.

Owing to the mixture of herring of different age groups in the samples, it was not feasible to take the average size in treating the material. The smallness of the numbers representing certain age groups in many of the samples rendered the results unsuitable for extensive statistical treatment. The only feasible method was a compromise and therefore somewhat open to objection.

The relative frequency of the various length groups in a sample indicated whether the sample consisted of more than one age group and also showed the mean size in each group. The various groups could in that way be traced through successive samples and their rates of growth determined.

The following table gives the results of the measurements:—

Locality.	Date.	Length in Centimetres.																					
		7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Back Bay	I, 14				2	3	38	140	89	16	2	2	1	1									
St. Andrews	IV, 16				3	5	16	43	79	59	26	3	3	4	3	1							
St. Andrews	V, 13	6	29	29	12	11	25	49	83	45	27	3	4	5	2	1							
St. Andrews	V, 24		4	103	92	32	15	10		1													
St. Andrews	VI, 2	1	32	150	46	32	18	10	5	5	7	2	1	1		1							
St. Andrews	VI, 15			7	22	53	68	60	40	25	12	3	1		1								
St. Andrews	VI, 28			76	183	29	9	3	1														
St. Andrews	VII, 20				7	155	47	17	10	4	1	1											
St. Andrews	VII, 27		2	5		28	68	20	17	18	38	36	22	6									
St. Andrews	VIII, 12			5	9	8	71	77	14	17	29	38	29	13	1	3	2						
St. Andrews	VIII, 19			1	9	2	21	60	30	25	26	38	37	26	8	2	2	1	1				
St. Andrews	VIII, 30				1	13	2	6	11	6	8	24	40	32	15	3		2					
St. Andrews	IX, 7			1	3	10	5	3	6	3	3	12	49	53	30	15	11	1		1	5		1
Jonesport	IX, 13					1				1	19	62	52	45	42	21	20	8	6	2			
L'Etang	IX, 14						2		2	4	10	51	98	47	20	2							
Lepreau	IX, 14		1	15	16	8	7	6	12	14	26	69	58	25	8	3	1						
Pocologan	IX, 14							3	8	14	33	55	39	24	2	2							
Grand Harbour	IX, 15						1		2	1	2	15	51	69	49	21	17	9	4	3	1	1	
Bocabec I	IX, 16									7	1	3	16	53	37	10	2		1				
Bocabec II	IX, 16								2	23	24	36	60	98	50	13	1	1	1				
Bocabec III	IX, 16					4	11	5	6	10	9	18	59	76	45	10							
Oak Bay	IX, 28				1	9	10	7	1	1	1	11	55	83	37	7	4	2	2	2	1		
Bocabec	X, 4					3	10	5	2	1	5	38	47	63	41	17	7	6	1				
St. Andrews I	X, 14				1	6	23	25	27	23	19	44	64	68	67	47	14	9	5	7	1	1	2
St. Andrews II	X, 14					12	28	18	17	20	24	45	36	46	35	20	5	8	7	2	2	2	
St. Andrews	X, 25					1	25	32	19	8	10	23	51	60	19	12	1	2					
St. Andrews	X, 29					20	124	69	5	1	1												
St. Andrews	XI, 3						16	49	75	38	16	38	46	24	6		1						
St. Andrews	XI, 10						9	32	49	28	19	26	43	61	37	13	2	3	1				
St. Andrews	XI, 23							12	43	58	26	18	13	31	23	10	4	3				1	
Back Bay	XI, 29					2	13	67	35	47	33	49	30	10	5	6	3						
St. Andrews	XII, 6					1	9	12	32	34	21	17	8	7	6	7	8	15	8	4	1		
Bliss Harbour	XII, 21	2	13	26	38	91	88	37	24	9	2	7	1										
Mascarene	XII, 24		2	4	17	83	91	72	16	6	4		2										
Bliss Harbour	XII, 29		2	5	18	95	111	63	21	10	4	6	4	2	4								

Two of the samples may be said to be homogeneous, consisting of only one age group. They are those of June 28 and October 29. In both the actual range in size is 6 cm. (9-14 and 11-16) and the practical range is only 4 cm. (9-12 and 11-14) or perhaps 3 cm. (9-11 and 11-13). There can be no doubt that in these cases we have to do with only one age group. The curve for the sample of June 28, obtained by plotting the lengths against the numbers of individuals is given by the continuous line in fig. 1. Evidently too few length groups have been taken to give the most satisfactory curve, but we will not be far astray in taking 10 cm. as representing the mean length of the herring in the sample of June 28 and 12 cm. for those of October 29.

If we take the sample of October 4 and plot a curve to show the frequencies of the various length groups (interrupted line in fig. 1) we see very definitely a bimodal condition with two age groups represented, for one of which the length of 12 cm. may be taken as representative and for the other 19 cm. There is, however, a decided difference in the ranges of the two groups. The smaller one may be considered to have a range of 4 cm. (11-14) and the larger of 8 cm. (16-23). This might be due to the phenomenon of dispersion, the older group showing a broad low curve, and the younger group a narrow high one. I do not believe that this is the full explanation. The range is too great in the older group. It probably indicates that the older group is only apparently homogeneous, that it really consists of two age groups so similar in size as to fuse and give a good unimodal curve. Other considerations to be mentioned later support this view.

The sample of September 28 shows a similar condition. The practical ranges of the two groups would be 3 and 5 cm., respectively. The significance of this would seem to be that by the third year the spring and fall spawned schools have fused into a single group.

The third sample (III) of September 16, from Bocabec shows imperfectly a trimodal curve (fig. 1, dotted line). The sizes representative of the three groups may be taken as 12, 15 and 19 cm. The ranges are 3 cm. (11-13), 3 cm. (14-16) and 5 cm., respectively. The first and third of these groups are evidently identical with the two groups of the sample of October 4. The second group (15 cm.) was doubtless present in the latter sample but not in sufficient numbers to appear distinctly.

Let us designate these three groups A (19 cm.), B (15 cm.) and C (12 cm.). B and C give a bimodal curve with a total range of 6 cm. The growth of the smaller group (C) appears to continue farther into the fall than that of the larger group (B). This would bring them close together and make them fuse into one group with a range of 5 cm. and a mean size of 14 cm. as seems to be the case in the samples of November 3 and November 10. (for the latter see the curve in fig. 1 with alternate dot and dash). In this latter sample the larger group with a mean size of 19 cm. is evidently A and the smaller group with a mean size of 14 cm. represents (if our interpretation be correct) B and C fused. In the spring of the year group A seems to have been in the same condition as shown in the sample of April 16, with a range of 5 cm. and a mean size of 14 cm.

The degree of fusion of B and C and the relative abundance of the two groups in the various samples give a varying picture as shown in the samples of October, November, and December from St. Andrews.

In the middle of September samples from widely separated localities along the coast were examined and also a number of samples from the same locality in order to determine whether the mean size of an age group varied greatly in the different localities and in different samples from the same locality. These samples were in great part obtained through the courtesy of Captain Calder of the Seacoast Canning Co., Eastport. The localities were Jonesport (Maine), Grand Harbour (Grand Manan), Lepreau, Pocologan, L'Etang, and Bocabec. The samples showed uniformly a great preponderance of the A group. The mean size varied, being 17 cm. (Jonesport, Lepreau, and Pocologan), 18 cm. (L'Etang), and 19 cm. (Grand Harbour and Bocabec). Evidently there is an appreciable difference in the size of the same age group from different localities.

Samples were taken from several boats bringing herring from Bocabec on September 16. These showed uniformly a preponderance of the A group with in each case a mean size of 19 cm. The same is shown in a sample of September 28 from Oak Bay. This shows that herring from the inner side of Passamaquoddy bay may be considered uniform and treated together. Those from points as far away as L'Etang must be treated separately. The differences shown in the samples of September 16 from Bocabec indicate the amount of uncertainty to be associated with deductions made from measurements of such small lots of individuals. All three show in their curves summits at 19 cm. Two show summits at 15 cm., and the third a definite step in the curve at 15 cm. Only one shows a summit at 12 cm., the other two samples having no individuals of that or neighbouring sizes. Summits (or steps) are therefore quite constant for the same age group in the same locality at any one time.

These examples will serve to show the manner in which the results of the measurements have been interpreted.

To determine the rate and period of growth of each of the different age groups, the representative length of each group, in each of the samples from Passamaquoddy bay in which it was represented in sufficient numbers, was determined in the manner described above. These lengths have been plotted against the dates on which the samples were obtained, in fig. 2. For each group a curve has been drawn connecting the circles that indicate the length of the group at different times. Where there are considerable gaps the curves have been continued with interrupted lines. There are occasional points that do not fit into the general scheme. Those of November and December, intermediate between B and C we have already interpreted as due to more or less complete fusion of B and C.

The fresh fish measure somewhat larger than the salted. For this reason the lengths in the samples of May 24 and September 16, seem high compared with the others. The samples of June 15 and November 3, show groups with mean sizes of 12·5 cm. and 18 cm. respectively. In these cases we may have group C of the preceding year which has failed to fuse with B of the same year, whereas in A these two groups are constantly fused.

In fig. 2 we have a graphic representation of the growth of the three groups A, B and C during the year. The period of growth for A and B is from May to the end of September. For C the beginning of the period is not shown, as at that time the fish were too small to be taken by the nets. It appears to continue later for this group, at least well on into October. The rate of growth for B and C is somewhat less than 2 cm. a month in the middle of the summer when the growth is most rapid. The rate for A is less, about 1·5 cm. a month as the maximum.

In many of the samples larger fish were present, but their numbers are so small as to be unsatisfactory for a determination of their mean sizes and growth. The little evidence there is, shows a group beginning at 19 cm (April 16 and May 13) and growing to 23 cm. (October 14, October 25, November 10, and December 6). Also a group reaching 26 cm. by September 7.

The determination of the ages of these groups presents difficulties. Groups B and C are quite evidently less than one year apart in age. The lack of material less than 7 cm. in length must leave the question in doubt but it is most reasonable to suppose from the rate of growth shown in 1915 that group B, beginning at a length of 8·5 cm., must have already passed through a full season's growth. The well-established fact of decrease in growth rate with increasing age would necessitate this interpretation, unless there were still greater growth during the first year. We would then reach the conclusion that group B was spawned in the spring of 1914, reached a length of 8·5 cm. by winter and in 1915 grew 6·5 cm. to a length of 15 cm. Group C would have been spawned in the fall of 1914, have reached a doubtful length by winter, perhaps 5·5 cm., and in 1915 grown perhaps 7 cm., reaching a total length of 12·5 cm.

Group A is evidently in its third summer and consists of a mixture of both spring and fall spawned fish. In the third year, therefore, the herring grow from a length of 14 cm. to a length of 19 cm. The group growing from 19 cm. to 23 cm. would consist of herring in their fourth year and those reaching 26 cm. of perhaps five year old fish.

This interpretation may be expressed in the following table:—

	First Year.	Second Year		Third Year.		Fourth Year		Fifth Year.	
	Size.	Increase	Size	Increase	Size	Increase	Size	Increase	Size
Spring spawned	8·5 cm.	6·5	15	5	19	4	23	3 (?)	28 (?)
Fall "	5·5 cm. (?)	7 (?)	12·5						

I have a small quantity of very young herring collected in the tide ripplings in Passamaquoddy bay in June, 1911. Two small lots were picked up in dip nets at an interval of one week. Eleven individuals taken on June 19, range from 3·7 to 4·8 cm. in length, with an average length of 4·4 cm. Twenty-six individuals taken on June 26 range from 4·3 to 5·5 cm., with an average length of 4·9 cm. This gives a growth of 0·5 cm. for one week. This is higher than the June rate for group B, but nearly equivalent to the August rate, as shown in fig. 2. A continuance of this rate to September would give fish averaging about 9 cm. These fish must have been spawned in the spring of 1911. The fall spawners which spawn at Grand Manan and on the Nova Scotia shore do not begin until the later part of July. This confirms our interpretation of group B as fish spawned in the spring of 1914.

A comparison of these results with what has been found in Europe with entirely different methods shows a fairly close agreement. By studying the increase in the zone on the scale of the herring outside the last winter ring in a series of samples taken during the years 1910 and 1911 Lea has shown (Publ. de Circonst., No. 61, 1911) that in the herring off Norway, growth takes place during the summer from April to September. This growth period is of the same duration but a month earlier than for our coast.

As concerns the amount of growth, Lea found it to be 7 cm. in the third summer, which is much higher than what we have found. By calculations based upon the distances between the winter rings, Hjort (Publ. de Circonst., No. 53, 1910, p. 23) found that for 246 spring-spawned fish the average growth in successive years was 8.3, 7.1, 5.9, 3.6, 2.4, and 1.7 cm. Our corresponding figures are 8.5, 6.5, 5, 4, and 3 cm. For 80 autumn spawned fish he found the following amounts 12.6, 5.1, 3.6, 2.6, 1.6, and 1.1 cm., believing that the first figure really represented two seasons' growth. Our corresponding figures are, 12.5, 5, 4, and 3 cm. The agreement is as close as could be expected, considering the imperfection in our material. We have also not been able to separate the spring spawned from the fall spawned after the second summer.

It would have been very valuable to have correlated the positions and number of the winter rings with this study of the growth from measurements. In the material examined it has been possible to make out the rings clearly only in a small number of cases. What has been seen on the whole corroborates the above mentioned interpretations as to the ages of the various groups.

CONCLUSIONS.

The data, though incomplete, indicate that: (1) there are both spring and fall-spawned young herring (sardines) in the Bay of Fundy; (2) the spring spawned schools reach a length of about 9 cm. (3.5 in.) by the first winter and of about 15 cm. (6 in.) by the second winter; (3) the fall-spawned schools reach a length of about 12·5 cm. (4 in.) by the second winter; (4) the growth during the third season is about 5 cm. (2 in.); (5) the growth during the fourth season is about 4 cm. (1·5 in.); and (6) the period of growth is from May to September.

It is most desirable that this study be continued in order to either confirm or refute these tentative conclusions and to extend the observations.

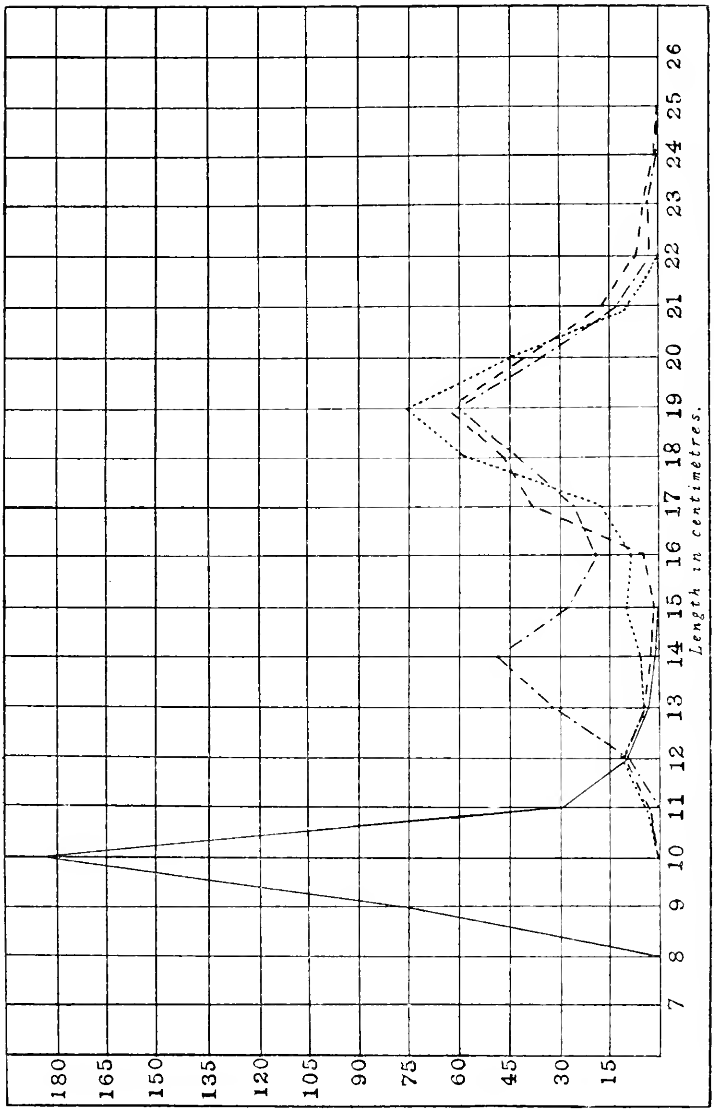

Fig. 1. Relative frequencies of length groups in samples of June 28 (———), Oct. 4 (- - -), Sept. 16 III (.........) and Nov. 10 (—. —. —.)

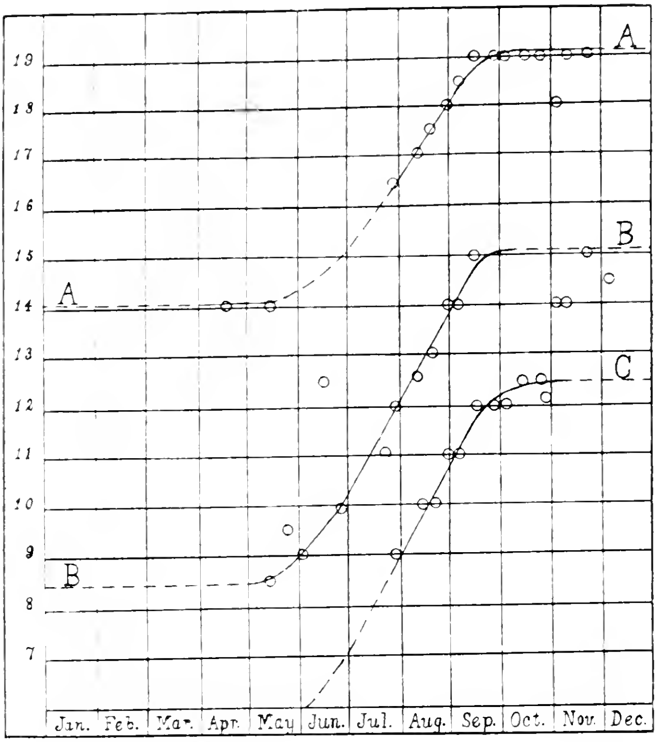

Fig. 2. Curves showing growth of Herring in 1915. The numbers indicate the length in centimetres.

Note (December 6, 1916).—A continuation of the investigations during this year has given results which agree well with those of last year. This last season differed from that of 1915 in that the "sardines" as a whole were small. This was due to the practical disappearance of the A group by the end of July, the B and C groups then in turn predominating. The A group was not as homogeneous as in 1915, consisting of varying proportions of its elements (B and C of the preceding year). It could therefore not be traced with any certainty.

The B group appeared at the end of May with an average length of about 10 cm. It was, however, mixed with larger fish until July and could be followed with difficulty. After August few were obtained. By October it had reached a length of 15 cm.

The C group was first obtained on July 8, with a length of 7 cm. By September it had become the dominant group and has remained so. During September, October and November it has continued to grow in length, increasing from 10·5 cm (September 6) to 13 cm. (November 24). The growth was not, however, as rapid as during July and August.

CANADIAN FISHERIES EXPEDITION
ATLANTIC WATERS OF CANADA

REPORT ON THE COPEPODA OBTAINED IN THE GULF OF ST. LAWRENCE AND ADJACENT WATERS, 1915.

BY

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PART I.

The pelagic Copepoda are small Crustacea averaging less than five millimetres in length, whose abundance in the sea is the measure of their importance as a direct source of food-supply for the young of the commercial fishes. In addition, they are pre-eminently the food of the herring which in its turn is preyed upon by larger fishes such as the cod and halibut. Accordingly, the investigation of their distribution as governed by depth, season, currents, salinity, and temperature, is generally recognized as having an economic bearing, for fishes will necessarily assemble in places where their food is plentiful. Much work has been devoted to this subject in recent years, especially in European waters, the general purpose of such investigations being to correlate the movements of these organisms with the seasonal migrations of fishes and with the seasonal variations of currents. In the Naples monograph of the pelagic Copepods (1892), the author, Dr. W. Giesbrecht, remarks that very little information was at that time available for the northern part of the Pacific ocean and for that part of the Atlantic ocean which lies between the 35th and 48th parallels of north latitude. It is convenient to remember that cape Cod is situated a little above 42° N. In Canadian waters there had been no quantitative study of the zooplankton up to the year 1915, but the gulf of Maine and the coastal waters between Nova Scotia and Chesapeake bay have quite recently been thoroughly explored during two seasons, the summers of 1912 and 1913, by the United States fisheries schooner *Grampus*, under the direction of Mr. Henry B. Bigelow.

The investigation has to be conducted along two lines: systematic and hydrographical, which in this case is tantamount to saying qualitative and quantitative. The object of the first method is to identify the species, in itself a matter of no little difficulty, involving many microscopic examinations. The second method seeks to determine their relations to the physical and biological conditions of the local environment. In 1901, Dr. W. M. Wheeler published a systematic report on the free-swimming Copepods of the Woods Hole region. The delimitation of this region was interpreted in a liberal sense so as to include not only Vineyard sound but also Plymouth harbour, Mass., and that part of the Gulf Stream which lies 60 to 80 miles due south of Martha's

Vineyard. The last two localities are within a day's journey of Woods Hole, Plymouth harbour being a boreal locality, whilst the Gulf Stream carries a tropical and subtropical fauna. As the four localities covered by Wheeler are typical of their respective districts, it may be desirable to tabulate his records for facility of reference and comparison. These records relate primarily to the fauna at or near the surface, a fact which may partly account for the absence of such representative boreal species as *Calanus hyperboreus, Euchaeta norvegica,* and *Metridia longa,* which frequent the deeper strata of water around 40 or 50 metres, although they sometimes ascend into the surface layers. They are essentially open-water forms, and it is probable that Plymouth harbour and Vineyard sound are too close to the land for them to find the necessary conditions.

TABLE A.—Wheeler's Records (July 1899).

Gymnoplea.	Woods Hole.	Vineyard Sd.	Plymouth Hr.	Gulf Stream.
1. Calanus finmarchicus		♀ XX		
2. Calanus minor				♀ XX
3. Eucalanus attenuatus				♀ 1
4. Eucalanus monachus				♂ 1
5. Mecynocera clausi				♀ 1
6. Paracalanus parvus				XX
7. Calocalanus pavo				♀ XX
8. Calocalanus plumulosus				♀ X
9. Clausocalanus arcuicornis				XX
10. Centropages typicus	X	X	XX	XX
11. Centropages hamatus	X	X		
12. Centropages bradyi				X
13. Temora longicornis	XX			
14. Metridia lucens (=M. hibernica)	♀ 1		XX	
15. Candacia armata (=Candace pectinata)				XX
16. Labidocera aestiva	XX			
17. Pontella meadii	X			
18. Anomalocera patersoni	X			XX
19. Pontellopsis regalis (=Monops regalis)				♂ 1
20. Acartia tonsa	XX		XX	X
21. Tortanus discaudatus (=Corynura bumpusii)	XX (♂ XX ♀ 1)	♂ XX		
Podoplea omitted				

X means present. XX means abundant.

Of the two divisions of the free-living Copepods, namely Gymnoplea or Calanoids and Podoplea or Harpacticoids, the former is more directly concerned with the purpose of the present investigation. Of all the species which have passed under review, the one that is most widely distributed and most abundant in the fishery districts is *Calanus finmarchicus,* known to the more observant fishermen as "red feed" or "herring feed". It is part of our problem to deal with this and some other species, not only in the full-grown condition but in such of the stages of early growth as are brought up in the tow-net. Six stages in the postlarval development of *C. finmarchicus* have been specified by Professor Gran (1902) who seems to have been the first to attempt an analysis and interpretation of the mode of occurrence of this species in the Norwegian North Sea, where its superabundance had been previously signalized by G. O. Sars. Gran's six stages, adopted with slight inversion by Damas (1905), may be regarded as typical for the Calanoids as a whole, although in some cases the procedure differs remarkably as regards the details of subdivision and fusion of the abdominal segments Thus, at a certain stage, the young *Metridia* has a four-jointed urosome (hind-body) in either sex; the adult female has a three-jointed urosome through fusion of the first and second segments; the adult male has a five-jointed urosome through subdivision of the earlier fourth segment. There is a similar sequence of segmentation in *Tortanus*. The development consists of three main periods: embryonic period within the egg; nauplius or larval period comprising six stages; post-larval or copepodid period comprising six stages, of which the sixth is the adult (see Lebour 1916).

TABLE B.—Copepodid Stages of *Calanus* (Damas 1905).

Stages.	Thoracic segments.	Abdominal segments.	Pairs of legs.
I	2	2	2 and rudiments of third pair.
II	3	2	3 " fourth pair.
III	4	2	4 " fifth "
IV	5	3	5
V	5	4	5
VI ♀	5	4	5
VI ♂	5	5	5

At least two other species, of small size, must be regarded as important sources of food for young fishes in the gulf of St. Lawrence, viz, *Pseudocalanus elongatus* which attains a length of 1·5 mm., and *Tortanus discaudatus* (about 2 mm.). The former abounds also in the Norwegian sea, the latter is a characteristic Laurentian species. When these forms and others which are commonly associated with them, *e. g. Temora longicornis* (1·5 mm.) and *Centropages hamatus* (1·5 mm.), occur in such numbers as to overshadow the larger forms, they give the plankton a distinctive character both as to colour and size, the dominant tone after preservation in formalin being a dusky grey, and the individual dimensions aggregating to give the aspect of a microcalanoid plankton. A microcalanoid plankton may also be brought about by the predominance of the young stages of larger species, especially those of *C. finmarchicus*. When the individuals are larger and the dominant colour, before and after preservation, is red, owing to the quantity of red oil in their bodies, the plankton wears a megacalanoid aspect. Such a sample may be composed in varying proportions of *Calanus finmarchicus* (3 to 5 mm.) *C. hyperboreus* (3 to 7 mm.) and *Euchaeta norvegica* (3 to 8 mm). Intermingled with these we find sometimes the white *Metridia longa* which according to Farran (1910) is the "most typically Arctic copepod of whose distribution there is any accurate knowledge" (quoted by Bigelow, 1915, p. 292). The four last-named species are as a general rule limited to the waters north of Cape Cod but *C. finmarchicus* ranges to the south of Nantucket, and *Euchaeta norvegica* was taken from 50-0 fathoms in lat. 40° N., long. 69° 29′ W. (Bigelow, 1915).

Giesbrecht tabulated the species of pelagic copepods under three leading regions: species of the warm region (between 47° N. and 44° S.); species of the northern cold region; species of the southern cold region. He showed that the copepod faunas on opposite sides of the American continent are more nearly related than those of the three hydrographical regions named above. Thus the main faunistic differences appear in following the distribution from the equator to the poles or from the poles to the equator, not from the eastern to the western hemispheres.

Calanus finmarchicus is not only the commonest copepod in eastern Canadian waters and in the North Atlantic coastwise waters generally, but it occurs more abundantly than any other form in the San Diego region where its daily vertical migrations have been studied by C. O. Esterly (1911). According to G. O. Sars (1901) both *C. finmarchicus* and *C. hyperboreus* extend throughout the Polar Sea from Greenland in the west to Behring Strait in the east. He adds that the former species is equally devoured by herring and mackerel and "in some cases, as stated by Prof. Robert Collett, forms almost the exclusive nourishment of one of our greatest whales, *Balae-*

noptera borealis." On account of the up-and-down movements referred to in the preceding paragraph, it becomes important to note the time of day when the hauls are made. The total quantity of *Calanus* present in the column of water filtered through the vertical net at a given station is of more practical concern than the quantity at any particular depth. Esterly found that the maximum abundance ("plurimum") at the surface occurred during evening twilight. The surface, in a quiet sea, is practically deserted during the daylight hours, the plurimum between 6 a.m. and 6 p.m. being located at about 200 fathoms. J. I. Peck (1896) found in Buzzards bay that from sunrise to sunset the copepods desert the surface almost completely. The factors which operate in causing this daily rhythm have been analysed in the case of *Labidocera aestiva* by G. H. Parker (1902). Other cases have been discussed by J. Loeb (1894). At station 48 of the *Michael Sars,* between the Canary islands and the Azores, on May 31, 1901, Dr. Hjort states that "the tow-net at 40 metres contained a mass of red copepods, which were not observed at the surface during the daytime, but suddenly appeared as soon as it grew dark soon after 6 p.m."

In addition to the diurnal there are seasonal migrations. Gran (1902) found off the Norwegian coast from Romsdal to Lofoten, females swarming in April and May over the coastal banks. In August and September great quantities of the young stages (II to IV) are found at the surface. In winter *Calanus* descends into deep water. Gran supposes that the autumnal juniors sink into deep water where they slowly complete their growth and rise again to the surface as the spring adults which then spawn, in Norwegian waters. On the other hand the first haul made by the "Princess" on May 11, 1915, between Prince Edward Island and the Magdalen Islands contained both adults and juniors amidst a swarm of *Pseudocalanus* (see table 1).

According to Giesbrecht's faunistic observations, the distribution of pelagic copepods does not conform to the oceanic currents although these are factors in their dispersal. Beyond a certain point the distribution of *Calanus finmarchicus* does not seem to be determined by ordinary physical factors. In the gulf of Maine this species was taken by the *Grampus* in water at temperatures ranging from 42° to 76° F., but was most abundant between 42° and 50° F. (5·5° to 10° C.). The density of the water in which it was living in swarms varied from 1·024 to 1·027. It was wholly absent in pure Gulf Stream water and in the very fresh water at the mouth of Chesapeake Bay. Bigelow adds that none of the physical constants which were determined in his exploration of 1913 will account for "the scarcity of Calanus in the waters south of New York in July, for the subsurface salinities, temperatures, and densities of many of those stations were well within the range occupied by the species in the gulf of Maine. What the limiting factor is, is one of the numerous questions raised, but not answered, by our cruise." (Bigelow, *op. cit.* 1915, p. 290-291). That the Gulf Stream is no barrier to *C. finmarchicus* in the proper latitude, is shown by the records of *Acadia* station 16, June 1, 1.45 a.m., where the surface copepod haul contained 82 per cent of this species, the temperature exceeding 12° C., and the salinity 35 per thousand.

The factor which determines the limit of southern dispersion of *C. finmarchicus* is clearly neither a simple physical constant nor a single organic tropism. It can only be explained at present in terms of endemicity, which includes the biological factors of food-supply and propagation. The Calani which swarm in and about the gulf of St. Lawrence have not been brought there by the Labrador current but are endemic in the Canadian waters. This is shown not only by the presence of the different stages but by the occasional capture of spawning females, taken in the act of extruding an egg or before the latter has had time to become detached from the body of the parent. This is not a frequent observation but was noted in several instances, viz., *Princess* stations 9 and 17; *Acadia* stations 3, 35, 65, 66, 88; *No. 33* stations 13, 14, 25, 26. Females with spermatophore were seen at *Princess* station 20; *Acadia* stations 66, 79, 85, 86, 87, 89; *No. 33* stations 13, 25, 58, 59, 64.

The endemicity of *C. finmarchicus* in the gulf of St. Lawrence being thus proved, it remains to consider its habit of assembling in swarms, in other words its gregarious habit. The records indicate that the Calanus inhabiting these waters is part of one vast, continuous community, whose southern frontier is not a straight parallel of latitude but a scalloped border which changes with the seasons; but it is none the less a definite boundary because the species holds together in virtue of the cohesion of the individuals. The Calani, with their rich oily bodies, form a floating mass which does not readily mix with the pure Atlantic water; the line of separation of the calaniferous water from the oceanic water is like a line of contact between fluids of different viscosity which have a slight tendency to mix; the degree of viscosity being influenced by the presence of the copepod swarm.

Calanus finmarchicus is both euryhaline and eurythermal, *i.e.* it is independent of ordinary diurnal and seasonal fluctuations of temperature and salinity. This fact is brought out very clearly by the records of *No. 33* station 23, which show a gradation in percentages of this species entirely disconnected with the gradations in temperature and salinity.

TABLE C.—Steam Trawler *No. 33*, station 23, June 25, 1915, between Anticosti and Gaspé; 49° 31′ N., 63° 58′ W.; depth 355 metres.

TEMPERATURES: CENTIGRADE.

Surface	+8·69°	75m.	—0·71°
10m.	+8·0°	100 "	—0·22°
20 "	+3·42°	125 "	+0·3°
30 "	+2·21°	150 "	+1·3°
40 "	+1·38°	250 "	+3·7°
50 "	+0·43°	350 "	+4·56°
60 "	—0·12°		

PERCENTAGE OF COPEPOD CONTENT IN PLANKTON.

Species.	Surface 5 mins. 10 CC.	Vertical 45—0m. 12 CC.	Closing net 100—60m. 15 CC.	Closing net 340—145m. 90 CC.
Calanus finmarchicus	100	39	33	20
Calanus hyperboreus		44	52	60
Pseudocalanus elongatus		8	6	2
Gaidius tenuispinus				5
Euchaeta norvegica		7	8	7
Scolecithrix minor		2	1	0
Metridia longa				6
	100	100	100	100

SALINITIES.

Surface	28·59	75m.	32·51
10m.	28·93	100 "	32·84
20 "	30·78	150 "	33·48
30 "	31·31	250 "	34·22
50 "	31·97	350 "	34·62

The tables (I-XII) accompanying this report display the distribution of the principal species met with. It is not necessary to continue the tabulation of every station from *Acadia* 57 to 90, and I will therefore deal with this portion of the exploration somewhat more summarily.

TABLE D.—Percentage of *C. finmarchicus* of all ages at *Acadia* stations 57 to 67.

Stations	57	58	59	60	61	62	63	65	66	67
Percentages	3	50	51	90	80	62	45	47	67	28

At stations 68 and 69 the hauls were so scanty as to be negligible, though *C. finmarchicus* from stage III onwards was present at both. At station 74 the subsurface haul was sparse and contained hardly any copepods; twenty-five were picked out, and these included *C. finmarchicus* III (5), IV (3), and ♀ (1). Here we have an example of a tongue of northern calaniferous water of salinity 33 per thousand bearing southwards over Atlantic water of salinity 35.

In the following table E the vertical hauls were made from 180-0 fathoms except at station 76, where the haul was from 150-0 fathoms.

TABLE E.—Copepod content in the vertical net over the Atlantic slope south of Cabot Strait, July 26-27.

Acadia Stations.	70	72	74	75	76	79
C. finmarchicus III–IV	...	7	...	...	3	30
" V–VI	2	19	...	3	27	50
C. hyperboreus III–V	3	5	...	...	10	×
C. gracilis	...	...	...	2	...	...
C. tenuicornis	...	...	×	...	...	...
Eucalanus elongatus	...	...	...	2	...	...
Rhincalanus nasutus	...	...	×	1	...	...
Clausocalanus arcuicornis	...	1	...	...	...	...
Pseudocalanus elongatus	...	1	...	...	2	...
Aetideus armatus	...	...	4	7	...	×
Gaidius tenuispinus	...	...	...	10	5	...
Undeuchaeta major	...	...	2	...	×	...
" minor	...	...	2	2	×	...
Euchirella rostrata	6	1	5	3	5	×
" pulchra	...	...	×	...	...	...
Euchaeta acuta	...	...	×	1	...	...
" tonsa	...	...	×	...	...	...
" norvegica	13	14	24	21	16	7
Scolecithrix minor	...	25	4	...	6	...
" ovata	...	...	9	5	5	...
" bradyi	...	...	...	1	...	...
" danae	...	...	×	...	...	...
" cuneifrons	...	...	×	1	...	...
" echinata	...	...	...	1	...	...
Centropages bradyi	...	...	...	1	...	...
Temora longicornis	...	...	...	...	...	×
Metridia longa	75	15	...	2	10	12
" lucens	...	10	7	10	5	1
Pleuromamma abdominalis	...	...	×	4	...	...
" robusta	...	...	8	8	5	...
" xiphias	...	...	×	2	...	...
" borealis	...	2	35	12	...	...
Heterorhabdus longicornis	...	...	×	×	...	...
" norvegicus	1	...	×	1	1	...
Candacia armata	...	...	...	×	...	...
	100	100	100	100	100	100

Acadia station 80, July 27, depth 168 metres, at the eastern end of St. Pierre bank, is of interest as lying close to station 24 of June 2 (see table X). On the earlier date there was a great paucity of copepods but stages II to V of *C. finmarchicus* were observed. At the end of July the same early stages were present and, in addition, the blue copepod, *Anomalocera patersoni,* had put in its summer appearance at the surface.

TABLE F.—Percentage of Copepod content in surface and vertical hauls at *Acadia* station 80, July 27, 4 p.m.

Species.	Surface.	Vertical: 145–0 metres.
C. finmarchicus II		.
" III	3	15
" IV	10	25
" V	13	14
" ♀	4	3
Pseudocalanus elongatus	2	15
Centropages hamatus	44	25
Temora longicornis	22	3
Anomalocera patersoni	2	0
	100	100

The next important station is *Acadia* 83, 20 miles south of St. Pierre island. This station, in its depth (172 metres) and proximity to the south coast of Newfoundland resembles *Princess station* 41, which was similarly situated with reference to the north shore of the gulf of St. Lawrence (see table VI). The plankton sample in the vertical haul (*Acadia* 83) consisted of about 85 c.c. of material, but this was highly gelatinous and there were only some 1,500 copepods altogether. In the surface haul (15 minutes) the net was weighted so as to sink it to 5 to 10 fathoms; the amount taken was about 350 c.c., with excessive numbers of Obelia medusæ and young schizopods, and a moderate infiltration of copepods. The plurality of *C. finmarchicus* in this tow (65 per cent) corresponds to its normal midnight plurimum at the same depth, according to Esterly's computations. The agreement is not always so close. At station 86, July 28, 11.10 a.m., the subsurface haul yielded 100 per cent of C. *finmarchicus,* of which 72 per cent belongel to stage V; at this station the temperature fell rapidly from 13·8° C. at the surface to 2·6° at 50 metres, and still further to -0·4° at 75 metres. Perhaps this minimum temperature, in conjunction with the currents, acted temporarily as a false bottom, obstructing the normal daylight descent to the deeper strata. The effect of currents upon the vertical migrations of *Calanus* have been little investigated. The area within which Esterly's collections were made was expressly chosen on account of its freedom from tidal currents and storms.

TABLE G.—*Acadia* 83, July 28, midnight (12.50 a.m.)

Species.	Surface.	Vertical: 160–0 metres.
C. finmarchicus III	2	16
" IV	27	34
" V	35	20
" ♀	1	3
Pseudocalanus elongatus		.
Centropages hamatus	25	20
Temora longicorsis	10	6
Anomalocera patersoni		1
	100	100

Stations 85 to 87 cross the Laurentian Channel and may be compared with *Princess* stations 45 to 47 (table VII) and *Acadia* stations 25 and 26 and 34 and 35 (table X).

It will be seen that the comparison of the vertical hauls is chiefly demonstrative of the relative constancy in the character of the Calanoid fauna in the Laurentian Channel from June to August.

In order to obtain full value from these tables it is necessary to distinguish between what may be called *eurytropic species* which are generally distributed throughout the area covered by the several cruises, and *stenotropic species* whose distribution is seemingly limited within a narrower range by physical factors of temperature, salinity, and depth. Such eurytropic species are *Calanus finmarchicus, Pseudocalanus elongatus, Euchaeta norvegica*, and *Metridia longa*. In consequence of their ready toleration of slight changes in the temperature and saltness of the water these species are not reliable indicators as regards the interaction of currents and the stratification of the water. On the other hand the stenotropic species such as *Calanus hyperboreus, Euchirella rostrata, Scolecithrix minor, Metridia lucens*, and *Heterorhabdus norvegicus*, are especially valuable as indicators. Thus the subjoined table shows that a greater number of these stenotropic species occurs on the eastern side of Cabot strait in the boreal oceanic water which is in the track of the inflowing Cape Ray current, than on the western side in the line of the Cape Breton current which conveys water out of the gulf of St. Lawrence. This agrees with the behaviour, in this region, of certain species of *Sagitta*, as I am informed by Dr. A. G. Huntsman, who has made a most intensive study of the distribution of the Chaetognaths and with whom I have discussed the bearing of some of the data presented in this report concerning the Copepods.

TABLE H.—Vertical hauls in *Acadia* stations 85 to 87, July 28, 1915. Across Laurentian Channel.

Species.	270-0 metres. 85	270-0 metres. 86	290-0 metres 87
Calanus finmarchicus III	1	×	3
" " IV	3	10	10
" " V	25	34	28
" " ♀	15	10	8
" " ♂	2	10	1
C. hyperboreus III	......	×	×
" IV	3	2	1
" V	2	×	×
" ♀	......	×	×
Pseudocalanus elongatus	2	2	1
Aetideus armatus	×	×	×
Gaidius tenuispinus	......	......	×
Euchirella rostrata	5	×	×
Euchaeta norvegica	16	22	26
Scolecithrix minor	5	2	1
" ovata	1	......	×
Centropages hamatus	......	......	×
Metridia longa	15	5	20
" lucens	5	3	1
Heterorhabdus norvegicus	×	×	......
	100	100	100

Acadia stations 88 and 89, on Misaine bank, both yielded Euthemisto plankton, including an abundance of *C. finmarchicus* from stage III to spawning females, with an excess of stage IV in all the hauls. On this bank at the beginning of June we encountered an Aglantha plankton, whereas at the end of July there were no medusæ here. As regards the Calanus, the chief change to be noticed was an increase in the number of adult females, 26 per cent in each of the surface hauls at stations 88 and 89. The latter station may be compared with station 79. Finally, at station 91 in the Gut of Canso there was an Evadne plankton with a copepod admixture consisting of

51 per cent *Tortanus*, 25 per cent *Temora*, 15 per cent *Pseudocalanus*, and 9 per cent *Centropages*. The temperature here fell from 12° C. at the surface to 11·45° C. at 45 metres and the salinity was 29·14 per thousand at 20 metres.

TABLE J.—Data for *Acadia* station 89, Misaine Bank, 132 metres, July 28, 1915, 8.35 p.m.

Species.	Surface.	30–0 f.	65–0 f.
C. finmarchicus III	6	1	3
" IV	26	44	34
" V	17	18	16
" ♀	26	10	6
" ♂	2	......	×
C. hyperboreus III	......	3	4
" IV	8	15	20
" V	......	×	1
" ♀	......	......	1
Pseudocalanus elongatus	1	4	12
Euchaeta norvegica	5	......	×
Centropages hamatus	5	5	2
Metridia longa	4	×	1
Anomalocera patersoni	×	......	
Tortanus discaudatus	×	×	
	100	100	100

In September, 1915, Dr. A. G. Huntsman made a short cruise in the Bay of Fundy in the ss. *Prince*, belonging to the Biological Station at St. Andrews. The data for the Copepods at the four stations are given in table XII. For the first time in the course of these investigations we meet with the species *Centropages typicus* which occurs regularly in the gulf of Maine and far to the southward of cape Cod, even reaching the latitude of cape Charles (Bigelow, 1915, p. 293, and fig. 70, p. 294).

At *Prince* station 1, Dr. Huntsman observed a great stirring up of the water from the bottom to the surface in consequence of the eddies caused by the tidal currents surrounding the points of land. The presence *en masse* of *C. finmarchicus* at the surface between 3 and 4 p.m. under a bright sun is unusual, and perhaps the deep-seated turbulence of the water, with the resulting lack of stratification, was responsible for it. It would be worth while to repeat the station, taking samples at intervals through the twenty-four hours, in order to ascertain whether the diurnal migration of Calanus is altogether inhibited. The effect of stratification of the water, so far as temperature is concerned, is seen in an experiment by Dr. G. H. Parker (1902). Female *Labidocera* are negatively geotropic, and remain at the top at all temperatures between 10° and 26° C. If the temperature is raised to 30° C. they become positively geotropic and swim to the bottom. The lower half of a large glass tube was filled with sea-water at 24° C.; into the upper half sea-water at 30° C. was poured gently. A female *Labidocera*, introduced at the top swam rapidly downward, but stopped at the plane of separation for the two temperatures.

Besides the diurnal and seasonal migrations of *Calanus* to which reference has been made, there is another kind of translation which has been called ontogenetic migration by Dr. Giesbrecht. Some pelagic copepods, as *Clausocalanus*, *Pseudocalanus*, *Euchæta*, *Eurytemora*, carry their eggs in an ovisac attached to the genital segment, but most species discharge their eggs directly into the sea. These eggs, according to Giesbrecht's observations, have a somewhat higher specific gravity than the water and consequently sink slowly; whilst they are sinking they accomplish their embryonic development. As soon as the Nauplius larva hatches out of the egg, it ascends towards the surface and towards the light, all copepod Nauplii being positively heliotropic.

The development of *Calanus* from the egg upwards was followed by C. Grobben in 1881, whose memoir I have not had for reference during the preparation of this report. The larval and copepodid stages have recently been described and figured by Marie C. Lebour (1916). All the larval stages are so small that they pass through the fine meshes of the silken tow-net, and this commonly happens with the first two copepodid stages as well. In order to obtain the earliest stages they must either be reared under laboratory conditions or the finest procurable silk bolting cloth must be used for making the tow-nets.

It is not known exactly when the ontogenetic migrations end and the diurnal migrations begin. Esterly (1911) confines his enumerations to stages V and VI which he considered together, rejecting the younger forms. Making allowance for the fact that stage I rarely comes under observation, we may still unite stages I, II, III, and IV as a superstage under the term *juniores* as employed by Gran, in order to compare it with the superstage of which stage V is the adolescent and stage VI the adult form. By grouping certain of the data contained in the tables in the manner indicated, a contrast appears between the distribution of the juniors and that of the two final stages, the former being more bound up with the surface layers than the latter. For example, at *No. 33* station 17 there was a copious and typical microcalanoid plankton of stages II and III, together with *Pseudocalanus* at the surface (see table VIII). The contrast which is brought out in the subjoined table K is a partial illustration of the ontogenetic migrations of *Calanus finmarchicus*. If the closing net could have been used more frequently, and if actual numbers were given instead of percentages, the differences in the behaviour of the two superstages would have been rendered much more manifest. Of course these ratios have no claim to exactness because so many interacting factors disturb the simple relations, but they may serve to bring the problem into relief.

There is reason to suppose that if stages V and VI were examined separately they might also exhibit differential behaviour. Indications of inverse behaviour of stage V and VI (♀) are to be found amidst the data recorded in the tables. At *Acadia* station 39 the surface ratio of V to VI was as 10:40; in the vertical haul from 25-0 metres as 15:24; in the vertical haul from 100-0 metres as 26:19. Again at *No. 33* station 23, the surface ratio of V to VI was as 0:90; in the vertical haul from 45-0 metres as 2:20; in the closing net from 100-60 metres as 5:23; in the closing net from 340-145 metres as 15:2.

TABLE K.—Ratio of juniors (II-IV) to adults (V-VI) of *C. finmarchicus* in surface and vertical hauls. *Ac.* = *Acadia;* Ps. = *Princess;* P. = *Prince;* m = metres; f = fathoms; jun = juniores; ad = adolescents and adults.

Station.	Depth.	Time.	Range of vertical haul.	Ratio of jun. to ad. in vertical haul.	Ratio of jun. to ad. at surface.
Ac. 5	72m	1 a.m.	60 - 0m	44 : 38	80 : 20
Ac. 14	2000m	12.50 p.m.	200 - 0m	20 : 56	nil
Ac. 16	"	1.45 a.m.	"	0 : 13	12 : 70
Ac. 26	500m	10 p.m.	100 - 0m	9 : 53	27 : 47
Ac. 28	"	6 a.m.	100 - 25m	8 : 41	51 : 36
Ac. 49	126m	3.40 p.m.	125 - 0m	42 : 46	80 : 7
Ac. 50	151m	7.30 p.m.	145 - 0m	21 : 47	40 : 40
Ac. 52	99m	1.45 a.m.	90 - 0m	35 : 51	60 : 32
Ps. 16	100f	1.15 p.m.	100 - 0m	24 : 40	66 : 12
Ps. 20	"	6 a.m.	"	23 : 37	81 : 9
Ps. 21	"	9.45 a.m.	"	26 : 43	89 : 2
Ps. 39	284m	7.30 p.m.	130 - 0m	60 : 15	50 : 5
Ps. 46	400m	6 a.m.	130 - 0m	17 : 74	47 : 53
P. 1	18f	3.45 p.m.	18 - 0 f	6 : 68	18 : 72
P. 2	60f	4.30 p.m.	55 - 0 f	3 : 70	25 : 17

PART II.

NOTES ON SPECIES.

1. *Calanus finmarchicus.*—There is a wide range of variation in the size of the individuals during the several copepodid stages and this is often to be observed at one and the same station. It is assumed that the transition from one stage to another is effected by a single exuviation. In one case I observed the new cuticle of stage V forming beneath the old cuticle of stage IV, as shown most clearly by the coxal denticulation of the fifth foot. The denticulation on the inner margin of the basal joint of the fifth foot occupies the whole of that margin in both stages V and VI; at stage IV only the middle third of the coxal joint shows the marginal denticulation (text fig. I). It is to be noted that the outer denticulation shown in the figure is much more restricted in certain individuals.

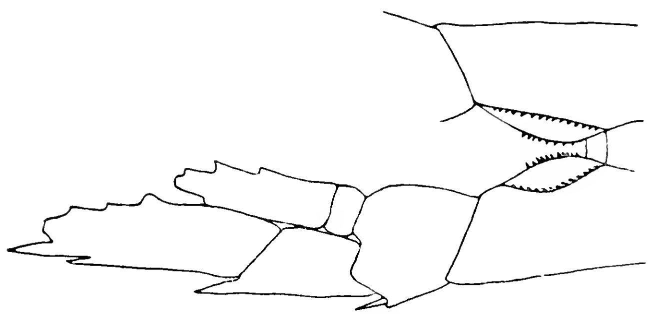

Fig. 1.—*C. finmarchicus* stage IV, length 3·2 mm.; fifth feet showing transition to succeeding stage. *Acadia* station 9.

By employing biometrical methods, Gran (1902) found that within the limits of the Norwegian North Sea, the individuals averaged larger in the north than in the south. For example at stage III (synonymous with Gran's fourth stage) the maximum length of the forebody in individuals captured in latitude 60° 43′ N. was 1·25 mm., while in those taken in latitude 67° 41′ N. the maximum length of forebody was 1·48 mm. Gran also found in general that the stages are smaller in summer than in spring. It is doubtful whether these biometrical results are applicable to other regions. To render the history complete, it would be necessary to take stock of the frequency of exuviations, and up to the present this has not been found practicable.

The following tables give a few examples of range of size at stages IV, V, and VI. The measurements were taken from the front of the head to the end of the caudal fork.

TABLE L.—Range of C. finmarchicus IV.

Station.	(measurements in millimetres.)
Ac. 9	2·2; 3·2
Ac. 28	2·0; 2·9
Ac. 79	1·9 to 2·0; small instars from 30-0 fathoms. In the haul from 180-0 fathoms some of 2·35 mm. were taken.
Ac. 88	2·75; 3·0
Ac. 89	3·0; large instars from 30-0 fathoms (compare Ac. 79).

TABLE M.—Range of C. finmarchicus V.

Ac. 5	2·9; 3·0; 3·5
Ac. 48	2·65; 4·5
Ac. 79	2·25; 2·5; 3·0; small instars as with stage IV at this station.
Ac. 80	4·9.
Ac. 85	3·6; 4·7; fat and oily.
Ac. 86	2·65; 4·5
Ac. 88	2·75; 4·0; 4·1; 4·5

TABLE N.—Range of C. finmarchicus VI (♀).

Ac. 4	3·0; 4·0; 5·0
Ac. 5	3·5; 3·65; 4·25
Ac. 8	3·35; 3·75
Ac. 79	2·9 with spermatophore; 3·0 with spermatophore. 3·2 with spermatophore; 4·5
Ac. 85	5·0 with spermatophore and turgid with pale pink oil.
Ac. 86	3·65; 5·0
Ac. 88	3·5
Ac. 89	5·2; 5·5 with spermatophore.

TABLE O.—Range of C. finmarchicus VI (♂).

Ac. 86	3·05; 5·0

The greatest contrast in average size is exhibited between stations 79 and 89. Table P accordingly gives the hydrographical data for these stations as worked out by Mr. Paul Bjerkan.

TABLE P.—Hydrographical data for *Acadia* stations 79 and 89.

Metres.	44° 47′ N., 55° 13′ W. Station 79.		45° 16′ N., 59° 4′ W. Station 89.	
	Salinity.	Temperature.	Salinity.	Temperature.
0	32·42		30·52	
		13·05		13·95
10	32·53			
		11·1		
25	32·85		30·90	
		9·5		9·1
50	33·06		31·92	
		5·5		0·75
75	33·33		32·13	
		2·5		0·15
100	33·97		32.13	
		4·9		0·15
125			32·24	0·05
150	34·40			
		5·9		
200	34·60			
		6·2		
300	34·61			
		4·65		
400	34·72			
		4·15		

2. *Calanus hyperboreus.* This Arctic species is nearly as widely distributed in our area as the preceding, but it is bound up with the deeper layers of water and in that sense it is stenotropic, rarely appearing in surface hauls in these latitudes. Moreover it does not range so far south as *C. finmarchicus*. The *Grampus* found that, like *Euchaeta norvegica* and *Metridia longa*, it was limited to the waters north of cape Cod and was taken only at four out of twenty one stations in the gulf of Maine. At *Grampus* station 10100 between cape Sable and Penobscot bay, opposite the mouth of the Bay of Fundy, the vertical net from 90-0 fathoms contained 270 individuals of *C. hyperboreus* to 5400 *C. finmarchicus*, this being its plurimum for the gulf of Maine (Bigelow, 1915, p. 293).

According to Damas and Koefoed (1905) *C. hyperboreus* is the commonest form at the surface in the Greenland sea. In Canadian waters there does not seem to be any regularity in its occurrence at or near the surface and each case would probably need to be accounted for by reference to local and temporary conditions. Its presence to the extent of 5 per cent in the deep surface haul with weighted net at *Acadia* station 85 and not at stations 86 and 87 is perhaps significant in view of what has been stated regarding this station (see above, table H).

No male was observed in any of the hauls. Sometimes there may be a little doubt regarding the identification of this species at stage IV with the three-jointed urosome. The postero-lateral angles of the forebody are not always so distinctly pointed as is usual. In such cases the doubt is at once removed by the examination of the fifth legs which although possessing coxal denticulations in the subsequent stages, are, unlike *C. finmarchicus*, devoid of them at stage IV in *C. hyperboreus*.

3. *Calanus vulgaris.*—Other species of Calanus were met with at stations in or near the Gulf Stream. Of these the most remarkable was *C. vulgaris* which is not mentioned in "Nordisches Plankton" (v. Breemen 1908). The female of this species has the postero-lateral angles of the forebody produced on each side as a ventrally

curved hook; in the male these edges are rounded, and the fifth feet have a peculiar vermiform process on the left side which distinguishes it from all others. It occurred at *Acadia* station 44 in the vertical haul, males and females, some of the latter having a spermatophore attached to the urosome or hind-body.

C. tenuicornis was recorded at *Acadia* stations 17, 74, and 75; *C. gracilis* at 42, 44, and 75; *C. minor* at 44 (18 per cent at the surface), 56 (one male in closing net from 210-140 fathoms), and 75 (males and females at the surface). *C. minor* is another species not mentioned in "Nordisches Plankton"; Wheeler observed numerous females taken in Gulf Stream tow, July 25, 1899, the locality being 60 to 80 miles south of Martha's Vineyard.

4. *Eucalanus* and *Rhincalanus*.—All the species of these two genera which are included in "Nordisches Plankton" were encountered in stations tangential to the Gulf Stream; many of the individuals were immature, especially was this the case with *Rhincalanus*. When attempting to differentiate the young stages of *Rh. cornutus* and *nasutus*, the conspicuous feature of the forwardly produced head with its rostral filaments is not an unfailing guide. Figs. 2 and 3 show the appearance of the fifth feet in young females of *cornutus* and *nasutus*: figs. 4 and 5 show the fifth feet in young males of *cornutus* of two sizes.

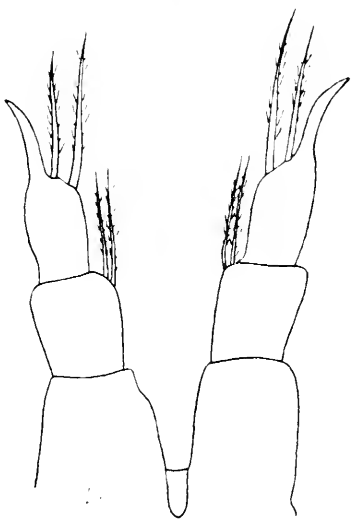

Fig. 2.—*Rhincalanus cornutus* juv. ♀. Length 3 mm. Fifth feet. *Acadia* station 44. 150-0 fathoms.

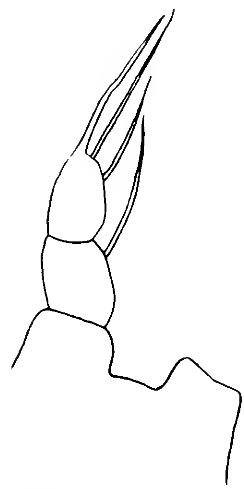

Fig. 3.—*Rhincalanus nasutus* juv. ♀ 3 mm. Fifth feet, one shown. Same station.

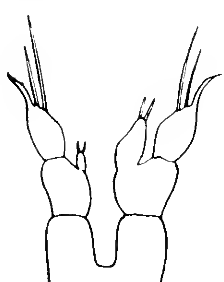

Fig 4.—*Rhincalanus cornutus* juv. ♂. Fifth feet, hinder surface.

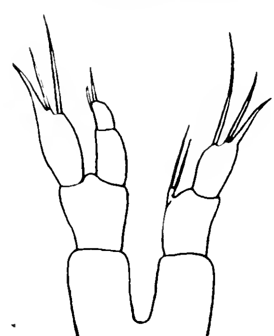

Fig. 5.—*Rhincalanus cornutus* juv. ♂. Fifth feet, front surface of older stage.

5. *Clausocalanus arcuicornis.*—Previously recorded by Wheeler from the Gulf Stream. In the deep surface tow of *Acadia* station 74 there were very few copepods; out of a total of 25 counted, 11 were of this species, the others being *C. finmarchicus* III (5), IV (3), ♀ (1); *C. minor* (2); *Scolecithrix minor* (1), *danæ* (1); *Acartia* sp. (1).

6. *Pseudocalanus elongatus.*—The abundance of this small but rich and oily species in the gulf of St. Lawrence is paralled by its frequency in the gulf of Maine. In the intervening stretch of water between the entrance to Cabot strait and to the bay of Fundy it does not occur in such great numbers. In the May plankton of the gulf of St. Lawrence between Prince Edward island and the Magdalen islands, it constituted on the average between eighty and ninety per cent of the copepod content. At several other stations inside the gulf it reached to 20 per cent and upwards. In none of the *Acadia* stations outside the gulf did it attain as much as 20 per cent, the nearest to this quantity being 17 per cent at station 67; 15 per cent at 80 and 90; 14 per cent at 36. In all the females which have come under my observation in the preserved material the ovisac was ruptured and the eggs appeared to be attached singly to the genital segment, sometimes one at a time, frequently two, rarely three. Often the shreds of the stalks of attachment are left behind after the egg has been liberated or torn away. When two eggs are present they may be seen to be attached separately side by side. Sometimes there will be one egg and the shrivelled stalk of another beside it. Spermatophores are sometimes applied to one and the same female in great numbers. In the example represented in fig. 6, I counted as many as twenty-four spermatophores.

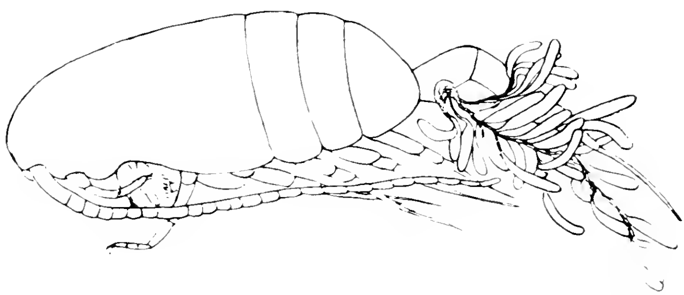

Fig. 6.—*Pseudocalanus elongatus* ♀, beset with spermatophores, "Princess" station 30, August 4th. 30-0 metres.

7. *Ætideus armatus* and *Gaidius tenuispinus.*—Neither of these species has been recorded previously from eastern American waters, that is to say not by Wheeler nor by Bigelow. They occurred together in *Acadia* station 75 in the vertical haul (180-0 fathoms or 325-0 metres) and again at station 87 (290-0 metres). Another noteworthy record for *Gaidius* was at *No. 33* station 23 in the closing net from 340-145 metres. Besides this it was present in the vertical haul at *Acadia* station 46 (270-0 metres).

Ætideus was not found at any station in the gulf of St. Lawrence. In addition to the two *Acadia* stations mentioned above it occured also at stations 17 (200-0 m); 25 (120-0 m.); 44 (270-0 m.); 74 (325-0 m.); 79 (325-0 m.); 85 (270-0 m.); 86 (290-0 m.).

8. *Undeuchæta major* and *minor.*—These were not found by Wheeler but they are mentioned by Bigelow (1915, p. 287). They are Gulf Stream species and *minor* is the more frequent. They occurred together at *Acadia* stations 46, 74, and 76. They are found also in the San Diego region whence the male of *U. major* has been described by C. O. Esterly (1905). The male of *U. minor* has remained hitherto unknown. Several examples were taken in the *Acadia* hauls. The structure of the fifth feet of

the male of *U. minor* differs from that of *U. major* in the absence of the forceps mechanism described by Esterly on the left foot and in some other respects. The chief differences are displayed in table Q, supplemented by text-fig. 7 and 8. The posterolateral angles of the forebody are rounded; rostrum strongly deflexed; anterior antennæ exceed length of forebody.

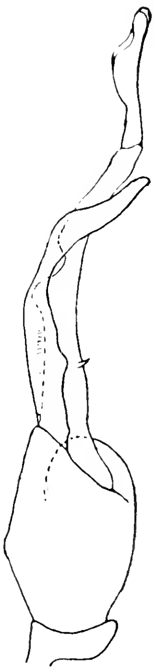

Fig. 8.—*Undeuchaeta minor* ♂
Right fifth foot from behind.
Re = outer branch.

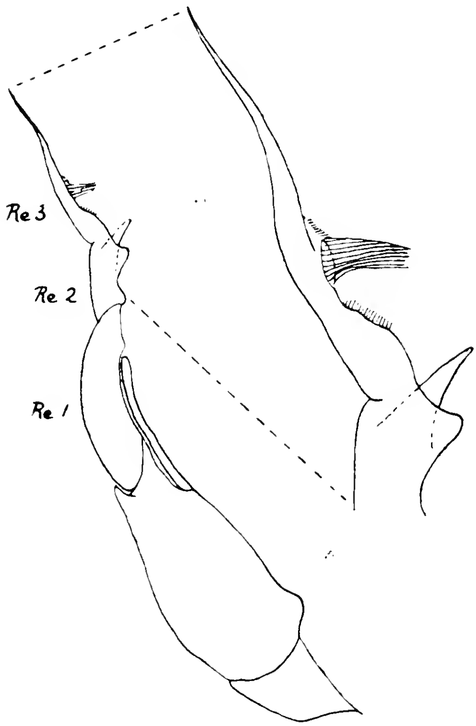

Fig. 7.—Same. Left fifth foot.

TABLE Q.—Comparison of fifth feet (p5) of *Undeuchaeta major and minor* ♂.

Features.	*Undeuchaeta major* ♂ (after Esterly.)	*Undeuchaeta minor* ♂ ("Acadia" material.)
Length	6·5mm	3·5 mm.
Right p5	Biramous	Biramous (fig. 8)
Outer branch (Re)	Terminal joint produced into a long stylet.	Terminal joint with spoon-shaped extremity.
Inner branch (Ri)	Simple.	Simple.
Left p5	Biramous	Biramous (fig 7).
Re.	Terminal joint ending in a short style which carries a pencil of long hairs near its centre. Second joint bearing a toothed process "which flares distally"; "at the base of this and on the second joint is articulated a process, which together with the terminal joint of the ramus and the toothed process forms a forceps."	Terminal joint ending in a stylet with a pencil of long hairs together with some denticulations near its centre, and a stout thorn at its base. Second and third joints incompletely separated.
Re	Vestigial	Vestigial

9. *Euchirella rostrata*.—Several species of *Euchirella* occurred in the vicinity of the Gulf Stream but the most widely distributed was this one. It has a distinctive appearance with its portly crimson-tinted forebody and short urosome. It was present in varying quantity at twenty-four of the *Acadia* stations but never in the surface hauls. At stations 85-87 which traversed the Laurentian channel between St. Pierre and Misaine banks, its mode of occurrence is significant in view of what has been said before. At each of these stations a vertical haul was taken from 30 fathoms to the surface, and another from 150 or 160 fathoms to the surface. At station 85, *Euchirella rostrata* occurred in both of the vertical hauls, two per cent from 30-0 fathoms, five per cent from 150-0 fathoms; at stations 86 and 87 it was present only in the deeper hauls. Its distribution within our area is shown on may (fig. 9). At station 54, where it appeasr with the high plurality of 43 per cent, it should be mentioned that the plankton here was very scanty, the vertical haul (150-0 fathoms) including only about 140 copepods in all. Other species of *Euchirella* were taken as indicated on table XI.

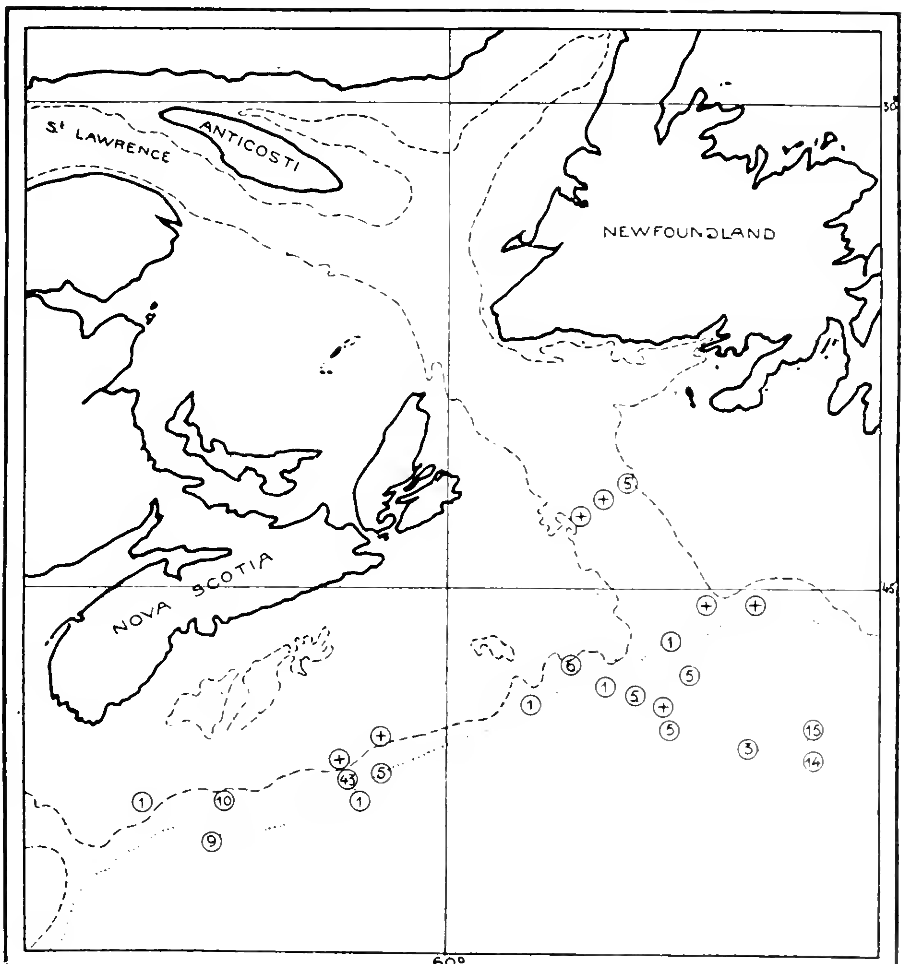

Fig. 9.—Distribution of *Euchirella rostrata*. The numbers indicate percentage of copepod content.

10. *Euchirella acadiana* n. sp.—A few examples were taken of the female only of this species which I have not been able to fit in with any published description. The occurrence was at *Acadia* stations 41 (200-0 m., one); 44 (270-0 m., two); 56 (210-140 fathoms, two). In the following diagnosis Giesbrecht's notation is employed: Length 6.25 mm. (5 + 1.25); rostrum deflexed, pointed (fig. 10); genital segment symmetrical except for a low oblique brown chitinous ridge on the left side seen from above near the hinder margin; postero-lateral angles of forebody broadly rounded.

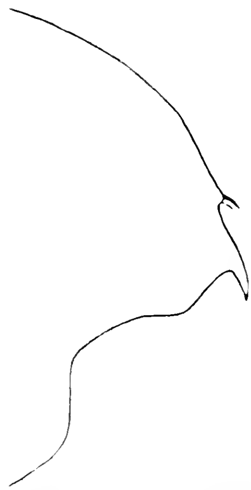

Fig. 10 *Euchirella acadiana.* Profile of head showing frontal organ and rostrum, after removal of right antenna.

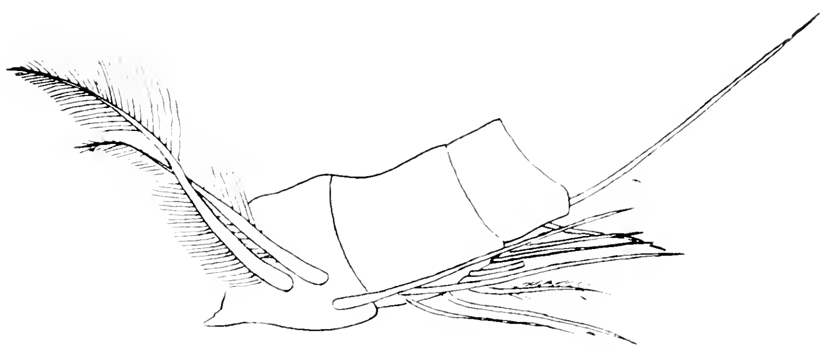

Fig. 11.—Same. Proximal joints of right anterior antenna from inner aspect.

Anterior antennae (fig. 11) of normal length, reaching to about the middle of the urosome.

Posterior antennæ (fig. 12) with three very long feathery setæ at the end of Re 7; B 1 with plumose Si (as in *messinensis*); B 2 with one Si (as in *messinensis*); Re 1 and 2 incompletely divided, with a crest and spur at inner distal margin of Re 1 (as in *curticauda*); Ri about four-fifths the length of Re 1 and 2; Ri 2 bearing 15 setæ, of which there are six in a row on Le, 7 in a row on Li, the innermost being the shortest, and in addition a very short Sp on Li near the point where it is continuous with Le, and a somewhat longer Sp on Le.

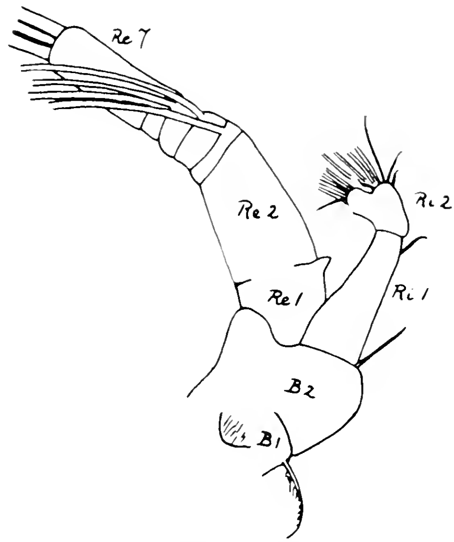

Fig. 12.—Same. Posterior antenna, hinder surface. The two posterior setæ on Ri 2 may be noted.

Maxilla (fig. 13): Le 1 with 8 setæ (as in *messinensis*), the fifth seta about three-fourths the length of its neighbours; Le 2 small, without seta (as in *rostrata*); Li 1, hinder surface glabrous (as in *rostrata*), in the typical group 11-14 there are only three setæ (as in *messinensis*); Li 2, with 4 setæ, Sp 1 and 2 equal, long and stout, Sa 1 much shorter, Sa 2 slender but nearly as long as the Sp; Li 3 with fringe of long hairs along the length of its anterior surface, at its end which is exactly on a level with the end of Li 2 there are only two setæ, a distal long and stout seta and near it a more proximal shorter seta; B 2, setæ as in *rostrata*, surface ciliation as in *messinensis*; Ri with 5 setæ of which four are subequal and the first, situated at the inner angle on the posterior surface, is short and slender like the two proximal setæ of B 2; Re with eleven setæ as in *messinensis*.

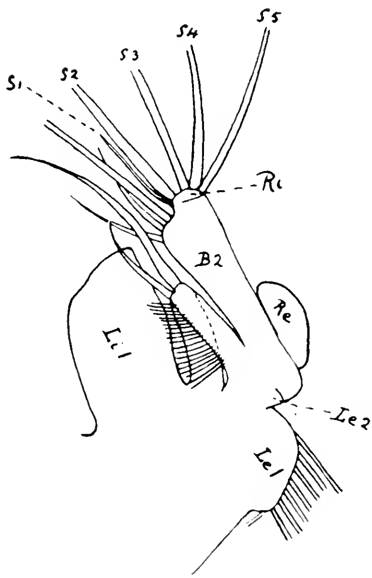

Fig. 13. Same. Maxilla, anterior surface. Setæ omitted from Li 1 and Re. Li 2 is partly concealed by Li 3 whose fringe of hairs passes over it. S 1 to S 5 are the five setæ of Ri; S 1 is seen with difficulty from this side, but is very distinct from the hinder aspect.

Anterior maxillipede (fig. 14): Distinctive are the close-set fringes of spine-like hairs on the posterior surface of L 1 to L 4; otherwise as in *rostrata*: the deep outer emargination of B 1, a generic character, forms a right angle with the succeeding portion of the margin which is nearly straight.

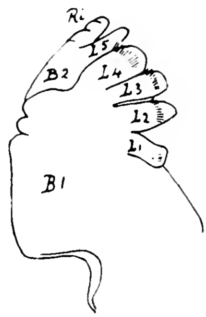

Fig. 14. Same. Anterior maxillipede hinder surface, setæ omitted.

Posterior maxillipede (fig. 15): the single seta of the first or proximal group (or "lobe") on B 1 is placed as in Giesbrecht's figure of *Chiridius poppei*; L 2 with two setæ, one long, one short; L 3 with three setæ (two long, one short); L 4 with three setæ, two long, one short; a short longitudinal series of points on anterior surface of B 2 near its proximal end; the first seta of B 2 lies very slightly distad of the centre of the inner margin.

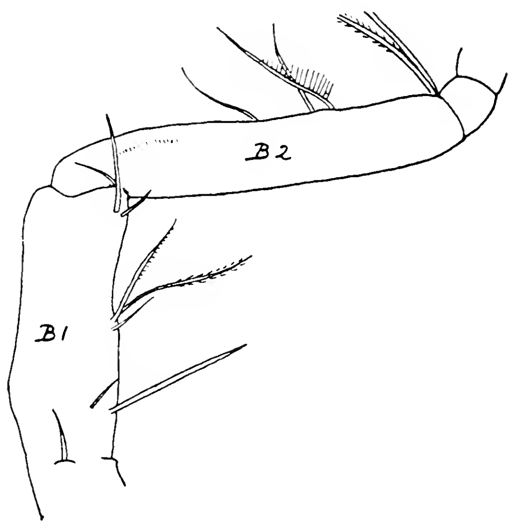

Fig. 15.—Same. Portion of posterior maxillipede.

Fourth legs: basal joints with the characters shown in fig. 16.

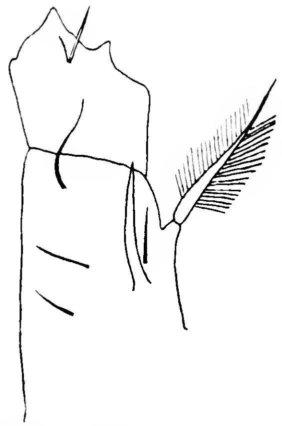

Fig. 16. Same. Basal joints of left fourth leg.

11. *Euchaeta norvegica.*—As mentioned this is a eurytropic species occurring in surface and vertical hauls both inside the Gulf of St. Lawrence and outside. It was found in different stages corresponding to those detailed for *C. finmarchicus* and *hyperboreus.* Ovigerous females with single large ovisac full of blue eggs were found, notably at *Acadia* station 48 on July 23, at *No. 33* station 57 (Bay of Islands) on August 9, and at *Prince* station 3 (Bay of Fundy) on September 15. Immature males were as common as immature females, but the adult males were very rarely captured. At *Acadia* station 11 (70-0m.) on May 30 one was found carrying a spermatophore; another at station 70 on July 26. The youngest captured was stage II with three pairs of swimming legs and two-jointed urosome, first noted in *No. 33* station 26 on June 26 in the subsurface haul (30-15 metres, towed for 20 minutes).

12. *Scolecithrix cuneifrons* n. sp.—Of the species of *Scolecithrix* met with, the commonest was *minor*, next to that *danæ*, and then *ovata*. The appendages of *danæ*, for a certain length of time after preservation in formalin, have a delicate mauve tint which enables the species to be recognized amidst a multitude of other Copepods. *Sc. ovata* is characterized by the oval fifth legs of the female; in many specimens they are not to be found.

There were two other species, only one of which I am describing here since it appears on table XI. I had at first identified it with *securifrons* but the structure of the fifth legs of the male seems to differentiate it from that species.

Description of *Sc. cuneifrons: Acadia* station 46, 150-0 fathoms. Length of female, 4·5 mm.; of male 4·8 mm.; high frontal crest and acuminate postero-lateral angles as in *securifrons*, but in *cuneifrons* there is an acumination in the male as well as in the female (fig. 17).

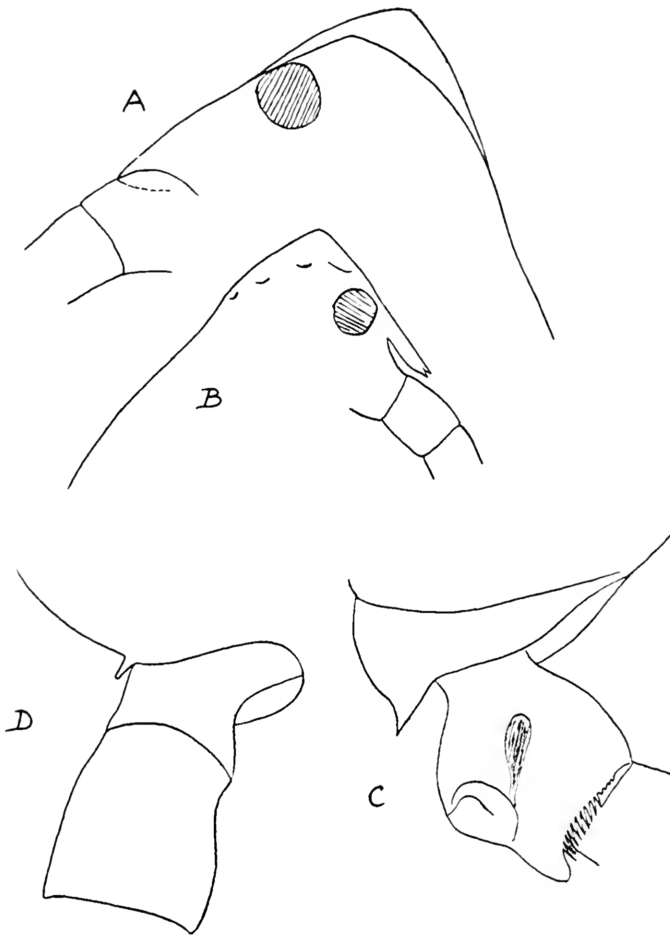

Fig. 17. Scolecithrix cuneifrons.

A. Frontal profile of female of 4·5 mm.
B. Frontal profile of female of 3·6 mm.
C. Postero-lateral angle and genital segment ♀.
D. Postero-lateral acumination of ♂.

Rostrum produced, bluntly bifid at extremity; anterior antennæ as long as body, 23-jointed in ♀, 18-jointed in ♂; mouth-parts not aborted in ♂. Posterior antennæ: Re one and a half times the length of Ri; B 1 with short plumose seta; B 2 with two setæ, one long, one short; Re 1 and 2 distinct, Re 2 twice as long as Re 1, Re 2 seven-eighths the length of Re 7, Re 1 and 2 one and a third times the length of Re 7, Re 2 with one distal slender seta, Re 3, 4, 5, and 6 each with a long plumose seta, Re 7 with a long proximal seta inserted at the proximal fifth of the joint and three long terminal plumose setæ; Ri 1 with slender distal seta which is about twice the length of Ri 2, distal outer convexity of Ri 1 fringed with cilia, Ri 2 with 8 setæ on Li and six on Le, outer convex margin of Le fringed with stiff curved cilia. Maxilla: Li 1 with crowded setæ, thirteen counted, Li 2 with two setæ, Li 3 with three equal setæ; Le 1 with nine setæ; Re with eight setæ; Ri with seven setæ; B 2 with five setæ. In Ri and B 2 the number of setæ given includes in each case one anterior seta.

Anterior maxillipede (fig. 18): B 2 with four setæ of which the largest is not articulated with the joint, another is transformed into a vermiform sensorium; Ri with seven setæ transformed into vermiform sensoria.

Posterior maxillipede: B 1 and B 2 subequal in length but B 1 much broader, B 2 longer than Ri: B 1 setæ: 1 + 2 + 1 + 3, a fringe of long hairs at distal end; B 2 with a fringe of stiff hairs or cilia running along the whole length of the joint near the inner margin, longer towards the proximal end; B 2 setæ: S 1 proximad of middle of joint longer than S 2, S 3 longer than S 2, S 4 shortest, S 5 longest.

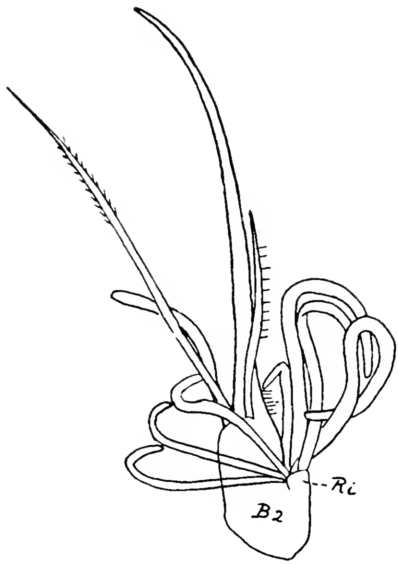

Fig. 18.—Same. Distal portion of anterior maxillipede.

First foot (fig. 19): Re 1 and Re 2 with Se of equal length.

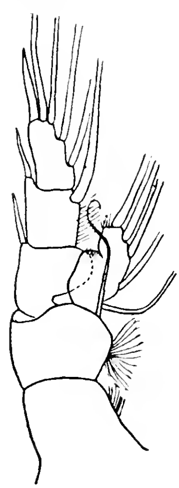

Fig. 19.—Same. First foot anterior surface.

Second foot: B 1 has an acumination on the outer margin like that on the third foot but standing closer into the border, convex inner margin below the Si with long cilia. Ri does not reach distal margin of Re 2; spinules on posterior surface of Ri 2: 2 + 2 + 2, the largest is the outer one of the proximal couple, the smallest is the inner one of the same couple. The spinules on the posterior surface of Re are: on Re 2 a transverse row of seven distal spinules continued proximad on the inner side by three longitudinally placed spinules, the whole forming a continuous arc; spinules on Re 3, two arcuate rows, namely: a distal arc of small unequal spinules, the two lowest of the arch being level with the bases of Se 2 and Si 3; a proximal arc between the bases of Se 1 and Si 2, the three inner spinules much larger than the rest.

Third foot (fig. 20 A and B): the character of B 1 and the spinulation of the rami are shown sufficiently in the figures; several minimal spinules at level of Si 2 on posterior surface of Re 3, otherwise no perceptible spinulation on that joint.

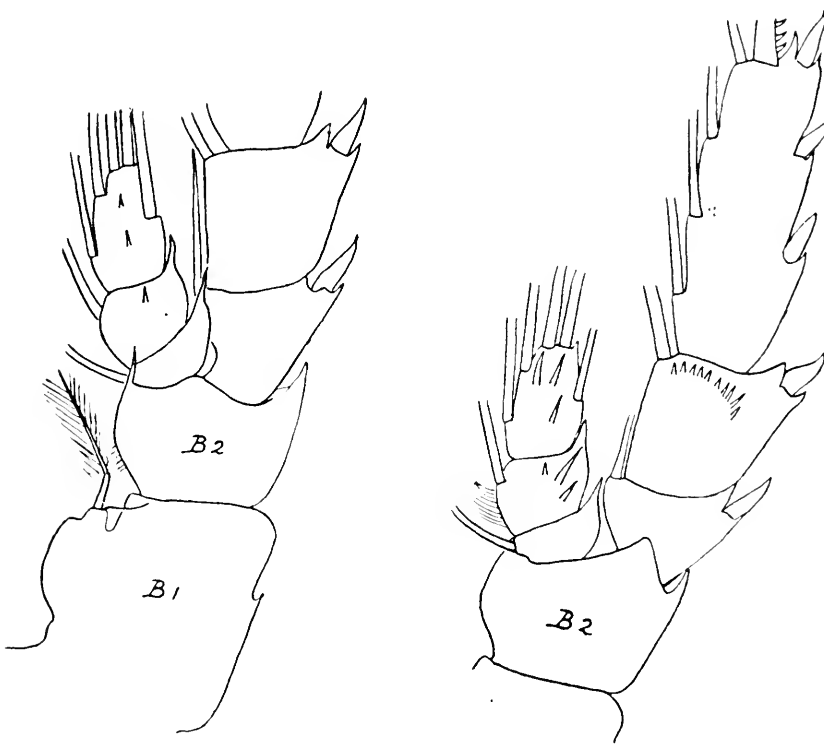

Fig. 20 Same. Third foot.
A. Anterior surface, including B 1. B. Posterior surface, including Re 3.

Fourth foot (fig. 21): B 1 with plumose seta; Ri extends beyond distal margin of Re 2, nearly reaching base of Si 1 of Re 3; Ri 2 two-thirds as long as Ri 3; Re 2 with outer margin ciliate; Re 3 with outer margin, below the proximal Se, ciliate.

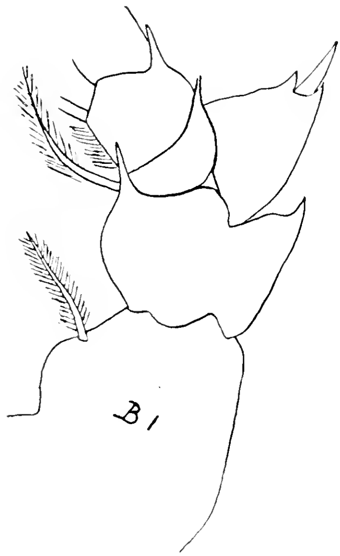

Fig. 21. Same. Portion of fourth foot, anterior surface.

Fifth foot of female (fig. 22): two-jointed ending in a curved seta and a small spine, as in *securifrons*.

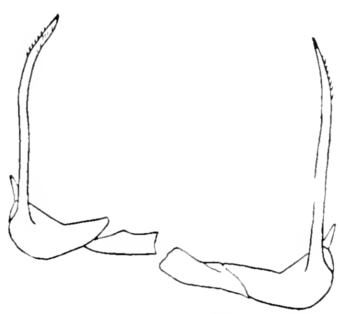

Fig. 22. Same. Fifth pair of appendages of female

Fifth appendages of male (fig. 23 A and B): Left foot biramous, right foot uniramous with a process on B 2 which might represent a rudimentary endopoditic process as described by Giesbrecht for *Scolecithrix vittata*; left Re and Ri two-jointed.

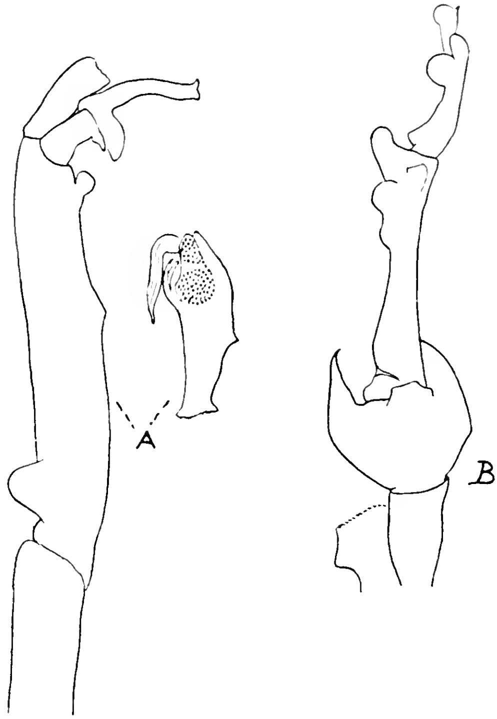

Fig. 23.—Same. Fifth appendages of male
A. Left foot; second joint of Re broke off and drawn separately, showing cushion of points.
B. Right foot.

The submature female of this species, 3.6 mm. in length, with the adult segmentation but not having attained the full size and maturity, differs in several points from the full-grown female. The genital segment (fig. 24) has a proximal protuberance in place of the distal process (compare fig. 17 C) and does not possess the serrations at the posterior lateral margin. In the full-grown form the second abdominal segment has a fringe of shorter spinules at the lower margin. In the submature individual while the fifth feet have the typical formation, the postero-lateral angle of the forebody is bluntly rounded instead of acuminate.

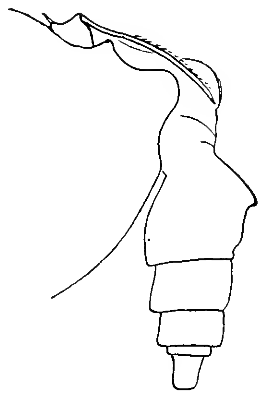

Fig. 24.—Same. Part of forebody and the urosome of a submature female.

13. *Centropages hamatus*.—This is a typical member of the microcalanoid plankton whose distribution is to a large extent parallel with that of *Tortanus discaudatus* but on the average it does not reach so near the shore line and extends further out to sea, that is to say, over greater depths. This may be gathered in a general way from the tables and it will suffice here to mention a typical example of a copious and clean, gray-toned microcalanoid plankton, namely, the Souris Tortanus plankton exemplified in *No. 33* station 7. In addition to the proceeds of this station, Dr. Huntsman on several occasions procured samples from canoes and motor boats, thus establishing the character of the Souris summer copepod plankton. Figure 25 shows the urosome of a submature female with the adult urosome forming within the adolescent cuticle. It was taken at the surface at *Acadia* station 62 on July 25.

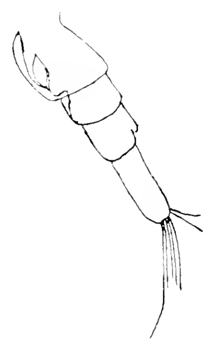

Fig. 25.—*Centropages hamatus* Urosome of adolescent female, shortly before an exuviation.

Centropages bradyi Wheeler was taken in *Acadia* stations adjoining the Gulf Stream in the vertical hauls, viz., at 41, 42; in deep surface haul and vertical haul at 75. *C. typicus* was taken by Dr. Huntsman in the Bay of Fundy at *Prince* stations 2, 3 and 4.

14. *Temora stylifera*.—Whereas *Temora longicornis* is as widely distributed as is *Centropages hamatus, Temora stylifera* occurred in some numbers only at *Acadia* station 44. Most of the animals were females in the adolescent stage which differs so remarkably from the adult form that I was for some time in doubt as to their identification. The lateral angles of the head are drawn out into two free processes like those of trilobites (fig. 26). Unfortunately I have not had access to the original description of the species by Claus, but the processes are not mentioned in the works of reference which I have consulted as they do not occur in the full-grown stage. Otherwise the structure of the appendages is typical. An adult male, 1·75 mm. had no prolongations of the lorica.

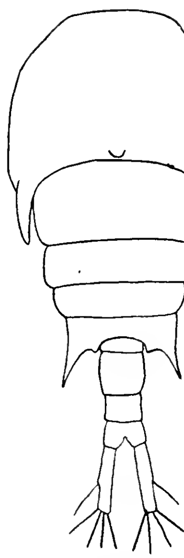

Fig. 26. *Temora stylifera*. Dorsal view of adolescent female to show the lateral processes of the head; anterior antennæ omitted. Length 1·5 mm. Furcal setæ broken.

15. *Metridia longa* and *lucens*.—The mutual relations of these two species in their distribution may be gathered from the tables. The former species ranges far and wide in the Gulf of St. Lawrence having been taken in deep water in the Gaspé channel at *No. 33* station 23. In the Bay of Islands at *No. 33* station 57 a typical *Metridia longa* plankton was obtained. On the other hand *Metridia lucens* does not seem to penetrate so deeply into the gulf of St. Lawrence being only recorded at two stations, namely, at *No. 33* station 69 (3 per cent) and *Princess* station 45 (5 per cent). It was also taken by Dr. Huntsman at *Prince* stations 1, 2, and 3. Its distribution at representative stations is shown on the map (fig. 27). It was generally taken in vertical hauls, rarely at or near the surface. It was taken regularly by the *Grampus* in the gulf of Maine, while *M. longa* only occurred sparsely. Bigelow states that *M. longa* was not found in the gulf of Maine in the 1912 cruise, and its discovery in the 1913 cruise was the first record for American waters.

Fig. 27. Distribution of *Metridia lucens*.

16. *Labidocera aestiva* Wheeler.—The capture of this species, which is very abundant in the summer at Woods Hole, at *Princess* station 28 is worthy of special mention. It is given as a generic character of *Labidocera* that there is no rostral lens, while the dorsal lenses are larger in the male than in the female. In the material examined by me the male measures 2mm. in length, the female 2·5mm. The dorsal lenses of the male are larger than those of the female and are contiguous; but in addition to the dorsal lenses a rostral lens is present and clearly seen in ventral view. It will be a simple matter to control this identification by re-examination of examples at Woods Hole.

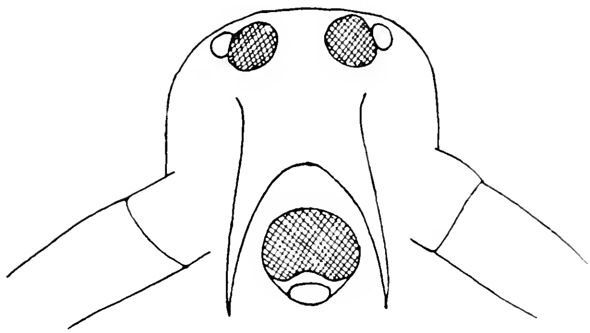

Fig. 28.—*Labidocera aestiva*, female. Ventral view of head from a compressed preparation showing dorsal and rostral lenses. Freehand. "Princess" station 28, 20-0 metres, August 3, 1915.

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TABLE I.—*Princess* Stations 1-4.—Prince Edward Island to Magdalen Islands.

Station.	Date 1915.	Depth.	Haul.	Calanus finmarchicus II.	Calanus finmarchicus III.	Calanus finmarchicus IV.	Calanus finmarchicus V.	Calanus finmarchicus ♀	Calanus finmarchicus ♂	Pseudocalanus elongatus	Centropages hamatus.	Temora longicornis.	Eurytemora herdmani.	Acartia longiremis.	Tortanus discaudatus.	Number counted.	Quantity. c.c.	Locality.	Remarks.
1	11. V.	38 fms.	Oblique. 15 mins.	....	1	+	1	3	1	94	+	+	+	+	+	100	52	35 miles E.N.E. of North Pt., P.E.I.	Abundant phytoplankton. Taken at 9 a.m.
2	11. V.	24 fms.	"	....	6	....	1	4	....	123	1	...	....	....	15	150	100	9½ miles N.W. of Grindstone Island.	Abundant phytoplankton. Taken at 3.20 p.m.
3	9. VI.	11 fms.	20-0m.	....	2	2	1	1	....	1	....	2	...	....	11	20	Scanty.	Northumberland Strait.	Taken at noon. No copepods at surface.
4	9. VI.	"	"	2	7	....	....	...	....	2	1	25	...	....	13	50	"	" "	Taken at 5 p.m.

TABLE II.—Princess Stations 5-13—Miramichi Bay to Anticosti.

Station.	Date. 1915.	Depth.	Haul.	Time.	Calanus finmarchicus II.	Calanus finmarchicus III.	Calanus finmarchicus IV.	Calanus finmarchicus V.	Calanus finmarchicus ♀.	Calanus finmarchicus ♂.	Calanus hyperboreus III.	Calanus hyperboreus IV.	Calanus hyperboreus V.	Calanus hyperboreus ♀.	Pseudocalanus elongatus.	Euchaeta norvegica.	Centropages hamatus.	Temora longicornis.	Metridia longa.	Eurytemora herdmani	Tortanus discaudatus.	Number counted.	Locality.	Remarks.
5	10 VI	17 fms...	Surface...	9 a.m...	..	13	..	.	...	.	.	...	...	..	9	..	4	16	.	..	58	100	Off Miramichi Bay....	Excess of phytoplankton.
5	"	" ...	30—0m.	" ...	+	55	3	...	...	..	2	...	...	..	24	..	1	16	..	..	19	120	"	Scanty and gelatinous.
6	"	32 fms..	Surface.	12.20 p.m.	+	37	..	..	..	...	...	...	...	...	3	..	1	12	..	..	47	100	27 miles NE	Tortanus plankton.
6	"	" ...	60 0m..	....	+	48	11	2	2	..	..	1	..	.	24	.	.	4	7	.	1	100	"	Scanty and gelatinous.
7	"	40 fms...	Surface...	4 p.m ...	+	56	1	...	...	...	1	..	...	...	8	...	..	121	..	1	9	200	About 30 miles NE....	Temora plankton.
7	"	" ...	80-0m..	" ...	+	31	1	2	1	.	9	.	1	.	3	..	.	2	..	..	.	50	" ..	Few copepods.
8	"	" ...	Surface...	9 p.m....	16	29	19	14	9	...	+	+	...	...	14	..	1	3	+	..	1	100	About 40 miles NE. Opposite Chaleur Bay..	C. hyperboreus III counted with C. finmarchicus III.
8	"	" ...	80—0m..	" ..	+	3	2	11	8	..	40	21	6	+	6	..	..	....	+	..	+	100	"	110cc. C. hyperboreus plankton.
9	11 VI	100 fms...	Surface..	12.15 a.m.	..	21	.	4	35	...	...	...	...	...	6	22	..	..	6	..	6	100	Deep channel, E. of Gaspé	Euchaeta stages III, IV and V.
9	"	" ...	80—0m..	"	.	18	6	11	19	1	16	32	19	.	15	6	..	1	5	..	1	150	"	Euchaeta young and adult ♀.
9	"	" ...	100 0m..	"	.	24	5	23	18	1	20	26	4	..	17	43	..	....	18	..	1	200	"	Euchaeta III, IV, V, and some ♀ with hypermatophore. C. hyperboreus III includes some II.
10	"	" ..	Surface...	7 a.m....	+	19	8	7	9	...	...	...	.	..	1	10	8	5	..		9	100	18 miles S. of E. Cape. Anticosti.	Scanty and gelatinous. Euchaeta III, IV, V.
10	"	" ..	100 -0m.	" ...	15	12	3	15	..	..	16	14	16	2	4	1	.	1	1	.	..	100	"	
11	"	27 fms...	Surface...	9.30 a.m.	+	18	5	..	4	...	..	1	.	.	13	.	2	...		..	7	50	Off E. Cape, Anticosti.	Scanty.
11	"	" ...	50 0m..	"	+	55	5	6	4	..	9	8	5	.	8	..	..	...	.	..	..	100	" ..	Scanty and gelatinous.
12	"	77 fms...	100—0m..	12.30 p.m.	+	16	..	.	...	..	..	.	...	...	3	..	1	...	..	..	..	50	24 miles N. of East Cape, Anticosti.	Radiolarians, phytoplankton and crab larvae at surface.
13	"	100 fms...	100—0m.	4 p.m....	18	1	...	.	.	..	.	...		.	..	..	1	...	..	...	..	20	Deep channel between Anticosti and N. Shore Mingan channel°	Scanty and gelatinous. Fish eggs present.

TABLE III.—Princess Stations 11-18, North Shore to Bay of Islands.

Station.	Date. 1915.	Depth.	Haul.	Time.	Calanus finmarchicus II.	Calanus finmarchicus III.	Calanus finmarchicus IV.	Calanus finmarchicus V.	Calanus finmarchicus ♀	Calanus hyperboreus III.	Calanus hyperboreus IV.	Calanus hyperboreus V.	Pseudocalanus elongatus.	Euchaeta norvegica.	Centropages hamatus.	Temora longicornis.	Tortanus discaudatus.	Halithalestris croni.	Number counted.	Locality.	Remarks.
11	11. VI.	22 fms	Surface.	7 p.m.	16	1	...	...	..	...	..	...	2	....	1	2	..	...	25	South of North Shore.	Numerous fish eggs.
14	"	"	35-0m.	"	17	5	2	...	..	...	..	...	...	..	1	....	...	...	25	"	Fish eggs present.
15	12. VI.	17 fms	Surface.	9.30 a.m.	4	5	2	1	1	1	..	1	5	...	5	....	..	..	25	35 miles S.E.	"
15	"	"	80-0m.	"	31	25	8	5	1	15	3	1	8	..	..	..	...	...	100	"	30 cc. Radiolaria.
16	"	100 fms	Surface	1.15 p.m.	25	10	1	3	9	..	1	...	2	....	17	1	1	....	100	About 30 miles S.E.	
16	"	"	100-0m.	"	7	16	1	21	16	9	7	7	9	2	...	1	1	.	100	" ..	Megacalanoid plankton.
17	"	71 fms	Surface	1.30 p.m.	..	—	...	.	—	...	...	....	—	..	—	....	....	....	..	About 25 miles S.E.	Gelatinous; many fish eggs. Hardly any copepods.
17	"	"	100-0m.	"	4	1	..	7	2	...	5	...	1	.	...	...	...	....	20	" ..	
18	"	35 fms	Surface	7.30 p.m.	12	3	...	3	..	...	..	...	13	...	111	10	5	90	250	Outside Bay of Islands.	Many fish eggs.
18	"	"	50-0m.	"	5	30	15	5	...	11	5	1	20	...	2	1	..	2	100	" .	Scanty.

TABLE IV.—Princess Stations 19-26—St. George Bay to Prince Edward Island.

Station.	Date 1915.	Depth.	Haul.	Time.	Calanus finmarchicus II.	Calanus finmarchicus III.	Calanus finmarchicus IV.	Calanus finmarchicus V.	Calanus finmarchicus ♀	Calanus finmarchicus ♂	Calanus hyperboreus II.	Calanus hyperboreus III.	Calanus hyperboreus IV.	Calanus hyperboreus V.	Calanus hyperboreus ♀	Pseudocalanus elongatus.	Euchaeta norvegiga.	Centropages hamatus.	Temora longicornis.	Metridia longa.	Tortanus discaudatus.	Number counted.	Quantity in cc.	Locality.	Remarks.
19	13. VI.	45fms.	Surface.	2.45a.m.	3	15	1	2	1	..	..	..	1	1		..	..	19	7	..	..	50	..	Off St. George Bay, N' land.	Ctenophores and fish eggs.
19	"	"	80-0m.	"	2	16	10	7	4	..	..	16	17	11	..	13	..	2	2	..	..	100	..	"	Sagitta and Amphipods.
20	"	100fms.	Surface.	6 a.m.	5	96	60	14	4	..		3	4	2	..	8	..	2	2	..	..	200	90	Lt. 48°9' N.; long. 59°40' W.	Red Calanoid plankton.
20	"	"	100-0m.	"	1	13	9	17	19	1	..	2	8	11	..	10	4	3	2	..	..	100	..	"	Euchaeta III.
21	"	"	Surface.	9.15a.m.	1	56	32	2	..	..		1	..		..	2	..	5	1	..	..	100	10	47°52' N.; 60°4' W.	C. finmarchicus III changing to IV
21	"	"	100-0m.	"	..	13	13	28	15	..	..	5	13	3	1	7	..	1	1	..	..	100	..	"	C. hyperboreus ♀ unique.
22	"	30fms.	50-0m.	1.30p.m.	2	6	4	4	5	..	..	8	10	..	..	10	..	..	..	2	..	51	..	47°34' N.; 60°39' W.	Scanty.
23	"	59fms.	100-0m.	4 p.m.	1	2	12	16	16	2	1	8	25	5	1	7	5	..	..	..	..	100	50	S. slope of Cabot Strait.	Euchaeta III and IV.
24	15. VI.	22fms.	Surface.	7.30a.m.	28	34	2	..	..	..		..	..	..	..	34	..	1	..	+	1	100	25	Bank E. Magdelan Islands.	Ceratium and fish eggs.
24	"	"	35-0m.	"	11	50	11	1	..	..	..	4	..	..	..	18	..	+	5	..	+	100		"	Microcalanoid plankton.
25	"	38fms.	Surface.	Noon.	32	41	4	3	..	..	..	..	2	..	..	4	..	2	..	1	11	100	50	46°45' N.; 61°38' W.	C. finmarchicus I present.
25	"	"	60-0m.	"	27	16	8	8	9	..	..	1	10	..	..	7	..	1	..	12	1	100	..	"	"
25	"	"	60-25m.	"	4	5	5	9	12	2	..	4	25	3	.	10	..	..	..	21	..	100	..	"	
26	"	22fms.	Surface.	3.30p.m.	3	26	3	..	3	..	..	..	..	..	..	3	..	3	17	..	12	100	..	46°20" N.; 62°5' W.	Acartia longiremis recorded.
26	"	"	40-0m.	"	..	21	8	7	9	1	..	..	2	1	..	9	..	1	18	5	18	100	..	"	

TABLE V.—Princess Stations 27-39.—Prince Edward Island to Anticosti.

Station.	Date. 1915.	Depth. Metres.	Haul.	Time.	Calanus finmarchicus III.	Calanus finmarchicus IV.	Calanus finmarchicus V.	Calanus finmarchicus ♀.	Calanus finmarchicus ♂.	Calanus hyperboreus III.	Calanus hyperboreus IV.	Calanus hyperboreus V.	Calanus hyperboreus ♀.	Pseudocalanus elongatus.	Euchaeta norvegica.	Scolecithrix minor.	Centropages hamatus.	Temora longicornis.	Metridia longa.	Labidocera æstiva.	Anomalocera patersoni.	Acartia sp.	Tortanus discaudatus.	Number counted.	Quantity in c.c.	Locality.	Remarks.
27	3. VIII.	23 m.	20-0 m.	6 p.m.													+						+			Northumberland Strait	Very scanty.
28	"	19 m.	20-0 m.	Midnight			+	+									42	2		8		6	12	100		"	Scanty gray microcalanoid plankton.
29	4. VIII.	32 m.	Surface	6.30 a.m.		5	1										18	18					58	100		Off Miramichi Bay	Many starfish larvæ.
29	"	"	20-0 m.	"	+	9	4										4	10	3				10	100		"	Metridia young.
30	"	66 m.	Surface	10.30 a.m.	5	44											3	3					15	100	165	25 miles N.E.	Tortanus mostly ♂.
30	"	"	30-0 m.	"	10	12								2			6	10					30	100	6	"	Tortanus many ♀ with spermatophores.
30	"	"	60-0 m.	"	6	55	20	+	+	+	7	+	+	+			3	7	+				2	100	22	"	
31	"	65 m.	Surface	2 p.m.	22	19	2							3			11	3					10	100	25	22 miles N.E	Many Pluteus larvæ.
31	"	"	30-0 m.	"	6	24	4				1			1			8	1					2	50	5	"	
31	"	"	60-0 m.	"	5	54	20	1		3	7	+		3	3		+	4	+					100	25	"	Clean pink Calanoids.
32	"	87 m.	Oblique	5 p.m.	6	50	25	2	1					2	2			2					19	100	300	19 miles N.E.	Pink megacalanoid plankton. Many fish eggs.
32	"	"	30-0 m.	"	5	18	18	1						1			+	5					2	50	24	"	
32	"	"	85-0 m.	"	13	21	17	3		3	10	+		15	2		+	3			+		10	100	50	"	Euchaeta III and IV.
33	"	78 m.	Oblique	9.30 p.m.	5	24	53	11	+		7			+	+			+	+				+	100	350	27 miles N.E.	Pink megacalanoid plankton.
33	"	"	75-0 m.	"	10	30	20	5	+	2	20	+	+	2	+			6	+				5	100	40	"	
34	"	105 m.	Oblique	Midnight		12	26	12	+					2	18				18				2	100	350	15 miles N.E.	Euchaeta III, IV and V; ♀ present.
34	"	"	130-0 m.	"	+	18	18	6	2	+	14	+		5	17	2			18				+	100	40	"	" "
35	5. VIII.		Surface	5 a.m.	5	65	25	5							+									100	200	20 miles N.E.	Pink Calanoids.
35	"	"	130-0 m.	"	10	20	30	10		1	5			10	12		1	1						100	25	"	Megacalanoid.
36	"	18 m.	Oblique	10 a.m.	13	60	7	2		1	1	+		5			10	1						100	70	25 miles N.E.	Bolinopsis jelly.
36	"	"	60-0 m.	"	10	38	16	5	2	4	+			10			10	5	+					100	20	"	60 metres wire out.
37	"	75 m.	Oblique	1 p.m.	13	40	16	3	+	5	1			2			8	12						100	15	East of Anticosti	Aurelia present.
37	"	"	80-0 m.	"	10	50	20	2		3	3			2			3	5	2				+	100	10	"	
38	"	180 m.	Oblique	1.30 p.m.	27	25	5		+	3				1			30	6			+			100	20	21 miles N.E. by N. ½ N.	Anomalocera two large ♂.
38	"	"	130-0 m.	"	20	14	3	5		3	3			10	+		7	2	3					100	12	"	Euchaeta III and V.
39	"	281 m.	Surface	7.30 p.m.	25	25	4	1									35	8					2	100	22	10 miles N	Shed tentacles of Medusa (Cyanea).
39	"	"	130-0 m.	"	10	50	10	5		3	3			5	+		5	1	8					100	16	"	Metridia young.

TABLE VI.—Princess Stations 40-44.—North Shore to Bay of Islands.

Station.	Date 1915.	Depth Metres.	Haul.	Time.	Calanus finmarchicus II	Calanus finmarchicus III.	Calanus finmarchicus IV.	Calanus finmarchicus V.	Calanus finmarchicus ♀	Calanus finmarchicus ♂	Calanus hyperboreus III.	Calanus hyperboreus IV.	Pseudocalanus elongatus.	Euchaeta norvegica.	Centropages hamatus.	Temora longicornis.	Metridia longa.	Anomalocera pattersoni.	Tortanus discaudatus.	Number counted.	Quantity in cc.	Locality.	Remarks.
40	5. VIII.	68 m.	Oblique.	Midnight	+	13	12	24	+	.	+	+	5	.	3	13	..	..	..	100	36	Off North Shore	
41	6. VIII	189 m.	Surface.	4 a.m.	..	15	30	10	1	1	.			..	40	3	.	+	..	100	20	27 miles S.E	Schizopod eggs.
41	"	"	130-0m	"	..	16	24	7	10		.		2	.	40	1	..	.	+	100	8	"	
42	"	90 m.	Sub-surface.	7.45 a.m.	+	3	32	3	..	.	.	.	.		12	+	.	+	+	50	15	21 miles S.E	Very gelatinous.
42	"	"	100-0m	"		+	+	+	..	..	..		..	.	+	+	.	+	.	..	..	"	Very exiguous.
43	"	265 m.	Sub-surface.	11.30 a.m.	..	2	3	2	1		.		..	..	4	..	..	37	1	50	30	29 miles S.E	Chiefly young amphipods.
43	"	"	130-0m.	"	..	14	12	17	4	1	1	7	5	+	3		6	+	..	100	10	"	Euchaeta and Metridia young.
44	"	157 m.	30-0m	3 p.m.	.	7	22	21	12			.		..	14	4	+	..	..	100	12	23 miles S.E	
44	"	"	130-0m	"	..	4	16	25	15	1	1	2	..	..	33	3	+	+	..	100	15	"	

TABLE VII. Princess Stations 45-50—St. George Bay to Prince Edward Island.

Station.	Date 1915.	Depth metres.	Haul.	Time.	Calanus finmarchicus III.	Calanus finmarchicus IV.	Calanus finmarchicus V.	Calanus finmarchicus ♀.	Calanus finmarchicus ♂.	Calanus hyperboreus III.	Calanus hyperboreus IV.	Calanus hyperboreus V.	Pseudocalanus elongatus.	Euchaeta norvegica.	Centropages hamatus.	Temora longicornis.	Metridia longa.	Metridia lucens.	Labidocera æstiva.	Anomalocera patersoni.	Tortanus discaudatus.	Number counted.	Quantity in cc.	Locality.	Remarks.
45	12. VII.	375m.	Surface.	3 a.m.	2	28	42	18	5			...					+	5	...	+	...	100	170	Off St. George Bay.....	Sagitta plankton with infiltration of pink Calanoids.
45	"	"	130-0m.	"	+	25	50	13	...		...	...	+	+			10	2	...	...	..	100	30	"	
46	"	over 100m	Surface	6 a.m.	12	35	35	15	3		...	...				...		...		...	.	100	250	16 miles W.S.W......	Nearly pure Calanus plankton.
46	"	"	30-0m.	"	4	12	25	7	+	...	.	...	+	2	...	...	...	...	...	...	...	50	15	"	Euchaeta IV et V.
46	"	"	130-0m.	"	5	12	60	14	+	.	2	..	+	7	..	.		...				100	30	"	Euchaeta III, IV, V and one ♀.
47	"	"	Surface	9 a.m.	4	15	12	1	...	...	...	...		..	25	40	..			.	6	100	35	19 miles W.S.W......	Many Echinoderm larvæ in transformation.
47	"	"	130-0m.	"	10	16	36	10	+	2	4	.		3	8	8	...			..	3	100	12	"	Sagitta and Calanoids.
48	"	171m.	Surface	4 p.m.		12	20	1				...	+	:	12	30				...	25	100	100	22 miles W.S.W......	Echinoderm content as in 47. Oithona present.
48	"	"	30-0m.	"	.	8	26	9	+	.	...	...		.	4	30			.	...	29	100	14	"	Sagitta and Calanoids.
48	"	"	130-0m.	"	5	20	25	1		1	8	+	8	+	2	10	+	.	..	...	17	100	24	"	Pink Calanoid plankton.
49	"	70m.	Surface	6.45 p.m.	.	18	25	1	+		.			.	12	32		.		.	12	100	60	13 miles W by S ½ S....	Echinoderms present.
49	"	"	70-0m.	"		15	10	1			15	+	10	.	..	12	7	...	...	...	.	100	40	"	Metridia adult ♂ and ♀.
50	"	42m.	Surface.	Midnight		10	10	.		.				.	.	70	+	...	...		10	100	100	42 miles W.S.W.......	Sagitta plankton with Copepod infiltration.
50	"	"	40-0m.	"				.			...		.		.	+		...	+		+	...	10	42 miles W.S.W., 46°18′ N., 61 59′ W.	Resembling surface except one Labidocera ♂.

TABLE VIII.—Steam-drifter No. 33.—Gulf of St. Lawrence.

Station.	Date 1915.	Depth Metres.	Haul. Metres.	Time.	Calanus finmarchicus II.	Calanus finmarchicus III.	Calanus finmarchicus IV.	Calanus finmarchicus V.	Calanus finmarchicus ♀.	Calanus finmarchicus ♂.	Calanus hyperboreus II.	Calanus hyperboreus III.	Calanus hyperboreus IV.	Calanus hyperboreus V.	Calanus hyperboreus ♂.	Pseudocalanus elongatus.	Gaidius tenuispinus.	Euchaeta norvegica.	Scolecithrix minor.	Centropages hamatus.	Temora longicornis.	Eurytemora herdmani.	Metridia longa.	Metridia lucens.	Anomalocera patersoni.	Tortanus discaudatus.	Halithalestris croni.	Number counted.	Quantity in cc.	Locality.	Remarks.
3	2. VI	40 m.	15-20m.	8.50 a.m.	5	24	5	12	35							6				4	4					5		100	40	46°18′, 61°59′, between P.E.I. and C. Breton	Horizontal tow.
7	9. VI	20 m.	2-0m.	10.30 a.m.	1	1	1	1	1											1						44	+	50	7	1 mile S. of Souris	This is the Souris Tortanus Plankton.
9	9. VI	10 m.	2-0m.	1 p.m.	8	17	28	1	9	1										1			1			4		100	10	46°22½″, 61°55′	
11	9. VI	59 m.	2-0m.	6 p.m.	11	7										7				5	4					66		100	20	46°30′, 61°30″	
13	9. VI	39 m.	3-0m.	10.30 p.m.	10	10	5	5	25	2						15				5	21					2		100	20	Close to Cape Breton Island	C. finmarchicus ♀ with spermatophore.
14	10. VI	58 m.	3-0m.	1.50 a.m.	15	20		3	10							20				2	10		+			20		100	50	46°51′, 61°16′	Sagitta predominates.
15	10. VI	38 m.	Surface	5 a.m.	30	45			2							3				5						15		100	5	47°6′, 61°27′	Calanus junior plankton.
17	11. VI	39 m.	"	8.40 a.m.	22	48	+		+							30												100	55	47°12′, 61°23′	" "
19	24. VI	90 m.	"	5 p.m.		2	12		17	1						2				6						12	48	100	35	Gaspé Basin	Gasterosteus aculeatus in surface tow.
21	25. VI	27 m.	5-0m.	7.50 a.m.		3	20	5	20		1	20	20			+		1								5	5	100	25	Gaspé Current	North of Cape Gaspé.
23	25. VI	355 m.	Surface	1 p.m.		1	9	+	90	+		+	+					+									+	100	10	Gaspé Channel, 49°3′, 63°58′	C. finmarchicus was spawning.
23	25. VI	"	45-0m.	"		5	10	2	20	2	1	13	30			8		7	2									100	12	" "	C. finmarchicus ♀ of large size.
23	25. VI	"	100-60m.	"			5	5	23			22	24	6		6		8	1									100	15	" "	Euchæta III and V.
23	25. VI	"	340-115m.	"			3	15	2			15	10	25	10	2	5	7					6					100	90	" "	Euchæta III, IV and ♀.
24	26. VI		Surface	5.25 a.m.					+																				65	Near Anticosti	Nearly pure culture of Crab larvæ.
25	26. VI	271 m.	"	6.20 a.m.	1	24	12	3	56			4																100	15	49°18½′, 63°42′	C. finmarchicus spawning.
26	26. VI	389 m.	"	9.35 a.m.	1	25	4		50							6				1						12	1	100	2	49°11½′, 63°50′	
26	26. VI	"	30-15m.	"		8	23	2	25	+	+	25	2			12		2								1		100	65	"	Euchæta II and III. Deep surface tow 20 minutes.
29	1. VII	41 m.	3-2m.	6 a.m.		10	12	+								25				16	30					7		100	75	Outside Chaleur Bay	Numerous fish eggs.
35	7. VII		Surface 15-6m.	6 a.m.			+														+					+			50	46°48′, 64°32′	Pluteus plankton with Ceratium.
36	8. VII	60 m.	20-8m.	7.30 a.m.		15	10	2								3				12	50					8		100	110	46°52′ 62°34′	Fish eggs and Ceratium.
39	13. VII		9-0m.			2	3									6				2	12	+				75		100	95	46°22′, 62°8′, 4 miles S. of Souris	Clean Tortanus plankton.

48	26. VII		40-0m.			8	51	9	3	.		2	12	1		12				.						2		100	90	47°35′, 60°36′	Red Calanoid Plankton.
49	27. VII		15-0m.				4	3	.							1				1	26					65		100	145	47°5′, 61°26′	Pink Microcalanoids.
57	9. VIII	210 m.	200-0m.	3.15 p.m.			15	10	+	3		2	5	5	+	20		+		+			40					100	50	Bay of Islands	Euchaeta ♀ with egg-sac.
58	10. VIII	50 m.	Subsurf'ce	11.10 a.m.			10	20	8	2						3				30	24					3		100	50	"	Plenty of Aglantha.
59	10. VIII	275 m.	270-0m	12.50 p.m.			40	5	+	4		5	12	2	2	25		+		+	+		5					100	125	"	C. finmarchicus IV plankton.
61	13. VIII		80-0m.				32	40	12	5			4					+		7	+					+		100	150	St. George Bay	C. finmarchicus V plankton.
68	17. VIII		70-20m.				5	30	23	+						+		42	+						+			100	350	"	Sagitta and Euchaeta plankton.
69	18. VIII		100-20m.				22	36	8			2	12	1	.	5		1		2	5		1	3		2		100	320	47 54′, 60 46′	Schizopods and Calanus.
70	18. VIII		2-0m.																	5	20					75		100	100	47°19′, 61 51′	Pluteus and Ceratium.

TABLE IX.—Acadia Stations 2-16.—South East from Nova Scotia.

Station.	Date 1915.	Depth metres.	Haul metres.	Time.	Calanus finmarchicus II.	Calanus finmarchicus III.	Calanus finmarchicus IV.	Calanus finmarchicus V.	Calanus finmarchicus ♀.	Calanus finmarchicus ♂.	Calanus hyperboreus II.	Calanus hyperboreus III.	Calanus hyperboreus IV.	Calanus hyperboreus V.	Calanus hyperboreus ♀.	Rhincalanus nasutus.	Pseudocalanus elongatus.	Undeuchaeta minor.	Euchirella rostrata.	Euchaeta norvegica	Scolecithrix minor.	Centropages hamatus.	Temora longicornis.	Pleuromamma abdominalis.	Pleuromamma xiphias.	Pleuromamma robusta.	Pleuromamma borealis.	Metridia longa.	Metridia lucens.	Heterorhabdus norvegicus.	Candacia armata.	Number counted.	Quantity in c.c.	Remarks.
*2	29. V.	60	50-25	11 a.m.																													15	Outside Halifax harbour.
3	"	144	0	2.30 p.m.		33	37	4	26																							100	20	20 miles S. 64° E.
3	"	144	100-50	"	5	10	15	9	9	1	+	12	30	2			6			1												100	30	"
4	"	171	30-0	7.30 p.m.		10	17	6	13				2									2										50	6	34 miles S. 68° E.
4	"	171	80-40	"		2	15	8	3				9	6			3											6				50	11	"
4	"	171	150-100	"	1	5	19	12	6	1		1	10	21	2		12			1								6	3			100	45	"
5	30. V.	72	0	1.00 a.m.		50	110	30	10			+					+			+									+			200	330	30 miles S. 74° E.
5	"	72	60-0	"		9	13	16	3			2	4				2						1									50	29	"
6	"	45	0	5.45 a.m.		3	18	11	3			1	1				5					6	2									50	scanty	29 miles S. 68 E.
6	"	45	40-0	"		7	19	11					1				10						2									50	"	"
7	"	108	0	10 a.m.	1	1	3	3									1						1									10	5	30 miles in same line.
8	"	50	0	12.50 p.m.		16	24	3	2								3					2										50	16	16 miles N. 22° E.
8	"	50	40-0	"		5	12		1				1				1															20	5	"
9	"	104	0	4.45 p.m.		3	35	39	18			2	3																			100	20	30 miles S. 79° E.
9	"	104	25-0	"		8	22	12	5					1			2															50	6	"
10	"	732	0	7.15 p.m.		2	20	65	6											7												100	800	15 miles S. 81° E.

11	"	2000	0	10.45 p.m.		1	42	23	4											6								4				100	800	20 miles S. 82 E.
11	"	2000	70-0	"			18	20	3			3	10				1		1	30	1					1		11	1			100	70	"
12	31. V.	2000	0	4.35 a.m.		7	52	30												9								2				100	250	35 miles S. 79° E.
12	"	2000	100-0	"		1	28	21	8			5	10	12			1			14												100	70	"
13	"	2000	70-0	8.45 a.m.		5	16	22	4				2							1												50	22	20 miles S. 81° E.
†14	"	2000	0	12.50 p.m.																													5	36 miles S. 78 E.
14	"	2000	200-0	"			20	32	21			1	3						5	9	1							1	2	2		100	60	"
15	"	2 00	0	7.15 p.m.			18	70	2											10												100	550	52 miles S. 78° E.
15	"	2000	100-0				4	70	10									1	3	12												100	175	"
16	1. VI.	2000	0	1.45 a.m.		2	10	54	16							2		2		14												100	120	51 m. S. 74 E. One *Calanus gracilis*
16	"	2000	200-0	"				10	3					+	+	14			11	29	2			1	2	5	7		11		2	100	75	" 42 53′ N., 54 9′ W.

* Copepods consist of a mixture in subequal numbers of Calanus finmarchicus and C. hyperboreus. † Scanty sample consisting largely of Calanoid exuviae.

TABLE X.—Acadia Stations 17-36.—Around and upon the Newfoundland Banks, and Cabot Strait.

Station.	Date. 1915.	Depth. Metres.	Haul. Metres.	Time.	Calanus finmarchicus II.	Calanus finmarchicus III.	Calanus finmarchicus IV.	Calanus finmarchicus V.	Calanus finmarchicus ♀.	Calanus hyperboreus III.	Calanus hyperboreus IV.	Calanus hyperboreus V.	Calanus hyperboreus ♀.	Calanus tenuicornis.	Rhincalanus nasutus.	Pseudocalanus elongatus.	Etideus armatus.	Euchirella rostrata.	Euchaeta norvegica.	Scolecithrix minor.	Centropages hamatus.	Temora longicornis.	Metridia longa.	Metridia lucens.	Heterorhabdus norvegicus.	Tortanus discaudatus.	Number counted.	Quantity in c.c.	
*17	1. VI.	2,000	0	9 a.m.																									43 30′50″ N., 54 12′50″ W. 37 miles N. 4° W. from Station 16.
17	"	"	200-0	"			2	12						5	5		4	15	5					2			50	10	" "
18	"	"	0	4.30 p.m.		5	39	4	1							1											50	60	50 miles N. 5° W.
19	"	"	0	8.15 p.m.		2	23	17	2							1			3		2						50	100	24 miles N. 2° W. Amphipod plankton.
20	2. VI.	90	0	1 a.m.		11	9	9	3												3	15					50	30	24 miles N. 4 W. Green Banks.
21	"	115	0	3.30 a.m.		1	1	4	3												1						10	45	29 miles N. 15° W. Copepods scarce.
**22	"	75	0	7.15 a.m.																									24 miles N. 23° W.
***23	"	99	0	10.35 a.m.																									19 miles S. 52° W. Eastern end of St. Pierre Bank.
23	"	99	70 0	"		+				+											+								" "
†24	"	118	0	2.15 p.m.																									29 miles S. 41° W. Eastern end of St. Pierre Bank.
24	"	118	100 0	"	2	5	1	2																			10	25	29 miles S. 41° W. Copepods very scarce.
††25	"	122	0	5.30 p.m.																									27 miles S. 38° W.
25	"	122	120 0	"		7	7	12	7		1					9	+	+		+	2	4		1			50	15	"
26	"	500	0	10 p.m.		9	18	39	8							1			21				3	1			100	400	32 miles S. 41° W. Between Banquereau and St. Pierre.
26	"	500	100 0	"	1	3	5	38	15	2	5	6				2		1	10	1			8	2	1		100	35	" "
27	3. VI.	500	0	2 a.m.		10	20	50	6							+			13		+		1				100	105	31 miles S. 40° W. S.E. of Banquereau.
28	"	500	0	6 a.m.		17	34	16	20							4			3		4					2	100	85	22 miles N. 75° W. Eastern slope of Banquereau.
28	"	500	100-25	"		2	6	24	17	15	21	16				5			+								100	45	" "
†††29	"	57	0	10.50 a.m.																									32 miles N. 73° W. Banquereau.
29	"	57	55 0	"		2	2	1	1	1	1					2											10	5	" "
‡30	"	126	0	3 p.m.																									31 miles N. 52° W. Banquereau.
30	"	126	100-0	"	1	2	3	2	1	12	14	1				13							1				50	10	" "
31	"	82	0	7.30 p.m.	4	9	7	1	1	7	18	1				2											50	50	39 miles N. 18° W. Misaine Bank.
31	"	82	75-0	"		5	3	10	2	10	10	4	1			4							1				50	45	" "
32	"	153	0	11.20 p.m.	1	4	3	3	36							2						1					50	100	34 miles N. 17° W. Off Misaine Bank. Aglantha plankton.
32	"	153	100-25	"	7	18	3	18	36	7	3	3	1			4											100	100	" "
34	4. VI.	360	0	7.45 a.m.		11	27	4	3												2	2				1	50	30	46°40′ N., 59° W. Outside Cabot Strait.
34	"	360	100-0	"	1	9	12	8	1	6	7					4					2						50	90	46°40′ N., 59° W. Sagitta plankton.
35	"	450	0	11.45 a.m.		9	10	12	13							2					4						50	30	33 miles N. 45° E.

35	"	450	125–25	"	.	3	3	31	16	9	12	13	.			7	..	..	4	..	1	1	..	..	..	..	100	....	33 miles N. 45° E. C. hyperboreus II present.
36	"	226	0	3.30 p.m.	6	40	10	7	5	..	.	.	..		.	14	..	..	..	..	15	3	.	..	.	..	100	15	Off Burgeo Islands, 50 miles east of Pointe Basque
36	"	226	100 15	"	..	8	11	15	7	1	3	2	..	..	.	2	..	..	1	..	.	.	.	..	..	.	50	Scanty.	" "

* Scanty sample consisting largely of Calanoid exuviæ; compare Station 14. ** Beroë and Aglantha; no Copepods. *** No Copepods. Scanty gelatinous plankton. † Ctenophores; no Copepods. †† Beroë and Aglantha; no Copepods. ††† Scanty gelatinous plankton; no Copepods. ‡ Ctenophores; no Copepods.

TABLE XI—Acadia—

Station.	Date. 1915.	Depth. Metres.	Haul. Metres.	Time.	Calanus finmarchicus III.	Calanus finmarchicus IV.	Calanus finmarchicus V.	Calanus finmarchicus.	Calanus finmarchicus ♂.	Hyperboreus III and IV.	Hyperboreus V and ♀.	Gracilis.	Minor.	Vulgaris.	Eucalanus attenuatus.	Elongatus.	Crassus.	Rhincalanus nasutus.	Cornutus.	Clausocalanus arcuicornis.	Pseudocalanus elongatus.	Aetideus armatus.	Gaidius tenuispinus.
37	21 VII	62	0	5 p.m.	8	31	17	32	12														
37	″	62	60-0	″	11	28	21	18	3	18	1										+		
38	″	170	0	8 p.m.	28	55	14	3															
38	″	170	100-0	″	30	30	20	7		7													
38	″	170	150-0	″	19	25	13	3	6	12	7												
39	″	95	0	11 p.m.	7	36	10	40	4														
39	″	95	25-0	″	10	48	15	24	1	1													
39	″	95	100-0	″	4	40	26	19	1	8	+												
40	22 VII	134	0	2 a.m.			2	30															
40	″	134	125-0	″		2	10	5	8	4	3										1		
*41	″	360	0	5.30 a.m.																			
*41	″	360	100-0	″																			
41	″	360	200-0	″														+					
**42	″	1000	0	9 a.m.																			
42	″	1000	200-0	″								+						+		+			
†43	″	1000	0	11.45 a.m.																			
44	″	1000	0	3 p.m.									18		2		1	14		3			
44	″	1000	270-0	″								4	5	10	5	3	+	20	+	+		+	
††45	″	1000	0	8.15 p.m.																			
45	″	1000	90-0	″				3															
45	″	1000	270-0	″				1										+					
46	23 VII	1000	0	1 a.m.																			
46	″	1000	270-0	″			+		+											+			+
47	″	140	0	6.30 a.m.	4	33	4	5	1														
47	″	140	125-0	″		9	64	10	1	3													
‡48	″	248	0	11 a.m.																			
48	″	248	230-0	″		10	24	14		15	15												
49	″	126	0	3.40 p.m.	20	60	6	1													4		
49	″	126	125-0	″	10	32	40	6		8	+										2		
50	″	151	0	7.30 p.m.	10	30	28	12													9		
50	″	151	145-0	″	6	15	41	5	1	5	+										4		
51	″	131	0	10.30 p.m.	3	17	52	6	3												2		
51	″	131	125-55	″	5	17	34	2	+	2											2		
52	24 VII	99	0	1.45 a.m.	10	50	14	18															
52	″	99	90-0	″	3	32	40	9	2	4											1		
53	″	95	0	4.45 a.m.	21	57	13	6	3														
53	″	95	90-0	″	20	38	30	3	2	5											1		
54	″	1000	0	7.40 a.m.																			
54	″	1000	270-0	″	+	10	6																
‡‡55	″	1000	....	10.30 a.m.																			
56	″	1000	375-0	2.20 p.m.		+							+		+			+					

* Very scanty, copepods nil. ** Very scanty. †Very scanty; Phronima and Euthemisto: no copepods. †† Phronima plankton; no copepods. ‡ Nil. ‡‡ Very scanty at all depthts.

Stations 37-56—July, 1915.

Undeuchæta minor.	Major.	Euchirella rostrata.	Pulchra.	Messinensis.	Acadiana.	Euchæta norvegica.	Marina.	Scolecithrix minor.	Danæ.	Ovata.	Cuneifrons.	Centropages hamatus.	Bradyi.	Temora longicornis.	Stylifera.	Pleuromamma abdominalis.	Xiphias.	Robusta.	Borealis.	Metridia longa.	Lucens.	Heterorhabdus norvegicus.	Candacia bipinnata simplex. variecans, etc.	Labidocera.	Pontellina plumata.	Anomalocera pattersoni.	Acartia clausi and danæ.	Tortanus discaudatus.	Podoplea.	Number counted.
												+																+		100
												+		+							+									100
																														100
																				3	3									100
						+														10	5									100
																					3									100
																				+	1									100
																					2									100
																			26		48					+				100
		1				1															65									100
					+								+								+									
																					+									
													+																+	
							1								28								4	1			1		27	100
					2	3	15		18						+								10	+	+		+		5	100
7																		8	25	1	56									100
3		9	+			3												8	+	1	75									100
5						12										9	10	3	34		27									100
4	+	10	+	+		32		+		+	+						2	15	5	9	21	2								100
																+	+		2		1									50
																					13									100
						8														1	13									100
												7														+		2		100
												2								+										100
												11																		100
						+														10	13									100
						+												+		3	14		+							100
																				26	12									100
																					8									100
														+							9									100
																														100
		+																			1									100
		43				4		+											1	5	31									100
					+				+												+									

TABLE XII—Prince Stations 1—4 Near St. Andrew's, New Brunswick, September 1915—Collected by Dr. A. G. Huntsman.

Station	Date 1915.	Depths fathoms.	Haul.	Time.	Calanus finmarchicus I.	Calanus finmarchicus II.	Calanus finmarchicus III.	Calanus finmarchicus IV.	Calanus finmarchicus V.	Calanus finmarchicus ♀	Calanus finmarchicus ♂.	Calanus hyperboreus III.	Calanus hyperboreus IV	Calanus hyperboreus V.	Pseudocalanus elongatus.	Euchæta norvegica.	Centropages typicus.	Centropages hamatus.	Temora longicornis.	Eurytemora herdmani.	Metridia longa.	Metridia lucens.	Acartia clausi.	Tortanus discaudatus.	Halithalestris croni.	Number counted.	Locality.
1	14. IX	18	Surface.	3.45 p.m.	..	..	10	8	62	6	4	..	..	..	10	.	.	..	..	..	..	..	..	..	..	100	Off Eastport; bright sun, calm.
1	14. IX	18	5-10	3.45 p.m.	..	..	2	7	60	12	3	..	3	1	12	..	..	..	..	.	..	..	..	..	..	100	" " deep tow.
1	14. IX	18	Vertical.	3.45 p.m.		..	3	3	51	14	3	.	2	..	21	1	..	.	..	..	..	2	.	..	..	100	" " from bottom up.
2	14. IX	50 70	Surface.	4.30 p.m.	+	..	15	10	15	1	1	..	..	.	54	.	3	..		..	..	..	..	1	..	100	Off Head Harbour Island.
2	14 IX	50 70	55-0	4.30 p.m.	..	.	..	3	55	12	3	..	..	.	20	2			..	.	..	5	..	..	..	100	" "
*3	15. IX	100	Surface.	10 a.m.	..	.	..	..	..	..	.	..	..	..	..	..	..	..	..	..	..	.	..	..	..	....	11½ miles SSE. of Grand Manan.
3	15. IX	100	8-10	10 a.m.	..	1	50	17	4	4	+	..	..	..	2		6	6	10	..	.	..	.	.	.	100	" " deep tow, 15 minutes
3	15. IX	100	100-0	10 a.m.	..	..	10	5	65	5	.	1	5	1	+	1	..	+	..	..	3	4	..	.		100	" " vertical haul.
4	15. IX	18	3-6	5.30 p.m.	..		6	4	32	7	4	..	..	..	20	..	..	..	..	..	.	..	25	2		100	Passamaquoddy Bay.
4	15. IX	18	18-0	5.30 p.m.	.	..	7	2	40	6	1	..	..	.	24	..	1	1	1	5	2	..	5	4	1	100	" scanty.

* Schizopod eggs, with very few Copepods.

CANADIAN FISHERIES EXPEDITION, 1914-15.

The Hydrodynamics of Canadian Atlantic Waters

BY

W. J. Sandström.

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FIGURES AND PLATES.

THE HYDRODYNAMICS OF CANADIAN ATLANTIC WATERS.

By J. W. Sandström.

PREFACE.

Dr. Johan Hjort has entrusted me with the task of working up, in dynamic form the results of his hydrographical observations in the Canadian Atlantic waters. It has been a great pleasure to me to undertake this work, as the observations, being restricted to the upper strata of dynamic interest, and with the consequent limitation in point of time, may be regarded as almost simultaneous; a feature of great importance when dealing dynamically with the material. In addition to this, the area in question is a most interesting one, presenting as it does a well-defined mass of water acted upon by various and very considerable forces. In the course of the work, valuable assistance has been afforded me by Mr. Paul Bjerkan's clear and concise report of the expedition, Mr. Thorolf Rasmussen's excellent draughtmanship in the elaboration of my rough pencil sketches, and Mr. W. J. A. Worster's translation into English of my hastily compiled Swedish text. Without such co-operation, I should scarcely have been able, in the scanty leisure left me by my official duties and other obligations, to carry through the work at all; as it is, I hope that the following pages may prove of some value, not only in discussion of the observations in question, but also as contributing to the general comprehension of various phenomena in the oceans of the world, in regard to which the conditions prevailing in Canadian waters may be taken as affording analogy and illustration.

The "Survey of Tides and Currents in Canadian Waters," "The Currents in the Gulf of St. Lawrence," and other publications kindly placed at my disposal by Dr. Hjort, contain a mass of most valuable observations as to the movement of the surface water in the gulf of St. Lawrence and adjacent waters.* A good indication of the reliability of these observations is the fact that the popular but erroneous theory of currents due to the action of wind, has here been abandoned. Instead of this, we frequently find the correct observation that a current may arise, or increase in force, some time before the appearance of a storm, such currents being as a rule in a direction contrary to that of the coming wind. These phenomena, which are explained by Bjerknes' circulation theory, give the observer generally an impression that the water in the sea has a very remarkable and unexpected tendency to opposition against the forces striving to act upon it. The usual primitive conception as to the laws which govern movement in liquids will not suffice to explain such paradoxical phenomena; it will be necessary to introduce new ideas, for the proper comprehension of which a considerable amount of mathematical knowledge will frequently be required. On the other hand, it seemed to me of the highest importance that the interested observers in the Canadian Atlantic waters, and also in other parts of the globe, should be able to familiarize themselves with these new principles, and I have therefore endeavoured to get around the mathematical difficulties as far as possible by extensive use of graphical illustrations, and by reference to well-known

* This series of valuable publications, embraces the results of many years' investigations by Dr. W. Bell Dawson, D.Sc., F.R.S.C., etc., Head of the Dominion Tidal Survey, Ottawa, and the staff under his direction.

principles, in particular the Archimedean, which, in addition to being generally understood, is simple and easily comprehensible in itself. I have, moreover, in order to exemplify these principles, given reports of some experiments and also taken some examples from the atmosphere when the hydrographical facts were insufficient. Such limitation and simplification will, I trust, render these complicated yet interesting theories accessible to a wider circle among those at all occupied with marine phenomena.

The following pages open with a short report of Dr. Hjort's observations. These naturally form the foundation upon which the whole of the subsequent discussion is based, as without knowledge of the conditions prevailing down in deep water, it would be impossible to explain the phenomena which take place in the sea, or even those apparent at the surface. The next sections will be devoted to my own explanation of the questions concerned, in the simplified manner above mentioned, leading up to an exposition of that part of Bjerknes' theory which directly applies to conditions in the sea, further the changes into different kinds of the energy in the sea and as summary an application of the laws found on the Canadian Atlantic waters.

I.—GEOGRAPHICAL CONDITIONS OF THE AREA OF INVESTIGATION.

I have before me a chart of the area in question, with numerous soundings, presenting a detailed survey of the bathymetrical conditions. In order to obtain some idea as to the dimensions of this marine basin, I draw out on the chart a system of parallel lines, at intervals of 100 km., each line being again divided up into lengths of 100 km., (fig. 1). At the points thus marked off, I draw short lines indicating the depth, these latter being perpendicular to the original system of parallels. By inserting the intermediate depths according to the chart, vertical sections are obtained for every 100 km. throughout the entire area. (Fig. 1.)

In marking off the depths, I endeavoured at first to adhere to the same scale as that for the horizontal dimensions of the chart, but found the lines thus drawn too short; I therefore multiplied them by ten, so that the lines for vertical dimension were drawn to a scale ten times that of the horizontal. Even this, however, proved insufficient, and I found it necessary to magnify them 100 times in order to render them reasonably legible.

In order, then, to obtain a correct idea as to the bathymetrical conditions within the area investigated, we must imagine the depth lines reduced to one-hundredth of the length shown in the figure. It now becomes apparent, that the vertical dimensions are extremely small in comparison with the horizontal. Drawn to the scale of the chart, the greatest depth within the area would appear about equal to the thickness of the paper on which it is printed. And if we should attempt to draw a vertical section across the area, maintaining the correct proportion between depth and horizontal extent, the result would be merely a line and this moreover in the shallower portions, so fine as to be invisible to the eye.

If we were to make an exact model, on a reduced scale, of the area in question, it would appear, at a first glance, to be perfectly flat. And on attempting to "fill" it with water to a level answering to that of the sea, as a first step to experimental reproduction of the actual hydrographical phenomena, even this would be found practically impossible, owing to the surface tension of the water. So thin a layer would either wet the entire surface of the model or leave dry patches here and there without regard to level. To obtain a basin suitable for the purposes of such experiment, the depth would have to be magnified 1,000 times in proportion to the horizontal extent.

This disproportion between the vertical and horizontal dimensions should be constantly borne in mind throughout the discussion of the sections dealt with in the following pages.

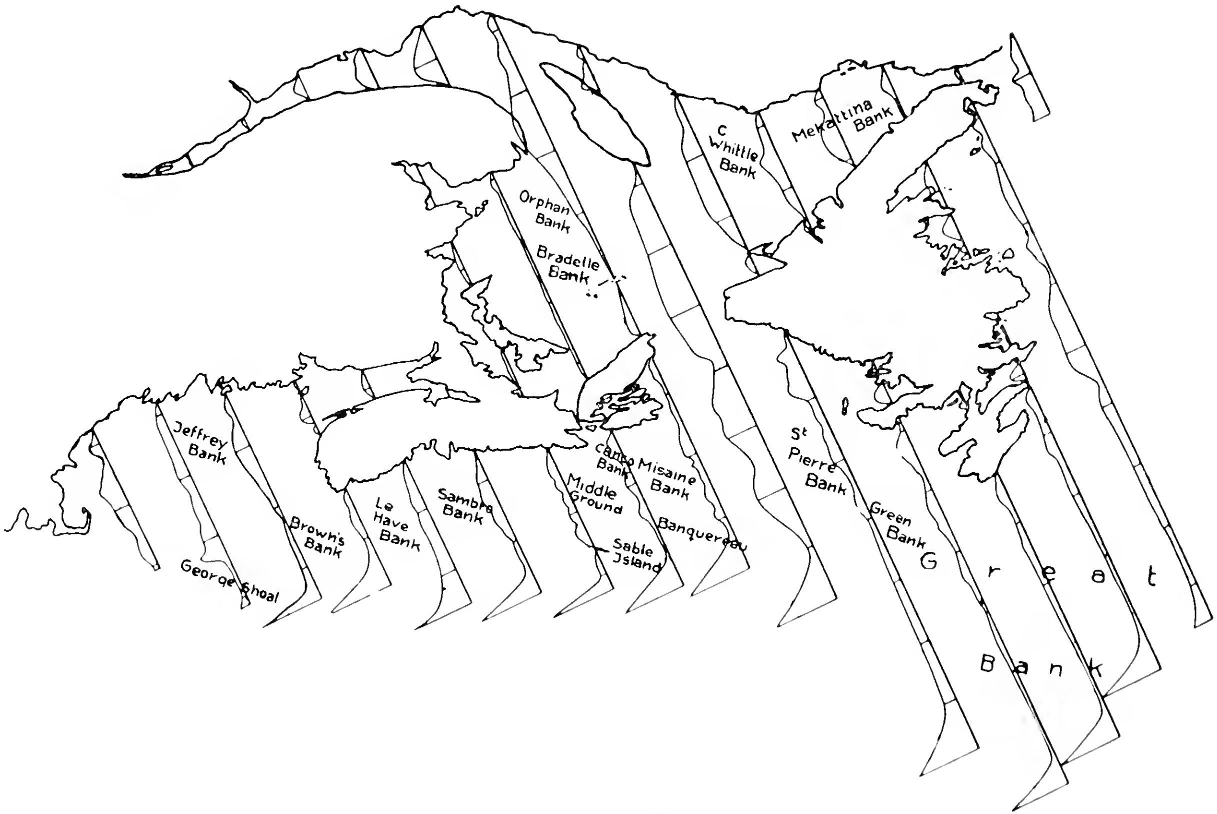


Fig. 1. Map, showing the dimension of the area investigated. The distance between the sections and the distance between the verticals in each section amounts to 100 kms. In relation to the horizontal dimensions the depths are very insignificant, the largest depths are about represented by the thickness of the paper used for printing. In the sections the depths are therefore enlarged 100 times, in relation to the horizontal dimensions, and the largest depth toward the Atlantic slopes drawn in the map represent 1000 m.

Let us now make a mental experiment. We imagine, in the centre of the area of investigation, e.g., on Cape Breton island, a high tower, built in the form of a gasholder. To the centre of the roof, on the inner side, is fastened a fine but strong cord, at the lower end of which, reaching nearly to the floor, a heavy weight is attached, forming a pendulum. This pendulum is set in motion, and the plane in which it moves marked off by a line drawn on the floor at certain intervals of time. It will then be found that the plane in question revolves in the same direction as the hands of a watch placed with the dial upwards. The rate of progress is about 11° per hour; i.e., the plane of the pendulum would make one complete revolution in thirty-three hours, supposing that the pendulum itself could be kept in motion for that time. Fig. 2 shows the course traversed by the plane in the space of twenty-four hours.

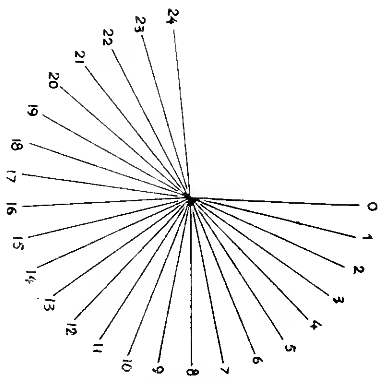


Fig. 2. — The rotation of the pendulum plane during 24 hours by a Foucault's pendulum experiment on the Newfoundland area.

The cause of this phenomenon is as follows: The plane in which the pendulum oscillates does not, as a matter of fact, revolve at all; what does revolve is Cape Breton island and its surroundings, which turns with the earth's rotation about its axis. Similarly, in our pendulum experiment, it is the tower which turns, at the rate of one complete revolution in thirty-three hours, while the true plane of oscillation for the pendulum remains unchanged. The revolution of this plane is thus only apparent, and, correctly interpreted, means simply that the whole of the Canadian Atlantic area is rotating, at what, in consideration of its enormous extent, must be regarded as a very high rate of speed. The direction of this rotary movement is counter-clockwise, i.e., the reverse of the movement made by the hands of a watch dial upwards; the rate of speed

$$\omega = \omega_0 \sin \varphi \qquad \ldots \ldots \ldots \ldots \ldots \ldots \ldots (1)$$

where φ is the latitude, ω_0 the angular velocity of the earth about its axis, ω the angular velocity of the surface of the earth at a latitude amounting for the area in question to about three-quarters of a revolution in the course of the twenty-four hours.

Fig. 3 shows the position of the Canadian Atlantic area at a moment of starting, after 6 hours and after 12 hours. At the moment of starting, we have drawn in the conventional manner N upwards, S downwards, with E on the right and W to the left. After the lapse of six hours, these points of the compass will have shifted 65°, and after the lapse of 12 hours, 130°, to the left. The Gaspé and Cape North currents, which in the first illustration are seen moving towards the right, continue their movement in this direction, despite the rotation of the substratum, thus curving round Gaspé and Cape Breton island, as shown in the two following diagrams. On the other hand, the current passing cape Ray commences towards the left, and in this direction, owing to its inertia, it still continues, although the substratum is under rotatory movement. Consequently, the current is seen to curve round the southwestern point of Newfoundland. This point is, however, so sharp, that the current cannot turn there, to enter St. George's bay, but does not become perceptible until reaching the Bay of Islands, and is then very distinctly apparent along the coast as far as Rich point. Owing to the same cause, the Labrador current turns up into the fjords along the whole of the east and southeast coasts of Newfoundland; hence the numerous shipwrecks in those waters. "Seamen should be on their guard against an indraught among the Fago and Wadham islands into Sir Charles Hamilton's sound, Bonavista, Trinity and Conception bays......On the southeast coast, so many wrecks have occurred, especially near cape Pine and St. Shot's cove, that the compass has been considered to be subject here to local disturbance, but special examination has shown that this is not the case, and that these disasters were mainly attributable to the effect of the currents". (Sailing directions of the North American coast).

The rotation of the earth about its axis, then, gives to the ocean currents an apparent tendency to turn off towards the right. As a matter of fact, the actual tendency of the water is owing to its inertia most emphatically towards direct forward progress, but the continual rotation of the ocean basins and the coasts towards the left (Fig. 3) makes the currents appear as persistently veering off to the right.

The reader should, throughout the following pages, continually bear in mind the three points which have been emphasized above, viz., the insignificance of the vertical dimension in the sea when compared with the horizontal, the continual rotary movement of the basins towards the left (in the northern hemisphere) due to the earth's rotation, and the obstinacy with which sea water opposes the action of external forces.

2. THE HYDROGRAPHICAL OBSERVATIONS.

Plate I shows the position of the hydrographical stations. Sections I-IX, carried out during the time between May 29 and June 26, 1915, give the hydrographical conditions in spring, and sections X-XX, July 21 to August 12, 1915, the same for summer. In addition, the separate stations, 1, 2, 3, and 4 in the gulf of St. Lawrence belong to the spring cruise, and stations 27, 28, 54, 58, and 59 in the same water to the summer cruise.

Plate I shows likewise the bathymetrical conditions in the area investigated. With regard to those, the remarks about Fig. 1 should be borne in mind, i.e., that the depths are extremely slight in proportion to the horizontal distances. The chart presents a fairly detailed picture of the bottom contour. The position of the banks, and their extent, should particularly be noted, as also the regular contour of the Laurentian channel leading in from the Atlantic deep to the gulf of St. Lawrence, and the channels between the banks and the coast.

The following plates are based on the hydrographical material placed at my disposal by Dr. Hjort.

Plates II and III show the distribution of salinity as noted on spring and summer cruises, respectively. A water layer of less than 30 per cent salinity flows out at the surface between the Gaspé coast and Anticosti, filling the southern portion of the gulf of St. Lawrence, rounding cape North, Breton island, and proceeding thence south and southwest along the coast of Nova Scotia. Throughout its course, this layer is continually absorbing water from the subjacent strata, whereby its salinity is increased, until it ceases to exist as a coastal water. A surface layer of like character is also found during spring in the northern portion of the gulf of St. Lawrence. With increasing depth, and farther out to sea, the salinity is augmented in the manner indi-

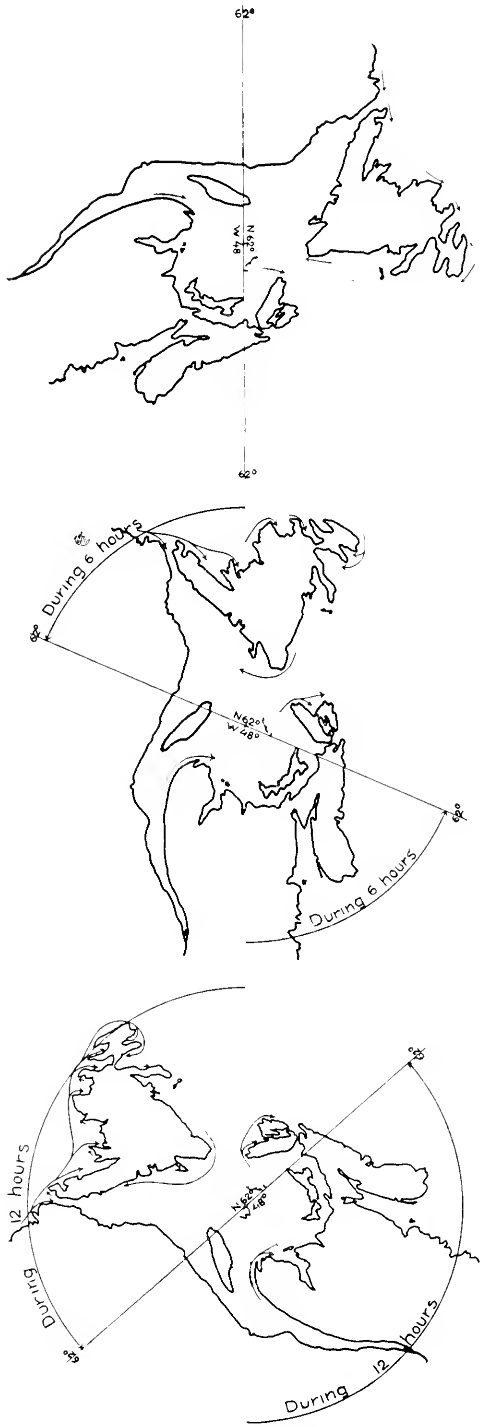


Fig. 3.—The rotation of the Newfoundland area owing to the rotation of the earth.

cated by plates II and III. Not until the very outermost stations are reached, however, do we encounter true Atlantic water of over 35 per cent salinity.

Plates IV and V show the distribution of temperature during the spring and summer cruises. Particularly noteworthy is the enormous intermediate layer of temperatures below zero, which fills the whole of the gulf of St. Lawrence and a great part of the coastal zones outside. During the spring, it also extends far down towards the coast of Nova Scotia, but in summer the extent is somewhat less. Both above and below this intermediate cold layer, the temperature increases. During summer, we find a surface layer of comparatively high temperature. At the outermost stations, the warm Atlantic water is found.

The distribution of temperature and salinity, and the hydrographical conditions generally, have been thoroughly dealt with by Mr. Paul Bjerkan,[1] to whose work on the subject the reader is referred.

Given salinity and temperature, we can, by means of Martin Knudsen's tables, calculate σ_t and the specific volume; i.e., the volume in ccm. of a gramme of water. If we designate the specific gravity of the sea-water by ρ and the specific volume by v then we have

$$v = \frac{1}{\rho} \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

If, for instance, σ=28.16, then ρ=1·02816, whence, according to formula (2), v= 0·97261. As, however, nearly all the values for specific volume within our area of investigation begin with 0.97, we may simplify matters by omitting this figure and multiplying the remainder by 10^5, whereby the specific volumes appear as whole numbers of three figures, and are thus far easier to manipulate. This is the more permissible, since we shall in the following only have occasion to reckon with differences of specific volume. Instead of v = 0·97261, then, we write v_1 = 261, the equation indicating that a gramme of the water in question represents a cubic capacity of 0·97261 ccm.

In table 1, the first column shows the depths in metres at the points where water samples were taken, and the second column v_1 for the samples in question, calculated according to the method indicated above, from the last column in Bjerkan's hydrographical table. Plates VI and VII show the distribution of specific volume within the area investigated. It is greatest at the surface, decreasing downwards, which naturally means, that the lightest water lies uppermost, and the heaviest at the bottom. In the Gaspé current and the southern portion of the gulf of St. Lawrence, the specific volume is particularly great. The lines for like values of specific volume, the so-called isosteres, exhibit a far more horizontal and regular course than the isohalines and isotherms. In the upper water layers, the specific volume decreases rapidly with increasing depth, especially during summer, when the surface water is warmed by the sun; in the lower strata, however, the decrease takes place far more slowly.

Plates VIII and IX present a more detailed view of the course of these isosteres. For the deeper water layers, they have been drawn for each tenth unit of v, in the upper strata for each fiftieth. For general convenience of reading the isostere v_1 = 500 is here prominently shown.

[1] Paul Bjerkan: Results of the hydrographical observations made in the Canadian Atlantic waters by Dr. Johan Hjort during the spring and summer of 1915.

3. DYNAMIC IMPORTANCE OF THE ISOSTERIC SURFACES.

The stable position of the strata in these waters is in many respects characteristic of the movement occasioned therein. In order to make this clear, we may take a simple example. Fig. 4, let us say, represents a sea basin filled with homogeneous water, i.e. in which no isosteric surfaces occur, subjected at the surface to the action of wind blowing in the direction of the larger arrow. The water will then commence to circulate in the manner indicated by the small arrows, the current thus induced increasing continually as long as the wind lasts. Take, then, fig. 5 as representing a basin containing different water layers in stable equilibrium, for the sake of convenience, we may presume that only three water layers of different specific gravity are represented. The layers themselves will then all be devoid of isosteric surfaces, but in the dividing surfaces between the layers, a large number of isosteres will be found. When not subjected to the action of external forces, the three different kinds of water will

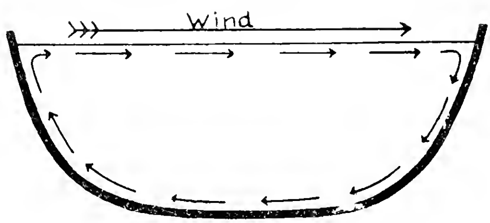


Fig. 4. —Wind currents in homogeneous water.

arrange themselves in horizontal strata, the specific gravity increasing with the depth. Should, now, a wind arise, it will act upon the surface of the uppermost and lightest layer, the water of which this is composed being forced along in the direction of the wind. This layer will then become wedge-shaped, as shown in fig. 6, its water at the same time circulating in the manner indicated in fig. 4. Owing to the friction thus caused, a certain amount of the movement in this surface layer will be communicated to the layer immediately beneath, which in its turn begins to circulate, but in the opposite direction, the combined movement exactly corresponding to that of two cog-wheels working together. Finally, the bottom layer will be similarly set in motion by the one above it, and will commence to circulate in the same direction as the surface layer, albeit at a slower rate.

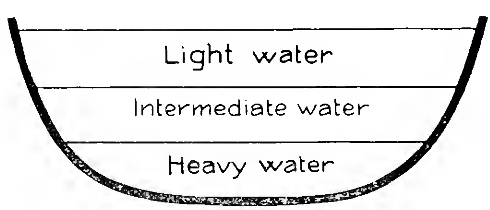


Fig. 5.—Water layers in stable juxtaposition.

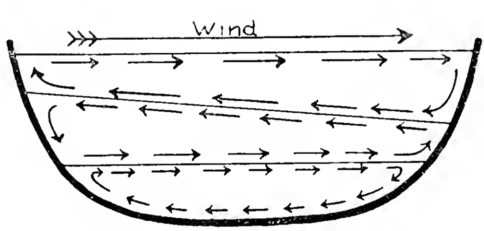


Fig. 6.—Wind currents in stable water layers.

The above simple example will serve to give an idea as to the complicated movement caused by the wind in water layers of stable relative position. The system of strata and movement of the water shown in figs. 5 and 6 are of very frequent occurrence in the sea; in some places, however, the density increases more continuously with the depth, and isosteric surfaces are then found in all parts of the water. Such waters may be regarded as consisting of an infinite number of infinitely thin strata. The movement of the water here is highly restricted, which gives rise to very peculiar dynamic phenomena. The water assumes a remarkable power of resistance against the action of external forces, and when these cease to operate, it returns to its original position.

Let us now endeavour to ascertain the cause of this. Taking any one of the isosteric sections in either of plates VIII and IX, we imagine a water sample from one of the isosteric surfaces transferred to a greater depth. It will here be lighter than its surroundings, and will therefore, according to the Archimedean principle, rise until it once more reaches the isosteric surface from which it was taken, and there it will remain. In the same way, if a sample of water be shifted to a point above that whence it was taken, it will be heavier than its surroundings, and will sink until it reaches the isosteric surface corresponding to its own specific gravity. It is otherwise, however, when a sample of water is moved along the isosteric surface. Here its specific gravity remains equal to that of its surroundings, and no force arises which would occasion its return to the original position. Thus we see that the water can only move along the isosteric surfaces, and not transversely through them. In other words, the scope of movement of the water, instead of being tri-dimensional, is restricted to the two dimensions.

The constant validity of this principle throughout the whole of our present area of investigation is most clearly shown by the existence, and extraordinary permanence, of the cold water layer. It is at once evident that no vertical convection can take place through this layer, the movement of the water being strictly confined to the horizontal.

It is therefore of particular importance to ascertain at what depths the water particles composing one and the same isosteric surface are to be found. For the sake of convenience we may here content ourselves with examining the isosteres $v_1 = 400$, 500, 600, etc. These depths may easily be found, by interpolation, from the v_1 column in table 1, and are here included in table 2. In this table, *B* indicates that the isosteric surface in question touches the bottom, and * that it cuts the surface of the sea before reaching the hydrographical station concerned. Plates X and XI show some of these figures for depth at their proper position within the area of investigation. Here also, lines are drawn to indicate the intersection of the isosteric surfaces with the surface of the sea. This figure shows at a glance why it is that the surface water, during the cold season, keeps to the coastal zone, but is able during the warmer months to move farther out. Another point immediately evident is the very high degree in which the heating of the surface water by the sun's rays contributes to its freedom of movement.

4. FORCES DERIVED FROM THE DISTRIBUTION OF DENSITY.

The Archimedean principle itself teaches us a great deal as to the forces in the sea which are derived from the distribution of density. When the water at a certain point is specifically lighter than its surroundings, it tends to rise, while if heavier, it will tend to sink. Let *A*, in the section fig. 7, represent light, and *B*, heavy water, the two strata being separated by an oblique surface. The deeper portion of the light layer *A* is then surrounded by heavier water, and is specifically lighter than its surroundings, according to the Archimedean principle, therefore, it will be driven upwards, as indicated by the arrow in the figure. The highest portion of the layer *B* is heavier than its surroundings, and has thus a tendency to downward movement here similarly indicated. Thus we see, that according to the Archimedean principle, the lower portion of the dividing surface will be raised, and the upper lowered; in other words, the dividing surface will become horizontal.

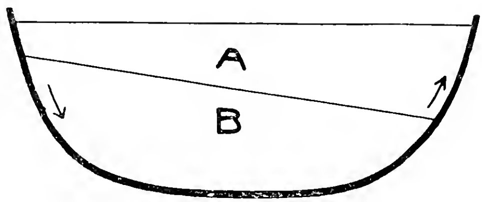


Fig. 7 —Archimedean forces in stable strata.

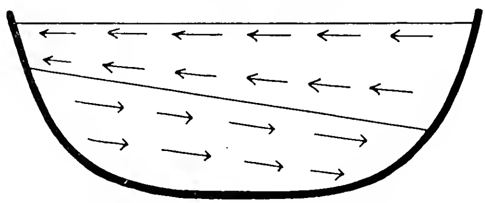


Fig. 8.—Movement occasioned by the forces shown in Fig. 7.

It is easy to understand what movements will be thus occasioned in the water itself. The water will be forced from the thicker to the thinner portion of the stratum, until finally a layer of uniform thickness is produced. We have thus horizontal movements, proceeding in a direction from the thicker towards the thinner portions of the layers, so that the forces indicated in fig. 7 occasion the movements shown in fig. 8.

This simple argument is, as we shall subsequently see, of fundamental importance for the comprehension of the actual conditions in the sea, and will also help us to explain an interesting effect of the wind. The surface water in fig. 6 has been transformed into a wedge-shaped stratum by the action of the wind. When the wind drops, this layer will, according to the Archimedean principle, tend to resume its normal uniform thickness, the water being forced from the thicker towards the thinner portion of the layer; i.e., in a direction contrary to that of the wind previously acting upon it. Thus the action of wind upon normally stable layers of water occasions, upon its cessation, a movement in the surface layer contrary to the former direction of the wind.

It may also happen that water is continually introduced into some portion of a stratum. The thickness of the stratum will then be greater at this point than in the surrounding portions, giving rise to Archimedean forces which drive the water from the point of inflow horizontally towards the farther limits of the stratum. In the tropics, great masses of water are heated by the rays of the sun. Such water becomes specifically lighter, and passes over into the surface layer, which in the tropics amounts to 600 metres depth, whereas at Spitzbergen it is only 200 metres. Thus the Archimedean forces drive the water from the tropics towards Spitzbergen. And the resulting current is that known as the Gulf Stream.

From the foregoing, also, it will be understood that the Gaspé current, the water of which is formed in the mouth of the St. Lawrence river, becomes continually shallower as it proceeds. To the west of the Gaspé peninsula it must be deeper than to the east of there, and still shallower in the Cabot strait. It is this variation in depths which gives the current its forward movement.

The difference of level in the separating surfaces in the sea is of the same importance to the movement of sea-water as the varying level of the surface of a river to the movement of the latter. The force impelling a sea current may be calculated from the slope of the separating surface in the same manner in which the force of a river's current is calculated from the slope of its surface water. In the case of marine currents, however, we have to take into consideration the *difference* in density $\rho_1 - \rho_2$ between the two layers, instead of reckoning merely with the full density of the sea-water. The same thing should, as a matter of fact, be done in the case of a river; the density of the air above the water, however, is so slight as to be negligible in comparison with that of the river water. Save for this, the methods of calculation would be exactly identical for both river and sea currents.

We can also, if preferred, reduce the difference in level of the separating surfaces correspondingly, multiplying them by

$$\frac{\rho_1 - \rho_2}{\rho}$$

and then reckon with the entire mass of the sea current.

This reduction of density naturally tends to diminish considerably the effect of a marine current; this is, however, great enough, owing to the enormous mass of water involved in the movement. Thus for instance, the difference in level of the separating surface in the course of the Gulf stream, amounting to 400 m., is reduced to only 1·5 m. But as the Gulf stream carries 25,000,000 tons of sea-water per second, this slight waterfall yet supplies a force equivalent to 500,000,000 horse-power, which is sufficient to overcome the friction and keep the current in motion.

From measurements of the depth and velocity of the Gaspé and Cabot currents we may calculate, in a similar way, the force and amount of energy which serves to maintain the movement of this current, so important for the hydrographical conditions in the Gulf of St. Lawrence.

Obviously, this simple quantitative method is enormously valuable in determining the causes, features and effects of a marine current.

The propulsion of the currents is thus the most important work performed by the Archimedean forces in the sea. They have, however, also another function of importance here. When an external force acts in the water, the latter is at first moved in the direction whither that force is tending, *vide* fig. 6. This gives rise to Archimedean forces tending in the opposite direction. As long as this displacement of the water continues the strength of the opposing Archimedean forces continually increases. When this has reached a power equal to that of the external force in operation, a state of equilibrium is attained, and the movement of the water ceases. From the Archimedean forces, therefore, we can ascertain in this case at once the direction and magnitude of the external force.

We can thus, from the form of the isosteric surfaces, discover what forces are acting upon the water. Plates X and XI, showing the shape of the isosteric surfaces in the Canadian Atlantic waters during the spring and summer of 1915, thus give us at the same time an idea of the forces then acting upon the water there. We see that the isosteric surfaces slope from out to sea inwards towards Cabot strait, reaching there a considerable depth. This shows, that some force is at work, tending in towards the gulf of St. Lawrence. It is the deflecting force of the earth's rotation, which presses the Labrador current to the right, in towards Cabot strait, and causes the isosteric surfaces to slope as we have seen. This obliquity, however, again gives rise to Archimedean forces in the water, pressing outwards, and opposing the inflow of the Labrador current into the gulf. And from the magnitude of the Archimedean forces here we can, as will la . be seen, ascertain the velocity of the Labrador current in this region. Doubtless, also, similar forces of resistance oppose the inflow of the Labrador current into Belle Isle strait.

Within the gulf of St. Lawrence, it is noticeable that the isosteric surfaces as a rule lie deeper in the peripheral portions than in the central part. This suggests the action of a force tending radially outward from the centre; evidently the centrifugal force occasioned by the cyclonic circulation of the water in the gulf.

Many other interesting details may be seen from Plates X and XI. In section IV, for instance, the 700 isosteric surface lies deeper in the middle of the sound than off the Gaspé coast, evidently a quite abnormal situation, due to some strong external force, which, at the time when the section was taken, must have been operating in a direction from the Gaspé coast to Anticosti, probably a strong south west wind.

5. STABILITY OF THE WATER IN THE NEWFOUNDLAND AREA.

The stability of sea-water may conveniently be characterized by noting the number of isosteric surfaces per 10 metres of depth. The third column in table 1 shows this value for all depth intervals in the present investigations.

It is of great importance to find a method of graphic illustration for this feature, indicating the condition of the water. After various attempts, I have selected the following as being most convenient. The state of a vertical in the sea is represented by a vertical line, the thickness of which is drawn proportionate to the stability. Plates XII and XIII illustrate, in this manner, the stability of the sea-water at the hydrographical stations with which we are here concerned.

By this method, homogeneous water is indicated by an infinitely narrow vertical, see fig. 9 a, and water of constant stability, i.e. the specific volume of which decreases in linear proportion to the depth, by a line of equal thickness throughout, (fig. 9 b). In the sea, owing to rainfall and the inflow of fresh water, as also to the heating of the surface water by the sun, the decrease of specific volume with increasing depth is far more marked in the upper water layers than at greater depths. This is correspondingly shown in fig. 9 c. During a heavy gale the surface water is so stirred as to produce a homogeneous surface layer, the transition here answering to that apparent in passing from fig. 9 c to fig. 9 d. In the spring, the melting of the ice occasions a downflow of ice-cold water from the surface to an intermediate depth. A homogeneous layer is thus produced, here indicated by the narrowed portions in the diagram, fig. 9e.

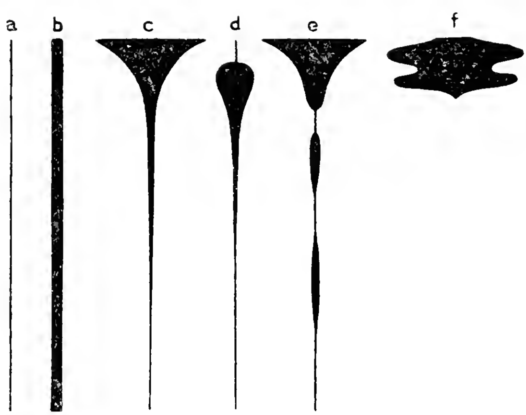


Fig. 9.—Diagram of the stability of the sea water.

In the coastal zones, there is often a current of specifically lighter water. Owing to the inflow from rivers and streams, the surface water becomes especially stable.

Another maximum of stability occurs at somewhat greater depth where the transition from the light coastal current to the heavier subjacent layer occurs. This is shown in fig. 9 f.

All these features, together with others, are illustrated in plates XII and XIII. The diagrams for stability are, as will have been seen from the foregoing, extremely instructive when discussing the condition of the sea and the causes which produce the various hydrographical situations there occurring.

6.—INFLUENCE OF THE WIND UPON THE MOVEMENT OF SEA-WATER.

In chapter 3, the various effects of the wind upon homogeneous water and upon water in layers, has already been shown, *vide* figs. 4 and 6. Still more remarkable is the action of the wind upon water in which the specific gravity increases continuously with the depth. Let fig. 10 be a vertical section through a sea basin containing such water, the horizontal lines 1-7 representing the isosteries. We presume that, for the time being, no other forces are at work here beyond that of gravitation, and that the water is at rest; the isosteric surfaces will thus lie perfectly horizontal. In fig. 10, the isosteres are closest at the surface of the sea, where the stability of the water will in consequence be the greatest. Fig. 9 e gives the diagram of stability for fig. 10. If now a wind commence to blow, a displacement of the upper water will occur, this following the direction of the wind; as, however, the water particles belonging to an isosteric surface cannot leave the same, and as no water can penetrate through these surfaces, the effect of the wind in this case will be confined to the deformation shown in fig. 11.

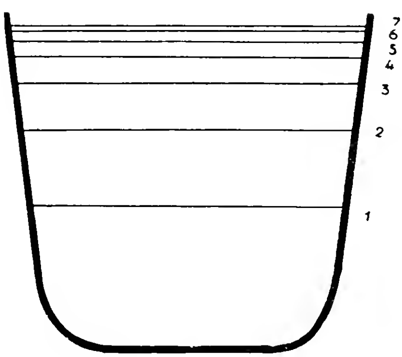


Fig. 10.—Stable sea water in equilibrium.

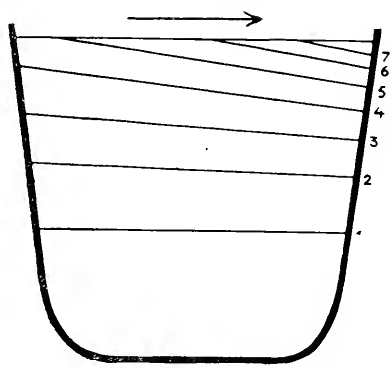


Fig. 11.—Influence of the wind on stable sea water.

The isosteric surfaces retain their individuality, and the volume of water between them remains unchanged despite the wind. The displacement of the water in the direction of the wind causes the isosteric surfaces to slope more and more, giving rise to a strong system of Archimedean forces, which tend to drive the surface water back against the wind. These opposing forces continue to increase, until at last the water no longer flows in the direction of the wind; a state of equilibrium is reached, and from the magnitude of the Archimedean forces required to bring about the same, we may subsequently calculate the force originally brought to bear by the wind itself. When the wind grows fainter, or ceases altogether, the Archimedean forces drive the water back in a direction opposite to that previously followed by the wind. As a rule, the water now flows back too far, so that the isosteric surfaces slope the reverse way. This gives rise to new Archimedean forces which send the water back once more in the original direction of the wind. In this way the backward and forward movement may be repeated several times, until equilibrium is attained. When this occurs, the isosteres will be in precisely their old position, and the state of the water exactly what it was before the commencement of the wind.

The sea-water thus reacts more after the manner of an elastic body than a fluid, when subjected to the influence of forces acting upon it. The forces in question can only occasion a certain degree of deformation, and as soon as they cease to operate, the water returns to its former condition. External forces produce, so to speak, effects as upon a mass of jelly.

The Archimedean forces thus play very much the same part in sea-water as that of elasticity in a solid. It may occasionally happen that the external forces acting upon the sea water reach a magnitude exceeding the highest possible value which can be attained by the Archimedean forces. A catastrophe then takes place, and an entirely new state of things is brought about, exactly as when the limit of elasticity in a solid is exceeded.

The maximal value of the Archimedean forces is reached when the isosteres become vertical. Should external forces exceeding this maximal value be brought into play, then the water layers will jibe over, as shown in fig. 12, which illustrates the distribution of density under a very strong wind. Now, however, light water is brought down beneath heavier; the stability is upset, and a strong vertical convection ensues, whereby the whole of the water affected is mixed up into one single homogeneous layer. The specific volume of this layer will, of course, be equal to the mean specific volume of the strata of which it was composed, and between this and the water beneath there will be a sharply defined difference of density. In the homogeneous layer, there are no isosteres, and consequently, no Archimedean forces will be formed, so that the water therein contained will follow without resistance the direction of external forces acting upon it. The circulation here will therefore be highly intensive, as shown in fig. 13, so that the water will continue homogeneous, and exert a continual friction upon the layer beneath, thus maintaining the sharply defined limit of density between the two. This friction occasions a gradual absorption of the water from the lower layer, so that the upper one will tend to increase in volume and specific gravity.

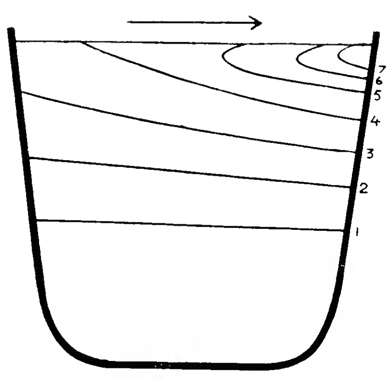


Fig. 12.—Water layers jibing in a high wind.

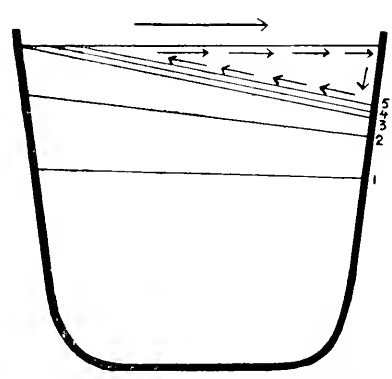


Fig. 13.—Strong circulation in surface layer after jibing.

When the external forces which brought about the transformation have subsided, and the isosteres have resumed their horizontal position, the distribution of density will naturally not be the same as before the forces in question had commenced to operate, *vide* fig. 10. Instead of this, we now find a homogeneous surface layer of great volume, and between this and the water beneath, a sharply marked break in the density, *vide* fig. 14. This is the reason why the greatest variation of density with depth in the sea is often found, not at the surface, but at some distance beneath, *vide*, fig. 9 d, and plates XII and XIII.

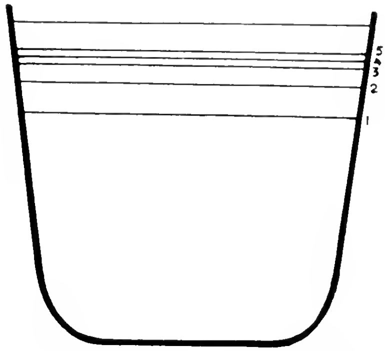


Fig. 14.—State of sea water after a storm.

Obviously the greater the stability of the water, the more difficult will it be to make the surface water jibe over in this manner; whence again it follows, that the phenomenon is more easily occasioned in winter than in summer. In other words, the surface water exhibits a far greater power of resistance to the wind in summer than in winter. This peculiarity has been remarked by fishermen on the west coast of Sweden, who declare that the sea-water is harder or heavier in summer than at other times of the year.

With water in layers, the matter is naturally far simpler, *vide* fig. 6, than where the density increases continuously with the depth. Even in such stratified water, however, many dynamically and hydrographically interesting phenomena may occur. It is instructive to begin by producing such experimentally, and afterwards observe the corresponding realities in the sea; by this method, as by no other, it is possible to arrive at an intimate understanding of oceanographical phenomena.

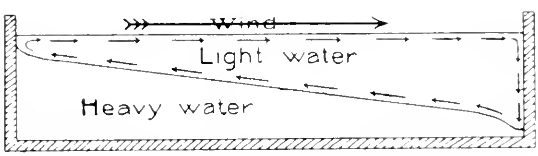


Fig. 15.—Experiment illustrating action of wind upon water in strata.

I purpose now to describe some experiments which I have carried out as illustrative of the influence of wind upon stratified water. A tank 100 cm. long, 25 cm. deep, and 3 cm. across, with glass walls, was filled to a height of 10 cm. with fresh water. By means of a thin tube, heavier salt water was then introduced beneath this, making another layer 10 cm. deep. With the aid of an electric arc lamp, a picture of the tank was then projected on to a white sheet, whereby the separating surface between the two water layers was rendered very distinctly visible, owing to the refraction of the light. As long as the water was left undisturbed, the boundary line was horizontal, and the layer of uniform thickness. By means of a blower, a strong current of air was then driven across the surface of the water, when the separating line took the direction shown in fig. 15. A point especially worthy of note is the depression at that end of the reservoir to which the wind was directed. This is caused by the water in the upper layer having its current there directed vertically downwards, and striking against the separating surface. At the other end of the

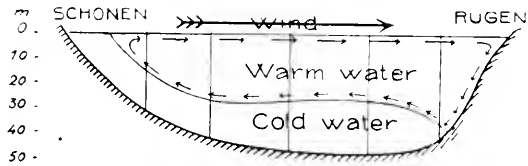


Fig. 16.—Wind and distribution of temperature, with probable movement of the water, in the southern part of the Baltic, 1 August 1907.

reservoir also, the separating surface is seen to be slightly rounded off where the current turns. That corresponding deformations of the surface layer occur in the sea will be seen from the hydrographical sections in figs. 16 and 17.

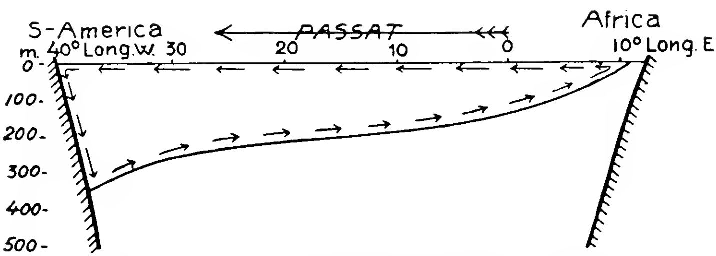


Fig. 17.—Wind, 15° isotherm, and probable movement of the water between Africa and S. America, lat. 20° S.

Owing to the circulation in the surface layer in fig. 15, the water therein remained very homogeneous. From the continual friction upon the layer beneath, the surface layer absorbed into itself some of the water adjacent, and thus gradually increased in volume. The longer the experiment lasted, the thicker and salter would the surface layer grow. The same thing would probably take place in the sea with a continual wind.

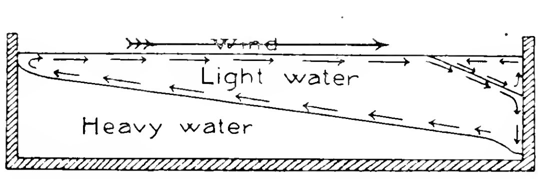


Fig. 18. Experiment illustrating current opposed to the wind on the weather toward shore.

I now poured a small quantity of fresh water into the water already in the tank, as answering to rainfall, or inflow from rivers and streams into the sea. This fresh water was driven by the current of air towards the end of the tank against which the wind was blowing, forming a triangular inset there, as shown in fig. 18. It was here distinctly subjected to two forces, firstly the wind, endeavouring to bring about a circulation where the surface water moves in the direction of the wind, and secondly the current beneath, seeking to induce a circulation where the surface water moves against the direction of the wind. The latter, however, obtained the mastery, as shown in fig. 18. We see, then, that the peculiar phenomenon may arise of the wind occasioning a surface current in a direction opposite to its own, on the weather shore. This I have, as a matter of fact, frequently observed myself in the Gullmarfjord, on the west coast of Sweden. When the wind is blowing directly on-shore, a situation exactly identical with that shown in fig. 18 may arise. Should it, however, be blowing obliquely towards land, then this will occasion a screwing movement in the triangular inset, also probably in that beneath, *vide* fig. 19, showing direction of the wind and movement of the water in Gullmarfjord, seen from above. The respective densities of the water layers in the gulf of St. Lawrence are so similar to those in the Gullmarfjord, that the same phenomenon should also be of frequent occurrence there.

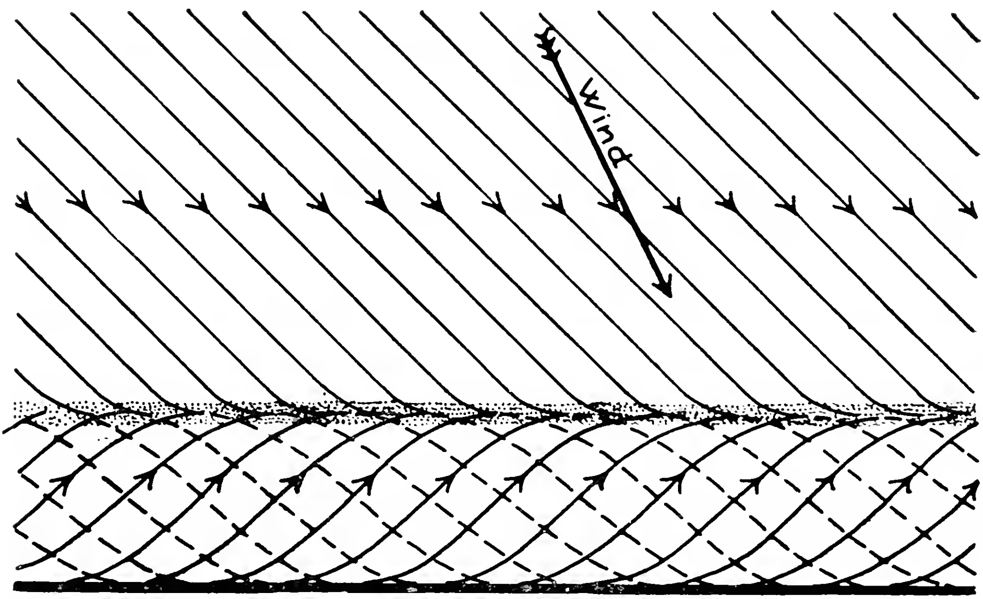


Fig. 19.—Wind and wind currents in the Gullmarfjord.

At the point where the two surface currents meet, all floating objects, such as driftwood, cork, froth, etc., will collect; this line is therefore easily distinguishable. Off the west coast of Sweden, there is, as a rule, a line of this sort generally to be seen running parallel with the shore. This is the boundary line between the Baltic current and the heavier water outside. When the fishing boats sail from Marstrand out to sea, they often follow one another in a straight line. On passing this boundary, however, their line is broken, and the boats outside do not move in the same direction as those within the margin, although steering the same course, and with their sails set just as before. This is evidently due to the fact that the movement of the water is not the same inside and outside the boundary line. A fisherman who had set his drift net out one night right across the line, had it cut clean across, and the pieces drawn into the mass of floating refuse. Next day he sailed northward along the line and found them there. This shows that high relative velocities are to be found in this drift line, which was only to be expected, after what we have seen in fig. 19.

The underlying strata are also affected, through friction, by the layers acted on directly by the wind. And it may then occur that even the cold deep water, when drawn up to the surface on the shore where the wind is blowing seawards will develop a movement opposed to the direction of the wind, *vide* fig. 20.

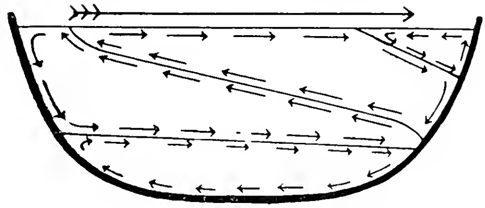


Fig. 20.—Current opposed to the wind on weather shore and lee.

In large areas, the wind cannot be regarded as a constant current of air progressing continuously over the whole area, but rather as a series of stormy gusts extending over a wide expanse. Such a storm, acting upon water in layers, produces a very large submarine wave, probably hundreds of metres high, which moves slowly forward in the direction of the wind, *vide* fig. 21. This wave is caused by the friction between the current of air and the surface layer. As the wave moves forward, the surface water in front of it must pass over behind the crest of the wave. A strong current, moving against the wind, thus arises in the surface layer, and this will make itself apparent even before the storm itself has reached the same point, thus serving as a storm warning. From fig. 21, it will be seen that the current flowing in a direction opposite to that of the wind continues to do so for some little time after the wind has come up,

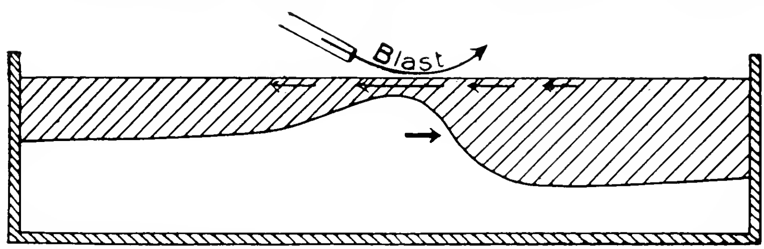


Fig. 21.—Surface current on the approach of a storm.

but then decreases in force. Such currents against the wind have frequently been observed in Canadian waters.

7.—INFLUENCE OF THE EARTH'S ROTATION ON THE MOVEMENTS OF THE WATER IN THE SEA.

Of all the forces acting upon the sea-water, that of the earth's rotation is the one which, as regards its effects, is most remarkable and difficult of comprehension. It is frequently found to force light water downwards, and heavier water to the surface, with the result that the distribution of density appears strange and mysterious. I am inclined to believe that our inability to comprehend the effects of this force is principally due to the fact that we have no senses for the direct perception of the rotation of the earth. All our direct perceptions indicate the earth as motionless. True, we have learned at school that the earth rotates, and can also more or less form an idea of its doing so, but as a matter of fact, in our daily life, as in the laboratory, we are independent of such rotation. All the small phenomena around us we are accustomed to view from the standpoint of an immobile earth. When, therefore, in discussing the movements of the sea, the rotation of the earth is seen to take a prominent place, its effects appear to us strange and inexplicable.

A being situated somewhere outside our planet, and observing, not only the phenomena taking place on the earth's surface, but also the rotation of the globe itself, would be far better able to comprehend the actual movements of the sea than we are. From our point of view, the currents of the sea appear to evince an irrational tendency to veer to the right; an extra-terrestrial being would, however, see in this nothing but the natural effort of the water to continue its forward movement in a straight line, as its inertia demands. Let us then imagine ourselves to be such beings, viewing the earth from outside. We find, first of all, that the body of the planet moves about its axis in the space of twenty-four hours. At the poles, the surface of the earth also moves at this rate of rotation. At the equator, the influence of the earth's rotation is nil, as may be ascertained also by experiment with the Foucault pendulum. In the Canadian Atlantic region, the rotation of the earth's surface amounts, as circumstantially demonstrated in chapter 1, to about 11° per hour; i.e., the Canadian waters make a full turn in something like thirty-three hours; *vide* figs. 2 and 3. From fig. 3, also, we may see why it is that the water in more or less inclosed areas circulates cyclonically. All the currents in the area tend towards the right bank, and move along the same. This rule will always be found to apply in high latitudes. The Gulf stream, for instance, transporting water from the tropics to the Arctic ocean, keeps close to the coast of Europe, while the Polar current, which carries the light Arctic water southwards, hugs the shores of Canada. The result is a very marked cyclonic circulation in the North Atlantic ocean. In the North sea, the Skagerak, and in the Newfoundland area, the surface water everywhere exhibits a cyclonic circulation.

In the lower latitudes, on the other hand, the circulation of the surface water is anticyclonic, owing to the strong anticyclonic winds, and the slight effect of the earth's rotation there.

Let us now consider how this cyclonic and anticyclonic circulation would appear to an extra-terrestrial observer. The earth's rotation is cyclonic; every sea-basin thus also rotates cyclonically. When the water in any such basin circulates cyclonically in relation to the basin itself, this merely means that the rotation of the water is more rapid than that of the basin. And when the water circulates anticyclonically in its basin, this is in reality nothing but a cyclonic movement of the water at a velocity inferior to that of the basin itself.

It is obvious, however, that the centrifugal force of a rapidly rotating water layer will be greater than that of one rotating more slowly. When, therefore, the

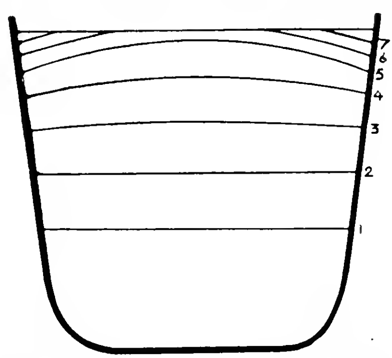


Fig. 22.—Distribution of density in a sea basin with cyclonic rotation of surface water.

surface water in a basin circulates cyclonically, this water will be flung radially outwards, so that the separating surface between this upper layer and the one immediately beneath will no longer be horizontal, but will develop a depression on the coasts, and a rise in the centre of the basin, *vide* fig. 22. The Archimedean forces thus called into play will be kept balanced by the difference between the centrifugal forces of the two layers.

From the Archimedean forces, therefore, we can calculate the centrifugal forces, and thus arrive at the transposition of the water. This ingenious method of calculating the movements of sea water will be employed in the following, when dealing with the Newfoundland area.

A contrasted distribution of density arises when the surface water circulates anticyclonically, as is the case in the horse latitudes. Here, the deep water rotates, as a matter of fact, with the Atlantic basin; the surface water, however, moving at a slower rate. The centrifugal force of the deep water is therefore greater than that of the surface water, and the former is consequently flung out more strongly than the latter. The result of this, again, is that the surface water keeps to the centre of the area (*vide* fig. 24 B), and this warm upper layer therefore reaches down at this point to a depth of 600 metres, whereas at the equator, its depth is only 200 metres.

Now, as we know, the diagram of velocity for a vertical line through a sea current assumes, owing to friction, the form of a parabola, the velocity being at its maximum a little below the surface of the sea. In the lower portions of the current it decreases greatly with increasing depth. When, therefore, the surface water in a basin circulates cyclonically, as before described, the cyclonic circulation and the

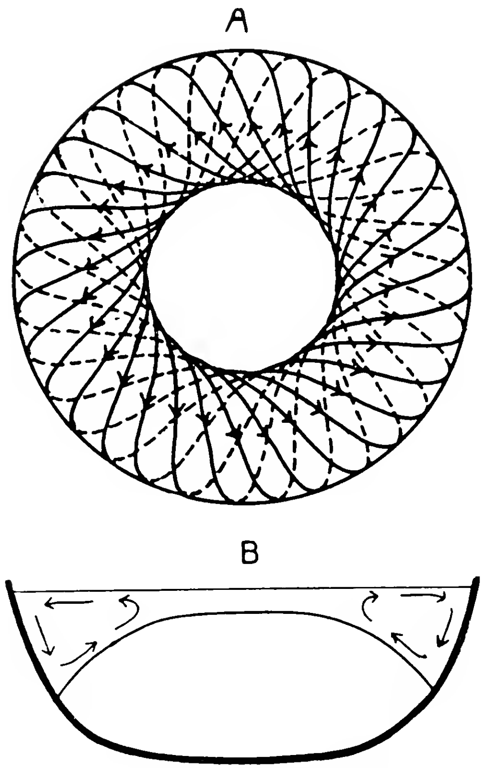


Fig. 23.—Screwing movement of surface water in cyclonic circulation.

centrifugal force will reach their maximum near the surface of the sea, decreasing rapidly with increasing depth. And the actual surface water will be flung out more strongly than the water in the lower portions of the surface layer. The effect of this is that the former moves toward land, and the latter out to sea (*vide* fig 23 B).

And in its forward progress, the current thus makes a kind of screw movement, exactly corresponding to the screwing forwards of an ordinary screw, fig. 23 A.

In the Sargasso sea, the anticyclonic circulation is at its maximum in the surface of the sea, the centrifugal force being there at a minimum. The lower portions of the surface layer are flung outwards with greater force than the surface water itself. This gives rise to a screwing movement of the water, the surface water tending towards the centre of the Sargasso sea, and the deep water moving outwards from that centre, as shown in fig. 24. This explains the collection of floating matter in the Sargasso sea.

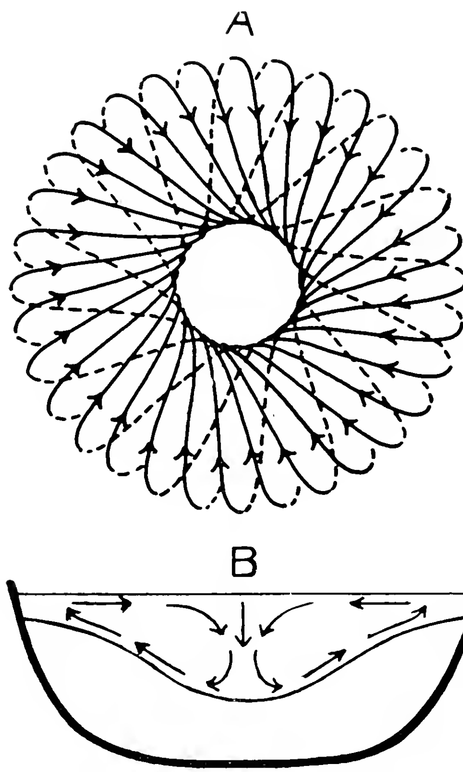


Fig. 24.—Movement of the water in the Sasgasso sea.

This tendency to screw forward is found in all sea currents in high latitudes, as a result of the earth's rotation. But the water of the northern hemisphere moves after the manner of an ordinary right-turned screw; that of the southern, however, screwing towards the left. The screwing tendency increases as $\sin \varphi$ where φ is the geographical latitude. Thus, at the equator, it is nil, and has its maximum at the poles.

If the water of an intermediate layer is moving in a certain direction, relatively to the layers above and below it, then it will turn off to the right from that direction, until it reaches the right side of the basin, against which it is pressed (fig. 25). Such a current will have its maximum of velocity at the centre, where the water is forced most strongly to the right, returning in the upper and lower portions of the stratum. There will thus be two screwing movements in such an intermediate layer. The divergence of the isosteric surfaces (*vide* fig. 25) is one of the surest indications of the existence of such a deep water current.

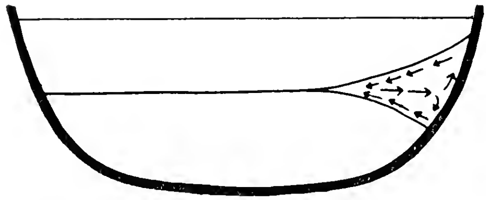


Fig. 25.—Screwing movement in a deep water current.

Finally, some experiments made with a rotating water tank remain to be described. This tank was 30 cm. long, 10 cm. broad, and 10 cm. high. A surface layer of fresh water, 4 cm. deep, was poured in, and a bottom layer of salt water, also 4 cm. deep, introduced beneath the first. Before the tank was set in motion, a vertical current of air was applied to the surface of the water; the result will be seen from fig. 26. Under the influence of this current of air, the surface layer diminished in thickness, the bottom layer increasing, evidently as a result of friction between the surface of the water and the air, which poured out radially to all sides. The tank was then caused to rotate about a vertical axis through its centre, when the situation shown in fig. 27 was observed; i.e., the exact opposite of that shown in fig. 26. The cause of this accumulation of the surface water under the air current is evidently this: the rotation of the surface water is somewhat retarded by the radially directed air, which renders its velocity less than that of the tank, whereas the bottom layer of water rotates at the same velocity as the tank itself. Consequently the centrifugal force would be greater in the bottom layer than in the surface water, and the bottom water would therefore be driven out to the ends of the tank, while the surface water massed in its centre.

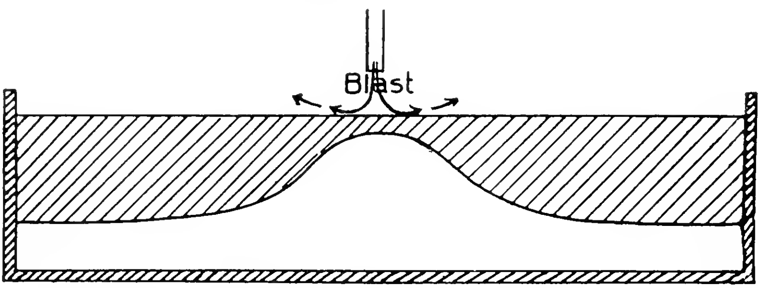


Fig. 26.—Experiment with vertical air blast against surface of water in layers. (Tank at rest.)

Lastly, by means of a series of obliquely placed tubes, a cyclonic circulation of air was applied to the surface of the water, the effect of this being to induce a rotation of the surface water at a higher velocity than that of the tank. This brought about the same distribution of the water mass as shown in fig. 26, evidently here owing to the fact that the centrifugal force was in this case greater in the surface layer than in the bottom water.

In the sea, therefore, an anticyclone should occasion an accumulation of the surface water beneath its centre, a good example of which is afforded by the Sargasso sea. A cyclone, on the other hand, would drive the surface water outwards to all sides, and draw up the bottom water beneath its centre.

The vertical movements of the water described in this chapter, which are due to the earth's rotation, are naturally opposed, in a very important degree, by the Archimedean forces. With water of very high stability, these forces may entirely prevent the screwing movement of the water, all that takes place being then a current

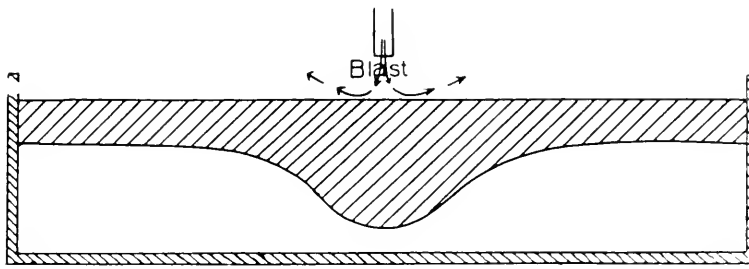


Fig. 27. Experiment with vertical air blast against surface of water in layers. (Tank rotating.)

in the isosteric surfaces, which are deformed in the manner shown in fig. 22. In a coastal current, where the water is in layers of great stability, the surface water will therefore flow parallel with the coast. If, however, the stability of the strata be so slight that the deflecting tendency of the earth's rotation exceeds the maximal value of the Archimedean forces, then the screwing movement will thoroughly stir the water in which it takes place, rendering the layer highly homogeneous, so that the dividing surface between it and the next will be sharply defined. After this, there will be nothing to hinder the screwing movement of the water in this homogeneous layer, and the movement in question will thus attain its full development. This explains the high component of movement towards the coast in the surface portion of the comparatively homogeneous water south of Newfoundland, whereas in the Gaspe current, a layer formation of great stability, no such landward movement takes place (*vide* fig. 28). Even down on the banks to the south of Newfoundland, the water often flows northward, the bottom water, owing to the screwing movement, naturally having a component southwards. Thus the dangerous character of the Canadian Atlantic coast as regards navigation is due to the homogeneous nature of the water. If at any season the sea-water there should be overlaid by lighter surface water in stable layer formation, there would then be no danger of ships being driven on shore by the current, as long as such surface water was present.

In a similar manner, we should be able, from the movement of the water, to ascertain the stability of the same. If the water flows parallel with the coast, it is stable; whereas water setting in towards the shore will be homogeneous. On the eastern side of Newfoundland, for instance, the water flows up into the bays (*vide*

Fig. 28.—Movement of the water according to chart from Belle Isle to Boston, compiled from Sailing Directions, Survey of Tides and Currents in Canadian waters, and other sources.

fig. 28). From this we may conclude that the water here is of but slight stability. On the southeast coast of Newfoundland, on the other hand, the water sets outwards from the shore, even occasioning a reverse current in towards land. Here, therefore, the water is in stable layer formation.

8. INFLUENCE OF MELTING ICE UPON THE MOVEMENTS OF SEA-WATER.

One of the strongest and most effective causes of ocean currents and hydrographical changes is, as Prof. Otto Pettersson[1] has shown, the melting of ice. If a piece of ice be placed in a tank of sea-water, the water will soon exhibit very strong and distinct current movements, the melting of the ice also occasioning marked alterations in the temperature, salinity, and specific gravity of the water.

Professor Pettersson found by his experiments that the melting of the ice gave rise to three currents in the water, a cold surface current of low salinity proceeding in a direction away from the ice; below this a warm salt current moving toward the ice; and finally a cold salt bottom current away from the ice again.

I have also carried out some experiments of this nature with melting ice in sea-water. A glass-walled tank, 350 cm. long, 40 cm. broad, and 40 cm. deep, was filled with sea-water to a height of 35 cm. In one end of the tank was then placed a rectangular piece of ice measuring 61 cm. length, by 40 cm. width, and 23 cm. thickness. At the other end of the tank a current of water was introduced at a temperature of 8° C. and with a salinity of 30 per cent, the inflow taking place at the rate of 12 cm. per second with a corresponding outflow from the surface so as to maintain a con-

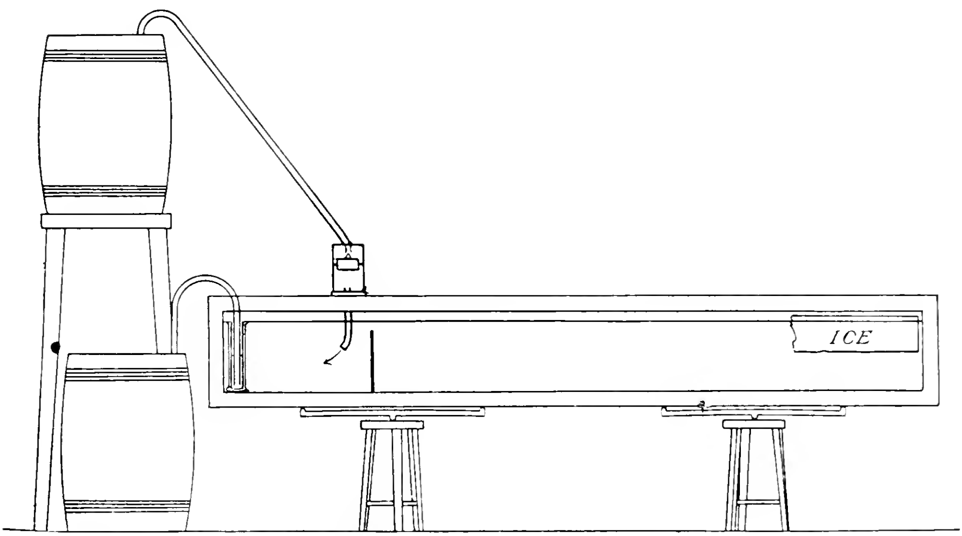


Fig. 29.—Ice melting experiment.

stant level. The outflow took place in a separate compartment of the tank, 75 cm. long, divided off from the remaining, consequently 275 cm. long by a partition 25 cm. high, so as to leave free communication between both portions of the tank through the space of 10 cm. above the partition, *vide* fig. 29. The object of this inflow arrangement was to procure stationary conditions in the tank. The system thus arrived at, by the way, is very much like the conditions prevalent in the gulf of St. Lawrence, which communicates with the ocean through Cabot strait.

The block of ice was placed in the tank at 11 a.m., and immediately commenced to melt at the rate of 0·80 cm.^{3} per second. As the surrounding water was brought into circulation, the rate of melting increased, so that by 12 o'clock it was 1·24 cm.^{3} per

1 *O. Pettersson.* On the influence of ice-melting upon oceanic conditions. Svenska hydrografisk-biologiska kommissionens skrifter II. Gothenburg, 1905.

second, and by 1 o'clock 1·26 cm.^{3} per second. After this it decreased, chiefly owing to the fact that the surface of the ice block had diminished in size, but also on account of the lower temperature of the water in the tank. At 2 o'clock the rate of melting was 0·97 cm.^{3} per second, at 3 o'clock 0·70, at 4 p.m. 0·60, at 5 p.m. 0·53, at 6 p.m. 0·50, at 7 p.m. 0·50, and at 8 o'clock 0.50 cm.^{3} per second. Fig 30 shows the changes which took place in the shape of the ice during the process of melting. The depression *A* on the front of the block was caused by the warm water pressing against the ice at this point, and giving off its heat there, whereafter the water now cooled sinks down past *B*, where the ice melts at a slower rate, owing to the lower temperature of the water coming in contact with it there.

In order to measure the movement of the water in the tank, a solution of fuchsin in alcohol was prepared, in such proportion as to get a specific gravity as nearly as possible equal to that of the water. A portion of this solution was discharged into the water through a capillary glass tube at a point some 20 cm. in front of the depression *A* in the ice (fig. 30). The solution was carried at an even rate of speed into the depression, then sinking downwards, following the outline of the ice. At *B*, the rate of movement was diminished, and a small cloud of fuchsin was formed off the projecting point there. After this, the fuchsin particles were gradually driven in under the ice. The lower portions of the block was passed by at a great rate of speed, until the fuchsin reached the point *C*, where it slowly sank, and was caught by the bottom current which carries the water away from the ice.

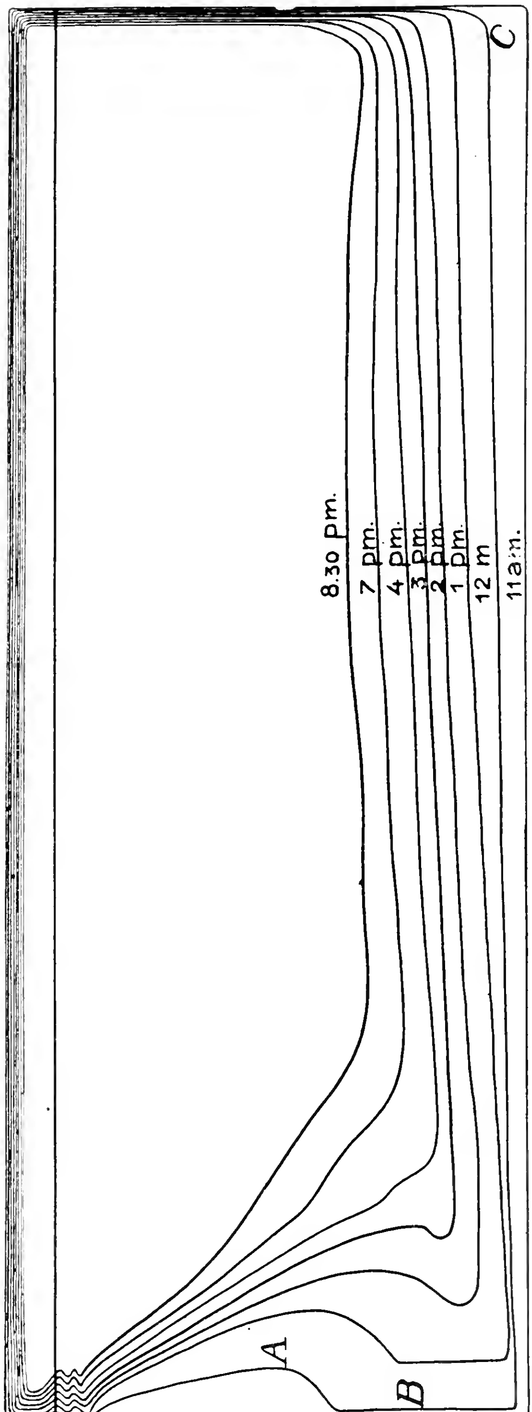


Fig. 30.—The melting of the ice.

A picture of the ice block being projected on to a white sheet by means of an arc lamp, it was seen that streaks were moving upward on the cloth, indicating that some of the melting water from the surface of the ice rises to the surface of the water, forming there a surface layer of fresher water; some portion of it, however, doubtless becoming mixed with the sea-water which is melting the ice and sinking

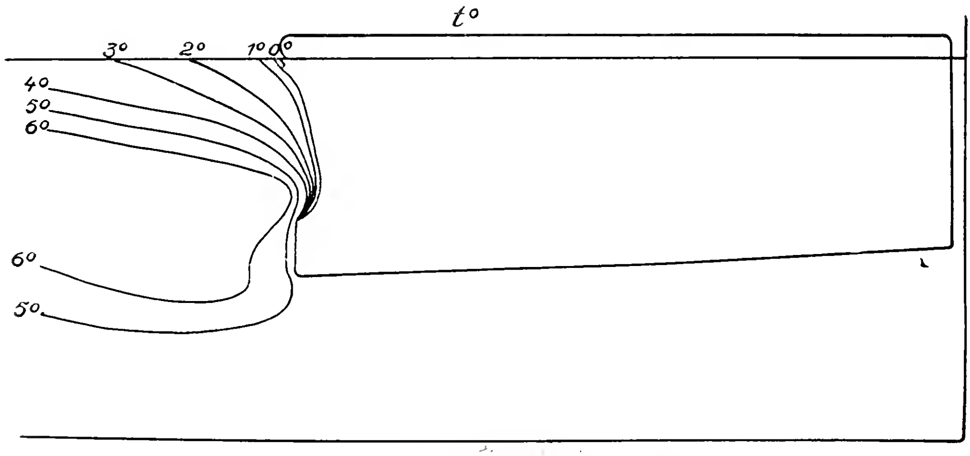


Fig. 31.—Distribution of salinity near the ice.

down with it. *Vide* figs. 31 and 32, showing distribution of salinity and temperature in front of the ice block.

In order to measure the movement of the water more exactly, a long capillary pipette was filled with potassium permanganate solution, and introduced vertically to the bottom of the tank from above. On being drawn up, it left behind it a fine vertical thread of the solution, which was afterwards visibly curved by the current. After the space of two minutes, a drawing was made of the thread as it then appeared. Fig.

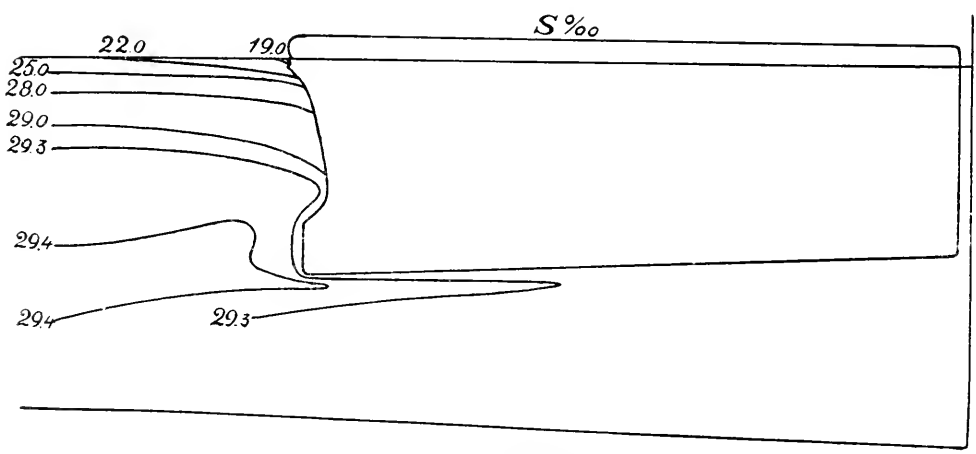


Fig. 32.—Distribution of the temperature near the ice.

33 shows the original vertical and subsequent altered course of the permanganate line. The horizontal lines thus indicates the movement of the water particles during the two minutes.

The velocity of the water was also measured in other parts of the tank. Fig. 34 shows the results of these measurements. It will be seen that the surface current is insignificant, that at the bottom, however, being quite considerable. The water actually moving towards the ice forms two currents, with a minimum of velocity between, the upper current being directed towards the front of the ice, and the lower against its underside, where the force of attraction appears to be very great. As a matter of fact,

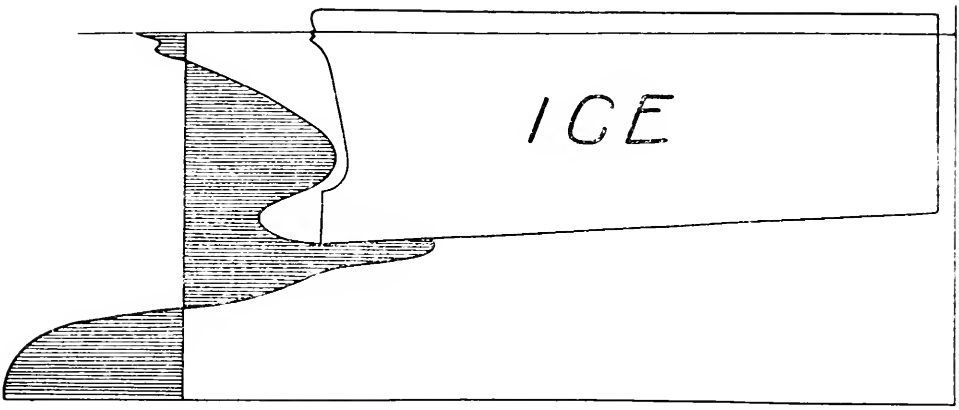


Fig. 33.—Movement of the water near the ice.

the ice melts equally much on its lower side as on its face, and the rear portion of the ice diminished, at any rate to begin with, more rapidly than the front part, *vide* fig. 30. The greatest velocity of the water and the greatest acceleration found in any part of the tank were localized about the lower side of the ice block. In the sea, where the vertical extent of the ice is insignificant as compared with its horizontal extension, this fact should probably be of the very highest importance.

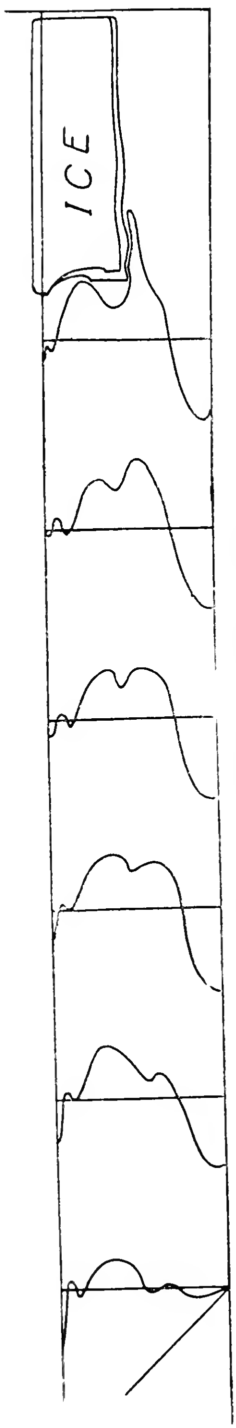


Fig. 34.—The movement of the water in the tank.

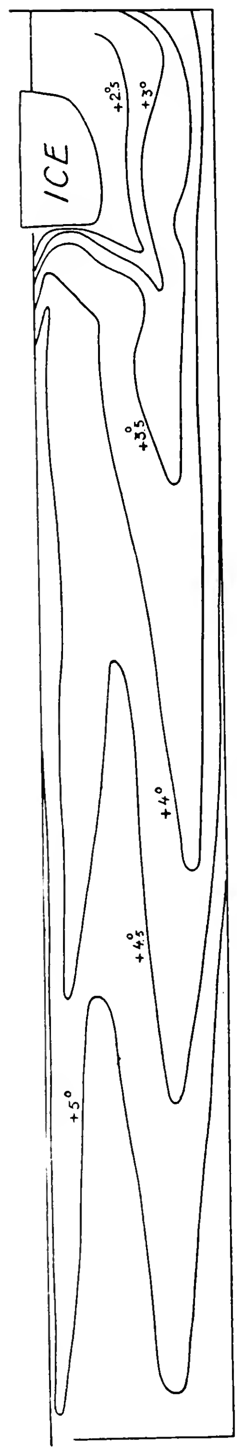


Fig. 35.—Distribution of the temperature by the melting of ice over a warm and very salt bottom layer.

In the experiment here described, it was not always possible to maintain a constant degree of salinity in the inflowing water. When the salinity increased, a warm saline layer with a slow inward movement was formed at the bottom of the tank. Above this was the cold outgoing current of lower salinity. And above this again warm water poured in towards the ice, with finally, at the surface, a thin layer of brackish water directed outwards, *vide* fig. 35. This situation corresponds very closely to the actual conditions in the gulf of St. Lawrence, where a cold intermediate layer is also found.

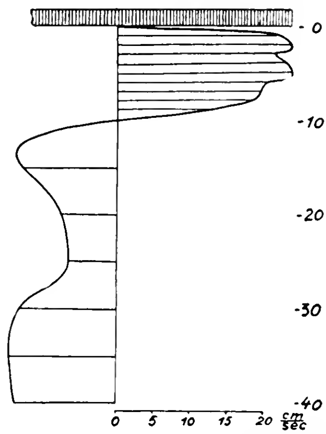


Fig. 36.—Movement of the water by the melting of the ice in the Gullmarfjord.

The experiment and observations mentioned above give a good insight into the origin and formation of the intermediate cold water layers in the Newfoundland area (*vide* tables IV and V). It has plainly been formed by the melting of the ice in the gulf of St. Lawrence and the Labrador current.

When the ice was melting in the Gullmarfjord I noticed it carefully, and measured the velocity of the water in a vertical line inside the ice edge, *vide* fig. 36, and also the temperature of the water in a section at right angles to the ice edge, *vide* fig. 37. From fig. 36 it will be seen that a strong current of water directed inward towards the ice existed down to 10 metres depth, and beneath this, a slighter outwards current right down to the bottom. Fig. 37 gives a very clear view of the manner in which the cooled water sinks in portions from the ice down into the depth below. The same thing doubtless takes place on the melting of the ice in the gulf of St. Lawrence, and in the Arctic ocean and other places.

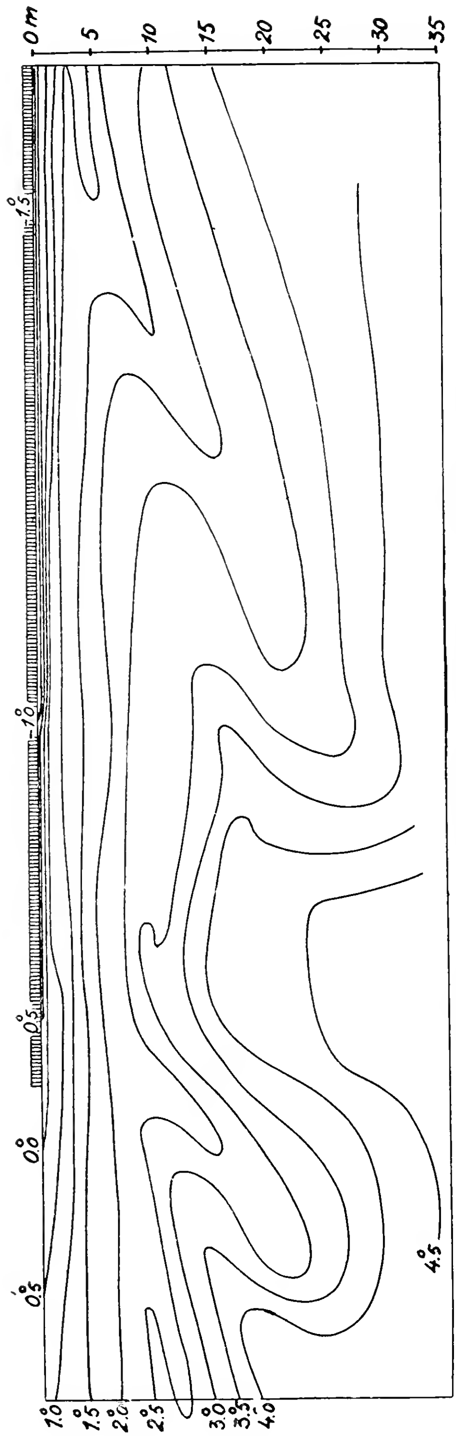


Fig. 37.—Distribution of the temperature by the melting of the ice in Gullmarfjord.

9. INFLUENCE OF FRICTION UPON THE MOVEMENT OF SEA-WATER.

Internal friction exerts a powerful regulating influence upon the movement of the water in an ocean current. In order to comprehend this, it will be necessary to consider the forces acting upon the water through friction. And it will simplify matters if we here disregard the insignificant vertical velocities in the water. Let us suppose that the water particle *a* has a velocity inferier both to that of the water above and of that below, *vide* fig. 38 a. The velocity of *a* will then be accelerated by friction with both these layers, until finally it attains their velocity. In this instance, then, the velocity of the water particle is accelerated by internal friction.

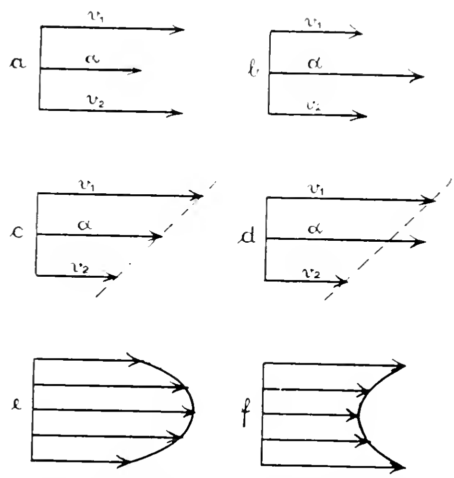


Fig. 38.—Frictional force as indicated by the movement of the water in a current

If, on the other hand, the water particle *a* is of greater velocity than the water above and below (fig. 38 b), it will be retarded until its velocity is equal to theirs. In this instance, the friction acts as a check upon the movement of *a*.

Again, if the velocity of *a* be equal to mean of the two values for velocity of the layer above and of that below, (fig. 38 c), then the retarding effect of the one will be equal to the accelerating influence of the other; i.e., the resultant value of the forces acting upon *a* through internal friction will be nil.

If the velocity of the particle *a* be not equal to the mean of the velocities above and below (fig. 38 d), then the friction in *a* will be the greater between it and the layer having the greater divergence in point of velocity from the particle *a*. The result of this will be that the velocity of *a* is finally brought, through friction, to a value equal to the mean of the two velocities in the water above and below it.

Where the current has a screwing movement, so that the vectors v_1 and v_2 (in fig. 38 d), do not lie in the same plane, or take opposite directions, then the vector representing *a* will constantly endeavour to attain a velocity and direction equal to the mean values for those of the vectors v_1 and v_2.

If we measure the velocity of the water at a great number of points in a vertical down through the sea, and draw up from these a co-ordinate system with the velocities as abscisses and depths as ordinates, then we obtain a diagram of velocity for the vertical in question. Where the resulting diagram is convex, as in fig. 38 e, then the velocity of each particle will be greater than the mean value of those immediately above and beneath; the current is then retarded by internal friction. If, on the other hand, the diagram presents a concave figure (fig. 38 f), then the velocity of each particle is less than the mean value of the velocities in the layers immediately above and below, wherefore the current will be accelerated by internal friction.

As a rule, the friction has a retarding effect upon the currents in the sea, so that the diagrams of velocity through these are generally convex. Let us suppose that all the water particles in one and the same current are retarded with the same force. The difference between the velocity of one water particle and the mean velocities above and below will then be constant for all water particles throughout the current. A diagram of velocity answering to these conditions is easily drawn, the figure being in this case a parabola (fig. 39).

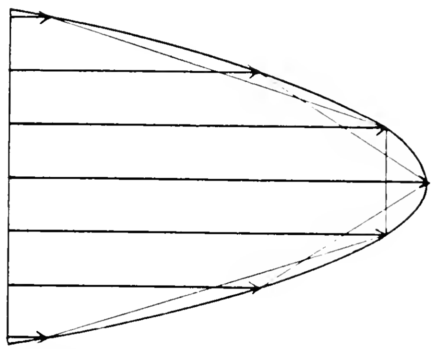


Fig. 39.—Diagram of velocity for a current with constant frictional resistance.

If the equation for this parabola be

$$u = az^2 \quad \ldots\ldots \quad (3a)$$

then the force with which the friction retards each ccm. of the current will be

$$f = -2\,ak \quad \ldots\ldots \quad (3b)$$

where k is the coefficient of friction. The more acute the parabola, the greater will be the check exerted upon the current by friction. In currents where the water flows at a great velocity in a thin layer, the retarding force is therefore very great, whereas in currents of great volume such as the Gulf Stream, it is insignificant.

In any current, where stationary conditions have been arrived at, the frictional resistance in the longitudinal direction of the current is nearly equal to, albeit naturally in an opposite direction to the force by which the current is impelled, and we can therefore, from the diagram of velocity, directly ascertain this force. If such a stationary current be disturbed by external influences, as for instance by that of the wind, the appearance of the diagram of velocity is at once changed, and we may, from the deformation occasioned therein, ascertain the magnitude and extent of the effect produced by the disturbing force upon the current. A diagram of velocity is therefore the best means we have of studying in detail the dynamic conditions of the ocean currents.

This analysis of the diagram of velocity is best carried out by dividing the curve into so small portions that each can be regarded as a parabolic curve with horizontal axis. For each such curve,, we then determine a and f, according to equations 3 a and 3 b.

Let us, for instance, consider the effect of the wind upon a surface current in the sea. The diagram of velocity for such a current normally takes the form of a parabola, the point of which lies immediately under the surface of the water, *vide* fig. 40 a, with a wind blowing across the sea in the same direction as the current, the diagram will assume the form shown in fig. 40 b, i.e. its upper portion will become concave, while the remaining parts will still continue convex. The upper portion of the current is thus accelerated by the friction. The effect of the wind extends down as far as the deformation of the diagram takes place, and by calculating a and f for the different parts of the current, we can immediately ascertain the magnitude of the force acting upon each ccm. of the water by means of the wind. If, however, the wind be blowing against the current, then the diagram of velocity will be strongly curved back at the surface, *vide* fig. 40 *c*. Here the retarding force of the friction is very great, whereas at greater depths it retains its normal value. In this case likewise we may, by dividing up the diagram and finding a and f for each portion, ascertain the magnitude of the effect produced by the wind at different depths.

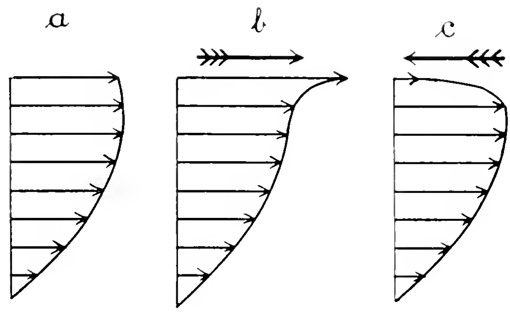


Fig. 40. Diagram of velocity for a surface current in calm weather and with wind in same and the opposite direction.

In dealing thus with the diagram of velocity, due regard should be had to the imperfection of the methods of measurement. Thus the small irregularities in the upper part of the diagram fig. 36 cannot be considered as reflecting actual conditions, but are rather due, partly to the inaccuracy of the instruments employed, partly to the fact that the measurements were not taken at exactly the same time for the different depths. If these irregularities be levelled down, however, the parabolic form is quite distinct. We find then, that the water down to 10 metres depth is sucked in under the ice with great force, and that beneath this surface current, two outward currents of inferior velocity are found at 13 and 35 metres depth. The water between these last-named currents is drawn along by them.

The foregoing examples should suffice to give an idea as to the great value of the diagram of velocity in calculating the forces acting upon a current, in considering the disturbances to which it is subjected, and in studying its nature and composition generally. Such diagrams should therefore be more widely employed in marine investigations than has hitherto been the case.

10.—ON THE CAUSE AND THE EFFECTS OF OCEAN CURRENTS.

The causes which give rise to currents in the sea are either external forces, such as the action of the wind, or physical changes in the sea-water itself, occasioning an alteration of its specific gravity. We have thus two distinct categories of ocean currents, differing widely in character, and it is important to have a clear understanding of these.

If the surface water in a given area be subjected to physical change tending to increase its specific gravity, as for instance by cooling or evaporation, it will commence to sink, and the lighter surface water surrounding will flow in from all sides. And owing to the rotation of the earth, a cyclonic movement then sets in about the sinking centre. We have thus a movement in towards the centre, and at the same time a cyclonic movement round that centre, as shown in fig. 41 a. If, again, a cyclonic wind, by friction upon the surface of the sea, should set the surface water in cyclonic circulation, then the current in question will, owing to the earth's rotation, veer off to the right, i.e. out from the centre. In this case, then, a cyclonic divergent movement is brought about, *vide* fig. 41 b.

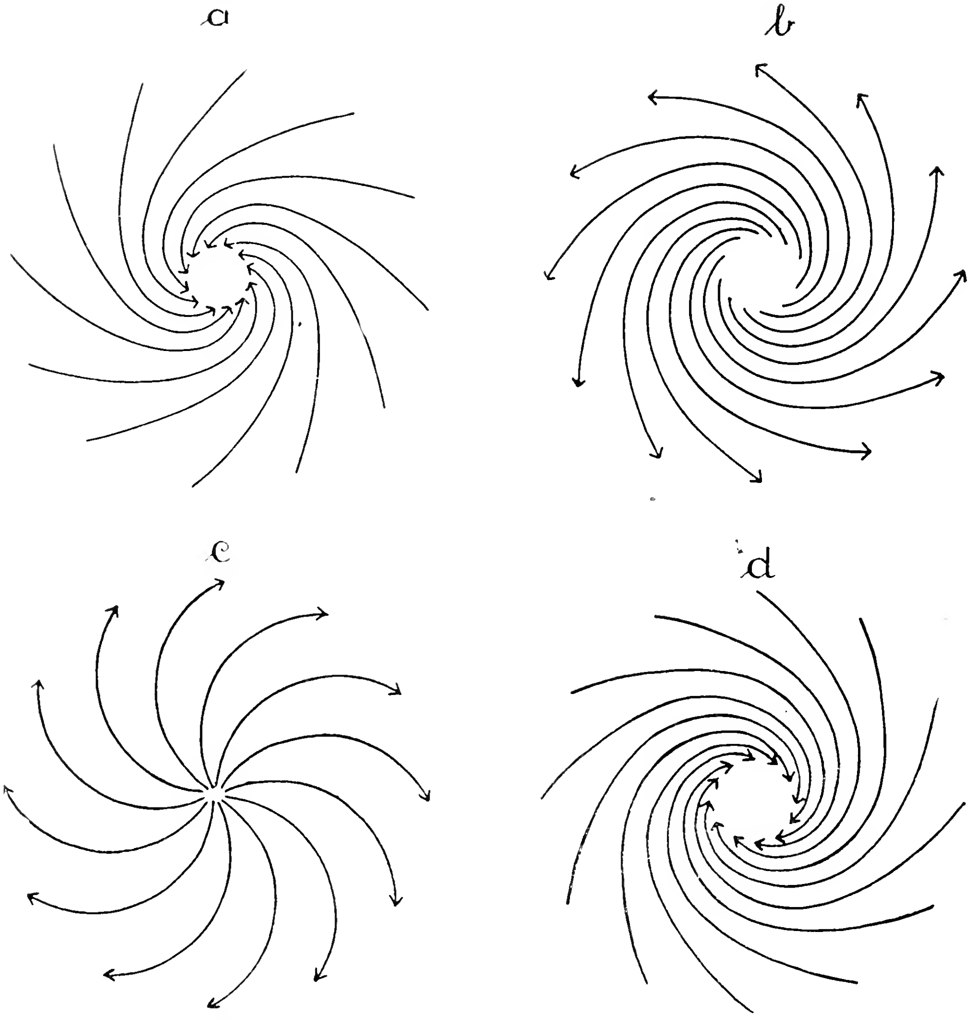


Fig. 41.—(*a*) Cyclonic current about a sinking centre.
(*b*) Cyclonic current produced by cyclonic wind.
(*c*) Anticyclonic current about a rising centre.
(*d*) Anticyclonic current produced by anticyclonic wind.

If, however, the specific gravity of sea water be diminished by physical change at any point, the water will rise towards the surface, spreading out there in all directions from the rising centre. And the earth's rotation occasioning at the same time an anticyclonic circulation, the total movement will then be divergently anticyclonic, fig. 41 c. If, on the other hand, an anticyclonic wind should set the surface water in anticyclonic circulation, then the current will be forced in by the earth's rotation towards the centre, giving rise to a convergent anticyclonic movement, fig. 41 d.

It is of course obvious, that a current concentrating upon a given centre will be far more strongly marked than one spreading its waters out in all directions. A current occasioned by cyclonic wind will therefore be but slightly perceptible, while those induced by the action of anticyclonic winds, such as the current round the Sargasso Sea, and the analogous currents in the South Atlantic, the Indian ocean and the Pacific, will be far more markedly apparent. Moreover, the anticyclonic currents proceeding from a rising centre outward, will be comparatively insignificant, whereas the cyclonic movement of water in towards a sinking centre, e.g., towards the Arctic region, or the point where the Labrador current disappears, etc., will be strongly marked. We have, then, the following rule: Cyclonic currents in the sea are occasioned by physical causes, the anticyclonic currents by the action of the wind.

As the wind has no immediate effect upon the specific gravity of water, it follows that a current occasioned by the wind will be restricted to a single water layer, and is, in consequence, limited in extent, and simple in character. The Sargasso current, (*vide* fig. 24) may, as a matter of fact, be taken as the type of all great wind currents in the sea.

Despite their simplicity of character, however, these anticyclonic wind currents nevertheless present many features of interest, and are well worthy of further study. Such a vortex, with its powerful pressure in towards its centre, will be highly coherent and, in spite of the enormous extent involved, of distinctly individual character, with marked isolation from the surrounding water. One result of the pressure on the centre is that the vortex there attains a considerable depth. The Sargasso current, for instance, extends down to 600 metres. And, further, the strong vertical movement of the water in such a vortex enables it to carry down the heat of the surface water to a great depth; there is a continual wearing upon and heating of the subjacent colder water, so that the vortex is constantly intaking and assimilating water from below. The Sargasso current discharges unto the Gulf Stream 25,000,000 tons of water per second, which is as much as to say that it draws from its substratum just that quantity of water every second.

Currents arising from physical changes in the sea-water, on the other hand, are otherwise constituted, and behave in a very different way. They are not restricted to a single layer, but may traverse several such, and have thus far greater freedom of movement than the wind currents. Consequently, it is upon the former that the task of bringing about interchange between the waters of different regions and different depths devolves. The Gulf Stream is the type of this category.

The motive power in these currents is supplied by the Archimedean forces in the sea. When the specific gravity of the water in a certain layer has been sufficiently increased by physical change, it sinks down thence to a subjacent layer answering to its own specific gravity: where a decrease in the specific gravity takes place, the movement is of course reversed. In the Gulf Stream layer, water is introduced from the subjacent layer owing to rise of temperature taking place in the tropics: in the Arctic regions, on the other hand, water from the Gulf Stream passes, on cooling, from that current to the layer beneath.

Where water is thus introduced into a layer, the layer in question becomes thicker than its surroundings, and Archimedean forces then arise which drive the water of that layer from its place. Similarly, a layer losing some of its water becomes thinner, and the same forces tend to lead water thither from without. Owing to the earth's rotation, this movement of the water proceeds, not in a straight line, but in a spiral, as shown in figs. 41 a and c. If, in one and the same layer, water is introduced at one point and water carried off at another, then the layer in question will become thicker at the former than at the latter, giving rise to Archimedean forces which drive the water from the point of inflow to the point where water passes out. The Gulf Stream, for instance, is 600 metres deep in the tropics, but only 200 metres deep at Spitzbergen. We see, then, that the Archimedean forces in the Gulf Stream drive the water from the tropics towards Spitzbergen. Owing to the earth's rotation, the movement in question becomes S-shaped, *vide* fig. 42. If the water at the point of inflow be set in motion by an anticyclonic wind, then the physical process by which the water is introduced is transferred to a greater depth, whereby the Archimedean

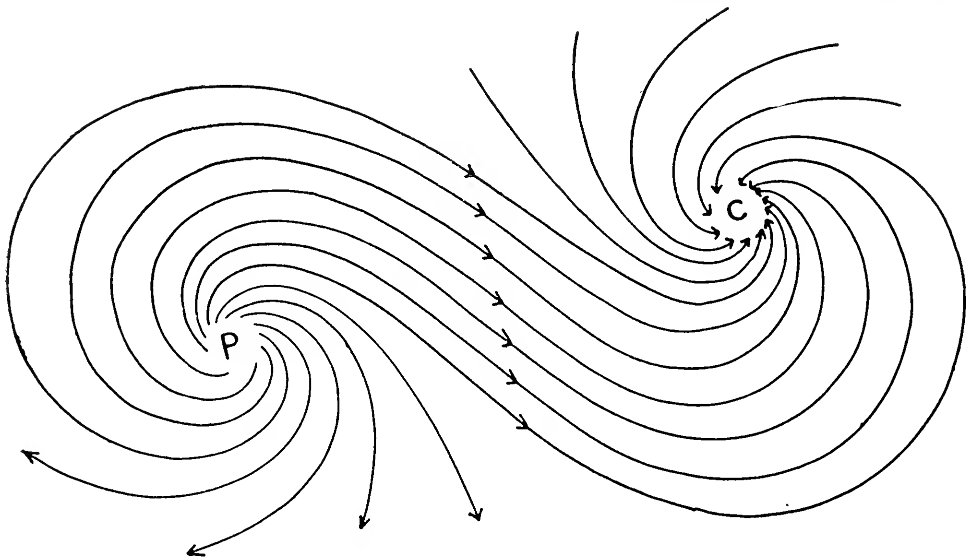


Fig. 42—Current from centre of production to centre of consumption in an oceanic layer.

forces attain a higher degree of intensity, and the current becomes greater. This takes place in the Gulf Stream, *vide* fig. 43.

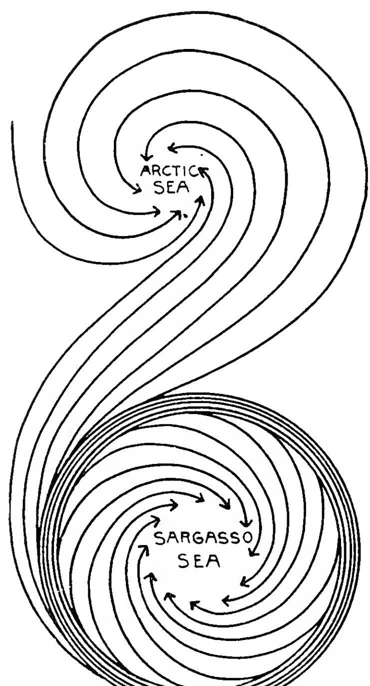


Fig. 43.—Schematic diagram showing movement of surface water in the Gulf Stream.

The effect of the currents originating in physical change in the water is then simply that of transporting water of a certain character from a region where such water abounds to regions where it is rare. And the quantity of water carried by such a current will depend entirely upon the production and consumption of the kind of water in question. The Gulf Stream carries about 25,000,000 tons of water per second. Hence, it follows that a corresponding amount of such water is produced in the tropics and consumed in the Arctic regions at the same rate.

And from this we may also conclude, that the complementary physical processes whereby water is added to or drawn from a certain layer adapt themselves so as to balance one another. What takes place is evidently this: a decrease of the quantity of water in a layer favours the development of forces tending to introduce water from without, and vice versa. And the present state of the water throughout the sea is the result of thousands of years of such adaptation.

The Archimedean forces which drive a current of this nature adapt themselves to the quantity of water to be carried forward and the degree of resistance to be encountered. In order to understand this, we may once more take the Gulf Stream as an example. If the production of Gulf Stream water in the tropics, and corresponding consumption of the same in the Arctic regions were to cease, then the lower boundary surface of the Gulf Stream would soon become horizontal, and the Archimedean forces which drive the current forward would disappear, with the result that the forward movement of the water itself would cease. If, on the other hand, the production and consumption of Gulf Stream water were to become greater than is at present the case, then the lower boundary surface of the Gulf Stream would assume a still steeper slope, and the Archimedean forces attain a higher degree of intensity than at present. This increase of force would arise in order to meet the necessity for transport of a greater volume of water than the Gulf Stream is now required to carry.

In order to demonstrate the importance of the Sargasso vortex to the Gulf Stream, the following experiment was made. A rectangular tank, 50 cm. long, 50 cm. deep, and 5 cm. broad, and having glass walls, was filled with water, and heating and cooling apparatus introduced, the latter constructed on the same principles as applied to the heating of rooms, etc., i.e., consisting of metal receptacles through which a current of warm or cold water could be transmitted. The pipes through which the heating or cooling water was carried to the receptacles were carefully isolated. In accordance with the conditions actually met with in the ocean, the cold centre was placed at the surface of the water at one end of the tank, and the warm one a little below the surface at the other end. The cold centre thus represents the cooling of the water in the Arctic regions, the heating apparatus answering to the corresponding influence at the bottom of the Sargasso vortex.

After the experiment had been in progress for some time, and stationary conditions arrived at, some potassium permanganate solution was introduced into the water near the middle of the tank, and immediately beneath the surface. The solution, easily visible on account of its colour, moved over to the cold centre, and then sank to the lower level of the warm centre, moved across to this, and then rose thence to the surface of the water, recommencing here its movement towards the cold centre again, as shown in fig. 44 a. Owing to the force of the circulation, the circulating layer of water soon became coloured right through, until only a narrow strip running obliquely down remained untinged, *vide* fig. 44 b. At last this, too, disappeared, and the entire layer was coloured. The water layer beneath the warm centre remained entirely uncoloured, thus indicating that no interchange takes place between the circulating layer and that subjacent. On introducing a similar coloured solution into this lower layer, it appeared that the movement of the water here was altogether insignificant. The temperature of this layer was the same as that of the cold centre itself. The current leading from the cold to the warm centre was slightly warmer than the bottom layer, but the warmest water in the tank was that which flowed from the warm centre to the cold.

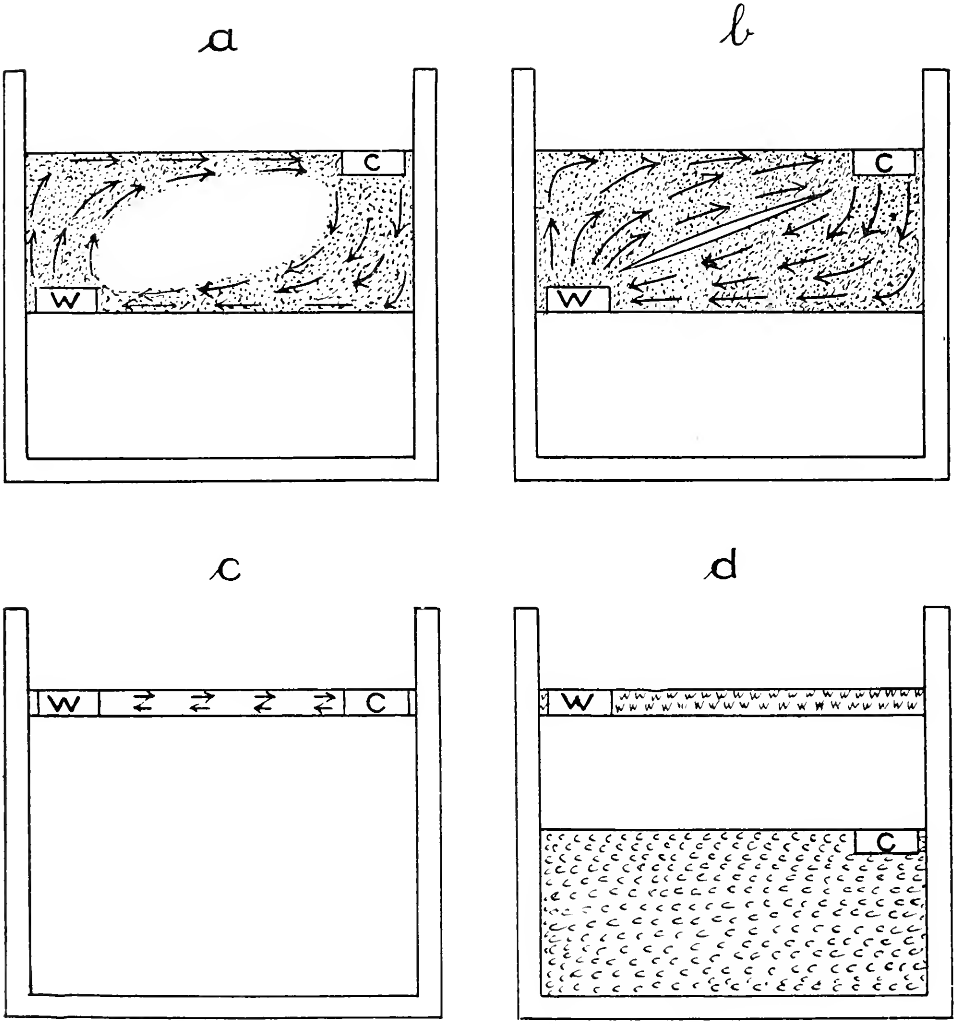


Fig. 44.—Experiment illustrating circulation of the Gulf Stream.

A further experiment was thereafter made with both warm and cold centres placed at the surface of the water. When stationary conditions had been reached, it was here found that a very slight degree of circulation was taking place between the warm and the cold centre, the entire remaining mass of water in the tank being motionless, as shown in fig. 44 c. Finally, the cold centre was placed at a lower level than the warm. In this case, as with the foregoing experiments, a highly intensive circulation at first arose throughout the whole of the tank, but as soon as this had given place to a stationary situation, it was seen that the entire mass of water in the tank remained altogether motionless. The water at a higher level than the lower side of the warm centre had then the same temperature as the warm centre itself, and that below the level of the top of the cold centre the same temperature as this latter, *vide* fig. 44 d.

From these experiments important conclusions may be drawn with regard to the Gulf Stream. The actual bottom water of the ocean does not participate in the circulation of this current, which affects only water within the depth to which heat is carried down by the vortex of the Sargasso sea. The Gulf Stream thus presents a well-defined, closed circulation with a warm surface current from the tropics to the Arctic ocean, and a cold, deep-water current in the opposite direction. It is at the surface of the water in the Arctic, and at the bottom of the Sargasso vortex in the south, that the physical changes take place which give rise to the circulation of the entire current. From the experiments referred to it is seen that these changes act in co-operation, the quantity of water heated in the tropics corresponding exactly to the amount cooled in the Arctic. Even when the warm and cold centres are placed at the same level, or the former at a higher level than the latter, this rule is strictly complied with. (In the last case, the quantity of water cooled and heated is nil, the centres being surrounded by water of their own respective temperature.) This remarkable adaptation of the physical processes is perhaps the most important factor in regulation of the condition of the sea.

From fig. 44 b it will be seen that if the Sargasso vortex did not exist, and the sea-water were only heated by the direct action of the sun's rays upon its surface, then there would be no Gulf Stream, but only a very slight surface current. The oblique strip in fig. 44 b corresponds to the lower surface of the Gulf Stream, which is likewise situated at a greater depth about its warm centre in the tropics than at the cold centre in the Arctic.

The experiments indicate, as a general rule, for the two complementary physical changes, that the process whereby the specific gravity of the water is reduced must take place at a greater depth than that which increases it, and that the greater this depth the more easily will a current develop. If, however, the two processes take place at the same level, or with the reduction of specific gravity at a higher level than the reverse process, then no current will be produced thereby. It is thus not all physical processes in the sea which give rise to ocean currents.

It may occasionally happen that two opposite physical processes at the same level enter into co-operation, and thus set up a current. This is accomplished by a massing of the products of the one process until the difference of level necessary for the propulsion of a current is reached. The Labrador current is itself an instance of a current originating in just this very way. The melting of the ice in the Arctic basin produces a mass of brackish water, which has to be carried away. This water therefore collects until it has formed a layer so deep as to be capable of forming a current, the volume of the latter then corresponding to the further production of brackish water beyond that point.

As to how far the Gaspé current should properly be considered as belonging to this last category is a question which can only be determined by further investigation. The physical process in which it originates is the mixing of St. Lawrence water with sea-water outside the mouth of the river. It is possible that this mixing process extends, owing to ebb and flow of the tide, down to a considerable depth. It may, however, take place at the surface, in which case the mixed water would only by accumulation attain a sufficient depth to give rise to a current, when the amount of water transported thereby would answer to the quantity of mixed water thereafter produced outside the mouth of the St. Lawrence.

The Gaspé current is one of the few ocean currents which may conveniently be observed and studied, as regards cause and progress, by hydrographical measurements at its point of origin, throughout its course, and at its termination. Such study is, moreover, of the highest importance, not least as a means towards the better comprehension of similar problems which present themselves in the case of other currents whose origin and progress are less easily discernible. The value of the Gaspé current in this particular respect has, as a matter of fact, already been manifested, the investigations of Dr. W. Bell Dawson[1] upon this current and its effect on the circulation in the gulf of St. Lawrence having been of great assistance to me in the preparation of this chapter.

In order to demonstrate the effect of the wind upon the Gulf Stream, the following experiment was carried out. An elongated rectangular tank with glass walls

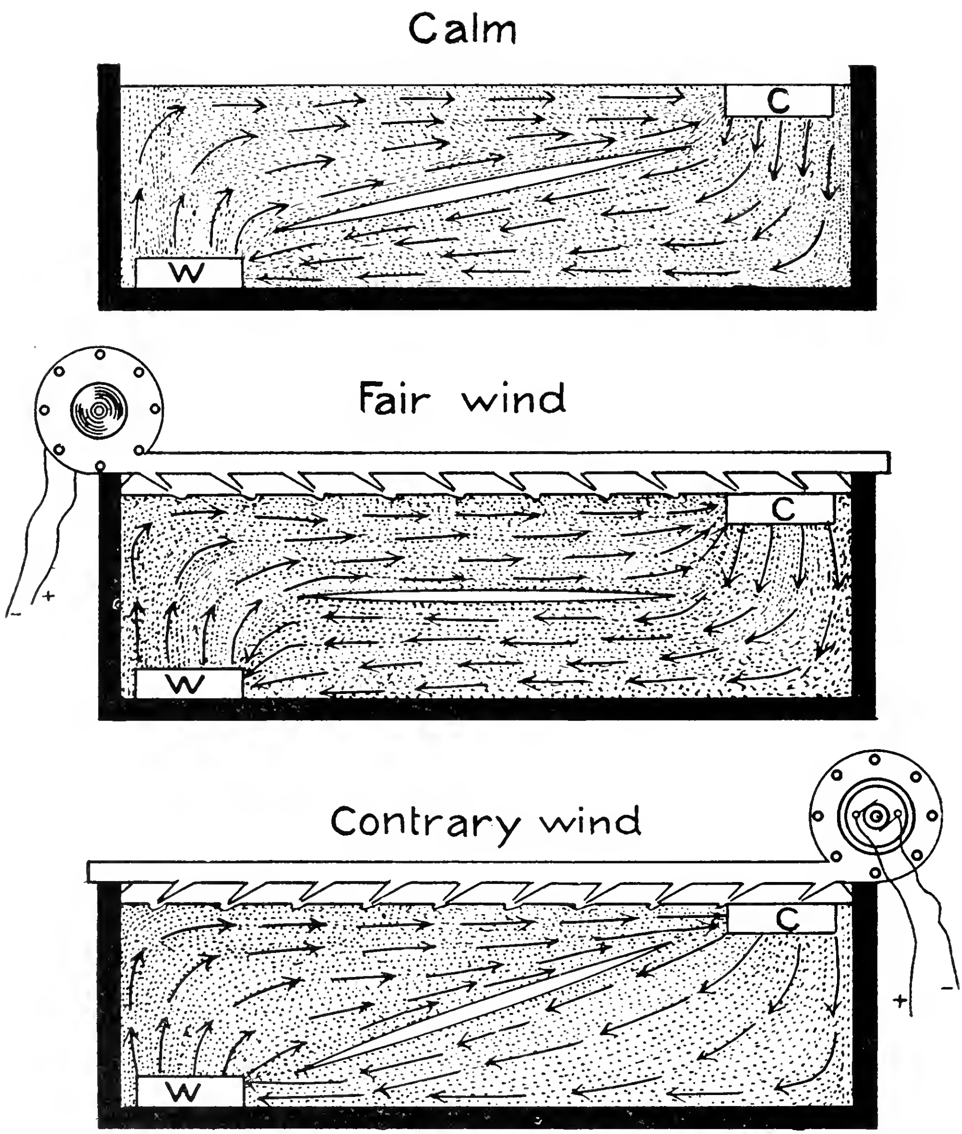


Fig. 45.—Influence of the wind upon the Gulf stream.

(*vide* fig. 45) was furnished with hot and cold centres, the former at one end of the tank, near the bottom, and the latter at the other, at the surface. The upper diagram in fig. 45 shows the circulation this produced. On introducing a coloured solution,

[1] *W. Bell Dawson.* Survey of Tides and Currents in the Canadian Waters. *Vide* series of Reports issued by the Department of Naval Service, Ottawa.

there appeared the oblique strip which separates the heated water from the cooled, answering to the under surface of the Gulf Stream in the sea. By means of an electric turbine, a current of air was then directed through a number of tubes set obliquely to the surface of the water, producing a very effective tangential wind action upon the same. The second diagram in fig. 45 illustrates the effect of the wind when blowing in the direction of the artificial stream answering to the Gulf Stream produced as above described. The oblique strip, corresponding the lower surface of the Gulf Stream, then approaches the horizontal, i.e., the Archimedean forces in the current are here highly weakened, and contribute only in a very slight degree to propulsion of the water. As a matter of fact, the strip can, by sufficiently increasing the force of the wind, be made to slope the opposite way, when the Archimedean forces will actually oppose the progress of the current. On the other hand, with a wind in the opposite direction to that of the current, as shown in the lowest diagram, fig. 45, the slope is increased, the Archimedean forces being then greatly augmented.

The meaning of this is not difficult to comprehend. The hot centre *W* produces a certain quantity of warm water, and the cold centre *K* a certain amount of cold each second, quite independently of the wind. By adaptation, consisting of change in temperature, a state of things is soon reached when the cold centre consumes warm water and produces cold at a rate per second exactly corresponding to the rate at which the warm centre consumes the cold and produces warm. The quantity of water flowing per second through any section of the current will be exactly equal to the amount of water thus transformed. Whether the current be subjected to the action of the wind or not, this quantity of water must flow on. In the case shown in the first diagram, fig. 45, the current is opposed only by the internal friction of the water itself, and the Archimedean forces have here only this resistance to overcome. In the second case, the progress of the current is aided to a high degree by the action of the wind. The result of this is, at first, an acceleration of the current; this, however, soon causes the oblique stratum to take up a more horizontal position, in consequence of which, the Archimedean forces are so diminished that their motive power only suffices to propel the requisite quantity of water when aided by the action of the wind. Finally, in the third case, where the forward movement of the water is greatly hindered by the wind, the current is at first retained, then, with the consequent increased slope, the Archimedean forces attain a higher degree of intensity, until at last they furnish motive power sufficient to propel the due quantity of water despite the resistance of the wind.

From this we see how insignificant is the part played by the wind as a motive power in currents of this nature.

11. BJERKNES' CIRCULATION THEORY.

The Bjerknes' theory of circulation, with the clear and profound insight which it displays, is in my opinion so eminently valuable an adjunct to the study of hydrographical phenomena that I have thought it necessary here to give a general idea of the principles contained therein, inasmuch as these bear directly upon marine conditions. I have endeavoured, in this survey, to keep to the simplest possible mathematical formulæ only; readers wishing to follow the entire process of deduction and examine for themselves the manner in which the results are arrived at, may refer to Bjerknes' own works on the subject, in particular to his comprehensive treatise on dynamic meteorology and hydrography, published by the Carnegie Institute, of Washington, U.S.A.

We may commence with Bjerknes' analysis of the Archimedean forces. As a result of this analysis it is shown that the measure of the forces in question may be taken as represented by the number of parallelograms formed in a hydrographic section by the intersection of the isobars with the isosteres. It is here presupposed that the figures in question are drawn for each whole unit of pressure or specific volume. Each such parallelogram endeavours to bring about a rotary movement of the water, whereby the isosteric lines would be brought into the horizontal, *vide* fig. 46.

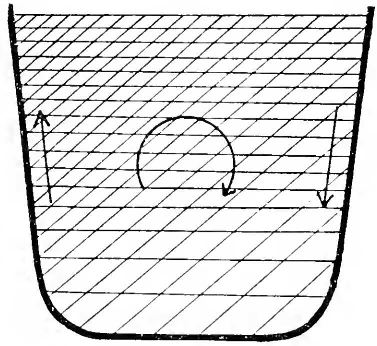


Fig. 46.—Bjerknes' diagram of the Archimedean forces in the sea.

It is interesting to pursue the study of this simple geometrical diagram so as to embrace the three dimensions. We have, then, in place of the isobars and isosteric lines shown in fig. 46, a series of isobar and isosteric surfaces, while the parallelograms become tubes, each presenting a parallelogram in section, these striving to turn the water round in such a manner as to render the isosteric surfaces horizontal. As the isobar and isosteric surfaces cannot terminate in the water itself, but must continue until they reach either surface or bottom, so also the isobar-isosteric tubes formed by intersection of the two must either continue until they reach one limit of the water or else turn back upon themselves. As each tube lies between two adjacent isobar surfaces, its course becomes horizontal.

These isobar-isosteric tubes are called solenoids. Each solenoid produces the same whirling effect in the water, and the number of solenoids is therefore a measure of the degree of intensity attained by the Archimedean forces.

The number of solenoids depends upon the number of isosteric surfaces; i.e., upon the stability of the sea-water, and upon the obliquity of the isosteric surfaces themselves. As the isosteric surfaces fall into a horizontal position, the solenoids disappear entirely. Consequently, the greater the stability of the water layers, and the greater the obliquity of the isosteric surfaces, the greater will be the number of solenoids.

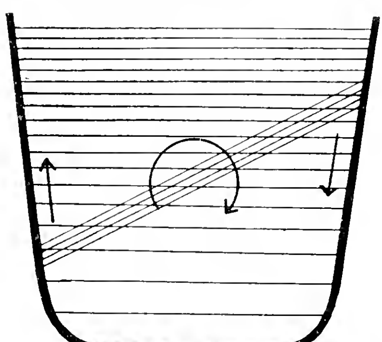


Fig. 47.—Solenoids in the separating surface between two water layers.

Where a homogeneous water layer rests upon another of higher specific gravity, there will be no isosteric surfaces within the layers; such will, however, be found in the separating surface between them. In this boundary surface, then, the solenoids will be located, *vide* fig. 47. It is easy to find the number of solenoids in this case. If the specific volume of the upper layer be v_1, and that of the lower v_0, there will then be $v_1 - v_0$ isosteral surfaces in the boundary surface. And if the pressure at the lowest point of the boundary surface be p_1, that at its uppermost point p_0, then these isosterical surfaces will be intersected by $p_1 - p_0$ isobaric surfaces. The number of solenoids A will thus be $A = (p_1 - p_0)\ (v_1 - v_0)$ where $p_1 - p_0$ indicates the slope of the isosteric surfaces, and $v_1 - v_0$ the stability of the water layers. The number of solenoids is the product of these two factors.

In order to ascertain the effect of the solenoids upon the movement of the water, Bjerknes takes a closed curve composed of water particles in the sea, and calculates the product of the curve's length and the mean velocity of the water along its course. This product is called the circulation of the curve. Where the velocity of the water is not uniform at all parts of the curve, the circulation may be most easily arrived at by integrating the tangential velocity of the water along the curve for the whole length of the same.

$$C = \int u_t\, ds \qquad (4)$$

This integration may best be represented graphically by setting out the length of the curve, reckoned from any point, in a rectangular co-ordinate system, as abscissa, with the tangential velocity of the water as ordinates, and then, by means of a planimeter, measuring the extent of the surface between the curve thus produced and the abscissal axis. Fig. 48 shows the application of this method for calculating the circulation of a circular curve situated in a current. The current is here taken as flowing

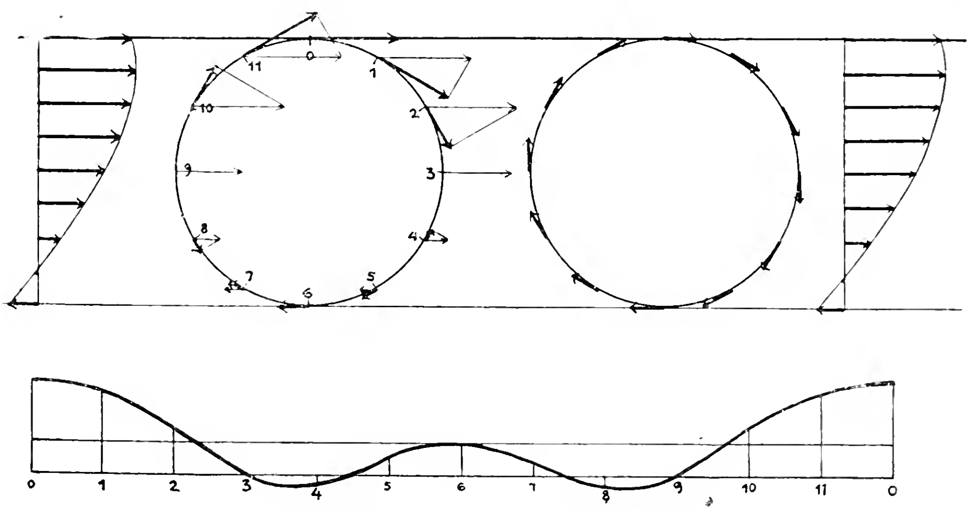


Fig. 48.—Method of calculating the circulation in a closed circulation curve in a sea current.

horizontally, at the velocities shown in the diagram on either side of the figure. The curve is first divided up into a suitable number of parts. At each point of division, the velocity of the water is marked off, and its tangential component along the curve constructed. In the diagram at the bottom of the figure, the length of the curve reckoned from the point 0 is set off as abscissa. At the points 0, 1, 2 of the abscissa, corresponding to the similarly designated point on the closed curve, the tangential velocities are thereafter marked off as ordinates. The area of the diagram is then measured with the planimeter, the part below the abscissa being of course taken as negative, and subtracted accordingly; this gives the circulation of the closed curve.

If we divide the circulation thus arrived at by the length of the curve, we obtain the mean tangential velocity along the closed curve. By marking this off on the diagram, we obtain in the horizontal line there dividing the same into two parts, so that the area above the line is equal to that below.

This mean tangential velocity may now be again applied to the original closed curve. Circle No. 2 in fig. 48 shows what is then arrived at, viz., the rotary movement of the water.

The circulation of closed curves in the sea thus affords a measurement of the rotation of the water. The translatory movement in the water is not discernible in the circulation. A closed curve in a current, where all the particles have the same velocity will always have a circulation = 0. By calculating the circulation, we thus obtain the pure rotary movement of the water, *vide* fig. 48.

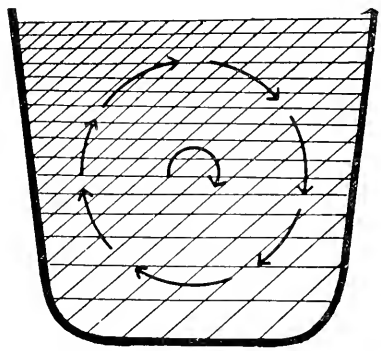


Fig. 49.—Relation between solenoids and circulation.

It now only remains to find the relation between the circulation C, and the number of solenoids A. To arrive at this, we lay out a closed curve in the section, fig. 46 (*vide* fig. 49), and calculate the circulation in the manner shown in fig. 48. This gives a certain value, C. This value is, however, not invariable, but is continually augmented by the rotary tendency of the solenoids. According to Bjerknes, the increase of circulation per second is equal to the number of solenoids within the closed curve. After the lapse of t seconds, therefore, the circulation of the curve will be

$$C = C_0 + A\,t$$

By derivation we then obtain,

$$\frac{d\ C}{d\ t} = A \quad \ldots\ldots\ldots\ldots\ldots \quad (5)$$

indicating that the increment of circulation per second is equal to the number of solenoids. By means of Bjerknes formula for the relation between distribution of density in the sea and movement of the water, we can thus in the easiest possible manner calculate the latter from the former.

Obviously, the circulation is affected, not only by the distribution of density, but also to a very high degree by the earth's rotation. Each latitude circle of the globe has a considerable circulation owing to the earth's rotation. By a simple calculation, this will be found to be $C = 2\omega S$ where ω is the angular velocity of the earth, and S the area of the latitude circle. Bjerknes has shown, however, that this formula applies equally to any closed curve on the globe, if we take S as indicating the area given by projection of the curve upon the equatorial plane; and, further, that the alternation in the circulation of such a closed curve per unit of time amounts to

$$\frac{dC}{dt} = 2\omega \frac{dS}{dt}$$

where $\frac{dS}{dt}$ indicates the alternation per second in the area of the curve's projection upon the equatorial plane. Where S is reduced, the curve assumes a cyclonic circulation, while when S is increased, the circulation will become anticyclonic.

Finally, the circulation is also influenced by the friction. For the effect of this, Bjerknes has introduced the symbol R. As both the earth's rotation and the friction as a rule oppose the distribution of density, Bjerknes gives the influence of both a minus sign, and writes

$$\frac{dC}{dt} = A - 2\omega \frac{dS}{dt} - R \ldots\ldots (6).$$

This formula contains all that influences the circulation of the water in the sea.

12. SOLENOIDS IN THE CANADIAN ATLANTIC AREA.

Bjerknes' circulation theory will, it may safely be said, play a prominent part in future oceanographical investigations, on account of the ease with which it may be applied to hydrographical observation material, and the clearness and direct practical value of the results thereby obtained.

Its chief importance in the immediate future will be as a system upon which to order and arrange the collecting of oceanographical observation material. The system requires, in this respect, certain conditions, of which those concerning the distribution of density and specific volume have been excellently fulfilled by Dr. Hjort's measurements in the Canadian waters, while those concerning the distribution of velocity have as yet proved impossible of realization.

I purpose, then, in the following pages to apply Bjerknes' circulation theory, as far as can possibly be done, to the present material, drawing such conclusions as may thence be arrived at, and finally indicating what yet remains to be done in order that the system may be utilized to its fullest extent, and by the gradual adaptation of measuring instruments, methods of observation, etc., directed towards the solution of still further oceanographical problems.

The weak point in the methods of observation hitherto in vogue is the system employed for measurements of velocities. Bjerknes' theory demands two kinds of measurements in this respect: one for the calculation of $2\omega \frac{ds}{dt}$ and the other for that of R. An instrument for the former already exists,[1] and all that remains here is to arrange the observations in such a manner as to render them suitable for the purpose of calculating the influence of the earth's rotation according to Bjerknes' theory. For the latter calculation, we have no suitable instrument as yet; it is, however, an easy matter to construct one, and to arrange the observations so as to furnish the requisite material for calculation of R.

As regards A, the material collected by Dr. Hjort from the Canadian waters is in this respect beyond question the best that has ever been obtained from the atmosphere and the sea. Hjort's idea was to procure the fullest possible survey of hydrographical conditions, spring and summer, in the North Atlantic area, and this, as it proved, coincided entirely with Bjerknes' requisition as to get two complete and simul-

[1] *Hans Pettersson.* A recording current meter for deep sea work. Quarterly Journal of the Royal Meteorological Society, vol. XLI, No. 173, January, 1915.

taneous surveys of density conditions in the area. From a dynamic point of view, Hjort's measurements leave absolutely nothing to be desired.

In applying Bjerknes' theory to hydrographic observations, it will be well to keep to one thoroughly connected system of units, as, for instance, the centimetregrammesecond system. Where these units do not suit, other convenient units can always be arrived at by multiplying by suitable powers of 10. Pressure in the sea increases by very nearly 100,000 c.g.s. units for every metre depth. If therefore, we take as unit of pressure of 10^5 c.g.s. then the pressure will increase by one such unit for every metre depth. Such unit of pressure we may call a decibar. To the pressure of the sea-water should be added that of the atmosphere, amounting to about 10 decibars. In the following, however, we shall not have occasion to reckon with absolute pressures, but only with differences of pressure, and may therefore neglect this initial pressure, taking the pressure at the surface of the sea as a starting point. The depth in metres will then likewise serve to express the pressure in decibars; thus at 10 metres' depth, the pressure is 10 decibars, at 300 meters, it is 300 decibars, and so on. This identity of values will, as we shall subsequently see, serve greatly to simplify the graphical and numerical operations involved.

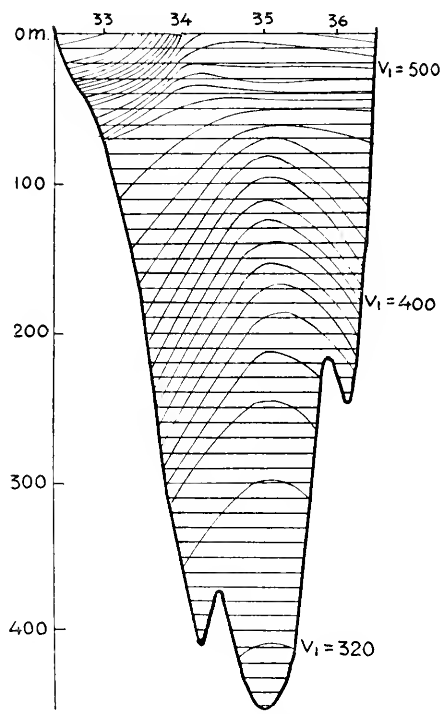


Fig. 50.—Isobars, isosters and solenoids in section IX.

For specific volume, it is convenient to take 10^{-5} c.g.s. as the unit. Then instead of writing, for instance, v=0·97261, we take 10^5 v=97261, and as the two first figures in values for specific volume are always 97, and we have only to reckon with differences of the same, we can discard these, and write $v_1 = 261$. Thus in the case of specific volume, we have only to deal with three-figure values, which again serves to render the necessary calculations easier.

By thus taking the isobars as 10^5 times too far apart, and the isosteres 10^5 too close, we obtain cgs. solenoids.

Fig. 50 shows isobars, isosteres, and solenoids in section IX. The isobars have been drawn for each ten metres depth, and the isosteres, for each tenth unit of v. In fig. 50, then, each square contains 100 cgs. solenoids.

If now, in the isosteric sections I-XX, plates VIII and IX we work out in a similar manner the isobars for each 1 metres depth, we obtain a good view of the distribution of the solenoids and their number throughout the entire area of investigation. Where the isosters have been drawn for each tenth unit of v_1, each square will contain 100 solenoids, but in the upper parts of the section, where they are taken for each fiftieth unit of v_1, there will be 500 solenoids to the square. It should hardly be necessary, however, to draw up in practice a linear system so simple as that of the isobars for each 10-metre depth; this may easily be imagined. On so doing, we obtain

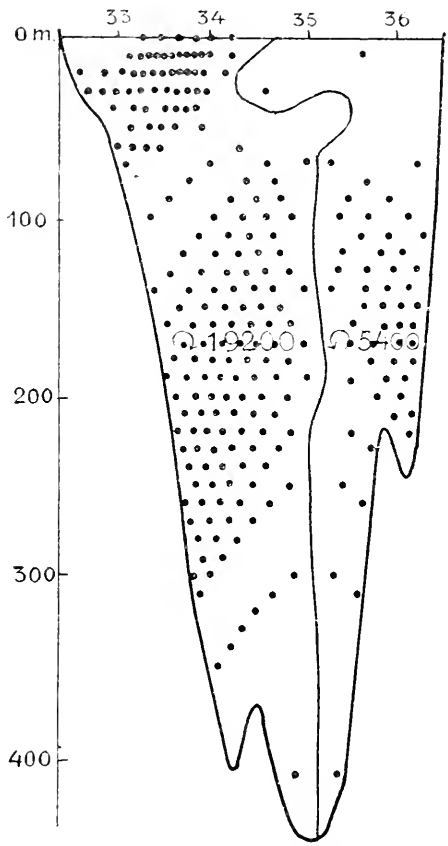


Fig. 51. Solenoids in section IX.

from the isosteric sections I-XX, an immediate idea as to the position of the solenoids and their numerical values during spring and summer in the Canadian waters.

Another good way of showing the number and distribution of the solenoids is as follows: After drawing up the isobars and isosteres, the points of intersection between them are marked out, and both line systems then erased. This gives a system of points, each representing 100 solenoids. By counting the points, and multiplying their number by 100, we obtain the number of solenoids (*vide* fig. 51).

Each solenoid lies between, and is bounded by two adjacent isobar surfaces. Its course is thus pefectly horizontal, and its vertical extent amounts to exactly one metre. Its breadth is considerably greater, being equal to the horizontal distance between the isosteric surfaces. And as it is always bounded horizontally by the same isosteric surfaces, its course may be arrived at by drawing upon a chart the isosteric lines for the level at which the isosteres are situated. This chart will then also give the course and number of all other solenoids in a water layer of one metre's thickness at the same level.

There are thus many ways of drawing up graphic presentments of solenoids. We need not, however, here devote more time to these, but may pass directly to the problem of calculating, in the simplest and surest manner, their number, *A*. The number of solenoids between two stations in a horizontal water layer of one metre is obviously equal to the difference in specific volume between the two stations at the level in question. Our first task, then, will be to calculate this difference. Let us, for instance, calculate the solenoids between the stations 34 and 35 in section IX. First of all, we note down the depth at which the water samples from each station were taken. This is shown in the first column of table 3. The second column shows the specific volumes for station 34, and the third those for station 35. The fourth column contains the differences between the specific volumes; i.e., the number of solenoids in a water layer one metre thick situated between the two. The signs before the figures shows the rotary tendency of the solenoids. In the vertical, with greater specific volume, the water will strive to move upwards; where it is less, the tendency will be downwards. The solenoids will thus endeavour to bring about such a rotary movement of the water as should cause it to rise at station 34 and sink at station 35. This is what the signs here show. The signs have thus a certain relation to the order in which the stations appear in the tables. If the stations be reversed, the signs will be changed.

The next operation is to calculate the number of solenoids in those rectangles in the sea which are bounded by the two stations and the different depths. For this purpose, we calculate, from the figures in column 4, mean values for 1-metre water layers at the different intervals of depth. These are shown in column 5. Multiplying by the depth of the intervals in metres, we obtain the desired number of solenoids, as shown in column 6. By this simple and rapid means, it is possible to calculate the number of solenoids between any pair of stations in the area where observations were carried out simultaneously, or nearly so, however great may be the distance between the stations. The number of solenoids between a station in the Arctic and another at the equator may be calculated as easily as the corresponding value for two stations in the gulf of St. Lawrence. And this is just one of the features which render Bjerknes' circulation theory so useful in discussing the greater phenomena of the sea.

If the two other pairs of stations in section IX, 33-34 and 35-36, be treated in the same manner, we shall then have obtained all the solenoids in section IX, which can be found from the hydrographical observations there carried out. Fig. 52 shows the number of these, and the areas within which they are found. Here, then, we have yet another method of presenting solenoids. Of the various methods in which this can be done,those shown in figs. 50 and 51 are clearer, but that in fig. 52 is more correct.

By the method shown in table 3 and fig. 52, we obtain only the solenoids which are found between the hydrographical stations, but not those lying outside. For the latter, the methods shown in figs 50 and 51 are more convenient, permitting, as they do, extrapolation so as to include also the area outside the stations. This extrapolation method cannot well be applied to the more exact procedure shown in fig. 52. The extrapolated values might also be of so little value as to leave no reason for preferring, on this account, figs. 50 and 51 to fig. 52. The numerical method shown in table 3 should therefore be regarded as the best way of arriving at the number of solenoids.

On adding up the figures in column 6 of table 3, we obtain the total number of solenoids between station IX 34 and IX 35. The addition may be made either from above or from below. The latter is preferable, the water at greater depths being as a rule calmer, with fewer solenoids. It is therefore advisable to commence from below, with O, and then let the perturbations in the upper water layers appear through the greater number of solenoids there present. The lowest level from which measurements are available will then be the starting point, and the number of solenoids will be shown as from this level to all levels above. Column 7 in table 3 shows the sums of the solenoids.

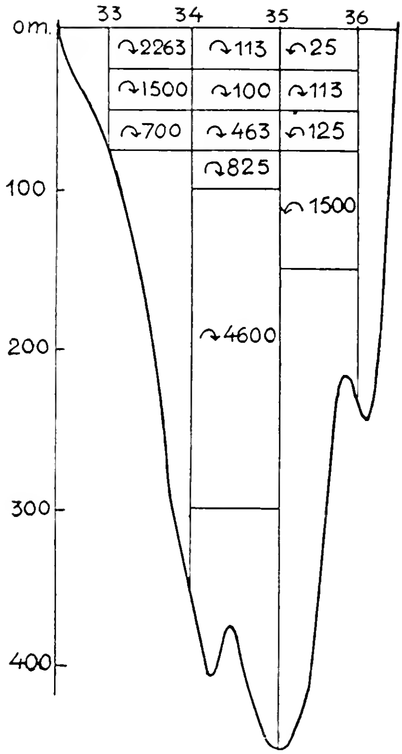


Fig. 52.—Amount of solenoids in section IX

Obviously, the number of solenoids as thus calculated will depend upon the distance between the stations. The farther one station lies from another, the greater will generally be the number of solenoids found between them. In order to obtain a correct idea as to the solenoid intensity in the sea, it will therefore be best to reduce the number of solenoids to a certain normal horizontal distance, e.g. 100 km. The distance between station 34 and 35 in section IX is 62 km. By multiplying the number of solenoids by 100 and dividing by 62, we obtain the normal values for this particular case. This operation should be carried out with the figures in columns 4 and 7 of table 3. Columns 8 and 9 contain these normal values. The figures in column 8 show the number of solenoids in 1 metre layers for 100 km., i.e. affords a measure of the variation in density in a horizontal direction, and column 9 the number of solenoids per 100 km. from the different levels of measurement down to the greatest depth from which observations are available. The figures in column 8 furnish the best means of indicating the intensity of the Archimedean forces in the section, while those in column 9 best show the effect of the forces in question.

Coming now to the question of publishing these different values for the number of solenoids between all pairs of stations in Dr. Hjort's sections, we may begin with eliminating the first two columns of table 3, these being contained in table 1. Columns 4 and 8 are left unaltered, column 5 is superfluous, and in columns 6, 7, and 9, the last figure of each value should be discarded, partly as having no real importance, and partly as rendering the values in question unnecessarily awkward to handle in calculation. This done, the solenoids in these columns are expressed in 10 cgs. Column 9 may also be said to indicate cgs. solenoids per 10 km. Table 4 shows the simpler form given to table 3 by this process. Table 5 contains the number of solenoids according to the scheme in table 4 for all pairs of stations in Dr. Hjort's sections. The heading above each pair of stations indicates the distance between them, and the approximate mean depth of the intervening area.

13.—INFLUENCE OF THE EARTH'S ROTATION UPON CIRCULATION.

The influence of the earth's rotation upon circulation makes itself apparent in a very simple manner in the atmosphere. When the air at any point commences to rise upwards, and the surrounding air in consequence pours in from all quarters to replace that which has risen, then this indrawn air will, as it approaches the centre of ascent, develop a marked cyclonic circulation. Thus in fig. 53, taking O as the centre of ascent, and A as a closed curve composed of air particles about the same, then, at the commencement of the movement, the velocity will be directed towards the centre, and the curve will have no circulation. After a certain lapse of time, the curve will, on account of the centripetal movement of the air, have contracted to the position b, at the same time developing a cyclonic circulation. The circulation increment per second is, according to Bjerknes:—

$$\frac{dC}{dt} = -2\omega\frac{dS}{dt} \quad \ldots\ldots\ldots \quad (7)$$

ω being here the angular velocity of the earth, and S the area of the closed curve's projection upon the equatorial plane. And as S decreases, C is increased, *vide* fig. 53.

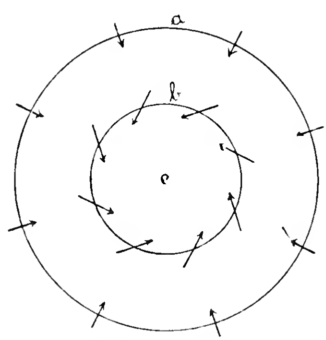


Fig. 53.—Cyclonic circulation produced by the earth's rotation.

In the sea, the movement of the water is to a very high degree restricted and deformed by the shape of the water basins. There is, therefore, in this case, no regular concentric movement about the centre of descent. In spite of this, however, we still find here a marked cyclonic circulation, which, in the Arctic ocean, where the Gulf stream sinks down, and in the waters south of Newfoundland, where the Labrador current disappears, attains very considerable dimensions.

The vertical velocities in the sea are insignificant in comparison with the horizontal, and we may therefore, in calculating the circulation, neglect the former altogether. We then obtain the area S of the projection of the closed curve upon the equatorial plane, by projecting the curve upon the level of the surface of the sea, and multiplying the area σ thus obtained by the sinus of the latitude φ i.e.,

$$S = \sigma \sin \varphi$$

Inserting this value for S in (7), we obtain

$$\frac{dC}{dt} = -2\omega \frac{d\sigma}{dt} \sin \varphi$$

And if, again, we insert in this formula the value for 2ω, viz., 0.0001458, we obtain

$$\frac{dC}{dt} = -0.0001458 \frac{d\sigma}{dt} \sin \varphi \quad \ldots\ldots\ldots\ldots \quad (8)$$

This formula (8) is specially suited to the treatment of measurements of velocity in the sea, as these measurements always give the horizontal components of the velocities, i.e., the projection of the direct velocity upon the level of the sea's surface.

No measurements of velocity were made during Dr. Hjort's expedition in the Canadian waters, and we have therefore no opportunity of applying the Bjerknes' formula for rotation of the earth to observations here in the regular manner above described. We have therefore recourse to another, more indirect application of the same, we can reckon out the velocities which the water should have in order to fulfil the requirements of Bjerknes' equation, with the distribution of density as found by Dr. Hjort. By this means, we obtain indirectly an idea as to the movement of the water within the area of investigation.

In Bjerknes' equation (6), the first and last terms are small in comparison with the two intermediate ones. As a first approximation, therefore, we may disregard the former and write

$$A = 2\omega \frac{dS}{dt}$$

or, instead of this, taking the projection of the closed curve upon the level of the sea

$$A = 0.0001458 \frac{d\sigma}{dt} \sin \varphi$$

From which we obtain

$$\frac{d\sigma}{dt} = \frac{A}{0.0001458 \sin \varphi} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

In this formula, the right side is determined by the distribution of density, and the left by the movement of the water. The right side is known from table 5, which shows A for a large number of closed curves throughout our area of investigation. In consequence, therefore $\frac{d\sigma}{dt}$ i.e., the deformation of these curves, due to the movement of the water, will likewise be known. By this means, we are able to calculate the movement of the water from the distribution of density.

Obviously, however, we cannot by this means obtain the whole movement of the water. We might imagine, for instance, a closed curve composed of water particles in a current, following the current in such a manner that the area of its projection upon the level of the sea's surface would not be altered thereby. This would, then, according to formula (9), contain no solenoids at all. But this does not necessarily imply that the water in which the curve appears, and of which it forms a part, has no great velocity. In other words, the formula (9) gives, not the absolute velocity of the curve, but only its deformation, i.e., the extent to which its one part moves relatively to the other.

The closed curve should therefore be selected in such a manner as to give the least possible degree of movement in the one part. As equation (9) gives the movement of the other part relative to this, it will in this case give the actual velocity of the same. Now, the movement of the water at great depths is inconsiderable, the greatest velocities occurring in the upper water layers. We therefore select the closed curve in such a manner that its one part is situated at the greatest possible depth, and calculate the velocity of the other, upper portion, relatively to this deeper part.

The values in table 5 best suited to this calculation are those indicated as ΣA_{10km}. This column gives A for closed curves having their vertical parts situated at a distance of 10 km. apart and with the one horizontal portion situated at the greatest depth from which measurements are available. Taking this lower horizontal portion as immobile, and the upper as moving at right angles to its own longitudinal direction with a velocity of u cm. per second, then obviously the increment of area in the projection of the curve upon the level of the sea's surface amounts to

$$\frac{d\sigma}{dt} = 10^6 u$$

per second, 10 km. here representing 10^6 cm. Inserting this value for $\frac{d\sigma}{dt}$ in (9), we obtain:

$$u = \frac{A}{145 \cdot 8 \sin \varphi} \quad \ldots\ldots\ldots\ldots \quad (10)$$

For the latitude $= 43°19'$, which falls within our area of investigation, is

$$145 \cdot 8 \sin \varphi = 100$$

and in consequence:

$$u = \frac{A}{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

i.e., the ΣA_{10km} columns in table 5 give the velocity in hundredths of a cm. per second. We need then only cut off two decimal points from the figures in this column in order to obtain the velocity in cm. per second.

In order to comprehend what is given in formula (11) we may consider a current in the sea flowing over a substratum of still water. Owing to the rotation of the earth, the current will veer off to the right until it encounters a coast, which it will then follow, still pressing towards the right, i.e., setting in towards the coast. In consequence of this pressure, the current will become deeper near the coast than farther out; i.e., the separating surface between the current and its substratum of heavier water will lie obliquely. In this surface, then, there will be a number of solenoids running in the longitudinal direction of the current. By taking a hydrographical section across the current, and treating the observations according to the scheme in table 3, we obtain the number of these solenoids. Formula (11) now shows, that if 10 km. breadth of current contain 100 solenoids, then the current will flow at a velocity of 1 cm. per second; if 1,000 solenoids, the velocity will be 10 cm. per second, and with 10,000 solenoids, the velocity of the current will be one metre per second. If the number of solenoids be 6,728, the volocity of the current will be 67·28 cm. per second.

This simple relation is, of course, strictly speaking, valid only for latitude 43° 19′. For other latitudes, we can obtain from table 6 the number of solenoids per 10 km. breadth of current which will give a velocity of 1 cm. per second. By dividing the values for number of solenoids obtained through the hydrographic measurements by the figure in table 6 corresponding to the latitude of the station, the due allowance for geographical situation will be made. The last column in table 5 contains the velocities thus calculated.

As regards direction of the current, this will be easily understood from the foregoing. The lighter surface water is pressed over to the right by the earth's rotation. Placing myself, for instance, in the section so as to have the lighter water on the right hand, and heavier on the left, I am then facing in the forward direction of the current.

It will also be evident from the foregoing, that the method in question gives only the component for current velocity in a direction at right angles to the section. This, however, is in the present case of but slight import, as Dr. Hjort has for the most part taken his sections in such a manner as to have them almost at right angles across the currents found. Dr. Hjort's measurements are, from a dynamic point of view, ideal in this respect.

In table 5, eight points of the compass have been used to designate the direction of the current. As usual, in dealing with ocean currents, the letter indicates the direction towards which the current flows. Thus *E*, for instance, denotes a current flowing from west to east.

Plates XIV and XV have been drawn up from the figures in the last column of table 5. The former gives the calculated velocities for spring, the latter for summer, 1915. From the intimate relation of these velocities to the number of solenoids (*vide* table 5), it follows that Plates XIV and XV also afford the best possible graphic presentment of the distribution of solenoids throughout the area of investigation.

14.—INFLUENCE OF FRICTION UPON CIRCULATION.

The influence of friction *R* upon the circulation of a closed curve, may be calculated in two different ways; either directly, from measurements of velocity taken for the purpose, or indirectly, by means of Bjerknes' equation for circulation, all the terms of this being known with the exception of R.

In the former case, three uniform current meters are set out on one and the same line, with say 5 metres vertical interval between each two, with which systems of instruments measurements are then taken at the different depths. From the measurements thus obtained, the parabolas for diagram of velocity are then constructed, and from these again the acceleration of the frictional force can be calculated (chapter 9). By integration of the tangential component for this along the closed curve, we obtain *R*.

In the second case, we have, according to (6),

$$R = A - 2\,\omega\,\frac{dS}{dt} - \frac{dC}{dt}$$

When the movement is stationary, $\frac{dC}{dt}$ disappears, and we have,

$$R = A - 2\,\omega\,\frac{dS}{dt} \quad \ldots\ldots\ldots\ldots\ldots \quad (12)$$

If the closed curve lies along a stationary current, then $2\omega\,\frac{dS}{dt}$ will likewise disappear, and we obtain

$$R = A \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

With this formula, it is a very simple matter to calculate the influence of friction upon the circulation, as also the acceleration of friction in a stationary current. As an example, we may take the Gulf Stream. A closed curve along this will include 150,000 solenoids, and consequently, in the Gulf Stream the retarding influence of the friction upon the circulation will amount to

$$R = 150{,}000 \ \frac{\text{cm.}^2}{\text{sec.}^2}$$

On dividing this figure by the length of the closed curve, $15 \cdot 10^8$ c.m., we obtain the mean value for retarding acceleration of friction for all water particles in the Gulf Stream,

$$f = 0 \cdot 0001 \ \frac{\text{cm.}}{\text{sec.}^2}$$

As a second example, we may take a closed curve along the Gaspé current at the surface, and at 60 metres depth, between Dr. Hjort's stations X 31 and XIII 38. On calculating A for this, according to the scheme shown in table 3, we find that the number of solenoids is 10880. For this, again, according to (12),

$$R = 10880 \ \frac{\text{cm.}^2}{\text{sec.}^2}$$

The length of the closed curve, via North, Cape Breton island, amounts to $2 \cdot 10^8$, i.e.,

$$f = 0 \cdot 00005 \ \frac{\text{cm.}}{\text{sec.}^2}$$

It is surprising that the retarding effect of friction upon ocean currents should be so great as this. If the solenoids ceased to operate, then the velocity of the Gulf Stream would be diminished by 1 cm. per second per 3 hours, and the Gaspé current by 1 cm. per second every 6 hours; in other words, save for the solenoids, currents of this nature would soon come to a standstill. We realize, then, the fundamental importance of the solenoids for propelling ocean currents.

If the closed curve be drawn *across* a stationary current, then R disappears, and (12) in consequence, gives place to

$$2\,\omega \, \frac{d\,S}{d\,t} = A \quad \ldots\ldots\ldots\ldots \quad (14)$$

by means of which formulæ we can calculate the movement of the water from the solenoids, see table 3 and plates XIV and XV.

These two formulæ (13) and (14) are, as hydrography now stands, the most important mathematical means for dynamic treatment of hydrographical observations.

In applying these formulæ, it is necessary to see that the conditions for which they are intended to apply are fulfilled. One disturbing factor which has to be reckoned with is the screwing movement of the water in a current. Owing to this, the influence of the earth's rotation does not altogether disappear in the case of closed curves lying in the longitudinal direction of a current. The part of such curves which is situated at the surface, is, by this screwing movement, carried towards the right, and we may easily find that the earth's rotation will therefore exert a retarding influence upon the current. The retardation calculated by formula (13), therefore, should not be ascribed exclusively to friction, as a part of it will be due to the earth's rotation. The more stable the layers in a current are, however, the less chance will there be for this screwing movement of the water to develop, and the more insignificant the correction of formula (13) owing to rotation of the earth. On the other hand, where the water in a current is homogeneous, the screwing movement will develop to a greater degree, and there is then the risk that formula (13) may give too high values for R.

Formula (14) will likewise require to be corrected for the same reason. The screwing movement of the water is naturally opposed by the friction, and the influence of the friction upon the circulation does not therefore altogether disappear in the case of closed curves drawn transversely across a current. In such curves, then the earth's rotation will have two forces to overcome; that of the solenoids, and that of the friction. Thus the velocities calculated according to (14) from the solenoids alone will be too low; i.e., the values for velocity given in table 5 and plates XIV and XV will be too small. The friction, on the other hand, will have no effect upon their direction. By increasing these calculated velocities slightly, they can thus be made more correct viz., the less stable the water layers are the more the velocities will require to be increased.

The most disturbing influence, however, which affects the velocities calculated from formula (14) is that of the wind. The friction exerted upon the surface of the water by wind corresponds to a very considerable value of R. This will naturally be variable to a very high degree, but the direction in which it takes effect, and its nature generally, will of course depend rather simply upon the direction of the wind. By taking a few simple cases as examples, we may gain some idea as to the effect of wind upon the distribution of density in a current, and the velocities thence obtained according to formula (14).

(*a*) *Wind blowing in the forward direction of the current.*—In this case, the velocity of the surface water will be increased, and the water in question consequently be thrown off with greater force than previously to the right. In a section across the current, the isosteres will become more vertical, and the number of solenoids, A, greater. The calculated velocities will thus become greater, which agrees with the increased velocity due to the action of the wind. In this instance, then the effect of the wind will not greatly disturb our calculations according to (14).

(*b*) *Wind blowing directly against the current.*—The surface water will here be retarded, and the force with which it veers off to the right will be diminished. The number of solenoids in a section across the current will be less, and thus the velocities calculated from the same will likewise be lower, agreeing, again, with the actual decrease in velocity due to the opposing action of the wind. In this case also, then, the disturbing influence of the wind upon the calculations according to (14) will be but slight

(*c*) *Wind blowing crosswise to the current, and in a shoreward direction.*—The surface water is here driven with great force to the right; the isosteres stand on end, and the number of solenoids in a section across the current will be abnormally increased. The velocities calculated from the solenoids according to (14) will therefore here be too great.

(*d*) *Wind blowing crosswise to the current, in a seaward direction.*—With a slight wind, the number of solenoids will be reduced, and the velocities thence calculated according to (14) too low. With a stronger wind, the entire current may be forced away form the shore and out to sea. This gives rise to a highly abnormal distribution of density and of solenoids, *vide* fig. 54 a, which on applying formula (14) gives the distribution of velocities shown in fig. 54 b. This is here so abnormal that it does not correspond in any way to the actual movement of the water. Dr. Hjort's section IV is a good example of such abnormal distribution of density.

By simple discussions of this kind one may soon become familiar with the various phases which the state of the sea may assume, and can thus learn to determine the causes by which they are produced.

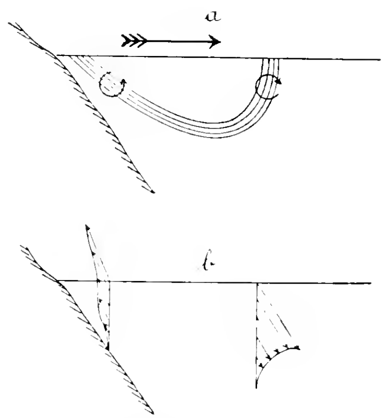


Fig. 54.—Distribution of density and calculated velocity according to formula (14) with offshore wind.

15. THE ACCELERATION OF CIRCULATION.

Let us imagine the sea and atmosphere in perfect calm and equilibrium. The isosteres and the isobars coincide with each other, and with the level surfaces of gravity, so that no solenoids exist.

In a part of this motionless sea, some physical process then takes place, whereby the specific gravity of the water there is altered. This gives rise to a local deformation of the isosteric surfaces, which now no longer coincide with the isobars, but intersect the same. The solenoids thus called into play then set the water in motion, according to the formula

$$\frac{dC}{dt} = A$$

At the commencement of this movement, therefore, the acceleration of the circulation $\frac{dC}{dt}$ will be equal to the number of solenoids.

As the velocity of the water increases, the resistance of friction R makes itself apparent. We have then

$$\frac{dC}{dt} = A - R$$

There R increases more and more, until at last it equals A. Then, according to the formula, $\frac{dC}{dt}$ disappears, and the movement becomes stationary. This is the sign of permanent currents, originating in and maintained by a perpetual physical change taking place in the sea water, such as the Gulf Stream.

The earth's rotation, however, also exerts a certain influence upon the circulation of the water. When the solenoids have set the water in motion, it is forced over to the right by the rotation of the earth. This pressure is augmented as the velocity of the water increases. Consequently, the rapidly moving surface water in a current is urged more forcibly to the right than the slower-moving water at greater depths, so that the total movement of the water mass will be a screwing one. And a transverse section across the current will therefore reveal a circulation taking place within the same. For this, the acceleration of circulation will be

$$\frac{dC}{dt} = 2\,\omega\,\frac{dS}{dt}$$

This circulation is itself opposed by the friction, wherefore

$$\frac{dC}{dt} = 2\omega\,\frac{dS}{dt} - R$$

As the circulation is increased, the opposing force of the friction will likewise be augmented, until the influence of the latter will attain a magnitude equal to that of the earth's rotation. Then $\frac{dC}{dt}$ will disappear, and the circulation become stationary.

If the water of the current be in stable layers, then a system of solenoids will arise in the section across the same, and will, like the friction, oppose the influence of circulation occasioned by the earth's rotation. In this case, then,

$$\frac{dC}{dt} = 2\omega\,\frac{dS}{dt} - A - R$$

Where the water is very stable, these reactionary solenoids may altogether arrest the circulation in the cross section. Then R will also disappear, and we have

$$\frac{dC}{dt} = 2\omega\,\frac{dS}{dt} - A$$

The number of solenoids increases until it attains the same value as the influence of the earth's rotation, whereby $\frac{dC}{dt}$ disappears, and a stationary situation sets in. It is on such a state of things that rates XIV and XV have been based.

In all the cases here described, the acceleration of circulation $\frac{dC}{dt}$ increases rapidly at first from its value nil when the sea is at rest, reaches a maximum, and then declines asymptotically towards nil, when stationary conditions are reached. Fig 55a shows this variation of $\frac{dC}{dt}$ in course of time.

If the physical change in the water which gave rise to the current be of temporary nature, then the number of solenoids thus produced will gradually decrease, the current meanwhile progressing by inertia. The effect of friction will then be superior to that of the solenoids, and $\frac{dC}{dt}$ will be negative. As the physical changes gradually cease, the final state will in this case be that of calm and equilibrium. Fig. 55b shows the variation in the acceleration of circulation for a casual and temporary current of this nature.

It may also happen that the water, through inertia, flows too far. This gives rise to a system of solenoids the reverse of the original, and tending to turn the current, and so drive the water back. If this reverse movement, in its turn, carry the water too far, then a new solenoid system, corresponding to the original one, will again arise, turning the current once more in its original direction. This may be repeated several times.

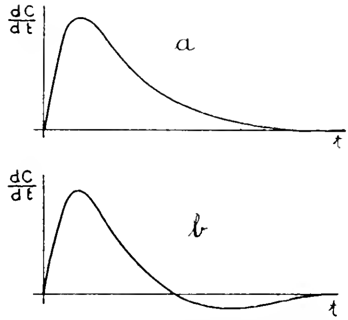


Fig 55.—Alteration of circulation acceleration on the appearance of a) a permanent current b) a casual and temporary current.

The alteration in the acceleration of circulation will then become periodical, *vide* fig. 56.

From the foregoing, it will be seen that the sea is continually striving towards a state where $\frac{d\,C}{d\,t}$ approaches nil, *i.e.* the three terms on the right side of Bjerknes circulation equation endeavour to adapt themselves one to another in such a manner that their sum shall be nil. This would also take place, were it not for the fact that one or other of them is from time to time subjected to disturbance which alters its magnitude. This disturbance may be of various sorts. A physical change in the water, as for instance that brought about by the heat of the sun, or by the melting of ice, will alter the value of A. If a current veers off owing to the topography of the sea basin, then $2\omega\,\frac{dS}{dt}$ will be altered. The action of the wind exerts a great influence upon R, etc. After each such disturbance $\frac{dC}{d\,t}$ attains a maximum, decreasing afterwards, however, towards nil. Where the stability of the water layers is very great, as in the gulf of St. Lawrence, this decrease may take place so forcibly that $\frac{dC}{d\,t}$ passes beyond zero and becomes negative, thereafter altering periodically with decreasing amplitude, *vide* fig 56. The greater the stability of the water layers, the more rapidly will these oscillations take place.

Such oscillation also, of course, take place in the surface movement of the water, and would appear to be particularly frequent in surface currents occasioned by the wind; also, other surface currents however arising from different causes, doubtless oscillate in the same way. As the water at any point of the surface can, at a given

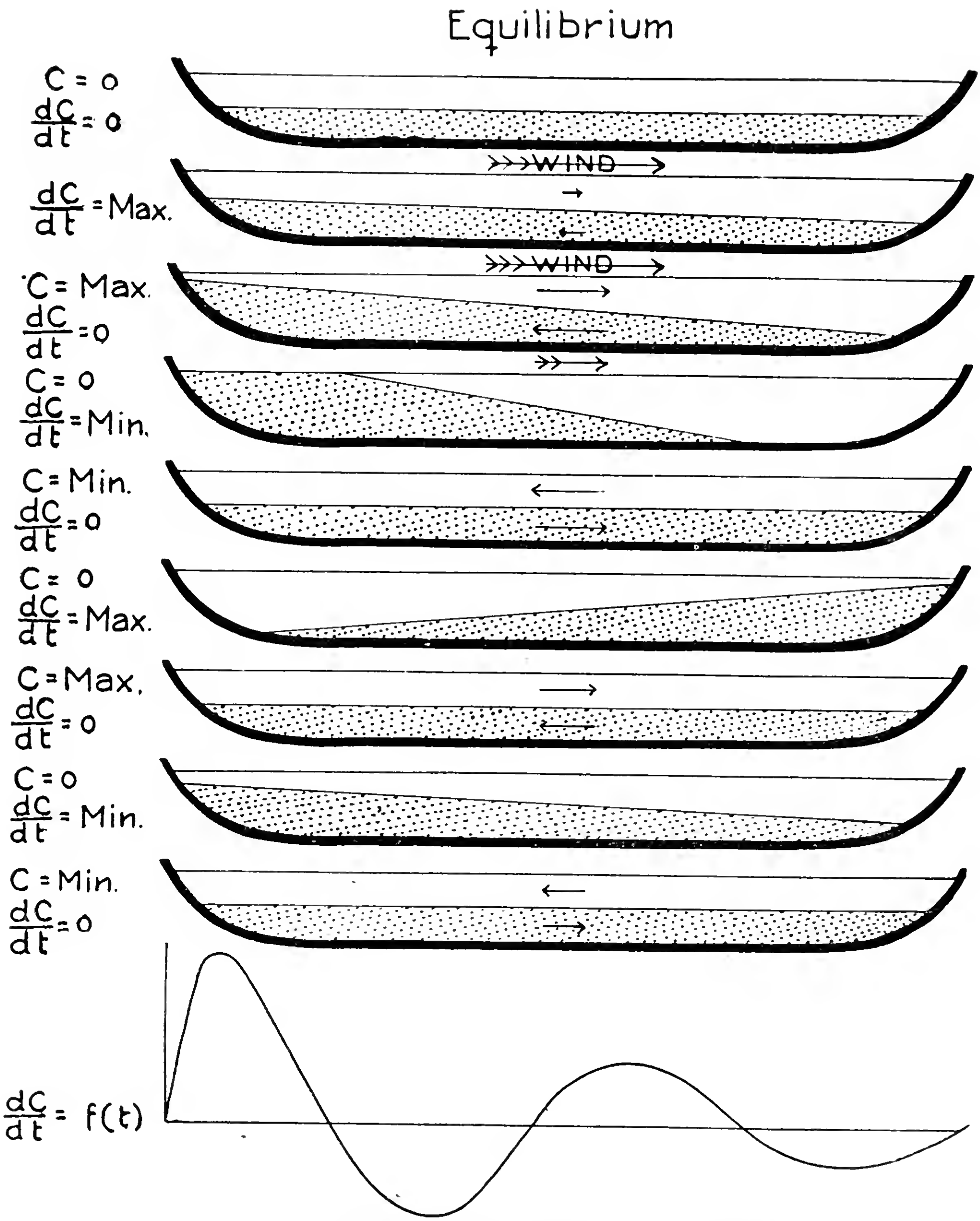


Fig. 56—Submarine seiches occasioned by brief but violent gales.

movement, have but a single direction of movement, it follows that the lines of current for surface water must answer to the equation

$$\frac{dy}{dx} = f(xy)$$

where x an y are the geographical co-ordinates of the sea's surface. For

$$\frac{dy}{dx} = sin\ (ax + by)$$

we obtain the courses of the current shown in fig. 57.

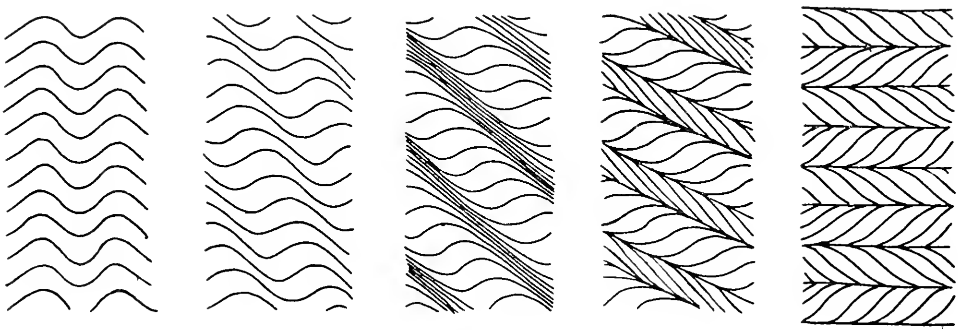


Fig. 57.—Oscillation of surface water, in area with water layers in stability.

The existing material of simultaneous measurements of velocity in the sea is unfortunately too small to permit of our verifying the current course here obtained by mathematical means. The meteorology is in this respect far more favourably situated, owing to the large number of stations from which the direction of the wind is observed simultaneously. And it is then a very simple matter to discover the existence of such oscillations. Figs. 58 and 59 serve to illustrate this. Fig. 58 shows direction and force of the wind, with distribution of atmospheric pressure on January 7, 1902, at 9 p.m. At a first glance, the direction of the wind would appear to be highly irregular, not only in comparison between the various stations, but also when compared with the regular course of the isobars. On drawing up the courses of the wind however (*vide* fig. 59) we find that the directions taken by the wind form part of a highly regular, and strongly oscillating wind system. Very much the same thing doubtless takes place in the sea. The observations of velocity, which at a first glance appear most irregular, might possibly turn out to be in actual fact, very regular and uniform, if only we could discern the oscillating system to which they belong.

Naturally, it will be out of the question to procure a network system of stations at sea as close as that for simultaneous observations on land. This would require too great a number of vessels. It would seem reasonable to ask, however, if the facility with which it is possible to ascertain conditions in a vertical direction in the sea, might not compensate for the greater facilities on land in a horizontal direction. Where the surface water, owing to the oscillating movement, is massed together, the surface layer must be thicker than where it flows apart. It should be an easy matter to construct an instrument for indicating, for instance, the depth of an isotherm situated not too far down, while the vessel lay motionless at a hydrographical station. If the depth be constant during the time the measurements are being made, then the sea is not in oscillation, and the hydrographical observations may be taken as representative of the place and season; if, however, the depth varies, then periodical oscillations take place, and the hydrographical conditions ascertained by measurements

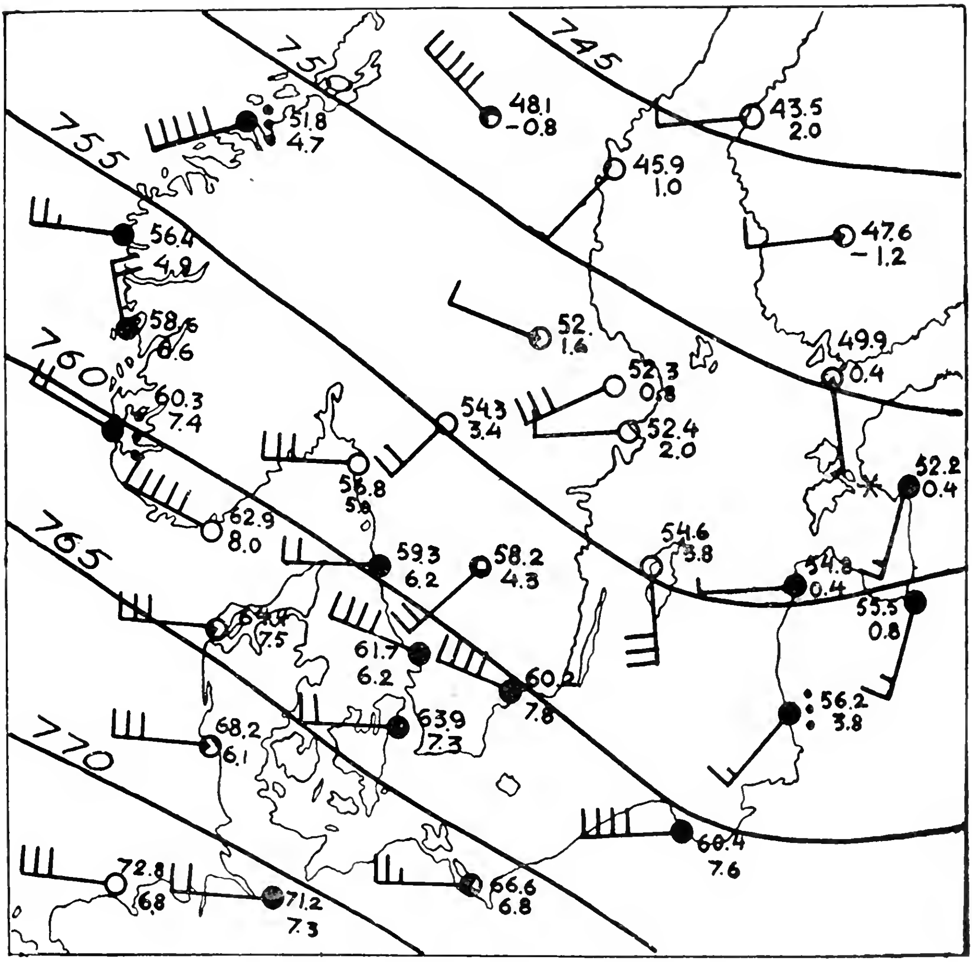


Fig. 58.—Direction of wind on 7 January, 1902, at 9 p.m.

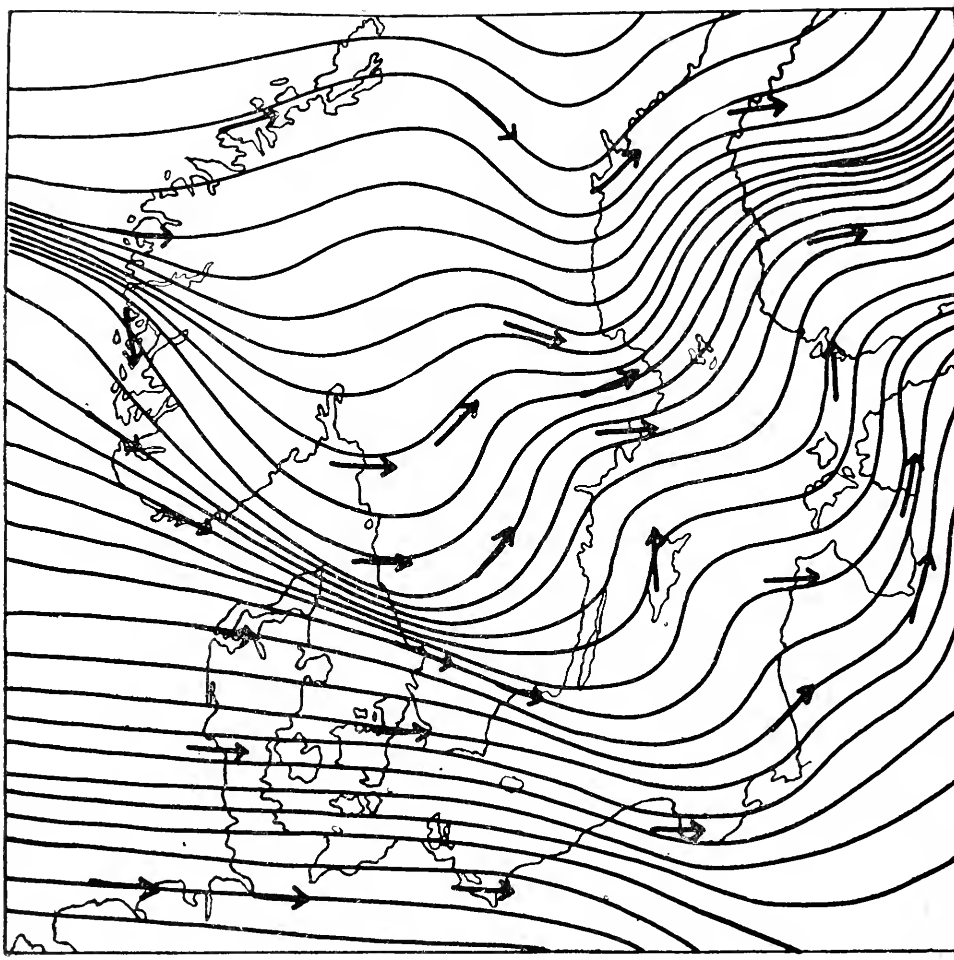


Fig. 59.—Courses of wind on 7 January, 1902, at 9 p.m.

will be dependent upon the phase of the oscillation. The variation in the depth of the isotherm gives this phase, and thus also furnishes a possibility of correcting for the same . It is an unsatisfactory matter of fact having frequently been noticed that hydrographical measurements repeated from the same station at a few hours' interval may give entirely different results, as well for velocity, temperature and salinity.

Obviously, these periodical oscillations are the exact opposite of stationary conditions, and the solenoids thus arising (*vide*, e.g., fig. 56) cannot therefore be used to calculate velocities according to formula (14). By so doing, entirely erroneous velocities would be obtained, with serious breaks to either side. Such breaks are, however an excellent indication of wave movements of this sort. The distribution of velocity in the boundary between the Labrador current and the Gulf Stream, *vide* plates XIV and XV, distinctly indicates that the sea is there in a state of violent oscillation.

Observations as to ebb and flow, and the currents occasioned thereby, should be treated according to the principles set forth in this chapter.

16. ON THE TOPOGRAPHY OF THE SEA'S SURFACE, THE DISTRIBUTION OF PRESSURE, AND TRANSFORMATION OF ENERGY IN THE SEA.

In order to illustrate further the enormous practical utility of Bjerknes' circulation theory in oceanographical work, I will here briefly touch upon one or two other examples.

Where a sea is in a state of perfect calm and equilibrium, all isobars and isosteres therein will coincide with the level surfaces of gravity. Such a state of equilibrium may be supposed to exist at great depths, so that the sea there would exhibit the same pressure at the same level. We can then, by means of the differential formula for measurement of barometric height,

$$dz = \frac{v\,dp}{g} \qquad (15)$$

which is equally applicable to the sea, arrive at the topography of the sea's surface. By integrating (15) from the surface down to the level of greatest pressure p_1, from which observations are available, we obtain

$$z = \frac{1}{g}\int_{p_0}^{p_1} v\,dp \qquad (16)$$

where z represents the height of the sea's surface above the isobaric surface p_1. If this calculation be carried out for several hydrographical verticals of measurement, we obtain the formation of the sea's surface $p=p_0$ relative to the isobaric surface $p=p_1$, i.e., the actual topography of the surface of the sea.

Owing to the great variation in the depths of the sea, the calculation may in practice best be carried out by reckoning the difference in height of the sea's surface at adjacent hydrographical stations, taken in pairs, and subsequently setting out all the results together in the form of a topographical map. According to (16), the difference in height between two hydrographical verticals will be as follows:—

$$z_1 - z_2 = \frac{1}{g}\int_{p_0}^{p_1} (v_1 - v_2)\,dp \qquad (17)$$

This integral operation is, however, identical with that carried out in tables 4 and 5. Using the terms there obtained, we get:

$$z_1 - z_2 = \frac{1}{g}\Sigma A \qquad (18)$$

i.e., we have here the data requisite for calculation of the topography of the sea's surface, by dividing the number of solenoids by the force of gravity.

Now table 5 contains values of Σ A not only for the surface of the sea, but also for isobars at deeper levels. The topography of these is then obtained in the same manner as that of the surface. We can thus, by the process here described, ascertain in the slope of the isobaric surfaces, and so arrive at the distribution of pressure throughout the entire portion of sea from which observations are available.

From the slope of the isobars, it is easy to ascertain the acceleration of the water. The most simple formulation of the relation between these two magnitudes is that given by Dr. J. Hann, viz., that the acceleration of the water is equal to that component for acceleration of gravity which falls in the isobar surface. Popularly speaking, we may say that the water slides down the sloping isobar surfaces, and that this sliding movement is practically frictionless.

This again, however, is as much as to say that the sea-water in such respect may be likened to the water of a river, and we can also apply the well-known laws for the flow of river water to the currents in the sea. As an example we may take the Gulf Stream. In this case,

$$\Sigma A = 150000$$

On inserting this value in (18) we find that the surface of the sea lies about $1\frac{1}{2}$ metres higher in the Tropics than in the Arctic ocean. In other words, the Gulf Stream may be regarded as a great river, flowing down from a higher to a lower level.

The Gulf Stream carries 25,000,000 tons of water per second. This, with a fall of 1·5 metres, amounts to a force of 500,000,000 horse-power, which is the amount of energy expended in the propulsion of the Gulf Stream. It is utilized to overcome friction, and is thus converted into heat.

If we now insert $\Sigma A = 10880$ in (18) we find that the surface of the sea during the summer of 1915 was 11·1 cm. higher at Station X 31 in the gulf of St. Lawrence than at station XIII 38 south of Nova Scotia. And as the Gaspé current carries 645,000 tons of water per second, its production of energy amounts to 955,000 horse-power, this force being utilized for its propulsion, and converted into heat by the internal friction of the water.

By thus directly comparing the ocean currents with rivers, we find it easier to comprehend the nature of the former, and the processes which take place therein. In a river, the slope of the river-bed occasions a continual transformation of potential energy into motive power. So also with ocean currents. In these, the slope of the sea's surface and of the isobars will represent a certain quantity of potential energy, which is gradually transformed into motive power, and thus maintains the movement of the current. And we have just seen, how the magnitude of this transformation of energy may be expressed in horse-power.

It is thus easy to follow the transformation of energy in the sea. The heat derived from the rays of the sun in the Tropics is first converted into potential energy, which again is then transformed into motive power, setting in motion currents which transport the warmer water to higher latitudes, where the heat is again given off from the sea. By periodical oscillations in the movement of the sea-water, the energy represented is continually being converted from potential force to motive power, and vice versa. The potential energy, however, after first being transformed into motive power, is thence again converted by the internal friction of the water into heat. We have thus the following system of transformation of energy in the sea:—

$$\text{HEAT} \longrightarrow \text{POTENTIAL ENERGY} \rightleftarrows \text{MOTIVE POWER} \longrightarrow \text{HEAT.}$$

This applies to all ocean currents. Thus the water in the St. Lawrence river, for instance, is due to the heating of the sea-water by the sun's rays, viz., firstly evaporation, then raining. The mixing of this fresh water with sea-water in the gulf of St. Lawrence gives rise to the potential energy which propels the Gaspé current. And finally, the motive power of this latter is transformed, by the internal friction of the water, into heat. In the case of the Gaspé current, the measure of these three transformations of energy will be 955,000 horse-power.

The divergence of the sea's surface from the level of gravity is primarily due to such physical changes in the sea-water as bring about an alteration of its specific gravity. The topography of the sea's surface is, however, further influenced by the earth's rotation, which forces the light surface water of the currents to the right; and also by the wind, which forces the water to store up. In addition, the surface of the sea is subjected to various periodical perturbations, taking the form of sea waves, seiches, swells, etc. In all such obliquities of the sea's surface, however, the water will always be accelerated by the component which falls in the surface of the sea, if the force of gravity is projected upon the same.

One deformation of the sea's surface should be reckoned in a class apart, viz., that due to atmospheric pressure. If, for instance, the pressure above a certain area of sea should fall from, say, 760 to 720 mm., then according to (15) the pressure will be correspondingly reduced, and this, moreover, right down to the bottom of the sea; *i.e.*, all isobar surfaces within the area in question, down to the greatest depth, will be lowered 54 cm. The result of this will be an inflow of water from all sides to the area in question, this taking place rapidly, and with imperceptible velocity, as all levels of the water contribute. When this process has been completed, the surface of the sea within the area of lowered atmospheric pressure will have risen 54 cm. above its former level, this height of the water exactly compensating the deficit in atmospheric pressure, so that the isobars will then resume their normal course, despite the atmospheric perturbation. The surface of the sea itself, however, will no longer be an isobar surface, and ceases therefore, to be an indication of the distribution of pressure in the sea. This it can only become through a combination of water level and atmospheric pressure.

It is therefore a question, whether it might not be worth while, for dynamic purposes to carry out this combination. The simplest method of so doing is to correct the water level to a certain pressure, *e.g.* 1,000000 CGS, corresponding to 750·08 mm. or 29·531 inches Hg. at 0°. This pressure will always be found near the surface of the sea. Insertinging now in (15) $g=980{\cdot}6$ and $v=0{\cdot}97264$, we obtain the required correction of the water level for the influence of atmospheric pressure:—

$$z = \frac{0.97264}{980{\cdot}6} \quad (p - 1000000)$$

or

$$z = 0{\cdot}00099919 \ (p - 1000000)$$

Taking now as unit of pressure 1 millibar = 1,000 C.G.S., then

$$z = \cdot 99919 \ (p - 1000) \qquad (19)$$

In mm. Hg.

$$z = 1{\cdot}3224 \ (p - 750{\cdot}08) \qquad (20)$$

and in inches Hg.

$$z = 33{\cdot}59 \ (p - 29{\cdot}531) \qquad (21)$$

Table 7, a, b, and c, gives the correction z to the water level expressed in cm. for different atmospheric pressures according to formulæ (19), (20), and (21), respectively.

By applying this correction to the water levels observed, we obtain the water level which determines the distribution of pressure in the sea and the movement of the water.

Finally, as regards transformation of energy in the sea, it should be borne in mind that the integral expression in formula (17) gives the area of the closed curve in Clapeyron's diagram. In the case of a current where the water flows in a Carnot circular process, as for instance the Gulf Stream, the quantity of energy converted from heat to motive power will thus be equal to the mass of water in circulation, multiplied by the number of solenoids. This calculation gives, for the Gulf Stream, 500,000,000 horse-power, which agrees with the value already known from other methods of calculation.

Nothing could show more clearly than this the fundamental importance of the solenoids for the origin and maintenance of the ocean currents.

17. SUMMARY.

Within the area of these investigations, from its boundary on the Gulf Stream side to the mouth of the St. Lawrence, a number of mostly interesting phenomena are encountered, which render the waters in question one of the most instructive fields on the face of the globe for hydrographical and hydrodynamic research.

Let us now glance briefly at some of the most important features. First of all, there are the physical processes which take place in the boundary surface between the Labrador current and the Gulf Stream occasioning the disappearance of the former, with regard to these, the reader is referred to Prof. Emil Witte's clear and simple treatment of the subject in the *Geogr. Anzeiger,* October, 1910:—

> "When, on the boundary of an ocean current, warm water of high salinity is brought into contact with colder water of less saline character, but having approximately the same specific gravity, then the resulting mixture will, as may easily be proved by the Knudsen tables, be of greater density than either of its component parts. It will consequently sink down, giving rise to the peculiar phenomenon known as cabbeling.
>
> "Obviously, this tendency in the water will likewise produce horizontal currents; as the mixed water sinks down, surface water must flow in from either side to take its place. By way of example, we may take the waters in the vicinity of the Newfoundland bank, where the Gulf Stream encounters the cold current flowing down from the Greenland seas. Throughout the wide extent of the boundary surface between these two, mixed water is constantly being formed, sinking down, and thus drawing in a continual further supply of surface water from either side."

It is this perpetual sinking of the water, of course, which renders the oceanic boundary line here so vertical.

Numerous pelagic organisms of slight mobility doubtless meet their death in this mixture of the water, and their shells sink to the bottom. With the aid of boring samples taken from the sea floor, therefore, we should probably be able to arrive at the geological history of these currents.

The water of the Gulf Stream is more homogeneous; that of the Labrador current being more in layers. In the boundary surfaces between the layers of the latter, wave movements take place. These waves strike against the vertical boundary wall, giving rise to submarine waves of great amplitude. In order to study these, it will be sufficient to measure the depth of an isotherm or isohaline at the juncture of two layers. This simple operation should be carried out at the same time as the hydrographical measurements.

Closer in towards land, the surface water of the Labrador current is driven by the earth's rotation in a shoreward direction, which is one of the causes of the numerous shipwrecks in the Newfoundland waters. The water pours up into the big bays on the eastern shore, keeping to their north side. The greater part of the water thus poured in at the surface makes its way out again as an under current, but there is, as a rule, also a slight surface current in an outward direction on the southern side of the bays.

South of Newfoundland, the landward current is often perceptible far out at sea. "A northerly set of 30 miles in twenty-four hours has frequently been experienced in this neighbourhood, at times at a distance of 50 miles from the coast (*vide* Sailing

Directions from Belle Isle to Boston). In the bays of the south coast of Newfoundland, the water flows in up their eastern side, and out along the bottom, with an outward-going surface current also on the western side.

From the foregoing, it will be plain that the majority of the icebergs drifting with the Labrador current will collect on its western side, making their way up into the bays on the east and south coasts of Newfoundland as far as Placentia bay. The suction towards the boundary between the Labrador current and the Gulf Stream will, however, draw a number of icebergs thither; they may be encountered far out at sea and to the southward, even occurring down towards the east and south sides of the Great Bank. In the intermediate zone, between the two ice lines, the current should be relatively free from ice.

At cape Ray, the water of the Labrador current pours into the gulf of St. Lawrence at the rate of some 12 cubic miles per day. Its place of destination is here the consumption area at the mouth of the St. Lawrence river, where this quantity of water is required for the production of the Gaspé current. We have thus in the gulf of St. Lawrence a solenoid system drawing this water towards the northwest. At cape Ray, however, where the velocity of the water becomes considerable, owing to the narrow passage through which it flows, the influence of the earth's rotation also makes itself strongly felt. The current, therefore, on entering the bay, veers off to the right in a curve, this curve being, however, of wide radius, owing to the pressure exerted by the solenoids in a northwesterly direction. It consequently passes by the bay of St. George without entering there, touching the west coast of Newfoundland for the first time at the bay of Islands, and setting on shore from there as far as point Rich.

On the way it loses a great deal of water which sets off westward out into the gulf of St. Lawrence, making for its destination, the mouth of the St. Lawrence river. The last remainder of the current also curves out from point Rich into the gulf, following the attraction of the solenoids. A slight westward current is still perceptible along the north coast of the bay, from Esquimaux island to cape Whittle. Morgan strait being shallower than the level of the solenoid system which draws the water westward, the current leaves the coast at cape Whittle, passing out east and south of Anticosti to reach its destination. In the region north of Anticosti, a slight back vortex seems to arise, as the current is directed eastward along the range of coast beyond Natashquan point.

South and west of Anticosti, the earth's rotation forces the current over to the northward. The effect, however, is insignificant, owing to the great extent of the current in transverse section, and its consequent slight velocity.

At the mouth of the St. Lawrence river, we encounter the mixing process which gives rise to the Gaspé current. In all probability, the ebb and flow of the tide are, for this process, of considerable importance.

In this mixed water of the Gaspé current, the fresh water from the St. Lawrence constitutes a quantitatively insignificant yet highly important ingredient; it is this which renders the Gaspé water slightly lighter than the surrounding sea-water, which again gives rise to the solenoid system that forces the Gaspé water out of the gulf of St. Lawrence, and draws in the Labrador water. Owing to the earth's rotation, the Gaspé current keeps to the southern side of the entrance to the St. Lawrence, rounding cape Gaspé, and filling the southern part of the gulf. Here the Gaspé water accumulates, forming a kind of cushion, and the Gaspé current itself flows thereafter on the north side of the same. As a rule, the current flows south of the Magdalen islands, but when the "cushion" is well developed, part of the current may go north of this group. Within the cushion itself reactionary currents arise, especially in the vicinity of the primary Gaspé current, and where the cushion is very strongly developed, such a reactionary current may even extend up as far as cape Gaspé, pressing the Gaspé current even here out from land.

Gradually, owing to rainfall, inflow of river water, melting of ice, etc., the water of the cushion becomes somewhat lighter than that of the Gaspé current, and is thus better able to resist the southward pressure of the current itself.

In Cabot strait, the continuation of the Gaspé current keeps close in to cape North, C. Breton island, owing to the earth's rotation. With a strong easterly wind, the whole of this current will be stopped, and all its water stored up in the cushion in the southern part of the gulf of St. Lawrence. The cushion is thereby increased both in depth and horizontal extent, and consequently, the solenoids in the gulf of St. Lawrence, which drive the Gaspé water forward, become stronger in turn. If the east wind keeps up for any length of time, this solenoid system will at last become so strong as to drive the Gaspé water past cape North, despite the wind against it. When the east wind drops, the current will be stronger than normal for a time, as it will then, in addition to the Gaspé water, also have to carry out the superfluous water of the cushion.

With a southwesterly wind, on the other hand, the water of the cushion will be driven out through Cabot strait. The current is thus increased at first, but when the water in the cushion has sufficiently diminished the current past cape North will once more become normal, despite the southwesterly wind. When the southwesterly wind ceases, the current will grow weaker, as a great part of the Gaspé water will then go to form a new cushion. In a word, the effect of this accumulated mass of water may be popularly described as similar to that of the air in the bag of a Scottish bagpipe.

The principal portion of the Gaspé water is naturally formed outside the mouth of the St. Lawrence river, but the current also absorbs a considerable amount of water from its surroundings throughout its course, by friction against the subjacent layer, and by diffusion. Consequently, the farther it proceeds, the more it increases in volume and salinity and the more it grows to resemble the water around it. On the coast of Nova Scotia, and even more in the gulf of Maine, it differs but slightly from its surroundings, and a storm will here suffice to mix it up completely with the adjacent water. Thus far at least, however, the water of the St. Lawrence river flows before losing its individuality and becoming finally intermingled with the ocean.

We now come to the most remarkable feature in the hydrography and hydrodynamics of the Canadian Atlantic area, viz., the cold intermediate layer. From plates IV and V it will be seen that this is of very great extent, and that it is largely restricted to a constant level. It is a result of the melting of ice in the gulf of St. Lawrence, and partly, also in all probability, in the Arctic ocean. From the section east of cape Ray, it would seem that this layer forms an important intermediate or lower portion of the Labrador current. Its movement, together with this latter, is unmistakable. The cold water presses against the banks and the coast, as a result of the earth's rotation, which forces it towards the right.

It is thus likely that the greater portion of this water is produced farther to the north, in the Greenland waters. Its thickness decreasing to the southward, we consequently find, in the cold layer itself, solenoids which force it towards this point of the compass. On reaching Cabot strait, it is forced by the earth's rotation into the gulf of St. Lawrence, and fills it to the level where it belongs by virtue of its specific gravity. From the gulf of St. Lawrence it pours out via cape North along the coast of Nova Scotia or rounding Banquereau. These outward currents are considerably stronger in spring than in summer, owing to the melting of the ice in the gulf during the former season. A peculiar phenomenon may be noted in connection with these. The screwing movement of the ocean current presses the cold subjacent water out from the shore, *vide* plates IV and V, where, owing to friction against the water above, it probably rotates in an opposite direction to the latter, exactly as two cogwheels in contact move opposite ways. In this manner, the cold water mass acquires its rounded form, as shown in fig. 60.

The layer of cold water is thinner in the centre of the gulf of St. Lawrence than at peripheral parts of the same; the layer is thus in cyclonic circulation.

The extent and permanence of the cold water layer show that no interchange of

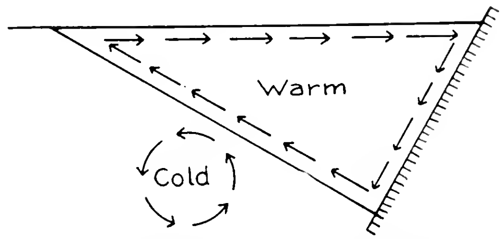


Fig. 60.—Circulation of the water in a transverse section of a current with cold bottom water.

water can take place between the surface and bottom layers in the gulf of St. Lawrence. The cold layer forms an elastic but impenetrable membrane between the surface water and the bottom water. Its level is dependent upon the state of the Labrador current, and thus probably determined by the seasons; also accidental causes may, however, have some effect. With an easterly wind, when great quantities of surface water will be pressed in and corresponding masses of bottom water forced out through Cabot strait, the level of the cold layer will sink in the gulf, and rise outside it. With a westerly wind, on the other hand, when the surface water is driven out and the bottom water sucked in through Cabot strait, then the level of the cold layer is raised inside the gulf and lowered outside. Enormous slow wave movements also probably take place within the layer. As its level approximately corresponds with that of the Banks, its change of level will obviously occasion marked changes of temperature there. These changes of temperature, moreover, probably affect the occurrence of fish on the banks, as the fish may be presumed to seek that water they best like. In seeking to locate the fish, therefore, it will undoubtedly be valuable to know at what level this cold water is to be found.

The warm bottom layer in the gulf of St. Lawrence is connected with the outer world only by the long, deep channel of the Cabot strait. No production or consumption of this water takes place in the gulf of St. Lawrence, and its movements there are consequently insignificant. In the deep channel through the Cabot strait, however, this water may at times exhibit no inconsiderable degree of movement. Measurements of this deep-water current would be of great dynamic importance, possibly also important in biological respects, since they would show whether the cold layer were rising or falling, i.e., in what direction the hydrographic condition of the gulf of St. Lawrence is tending. The deep water of the gulf of St. Lawrence may be considered as an elastic membrane exhibiting a number of important hydrographical phenomena, all of which exert their influence upon it. The current flowing inward and outward through the deep channel of Cabot strait indicates the measure of this influence, and thus affords a valuable means of discerning what is taking place in the gulf of St. Lawrence.

TABLE 1a.—Specific volume v_1 and stability S of the water in the Gulf of St. Lawrence during the spring 1915.

C. G. S. "PRINCESS".

Station, time, position, depth.	Depth m.	v_1.	S.
Stat. 1 May 11	0	663	0
N. 47° 30′ 00″ W. 63° 23′ 00″	10	663	47
69 m.	20	616	16
	30	600	46
	40	554	6
	50	548	4
	65	542	
Stat. 2 May 11	0	671	0
N. 47° 27′ 00″ W. 62° 10′ 30″	10	671	20
45 m.	20	651	28
	30	623	68
	40	555	
Stat. 3 June 9	0	930	134
N. 46° 02′ W. 63° 25′	10	796	19
25 m.	20	777	30
	22	771	
Stat. 4 June 9	0	899	18
N. 46° 28′ W. 64° 21′	5	890	28
21 m.	10	876	32
	20	844	
Sect. I, 5. June 10	0	935	58
N. 47° 15′ W. 64° 35′	10	877	135
31 m.	20	742	107
	30	635	
Sect. I, 6. June 10	0	909	221
N. 47° 30′ W. 64° 08′	10	688	58
61 m.	20	630	72
	30	558	1
	40	557	16
	60	525	
Sect. I, 7. June 10	0	934	89
N. 47° 50′ W. 63° 37′	10	845	169
76 m.	25	592	12
	50	562	19
	75	514	
Sect. I, 8. June 10	0	802	62
N. 48° 14′ W. 63° 04′	10	740	147
92 m.	20	593	20
	40	553	24
	60	506	12
	90	469	
Sect. I. 9. June 11	0	642	37
N. 48° 27′ W. 62° 37′	25	550	16
160—300 m.	75	471	17
	100	428	9
	150	382	
Sect. I, 10. June 11	0	631	35
N. 48° 53′ W. 61° 50′	25	538	14
150—250 m.	50	503	20
	75	452	10
	100	427	6
	150	395	5
	200	370	
Sect. I, 11. June 11	0	617	6
N. 49° 02′ W. 61° 32′	10	611	39
51 m.	20	572	39
	25	513	3
	40	508	19
	50	489	

TABLE 1*a*.—Specific volume v_1. and stability *S* of the water in the Gulf of St. Lawrence during the spring 1915—*Continued*.

G. C. S. "PRINCESS"—*Continued*.

Station, time, position, depth.	Depth m.	v_1.	*S*.
Sect. I, 12. June 11	0	630	65
N. 49° 27′ W. 61° 20′	10	565	26
140 m.	25	526	12
	50	495	19
	75	448	8
	100	427	2
	125	421	
Sect. I, 13. June 11	0	819	103
N. 49° 45′ W. 61° 15′	25	561	27
ca. 200 m.	50	493	18
	75	449	3
	100	441	11
	125	414	2
	150	408	5
	200	384	
Sect. I, II, 14. June 11	0	996	311
N. 50° 07′ W. 61° 09′	10	685	150
40 m.	20	535	26
	35	496	
Sect. II, 15. June 12	0	769	7
N. 49° 45′ W. 60° 08′	10	762	126
85 m.	20	636	77
	40	483	14
	60	455	17
	80	422	
Sect. II, 16. June 12	0	580	12
N. 49° 33′ W. 59° 31′	25	550	21
260 m.	50	497	23
	75	440	8
	100	420	5
	150	394	0
	200	392	6
	250	364	

Station, time, position, depth.	Depth m.	v_1.	*S*.
Sect. II, 17. June 12	0	564	8
N. 49° 22′ W. 58° 56′	25	544	16
130 m.	50	505	20
	75	456	6
	100	440	10
	125	415	
Sect. II, 18. June 12	0	590	26
N. 49° 16′ W. 58° 37′	30	513	32
61 m.	40	481	8
	50	473	
Sect. III, 19. June 13	0	563	10
N. 48° 20′ W. 59° 13′	10	553	1
82 m.	20	552	41
	30	511	11
	50	490	31
	60	458	7
	80	445	
Sect. III, 20. June 13	25	556	7
N. 48° 06′ W. 59° 40′	50	538	22
250—400 m.	75	482	12
	100	451	10
	125	427	7
	150	409	8
	200	371	
Sect. III, 21. June 13	0	543	0
N. 47° 52′ W. 60° 04′	25	542	17
ca. 500 m.	50	499	13
	75	466	10
	100	442	9
	200	355	1
	300	341	3
	400	314	

TABLE 1*a*.—Specific volume v_1 and stability *S* of the water in the Gulf of St. Lawrence during the spring 1915—*Continued.*

C. G. S. "PRINCESS"—*Concluded.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. III, 22. June 13	10	565	
N. 47° 33′			15
W. 60° 39′	20	550	
55 m.			49
	30	501	
			1
	40	500	
			5
	50	495	
Sect. III, 23. June 13	20	555	
N. 47° 37′			25
W. 60° 31′	40	505	
ca. 100 m.			48
	45	481	
			7
	55	474	
			28
	60	460	
			7
	80	446	
			16
	100	414	
Sect. III, 24. June 15	0	607	
N. 47° 12′			2
W. 61° 20′	10	665	
40 m.			27
	25	624	
			56
	35	568	
Sect. III, 25. June 15	0	746	
N. 46° 45′			7
W. 61° 27′	10	739	
63 m.			145
	20	594	
			47
	30	547	
			6
	40	541	
			4
	60	533	
Sect. III, 26. June 15	0	782	
N. 46° 20′			17
W. 62° 04′	10	771	
40 m.			53
	20	712	
			58
	25	683	
			90
	35	593	

STEAM DRIFTER "33".

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. IV, 21. June 25	0	805	
N. 48° 51′			163
W. 64° 16′	10	642	
27 m.			62
	24	555	
Sect. IV, 22. June 25	0	826	
N. 48° 54′			95
W. 64° 07′	10	731	
195 m.			145
	20	586	
			47
	30	539	
			24
	50	492	
			11
	75	464	
			20
	100	415	
			14
	125	388	
			2
	150	375	
			2
	190	368	
Sect. IV, 23. June 25	0	823	
N. 49° 03′			27
W. 65° 58′	10	796	
355 m.			188
	20	608	
			51
	30	557	
			3
	50	497	
			18
	75	452	
			10
	100	428	
			8
	150	388	
			7
	250	351	
			2
	350	328	
Sect. IV, 24. June 26	0	641	
N. 49° 23′			32
W. 63° 38′	10	609	
45 m.			16
	24	587	
			66
	42	469	

TABLE 1*a*.—Specific volume v_1 and stability *S* of the water in the Gulf of St. Lawrence during the spring 1915—*Concluded.*

STEAM DRIFTER "33"—*Concluded.*

Station, time, position, depth.	Depth m.	v_1.	*S*.
Sect. IV, 25. June 26	0	744	4
N. 49° 18′ 30″ W. 63° 42′ 00″	10	740	38
	20	702	151
271 m.	30	551	26
	50	499	18
	75	455	15
	100	418	5
	150	393	5
	269	335	

Station, time, position, depth.	Depth m.	v_1.	*S*.
Sect. IV, 26. June 26	0	825	42
N. 49° 11′ 30″ W. 63° 50′ 00″	10	783	101
	20	682	149
389 m.	30	533	36
	50	462	9
	75	440	7
	100	422	6
	150	394	7
	200	358	2
	250	347	2
	380	321	

TABLE 1*b*.—Specific volume v_1 and stability *S* of the water at the Nova Scotian and Newfoundland banks during the spring 1915.

C. G. S. "ACADIA".

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. V, 1. May 29	10	611	57
N. 44° 35′ 00″ W. 63° 32′ 00″ 25 m.	20	554	
Sect. V, 2. May 29	0	603	0
N. 44° 29′ 00″ W. 63° 22′ 00″	10	603	4
60 m.	20	599	28
	30	571	29
	40	542	16
	55	518	
Sect. V, 3. May 29	0	606	2
N. 44° 22′ 30″ W. 62° 55′ 00″	10	604	12
146 m.	20	592	63
	30	529	31
	40	498	12
	50	486	3
	60	483	7
	75	472	12
	90	454	5
	110	445	
Sect. V, 4. May 29	0	564	0
N. 44° 07′ 14″ W. 62° 11′ 36″	10	564	6
173 m.	25	555	21
	40	524	21
	50	503	29
	60	474	12
	100	425	10
	120	406	7
	160	379	
Sect. V, 5. May 30	0	505	7
N. 43° 56′ 00″ W. 61° 32′ 00″	10	498	11
73 m.	25	408	8
	50	460	12
	70	437	
Sect. V, 6. May 30	0	519	0
N. 43° 47′ 00″ W. 60° 52′ 00″	10	519	0
45 m.	20	519	2
	30	517	9
	40	508	
Sect. V, 7. May 30	0	528	6
N. 43° 35′ 30″ W. 60° 13′ 30″	25	514	34
109 m.	50	429	0
	75	429	17
	100	387	
Sect. V, 8. May 30	0	539	1
N. 43° 50′ 30″ W. 60° 04′ 30″	10	538	14
51 m.	20	524	14
	30	510	1
	40	509	80
	50	501	
Sect. V, 9. May 30	25	501	43
N. 43° 44′ 00″ W. 59° 24′ 00″	40	437	16
106 m.	50	421	0
	75	421	8
	100	401	

TABLE 1b.—Specific volume v_1 and stability S of the water at the Nova Scotian and Newfoundland banks during the spring 1915—*Continued.*

C. G. S. "ACADIA"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. V, 10. May 30	0	488	4
N. 43° 41′ 30″ W. 59° 02′ 00″	25	476	10
740 m.	50	451	10
	60	441	6
	75	432	26
	90	393	5
	100	388	6
	150	360	2
	300	332	1
	400	318	
Sect. V, 11. May 30	25	471	6
N. 43° 38′ 00″ W. 58° 35′ 00″	50	455	23
over 500 m.	75	398	8
	100	378	5
	125	366	7
	150	348	1
	300	338	1
	400	328	
Sect. V, 12. May 31	0	479	2
N. 43° 31′ 00″ W. 57° 46′ 00″	10	477	31
over 500 m.	25	431	2
	50	427	4
	75	418	4
	100	408	3
	125	400	9
	150	377	5
	175	364	2
	300	345	1
	400	333	
Sect. V, 13. May 31	0	508	20
N. 43° 27′ 35″ W. 27° 18′ 25″	25	459	23
over 500 m.	50	402	6
	75	387	8
	100	366	4
	150	347	2
	200	337	
Sect. V, 14. May 31	0	451	3
N. 43° 20′ 00″ W. 56 28′ 30″	25	443	5
over 500 m.	50	430	0
	75	430	61
	85	369	2
	100	366	5
	125	353	2
	150	348	1
	300	327	1
	400	321	
Sect. V, 15. May 31	0	472	1
N. 43 07′ 50″ W. 55 17′ 55″	25	470	15
over 500 m.	50	433	0
	75	432	18
	100	388	5
	150	362	2
	300	337	1
	400	326	

TABLE 1b.—Specific volume v_1 and stability S of the water at the Nova Scotian and Newfoundland banks during the spring 1915—*Continued.*

C. G. S. "ACADIA"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. V, VI, 16. June 1	0	411	
N. 42° 53′ 00″			1
W. 54° 09′ 00″	25	409	
			2
over 500 m.	75	399	
			3
	100	391	
			2
	200	375	
			1
	300	362	
			2
	400	346	
Sect. VI, 17. June 1	25	405	
N. 43° 13′ 50″			3
W. 54° 12′ 50″	50	397	
			0
over 500 m.	100	395	
			3
	150	379	
			1
	300	364	
			1
	400	352	
Sect. VI, 17*a*. June 1	0	436	
N. 43° 56′ 00″			7
W. 54° 16′ 00″	75	383	
			1
over 500 m.	100	380	
Sect. VI, 18. June 1	0	460	
N. 44° 11′ 30″			2
W. 54° 13′ 00″	25	455	
			4
over 500 m.	50	446	
			20
	75	396	
			5
	100	383	
			4
	150	362	
			2
	300	327	
			1
	400	317	
Sect. VI, 19. June 1	0	462	
N. 44° 35′ 00″			0
W. 54° 15′ 00″	25	462	
			3
over 500 m.	50	454	
			31
	75	377	
			0
	100	376	
			2
	150	366	
			2
	300	340	
			0
	400	339	

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. VI, 20. June 2	0	463	
N. 44° 59′ 00″			1
W. 54° 17′ 00″	25	460	
			6
91 m.	50	445	
			12
	75	416	
Sect. VI, 21. June 2	0	453	
N. 45° 28′ 00″			6
W. 54° 28′ 00″	35	433	
			1
116 m.	50	432	
			15
	65	409	
			4
	100	394	
Sect. VI, VII, 22. June 2	0	460	
N. 45° 50 ′30″			3
W. 54° 20 ′00″	20	455	
			8
73 m.	40	445	
			20
	50	425	
			14
	60	411	
Sect. VII, 23. June 2	0	459	
N. 45° 39′ 00″			1
W. 55° 03′ 00″	25	456	
			8
100 m.	50	435	
			14
	60	421	
			0
	75	421	
Sect. VII, 24. June 2	0	465	
N. 45° 16′ 30″			6
W. 59° 29′ 50″	50	436	
			8
120 m.	75	416	
			0
	100	415	
Sect. VII, 25. June 2	0	457	
N. 44° 56′ 00″			5
W. 55° 54′ 00″	25	445	
			11
124 m.	50	418	
			3
	100	404	
			7
	120	391	

TABLE 1*b*.—Specific volume v_1 and stability S of the water at the Nova Scotian and Newfoundland banks during the spring 1915—*Continued.*

C. G. S. "ACADIA"—*Continued.*

Station, time, position, depth.	Depth m.	v_8.	S.
Sect. VII, 26. June 2	0	507	
			14
N. 44° 31′ 00″ W. 56° 25′ 30″	25	473	
			6
	50	457	
over 500 m.			13
	100	391	
			11
	125	363	
			7
	150	346	
			16
	300	322	
			1
	400	313	
Sect. VII, VIII, 27. June 3	25	464	
			10
N. 44° 06′ 00″ W. 56° 54′ 00″	50	438	
			13
	75	406	
over 500 m.			10
	100	386 / 376	
			2
	150	369	
			3
	300	327	
			1
	400	315	
Sect. VIII, 28. June 3	0	542	
			12
N. 44° 12′ 00″ W. 57° 24′ 00″	25	513	
			7
	50	495	
over 500 m.			18
	75	450	
			11
	100	423	
			10
	150	373	
			2
	300	340	
			3
	400	314	
Sect. VIII, 29. June 3	0	550	
			7
N. 44° 21′ 36″ W. 58° 08′ 00″	40	522	
			32
	55	475	
58 m.			

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. VIII, 30. June 3	0	563	
			8
N. 44° 40′ 50″ W. 58° 42′ 00″	25	542	
			21
	50	490	
127 m.			1
	75	487	
			6
	100	472	
			7
	125	454	
Sect. VIII, 31. June 3	0	584	
			8
N. 45° 13′ 00″ W. 58° 59′ 00″	25	563	
			28
	50	493	
85 m.			5
	75	481	
Sect. VIII, 32. June 3	0	572	
			16
N. 45° 48′ 30″ W. 59° 13′ 00″	25	532	
			6
	50	517	
155 m.			12
	100	455	
			7
	150	419	
Sect. VIII, IX, 33. June 4	0	630	
			4
N. 46° 16′ 30″ W. 59° 33′ 00″	15	624	
			53
	25	571	
ca. 73 m.			26
	40	532	
			16
	50	516	
			18
	75	470	
Sect. IX, 34. June 4	0	522	
			10
N. 46° 40′ 00″ W. 59° 00′ 00″	25	498	
			12
	50	469	
ca. 350 m.			3
	100	453	
			6
	200	394	
			6
	300	339	

TABLE 1*b*.—Specific volume v_1 and stability *S* of the water at the Nova Scotian and Newfoundland banks during the spring 1915—*Concluded.*

C. G. S. "ACADIA"—*Concluded.*

Station, time, position, depth.	Depth m.	v_1.	*S*.
Sect. IX, 35. June 4	0	514	
			5
N. 47° 04′ 00″ W. 58° 26′ 00″	15	507	
			10
	30	492	
ca. 450 m.			13
	50	462	
			12
	75	431	
			6
	100	417	
			7
	150	380	
			3
	300	329	
			1
	400	321	

Station, time, position, depth.	Depth m.	v_1.	*S*.
Sect. IX, 36. June 4	0	521	
			12
N. 47° 26′ 00″ W. 57° 57′ 00″	25	492	
			14
	50	458	
230 m.			5
	75	445	
			5
	150	406	
			7
	200	369	

TABLE 1c.—Specific volume v_1 and stability S of the water in the Gulf of St. Lawrence during the summer 1915.

C. G. S. "PRINCESS"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	S.
Stat. 27. Aug. 3	0	1019	
N. 46° 02″ W. 63° 24′			22
23 m.	10	997	
			253
	20	744	
Stat. 28. Aug. 3	0	1082	
N. 46° 31′ W. 64° 20′			38
23 m.	10	1044	
			12
	20	1032	
Sect. X, 29. Aug. 4	0	1122	
N. 47° 13′ W. 64° 36′			90
32 m.	10	1032	
			294
	15	885	
			140
	20	815	
			60
	25	785	
Sect. X, 30. Aug. 4	0	1013	
N. 47° 31′ W. 64° 09′			6
66 m.	10	1007	
			105
	25	850	
			65
	40	753	
			94
	50	659	
			136
	60	523	
Sect. X, 31. Aug. 4	0	1068	
N. 47° 47′ W. 63° 45′			68
65 m.	10	1000	
			144
	25	784	
			78
	40	667	
			132
	50	535	
			38
	60	497	
Sect. X, 32. Aug. 4	0	982	
N. 48° 00′ W. 63° 25′			208
87 m.	10	774	
			111
	25	607	
			37
	50	514	
			10
	75	489	
			7
	85	482	
Sect. X, 33. Aug. 4	0	954	
N. 48° 17′ W. 62° 54′			202
78 m.	10	752	
			123
	25	567	
			32
	50	487	
			20
	75	438	
Sect. X, 34. Aug. 4	0	828	
N. 48° 27′ W. 62° 37′			122
405 m.	10	706	
			53
	25	626	
			55
	50	488	
			13
	75	454	
			12
	100	424	
			8
	150	383	
			4
	200	363	
			3
	300	329	
			2
	350	321	
Sect. X, 35. Aug. 5	0	775	
N. 48° 41′ W. 62° 15′			19
ca. 400 m.	10	756	
			125
	25	568	
			39
	50	471	
			9
	75	449	
			8
	100	428	
			6
	150	396	
			6
	200	367	
			4
	300	331	
			1
	350	326	

TABLE 1c.—Specific volume v_1 and stability S of the water in the Gulf of St. Lawrence during the summer 1915—*Continued.*

C. G. S. "PRINCESS"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. X, 36. Aug. 5	0	827	1
N. 48° 58′ W. 61° 48′	10	826	106
53 m.	25	667	144
	35	523	17
	50	497	
Sect. X, 37. Aug. 5	0	785	11
N. 49° 06′ W. 61° 21′	10	774	150
75 m.	25	549	30
	50	474	16
	70	443	
Sect. X, 38. Aug. 5	0	816	19
N. 49° 28′ W. 61° 22′	10	797	183
180 m.	25	523	24
	50	462	11
	75	434	7
	100	417	5
	150	392	0
	175	392	
Sect. X, 39. Aug. 5	0	801	11
N. 49° 45′ W. 61° 19′	10	790	175
284 m.	25	527	26
	50	462	10
	75	437	8
	100	417	3
	150	400	3
	200	385	6
	275	338	
Sect. X, XI, 40. Aug. 5	0	848	233
N. 50° 05′ W. 61° 16′	10	615	62
68 m.	25	522	24
	40	486	17
	50	469	0
	65	468	
Sect. XI, 41. Aug. 6	0	776	1
N. 49° 54′ W. 60° 37′	10	775	119
189 m.	25	597	37
	50	504	20
	75	455	10
	100	431	8
	150	411	9
	180	385	
Sect. XI, 42. Aug. 6	0	749	1
N. 49° 45′ W. 60° 07′	10	748	89
90 m.	25	615	48
	50	496	24
	75	437	1
	85	436	
Sect. XI, 43. Aug. 6	0	749	1
N. 49° 33′ W. 59° 28′	10	748	98
265 m.	25	601	42
	50	496	20
	75	445	20
	100	427	5
	150	402	5
	200	374	6
	250	346	

TABLE 1c.—Specific volume v_1 and stability S of the water in the Gulf of St. Lawrence during the summer 1915—*Continued.*

C. G. S. "PRINCESS"—*Concluded.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. XI, 44. Aug. 6	0	753	2
N. 49° 24′	10	751	108
W. 58° 55′	25	589	42
157 m.	50	485	14
	75	451	8
	100	430	6
	150	401	
Sect. XII, 45. Aug. 12	0	660	14
N. 47° 53′	25	624	44
W. 59° 38′	50	513	18
380 m.	75	467	5
	100	454	4
	150	436	8
	200	398	9
	300	313	0
	375	310	
Sect. XII, 46. Aug. 12	0	690	36
N. 47° 41′	25	600	49
W. 59° 52′	50	477	9
ca. 455 m.	75	454	6
	100	438	8
	150	399	7
	200	365	3
	300	332	1
	400	320	
Sect. XII, 47. Aug. 12	0	833	55
N. 47° 25′	25	696	58
W. 60° 10′	50	552	28
410 m.	75	481	12
	100	451	10
	150	402	5
	200	378	4
	300	342	2
	400	321	
Sect. XII, 48. Aug. 12	0	878	99
N. 47° 08′	25	631	53
W. 60° 31′	50	498	21
175 m.	75	446	8
	100	427	18
	125	383	4
	170	364	
Sect. XII, 49. Aug. 12	0	990	30
N. 46° 40′	10	960	206
W. 61° 14′	25	651	116
75 m.	35	535	8
	50	523	19
	60	504	37
	70	467	
Sect. XII, 50. Aug. 12	0	959	2
N. 46° 18′	10	957	97
W. 61° 59′	25	811	150
42 m.	40	586	

TABLE 1c.—Specific volume v_1 and stability S of the water in the Gulf of St. Lawrence during the summer 1915—*Concluded.*

STEAM DRIFTER "33".

Station, time, position, depth.	Depth m.	v_1.	S.
Stat. 54. Aug. 7	0	1393	
			679
South Arm, Bay of Island, Newfoundland.	10	714	
			105
	25	557	
			15
110 m.	50	519	
			18
	75	473	
			3
	100	465	
Stat. 58. Aug. 10	0	784	
			72
Off South Head, Bay of Island.	10	712	
			99
	25	564	
			32
50 m.	45	501	

Station, time, position, depth.	Depth m.	v_1.	S.
Stat. 59. Aug. 10	0	790	
			88
Inside South Head, Bay of Island.	10	702	
			101
	25	551	
			25
275 m.	50	488	
			6
	75	472	
			5
	100	460	
			3
	150	446	
			0
	200	444	
			0
	270	442	

TABLE 1*d*.—Specific volume v_1, and stability *S* of the water on the Nova Scotian and Newfoundland banks during the summer 1915.

C. G. S. "ACADIA"

Station, time, position, depth.		Depth m.	v_1.	*S*.
Sect. XIII. 37.	July 21	0	653	
				37
N. 43° 33′ 00″		20	579	
W. 65° 12′ 50″				27
		40	525	
62 m.				8
		60	509	
Sect. XIII. 38.	July 21	0	709	
				32
N. 43° 14′ 00″		25	630	
W. 65° 02′ 00″				29
		50	558	
170 m.				23
		75	501	
				19
		100	453	
				5
		125	440	
				5
		150	427	
Sect. XIII. 39.	July 21	0	693	
				20
N. 42° 55′ 00″		25	642	
W. 64° 51′ 00″				18
		40	606	
95 m.				84
		50	522	
				16
		75	483	
				1
		90	481	
Sect. XIII. 40.	July 22	0	738	
				83
N. 42° 36′ 00″		25	531	
W. 64° 41′ 00″				26
		50	467	
134 m.				17
		75	425	
				6
		100	410	
				8
		125	389	
Sect. XIII. 41.	July 22	0	594	
				17
N. 42° 17′ 00″		25	551	
W. 64° 30′ 30″				52
		50	421	
420 m.				4
		75	410	
				7
		100	392	
				3
		150	376	
				2
		200	366	
				2
		300	345	
				1
		400	326	
Sect. XIII. 42.	July 22	0	599	
				18
N. 41° 58′ 00″		25	554	
W. 64° 20′ 00″				47
		50	437	
over 1,000 m.				14
		75	402	
				6
		100	388	
				3
		150	371	
				3
		200	359	
				1
		300	345	
				2
		400	328	
Sect. XIII. 43.	July 22	0	609	
				18
N. 41° 38′ 30″		25	563	
W. 64° 10′ 00″				21
		50	510	
over 1,000 m.				32
		75	430	
				2
		100	424	
				6
		150	396	
				1
		200	391	
				3
		300	362	
				2
		400	340	

TABLE 1*d*.—Specific volume v_1, and stability *S* of the water on the Nova Scotian and Newfoundland banks during the summer 1915—*Continued.*

C. G. S. "ACADIA"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	*S*.
Sect. XIII, XIV, 44. July 22	0	646	13
N. 41° 19′ 00″	25	613	40
W. 63° 59′ 00″	50	514	28
Over 1,000 m.	75	445	17
	100	402	4
	150	380	2
	200	369	2
	300	348	2
	400	325	
Sect. XIV, 45. July 22	0	588	4
N. 42° 02′ 00″	25	577	35
W. 63° 43′ 00″	50	490	22
Over 1,000 m.	75	434	10
	100	410	6
	150	382	3
	200	369	4
	300	328	1
	400	316	
Sect. XIV, 46. July 23	0	695	38
N. 42° 31′ 00″	25	600	64
W. 63° 31′ 30″	50	442	10
Over 1,000 m.	75	418	4
	100	409	7
	150	375	1
	200	371	4
	300	333	0
	400	332	
Sect. XIV, 47. July 23	0	610	11
N. 43° 15′ 00″	25	582	34
W. 63° 13′ 30″	50	498	34
144 m.	75	413	7
	100	396	6
	125	380	
Sect. XIV, 48. July 23	0	724	37
N. 43° 53′ 30″	25	632	66
W. 62° 58′ 30″	50	468	12
264 m.	75	439	13
	100	407	12
	125	378	4
	150	369	3
	200	356	1
	250	349	
Sect. XIV, XV, 49. July 23	0	750	61
N. 44° 30′ 30″	25	598	55
W. 62° 43′ 00″	40	516	12
135 m.	50	504	9
	75	482	4
	100	472	7
	125	454	
Sect. XV, 50. July 23	0	714	51
N. 44° 12′ 15″	25	587	48
W. 62° 35′ 00″	50	467	12
155 m.	75	436	11
	100	408	6
	125	393	3
	150	386	
Sect. XV, 51. July 23	0	688	35
N. 43° 52′ 00″	25	601	87
W. 62° 18′ 00″	40	471	16
133 m.	50	455	15
	75	417	9
	100	395	2
	125	389	

TABLE 1*d*.—Specific volume v_1, and stability S of the water on the Nova Scotian and Newfoundland banks during the summer 1915—*Continued.*

C. G. S. "ACADIA"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. XV, 52. July 24	0	645	
			30
N. 43° 31′ 00″ W. 62° 01′ 00″	25	569	
			58
	40	482	
			25
95 m.	50	457	
			20
	60	437	
			5
	75	430	
			13
	90	404	
Sect. XV, 53. July 24	0	618	
			35
N. 43° 14′ 30″ W. 61° 48′ 00″	25	530	
			52
	40	452	
			7
99 m.	50	445	
			7
	75	428	
			5
	95	419	
Sect. XV, 54. July 24	0	670	
			43
N. 42° 57′ 30″ W. 61° 34′ 00″	25	563	
			56
	50	422	
			14
Over 1,000 m.	75	387	
			1
	100	385	
			6
	150	357	
			1
	200	353	
			4
	300	317	
			1
	400	309	
Sect. XV, 55. July 24	0	712	
			70
N. 42° 41′ 15″ W. 61° 21′ 00″	25	536	
			40
	50	437	
			17
Over 1,000 m.	75	395	
			1
	100	393	
			6
	150	361	
			1
	200	355	
			1
	300	345	
			3
	400	320	
Sect. XV, XVI, 56. July 24	0	768	
			94
N. 42° 16′ 00″ W. 61° 01′ 00″	25	533	
			40
	50	434	
			7
Over 1,000 m.	100	398	
			5
	150	372	
			0
	200	371	
			3
	300	344	
			1
	400	339	
Sect. XVI, 57. July 24	0	679	
			50
N. 42° 57′ 20″ W. 60° 56′ 00″	25	553	
			40
	50	452	
			19
Over 1,000 m.	75	405	
			8
	100	386	
			6
	150	356	
			3
	200	342	
			2
	300	322	
			1
	400	311	
Sect. XVI, 58. July 24	0	658	
			43
N. 43° 23′ 00″ W. 60° 53′ 00″	25	550	
			42
	50	445	
			3
187 m.	75	437	
			18
	100	393	
			6
	125	378	
			4
	150	367	
			3
	175	359	
Sect. XVI, 59. July 25	0	642	
			5
N. 43° 48′ 30″ W. 60° 50′ 00″	15	635	
			47
45 m.	30	565	
			37
	45	510	

TABLE 1*d*.—Specific volume v_1, and stability S of the water on the Nova Scotian and Newfoundland banks during the summer 1915—*Continued.*

C. G. S. "ACADIA"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. XVI, 60. July 25	0	668	
			38
N. 44° 13′ 30″ W. 61° 14′ 00″	25	573	
			42
	50	469	
98 m.			17
	75	427	
			6
	95	414	
Sect. XVI, 62. July 25	0	691	
			22
N. 44° 34′ 30″ W. 60° 47′ 00″	25	637	
			62
	40	544	
62 m.			32
	50	512	
			15
	60	497	
Sect. XVI, 63. July 25	0	693	
			44
N. 44° 43′ 30″ W. 60° 46′ 00″	25	584	
			35
55 m.	50	496	
Sect. XVI, 64. July 25	0	754	
			40
N. 45° 04′ 00″ W. 60° 46′ 00″	25	653	
			41
	50	551	
120 m.			30
	75	476	
			6
	110	454	
Sect. XVI, XVII, 65. July 25	0	793	
			46
N. 45° 17′ 00″ W. 60° 42′ 30″	10	747	
			86
	25	618	
105 m.			44
	50	509	
			5
	75	497	
			7
	100	480	
Sect. XVII, 66. July 25	0	732	
			4
N. 45° 08′ 00″ W. 60° 23′ 00″	10	728	
			1
	25	726	
64 m.			79
	40	608	
			80
	50	528	
			37
	60	491	
Sect. XVII, 67. July 25	0	699	
			1
N. 44° 49′ 00″ W. 59° 40′ 00″	10	698	
			58
	25	611	
205 m.			50
	50	486	
			10
	75	460	
			2
	100	455	
			3
	150	438	
			2
	200	429	
Sect. XVII, 68. July 26	0	673	
			18
N. 44° 32′ 00″ W. 59° 04′ 00″	10	655	
			91
	25	518	
54 m.			13
	40	498	
			13
	50	485	
Sect. XVII, 69. July 26	0	693	
			1
N. 44° 19′ 15″ W. 58° 36′ 00″	10	692	
			61
	25	641 558	
64 m.			74
	40	493 485	
			5
	50	484	
Sect. XVII, 70. July 26	0	659	
			52
N. 44° 05′ 00″ W. 58° 05′ 00″	25	528	
			35
	50	441	
Over 1,000 m.			16
	75	401	
			10
	100	375	
			5
	150	352	
			3
	200	338	
			1
	300	326	
			1
	400	315	

TABLE 1*d*.—Specific volume v_1, and stability *S* of the water on the Nova Scotian and Newfoundland banks during the summer 1915—*Continued.*

C. G. S. "ACADIA"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	*S*.
Sect. XVII, 71. July 26	0	605	46
N. 43° 57′ 00″ W. 57° 46′ 30″	25	545	39
Over 1,000 m.	50	448	21
	75	396	9
	100	373	
Sect. XVII, 72. July 26	0	708	75
N. 43° 51′ 30″ W. 57° 33′ 00″	25	521	36
Over 1,000 m.	50	430	12
	75	401	8
	100	381	4
	150	362	2
	200	353	2
	300	333	1
	400	321	
Sect. XVII, 73. July 26	0	703	66
N. 43° 46′ 00″ W. 57° 21′ 00″	25	539	46
Over 1,000 m.	50	424	12
	75	394	6
	100	379	
Sect. XVII, 74. July 26	0	697	72
N. 43° 41′ 00″ W. 57° 08′ 00″	25	517	35
Over 1,000 m.	50	429	10
	75	403	4
	100	392	3
	150	375	1
	200	369	2
	300	346	2
	400	329	
Sect. XVII, XVIII, 75. July 26	0	649	10
N. 43° 30′ 00″ W. 56° 43′ 00″	10	639	61
Over 1,000 m.	25	548	17
	50	506	37
	75	413	8
	100	394	3
	150	381	3
	200	367	2
	300	344	1
	400	329	
Sect. XVIII, 76. July 27	0	775	60
N. 43° 55′ 30″ W. 56° 13′ 00″	25	626	70
Over 1,000 m.	50	451	14
	75	417	11
	100	389	5
	150	362	4
	200	341	2
	300	322	1
	400	314	
Sect. XVIII, 77. July 27	0	747	80
N. 44° 21′ 15″ W. 55° 42′ 30″	10	667	96
Over 1,000 m.	25	523	36
	50	433	10
	75	407	6
	100	391	6
	150	362	4
	200	344	2
	300	326	1
	400	317	

TABLE 1*d*.—Specific volume v_1, and stability *S* of the water on the Nova Scotian and Newfoundland banks during the summer 1915—*Continued.*

C. G. S. "ACADIA"—*Continued.*

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. XVIII, 78. July 27			
N. 44° 33′ 00″	0	667	
W. 55° 29′ 00″			50
	50	418	
Over 1,000 m.			9
	75	395	
			10
	100	370	
Sect. XVIII, XIX, 79. July 27	0	617	
			43
N. 44° 47′ 00″	10	574	
W. 55° 13′ 00″			33
	25	525	
410 m.			28
	50	456	
			20
	75	407	
			10
	100	381	
			4
	150	361	
			2
	200	350	
			2
	300	330	
			1
	400	318	
Sect. XIX, 80. July 27	0	637	
			21
N. 45° 17′ 00″	10	616	
W. 55° 27′ 00″			37
	25	561	
155 m.			55
	40	478	
			33
	50	445	
			13
	75	412	
			2
	100	407	
			0
	125	406	
			0
	150	406	
Sect. XIX, 81. July 27	0	611	
			14
N. 45° 48′ 30″	10	597	
W. 55° 43′ 00″			59
	25	508	
56 m.			29
	40	464	
			4
	54	459	

Station, time, position, depth.	Depth m.	v_1.	S.
Sect. XIX, 82. July 27	0	616	
			0
N. 46° 11′ 00″	10	616	
W. 55° 54′ 00″			43
	25	551	
58 m.			28
	40	509	
			64
	50	445	
Sect. XIX, XX, 83. July 28	0	625	
			18
N. 46° 32′ 00″	25	580	
W. 56° 04′ 00″			49
	50	457	
172 m.			8
	75	437	
			4
	100	428	
			3
	125	420	
			3
	150	413	
			2
	170	409	
Sect. XX, 84. July 28	0	610	
			3
N. 46° 17′ 00″	10	607	
W. 56° 37′ 00″			38
	25	550	
60 m.			41
	40	489	
			51
	50	438	
Sect. XX, 85. July 28	0	724	
			66
N. 46° 02′ 45″	20	592	
W. 57° 09′ 00″			53
	40	487	
492 m.			35
	50	452	
			14
	75	418	
			9
	100	395	
			5
	150	368	
			4
	200	347	
			2
	300	324	
			1
	400	311	

TABLE 1*d*.—Specific volume v_1, and stability *S* of the water on the Nova Scotian and Newfoundland banks during the summer 1915—*Concluded.*

C. G. S. "ACADIA"—*Concluded.*

Station, time, position, depth.	Depth m.	v_1.	*S*.
Sect. XX, 86. July 28	0	726	
N. 45° 47′ 00″			84
W. 57° 34′ 00″	25	515	
455 m.			30
	50	439	
			15
	75	402	
			1
	100	399	
			7
	150	362	
			2
	200	352	
			3
	300	326	
			2
	400	311	
Sect. XX, 87. July 28	0	726	
N. 45° 38′ 30″			85
W. 57° 59′ 30″	15	598	
330 m.			86
	25	512	
			31
	50	434	
			10
	75	408	
			4
	100	399	
			5
	150	372	
			4
	200	352	
			3
	300	325	
Sect. XX, 88. July 28	0	792	
N. 45° 26′ 00″			88
W. 58° 34′ 30″	25	573	
130 m.			33
	40	524	
			12
	50	512	
			12
	75	483	
			11
	100	456	
			16
	125	417	
Sect. XX, 89. July 28	0	775	
N. 45° 16′ 00″			44
W. 59° 04′ 00″	25	665	
130 m.			65
	50	503	
			8
	75	484	
			0
	100	484	
			4
	125	475	
Stat. 91. July 29	0	846	
Canso Strait			10
50 m.	10	836	
			1
	20	835	
			3
	30	832	
			1
	40	831	

TABLE 2.—Depth of the Isosteric surfaces in metres. Spring cruises.

THE GULF OF ST. LAWRENCE.

"*" and "B" denotes that the isosteric surface in question has intersected the surface or the bottom, respectively, beyond the station.

	Section I.														Section II.				
Stat.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	14	15	16	17	18
Depth m.	69	45	25	21	31	61	76	92	160–300	150–250	51	140	ca. 200	40	40	85	260	130	64
v_1 = 900......	*	*	2	0	6	0	4	*	*	*	*	*	*	3	3	*	*	*	*
v_1 = 800......	*	*	10	B	16	5	13	0	*	*	*	*	2	6	6	*	*	*	*
v_1 = 700......	*	*	B	B	24	9	19	13	*	*	*	*	11	10	10	15	*	*	*
v_1 = 600......	30	33	B	B	B	24	24	20	11	9	13	5	21	16	16	25	*	*	*
v_1 = 500......	B	B	B	B	B	B	B	65	57	51	44	46	47	33	33	38	49	52	34
v_1 = 400......	B	B	B	B	B	B	B	B	130	142	B	B	167	B	B	B	138	B	B

	Section III.								Section IV.					
Stat.	19	20	21	23	22	24	25	26	21	22	23	26	25	24
	82	250–400	ca. 500	ca. 100	55	40	63	40	27	195	355	389	271	45
v_1 = 900..............................	*	*	*	*	*	*	*	*	*	*	*	*	*	*
v_1 = 800..............................	*	*	*	*	*	*	*	*	0	3	9	6	*	*
v_1 = 700..............................	*	*	*	*	*	*	13	22	6	12	14	18	20	*
v_1 = 600..............................	*	*	*	*	*	29	20	34	17	19	21	26	27	16
v_1 = 500..............................	40	67	50	41	40	B	B	B	B	47	49	39	50	37
v_1 = 400..............................	B	161	150	B	B	B	B	B	B	111	135	139	136	B

TABLE 2.—Depth of the Isosteric surfaces in metres.—Spring cruises—*Con.*

THE NOVA SCOTIA AND NEWFOUNDLAND BANK.

	Section V.															
Stat.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Depth m.	25	60	146	173	73	45	109	51	106	740	Over 500					
v_1 = 600	12	17	13	*	*	*	*	*	*	*	*	*	*	*	*	*
v_1 = 500	B	B	39	51	7	45	29	60	25	*	*	*	*	*	*	*
v_1 = 400	B	B	B	129	B	B	92	B	101	87	74	125	53	80	93	70

	Section VI.								Section VII.					
Stat.	16	17	17*a*	18	19	20	21	22	22	23	24	25	26	27
Depth m.	Over 500					91	116	73	73	100	120	124	Ov. 500.	
v_1 = 600	*	*	*	*	*	*	*	*	*	*	*	*	*	*
v_1 = 500	*	*	*	*	*	*	*	*	*	*	*	*	5	*
v_1 = 400	70	41	51	73	68	B	86	B	B	B	B	106	93	81

	Section VIII.							Section IX.			
Stat.	27	28	29	30	31	32	33	33	34	35	36
Depth m.	Over 500		58	127	85	155	ca. 73	ca. 73	ca. 350	ca. 450	230
v_1 = 600	*	*	*	*	*	*	19	19	*	*	*
v_1 = 500	*	43	47	45	47	64	59	59	23	22	18
v_1 = 400	81	123	B	B	B	B	B	B	190	115	158

TABLE 2.—Depth of the Isosteric surfaces in metres. Summer cruises.

THE GULF OF ST. LAWRENCE.

	—		Section X.											
Stat.	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Depth m.	23	22	32	66	65	87	78	405	ca. 400	53	75	180	284	68
v_1 = 1100	*	*	2	*	*	*	*	*	*	*	*	*	*	*
v_1 = 1000	8	B	11	11	10	*	*	*	*	*	*	*	*	*
v_1 = 900	14	B	14	20	17	4	3	*	*	*	*	*	*	*
v_1 = 800	18	B	23	33	24	9	8	2	*	12	*	8	1	2
v_1 = 700	B	B	B	46	36	17	14	11	14	22	15	15	15	7
v_1 = 600	B	B	B	54	45	27	22	30	22	30	22	21	21	12
v_1 = 500	B	B	B	B	59	64	46	48	42	48	41	35	35	34
v_1 = 400	B	B	B	B	B	B	B	130	143	B	B	134	150	B

	Section XI.					Section XII.						—			
Stat.	40	41	42	43	44	45	46	47	48	49	50	54	58	59	91
Depth m.	68	189	90	265	157	380	ca. 455	410	175	75	42	110	50	275	50
v_1 = 1100	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
v_1 = 1000	*	*	*	*	*	*	*	*	*	*	*	6	*	*	*
v_1 = 900	*	*	*	*	*	*	*	*	*	13	16	7	*	*	*
v_1 = 800	2	*	*	*	*	*	*	6	8	18	26	9	*	*	B
v_1 = 700	7	16	17	15	15	*	*	24	18	23	32	11	11	10	B
v_1 = 600	12	24	28	25	24	30	25	42	31	31	39	21	21	20	B
v_1 = 500	34	52	49	49	46	57	45	69	50	61	B	61	45	46	B
v_1 = 400	B	162	B	154	152	198	149	148	115	B	B	B	B	B	B

TABLE 2.—Depth of the Isosteric surfaces in metres. Summer cruises—*Con.*

THE NOVA SCOTIA AND NEWFOUNDLAND BANKS.

	Section XIII.								Section XIV.					
Stat.	37	38	39	40	41	42	43	44	44	45	46	47	48	49
Depth m.	62	170	95	134	420	Over 1000			Over 1000			144	246	135
v_1 = 700	*	3	*	5	*	*	*	*	*	*	*	*	7	8
v_1 = 600	14	35	41	17	*	0	5	28	28	*	25	9	30	25
v_1 = 500	B	75	64	37	35	37	53	55	55	47	41	49	45	55
v_1 = 400	B	B	B	112	89	78	143	105	105	117	113	94	106	B

	Section XV.								Section XVI.								
Stat.	49	50	51	52	53	54	55	56	56	57	58	59	60	62	63	64	65
Depth m.	135	155	133	95	99	Over 1000			Over 1000		187	45	98	62	55	120	105
v_1 = 700	8	3	*	*	*	*	2	7	7	*	*	*	*	*	*	13	15
v_1 = 600	25	22	25	15	5	16	16	18	18	16	13	22	18	31	21	38	29
v_1 = 500	55	43	37	37	31	36	34	33	33	38	37	B	43	58	49	67	69
v_1 = 400	B	113	94	92	B	66	72	97	97	82	96	B	B	B	B	B	B

	Section XVII.											Section XVIII.				
Stat.	65	66	67	68	69	70	71	72	73	74	75	75	76	77	78	79
Depth m.	105	64	205	54	64	Over 1000						Over 1000				410
v_1 = 700	17	28	0	*	*	*	*	1	0	0	0	*	13	6	*	*
v_1 = 600	29	41	27	16	25	11	13	14	16	13	16	16	29	17	13	4
v_1 = 500	69	58	47	38	39	33	37	31	34	30	52	52	43	31	33	34
v_1 = 400	B	B	B	B	B	76	73	76	70	82	92	92	90	86	69	82

TABLE 2.—Depth of the Isosteric surfaces in metres. Summer cruises—*Con.*

THE NOVA SCOTIA AND NEWFOUNDLAND BANKS—*Concluded.*

	Section XIX.					Section XX.						
Stat.	79	80	81	82	83	83	84	85	86	87	88	89
Depth m.	410	155	56	58	172	172	60	492	455	330	130	130
v_1 = 700	*	*	*	*	*	*	*	4	3	3	10	17
v_1 = 600	4	14	8	14	14	14	12	19	15	15	22	35
v_1 = 500	34	36	28	41	41	41	37	37	30	29	60	54
v_1 = 400	82	B	B	B	B	B	B	95	92	97	B	B

TABLE 3.—Form for calculation of amount of solenoids in the sea.

1	2	3	4	5	6	7	8	9
Depth	v_{34}	v_{35}	a	a_m	A	ΣA	a_{100}	ΣA_{100}
0	522	514	r 8			r 6101	r 13	9840
				r 4·5	r 113			
25	498	497	r 1			r 5988	r 2	9658
				r 4	r 100			
50	469	462	r 7			r 5888	r 11	9497
				r 18·5	r 463			
75	461	431	r30			r 5425	r 48	8750
				r 33	r 825			
100	453	417	r36			r 4600	r 58	7419
				r 23	r 4600			
300	339	329	r10			0	r 16	0

TABLE 4.—Amount of solenoids between Stations IX. 34 and IX. 35.

Depth.	a	0·1 A	0·1 ΣA	$a_{100km.}$	$\Sigma A_{10km.}$
0	r 8		r 610	r 13	r 984
		r 11			
25	r 1		r 599	r 2	r 966
		r 10			
50	r 7		r 589	r 11	r 950
		r 46			
75	r 30		r 543	r 48	r 875
		r 83			
100	r 36		r 460	r 58	r 742
		r 460			
300	r 10		0	r 16	0

TABLE 5.—The Solenoids in Canadian waters.

—	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	$ΣA_{10km}$	u.
Sect. I, 5–6, 47 km. 48 m.	0	r 26		r353	r 55	r750	SE. 7·0
			r108				
	10	r189		r245	r402	r521	SE. 4·8
			r150				
	20	r112		r 95	r238	r201	SE. 1·9
			r 95				
	30	r 77		0	r164	0	0
Sect. I, 6–7 54 km. 68 m.	0	l 25		l 329	l 46	l 607	NW. 5·6
			l 92				
	10	l 157		l 237	l 290	l 438	NW. 4·1
			l 141				
	20	l 126		l 96	l 233	l 178	NW. 1·7
			l 30				
	25	r 8		l 66	r 15	l 122	NW. 1·1
			l 5				
	30	l 28		l 61	l 52	l 113	NW. 1·0
			l 23				
	40	l 17		l 38	l 31	l 70	NW. 0·7
			l 19				
	50	l 21		l 19	l 39	l 35	NW. 0·3
			l 19				
	60	l 18		0	l 33	0	0
Sect. I, 7–8 57 km., 78 m.	0	r 132		r 542	r 231	r 951	SE. 8·7
			r 118				
	10	r 105		r 424	r 184	r 743	SE. 6·8
			r 134				
	20	r 163		r 290	r 285	r 508	SE. 4·7
			r 184				
	40	r 21		r 106	r 37	r 186	SE. 1·7
			r 58				
	60	r 37		r 48	r 65	r 84	SE. 0·8
			r 48				
	75	r 27		0	r 47	0	0
Sect. I, 8–9 44 km., 100 m.	0	r 160		r 414	r 363	r 941	SE. 8·7
			r 241				
	25	r 33		r 173	r 75	r 393	SE. 3·6
			r 123				
	75	r 16		r 50	r 36	r 114	SE. 1·0
			r 50				
	100	r 24		0	r 54	0	0
Sect. I, 9–10 75 km., 325 m.	0	r 11		r 81	r 15	r 108	SE. 1·0
			r 29				
	25	r 12		r 52	r 16	r 69	SE. 0·6
			r 24				
	50	r 7		r 28	r 9	r 37	SE. 0·3
			r 33				
	75	r 19		l 5	r 25	l 7	NW. 0·1
			r 25				
	100	r 1		l 30	r 1	l 40	NW. 0·4
			l 30				
	150	l 13		0	l 17	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	u.
Sect. I, 10–11 .... 28 km., 90 m.	0	r 14	r 48	r 97	r 50	r 346	SE. 3·1
	25	r 25	r 49	r 49	r 89	r 175	SE. 1·6
	50	r 14		0	r 50	0	0
Sect. I, 11–12 .... 49 km., 90 m.	0	l 13	r 16	r 17	l 27	r 35	SE. 0·3
	10	r 46	r 25	r 1	r 94	r 2	SE. 0
	25	l 13	l 24	l 24	l 27	l 49	NW. 0·4
	50	l 6		0	l 12	0	0
Sect. I, 12–13 .... 34 km., 250 m.	0	l 189	l 280	l 348	l 556	l 1023	NW. 9·2
	25	l 35	l 42	l 68	l 103	l 200	NW. 1·8
	50	r 2	r 2	l 26	r 6	l 76	NW. 0·7
	75	l 1	l 19	l 28	l 3	l 82	NW. 0·7
	100	l 14	l 9	l 9	l 41	l 26	NW. 0·2
	125	r 7		0	r 21	l 0	0
Sect. I, 13–14 .... 41 km., 110 m.	0	l 177	l 132	l 70	l 432	l 171	NW. 1·5
	20	r 45	r 62	r 62	r 110	r 151	SE. 1·4
	35	r 38		0	r 93	0	0
Sect. II, 14–15 .... 83 km., 110 m.	0	r 227	r 75	l 115	r 273	l 139	NE. 1·3
	10	l 77	l 89	l 190	l 93	l 230	NE. 2·1
	20	l 101	l 101	l 101	l 122	l 122	NE. 1·1
	40	0		0	0	0	0
Sect. II, 15–16 .... 49 km., 180 m.	0	r 189	r 192	r 287	r 386	r 585	SW. 5·3
	10	r 194	r 137	r 95	r 396	r 194	SW. 1·7
	20	r 80	r 45	l 42	l 163	l 86	NE. 0·8
	40	l 35	l 54	l 87	l 71	l 177	NE. 1·6
	60	l 19	l 33	l 33	l 39	l 67	NE. 0·6
	80	l 14		0	l 29	0	0
Sect. II, 16–17 .... 47 km., 210 m.	0	r 16	r 28	l 85	r 34	l 181	NE. 1·6
	25	r 6	l 3	l 113	r 13	l 241	NE. 2·2
	50	l 8	l 30	l 110	l 17	l 234	NE. 2·1
	75	l 16	l 45	l 80	l 34	l 170	NE. 1·5
	100	l 20	l 35	l 35	l 43	l 75	NE. 0·7
	125	l 8		0	l 17	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth	a.	0·1 Λ.	0·1 ΣΛ.	a_{100km}.	ΣΛ $_{10km}$	u.
Sect. II, 17–18. 26 km., 100 m.	0	*l* 26	*l* 10	*r* 53	*l* 100	*r* 204	SW. 1·8
	25	*r* 18	*r* 63	*r* 63	*r* 69	*r* 242	SW. 2·2
	50	*r* 32		0	*r* 123	0	0
Sect. III, 19–20. 42 km., 130 m.	0	*r* 3	*l* 29	*l* 264	*r* 7	*l* 628	SE. 5·8
	25	*l* 26	*l* 93	*l* 235	*l* 62	*l* 559	SE. 5·1
	50	*l* 48	*l* 53	*l* 142	*l* 114	*l* 338	SE. 3·1
	60	*l* 58	*l* 89	*l* 89	*l* 138	*l* 212	SE. 2·0
	80	*l* 31		0	*l* 74	0	0
Sect. III, 20–21. 39 km., 369 m.	0	*r* 17	*r* 39	*r* 330	*r* 44	*r* 846	NW. 7·8
	25	*r* 14	*r* 66	*r* 291	*r* 36	*r* 746	NW. 6·9
	50	*r* 39	*r* 69	*r* 225	*r* 100	*r* 577	NW. 5·3
	75	*r* 16	*r* 31	*r* 156	*r* 41	*r* 400	NW. 3·7
	100	*r* 9	*r* 125	*r* 125	*r* 23	*r* 321	NW. 3·0
	200	*r* 16		0	*r* 41	0	0
Sect. III, 21–23. 44 km., 400 m.	0	*l* 42	*l* 55	*r* 62	*l* 95	*r* 141	NW. 1·3
	20	*l* 13	*l* 2	*r* 117	*l* 30	*r* 266	NW. 2·5
	40	*r* 11	*r* 16	*r* 119	*r* 25	*r* 270	NW. 2·5
	50	*r* 22	*r* 48	*r* 103	*r* 50	*r* 234	NW. 2·2
	75	*r* 16	*r* 55	*r* 55	*r* 36	*r* 124	NW. 1·1
	100	*r* 28		0	*r* 64	0	0
Sect. III, 23–22. 11 km., 70 m.	0	*r* 5	*r* 10	*r* 9	*r* 45	*r* 82	NW. 0·8
	20	*r* 5	*r* 10	*l* 1	*r* 45	*l* 9	SE. 0·1
	40	*r* 5	*l* 11	*l* 11	*r* 45	*l* 100	SE. 0·9
	55	*l* 19		0	*l* 173	0	0
Sect. III, 22–24. 65 km., 45 m.	0	*l* 102	*l* 190	*l* 307	*l* 157	*l* 473	SE. 4·4
	20	*l* 88	*l* 117	*l* 117	*l* 136	*l* 180	SE. 1·7
	35	*l* 68		0	*l* 105	0	0

TABLE 5.—The Solenoids in Canadian waters.—*Continued*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA 10km	u.
Sect. III, 24-25 .... 51 km., 50 m.	0	l 79		l 27	l 155	l 53	SE. 0·5
			l 77				
	10	l 74		r 50	l 145	r 98	NW. 0·9
			l 15				
	20	r 44		r 65	r 86	r 127	NW. 1·2
			r 47				
	30	r 49		r 18	r 96	r 35	NW. 0·3
			r 18				
	35	r 24		0	r 47	0	0
Sect. III, 25-26 .... 66 km., 60 m.	0	l 36		l 234	l 54	l 354	SE. 3·3
			l 34				
	10	l 32		l 200	l 48	l 303	SE. 2·9
			l 75				
	20	l 118		l 125	l 179	l 189	SE. 1·8
			l 125				
	35	l 49		0	l 74		0
Sect. IV, 21-22........ 7 km., 50 m.	0	l 21		l 126	l 300	l 1802	NW. 16·4
			l 55				
	10	l 89		l 71	l 1271	l 1015	NW. 9·2
			l 71				
	24	l 12		0	l 171	0	0
Sect. IV, 22-23 .... 20 km., 240 m.	0	r 3		l 229	r 15	l 1145	NW. 10·4
			l 31				
	10	l 65		l 198	l 325	l 990	NW. 9·0
			l 44				
	20	l 22		l 154	l 110	l 770	NW. 7·0
			l 20				
	30	l 18		l 134	l 90	l 670	NW. 6·1
			r 23				
	50	l 5		l 111	l 25	l 555	NW. 5·1
			r 9				
	75	r 12		l 120	r 60	l 600	NW. 5·5
			l 2				
	100	l 13		l 118	l 65	l 590	NW. 5·4
			l 41				
	125	l 20		l 77	l 100	l 385	NW. 3·5
			l 41				
	150	l 13		l 36	l 65	l 180	NW. 1·6
			l 36				
	190	l 5		0	l 25	0	0
Sect. IV, 23-26........ 19 km., 350 m.	0	l 2		r 105	l 11	r 553	SE. 5·0
			r 5				
	10	r 13		r 100	r′ 68	r 526	SE. 4·8
			l 30				
	20	l 74		r 130	l 389	r 684	SE. 6·2
			l 25				
	30	r 24		r 155	r 126	r 816	SE. 7·4
			r 59				
	50	r 35		r 96	r 184	r 505	SE. 4·6
			r 59				
	75	r 12		r 37	r 63	r 195	SE. 1·8
			r 22				
	100	r 6		r 15	r 32	r 79	SE. 0·7
			0				
	150	l 6		r 15	l 32	r 79	SE. 0·7
			l 10				
	250	r 4		r 25	r 21	r 132	SE. 1·2
			r 25				
	350	r 1		0	r 5	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	u.
Sect. IV, 26–25.......... 16 km., 256 m.	0	r 81		l 46	r 506	l 289	NW. 2·6
			r 62				
	10	r 43		l 108	r 269	l 675	NW. 6·1
			r 12				
	20	l 20		l 120	l 125	l 750	NW. 6·8
			l 19				
	30	l 18		l 101	l 113	l 631	NW. 5·7
			l 55				
	50	l 37		l 46	l 231	l 288	NW. 2·6
			l 65				
	75	l 15		r 19	l 94	r 119	SE. 1·1
			l 14				
	100	r 4		r 33	r 25	r 206	SE. 1·9
			r 13				
	150	r 1		r 20	r 6	r 125	SE. 1·1
			r 20				
	250	r 3		0	r 19	0	0
Sect. IV, 25–24.......... 11 km., 130 m.	0	r 103		r 318	r 936	r 2890	SE. 26·0
			r 117				
	10	r 131		r 201	r1191	r 1827	SE. 16·4
			r 120				
	20	r 109		r 81	r 991	r 736	SE. 6·6
			r 56				
	30	r 3		r 25	r 27	r 227	SE. 2·0
			r 25				
	42	r 38		0	r 345	0	0
Sect. V, 1–2.......... 17 km., 27 m.	0	r 9		l 10	r 53	l 59	NE. 0·6
			r 9				
	10	r 8		l 19	r 47	l 112	NE. 1·1
			l 19				
	20	l 45		0	l 265	0	0
Sect. V, 2–3.......... 38 km., 90 m.	0	l 3		r 143	l 8	r 376	SW. 3·7
			l 2				
	10	l 1		r 145	l 3	r 381	SW. 3·7
			r 3				
	20	r 7		r 142	r 18	r 373	SW. 3·7
			r 25				
	30	r 42		r 117	r 110	r 308	SW. 3·0
			r 49				
	40	r 56		r 68	r 147	r 179	SW. 1·8
			r 68				
	55	r 34		0	r 89	0	0
Sect. V, 3–4.......... 65 km., 170 m.	0	r 42		r 131	r 65	r 201	SW. 2·0
			r 41				
	10	r 40		r 90	r 62	r 139	SW. 1·4
			r 37				
	20	r 34		r 53	r 52	r 82	SW. 0·8
			r 9				
	30	l 16		r 44	l 25	r 68	SW. 0·7
			l 21				
	40	l 26		r 65	l 40	r 100	SW. 1·0
			l 22				
	50	l 17		r 87	l 26	r 134	SW. 1·3
			l 4				
	60	r 9		r 91	r 14	r 140	SW. 1·4
			r 19				
	75	r 16		r 72	r 25	r 111	SW. 1·1
			r 25				
	90	r 17		r 47	r 26	r 72	SW. 0·7
			r 47				
	110	r 30		0	r 46	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	*a.*	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	*u.*
Sect. V, 4–5 ... 56 km., 140 m.	0	*r* 59	*r* 63	*r* 406	*r* 106	*r* 725	SW. 7·2
	10	*r* 66	*r* 105	*r* 343	*r* 118	*r* 612	SW. 6·1
	25	*r* 74	*r* 146	*r* 238	*r* 132	*r* 425	SW. 4·2
	50	*r* 43	*r* 92	*r* 92	*r* 77	*r* 164	SW. 1·6
	70	*r* 49		0	*r* 88	0	0
Sect. V, 5–6 ... 56 km., 120 m.	0	*l* 14	*l* 17	*l* 121	*l* 25	*l* 216	NE. 2·1
	10	*l* 21	*l* 27	*l* 104	*l* 38	*l* 186	NE. 1·8
	20	*l* 33	*l* 37	*l* 77	*l* 59	*l* 138	NE. 1·4
	30	*l* 40	*l* 40	*l* 40	*l* 72	*l* 71	NE. 0·7
	40	*l* 40		0	*l* 72	0	0
Sect. V, 6–7 ... 56 km., 40 m.	0	*l* 9	*l* 6	*r* 37	*l* 16	*r* 66	SW. 0·7
	10	*l* 3	*l* 1	*r* 43	*l* 5	*r* 77	SW. 0·8
	20	*r* 2	*r* 11	*r* 44	*r* 4	*r* 79	SW. 0·8
	30	*r* 20	*r* 33	*r* 33	*r* 36	*r* 59	SW. 0·6
	40	*r* 45		0	*r* 81	0	0
Sect. V, 6–8 ... 64 km., 40 m.	0	*l* 20	*l* 20	*l* 28	*l* 31	*l* 44	N. 0·4
	10	*l* 19	*l* 12	*l* 8	*l* 30	*l* 12	N. 0·1
	20	*l* 5	*r* 1	*r* 4	*l* 8	*r* 6	S. 0·1
	30	*r* 7	*r* 3	*r* 3	*r* 11	*r* 5	S. 0·0
	40	*l* 1		0	*l* 2	0	0
Sect. V, 7–8 ... 30 km., 50m.	0	*l* 11	*l* 14	*l* 124	*l* 37	*l* 413	W. 4·1
	10	*l* 16	*l* 11	*l* 110	*l* 53	*l* 366	W. 3·6
	20	*l* 7	*l* 10	*l* 99	*l* 23	*l* 330	W. 3·3
	30	*l* 13	*l* 30	*l* 89	*l* 43	*l* 296	W. 2·9
	40	*l* 46	*l* 59	*l* 59	*l* 153	*l* 196	W. 2·0
	50	*l* 72		0	*l* 240	0	0
Sect. V, 8–9 ... 55 km., 50 m.	0	*r* 29	*r* 36	*r* 198	*r* 53	*r* 360	SW. 3·6
	25	*r* 16	*r* 66	*r* 142	*r* 29	*r* 258	SW. 2·6
	40	*r* 72	*r* 76	*r* 76	*r* 131	*r* 138	SW. 1·4
	50	*r* 80		0	*r* 146	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	*a*.	0·1 A.	0·1 ΣA.	a_{100km}.	$ΣA_{10km}$	*u*.
Sect. V, 9-10...... 30 km., 100 m.	0	*r* 22		*r* 5	*r* 73	*r* 17	SW. 0·2
			r 59				
	25	*r* 25		*l* 54	*r* 83	*l* 180	NE. 1·8
			l 6				
	50	*l* 30		*l* 48	*l* 100	*l* 160	NE. 1·6
			l 51				
	75	*l* 11		*r* 3	*l* 37	*r* 10	SW. 0·1
			r 3				
	100	*r* 13		0	*r* 43	0	0
Sect. V, 10-11...... 37 km., >400 m.	0	*r* 8		*r* 131	*r* 22	*r* 354	SW. 3·5
			r 17				
	25	*r* 5		*r* 114	*r* 14	*r* 308	SW. 3·1
			r 1				
	50	*l* 4		*r* 113	*l* 11	*r* 305	SW. 3·0
			r 38				
	75	*r* 34		*r* 75	*r* 92	*r* 203	SW. 2·0
			r 55				
	100	*r* 10		*r* 20	*r* 27	*r* 54	SW. 0·5
			r 55				
	150	*r* 12		*l* 35	*r* 32	*l* 95	NE. 0·9
			r 45				
	300	*l* 6		*l* 80	*l* 16	*l* 216	NE. 2·1
			l 80				
	400	*l* 10		0	*l* 27	0	0
Sect. V, 11-12...... 67 km., >400 m.	0	*r* 1		*l* 397	*r* 1	*l* 592	NE. 5·9
			r 51				
	25	*r* 40		*l* 448	*r* 60	*l* 817	NE. 8·2
			r 85				
	50	*r* 28		*l* 533	*r* 42	*l* 794	NE. 7·9
			r 10				
	75	*l* 20		*l* 543	*l* 30	*l* 809	NE. 8·1
			l 63				
	100	*l* 30		*l* 480	*l* 45	*l* 715	NE. 7·2
			l 150				
	150	*l* 29		*l* 330	*l* 43	*l* 492	NE. 4·9
			l 270				
	300	*l* 7		*l* 60	*l* 10	*l* 89	NE. 0·9
			l 60				
	400	*l* 5		0	*l* 7	0	0
Sect. V, 12-13...... 28 km., >400 m.	0	*l* 29		*r* 404	*l* 104	*r*1442	SW. 14·4
			l 71				
	25	*l* 28		*r* 475	*l* 100	*r*1696	SW. 17·0
			l 4				
	50	*r* 25		*r* 479	*r* 89	*r*1710	SW. 17·1
			r 70				
	75	*r* 31		*r* 409	*r* 111	*r*1460	SW. 14·6
			r 91				
	100	*r* 42		*r* 318	*r* 150	*r*1135	SW. 11·4
			r 180				
	150	*r* 30		*r* 138	*r* 107	*r* 493	SW. 4·9
			r 138				
	200	*r* 25		0	*r* 89	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	$ΣA_{10km}$	u.
Sect. V, 13–14 .... 69 km., >400 m.	0	r 57		l 79	r 83	l 115	NE. 1·2
			r 91				
	25	r 16		l 170	r 23	l 247	NE. 2·5
			l 15				
	50	l 28		l 155	l 41	l 225	NE. 2·3
			l 89				
	75	l 43		l 66	l 62	l 96	NE. 1·0
			l 53				
	100	0		l 13	0	l 19	NE. 0·2
			l 3				
	150	l 1		l 10	l 1	l 15	NE. 0·2
			l 10				
	200	l 3		0	l 4	0	0
Sect. V, 14–15.......... 98 km. >400 m.	0	l 21		l 479	l 21	l 489	NE. 4·9
			l 60				
	25	l 27		l 419	l 28	l 427	NE. 4·3
			l 38				
	50	l 3		l 381	l 3	l 388	NE. 3·9
			l 6				
	75	l 2		l 375	l 2	l 382	NE. 3·8
			l 30				
	100	l 22		l 345	l 22	l 351	NE. 3·5
			l 90				
	150	l 14		l 255	l 14	l 260	NE. 2·6
			l 180				
	300	l 10		l 75	l 10	l 77	NE. 0·8
			l 75				
	400	l 5		0	l 5	0	0
Sect. V, 15–16 .... 97 km., >400 m.	0	r 61		l 186	r 63	l 192	NE. 1·9
			r 159				
	25	r 61		l 345	r 63	l 355	NE. 3·6
			r 113				
	50	r 29		l 458	r 30	l 472	NE. 4·8
			r 78				
	75	r 33		l 536	r 34	l 552	NE. 5·6
			r 39				
	100	l 3		l 575	l 3	l 592	NE. 6·0
			l 120				
	200	l 21		l 455	l 22	l 469	NE. 4·7
			l 230				
	300	l 25		l 225	l 26	l 232	NE. 2·3
			l 225				
	400	l 20		0	l 21	0	0
Sect. VI, 16–17 .... 70 km., >400 m.	0	r 4		r 3	r 6	r 4	E. 0·0
			r 10				
	25	r 4		l 7	r 6	l 10	W. 0·1
			r 14				
	50	r 7		l 21	r 10	l 30	W. 0·3
			r 12				
	75	r 3		l 33	r 4	l 47	W. 0·5
			l 1				
	100	l 4		l 32	l 6	l 46	W. 0·5
			0				
	150	r 4		l 32	r 6	l 46	W. 0·5
			r 13				
	200	r 1		l 45	r 1	l 64	W. 0·6
			l 5				
	300	l 2		l 40	l 3	l 57	W. 0·6
			l 40				
	400	l 6		0	l 9	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

	Depth.	a.	0·1 Λ.	0·1 ΣΛ.	a_{100km}.	$\Sigma\Lambda_{10km}$	u.
Sect. VI, 17–18	0	l 53		r 539	l 70	r 709	E. 7·1
76 km., >400 m.			l 129				
	25	l 50		r 668	l 66	r 878	E. 8·8
			l 124				
	50	l 49		r 792	l 65	r1051	E. 10·5
			l 61				
	75	0		r 853	0	r1122	E. 11·2
			r 15				
	100	r 12		r 838	r 16	r1102	E. 11·0
			r 72				
	150	r 17		r 767	r 22	r1007	E. 10·1
			r 405				
	300	r 37		r 360	r 49	r 474	E. 4·7
			r 360				
	400	r 35		0	r 46	0	0
Sect. VI, 17*a*–18	0	l 24		l 159	l 83	l 549	W. 5·4
29 km., >400 m.			l 139				
	75	l 13		l 20	l 45	l 69	W. 0·7
			l 20				
	100	l 3		0	l 10	0	0
Sect. VI, 18–19	0	l 2		l 278	l 5	l 631	W. 6·2
44 km., >400 m.			l 11				
	25	l 7		l 267	l 16	l 606	W. 6·0
			l 19				
	50	l 8		l 248	l 18	l 563	W. 5·5
			r 14				
	75	r 19		l 262	r 43	l 595	W. 5·9
			r 33				
	100	r 7		l 295	r 16	l 670	W. 6·6
			r 8				
	150	l 4		l 303	l 9	l 688	W. 6·8
			l 128				
	300	l 13		l 175	l 30	l 397	W. 3·9
			l 175				
	400	l 22		0	l 50	0	0
Sect. VI, 19–20	0	l 1		l 23	l 2	l 51	W. 0·5
45 km., >400 m.			r 1				
	25	r 2		l 24	r 4	l 53	W. 0·5
			r 14				
	50	r 9		l 38	r 20	l 84	W. 0·8
			l 38				
	75	l 39		0	l 87	0	0
Sect. VI, 20–21	0	r 10		r 112	r 18	r 200	E. 1·9
56 km., 110 m.			r 39				
	25	r 21		r 73	r 38	r 131	E. 1·3
			r 43				
	50	r 13		r 30	r 23	r 54	E. 0·5
			r 30				
	75	r 11		0	r 20	0	0
Sect. VI, 21–22	0	l 7		l 38	l 16	l 89	W. 0·9
43 km., 85 m.			l 20				
	20	l 13		l 18	l 30	l 42	W. 0·4
			l 25				
	40	l 12		r 7	l 28	r 16	E. 0·2
			l 2				
	50	r 7		r 9	r 16	r 21	E. 0·2
			r 9				
	65	r 5		0	r 12	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

—	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	u.
Sect. VII, 22–23	0	r 1		l 31	r 2	l 52	SE. 0·5
60 km., 80 m.			l 3				
	25	l 4		l 28	l 7	l 47	SE. 0·5
			l 18				
	50	l 10		l 10	l 17	l 17	SE. 0·2
			l 10				
	60	l 10		0	l 17	0	0
Sect. VII, 23–24	0	l 6		l 13	l 11	l 24	SE. 0·2
54 km., 140 m.			l 18				
	50	l 1		r 5	l 2	r 9	NW. 0·1
			r 5				
	75	r 5		0	r 9	0	0
Sect. VII, 24–25	0	r 8		r 138	r 16	r 282	NW. 2·7
49 km., 100 m.			r 65				
	50	r 18		r 73	r 37	r 149	NW. 1·4
			r 73				
	100	r 11		0	r 22	0	0
Sect. VII, 25–26	0	l 50		l 212	l 81	l 341	SE. 3·3
62 km., > 400 m.			l 98				
	25	l 28		l 114	l 45	l 184	SE. 1·8
			l 84				
	50	l 39		l 30	l 63	l 48	SE. 0·5
			l 65				
	100	r 13		r 35	r 21	r 56	NW. 0·5
			r 35				
	120	r 22		0	r 35	0	0
Sect. VII, 26–27	0	r 9		l 147	r 15	l 245	SE. 2·4
60 km., >400 m.			r 23				
	25	r 9		l 170	r 15	l 284	SE. 2·8
			r 35				
	50	r 19		l 205	r 32	l 342	SE. 3·4
			r 73				
	100	r 10		l 278	r 17	l 464	SE. 4·5
			l 33				
	150	l 23		l 245	l 38	l 409	SE. 4·0
			l 210				
	300	l 5		l 35	l 8	l 58	SE. 0·6
			l 35				
	400	l 2		0	l 3	0	0
Sect. VIII, 27–28	0	l 44		l 785	l 105	l 1868	SW. 18·4
42 km., >400 m.			l 116				
	25	l 49		l 669	l 117	l 1592	SW. 15·6
			l 133				
	50	l 57		l 536	l 136	l 1276	SW. 12·6
			l 126				
	75	l 44		l 410	l 105	l 976	SW. 9·6
			l 107				
	100	l 42		l 303	l 100	l 721	SW. 7·1
			l 115				
	150	l 4		l 188	l 12	l 447	SW. 4·4
			l 128				
	300	l 13		l 60	l 31	l 143	SW. 1·4
			l 60				
	400	r 1		0	r 2	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	u.
Sect. VIII, 28–29, 61 km., 90 m.	0	l 8	l 5	l 5	l 13	l 8	SW. 0·1
	50	r 6		0	r 10	0	0
Sect. VIII, 29–30, 57 km., 60 m.	0	l 13	l 165	l 165	l 23	l 289	SW. 2·8
	50	l 53		0	l 93	0	0
Sect. VIII, 30-31, 64 km., 140 m.	0	l 21	l 53	l 79	l 33	l 123	SW. 1·2
	25	l 21	l 30	l 26	l 33	l 41	SW. 0·4
	50	l 3	r 4	r 4	l 5	r 6	NE. 0·1
	75	r 6		0	r 9	0	0
Sect. VIII, 31–32, 68 km., 160 m.	0	r 12	r 54	r 26	r 18	r 38	NE. 0·4
	25	r 31	r 8	l 28	r 46	l 41	SW. 0·4
	50	l 24	l 36	l 36	l 35	l 53	SW. 0·5
	75	l 5		0	l 7	0	0
Sect. VIII, 32–33, 60 km., 75 m.	0	l 58	l 121	l 148	l 97	l 247	SW. 2·3
	25	l 39	l 48	l 27	l 65	l 45	SW. 0·4
	50	r 1	r 21	r 21	r 2	r 35	NE. 0·3
	75	r 16		0	r 27	0	0
Sect. IX, 33-34, 61 km., 180 m.	0	r 108	r 226	r 446	r 177	r 731	SE. 6·9
	25	r 73	r 150	r 220	r 120	r 361	SE. 3·4
	50	r 47	r 70	r 70	r 77	r 115	SE. 1·1
	75	r 9		0	r 15	0	0
Sect. IX, 34-35, 62 km., >400 m.	0	r 8	r 11	r 610	r 13	r 984	SE. 9·2
	25	r 1	r 10	r 599	r 2	r 966	SE. 9·1
	50	r 7	r 46	r 589	r 11	r 950	SE. 8·9
	75	r 30	r 83	r 543	r 48	r 875	SE. 8·2
	100	r 36	r 460	r 460	r 58	r 742	SE. 7·0
	300	r 10		0	r 16	0	0
Sect. IX, 35-36, 55 km., 230 m.	0	l 7	l 3	l 155	l 13	l 282	NW. 2·6
	25	r 5	r 11	l 152	r 9	l 277	NW. 2·6
	50	r 4	l 13	l 163	r 7	l 297	NW. 2·8
	75	l 14	l 150	l 150	l 25	l 273	NW. 2·5
	150	l 26		0	l 47	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

—	Depth.	*a*.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	*u*.
Sect. X, 29–30 .... 48 km., 50 m.	0	*r* 109	*r* 67	*r* 37	*r* 227	*r* 77	SE. 0·7
	10	*r* 25	*l* 30	*l* 30	*r* 52	*l* 62	NW. 0·6
	25	*l* 65		0	*l* 135	0	0
Sect. X, 30–31 .... 42 km., 60 m.	0	*l* 55	*l* 24	*r* 325	*l* 131	*r* 774	SE. 7·2
	10	*r* 7	*r* 55	*r* 349	*r* 17	*r* 831	SE. 7·7
	25	*r* 66	*r* 114	*r* 294	*r* 157	*r* 700	SE. 6·5
	40	*r* 86	*r* 105	*r* 180	*r* 205	*r* 428	SE. 4·0
	50	*r* 124	*r* 75	*r* 75	*r* 295	*r* 179	SE. 1·7
	60	*r* 26		0	*r* 62	0	0
Sect. X, 31–32 .... 35 km., 60 m.	0	*r* 86	*r* 156	*r* 713	*r* 246	*r*2039	SE. 18·8
	10	*r* 226	*r* 302	*r* 557	*r* 646	*r*1593	SE. 14·7
	25	*r* 177	*r* 248	*r* 255	*r* 506	*r* 729	SE. 6·7
	50	*r* 21	*r* 7	*r* 7	*r* 60	*r* 20	SE. 0·2
	60	*l* 7		0	*l* 20	0	0
Sect. X, 32–33 .... 50 km., 75 m.	0	*r* 28	*r* 25	*r* 253	*r* 56	*r* 506	SE. 4·7
	10	*r* 22	*r* 47	*r* 228	*r* 44	*r* 456	SE. 4·2
	25	*r* 40	*r* 83	*r* 181	*r* 80	*r* 362	SE. 3·3
	50	*r* 27	*r* 98	*r* 98	*r* 54	*r* 196	SE. 1·8
	75	*r* 51		0	*r* 102	0	0
Sect. X, 33–34 .... 28 km., 95 m.	0	*r* 126	*r* 86	*l* 18	*r* 450	*l* 64	NW. 0·6
	10	*r* 46	*l* 10	*l* 104	*r* 164	*l* 371	NW. 3·4
	25	*l* 59	*l* 73	*l* 94	*l* 211	*l* 336	NW. 3·1
	50	*l* 1	*l* 21	*l* 21	*l* 4	*l* 75	NW. 0·7
	75	*l* 16		0	*l* 57	0	0
Sect. X, 34–35 .... 37 km., 390 m.	0	*r* 53	*r* 2	*r* 1	*r* 143	*r* 3	SE. 0·0
	10	*l* 50	*r* 6	*l* 1	*l* 135	*l* 3	NW. 0·0
	25	*r* 58	*r* 96	*l* 7	*r* 157	*l* 19	NW. 0·2
	50	*r* 17	*r* 28	*l* 103	*r* 46	*l* 278	NW. 2·5
	75	*r* 5	*r* 2	*l* 131	*r* 14	*l* 354	NW. 3·2
	100	*l* 4	*l* 43	*l* 133	*l* 11	*l* 359	NW. 3·3
	150	*l* 13	*l* 42	*l* 90	*l* 35	*l* 243	NW. 2·2
	200	*l* 4	*l* 30	*l* 48	*l* 11	*l* 130	NW. 1·2
	300	*l* 2	*l* 18	*l* 18	*l* 5	*l* 48	NW. 0·4
	350	*l* 5		0	*l* 14	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	*a.*	0·1 Λ.	0·1 ΣΛ.	a_{100km}.	$\Sigma\Lambda_{10km}$	*u.*
Sect. X, 35–36 46 km., 270 m.	0	*l* 52	*l* 61	*l* 344	*l* 113	*l* 746	NW. 6·8
	10	*l* 70	*l* 127	*l* 283	*l* 152	*l* 614	NW. 5·6
	25	*l* 99	*l* 156	*l* 156	*l* 245	*l* 339	NW. 3·1
	50	*l* 26		0	*l* 56	0	0
Sect. X, 36–37 36 km., 50 m.	0	*r* 42	*r* 47	*r* 351	*r* 117	*r* 975	SE. 8·9
	10	*r* 52	*r* 128	*r* 304	*r* 145	*r* 845	SE. 7·7
	25	*r* 118	*r* 176	*r* 176	*r* 328	*r* 489	SE. 4·4
	50	*r* 23		0	*r* 64	0	0
Sect. X, 37–38 41 km., 100 m.	0	*l* 31	*l* 27	*r* 38	*l* 76	*r* 92	SE. 0·8
	10	*l* 23	*r* 2	*r* 65	*l* 56	*r* 159	SE. 1·4
	25	*r* 26	*r* 48	*r* 63	*r* 63	*r* 154	SE. 1·4
	50	*r* 12	*r* 15	*r* 15	*r* 29	*r* 37	SE. 0·3
	70	*r* 3		0	*r* 7	0	0
Sect. X, 38–39 32 km., 240 m.	0	*r* 15	*r* 11	*l* 30	*r* 47	*l* 94	NW. 0·8
	10	*r* 7	*r* 2	*l* 41	*r* 22	*l* 128	NW. 1·2
	25	*l* 4	*l* 5	*l* 43	*l* 13	*l* 134	NW. 1·2
	50	0	*l* 4	*l* 38	0	*l* 119	NW. 1·1
	75	*l* 3	*l* 4	*l* 34	*l* 9	*l* 106	NW. 1·0
	100	0	*l* 20	*l* 30	0	*l* 94	NW. 0·8
	150	*l* 8	*l* 10	*l* 10	*l* 25	*l* 31	NW. 0·3
	175	0		0	0	0	0
Sect. X, 39–40 37 km., 120 m.	0	*l* 47	*r* 64	*r* 175	*l* 127	*r* 473	SE. 4·2
	10	*r* 175	*r* 135	*r* 111	*r* 473	*r* 300	SE. 2·7
	25	*r* 5	*l* 3	*l* 24	*r* 14	*l* 65	NW. 0·6
	50	*l* 7	*l* 21	*l* 21	*l* 19	*l* 57	NW. 0·5
	65	*l* 21		0	*l* 57	0	0
Sect. XI, 40–41 51 km., 100 m.	0	*r* 72	*l* 44	*l* 390	*r* 141	*l* 764	NE. 6·8
	10	*l* 160	*l* 176	*l* 346	*l* 314	*l* 678	NE. 6·1
	25	*l* 75	*l* 138	*l* 170	*l* 147	*l* 333	NE. 3·0
	50	*l* 35	*l* 32	*l* 32	*l* 69	*l* 63	NE. 0·6
	65	*l* 7		0	*l* 14	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

—	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA_{10km}	u.
Sect. XI, 41–42, 40 km., 80 m.	0	r 27		r 67	r 68	r 168	SW. 1·5
			r 27				
	10	r 27		r 40	r 68	r 100	SW. 0·9
			r 7				
	25	l 18		r 33	l 45	r 83	SW. 0·7
			l 13				
	50	r 8		r 46	r 20	r 115	SW. 1·0
			r 32				
	75	r 18		r 14	r 45	r 35	SW. 0·3
			r 14				
	85	r 9		0	r 23	0	0
Sect. XI., 42–43, 52 km., 210 m.	0	0		r 14	0	r 27	SW. 0·2
			0				
	10	0		r 14	0	r 27	SW. 0·2
			r 11				
	25	r 14		r 3	r 27	r 6	SW. 0·1
			r 18				
	50	0		l 15	0	l 29	NE. 0·3
			l 10				
	75	l 8		l 5	l 15	l 10	NE. 0·1
			l 5				
	85	l 2		0	l 4	0	0
Sect. XI, 43–44, 43 km., 210 m.	0	l 4		r 22	l 9	r 51	SW. 0·5
			l 4				
	10	l 3		r 26	l 7	r 60	SW. 0·5
			r 7				
	25	r 12		r 19	r 28	r 44	SW. 0·4
			r 29				
	50	r 11		l 10	r 26	l 23	NE. 0·2
			r 6				
	75	l 6		l 16	l 14	l 37	NE. 0·3
			l 11				
	100	l 3		l 5	l 7	l 12	NE. 0·1
			l 5				
	150	r 1		0	r 2	0	0
Sect. XII, 45–46, 28 km., >400 m.	0	l 30		r 392	l 107	r 1403	NW. 13·0
			l 8				
	25	r 24		r 400	r 86	r 1432	NW. 13·3
			r 75				
	50	r 36		r 325	r 129	r 1164	NW. 10·8
			r 61				
	75	r 13		r 264	r 46	r 945	NW. 8·7
			r 36				
	100	r 16		r 228	r 57	r 814	NW. 7·5
			r 132				
	150	r 37		r 95	r 132	r 339	NW. 3·1
			r 175				
	200	r 33		l 80	r 118	l 286	SE. 2·6
			r 70				
	300	l 19		l 150	l 68	l 536	SE. 5·0
			l 150				
	400	l 11		0	l 39	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

—	Depth	a.	0·1 Λ.	0·1 ΣΛ.	a_{100km}.	$ΣΛ_{10km}$.	u.
Sect. XII, 46-47 .... 37 km., >400 m.	0	*l* 143		*l* 941	*l* 386	*l* 2541	SE. 23·6
			l 299				
	25	*l* 96		*l* 642	*l* 259	*l* 1735	SE. 16·1
			l 214				
	50	*l* 75		*l* 428	*l* 203	*l* 1157	SE. 10·8
			l 128				
	75	*l* 27		*l* 300	*l* 73	*l* 811	SE. 7·5
			l 50				
	100	*l* 13		*l* 250	*l* 35	*l* 676	SE. 6·3
			l 40				
	150	*l* 3		*l* 210	*l* 8	*l* 568	SE. 5·3
			l 40				
	200	*l* 13		*l* 170	*l* 35	*l* 459	SE. 4·3
			l 115				
	300	*l* 10		*l* 55	*l* 27	*l* 149	SE. 1·4
			l 55				
	400	*l* 1		0	*l* 3	0	0
Sect. XII, 47-48 .... 41 km., 150 m.	0	*l* 45		*r* 494	*l* 110	*r* 1205	NW. 11·2
			r 25				
	25	*r* 65		*r* 469	*r* 159	*r* 1144	NW. 10·6
			r 149				
	50	*r* 54		*r* 320	*r* 132	*r* 781	NW. 7·3
			r 111				
	75	*r* 35		*r* 209	*r* 85	*r* 510	NW. 4·7
			r 74				
	100	*r* 24		*r* 135	*r* 59	*r* 329	NW. 3·1
			r 137				
	150	*r* 30		0	*r* 73	0	0
Sect. XII, 48-49 .... 75 km., 120 m.	0	*l* 112		*l* 257	*l* 149	*l* 342	SE. 3·2
			l 165				
	25	*l* 20		*l* 92	*l* 27	*l* 122	SE. 1·1
			l 56				
	50	*l* 25		*l* 36	*l* 33	*l* 48	SE. 0·5
			l 36				
	70	*l* 11		0	*l* 15	0	0
Sect. XII, 49-50 .... 71 km., 60 m.	0	*r* 31		*l* 262	*r* 44	*l* 369	SE. 3·5
			r 17				
	10	*r* 5		*l* 279	*r* 4	*l* 393	SE. 3·7
			l 118				
	25	*l* 160		*l* 161	*l* 225	*l* 227	SE. 2·2
			l 161				
	40	*l* 57		0	*l* 78	0	0
Sect. XIII, 37-38 .... 38 km., 90 m.	0	*l* 76		*l* 340	*l* 147	*l* 895	NE. 9·0
			l 123				
	20	*l* 67		*l* 217	*l* 176	*l* 571	NE. 5·7
			l 129				
	40	*l* 62		*l* 88	*l* 163	*l* 232	NE. 2·3
			l 88				
	60	*l* 26		0	*l* 68	0	0
Sect. XIII, 38-39 .... 38 km., 130 m.	0	*r* 16		*r* 65	*r* 42	*r* 171	SW. 1·7
			r 5				
	25	*l* 12		*r* 60	*l* 32	*r* 158	SW. 1·6
			l 25				
	40	*l* 19		*r* 85	*l* 56	*r* 218	SW. 2·2
			r 8				
	50	*r* 36		*r* 75	*r* 95	*r* 197	SW. 2·0
			r 68				
	75	*r* 18		*r* 7	*r* 47	*r* 18	SW. 0·2
			r 7				
	90	*l* 9		0	*l* 24	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

—	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	u.
Sect. XIII, 39–40 .... 38 km., 115 m.	0	l 45	r 82	r 568	l 118	r 1495	SW. 15·1
	25	r 111	r 168	r 486	r 292	r 1278	SW. 12·9
	40	r 113	r 84	r 318	r 297	r 836	SW. 8·4
	50	r 55	r 142	r 234	r 145	r 616	SW. 6·2
	75	r 58	r 92	r 92	r 153	r 242	SW. 2·4
	90	r 65		0	r 171	0	0
Sect. XIII, 40–41 .... 38 km., 270 m.	0	r 144	r 155	r 344	r 379	r 905	SW. 9·2
	25	l 20	r 33	r 189	l 53	r 497	SW. 5·1
	50	r 46	r 76	r 156	r 121	r 410	SW. 4·2
	75	r 15	r 41	r 80	r 39	r 210	SW. 2·1
	100	r 18	r 39	r 39	r 47	r 103	SW. 1·1
	125	r 13		0	r 34	0	0
Sect. XIII, 41–42 .... 38 km., >400 m.	0	l 5	l 10	r 49	l 13	r 129	SW. 1·3
	25	l 3	l 24	r 59	l 8	r 155	SW. 1·6
	50	l 16	l 10	r 83	l 42	r 218	SW. 2·2
	75	r 8	r 15	r 93	r 21	r 245	SW. 2·5
	100	r 4	r 23	r 78	r 11	r 205	SW. 2·1
	150	r 5	r 30	r 55	r 13	r 145	SW. 1·5
	200	r 7	r 35	r 25	r 18	r 66	SW. 0·7
	300	0	l 10	l 10	0	l 26	NE. 0·3
	400	l 2		0	l 5	0	0
Sect. XIII, 42–43 .... 39 km., >400 m.	0	l 10	l 24	l 1018	l 26	l 2610	NE. 26·9
	25	l 9	l 103	l 994	l 23	l 2549	NE. 26·3
	50	l 73	l 126	l 891	l 187	l 2284	NE. 23·5
	75	l 28	l 80	l 765	l 72	l 1961	NE. 20·2
	100	l 36	l 152	l 685	l 92	l 1756	NE. 18·1
	150	l 25	l 143	l 533	l 64	l 1366	NE. 14·1
	200	l 32	l 245	l 390	l 82	l 1000	NE. 10·3
	300	l 17	l 145	l 145	l 44	l 372	NE. 3·8
	400	l 12		0	l 31	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth	a.	0·1 Λ.	0·1 ΣΛ	a_{100km}.	ΣΛ 10km	u.
Sect. XIII, 43–44 39 km., >400 m.	0	*l* 37		*r* 323	*l* 95	*r* 828	SW. 8·6
			l 109				
	25	*l* 50		*r* 432	*l* 128	*r* 1107	SW. 11·5
			l 68				
	50	*l* 4		*r* 500	*l* 10	*r* 1282	SW. 13·3
			l 24				
	75	*l* 15		*r* 524	*l* 38	*r* 1343	SW. 14·0
			r 9				
	100	*r* 22		*r* 517	*r* 56	*r* 1320	SW. 13·7
			r 95				
	150	*r* 16		*r* 420	*r* 41	*r* 1077	SW. 11·2
			r 97				
	200	*r* 22		*r* 327	*r* 56	*r* 833	SW. 8·7
			r 180				
	300	*r* 14		*r* 147	*r* 36	*r* 372	SW. 3·9
			r 145				
	400	*r* 15		0	*r* 38	0	0
Sect. XIV, 44–45 83 km., >400 m.	0	*r* 58		*r* 456	*r* 70	*r* 549	E. 5·7
			r 118				
	25	*r* 36		*r* 338	*r* 43	*r* 407	E. 4·2
			r 75				
	50	*r* 24		*r* 263	*r* 29	*r* 317	E. 3·3
			r 43				
	75	*r* 11		*r* 219	*r* 13	*r* 264	E. 2·7
			r 4				
	100	*l* 8		*r* 215	*l* 10	*r* 259	E. 2·7
			l 25				
	150	*l* 2		*r* 240	*l* 2	*r* 289	E. 3·0
			l 5				
	200	0		*r* 245	0	*r* 295	E. 3·0
			r 100				
	300	*r* 20		*r* 147	*r* 24	*r* 175	E. 1·8
			r 145				
	400	*r* 9		0	*r* 11	0	0
Sect. XIV, 45–46 56 km., >400 m.	0	*l* 107		*l* 138	*l* 192	*l* 246	W. 2·5
			l 163				
	25	*l* 23		*r* 25	*l* 41	*r* 45	E. 0·5
			r 31				
	50	*r* 48		*l* 6	*r* 86	*l* 11	W. 0·1
			r 80				
	75	*r* 16		*l* 86	*r* 29	*l* 154	W. 1·6
			r 22				
	100	*r* 1		*l* 108	*r* 2	*l* 193	W. 2·0
			r 20				
	150	*r* 7		*l* 128	*r* 13	*l* 229	W. 2·3
			r 12				
	200	*l* 2		*l* 140	*l* 4	*l* 250	W. 2·6
			l 35				
	300	*l* 5		*l* 105	*l* 9	*l* 187	W. 1·9
			l 105				
	400	*l* 16		0	*l* 29	0	0
Sect. XIV, 46–47 85 km., 150 m.	0	*r* 85		*r* 72	*r* 100	*r* 85	E. 0·9
			r 129				
	25	*r* 18		*l* 57	*r* 21	*l* 67	W. 0·7
			l 47				
	50	*l* 56		*l* 10	*l* 66	*l* 12	W. 0·1
			l 64				
	75	*r* 5		*r* 54	*r* 6	*r* 64	E. 0·6
			r 23				
	100	*r* 13		*r* 31	*r* 15	*r* 36	E. 0·4
			r 31				
	125	*r* 12		0	*r* 14	0	

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	u.
Sect. XIV, 47–48 .... 74 km., 170 m.	0	l 114		l 282	l 154	l 381	W. 4·0
			l 205				
	25	l 50		l 77	l 68	l 104	W. 1·2
			l 25				
	50	r 30		l 52	r 41	l 70	W. 0·9
			r 6				
	75	l 26		l 58	l 35	l 78	W. 0·8
			l 47				
	100	l 11		l 11	l 15	l 15	W. 0·1
			l 11				
	125	r 2		0	r 3	0	0
Sect. XIV, 48–49 .... 72 km., 180 m.	0	l 26		l 370	l 36	l 514	W. 5·0
			r 10				
	25	r 34		l 380	r 47	l 528	W. 5·2
			r 39				
	40	r 18		l 419	r 25	l 582	W. 5·7
			l 9				
	50	l 36		l 410	l 50	l 570	W. 5·6
			l 99				
	75	l 43		l 311	l 60	l 432	W. 4·2
			l 135				
	100	l 67		l 176	l 90	l 244	W. 2·4
			l 176				
	125	l 76		0	l 106	0	0
Sect. XV, 49–50 .... 35 km., 130 m.	0	r 36		r 517	r 103	r 1477	SW. 14·5
			r 59				
	25	r 11		r 458	r 31	r 1309	SW. 12·8
			r 60				
	50	r 37		r 398	r 106	r 1138	SW. 11·2
			r 103				
	75	r 46		r 294	r 132	r 840	SW. 8·2
			r 138				
	100	r 64		r 156	r 183	r 446	SW. 4·4
			r 156				
	125	r 61		0	r 174	0	0
Sect. XV, 50–51 .... 44 km., 180 m.	0	r 26		r 112	r 59	r 255	SW. 2·5
			r 15				
	25	l 14		r 97	l 32	r 220	SW. 2·2
			l 3				
	50	r 12		r 100	r 27	r 227	SW. 2·2
			r 39				
	75	r 19		r 61	r 43	r 138	SW. 1·4
			r 40				
	100	r 13		r 21	r 30	r 48	SW. 0·5
			r 21				
	125	r 4		0	r 9	0	0
Sect. XV, 51–52 .... 45 km., 120 m.	0	r 43		r 74	r 95	r 164	SW. 1·6
			r 94				
	25	r 32		l 20	r 71	l 44	NE. 0·4
			r 16				
	40	l 11		l 36	l 24	l 80	NE. 0·8
			l 6				
	50	l 2		l 30	l 4	l 67	NE. 0·7
			l 20				
	75	l 15		l 10	l 29	l 22	NE. 0·2
			l 10				
	90	0		0	0	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

	Depth.	a.	0·1 Δ.	0·1 ΣΔ.	a_{100km}.	$ΣΔ_{100km}$.	u.
Sect. XV, 52–53 .... 35 km., 90 m.	0	r 27	r 83	r 163	r 77	r 466	SW. 4·7
	25	r 39	r 52	r 80	r 112	r 229	SW. 2·3
	40	r 30	r 21	r 28	r 86	r 80	SW. 0·8
	50	r 12	r 18	r 7	r 34	r 20	SW. 0·2
	75	r 2	l 11	l 11	r 6	l 31	NE. 0·3
	90	l 17		0	l 49	0	0
Sect. XV, 53–54 .... 41 km., 105 m.	0	l 52	l 106	r 36	l 127	r 89	SW. 0·9
	25	l 33	l 13	r 142	l 81	r 351	SW. 3·5
	50	r 23	r 80	r 155	r 56	r 378	SW. 3·8
	75	r 41	r 75	r 75	r 100	r 183	SW. 1·8
	95	r 34		0	r 83	0	0
Sect. XV, 54–55 .... 35 km., >400 m.	0	l 42	l 19	l 443	l 120	l 1265	NE. 12·8
	25	r 27	r 15	l 424	r 77	l 1211	NE. 12·2
	50	l 15	l 29	l 439	l 43	l 1254	NE. 12·7
	75	l 8	l 20	l 410	l 23	l 1171	NE. 11·8
	100	l 8	l 30	l 390	l 23	l 1114	NE. 11·3
	150	l 4	l 15	l 360	l 11	l 1028	NE. 10·4
	200	l 2	l 150	l 345	l 6	l 986	NE. 10·0
	300	l 28	l 195	l 195	l 80	l 557	NE. 5·6
	400	l 11		0	l 31	0	0
Sect. XV, 55–56 .... 48 km., >400 m.	0	l 56	l 66	l 336	l 116	l 700	NE. 7·1
	25	r 3	r 8	l 270	r 6	l 563	NE. 5·7
	50	r 3	l 5	l 278	r 6	l 579	NE. 5·9
	100	l 5	l 40	l 273	l 16	l 569	NE. 5·8
	150	l 11	l 68	l 233	l 23	l 485	NE. 4·9
	200	l 16	l 75	l 165	l 33	l 343	NE. 3·5
	300	r 1	l 90	l 90	r 2	l 187	NE. 1·9
	400	l 19		0	l 40	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	u.
Sect. XVI, 56–57. 77 km., >400 m.	0	r 89	r 86	r 711	r 116	r 924	E. 9·4
	25	l 20	l 48	r 625	l 26	r 812	E. 8·2
	50	l 18	l 15	r 673	l 23	r 874	E. 8·9
	100	r 12	r 70	r 688	r 16	r 894	E. 9·1
	150	r 16	r 113	r 618	r 21	r 803	E. 8·2
	200	r 29	r 255	r 505	r 38	r 656	E. 6·7
	300	r 22	r 250	r 250	r 29	r 325	E. 3·3
	400	r 28		0	r 36	0	0
Sect. XVI, 57–58. 47 km., >400 m.	0	r 21	r 30	l 108	r 45	l 230	W. 2·3
	25	r 3	r 13	l 138	r 6	l 293	W. 2·9
	50	r 7	l 31	l 151	r 15	l 321	W. 3·2
	75	l 32	l 49	l 120	l 68	l 255	W. 2·6
	100	l 7	l 45	l 71	l 15	l 151	W. 1·5
	150	l 11	l 26	l 26	l 23	l 55	W. 0·6
	175	l 10		0	l 21	0	0
Sect. XVI, 58–59. 47 km., 70 m.	0	r 16	l 20	l 139	r 34	l 296	W. 3·0
	15	l 42	l 59	l 119	l 89	l 253	W. 2·5
	30	l 36	l 60	l 60	l 77	l 128	W. 1·3
	45	l 44		0	l 94	0	0
Sect. XVI, 59–60. 56 km., 60 m.	0	l 26	l 2	r 51	l 47	r 91	E. 0·9
	15	r 24	r 28	r 53	r 43	r 94	E. 0·9
	30	r 13	r 25	r 25	r 23	r 44	E. 0·4
	45	r 20		0	r 36	0	0
Sect. XVI, 60–62. 53 km., 90 m.	0	l 23	l 109	l 287	l 43	l 542	W. 5·3
	25	l 64	l 134	l 178	l 121	l 336	W. 3·3
	50	l 43	l 44	l 44	l 81	l 83	W. 0·8
	60	l 45		0	l 85	0	0
Sect. XVI, 62–63. 17 km., 50 m.	0	l 2	r 64	r 150	l 12	r 882	E. 8·6
	25	r 53	r 86	r 86	r 312	r 506	E. 4·9
	50	r 16		0	r 94	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	*a.*	0·1 Λ.	0·1 ΣΛ.	a_{100km}.	$ΣΛ_{10km}$	*u.*
Sect. XVI, 63–64 .... 38 km., 150 m.	0	*l* 61	*l* 163	*l* 318	*l* 160	*l* 837	W. 8·1
	25	*l* 69	*l* 155	*l* 155	*l* 181	*l* 408	W. 4·0
	50	*l* 55		0	*l* 145	0	0
Sect. XVI, 64–65 .... 24 km., 130 m.	0	*l* 39	*l* 7	*r* 66	*l* 163	*r* 277	E. 2·7
	25	*r* 35	*r* 96	*r* 71	*r* 146	*r* 296	E. 2·9
	50	*r* 42	*r* 26	*l* 25	*r* 175	*l* 104	W. 1·0
	75	*l* 21	*l* 51	*l* 51	*l* 88	*l* 212	W. 2·0
	100	*l* 20		0	*l* 83	0	0
Sect. XVII, 65–66 .... 30 km., 130 m.	0	*r* 61	*r* 40	*l* 189	*r* 203	*l* 630	NE. 6·0
	10	*r* 19	*l* 67	*l* 229	*r* 63	*l* 763	NE. 7·3
	25	*l* 108	*l* 159	*l* 162	*l* 360	*l* 540	NE. 5·2
	50	*l* 19	*l* 3	*l* 3	*l* 63	*l* 10	NE. 0·1
	60	*r* 13		0	*r* 43	0	0
Sect. XVII, 66–67 .... 67 km., 90 m.	0	*r* 33	*r* 31	*r* 365	*r* 49	*r* 545	SW. 5·3
	10	*r* 30	*r* 108	*r* 334	*r* 45	*r* 499	SW. 4·8
	25	*r* 115	*r* 196	*r* 225	*r* 171	*r* 336	SW. 3·3
	50	*r* 42	*r* 29	*r* 29	*r* 63	*r* 43	SW. 0·4
	60	*r* 15		0	*r* 22	0	0
Sect. XVII, 67–68 .... 57 km., 140 m.	0	*r* 26	*r* 35	*r* 255	*r* 46	*r* 447	SW. 4·4
	10	*r* 43	*r* 102	*r* 220	*r* 75	*r* 386	SW. 3·8
	25	*r* 93	*r* 118	*r* 118	*r* 163	*r* 207	SW. 2·0
	50	*r* 1		0	*r* 2	0	0
Sect. XVII, 68–69 .... 44 km., 70 m.	0	*l* 20	*l* 28	*l* 167	*l* 45	*l* 379	NE. 3·7
	10	*l* 37	*l* 89	*l* 139	*l* 84	*l* 316	NE. 3·1
	25	*l* 82	*l* 55	*l* 50	*l* 186	*l* 114	NE. 1·1
	40	*r* 9	*r* 5	*r* 5	*r* 20	*r* 11	SW. 0·1
	50	*r* 1		0	*r* 2	0	0
Sect. XVII, 69–70 .... 49 km., 130 m.	0	*r* 34	*r* 133	*r* 277	*r* 69	*r* 565	SW. 5·5
	25	*r* 72	*r* 144	*r* 144	*r* 147	*r* 294	SW. 2·9
	50	*r* 43		0	*r* 88	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	*a*.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA 10km	*u*.
Sect. XVII, 70–71 .... 29 km., >400 m.	0	0		*l* 45	0	*l* 155	NE. 1·5
			l 21				
	25	*l* 17		*l* 24	*l* 58	*l* 82	NE. 0·8
			l 30				
	50	*l* 7		*r* 6	*l* 24	*r* 21	SW. 0·2
			l 3				
	75	*r* 5		*r* 9	*r* 17	*r* 31	SW. 0·3
			r 9				
	100	*r* 2		0	*r* 7	0	0
Sect. XVII, 71–72 .... 21 km., >400 m.	0	*l* 49		*r* 21	*l* 233	*r* 100	SW. 1·0
			l 32				
	25	*r* 24		*r* 53	*r* 114	*r* 250	SW. 2·5
			r 53				
	50	*r* 18		0	*r* 86	0	0
			r 16				
	75	*l* 5		*l* 16	*l* 24	*l* 76	NE. 0·8
			l 16				
	100	*l* 8		0	*l* 38	0	0
Sect. XVII, 72–73.......... 19 km., >400 m.	0	*r* 5		*l* 3	*r* 26	*l* 16	NE. 0·2
			l 16				
	25	*l* 18		*r* 13	*l* 95	*r* 68	SW. 0·7
			l 15				
	50	*r* 6		*r* 28	*r* 32	*r* 147	SW. 1·5
			r 17				
	75	*r* 7		*r* 11	*r* 37	*r* 58	SW. 0·6
			r 11				
	100	*r* 2		0	*r* 11	0	0
Sect. XVII, 73–74 .... 20 km., >400 m.	0	*r* 6		*r* 11	*r* 30	*r* 55	SW. 0·5
			r 35				
	5	*r* 22		*l* 24	*r* 110	*l* 120	NE. 1·2
			r 21				
	50	*l* 5		*l* 45	*l* 25	*l* 225	NE. 2·2
			l 17				
	75	*l* 9		*l* 28	*l* 45	*l* 140	NE. 1·4
			l 28				
	100	*l* 13		6	*l* 65	0	0
Sect. XVII, 74–75 .... 39 km., >400 m.	0	*r* 48		*l* 238	*r* 123	*l* 610	NE. 6·1
			r 21				
	25	*l* 31		*l* 259	*l* 79	*l* 664	NE. 6·6
			l 135				
	50	*l* 77		*l* 124	*l* 197	*l* 318	NE. 3·2
			l 109				
	75	*l* 10		*l* 15	*l* 26	*l* 38	NE. 0·4
			l 15				
	100	*l* 2		0	*l* 5	0	0
			l 20				
	150	*l* 6		*r* 20	*l* 15	*r* 51	SW. 0·5
			l 10				
	200	*r* 2		*r* 30	*r* 5	*r* 77	SW. 0·8
			r 20				
	300	*r* 2		*r* 10	*r* 5	*r* 26	SW. 0·3
			r 10				
	400	0		0	0		0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth	*a.*	0·1 Λ.	0·1 ΣΛ.	a_{100km}.	$\Sigma\Lambda_{10km}$	*u.*
Sect. XVIII, 75-76........ 62 km., >400 m.	0	*l* 126		*r* 379	*l* 203	*r* 611	SE. 6·1
			l 255				
	25	*l* 78		*r* 634	*l* 126	*r* 1024	SE. 10·2
			l 29				
	50	*r* 55		*r* 663	*r* 89	*r* 1069	SE. 10·6
			r 64				
	75	*l* 4		*r* 599	*l* 6	*r* 966	SE. 9·6
			r 1				
	100	*r* 5		*r* 598	*r* 8	*r* 964	SE. 9·6
			r 60				
	150	*r* 19		*r* 538	*r* 31	*r* 867	SE. 8·6
			r 113				
	200	*r* 26		*r* 425	*r* 42	*r* 685	SE. 6·8
			r 240				
	300	*r* 22		*r* 185	*r* 35	*r* 298	SE. 3·0
			r 185				
	400	*r* 15		0	*r* 24	0	0
Sect. XVIII, 76-77 ..... 63 km., >400 m.	0	*r* 28		*r* 277	*r* 47	*r* 440	SE. 4·3
			r 164				
	25	*r* 103		*r* 113	*r* 164	*r* 180	SE. 1·8
			r 151				
	50	*r* 18		*l* 38	*r* 29	*l* 60	NW. 0·6
			r 35				
	75	*r* 10		*l* 73	*r* 16	*l* 116	NW. 1·1
			r 10				
	100	*l* 2		*l* 83	*l* 3	*l* 132	NW. 1·3
			l 5				
	150	0		*l* 78	0	*l* 124	NW. 1·2
			l 8				
	200	*l* 3		*l* 76	*l* 5	*l* 111	NW. 1·1
			l 35				
	300	*l* 4		*l* 35	*l* 6	*l* 56	NW. 0·6
			l 35				
	400	*l* 3		0	*l* 5	0	0
Sect. XVIII, 77-78 ..... 28 km., >400 m.	0	*r* 80		*r* 313	*r* 286	*r* 1117	SE. 11·0
			r 238				
	50	*r* 15		*r* 75	*r* 54	*r* 268	SE. 2·6
			r 34				
	75	*r* 12		*r* 41	*r* 45	*r* 146	SE. 1·4
			r 41				
	100	*r* 21		0	*r* 75	0	0
Sect. XVIII, 78-79 ..... 34 km., >400 m.	0	*r* 50		*l* 62	*r* 147	*l* 182	NW. 1·8
			r 30				
	50	*l* 38		*l* 92	*l* 112	*l* 271	NW. 2·6
			r 63				
	75	*l* 12		*l* 29	*l* 35	*l* 85	NW. 0·8
			l 29				
	100	*l* 11		0	*l* 32	0	0
Sect. XIX, 79-80 ..... 59 km., 250 m.	0	*l* 20		*l* 329	*l* 34	*l* 558	SW. 5·4
			l 31				
	10	*l* 42		*l* 298	*l* 71	*l* 505	SW. 4·9
			l 59				
	25	*l* 36		*l* 239	*l* 61	*l* 405	SW. 3·9
			l 31				
	50	*r* 11		*l* 208	*r* 19	*l* 353	SW. 3·4
			r 8				
	75	*l* 5		*l* 216	*l* 8	*l* 366	SW. 3·6
			l 38				
	100	*l* 26		*l* 178	*l* 44	*l* 302	SW. 2·9
			l 178				
	150	*l* 45		0	*l* 76	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

——	Depth.	a.	0·1 A.	0·1 ΣA.	a_{100km}.	ΣA $_{10km}$	u.
Sect. XIX, 80–81 .... 62 km., 65 m.	0	r 26		r 121	r 42	r 195	NE. 1·9
			r 23				
	10	r 19		r 98	r 31	r 158	NE. 1·5
			r 54				
	25	r 53		r 44	r 85	r 97	NE. 0·9
			r 50				
	40	r 14		l 6	r 23	l 10	SW. 0·1
			l 6				
	54	l 22		0	l 35	0	0
Sect. XIX, 81–82 .... 44 km., 60 m.	0	l 5		l 140	l 11	l 318	SW. 3·0
			l 12				
	10	l 19		l 128	l 43	l 291	SW. 2·8
			l 47				
	25	l 43		l 81	l 98	l 184	SW. 1·7
			l 66				
	40	l 45		l 15	l 102	l 34	SW. 0·3
			l 15				
	50	r 16		0	r 36	0	0
Sect. XIX, 82–83 .... 41 km., 140 m.	0	l 9		l 99	l 22	l 241	SW. 2·3
			l 48				
	25	l 29		l 51	l 71	l 124	SW. 1·2
			l 51				
	50	l 12		0	l 29	0	0
Sect. XX, 83–84 .... 51 km., 64 m.	0	r 15		r 118	r 29	r 231	NW. 2·2
			r 57				
	25	r 30		r 61	r 59	r 120	NW. 1·1
			r 61				
	50	r 19		0	r 37	0	0
Sect. XX, 84–85 .... 49 km., 60 m.	0	l 114		l 178	l 233	l 363	SE. 3·4
			l 144				
	20	l 30		l 34	l 61	l 69	SE. 0·7
			l 28				
	40	r 2		l 6	r 4	l 12	SE. 0·1
			l 6				
	50	l 14		0	l 29	0	0
Sect. XX, 85–86 .... 44 km., >400 m.	0	l 2		r 155	l 5	r 352	NW. 3·3
			r 61				
	25	r 51		r 94	r 116	r 213	NW. 2·0
			r 80				
	50	r 13		r 14	r 30	r 32	NW. 0·3
			r 36				
	75	r 16		l 22	r 36	l 50	SE. 0·5
			r 15				
	100	l 4		l 37	l 9	l 84	SE. 0·8
			r 5				
	150	r 6		l 42	r 14	l 95	SE. 0·9
			r 3				
	200	l 5		l 45	l 11	l 102	SE. 1·0
			l 35				
	300	l 2		l 10	l 5	l 23	SE. 0·2
			l 10				
	400	0		0	0	0	0

TABLE 5.—The Solenoids in Canadian waters—*Continued.*

—	Depth.	a.	0·1 Λ.	0·1 ΣΛ.	$a_{10\,km}$.	$\Sigma\Lambda_{1\,km}$	u.
Sect. XX, 86–87. 37 km., >400 m.	0	0	r 4	l 40	0	l 108	SE. 1·0
	25	r 3	r 10	l 44	r 8	l 119	SE. 1·1
	50	r 5	l 1	l 54	r 14	l 146	SE. 1·4
	75	l 6	l 8	l 53	l 16	l 143	SE. 1·4
	100	0	l 25	l 45	0	l 122	SE. 1·2
	150	l 10	l 25	l 20	l 27	l 54	SE. 0·5
	200	0	r 5	r 5	0	r 14	NW. 0·1
	300	r 1		0	r 3	0	0
Sect. XX, 87–88. 51 km., 125 m.	0	l 66	l 159	l 800	l 129	l 1569	SE. 15·1
	25	l 61	l 173	l 641	l 120	l 1257	SE. 12·1
	50	l 78	l 192	l 468	l 153	l 917	SE. 8·8
	75	l 75	l 165	l 276	l 147	l 541	SE. 5·2
	100	l 57	l 111	l 111	l 112	l 218	SE. 2·1
	125	l 32		0	l 63	0	0
Sect. XX, 88–89. 43 km., 125 m.	0	r 17	l 94	l 332	r 40	l 772	SE. 7·4
	25	l 92	l 104	l 238	l 214	l 554	SE. 5·3
	50	r 9	r 10	l 134	r 21	l 312	SE. 3·0
	75	l 1	l 36	l 144	l 2	l 335	SE. 3·2
	100	l 28	l 108	l 108	l 65	l 251	SE. 2·4
	125	l 58		0	l 135	0	0

TABLE 6.—The amount of solenoids per 10 km., equivalent to a velocity of the current of 1 cm/sec., at different latitudes.

ϕ	0	1	2	3	4	5	6	7	8	9
0	0	3	5	8	10	13	15	18	20	23
10...............	25	28	30	33	35	38	40	43	45	48
20	50	52	55	57	59	62	64	66	68	71
30...............	73	75	77	79	82	84	86	88	90	92
40...............	94	96	98	100	101	10[illegible]	105	107	108	110
50...............	112	113	115	116	118	119	121	122	124	125
60...............	126	128	129	130	131	132	133	134	135	136
70...............	137	138	139	139	140	141	142	142	143	143
80...............	144	144	144	145	145	145	145	146	146	146

TABLE 7.—Correction in cm. of level of water under atmospherical pressure.

(a) MILLIBAR.

m.bar.	0	1	2	3	4	5	6	7	8	9
940............	−60	−59	−58	−57	−56	−55	−54	−53	−52	−51
950	−50	−49	−48	−47	−46	−45	−44	−43	−42	−41
960	−40	−39	−38	−37	−36	−35	−34	−33	−32	−31
970	−30	−29	−28	−27	−26	−25	−24	−23	−22	−21
980	−20	−19	−18	−17	−16	−15	−14	−13	−12	−11
990	−10	− 9	− 8	− 7	− 6	− 5	− 4	− 3	− 2	− 1
1000	0	1	2	3	4	5	6	7	8	9
1010	10	11	12	13	14	15	16	17	18	19
1020	20	21	22	23	24	25	26	27	28	29
1030	30	31	32	33	34	35	36	37	38	39
1040	40	41	42	43	44	45	46	47	48	49

TABLE 7.—Correction in cm. of level of water under atmospherical pressure—*Concluded.*

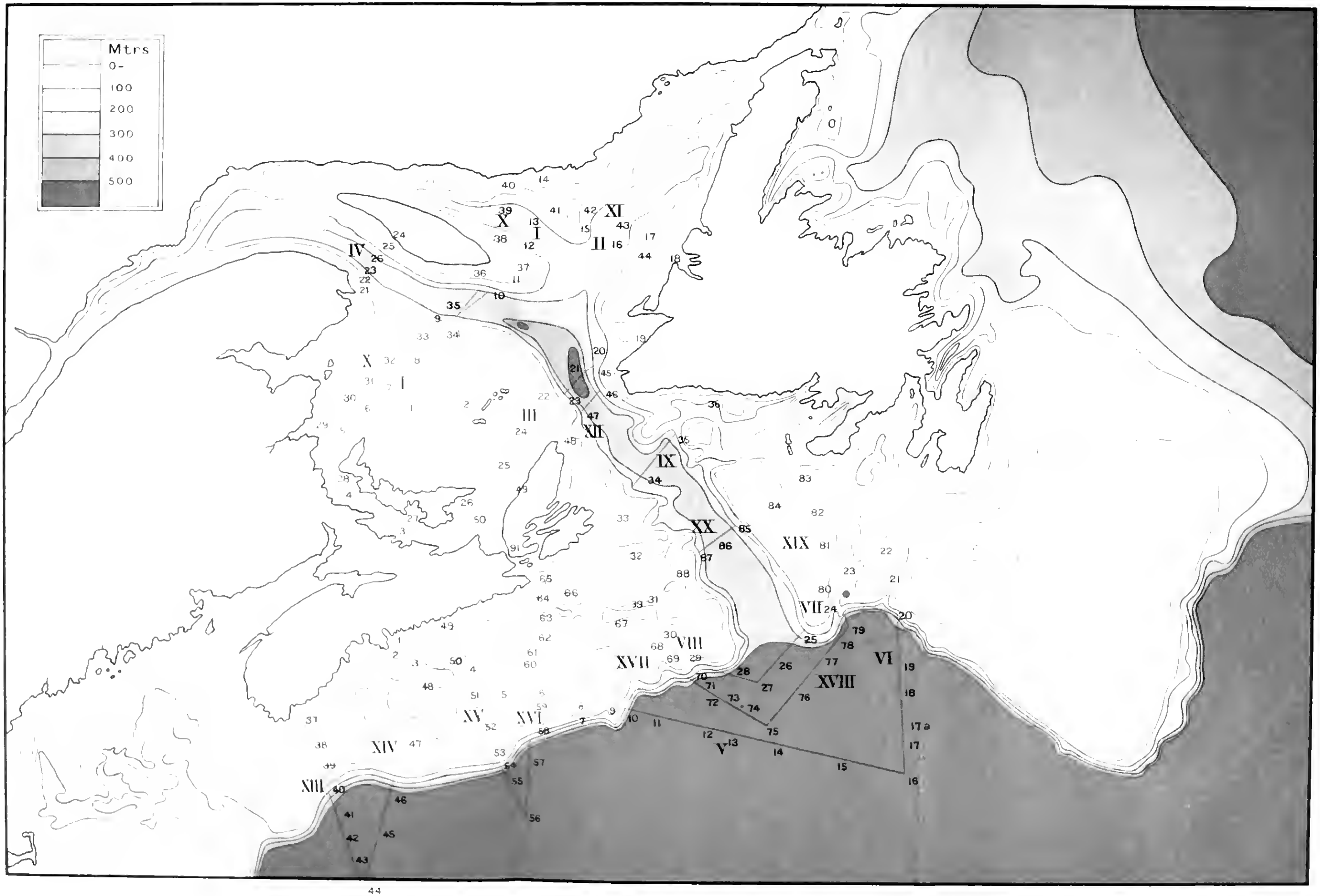
(*b*) MILLIMETER Hg.

mm.	0	1	2	3	4	5	6	7	8	9
700	−66	−65	−64	−62	−61	−60	−58	−57	−56	−54
710	−53	−52	−50	−49	−48	−46	−45	−44	−42	−41
720	−40	−38	−37	−36	−34	−33	−32	−31	−29	−28
730	−27	−25	−24	−21	−25	−21	−19	−17	−16	−15
740	−13	−12	−11	− 9	− 8	− 7	− 5	− 4	− 3	− 1
750	0	1	3	4	5	7	8	9	10	12
760	13	14	16	17	18	20	21	22	24	25
770	26	28	29	30	32	33	34	36	37	38
780	40	41	42	44	45	46	48	49	50	51
790	53	54	55	57	58	59	61	62	63	65

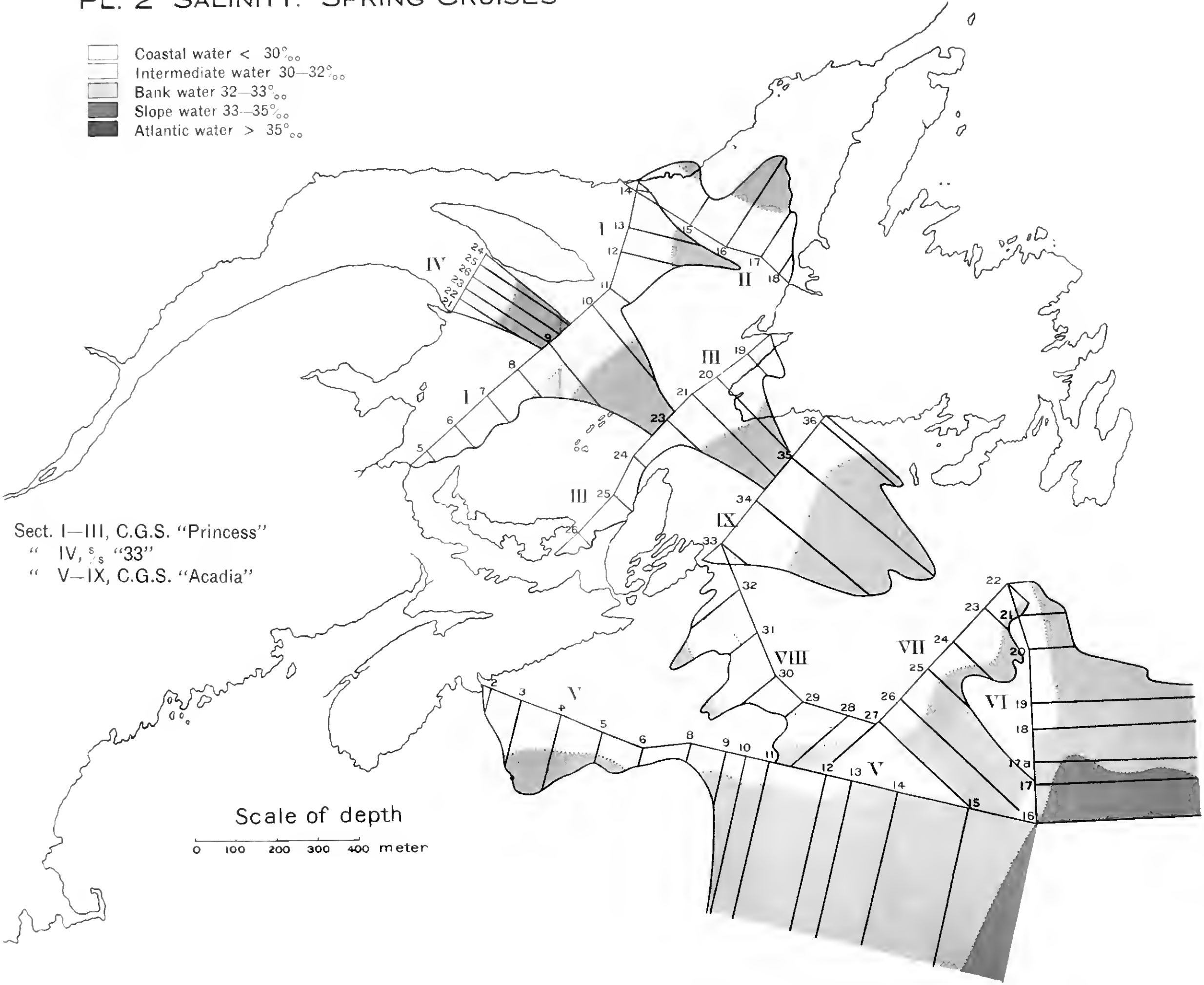
(*c*) 1/10 OF AN INCH Hg.

in	0	1	2	3	4	5	6	7	8	9
28	−51	−48	−45	−41	−38	−35	−31	−28	−25	−21
29	−18	−14	−11	− 8	− 4	− 1	2	6	9	12
30	16	19	22	26	29	33	36	39	43	46

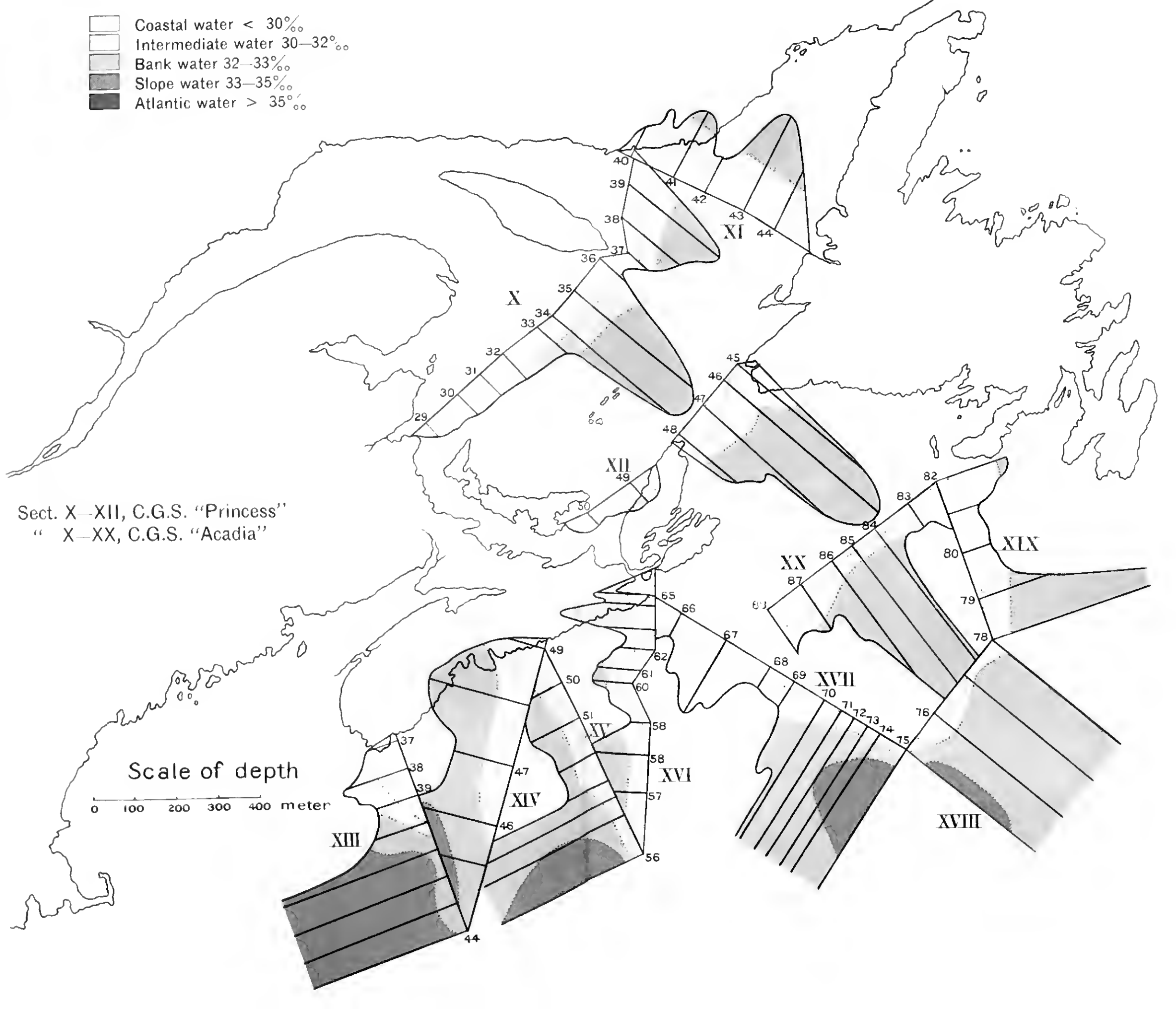
PL. 1



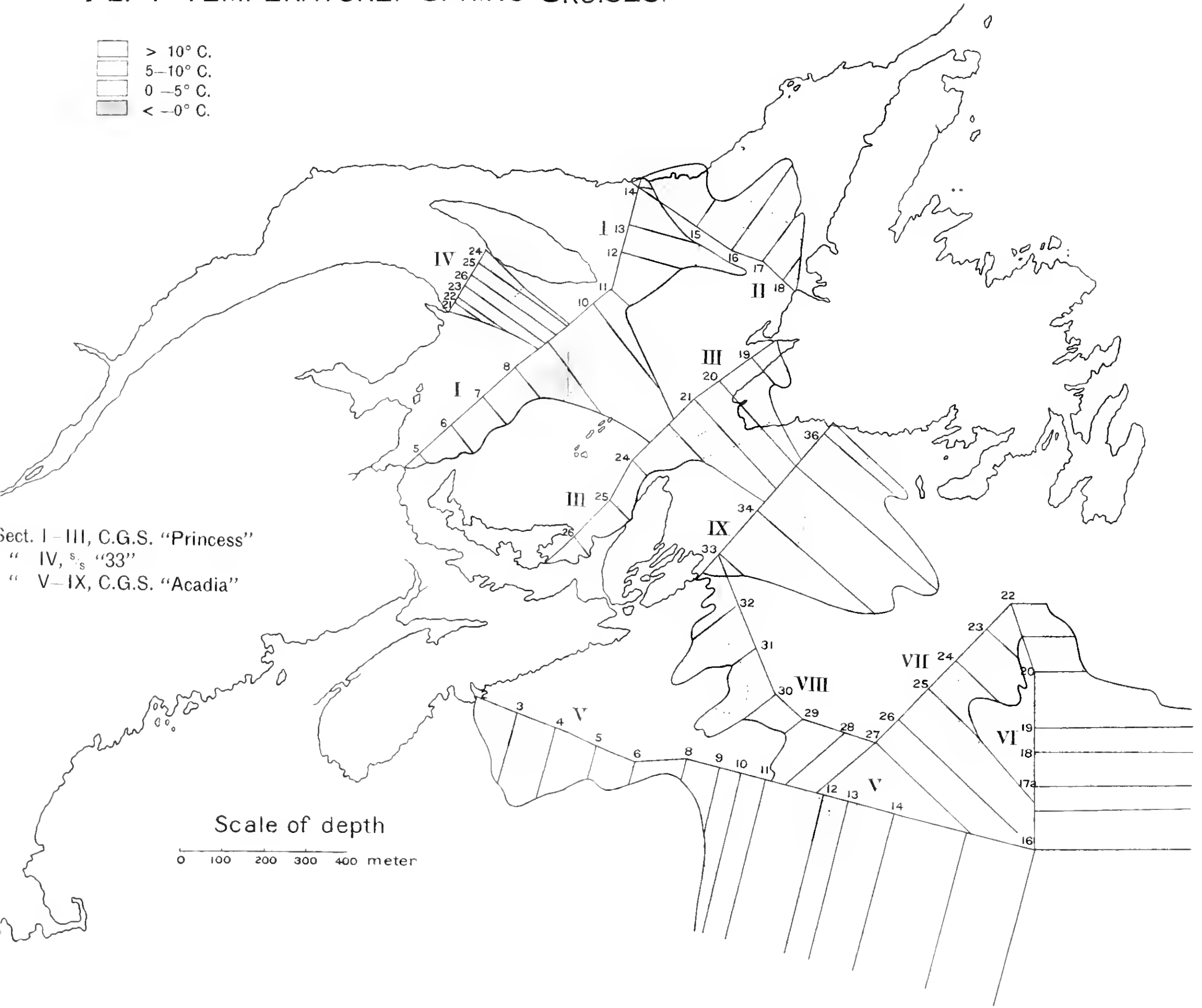
PL. 2 SALINITY. SPRING CRUISES



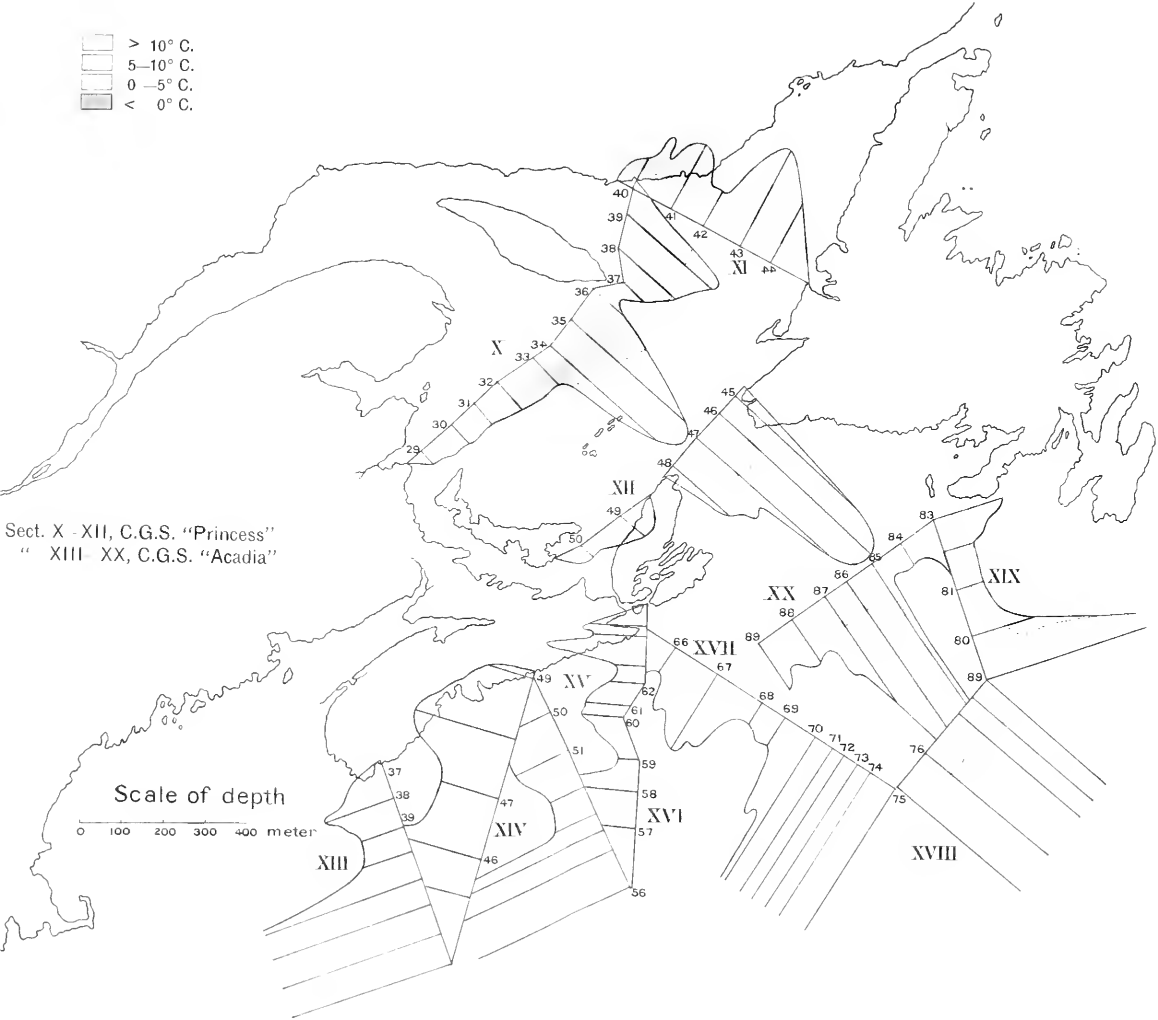
PL. 3 SALINITY. SUMMER CRUISES.



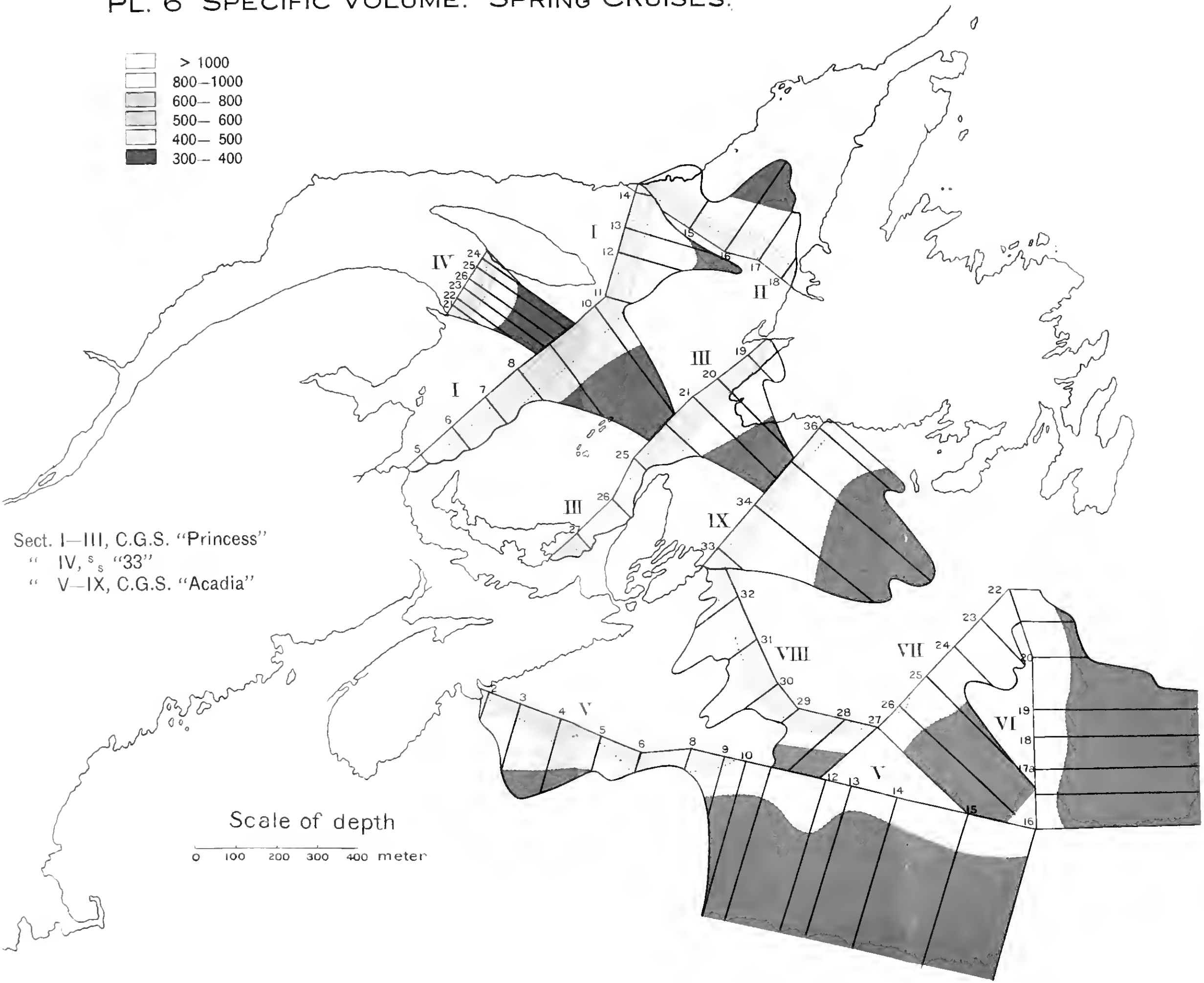
PL. 4 TEMPERATURE. SPRING CRUISES.



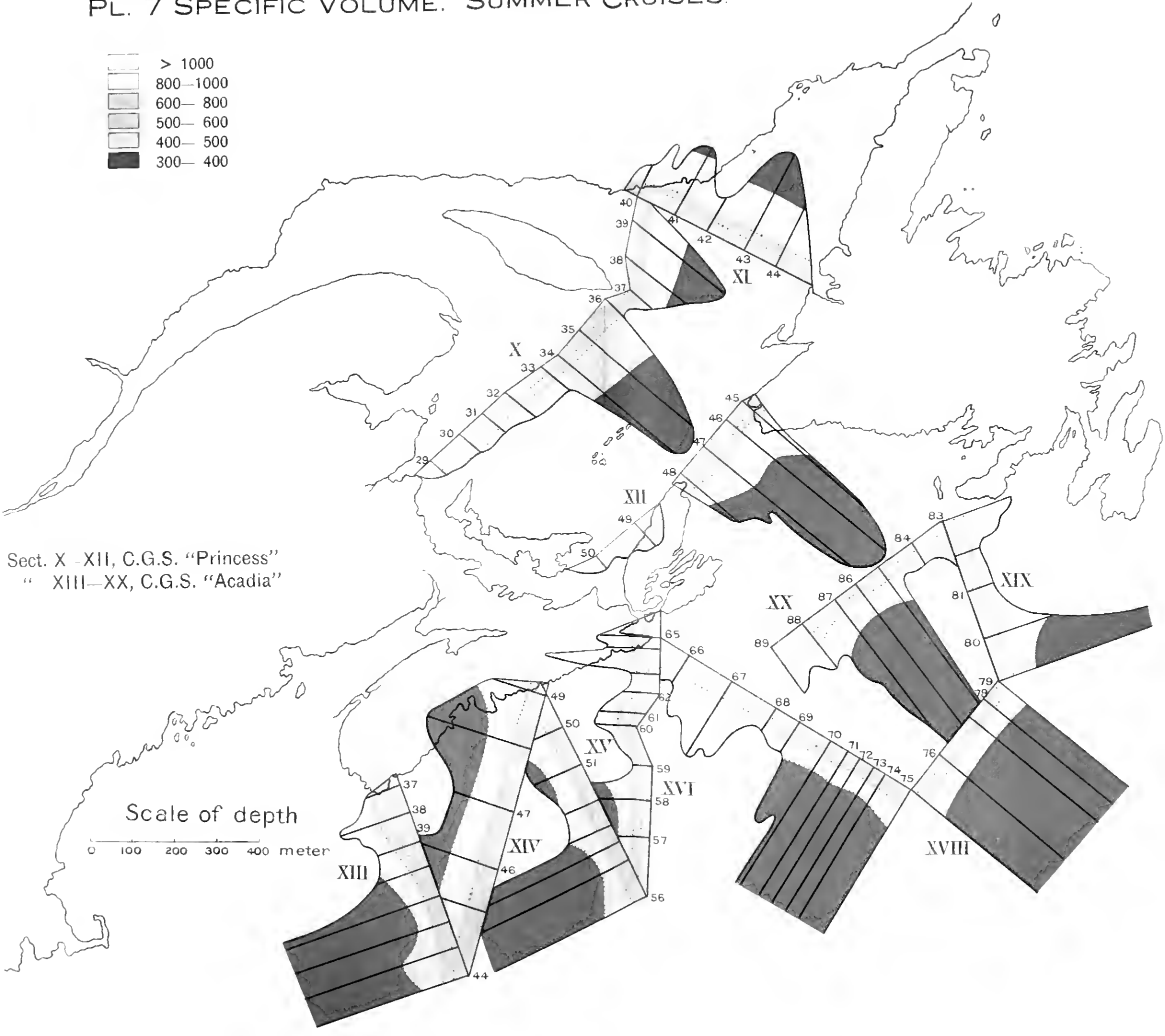
Pl. 5 Temperature. Summer Cruises.



PL. 6 SPECIFIC VOLUME. SPRING CRUISES.



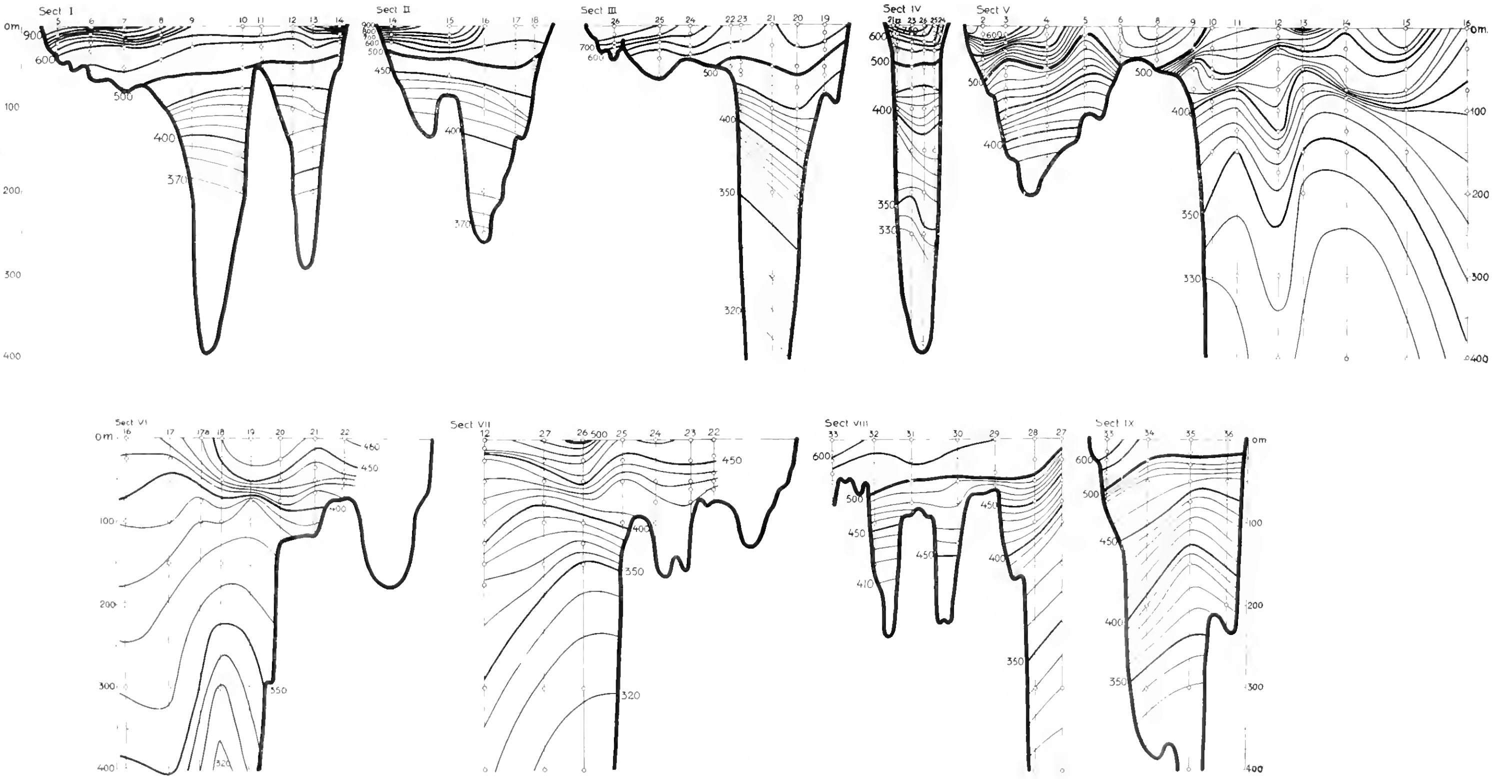
PL. 7 SPECIFIC VOLUME. SUMMER CRUISES.



VIII

ecific volume

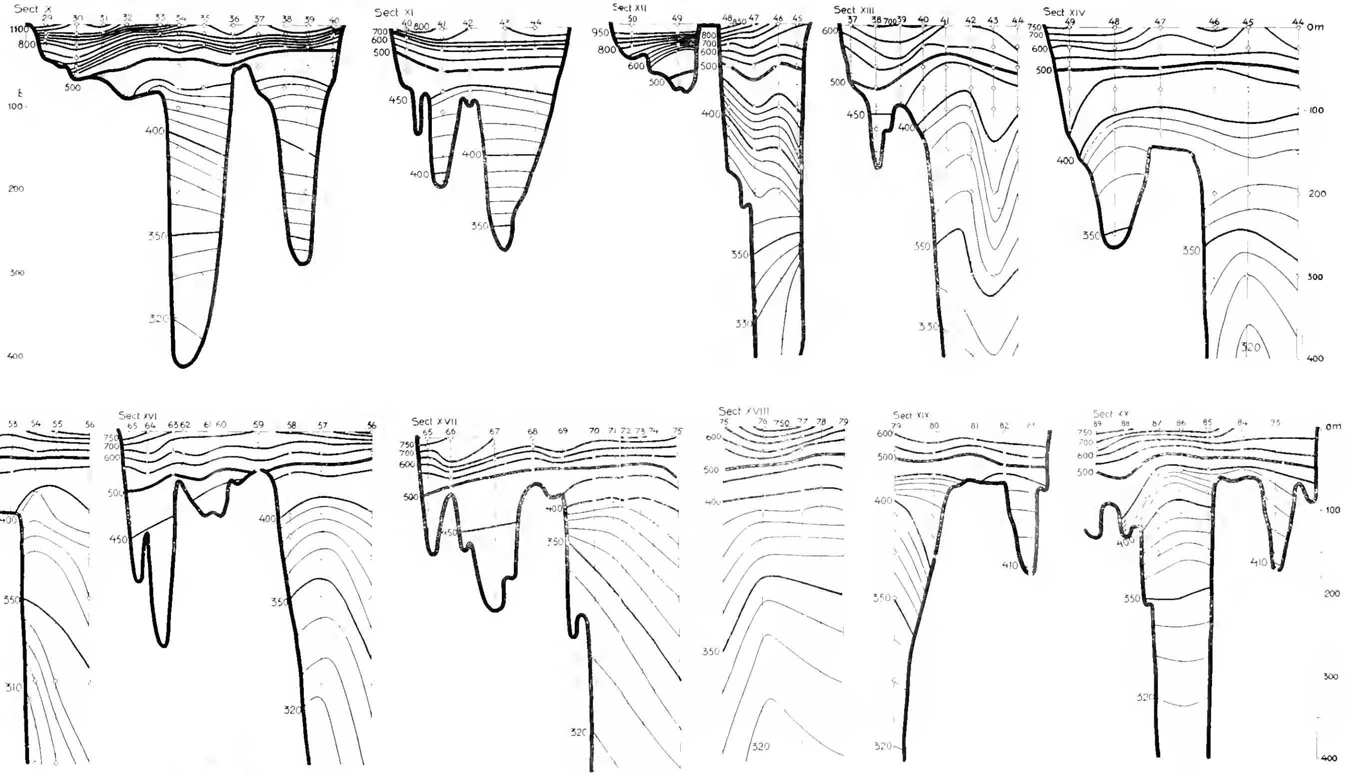
pring cruises



Pl IX

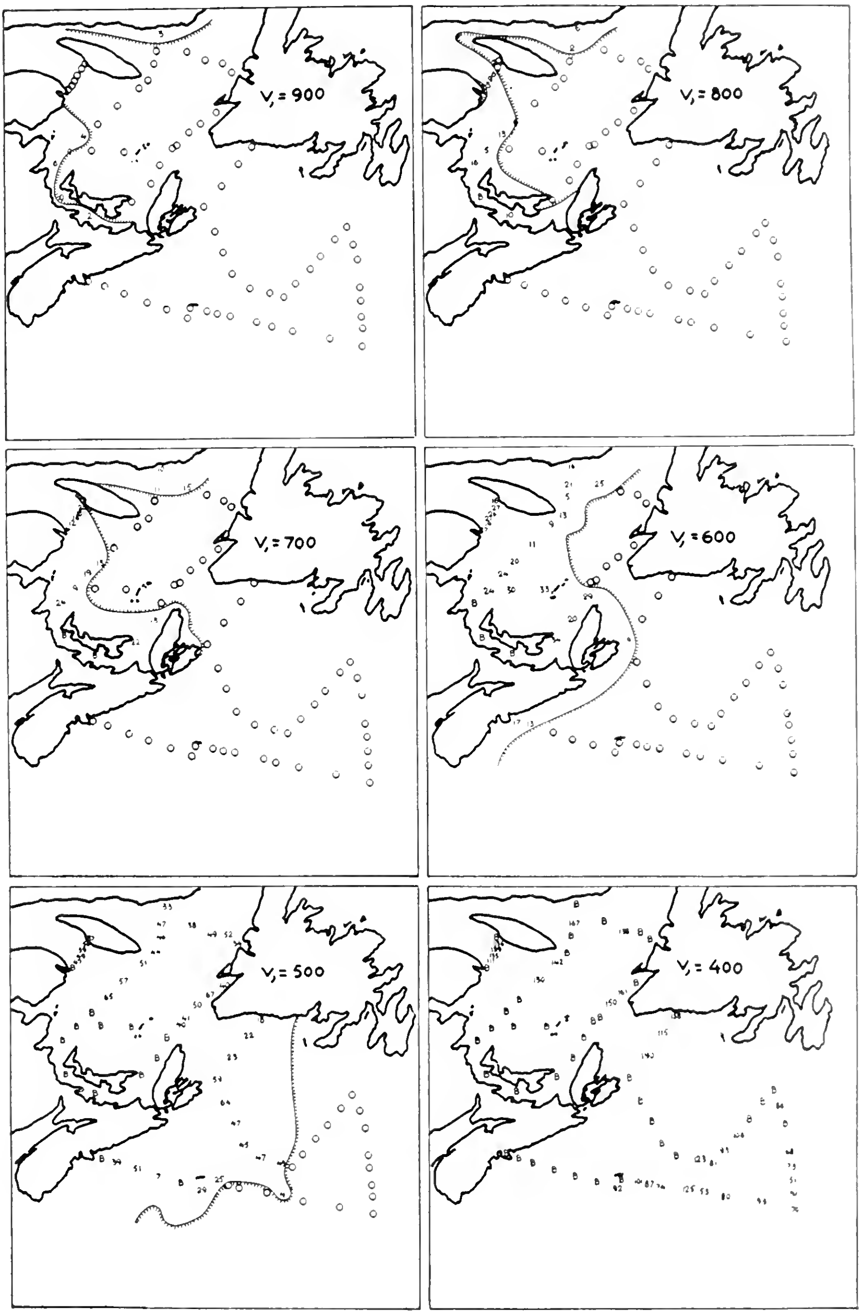
Specific volume

Summer cruises



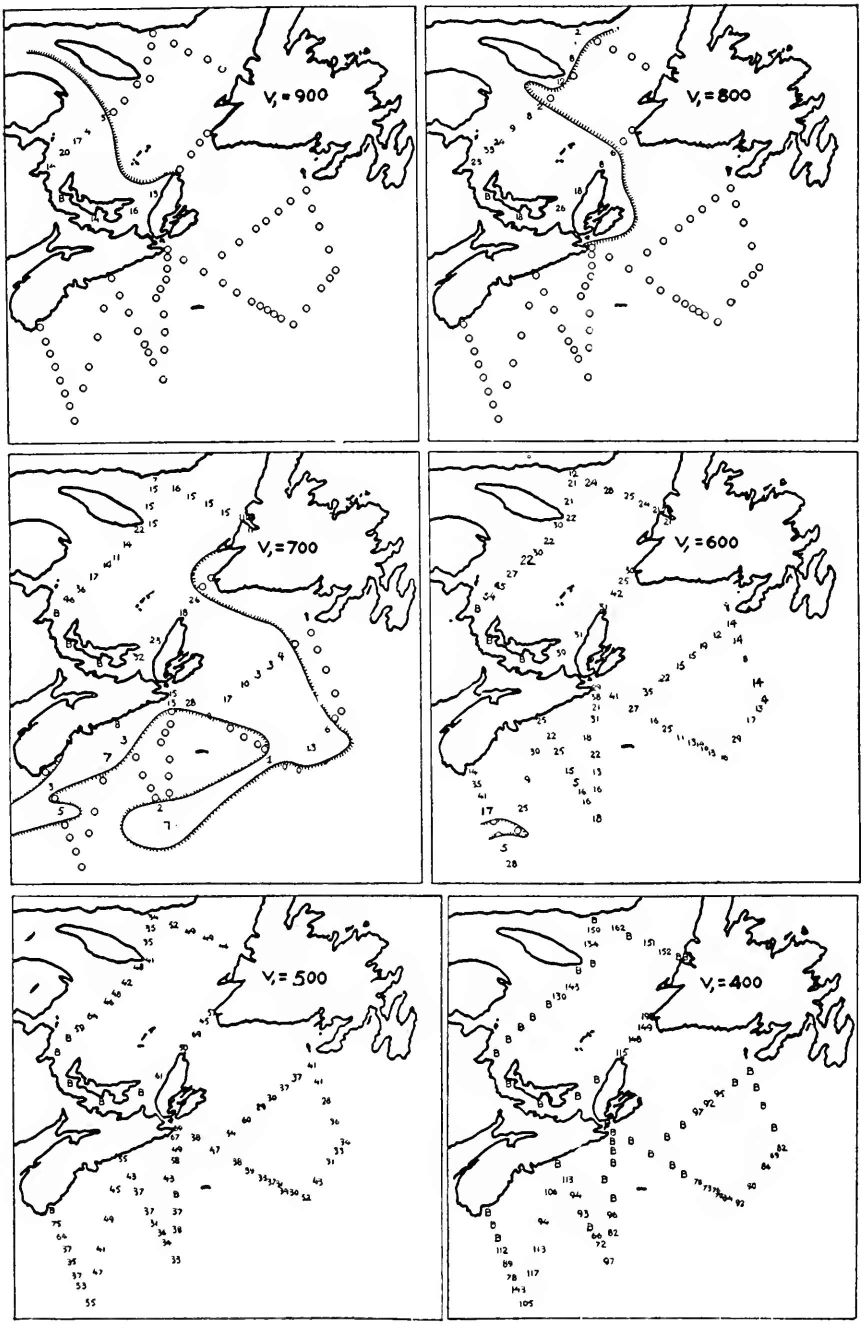
Pl. X

Depth in metres of the Isosteric Surfaces
Spring Cruises



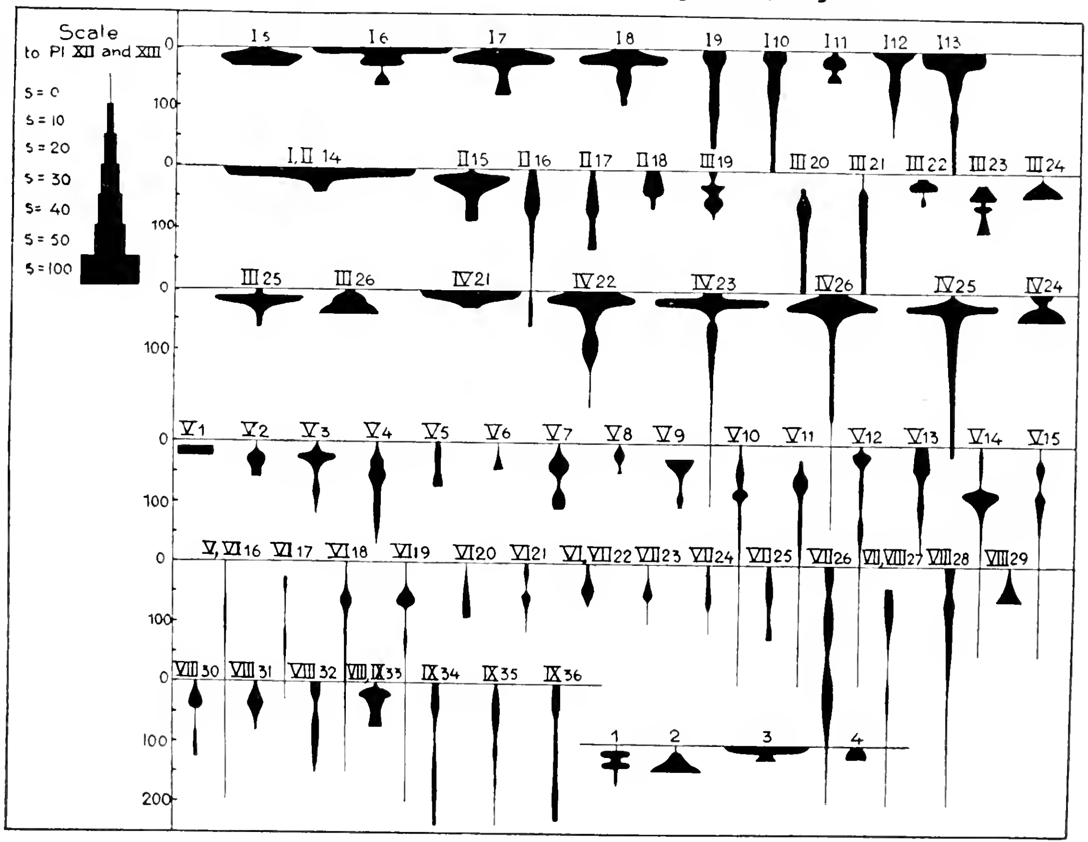
Pl. XI

Depth in metres of the Isosteric Surfaces
Summer Cruises



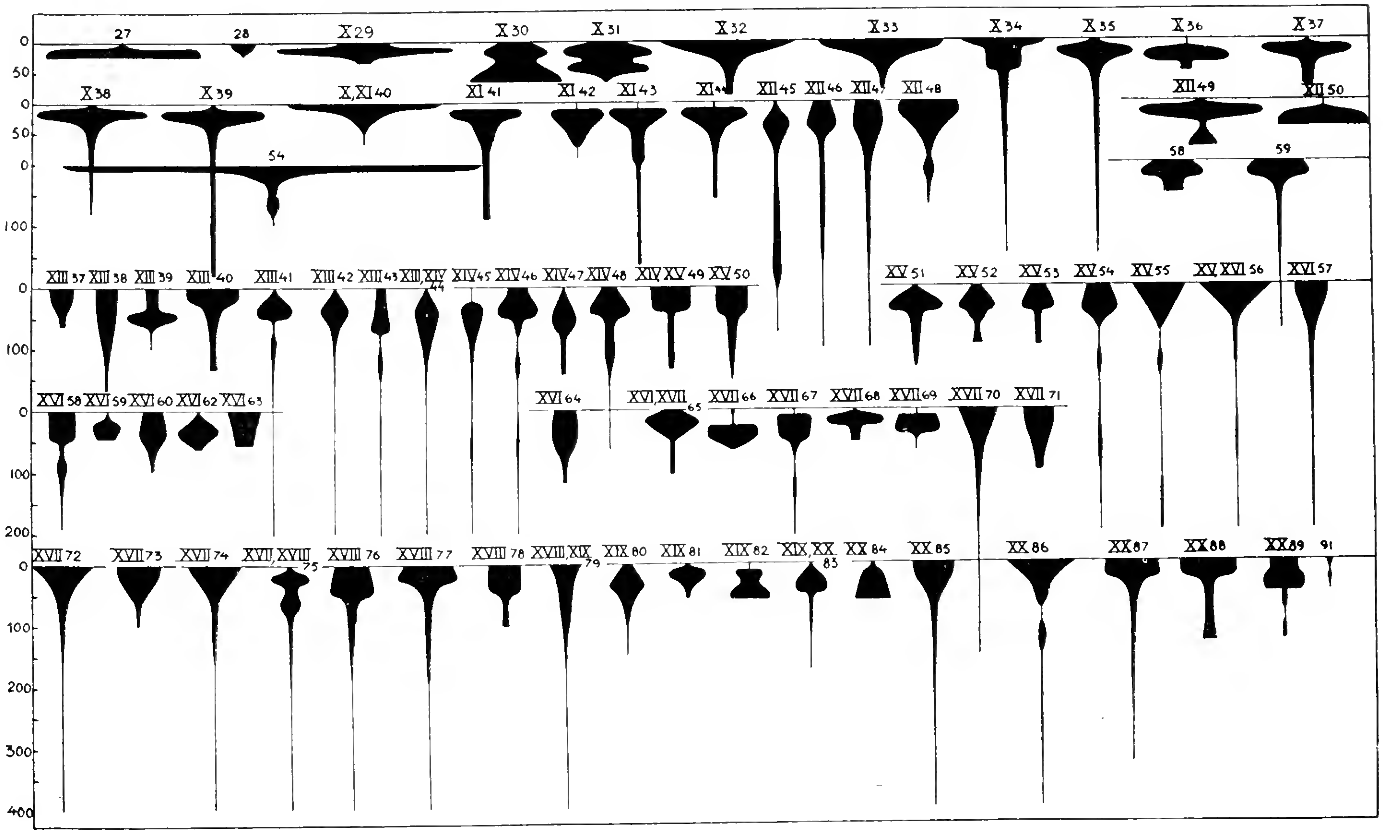
Pl. XII

Stability conditions in the Canadian Atlantic waters during the spring 1915

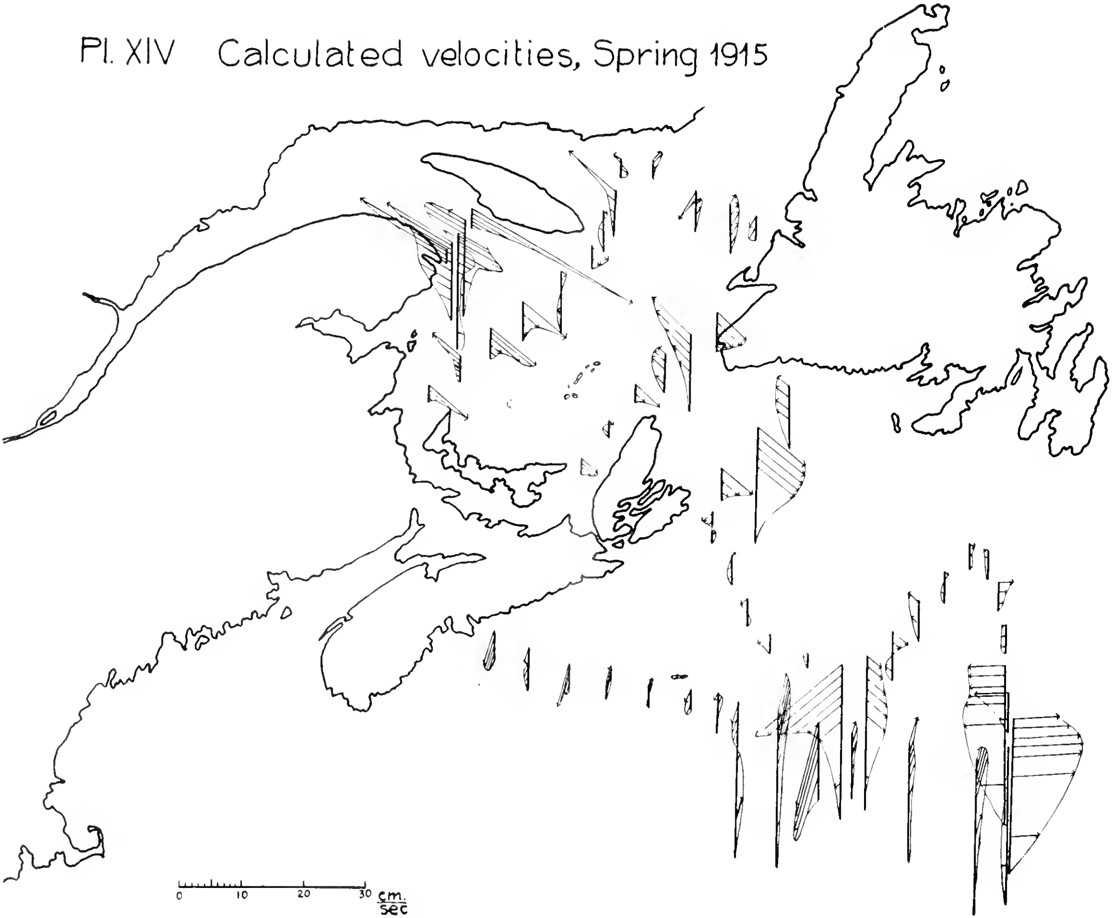


Pl. XIII

Stability conditions
in the Canadian Atlantic waters during the summer 1915

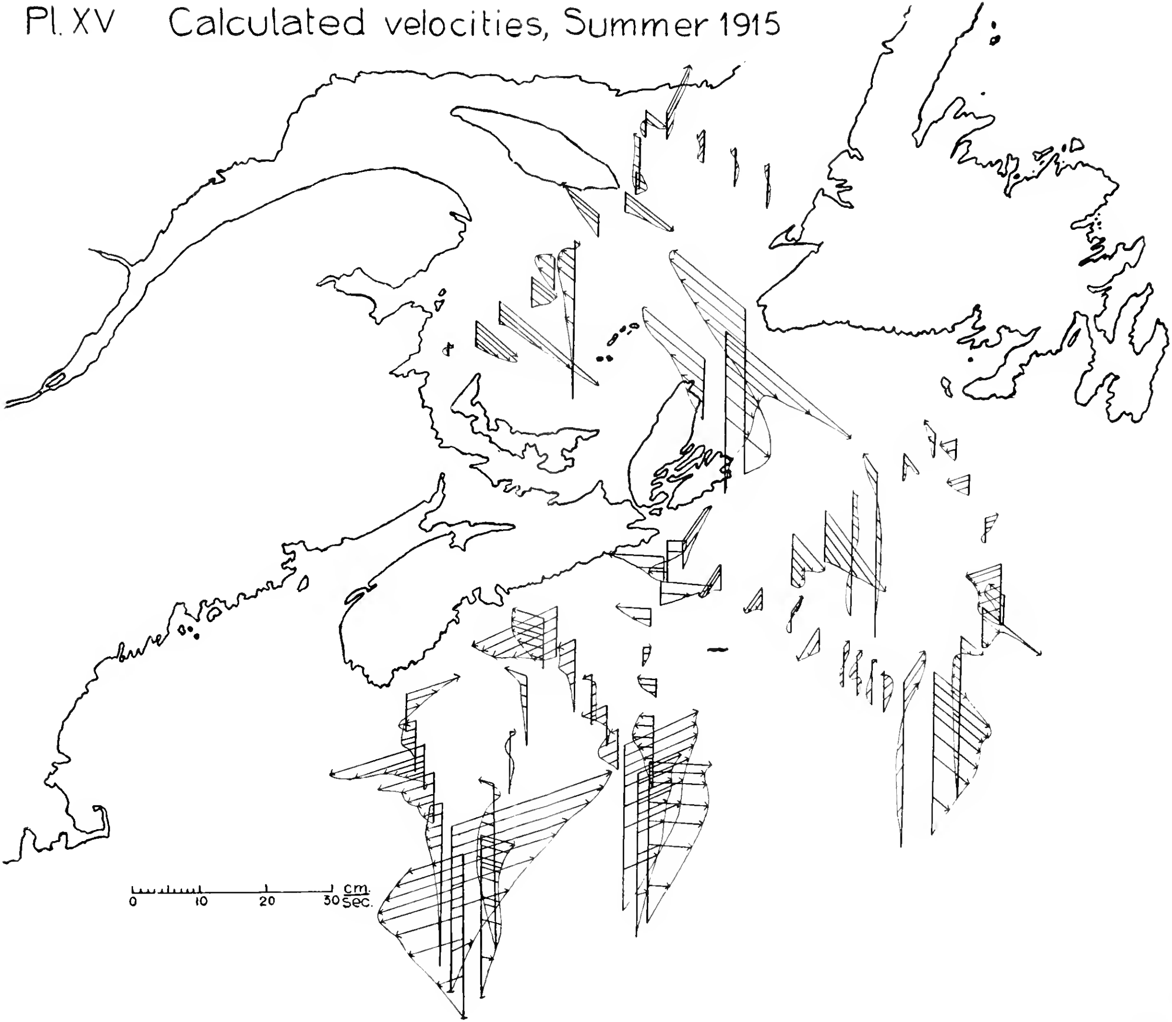


Pl. XIV Calculated velocities, Spring 1915



6551—25 k

Pl. XV Calculated velocities, Summer 1915



CANADIAN FISHERIES EXPEDITION, 1914-15.

Results of the Hydrographical Observations made by Dr. Johan Hjort in the Canadian Atlantic Waters during the year 1915

BY

PAUL BJERKAN, Bergen, Norway

(With Three Plates and Eleven Figures in the Text.)

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RESULTS OF THE HYDROGRAPHICAL OBSERVATIONS MADE BY DR. JOHAN HJORT IN THE CANADIAN ATLANTIC WATERS DURING THE YEAR 1915.

By Paul Bjerkan, Bergen, Norway.

In the following account of the hydrographical observations made by Dr. Johan Hjort in the Canadian Atlantic waters during the spring and summer of 1915, the main features of the expedition and the implements used in the work at sea and in the laboratory are first briefly dealt with, followed by an account on the hydrographical observations illustrated by sections and maps showing the results of the expedition.

I. THE EXPEDITION.

On Dr. Hjort's arrival in Souris, Prince Edward Island, the headquarters chosen for the expedition, on the first of May the harbour and adjacent waters were filled with ice as far as the eye could see, and reports from outside showed that the pack ice lay to the north of Prince Edward Island and round the Magdalen Islands. These conditions prevailed during the week from the 2nd to the 8th of May. The ice was supposed to have been forced southward against Prince Edward Island from the northern areas of the gulf of St. Lawrence by the prevailing northwesterly winds. Northumberland strait and the Picton coast were also barred by ice, and the steamboat communication between the latter place and Charlottetown, P.E.I., was interrupted and at times quite brought to a standstill. The C.G.S. *Princess* tried twice during the week to force its way through the ice eastward to Souris in order to take Dr. Hjort for a preliminary cruise north to the Magdalen islands and adjacent waters. At last she reached Charlottetown. Dr. Hjort and Professor Willey, of McGill University, went on board there, and on the 10th of May the *Princess* started for the cruise. It was decided that the *Princess* should run west of Prince Edward Island and try to pierce the ice up to Magdalen islands. In Northumberland strait, ice-packs were met with everywhere, but the air was pleasant and mild. The *Princess* got out of the ice west of Prince Edward Island and headed for Magdalen islands. Station 1 was taken to the west of Bradelle bank, and heading east the *Princess* entered small areas of pack-ice. When well out of the ice, station 2 was taken. Arrived at the west side of the Magdalen islands, she steamed round the archipelago to Pleasant bay, where the ice had been driven away by northwesterly winds. Herrings had been observed near the island, but the fishing gear had not yet been placed in position owing to the ice.

On account of the severe illness of Commander Wakeham, the expedition was discontinued on the 13th of May.

[illegible] the middle of May the ice conditions in the gulf of St. Lawrence changed totally. About the 20th of May the Halifax papers stated that the gulf ice had been driven towards Cape Breton island by the northwesterly winds, and had barred the Gut of Canso. About the 25th of May the rest of the ice was gone, having been melted or driven out through the Gut of Canso. The prolonged ice-bound conditions in the gulf of St. Lawrence this spring were, however, felt on land as well as at sea. The seasonal developments on Prince Edward Island were, according to the statements of the inhabitants, put back to the extent of about one and a half months, and at sea the extraordinary conditions were shown by the retardation of the main fisheries, especially the herring fishery. Thus the herring fishery round Magdalen islands in the spring was a failure, and the herring the fishermen got arrived comparatively late. It was thus to be expected that the hydrographical and biological conditions in the waters of the gulf of St. Lawrence might be somewhat unusual, and the seasonal development considerably retarded.

After this preliminary cruise the final plans of the expedition were settled.[1] For the scientific work the Canadian Government placed two ships at Dr. Hjort's disposal, the C.G. cruisers *Princess* and *Acadia*. The *Princess,* after the death of Commander Wakeham, commanded by Captain J. Chalifour, was to undertake two cruises, one in the spring, and the other in the summer in the gulf of St. Lawrence, and the *Acadia*, Commander Anderson, was to undertake two similar cruises in the Atlantic east of Nova Scotia. The steam drifter *No. 33* all the time was to carry on fishing experiments in the gulf of St. Lawrence, this part of the expedition being conducted by Captain Thor Iversen, who occasionally made hydrographical investigations, partly embodied in this account. In Souris, Prince Edward Island, a laboratory had to be improvised for hydrographical and biological work, and here the author took charge of the working up of the hydrographical material collected on the special cruises.

From May 29 to June 4 the C.G.S. *Acadia* made investigations in the Atlantic at stations 1-36 marked on the map, plate I, while from June 9 to June 15 the C.G.S. *Princess* made similar observations in the gulf of St. Lawrence at stations 3-26 marked on the same map.

From July 21 to July 29 the C.G.S. *Acadia* made observations in the Atlantic at stations 37-91, while from August 3 to August 12 the C.G.S. *Princess* made similar observations in the gulf of St. Lawrence at stations 27-50.

All the time, Dr. Hjort superintended the scientific work at sea with several collaborators. Water samples and temperatures were taken down to a depth of 400 metres at nearly all the stations, where such depths were found.

In the laboratory at Souris the water samples were tested for salinity, the preliminary calculations made, and the hydrographical material as a whole brought into such a state as to facilitate its transportation to Norway, where the final elaboration of the results was to be carried out after the conclusion of the expedition. By working up the material in this way immediately after each cruise, reliable conclusions could be drawn as to the best course of the next cruise in the same waters.

II. THE GEAR AND METHODS.

In the hydrographical work on board, a reversing stopcock water-bottle of a new pattern without frame, invented by Prof. Dr. Nansen (figs. 1 and 2)[1] was used. It is very light and easy to handle, and relatively cheap. The tube is made of tinned brass. On the outside of the main tube two brass tubes of the ordinary type for thermometers are fastened. The reversing mechanism is released by a messenger of the usual type used in oceanographical work.

Six of these water-bottles, brought over from Norway, were used in all the regular cruises, and always worked very well. During the preliminary cruise up to Magdalen islands in the first days of May a water-bottle of another pattern was used.

The water samples were kept in ordinary magnesium citrate bottles, which were found very satisfactory for the purpose.

[1] Prior to the actual work of the expedition, Dr. W. Bell Dawson, the head of the Tidal Survey of Canada, was consulted as to the best routes for the various scientific cruises embraced in the scheme. Dr. Dawson's opinion as to these was obtained, based upon the investigations already carried on for many years past in these waters—the special object in view being the determination of the conditions affecting the migrations of the great schools of economic fishes in the gulf and adjacent waters.

[1] According to a letter from Dr. Nansen he has now improved the releasing mechanism of his water bottle considerably and the messenger now used is not so heavy as that shown in the figures.

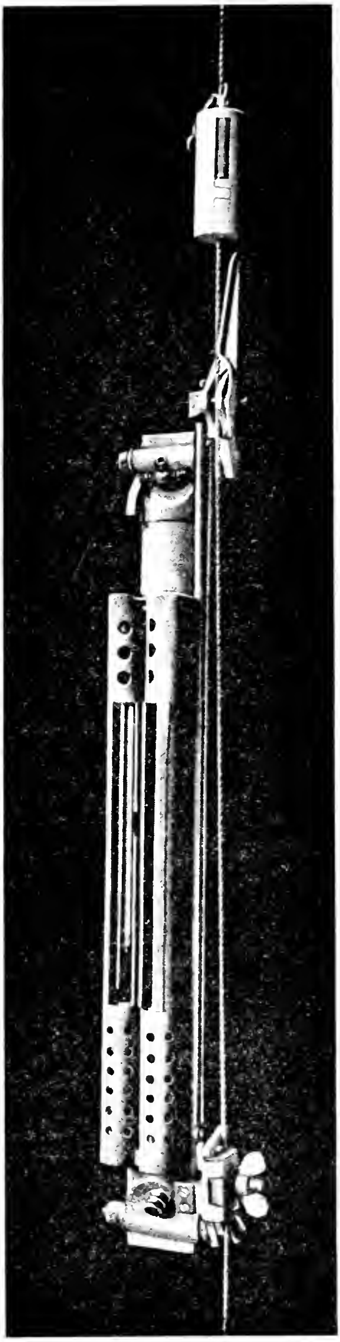

Fig. 1.—The new Nansen stopcock waterbottle, open.

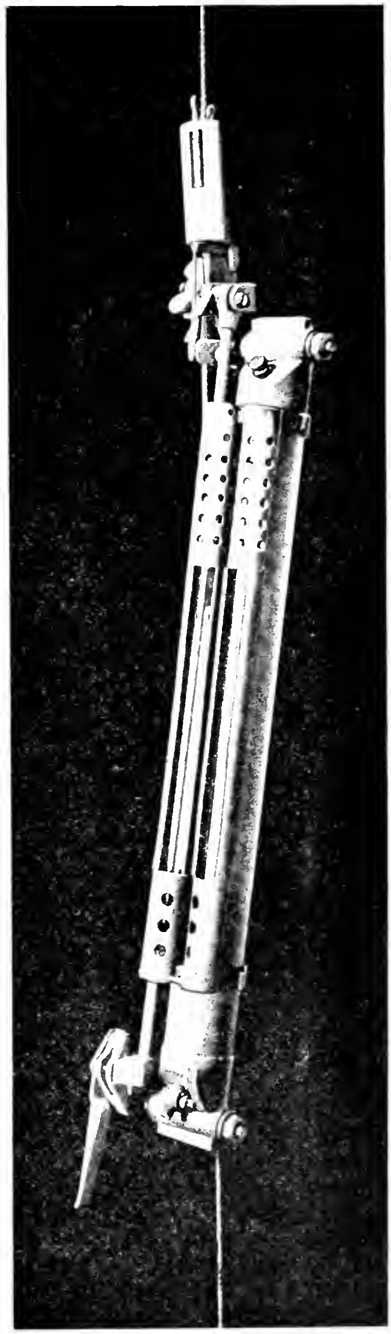

Fig. 2.—The waterbottle reversed and closed.

Ten Richter reversing thermometers (fig. 3) from Schmidt and Vossberg, calibrated to 0·1° Centigrade, were in use, two for each water-bottle. For the surface temperatures four thermometers (Schmidt and Vossberg), also calibrated to 0·1° Centigrade were used. The thermometers were delivered by the international hydrographical laboratory at Copenhagen, and were specially tested in the laboratory. With

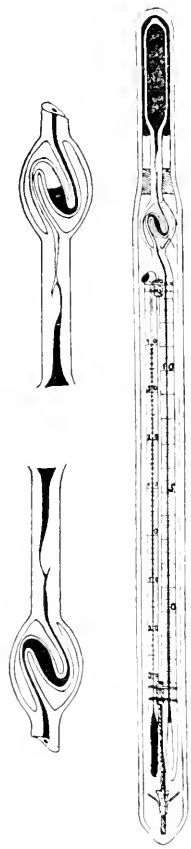

Fig. 3.—Richter's reversing thermometer.

these thermometers it is possible to read off the temperature to 0·01° Centigrade, but during the expedition the temperatures, after due correction, were rounded off to the nearest 0·05 Centigrade, which was found to be sufficiently accurate for those waters.

For sending down and hauling up the apparatus two hand-winches with wire reels taking about 500 metres of wire were in use, the wire having a diameter of about 4 millimetres. A meter wheel of the usual pattern for oceanographical research was used for determining the depth. By the special lateral arrangement for fastening the water-bottles to the wire, several water-bottles could be used at the same time.

In the laboratory the salinity of the water samples was determined by means of chlorine titration, which is the method mostly used in practical work. The amount of chlorine in sea-water is stated per mille in the same way as the salinity, and defined as follows:—

By the amount of chlorine we mean the number of grammes of chlorine contained in 1 kg. of water, supposing the small quantities of bromine and iodine to be replaced by chlorine. The amount of chlorine is determined in different ways. The most commonly used is Mohr's titrimetric method, which is both rapid and accurate:[1] to a certain quantity of the water sample a solution of nitrate of silver is added; the silver chloride being precipitated as a white flocculent deposit:—

$$Na\ Cl + Ag\ N\ O_3 = Ag\ Cl + Na\ N\ O_3.$$

An indicator is applied to show when all the chlorine has been precipitated, and the amount of nitrate of silver added is measured. As an indicator, yellow potassic chromate ($K_2\ Cr\ O_4$) in nearly saturated solution is used. It combines with the

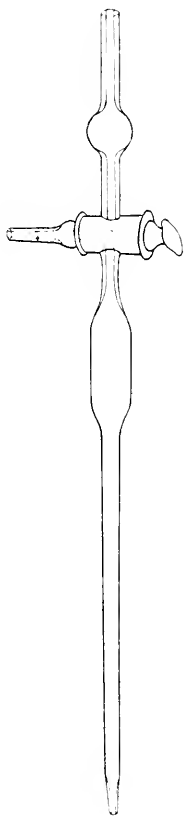

Fig. 4.—Knudsen's automatic pipette

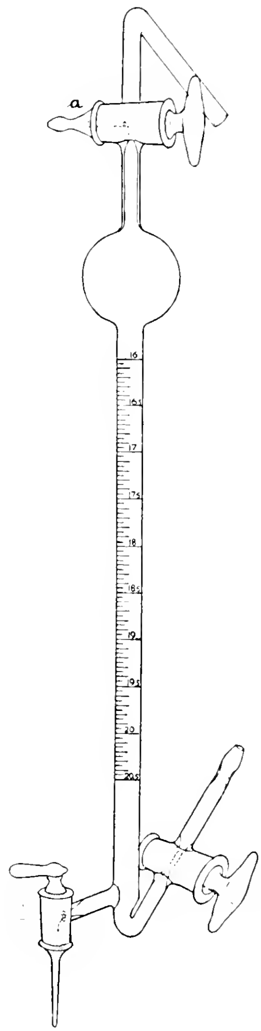

Fig. 5.—A bulb-burette for titration.

nitrate of silver ($Ag_2\ Cr\ O_4$); but this reaction does not take place until there is no chlorine left. When a few drops of the potassic chromate is added to the water-sample the latter turns yellow, but when all the chlorine has been precipitated by the addition of nitrate of silver the sample turns red, and the titration is completed.

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[1]The method is thoroughly described in B. *Helland-Hansen*, The Ocean waters, International Revue der gasamten Hydrobiologie und Hydrobidogie und Hydrographie, Leipzic, Hydr. Suppl. Ser. III, 2 p. 34 af.

For measuring the water-samples, a Knudsen's automatic pipette (fig. 4.) was used. The pipette is provided with a stopcock, and after sucking up the water to a little above the stopcock, the latter is turned; to empty the pipette the stopcock is

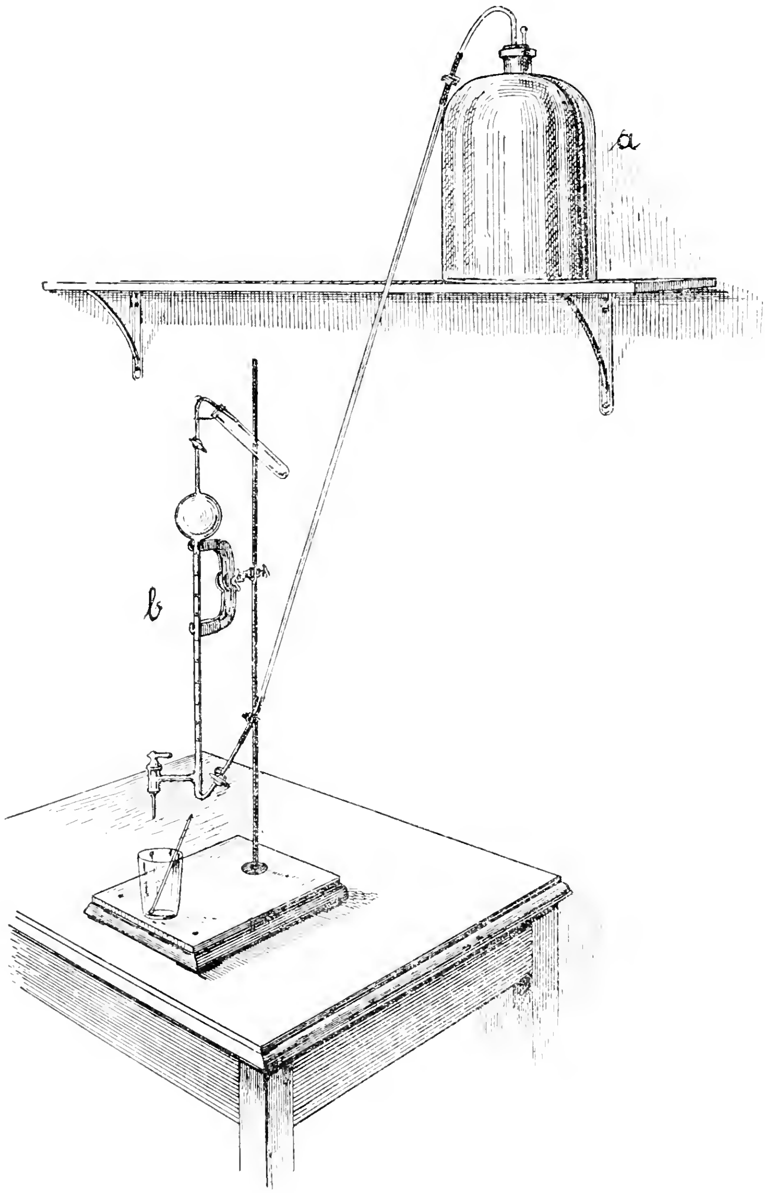

Fig. 6.—Arrangement for chlorine titration.

turned further round, so as to be open to the air. The pipette measure 15 or 20 ccm. For the titration a bulb-burette (fig. 5) was used with an upper stopcock (*a*) perforated in the same way as in the automatic pipette. In filling and emptying the burette tube by the stopcocks *b* and *c* the upper stopcock is used in quite the same way as in the automatic pipette. From the burette the silver nitrate solution is emptied into an ordinary smooth tumbler in which the measured portion of the water-sample has been previously placed. The fluid in the tumbler is stirred by a glass rod to further the process, and the indicator is added when the chlorine is nearly saturated. When nearing the saturation of the chlorine in the water the

Fig. 7.—A standard-water tube.

silver nitrate solution is added in drops while stirring. The reading of the burette is made at once while the red colour of the fluid lasts. The essential point in the titration is that all the different operations in one series of water-samples are done in exactly the same way each time, quite automatically, and the nearer one can approach the ideal of a titration machine, the better are the results.

The arrangement of the titration apparatus with bottle of silver nitrate solution (*a*) and burette (*b*) is shown in fig. 6. For further details about the titration method, see Helland-Hansen (l. c).

For the titration, standard water was used. The standard water, introduced into hydrographical investigation by Professor Pettersson is ordinary sea-water with a salinity of about 35 ‰. It is examined with the greatest care by different methods and kept in soldered glass tubes (fig. 7). The standard water is now prepared at the international hydrographical laboratory at Copenhagen.

The chlorine value of the standard water is known, and can be used to determine the strength of the silver solution, a certain amount of the solution being found to correspond to the chlorine value of the standard water. When in this manner the strength of the silver solution has been determined, it is easy afterwards to calculate the amount of chlorine in a series of water samples. It is assumed that the silver solution is so made that a titration of standard water gives a reading on the burette that corresponds nearly with the actual chlorine value of the standard water. To facilitate the operation in this respect the hydrographical laboratory at Copenhagen deliver measured quantities of silver nitrate, each to be dissolved in a certain quantity of distilled water.

The calculation of salinity and density from the chlorine value found and from the corrected temperature was made by means of Knudsen's hydrographical tables.[1]

After the conclusion of the expedition the gear and the laboratory outfit were given in charge of the naval store office of H.M.C. dockyard, Halifax, to be used in a supplementary autumn cruise in the Atlantic waters east of Nova Scotia by C.G.S. *Acadia* under Commander F. Anderson.

III. THE HYDROGRAPHICAL OBSERVATIONS.

In the hydrographical table the results as to salinity, temperature, and density are given for each station. The salinity and temperature are dealt with here, while the density, which is calculated only for use in hydrodynamic studies is given only in tabular form. As this part of investigation has been taken over by Mr. J. W. Sandström, Stockholm, I refer the reader to his paper for details.

The figures for salinity and temperature in the table have been worked out in the sections, plates II and III; sections I-IX (plate II) are devoted to the spring cruises, sections X-XX (plate III) to the summer cruises. The observations shown in sections I-III and X-XII were made by the C.G.S. *Princess*, those in section IV by steam drifter *33*, both working in the gulf of St. Lawrence; sections V-IX and XIII-XX deal with the observations taken on board C.G.S. *Acadia*, working in the Atlantic waters east of Nova Scotia.

The positions of the sections and stations will be found in the general map (plate I) and are also inserted in the hydrographical table, together with time and depth. The *Princess* stations 1-4 and 27-28, and the *33* stations 54 and 58-59, with hydrographical data in the table, are not included in any of the sections; each of the three ships used their special number-series of stations, and I have where necessary used a double designation for the stations, viz., V. 10, XIII, 40, etc.

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[1] *Martin Knudsen*, Hydrographical Tables, Copenhagen and London. 1901.
Martin Knudsen, 6: Tabelle, Anhang zu 1901 herausgegebene.
Hydrographische Tabellen, Publ. de Circ. Copenhagen, 1904.

In working certain main features in the distribution of waters of different salinities in the area investigated, I have found it convenient to introduce a special terminology:—

			Per cent.
1. Coastal water..		Salinity.	below 30
2. Intermediate water...	30-water..	"	30-31
	31 "	"	31-32
3. Bank water	inner..	"	32-32, 5
	outer..	"	32, 5-33
4. Slope water..	33-water..	"	33-34
	34 "	"	34-35
5. Atlantic water..		"	above 35

These varieties, and the limits between them, are of course only approximate, and the terms are used according to the prevailing conditions. The subdivision is analogous with that used by Pettersson and Ekman[1] in the treatment of the Skager Rack and Cattegat waters.

In the sections the isohalines are represented by continuous lines, those denoting the main division somewhat thicker than the others. In some cases, especially in coastal water, additional isohalines, viz., 29 ‰, 34·5 ‰, and 35·5 ‰ are drawn in. The isotherms are represented by dotted lines. Each observation is marked with a little circle: the figures are not inserted in the sections, but will be found in the hydrographical table.

Spring Cruises.

GULF OF ST. LAWRENCE (TABLE Ia)

1. C.G.S. "Princess" (May 10 to May 13).

During the preliminary cruise in the gulf of St. Lawrence in the *Princess*, two stations were taken: one on the Bradelle bank and the other on the southwestern part of the Magdalen Islands bank.

Stations 1 and 2.

Salinity.—In the upper strata, down to below 10m., coastal water is found at station 1, thence to the bottom (69m.) intermediate water with a maximum salinity of 31·31 ‰ at 65m. At station 2 the coastal water extends down to below 20m., but at 40m. (bottom 45m.) the salinity is nearly the same as at station 1, viz., 31·16‰.

Temperature.—The melting of the floating ice has cooled down the surface water to 0° C. at station 1, and 0·35° C. at station 2. At 10m. the temperature is somewhat higher at both stations, but from 20m. down to the bottom the temperature is below zero, being at both stations ÷ 1·2° C. at 40m., and ÷ 1·4° C. near the bottom at station 1.

2. C.G.S. "Princess" (June 9 to June 15).

The first two stations on this cruise were taken in the shallow water of the Northumberland strait, and are not included in any of the sections.

Stations 3 and 4.

Salinity.—Coastal water of low salinity, about 28 ‰, is found from the surface down to 20m. at both stations, at station 3 ranging from 27·83 ‰ to 28·60 ‰, and at station 4 from 27·65 to 28·12 ‰. The eastern station thus shows the highest salinity and the greatest difference between the surface and bottom layers.

[1] *Pettersson* ock *Ekman*: Grunddragen af Skageracks ock Kattegats Hydrografi. Kgl. S. Vetenskaps Akads. Handlingar, v. 24 no. 11

Temperature.—There is a similar difference in the temperature. The surface temperature being highest (11·5° C.) at the eastern station, and falling rapidly to 3·6° C. at the bottom (28m.). At station 4 the surface temperature is 8·6° C., and the bottom temperature 7° C. (20m.).

Section I. Stations 5-14.

This section runs from off Escuminac point over Anticosti east bank to Natashkwan bank near the north shore, crossing the Laurentian and Anticostian channels to the north and south of the former bank. This section represents the first attempt to get a general view of the changes caused by the in- and out-flowing currents of the St. Lawrence river.

Salinity.—In the southern part of the section, as far as stations 8 and 9 we find coastal water down to a depth of 25-15m. deepest at the southernmost station. At the two northern stations near the north shore the coastal water goes down to 10m. The rest of the surface is occupied by intermediate water, which on the slopes of the southern banks goes down to about 80m. at Anticosti bank, nearly touches the bottom at 50m. and keeps to the latter depth over the Anticostian channel. Bank water covers the Anticosti bank down to a depth of about 110m. on the southern side and 130m. on the northern side. The 33 ⁰/₀₀ isohaline in the main runs at a depth of 120m. over both channels. No observations were taken deeper than 200m. in any of the channels. At this depth a salinity of 33.80⁰/₀₀ was found in the Laurentian channel near the northern slopes (station 10), and 33.51 ⁰/₀₀ at station 13 in the Anticostian channel.

Temperature.—The surface temperature is highest, up to 10° C., in the south, and falls towards a minimum (6.45° C.), at station 10. Towards the north shore it attains 8° C., at station 14 over Natashkwan bank. At a depth of from 25 to 50m. the temperature falls below zero. The upper 0° isotherm has a very undulating course, at two places extending a little below 50m. This undulating course corresponds to the rapidity of the decrease of the temperature from the surface downwards. At most stations the decrease is most rapid at a depth of 20-25m. The lower 0° isotherm lies at a depth of 120-150m. over the Laurentian channel and about 160m. over the Anticostian channel. The minimum, below ÷ 1° C. lies between 50-75m. over the former, and between 60-100m. over the latter channel. The highest observed temperature in the depth of the southern channel is 3.0° C. and in the northern 1.2° C. both at 200m.

Section II. Stations 14-18.

This section runs from station 14 over C. Wittle bank towards the Newfoundland coast, crossing the Esquiman channel (the deep channel running through Belle Isle strait).

Salinity.—Coastal water is found from the surface down to 15-20m. at the two first stations. The surface over the Esquiman channel is occupied by intermediate water, which here extends down to a depth of about 50m., while over the western banks it is restricted to the strata between 20-35m. From here we find bank water down to a depth of 100-120m.., and below this we find only slope water with a salinity of 33.69⁰/₀₀ near the bottom (250m.) at the deepest station (station 16). The surface salinity thus falls 0.5 ⁰/₀₀ lower over the western channels than over the Esquiman channel, and no coastal water is found at station 18 near the Newfoundland coast, the surface salinity being there 31.25 ⁰/₀₀.

Temperature.—The surface temperature decreases but somewhat unevenly from west to east from 8° C. at station 14 to 5·95° C. at station 18. The decrease downwards is most rapid over the banks, where the 4° isotherm is found at a depth of about 13m., while over the channel it sinks to about 25m. The layer of water having a temperature below zero is found from 30m. over the banks, and 60m. over the channel, down to about 125m., whence the temperature increases slowly to 2·4° C. at a depth of 250m.

Section III., Stations 19-26.

This section runs from St. George bay, Newfoundland, to off Souris, Prince Edward Island, over the eastern part of the Magdalen Islands bank, crossing the Laurentian channel to the west of Cabot strait.

Salinity.—The coastal water is restricted to the two southernmost stations, extending down to about 30m. at station 26. The banks are covered by intermediate water, which from station 24 occupies the surface with 31-water over the deep channel. The bank water we find on the slopes towards the channel in a depth of 50–100m. In the middle of the channel at Station 20 it is found at a depth from 70-140m., but is again stowed up against Newfoundland. The 34 isohaline lies at a depth of about 240m., and at a depth of 400m. we have a salinity of 34·78 ⁰/₀₀.

Temperature.—The temperature of the surface waters down to a depth of 20–30m. is higher than 4° C., the highest readings being found in the south, where the temperature is about 7° C. The bottom on the banks is covered by water with temperatures below zero. The upper 0° isotherm runs between 20 and 40m. over the banks, but sinks to between 50 and 70m. over the channel. The lower 0° isotherm lies at about 100m. on the slopes of the southern banks, but sinks down to 130–140m. over the northern part of the channel. The temperature increases again towards the deep water, and in 400m. we find a temperature of 4·25°C.

The salinity, as well as the temperature, seems to indicate an outflowing current from the gulf towards the slopes of the southern banks, and an inflowing current in the middle part of the channel, the changes being mostly restricted to the upper 100m.

3. Steam Drifter "No. 33" (June 25 to June 26).

Section IV. Stations 21-26.

This section was taken by the steam drifter *No. 33* from the New Brunswick coast to Anticosti island in order to show the changes in the sea further up towards the St. Lawrence river.

Salinity.—The salinity of the surface water increases from south to north from 28·07 at station 21 to 30·85 ⁰/₀₀ at station 24 near the Anticosti coast. At 20m. this condition is reversed in the middle part of the channel, from 31·01 ⁰/₀₀ at station 22 to 30·07 ⁰/₀₀ at Station 26. The coastal water thus in the middle of the channel extends down to about 20m., while in the north the intermediate water is lifted up to the surface. Bank-water in the main occupies the strata between 50 and 100m., though somewhat deeper in the middle. The 34 isohaline runs at a depth of about 215m., and at a depth of 380m., near the bottom, we have a salinity of 34·72 ⁰/₀₀.

Temperature.—The surface temperature is fairly uniform, from 7·0°-8·9° C., but in the southern part of the section it falls very rapidly down to 20m., while in the rest of the section the decrease is greater between 20 and 25m. The layer between 50 and 100m. has a temperature below zero, and the limits of the water of negative temperature follow very closely the isohalines limiting the bank-water. From 100m. downwards the temperature increases very slowly to about 4·5° C. at 350-380m.

After this the principal changes seem to be restricted to the upper strata with an outflowing surface current along the southern coast, causing a reaction current in the opposite direction at a depth of about 20m., while along the Anticosti coast the current seems to be inflowing.

NOVA SCOTIA AND NEWFOUNDLAND BANKS (TABLE 1*b*).

4. C.G.S. "Acadia" (May 29 to June 4).

Section V. Stations 1-16.

This section runs from the Nova Scotian coast off Halifax, over Sable Island bank towards the Gulf Stream. The section in its seaward half seems to run along the border region between the salter and warmer Atlantic water and the cold water from the north. This is shown by the undulating course of the isohalines as well as by the successive temperature maxima and minima all along the section.

Salinity.—From the surface down to a depth of about 50m. intermediate water is found at the first four stations; over the Sable Island bank it appears again very faintly near the surface. The bank-water we find near the coast in a stratum between 50 and 125m., and over Sable Island bank it is present from the surface down to 70m .to the west, and 60m. to the east of the bank. Out from the bank the 33 isohaline has an undulating course between 50 and 80m., rising suddenly between stations 12 and 13 and reaching the surface between 13 and 14. The slope water occupies the rest of the section, with the exception of station 16, where Atlantic water is found from the surface down to 400m.

The extensive masses of slope-water may be understood when we remember that this part of the section runs along the southern slopes of the Newfoundland banks.

Temperature.—The surface temperature is comparatively uniform between 4° and 5·5° C. as far out as station 13, thence the temperature increases to 12·2° C. at station 16. In the upper stratum between 25 and 30m. the vertical changes in the temperature are small. At station 1, near land, and at station 12, with its strong vertical minimum, the decrease is more rapid. The greatest mean fall in the temperature we find between 30 and 50m. In depths of 30 to 100m. we have horizontally the greatest changes of temperature, with maxima and minima in succession from station to station. The first minimum ÷ 0·25° C. we meet with at stations 3 and 4; on the western slopes of the Sable Island bank the temperature is not much lower than at the surface, but on the eastern side a minimum of 1·25° C. is found at station 11. The great minimum at station 12, where readings down to ÷ 1·7° C. were recorded in the most conspicuous in the section, and has a marked vertical extension.

Below we find a slightly marked maximum with temperature a little higher than 6° C. in depths of 175 – 225m., indicating that we are near to the Gulf Stream. From station 13 the temperature increases, but unevenly, indicating that cold water masses are still present to the north. At station 16 the temperature steadily decreases from a maximum at 75m. down to 400m. The course of the 6° isotherm in depth of 100 – 150, may help to explain the above mentioned maxima at stations 11 and 12.

Section VI. Stations 16-22.

This section runs from station 16 towards the Newfoundland coast, with the last station, station 22, over Green bank.

Salinity.—The salinity of the surface decreases from station 16 towards the bank, the decrease is most rapid between stations 17*a* and 18. Over the bank and south to station 18, bank-water of high salinity occupies the superficial layers down to 50 – 60m. The bottom of the bank is covered by slope-water with the 34 isohaline sloping down from the surface at station 17a to a depth of about 140m. on the slopes of the bank. The Atlantic water occupies most of the outer part of the section, and the 35 isohaline has in the upper 70m. a sloping course touching the surface near station 16.

Temperature.—We have also a decrease in the surface temperature towards the bank, and this decrease is most conspicuous between stations 17*a* and 18, with a sudden fall of 4° C. A minimum with temperature below zero lies over Green bank from about 50m. down to 125m., and a maximum caused by the invasion of Atlantic water is found, farther out, between 50 and 100m. These two conditions seem to be the cause of the successive maxima and minima in a vertical direction in the middle part of the section (station 18), the temperature ranging from about 2° to 5° C.

Section VII. Stations 22-27.12.

This section runs from station 22 on Green bank over the southeastern slopes of St. Pierre bank out to section V, station 12.

Salinity.—From the surface down to a depth of 60-100m. over the banks and 45-85m. farther out, bank-water of high salinity is found. The rest of the section is occupied by slope-water, and the 34 isohaline runs at a depth of aboat 125-150m.

Temperature.—The surface temperature is comparatively uniform throughout the section from about 3.5° to 4.5° C., but the decrease downwards varies greatly at the different stations, while temperature minima are found at different depths. Over the banks a layer of water of negative temperature is found from 50m. down to the bottom and at station 12 we have the marked minimum noted in section V. These two minima seem to be connected with each other, but their connection is only indicated in the section by the low temperature (1.9° C.), at station 27 at a depth of 75m. This connection might be found between this section and section VI, though nearer to the first. Below 150m. we find at station 12 a tongue of water having a temperature of 5.0° to 6.5° C., pressing against the slope, and at station 26 extending above 125m.

The conditions at stations 12 and 27 seem to indicate that rapid changes in salinity as well as temperature take place.

At station 27 two observations of salinity and temperature were made with about half an hour's interval (see table 1b). The first gave a salinity of 33.88 ‰ and a temperature of 4.7° C., the second 34.42 ‰ and 7° C. The density varied little, viz., 1.02684 and 1.02695 and it thus seems that in the short interval, referred to, more southerly, salter and warmer water has displaced the northern, colder water of about the same specific gravity.

We may here review the conditions obtained in this area at the time of the cruise: From the banks in the north we have a south-flowing cold current with its middle part somewhat east of section VII. On meeting the strong Atlantic warm current the colder water is stowed up, and a back-water is formed as indicated at station 12. The colder water is forced upwards and downwards through the contact, as shown by the vertical extension of the minimum, and is at last deflected in a westerly direction towards the slopes of the Nova Scotian banks, where we find indications of colder water in the minima at stations VIII, 28-29 and V 9-10.

Section VIII. Stations 27-33.

This section runs from station 27 over Banquereau, Misaine bank, and C. Breton bank to station 33 off Cape Breton; it crosses the channels between the banks and lies parallel with the Laurentian channel.

Salinity.—From the surface down to a depth of 50m. is a layer of intermediate water of high salinity. From 50m. down to 125-150m., bank water covers the bank, and rises to the surface at station 27. The outer slopes of Banquereau, from a depth of about 150m., are covered by slope-water, which must be presumed to occupy the deepest part of the channels between the banks.

Temperature.—The surface temperature is very uniform from 4.0° to 4.75° C. The banks up to 25-40m. are covered by water of a temperature lower than 2° C., with a minimum of 0.0° C. at Banquereau and about ÷ 0.3° C. at Misaine bank. Only the shallowest parts of the banks are thus covered by water of negative temperature. Towards the deeper water the temperature increases very slowly in the channels between the banks, and comparatively rapidly on the outside of Banquereau, where a temperature above 5° C. is reached at a depth of 150m.

Section IX. Stations 33-36.

The last section on this cruise runs from station 33, off Cape Breton, to station 36, near the coast of Newfoundland, crossing the Laurentian channel at the outer part of Cabot strait.

Salinity.—From the surface north of station 34, down to a depth of 60m. near the southern slopes, is a layer of intermediate water stowed up against the south shore. The bank water in the northern part of the section occupies the surface and reaches down to 100-160m. The 33 isohaline has an undulating course, rising as a wave up to 100m. at station 35, and sinking down towards the slopes on both sides of the channel. The rest of the section down to the bottom is occupied by slope water with a salinity of 34.66 ‰ near the bottom (400m.). The 34 isohaline runs at a depth of 225-250m., displaying a wave similar to that of the 33 isohaline.

Temperature.—As in the foregoing sections the surface temperature is very uniform 4-4.5° C. At a depth of 30-125m. on the southern slopes, and of 60-115m. on the northern slopes, we find water layers with temperature below zero. These two minima are separated by somewhat higher temperature in the middle of the channel at station 35, and their influence is shown by the course of most of the isotherms in the section, the upper 2° and 4° isotherms running somewhat deeper at station 35, and the lower 2° and 4° isotherms forming waves upwards at the same station. Near the bottom (400m.) we find a temperature of about 4° C., almost identical with the surface temperature.

This section confirms the impression mentioned under section III, that the gulf-water forms an outflowing current along the north shore of Cape Breton island. This current seems to be more superficial and its water fresher, salinity from 30·5 ‰ to about 32 ‰, than the water of the inflowing current in the northern part of the channel, which seems to be strongest in depth of 50-100m. The outflowing water is thus intermediate water and inner-bank water, while the inflowing water is outer-bank water having a salinity characteristic of the Newfoundland banks. The positions of the two temperature minima in the section seem to confirm this idea about the origin of the superficial layers in the Cabot strait.

REVIEW OF THE SPRING CRUISES.

After this description of the sections made during the cruises in the spring it may be of interest to review the hydrographical conditions in the area investigated. In doing so I may conveniently refer to the section maps constructed by Mr. Sandström and given in his report (The Hydrodynamics of the Canadian Atlantic Waters, plates II and IV).

Salinity (Sandström, Plate II).

Coastal Water (below 30 ‰).—At the surface, water of this salinity is found in the inner, and especially in the southern part of the gulf, round Prince Edward Island, and in the north out towards the middle of the Esquiman channel. In the south we find the coastal water down to a depth of about 25m. Water of a salinity below 30‰ must also presumably occur almost everywhere nearer to the coast, and especially in bays with outlets of fresh water. Thus it is certain that the surface water of the Nova Scotian banks off the Gut of Canso to some extent consists of coastal water, though the spring cruises did not include this area.

Intermediate Water (30-32 ‰) is found at the surface in the middle part of the gulf of St. Lawrence, over the inner and northern parts of the Nova Scotian banks, in the latter area out towards the slopes, and over the southern and larger part of the Laurentian channel. The 31-water forms the mass of this surface water and the 30-water is mostly present only as a rim round the salter water. Only in the Nova Scotian bank area, off the Gut of Canso, we find the 30-water at the surface projecting as a broad tongue out towards the Banquereau. At a depth of 25m. the intermediate water occupies the gulf, with the exception of the area close up to Prince Edward Island, and the Nova Scotian bank area, south to Sable island, and out to the slopes in the north, near to the Laurentian channel. At a depth of 50m. intermediate water is found in the larger part of the gulf, excepting the northern middle part, and on the inner part of the Nova Scotian banks. At a depth of 100m. only slight indications of intermediate water are found close to the southern slopes of the Laurentian channel off Gaspé.

Bank water (32-33 ‰). At the surface, water of this salinity seems to occupy the large Newfoundland banks to a little out from the slopes towards the Atlantic depths and the Laurentian channel. Off the latter it occupies a wider area of the surface out from the slopes, but farther south and west it is again restricted to a rim over the slopes. At a depth of 25m. the intermediate water occupies about the same area as at the surface, but at 50m. we find it in the northern middle part of the gulf with a very narrow tongue projecting up the Laurentian channel close to Anticosti island. The Newfoundland bank area at the latter depth, too, is covered by bank-water, but off the Laurentian channel the Atlantic influence is felt as a broad tongue of salter water projecting north and west towards the channel. At a depth of 100m. the bank-water occupies the Nova Scotian and Newfoundland banks, with the exception of part of the areas near the southern slopes, where salter water is found. Salter water is also found as a tongue projecting north and west along the northern slopes of the Laurentian channel through Cabot strait, with a bend to the south of the tip of the tongue towards the Magdalen Island east bank. The rest of the gulf at this depth is occupied by bank-water.

Slope water (33-35 ‰). At the surface down to a depth of 25m. we find the slope water only as a rim off the slopes towards the Atlantic ocean, somewhat broader in the west, narrower in the east off the Great bank, where the Atlantic water sets on. At 50m. we find the slope water as the above-named broad tongue towards the Laurentian channel. At 75m. the rim of slope water lies close up to the slopes and the above-named tongue is broader. At 100m. the tongue projets up the Laurentian channel, through Cabot strait, and touches the Magdalen Island east bank, as mentioned above.

Atlantic water (above 35 ‰).—Only at stations V, VI, 16 do we find water of this high salinity at the surface and down to 400m. At station VI, 17 we find it from 50m. down to 400m., and at a depth of 100m. it reaches as far towards the Great bank as station VI, 17a, but only as a wave confined to this depth.

6. *Temperature (Sandström Plate IV)*.

The surface temperature in the gulf of St. Lawrence during the first part of June mostly falls between 5° and 10° C. The highest surface temperature, 11·5° C., is found at station 3, and the lowest, 4·2° C., at station 21. It is of interest to note that the higher surface temperatures are found in the southern part of the gulf near the coasts, and the lower over the channels leading out to the Atlantic ocean. The surface temperature thus found over the Laurentian and Esquiman channels seems to be the common surface temperature over a great part of the Nova Scotian and Newfoundland bank area, where the surface temperature seems to be fairly uniform, between 3·5° and 5·5° C. A higher surface temperature is found further out at stations V 14-16 and at VI 17-17a, where temperature from 8·1° to 12·2°C. are met with. This is due to the influence of the Atlantic water. A lower temperature is found at the northern stations off the Newfoundland bank, down to 2·2°C. at station VI 21, where the influence of the Arctic current is strongest. In the gulf the temperature decreases from the surface down to the intermediate minimum layer with a temperature below zero. This decrease is more rapid nearer the coasts, and especially so in the southern part of the gulf, near Magdalen bay, where the highest surface temperature was found. The intermediate minimum layer of negative temperature is most prominent in the middle part of the gulf, round Anticosti east bank, and especially over the Anticostian channel, where it forms a layer 120 to 150m. in depth. Over the Newfoundland banks we meet with a similar intermediate layer of cold water with temperature down to ÷ 1·4° C, lying somewhat deeper. Through the northern half of Cabot strait this stratum seems to be connected with other areas of intermediate cold water. It seems probable that this cold intermediate layer in the gulf has its principal source in inflowing currents from the cold water-layers south and east of Newfoundland. This inflowing current is indicated in section IX from Cabot strait, but similar conditions might have been found to obtain in Belle Isle strait, had this area been covered by the investigation. These currents are presumably reaction currents, acting against the outflowing currents in the upper strata, as found in the southern part of the Cabot strait. The melting of the winter ice in the gulf may be another source, but this is not nearly sufficient to account for the mighty proportions of these intermediate, cold water-layers in the gulf. The outflowing cold water from the gulf, indicated by the southern minimum found in section IX, Cabot strait, forms another area of intermediate cold water-layers over the inner part of the Nova Scotian banks (section VIII). The extension of this area is merely indicated by the investigations, but we find that part of it extends as far south as station V 3.

As stated on p. 360, the cold-water layers of the Newfoundland banks have another outlet in a southwesterly direction towards station V 12, where they are deflected in a westerly direction towards the Nova Scotian banks by contact with the Atlantic water. This concentrated, strong current might be connected with the inner, intermediate minimum area of the banks through several of the deep channels between the banks; for instance, the Gully. At least we find indications of it along the slopes far south and west (see p. 369).

Towards the deep water the temperature again increases, but slowly, out from the Atlantic slopes through a water-layer with higher temperature (over 5° C.) in depths from 100 to 250m. The latter is connected with the warmer layers farther out. At a depth of 400m. the temperature is about 4° C. near the slopes, and it increases towards the Atlantic ocean to 9·30° C. (station V, VI. 16) at the same depth.

Summer Cruises.

GULF OF ST. LAWRENCE (TABLE Ic).

1. C. G. S. "Princess" (August 3 to August 12).

Stations 27 and 28.

The two first stations on this cruise were taken in the shallow water of Northumberland strait, very near to the corresponding stations 3 and 4 of the spring cruise.

Salinity.—At both stations we find coastal water from the surface down to the bottom. While, however, at the western station (station 28) the salinity is fairly constant down to the bottom (20m) we find at the eastern station a difference of about 1 ‰ between the surface and bottom salinity.

Temperature.—The same difference is shown by the temperature, which at station 28 is fairly uniform, 18·5°-17·0° C, from the surface down to 20m., while at station 27 we find 16·4°-16·5° C from the surface down to 10m., but 8·4° at a depth of 20m. This difference indicates a surplus of fresh water at the western station and the presence of a strong current round the western point of Prince Edward Island, which mixes the water-masses and brings relative fresh water down to the bottom layers.

Section X, Stations 29-40.

This section corresponds to section I of the spring cruises. The resemblance between the two sections is obvious, but in the upper 50m. we find marked differences, mostly due to the presence of large quantities of fresher water during the summer cruise.

Salinity.—Coastal water is during the summer found at the surface out to the slopes towards the Laurentian channel and towards deep water it is in the southern part found down to 50m., but this layer of fresher water is rapidly flattened out superficially towards the slopes. From station 34 the salinity of the surface water keeps about 30 ‰ with small maxima and minima, to 29·49 ‰ near the north shore (station 40). In the latter northern half of the section the intermediate water occupies the superficial layer down to about 50m. In the south it is forced down to about 70m., by the coastal water and over the Anticostian channel, bank water is forced up to 35-40m. The bank water thus occupies the deeper parts of the southern banks the Anticosti east bank and the slopes towards the channels down to 100-125m. The rest of the channels towards the deeper water is occupied by slope water, with from 34·65 to 34·72 ‰ at a depth of 350m. in the Laurentian channel and 34·29 ‰ in 275m. in the Anticostian channel.

Temperature.—The temperature corresponds with the salinity. The temperature at the surface is much higher than in the spring, and falls from 17·0° C. at the southern stations through several minima and maxima to 11·15° C. at station 40. The decrease towards deep water is very variable relatively more rapid in the northern half than over the southern banks, where we find a temperature of 5·65° at 100m. at station 30. The upper 0° isotherm nearly falls in with the isohaline for 32 ‰, and thus lies about 30m. deeper in the south than in the north. The lower 0° isotherm has a slanting course over the channels, from about 105m. towards the southern slopes to about 170m. towards the northern slopes in the Laurentian channel, and from 130 to 185m. over the Anticostian channel. The waterlayer of negative temperature is thus in the summer also more prominent near the Anticosti bank and the northern channel than farther south. The minimum is, however, less marked in summer than in spring. The area having a temperature below ÷ 1° C. is comparatively small and the lowest temperature is ÷ 1·15° C. as compared with ÷ 1·35° C. found during the spring. In the depth of the channels we find temperature 4·45° C. at 350m. over the Laurentian channel, and 3·95° at 275m. over the Anticostian channel.

Section XI, Stations 40-44.

This section corresponds to section II of the spring cruise, and thus runs over C. Wittle bank and crosses the Esquiman channel.

Salinity.—Coastal water is only found at a thin layer at the surface at Natashkwan bank towards the shore, thus having a much smaller extension than in the spring. The intermediate water occupies most of the section from the surface down to 50m. Over Natashkwan bank and towards the shore, however, it only reaches down to 30-40m., and near to the Newfoundland coast down to 40m. The bank water occupies the rest of the water-layers over the banks and channels from 50m. down to 125-140m. The bottom of the channels is covered by slope water with a salinity of 34·27 ‰ at 250m. over the Esquiman channel.

Temperature.—The surface temperature is comparatively uniform from 11·65° C. at station 40 to 13·45° C. at station 44. The temperature decreases more rapidly over the Natashkwan bank, 8° C. being found at a depth of 8m., while farther out it is found in depth of 18-25m. The layer of negative temperature is more prominent in this part of the gulf in the summer than in the spring, in contrast to the conditions found in the western section. It reaches from 35-60m. down to 150-170m. The temperature near the bottom (250m.) over the Esquiman channel is 3·75° C.

Section XII, Stations 50-45.

This section corresponds to section III of the spring cruises, though farther east, cutting through the northwestern point of C. Breton island.

Salinity.—Coastal water is found from the surface down to 20-30m. in the southern part of the section, deeper in the south. In the southern half of the Cabot strait, coastal water is found as a layer at the surface 5m. thick. Intermediate water occupies the bottom layers of the southern banks with the exception of station 49, where bank water is found at a depth of 70m. Over the Laurentian channel, intermediate water is found down to 50-60m. in the larger part of the section, but only down to about 30m. near the Newfoundland coast. Bank water is found at the deeper part of the southern banks and over the Laurentian channel from about 100m. at the southern slopes to 150-170m. near the Newfoundland coast. The rest of the channel towards deep water is filled with slope water with a salinity of 34·70 ‰ in 400m.

Temperature.—The surface temperature is highest in the southern part of the section, with temperature above 16° C. From station 48, however, we find a successive decrease of the temperature, to 12·45° C. near Newfoundland. The decrease of temperature towards deep water is very sudden from 25m. at the three southernmost stations, while towards the north we find a more uniform decrease between 25 and 100m. The layer with negative temperature is at the southern bank found at a depth of about 35-65m. Near to the southern slopes we find cold water in the Cabot strait, too, but no layer with negative temperature. At stations 47 and 46 we find traces of such a layer with temperature about 0° C. at a depth of 100-125m. This position of the cold water-layer explains the more uniform decrease of the temperature, towards deep water at the northern stations. From this cold water-layer we find an increase of temperature towards deep water, but in such a way as to indicate that colder water-masses are stowed up towards the northern slopes than towards the south. At a depth of 400m. we find temperature of about 4° C. The conditions as regards salinity as well as temperature seem to indicate that the two opposing currents: the outflowing one along the southern shore and the inflowing one along the northern shore, found during the spring, still prevail.

NOVA SCOTIA AND NEWFOUNDLAND BANKS (TABLE Id).

2. C.G.S. "ACADIA" (JULY 21 TO 29).

Section XIII, Stations 37-44.

The section runs from Shelburne, Nova Scotia, in a southeasterly direction to station 44, off the slopes towards deep water, and crosses La Have bank at about the middle.

Salinity.—Intermediate water of high salinity (31-water) is found near the coast from the surface down to about 80m. The 32 ‰ isohaline slopes steeply and reaches the surface a little out from station 40. Over the bank the water-layers thus have a sloping direction, and the salinity increases very rapidly between stations 40 and 41. The layer of bank water is of comparatively small extent. Over the bank it extends from 50 to 100m., and covers the bottom at the edge of the bank. From there the layer ascends as a narrow rim towards the surface. The slope water covers the slopes of the bank between 100 and 160m., and thence ascends to the surface where it forms a layer down to 20-25m., making a conspicuous bend down to 50m. at station 43. The rest of the section out from the slopes and below 25-50m., is occupied by Atlantic water, with a salinity in places as high as 35·99 ‰ (station 33, 75m.). Layers of very high salinity (above 35·50 ‰ descend as a tongue down to about 170m. at station 43.

Temperature.—Near the coast at stations 37 and 38 we find a minimum with temperatures below 2° C. in depths of 60-80m. This minimum shows its influence vertically as well as horizontally, and the isotherms run almost concentrically to the minimum in the bank part of the section. The surface temperature increases from a minimum of 9° C. at station 37 to 19·7° C. at station 44, with a very rapid increase between stations 40 and 41. Between these two stations all the isotherms in question trend vertically, to become horizontal again: the 15° isotherm at a depth of 45m., the 12° isotherm at about 165m. and the 10° isotherm at a depth of 250m. All these isotherms display a conspicuous bend downwards at station 43, where layers of salt and warm Atlantic water seem to have sunk down (see above). The influence of the Gulf Stream is very conspicuous in this section, but the bank proves a strong barrier against the warmer water-masses, limiting their influence to the slopes facing the ocean.

Section XIV, Stations 49-44.

The section runs from station 49, near the coast of Nova Scotia, northeast of Halifax, to station 44 of the foregoing section, and crosses the Sambro bank.

Salinity.—From the coast and almost out to station 46, just over the seaward slopes of the bank, intermediate water is found from the surface down to 25-30m. The surface about station 46 is occupied by bank water, which from there descends below the intermediate water as a comparatively thin layer 20m. in thickness, increasing in bulk towards the coast, where it covers the slopes in depths of 30-150m. The rest of the surface is covered by slope water down to about 20m. at the outermost station (station 44), and to about 250m. on the slopes of the bank. The bank is covered by a layer of slope water about 80m. in thickness. From about 20m. downwards we find Atlantic water at station 44. The Atlantic water is found as far inwards as the slopes of the bank in depth of 250-350m. As in the foregoing section the influence of the Gulf Stream is very marked. The edge of the bank lies deeper, and the slope water has flowed over it, forcing the layer of bank water to a more horizontal position than shown in that section, though the shape of the layer is similar, a horn of plenty with the opening downwards and coastwards.

Temperature.—Near the coast we find the same minimum (below 2°C.) as in section XIII, though more marked, from 65-135m. This minimum shows its influence horizontally and vertically, especially downwards. The surface temperature increases from the coast seawards, with a very marked jump from 13·35° to 17·0°C. between stations 47 and 46, which corresponds to the changes in the salinity near the same place. In the outer part of the section the 15° isotherm has a markedly sloping course, cutting the surface between station 47 and 46 and running at a depth of about 90m. at station 44. The bulk of the section, near the surface and round the bank, is occupied by water having a temperature between 8°-15° C., with somewhat colder water at a depth of 300-360m. out from the slopes.

Section XV, Stations 49-56.

The section runs from station 49 of the foregoing section to station 56 off the slopes towards the ocean, and crosses Sable Island bank at its southwestern part.

Salinity.—The surface layers lie still more horizontally than in section XIV. Intermediate water is found near the coast from the surface down to about 45m., and the 32 ‰ isohaline cuts the surface near station 52, and almost follows this, displaying small minima in the salinity as far seawards as station 56.

Bank water is more pronounced than in any of the foregoing sections of this cruise, forming a continuous layer all over the section in a horizontal direction. Near the slopes from the coast the layer is about 80 to 100m. in depth, but is thinned out over the inner channel and over the deeper water. Slope water covers the bank and the slopes on each side with 34-water from 125m. downwards on the slopes facing the ocean. Atlantic water is found from 45m. down to 400m. at station 56, and at depths of 150-250m. it forces its way as near to the slopes as midway between stations 54 and 55.

Temperature.—In this section we find two minima, with temperatures below 2° C., one placed as in section XIV close up to the coast, the other over the seaward edge of the bank. The position of these two minima determines the character of the temperature conditions in the water-masses occupying the bank and the channel on the inside. The water from the surface down to 20-25m. has a temperature above 10°C. The surface temperature increases from the coast seawards, with a sudden jump between stations 54 and 55 from 13·9° to 16·35° C. The 10° isotherm trends vertically from a depth of 20-25m. at station 56, where we find a temperature above 10°C. between 20 and 275m., proceeding towards the slopes of the bank at a depth of 100 to 150m. The slopes below 125m. are covered by water having a temperature between 5 and 10°C.

Section XVI, Stations 65-56.

The section runs from station 65 off Canso, to station 56 of the foregoing section, and crosses the Middle bank and Sable Island bank somewhat west of the island.

Salinity.—Off Canso we find traces of coastal water near the surface. Intermediate water goes down to 75-50m. between the coast and Middle bank, but is restricted to the upper 25m. over Sable Island bank. The banks are covered by bank water down to 60-80m. in the outer part, but in the inner channel the bank water is found to at least 150m. As far out as over the edge of the bank we find a layer of bank water from the surface down to about 40m., with a minimum of intermediate water at the surface at station 56. The deeper parts of the channels and the slopes towards the ocean are covered by slope water. Atlantic water is only found at station 56, from 45m. down to 400m.

Temperature.—The minimum with temperatures below 2° C. is restricted to the inner channel, while the banks are covered by water having a temperature between 2 and 5° C. The 10° isotherm runs at a depth of 8 to 25m. and in the inner half of the section the temperature is between 11·5° and 13·5° C., with a rapid increase between stations 59 and 57 from 11·55° to 17·5° C. From station 56 the 10° isotherm trends vertically, and at this station we find temperatures above 10° between 25 and 290m. The seaward slopes of Sable Island bank are covered by water having a temperature between 5° and 8° C., with a minimum of 3·5° C. at a depth of 100m.

The influence of the Gulf Stream is less pronounced in the two last sections than in the others, and the outer edge of Sable Island bank is influenced by temperature minima displaying the presence of water of northern origin.

Section XVII, Stations 65-75.

The section runs from station 65 off Canso in an easterly direction to station 75 in deep water, and crosses the Canso bank and Banquereau.

Salinity.—The traces of coastal water at the surface at station 56 are mentioned above. Intermediate water is found at the surface as far seawards as station 71. Near the coast it goes down to 75m., and the 32 ‰ isohaline runs in a slanting direction, cutting the surface at station 75. Bank water occupies the bank and the channels, and from the outer edge of the Banquereau there is a layer of water about 30m. thick, thinning out towards the surface until it is restricted to the upper 10m. at station 75. Slope water occupies the seaward slopes of the Banquereau, and Atlantic water is found at stations 72 to 75 in depths of 130-220m. to 55-325m. at the last-mentioned station.

Temperature.—There are two minima with temperatures below 2° C., one occupying the banks and the channels and the other situated at a depth of 30-80m. at stations 72 and 73. The position of the latter minimum is almost identical with that of the conspicuous minimum at station V 12 of the spring cruise. The conditions seem to be similar to those found in the spring. The course of the current of cold water seems to be the same, and the temperature over the banks to the west shows that the current of cold water is later on deflected to the west, as was found in the spring. The surface temperature has a minimum over the edge of Banquereau, and from there it increases very slowly towards the coast, and more rapidly seawards. The 8° isotherm runs horizontally, though somewhat undulating, at a depth of about 25m., from the coast to station 73, where it trends vertically, and at station 75 runs at a depth of 325m.

Section XVIII, Stations 75-79.

The section runs in a northerly direction from station 75 of the foregoing section to station 79, towards the slopes of the Newfoundland banks.

Salinity.—Off the mouth of the Laurentian channel we find intermediate water at station 76 from the surface down to a depth of 35m. It covers the surface to a little north of station 77. Bank water is found at the surface in the northern and southern parts of the section, at station 76 it goes down to 75m. The layer of bank water is very limited in extent, only 10 to 30m. This seems to be due to the influence of the superficial intermediate water from within, and the slope water from without, which latter forces its way up the Laurentian channel at a considerable depth. The deeper parts of the section are almost exclusively occupied by slope water, and the Atlantic water is limited to the southernmost station (station 75) at a depth of 60 to 325m.

Temperature.—The surface temperature decreases from the south towards the banks, from 16° C. to about 13° C. At station 76 we find a minimum with temperatures below 2° C. This minimum is most probably the same as that found in section XVII, stations 72 and 73. The course of the 8° isotherm is similar to that in section XVII, running horizontally at a depth of 30-40m. in the northern part of the section, trending vertically at station 76. The minimum lies in the deeper part of the bank water, and the slope water has mostly a temperature between 4° and 6° C.

Section XIX, Stations 79-83.

The section runs from station 79 of the foregoing section in a northwesterly direction to station 83, crossing St. Pierre bank.

Salinity.—Only traces of intermediate water are found near the surface at stations 80 and 83, the rest of the surface being occupied by bank water, which covers the bank down to about 75m. at the seaward slopes, and occupies the channel down to 150m. The deeper parts of the channel and the rest of the sections below 50-75m. are occupied by slope water.

Temperature.—The surface temperature lies between 11° and 13° C., and the 8° isotherm runs horizontally at a depth of about 25m. The slopes of the bank on both sides are covered by water with a temperature below 0° C., at places as low as ÷ 1·45° C. and the temperature on the bank lies between 0° and 2·5° C.

Section XX, Stations 89-83.

The section runs from station 89 off Canso to station 83 of the foregoing section, and crosses Misaine bank, the Laurentian channel and St. Pierre bank.

Salinity.—The surface down to 10 to 30m. is mostly occupied by intermediate water, for only over St. Pierre bank is bank water found at the surface. Over the southern bank intermediate water goes down to about 60m. Bank water covers the shallowest parts of the banks on each side, and fills the channel north of St. Pierre bank almost to the bottom. Over the Laurentian channel the bank water keeps to a depth of 10 to 60m., and the rest of the channel is occupied by slope water with a salinity as low as 34·78 ‰ at a depth of 400m.

Temperature.—The surface temperature is comparatively uniform with a maximum of 14·65° over the Laurentian channel. The 5° isotherm runs at a depth of 40m. over St. Pierre bank, and rises to about 25m. over Misaine bank, with a peculiar bend down to 60m. near the outer edge of the former bank. At a depth of 75m. we find a minimum, with temperatures below 0°, at stations 87 and 86, which in some way seems to be in connection with the water-masses, having a temperature below zero, which occupy the channel between St. Pierre and Newfoundland. At least the layers between 50 and 125m. have a comparatively low temperature, below 3° C. The water-masses occupying the deeper parts of the Laurentian channel have a very uniform temperature between 4 and 5° C. with a slightly marked maximum above 5° C. at a depth of 150 to 225m. close up to the northern slopes.

REVIEW OF THE SUMMER CRUISES AND COMPARISON WITH THE RESULTS OF THE OBSERVATIONS IN THE SPRING.

As with the spring cruises, it may be of interest to review the hydrographical conditions found in the summer, and then compare the results from both seasons. As before, I refer the reader to the section maps in Mr. Sandström's publication (Sandström, plates III and V).

a. SALINITY (SANDSTRÖM, PLATE III.)

Coastal water (below 30 ‰).—As in the spring, water of this salinity is found especially in the southern part of the gulf, round Prince Edward Island. The most conspicuous difference is that coastal water in the summer is found to a considerable depth (45m.) northwest of the island, while in the other parts of the gulf, where coastal water was found in the spring, it seems to be more thinned out and limited to the surface. Thus in the north along section XI, we only find it near the coast, while in the spring we found it occupying the surface as far out as C. Wittle bank. On the other hand, we find it in areas, where it could not be traced in the spring, as in the southern part of Cabot strait, stations XII 46 and 47, and off Canso, thus indicating that C. Breton island is surrounded by a broad rim of coastal water. Traces of these conditions might have been found in the spring as suggested by me as regards the area outside the Gut of Canso, but the investigations did not cover this area. The observations are, however, sufficient to show that the outflow of relatively fresh gulf water from the superficial layers is more pronounced in the summer than in the spring. This circumstance might explain the thinning out of the superficial coastal layer over the greater part of the gulf, though the coastal water is found far more extensively in the southwestern part during the summer.

Intermediate water (30-32 °/₀₀).—At the surface the intermediate water is found in the northeastern part of the gulf, the northern half of Cabot strait, as a broad rim south of Newfoundland, and occupying the Nova Scotian bank area with the Laurentian channel. In two places the superficial layers of intermediate water force their way out over the Atlantic depth, viz., off the Laurentian channel and east of Shelburne, N.S. At a depth of 25m., intermediate water occupies the gulf with the exception of the larger southern bank area, in the Atlantic it is found over the Nova Scotian bank area, with the exception of the larger part of the Sable Island bank, and further it is found as a broad rim south of Newfoundland, but not over the outer part of the Laurentian channel. The two offshoots of intermediate water in the direction of the Atlantic depths, noted at the surface, are marked at this depth as well. At a depth of 50m., intermediate water occupies the southern and western parts of the gulf, the southern and larger part of Cabot strait, and a rim east of Nova Scotia, with broader portions in the north and south, marking off the two offshoots of intermediate water in the more superficial layers, mentioned above. At a depth of 75m. intermediate water is only found in the gulf over the deeper parts of the southern banks between Gaspé and Magdalen islands. When we compare the extension of the intermediate water during the summer with that found in the spring, it is noteworthy that water of this low salinity is found farther out at the surface during the summer, thus showing the influence of the outflow of fresher water from the estuaries near the coast. The northern offshoot very sharply marks off the water-masses from the gulf of St. Lawrence, and the southern one is most probably a result of the outflowing fresher water from the Bay of Fundy.

Bank water (32-33 °/₀₀).—At the surface, water of this salinity is only found on the shallower parts of the Newfoundland banks, and on the slopes of Sable Island bank and La Have bank. Between these three areas it is forced seawards by the abovementioned offshoots of intermediate water. At a depth of 25m. it occupies the area covering the Newfoundland banks and their slopes, the outer part of the Laurentian channel, the slopes of the Nova Scotian banks and the larger part of Sable Island bank. At 50m., bank water occupies the northeastern part of the gulf, the northern part of Cabot strait, the Newfoundland and Nova Scotian bank area, with the exception of Canso bank and part of Misaine bank. In the Laurentian channel, salter water at this depth forces its way along the northern slopes, while on the other hand the bank water sets on off the mouth of the channel and penetrates a distance out from the slopes. At 75-100m., bank water occupies the middle part of the gulf, the landward slopes of the Newfoundland banks, the slopes and the channels of the inner Nova Scotian bank area, and the Laurentian channel out to a line off the western point of St. Pierre bank. At 200m. no trace of bank water is found.

Comparing the spring and summer conditions as regards the distribution of bank water we find that superficially it is forced seawards in the summer by the outflowing fresher water. This influence is felt down to at least 25m. Deeper down the salter water sets on and forces the bank water back, especially in the Laurentian channel, where at a depth of 75-100m., it is found only as far out as off the western point of St. Pierre bank. At a depth of 100m. we found in the spring an off-shoot of salter water along the northern slopes of the channel as far in as Cabot strait; this we do not find during the summer, for it has been forced away by the bank water, which farther out in the channel is carried towards the surface, and pushes its way through the southern part of the channel out over the Atlantic slopes down to a depth of 50m.

Slope water (33-35 ⁰/₀₀).—At the surface down to 25m. slope water is only found over the Atlantic depths, close up to the slopes off La Have bank and Great bank, farther out in the larger part of the area between them, though somewhat nearer the slopes south of Sable Island bank. At 50m. the seaward slopes of the Newfoundland and Nova Scotian banks are covered by slope water. Along the southern slopes of St. Pierre bank a tongue of slope water is found, while the southern part of the channel is occupied by fresher water. At 75 and 100m. the seaward slopes and the deeper parts of the Newfoundland banks, as well as the outer Nova Scotian banks, are occupied by slope water, and in the Laurentian channel it penetrates as far as off the the western point of St. Pierre bank. At 200m. slope water occupies the submarine channels, the Atlantic slopes and the deeper pits of the Nova Scotian bank area.

Comparing the spring and summer conditions as regards the slope water we find the difference most marked in the Laurentian channel, where in the summer it is stoved up by a wall of bank water at a line off the western point of St. Pierre bank, at a depth of 75-100m., while in the spring it is confined to the mouth of the channel, and only sends a long and narrow offshoot along the northern slopes of the channel as far inward as Cabot strait.

Atlantic water (above 35 ⁰/₀₀).—Water of this high salinity is not found at the surface in any of the sections, but on the slopes of La Have bank and Sambro bank we find it close up to the slopes at a depth of 150-175m. and downwards. Farther out at sea we find it as close to the surface as 25-50m. south of La Have, Sambro, and Sable Island banks, and off the Laurentian channel it seems to have penetrated farther in towards the channel at a depth of 100 to 200m. than in the spring.

b. Temperature (Sandström Plate V).

The surface temperature is naturally much higher in the summer than in the spring; this is mostly due to the influence of the fresher water from the coast, which as we have seen forces its way far out to sea, but also to the force of the Gulf Stream, which especially at some places sets on stronger than in the spring. This circumstance is shown most plainly when we draw in the 16° isotherm. In the gulf it runs from Gaspé to Cape Breton; south of this line the surface temperature is higher than 16° C. The highest surface temperature in the gulf is found in Northumberland strait (station 28), viz., 18.5° C., and the lowest close up to the north shore (station X 40), viz., 11.65° C. In the main the surface temperature decreases from south to north, and from the Newfoundland coast towards the north shore. In the Atlantic ocean the 16° isotherm runs along the slopes of the bank; only off the mouth of the Laurentian channel the isotherm bends seawards. Out from the slopes we have higher temperatures, the highest temperature being observed at station XIII 44 (19.7° C.). The lowest surface temperature observed during the summer cruise is found at station XIII 37, near the coast off Shelburne, viz., 9.7° C. The surface temperature in the Atlantic generally increases from the coast towards the ocean. The lower readings being found very often over the edge of the banks, especially in the northern part of the area.

Downwards the temperature decreases towards a layer of water of minimum temperature. In the inner part of the gulf of St. Lawrence, the 10° isotherm mostly runs at a depth of about 10m., but in the outer part at a depth of about 20m. The layers of water of negative temperature we mostly find from a depth of 50-80m. downwards. The lower 0° isotherm runs deeper in the northern part of the gulf, and the layers of water of negative temperature are thus more extended in the north especially over the Esquiman channel, where the lower 0° isotherm runs at a depth of about 160m.

Over this channel these cold-water layers are more extended during the summer than in the spring, a circumstance which seems to confirm the idea that there is a constant inflow of colder water through the deeper parts of Belle Isle strait. In Cabot strait we find traces of water layers of negative temperature, a slight minimum occurring in the middle of the strait at a depth of 95-125m., where the salinity is between 32·5 and 33 ‰ (outer bank water). In the Atlantic ocean, the 10° isotherm runs mostly horizontally at a depth of 15 to 30m. In the two southernmost sections it very suddenly trends vertically over the edge of the banks, farther north it trends vertically at a distance off the slopes, especially off the mouth of the Laurentian channel. It becomes horizontal again at a depth of 250-300m. The deeper parts of these warm water-masses (below 20m.) belong to the Gulf Stream, as shown by the salinity, while the upper strata seem to be of more continental origin. Off the Laurentian channel the influence of the water from the gulf of St. Lawrence at the surface seems to be unquestionable, at least as far out as station XVII 74, and the offshoot of relatively fresh water at the surface south of Sable Island bank indicates that similar conditions prevail in this area too. Water having a temperature between 0 and 5° C. occupies the deeper parts of the Laurentian channel and the channels between the Nova Scotian banks, as was the case in the spring. In the spring we found layers of water of negative temperature at least over the northern Nova Scotian banks; in the summer in the Atlantic part of the area investigated these layers are limited to the channels and slopes of the Newfoundland banks, with slight minima situated over deep water as found at stations XVIII 76 and XX 86 and 87.

The conditions reviewed above seem to indicate an increase in the influence of the Gulf Stream and of the currents of continental origin, while the influence of the Labrador current seems to have decreased from spring to summer. The water-masses of continental origin have enlarged their area of distribution in a more horizontal direction, occupying the superficial strata, while the Gulf Stream has forced its way close up to the slopes with water-masses of immense vertical extension. The Labrador (Arctic) current displays its influence in nearly the same areas as in the spring, but the higher temperatures and salinities show that its influence has diminished. The northern branch of the current turns round cape Ray and runs westward along the Newfoundland coast; the southern branch runs more to the south at right angles to the direction of the Laurentian channel. This latter branch is deflected towards the Nova Scotian banks through contact with water-masses of Atlantic origin. As shown above (p. 369) these conditions are found during the summer as well as in the spring. The water-masses especially characteristic of this current are mostly found at a depth of 80 to 250m. during the summer, and from about 30m. downwards in the spring. Though the influence of the Labrador current off the Newfoundland banks seems to have decreased in the summer, the contrary seems to be the case with the branch of the current entering the gulf of St. Lawrence through Belle Isle strait, as shown by the masses of water of negative temperature over the Esquiman channel. I cannot find any other explanation of this fact than an increased inflow of cold water from the north, and at the same time I take it as an indication that the principal source of the layers of excessively cold water in the gulf of St. Lawrence is to be found in the inflowing currents of Arctic water entering the gulf through Belle Isle strait and Cabot strait.

Before concluding this paper I must express my sincere thanks to Dr. Johan Hjort for his kindness in giving me the opportunity of working out the results of the expedition as regards the hydrographical observations, and also for his suggestions as to the best way of attacking the work, and for his valuable help in the details. My best thanks are also due to Mr. James Chumley, Glasgow, who has revised my manuscript in a masterly manner, and to Messrs. Einar Lea and Thv. Rasmussen, Bergen, for valuable help by preparing the figures.

IV. ADDENDUM.

SUPPLEMENTASY CRUISE IN C.G.S. "ACADIA" CONDUCTED BY COMMANDER F. ANDERSON IN THE AUTUMN OF 1915.

As stated on p. 356, a supplementary cruise in the autumn of 1915 had been planned in order to follow up some of the most important features in the hydrographical conditions of the waters investigated. This cruise took place in C.G.S. *Acadia* from November 14 to November 22, and the hydrographical material collected has been sent to Norway for further elaboration in connection with that from the spring and summer cruises. As, however, the latter material had been worked up, the sketches drawn, and the manuscript almost ready for printing, it was found most convenient to finish this part according to the original plans, and to work up the results of the autumn cruise as an addendum.

The cruise was laid from Halifax, N.S., out to station V 4 of the spring cruise, and from there along the coast of Nova Scotia and C. Breton island north to the Newfoundland coast and back again to C. Breton island, twice crossing Cabot strait. The most interesting part of the cruise is the two cross-sections of the Laurentian channel, the one almost identical with section IX of the spring cruise, the other more westerly.

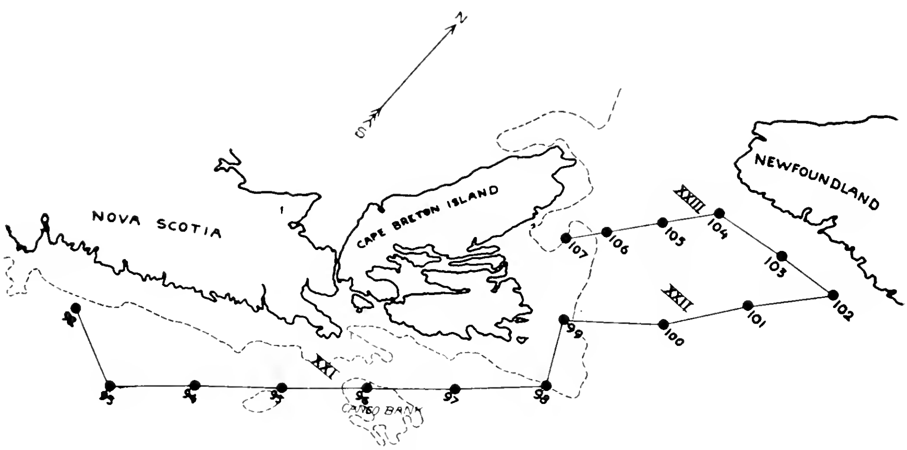

Fig. 8.—Map showing the course of the Autumn cruise.

Fig. 8 shows the course of the cruise and the most interesting features of the bottom configuration.

AUTUMN CRUISE (Table 1e).

Station 92.

The position of this station is the same as station V 3 of the spring cruise. As it cannot very well be included in any of the sections it is taken apart.

Salinity.—The salinity of the surface water is not as high as in the spring, 30·40 against 30·92 ‰. The 30-water reaches down to 40m., against 10m. in the spring. Down to 60m. the water is salter in the spring than in the autumn, but from there down to the bottom the salinity is almost identical in both seasons.

Temperature.—From the surface down to about 40m. we find that the temperature is very uniform, between 8·2° and 8·4° C. From this depth the temperature decreases evenly to 1·9° C. at 110m. During the spring we found a uniform temperature (a little above 4° C.) down to 20m, but from there a sudden fall to temperatures below zero between a depth of *40*–75m. and an increase farther downwards to 2·4° C. at 110m.

Section XXI, Stations 93-98. (Fig. 9).

The section runs from station 93, identical with station V 4 of the spring cruise to station 98 off Cape Breton, and crosses Canso bank.

Salinity.[1]—Intermediate water is found from the surface down to 50m. in the southern part of the section; north of Canso bank it goes down to about 75m. In the

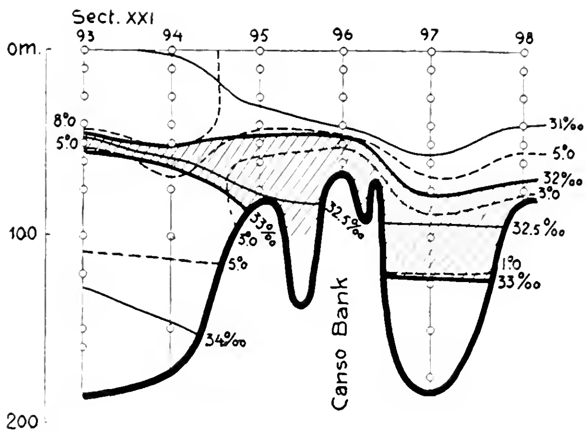

FIG. 9—Salinity and temperature along the coast from off Halifax to off Cape Breton.

south the 31-water predominates, in the north the 30-water. Off Halifax the bank water is only present as a thin layer in a depth of about 50-60m., over the banks it occupies the strata from 50m. down to the bottom and north of the banks from about 75m. to 125m. The deeper parts between the banks are filled with slope water, mostly 33-water, but south of the banks we find 34-water near the bottom (150-185m.). The lower salinity of the water in the northern part of the section is obviously due to the outflow through the Gut of Canso, from which a deep submarine channel leads towards station 97.

Temperature.—The temperatures confirm the facts found by the salinity, with the exception of those found from the surface down to 50m. at station 94 (*see* the footnote, below). The 31-water in the south has a temperature higher than 8° C. and the 30-water in the north mostly has a temperature between 5° and 8° C. From about 50m. in the south, and 75m. in the north, the temperature decreases rapidly, in the south towards a minimum with temperatures about 4° C. at 75-100m. with higher temperatures, up to 7·4° C. in a depth of 150m., while over the banks and over the northern channel it is continuously decreasing towards the bottom. Near the bottom of the banks we find temperatures of about 1·9° C., and near the bottom in the channel north of the same we find a temperature of 0·8° C.

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[1] N.B.—As regards the salinities from the upper 50m. at station 94 (table Ie), I find that some errors in the labelling of the water samples must have taken place. The salinities found in the table fall quite inversely to what might be expected, but comparing the salinities with the corresponding temperatures the latter display a very uniform character corresponding to the temperature at the same depths at the neighbouring stations 92, 93, and 95. The isohalines in section XXI are therefore drawn according to a revision of the salinities made by the author, while the observed (?) salinities might be found in the table.

Section XXII, Stations 99–102 (Fig. 10).

The course of the section and the position of the stations are almost identical with those of section IX of the spring cruise.

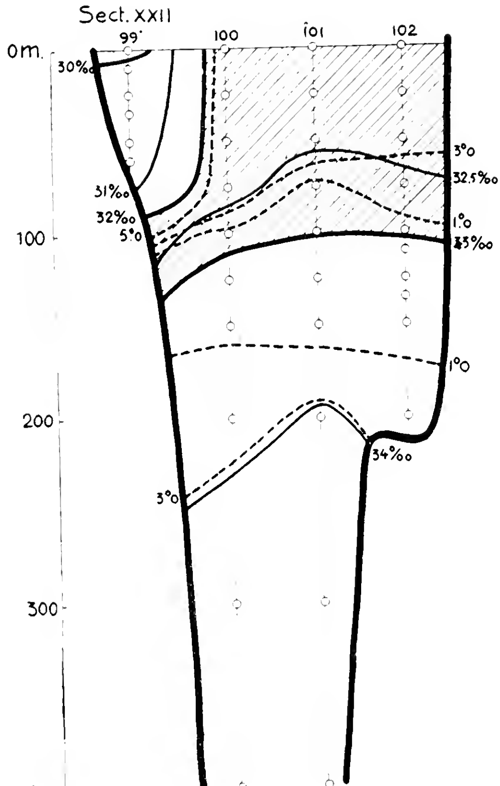


FIG. 10.—Salinity and temperature across Cabot strait, eastern section.

Salinity.—Coastal water is found near the surface at station 99, but the salinity of the surface water increases rapidly to 32·24 ‰ at station 100. Down to a depth of about 90m. we have, however, a wedge of intermediate water, mostly 30-water, displaying the outflow of the water-masses from the gulf. Bank water occupies the rest of the section down to 100-125m., consisting from the surface down to 60-75m., mostly of inner bank water, while higher salinities are not as commonly distributed. From 100-125m. down to 400m. we find slope water, with the 34 ‰ isohaline at a depth of 300-350m., forming a wave to a little above 300m. at station 101. The salinity in 400m. runs from 34·70 to 34·80 ‰.

Temperature.—The temperature at station 99 from the surface to the bottom (60m.) is very uniform, falling between 7·35° and 7·5° C., and the wedge of intermediate water near the coast seems to have a temperature higher than 5° C. The inner bank water from the surface down to 50-75m. in the northern part of the section mostly has a temperature between 4·5° and 5·0° C., while up to the Newfoundland coast we find temperatures a little below 4° C. in 25 and 50 metres depth. The temperature decreases very suddenly when descending into the outer bank water, where we find temperatures between 0·2 and 1·8° C. From 75-100m. to about 160m. we find temperatures between 0·0° and 1·0° C., but farther downwards the temperature increases to about 4° C. in 300 and 400m. The layers of water of temperatures below zero, found especially in the spring, are not found during the autumn, but the intermediate temperature minimum at a depth of 100 to 160m. indicates that identical water-layers are still found there, but their temperature is increased during the summer.

Section XXIII, Stations 107-102 (Fig. 11).

The section runs from station 107 off cape Smoke on C. Breton island to station 102 of the foregoing section, and crosses the Cabot strait like section XXII, but more westerly.

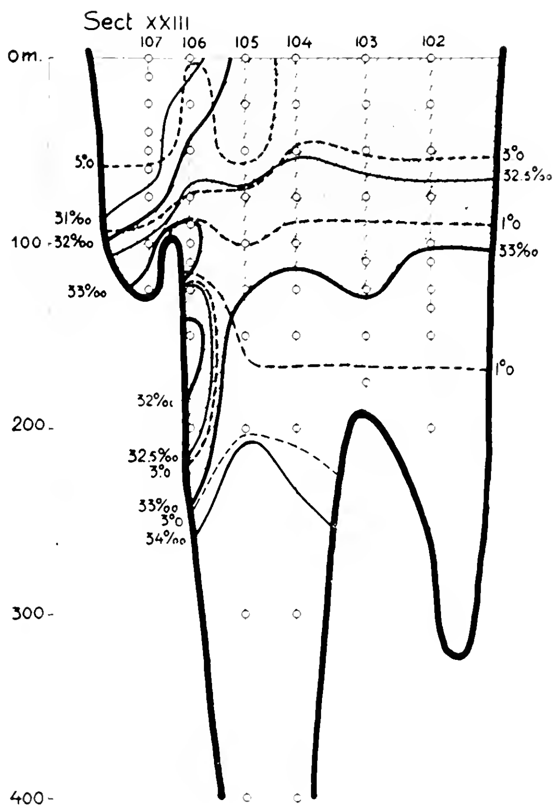


FIG. 11.—Salinity and temperature across Cabot strait, western section.

Salinity.—Coastal water is not found by the observations but intermediate water of low salinity (30-water) is found at station 107 from the surface down to at least 60m., thus indicating that coastal water is found at the surface nearer to the coast. This suggestion is confirmed by the observations at station 99 of the foregoing section. The intermediate water covers the surface seawards to about station 105, and vertically extends down to about 100m. near the coast. As in the foregoing section the 30-water is predominant and the 31-water only forms a rim close up to the 32 ‰ isohaline. This feature seems to indicate that we have to do with water of different origin, the fresher outflowing water near the southern coast and the salter water in the northern part of the section. From the surface down to 100-125m. this consists of bank water with the 32·5 $^0/_{00}$ isohaline running at a depth of 50-75m. The deeper part of the section down to 400m. is occupied by slope water with a salinity between 34·70 and 34·80 $^0/_{00}$ at 400m. The conditions so far confirm those found in section XXII, only at the slopes of the bank found between stations 107 and 106 they seem to be somewhat different. As will be seen in the table, the position of the water-masses along the slopes of this bank seems to be quite disturbed. The bottom of the bank and the slopes down to about 25m. from its edge are covered by 33-water, while deeper down, at about 140 to 180m. we find 31-water. The temperatures, as seen below, correspond with this inverse position of the water-masses. I can only explain the fact as follows: A wedge of salter water is, by the configuration of the bottom or other agencies, forced upwards and inwards, being at the same time undermined by a similar wedge of fresher water running in the opposite direction. This position of the water-masses is not stable, but as, however, the salinity and the temperature are in conformity we are forced to acknowledge the fact.

Temperature.—The temperature of the intermediate water-masses seems to be somewhat lower than in section XXII . This is, however, only apparent as station XXIII 107 lies more seaward than station XXII 99, which is also shown by the higher salinity at the former station. Nearer up to the coast we should most possibly find about the same temperature up to 7°–8° C., as in that section, the position of the isotherms is almost the same in both sections, and the only exception is the cooling down of the neighbouring water-masses over the bank, where the wedge of salter and colder water from the deeper parts has ascended.

Compared with conditions in the spring and summer it seems as if the inflowing current in the northern part of Cabot strait, whose activity we found had diminished somewhat in the summer time, has again increased and forced the more continental water-masses up to the southern shore of the strait. The salinity of this inflowing current, the western branch of the Labrador current, is however somewhat lower, and the temperature, at least deeper down, somewhat higher than in the spring. This is obviously due to the mixing of the Labrador water over the banks with the warmer and fresher continental water-masses, which during the summer predominated at the surface far seawards over the banks.

TABLE Ia.—Salinity, Temperature and Density of the water in the Gulf of St. Lawrence during the spring of 1915.

C. G. S. "PRINCESS".

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Stat. 1. May 11	0	29·79	0·0	1·02393
9 a.m. N. 47° 30′ 00″ W. 63° 23′ 00″	10	29·88	1·5	1·02393
	20	30·38	÷ 0·2	1·02442
69 m.	30	30·59	÷ 0·7	1·02459
	40	31·17	÷ 1·2	1·02507
	50	31·25	÷ 1·4	1·02514
	65	31·31	÷ 1·4	1·02520
Stat. 2. May 11	0	29·70	0·35	1·02385
3.20—4.30 p.m. N. 47° 27′ 00″ W. 62° 10′ 30″	10	29·75	0·8	1·02385
	20	29·92	÷0·3	1·02405
45 m.	30	30·31	÷0·15	1·02435
	40	31·16	÷1·2	1·02506
Stat. 3. June 9	0	27·83	11·5	1·02115
11 a.m.—12 noon. N. 46° 02′ W. 63° 25′	10	28·44	4·8	1·02254
	20	28·72	3·15	1·02274
25 m.	22	28·60	3·2	1·02280
	25		3·6	
Stat. 4. June 9.	0	27·65	8·6	1·02146
5.10 p.m. N. 46° 28′ W. 64° 21′	5	27·73	8·4	1·02155
	10	27·87	8·1	1·02170
21 m.	20	28·12	7·0	1·02204
Sect. I, 5. June 10	0	27·46	10·1	1·02109
8.50—9.35 p.m. N. 47° 13′ W. 64° 35′	10	27·82	8·6	1·02169
	15	..	5·8	
31 m.	20	29·11	4·35	1·02310
	30	30·32	2·4	1·02422

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. I, 6. June 10	0	27·71	9·6	1·02136
12.20 p.m. N. 47° 30′ W. 64° 08′	10	29·83	4·4	1·02367
	20	30·46	3·1	1·02428
61 m.	25		1·8	
	30	31·12	÷0·75	1·02503
	40	31·14	÷0·8	1·02504
	60	31·54	÷1·15	1·02538
Sect. I, 7. June 10	0	27·35	9·5	1·02110
3.40—4.30 p.m. N. 47° 50′ W. 63° 37′	10	27·86	5·3	1·02202
	20	.	5·1	
76 m.	25	30·85	2·0	1·02467
	50	31·12	0·4	1·02499
	75	31·68	÷0·95	1·02549
Sect. I, 8. June 10 8.15—10.00 p.m.	0	29·04	9·1	1·02247
N. 48° 11′ W. 63° 04′	10	29·62	7·75	1·02312
	15		7·1	
92 m.	20	30·82	1·85	1·02466
	40	31·23	0·2	1·02508
	50	. .	÷1·1	
	60	31·81	÷0·6	1·02558
	75	.	÷0·6	
	90	32·30	÷0·5	1·02597

TABLE Ia.—Salinity, Temperature and Density of the water in the Gulf of St. Lawrence during the spring of 1915—*Continued.*

C. G. S. "PRINCESS."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. I, 9. June 11	0	31·00	8·05	1·02415
12.15—1.00 a.m. N. 48° 27′ W. 62° 37′	10	....	5·9	....
	25	31·46	2·5	1·02512
160—300 m.	40	....	0·7	....
	50	....	÷1·15	....
	75	32·25	÷1·2	1·02595
	100	32·84	÷0·35	1·02640
	125	....	0·4	......
	150	33·53	1·25	1·02688
	200	....	3·0	....
Sect. I, 10. June 11	0	30·86	6·45	1·02426
7.00 a.m. N. 48° 53′ W. 61° 50′	25	31·66	3·1	1·02524
	50	31·92	0·8	1·02561
150—250 m.	75	32·49	÷1·1	1·02615
	100	32·86	÷0·35	1·02641
	150	33·30	0·05	1·02675
	200	33·80	2·25	1·02701
Sect. I, 11. June 11	0	31·10	6·75	1·02441
9.30 a.m. N. 49° 02′ W. 61° 32′	10	31·09	6·2	1·02448
	20	31·49	5·4	1·02488
51 m.	25	31·85	1·55	1·02550
	30	....	1·15	....
	40	31·88	1·15	1·02556
	50	32·07	0·5	1·02576
Sect. I, 12. June 11	0	31·07	7·55	1·02427
12.30—1.30 p.m. N. 49° 27′ W. 61° 20′	10	31·47	4·45	1·02496
	25	31·75	2·35	1·02537
140 m.	40	.....	0·3	.....
	50	31·96	÷0·15	1·02569
	60	.....	÷1·3	.....
	75	32·54	÷1·35	1·02619
	100	32·83	÷0·8	1·02641
	125	32·92	÷0·45	1·02647

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. I, 13. June 11	0	28·44	6·9	1·02230
4.00 p.m. N. 49° 45′ W. 61° 15′	10	....	3·1	....
	25	31·18	0·85	1·02500
ca. 200 m.	40	....	÷0·55	....
	50	31·98	÷0·6	1·02571
	75	32·54	÷0·9	1·02618
	100	32·63	÷1·05	1·02626
	125	33·02	÷0·6	1·02655
	150	33·11	÷0·25	1·02661
	200	33·51	1·2	1·02686
Sect. I & II, 14. June 11	0	26·15	8·1	1·02044
7.00 p.m. N. 50° 07′ W. 61° 09′	10	29·78	3·5	1·02370
	20	31·50	0·9	1·02527
40 m.	25	....	1·0	....
	35	31·95	÷0·15	1·02568
Sect. II, 15. June 12	0	28·94	5·75	1·02282
9.00—10.00 a.m. N. 49° 45′ W. 60° 08′	10	28·96	5·4	1·02289
	20	30·51	4·3	1·02421
85 m.	30	....	0·7	....
	40	32·10	÷0·75	1·02582
	60	32·43	÷1·3	1·02611
	80	32·90	÷0·85	1·02646
Sect. II, 16. June 12	0	31·50	6·2	1·02480
1.15 p.m. N. 49° 33′ W. 59° 31′	25	31·61	3·9	1·02512
	50	32·02	1·1	1·02567
260 m.	60	....	÷0·7	....
	75	32·66	÷0·7	1·02627
	85	....	÷0·7	....
	100	32·94	÷0·5	1·02648
	150	33·33	0·4	1·02676
	200	33·34	0·1	1·02678
	250	33·89	2·4	1·02707

TABLE Ia.—Salinity, Temperature and Density of the water in the Gulf of St. Lawrence during the spring of 1915—*Continued.*

C. G. S. "PRINCESS."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. II, 17. June 12	0	31·55	4·9	1·02497
4.30 p.m.	25	31·69	4·0	1·02518
N. 49° 22′ W. 58° 56′	35	..	3·5	......
130 m.	50	31·87	0·4	1·02559
	60	.....	÷0·95	....
	75	32·43	÷1·1	1·02610
	100	32·66	÷0·7	1·02627
	125	33·04	0·2	1·02654
Sect. II, 18. June 12	0	31·35	5·95	1·02470
7.30 p.m.	20	....	4·2	.....
N. 49° 16′ W. 58° 37′	30	31·79	0·7	1·02550
64 m.	40	32·16	0·0	1·02584
	50	32·26	÷0·3	1·02593
Sect. III, 19. June 13	0	31·61	5·35	1·02498
2.45 a.m.	10	31·62	4·4	1·02508
N. 48° 20′ W. 59° 13′	20	31·63	4·4	1·02509
82 m.	30	31·92	1·9	1·02553
	40		1·1	
	50	32·10	0·8	1·02575
	60	32·45	0·1	1·02608
	70		0·0	
	80	32·63	÷0·1	1·02622
Sect. III, 20. June 13	25	31·57	4·4	1·02505
6.00 a.m.	50	31·61	2·6	1·02524
N. 48° 06′ W. 59° 40′	60	....	÷0·2	.
250—400 m.	75	32·11	÷0·8	1·02583
	85		÷0·9	....
	100	32·52	÷0·8	1·02616
	125	32·86	÷0·25	1·02641
	150	33·12	0·3	1·02660
	200	33·77	1·95	1·02700

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. III, 21. June 13	0	31·73	4·2	1·02519
9.45 a.m.	25	31·72	4·0	1·02520
N. 47° 52′ W. 60° 04′	50	32·12	2·45	1·02565
ca. 500 m.	60		1·2	
	75	32·36	−0·1	1·02600
	85		−0·2	
	100	32·66	−0·4	1·02625
	200	33·89	2·4	1·02717
	300	34·41	4·1	1·02732
	400	34·78	4·25	1·02760
Sect. III, 22. June 13	10	31·45	4·3	1·02496
1.30 p.m.	20	31·54	3·4	1·02512
N. 47° 33′ W. 60° 39′	30	31·89	÷0·3	1·02563
55 m.	40	31·89	÷0·4	1·02564
	50	31·97	÷0·5	1·02569
Sect. III, 23. June 13	0	31·42		.....
4.00 p.m.	20	31·59	4·45	1·02506
N. 47° 37′ W. 60° 31′	40	32·04	2·4	1·02559
ca. 100 m.	45	32·16	0·0	1·02584
	50		÷0·8	.
	55	32·21	÷0·8	1·02591
	60	32·41	÷0·5	1·02606
	80	32·60	÷0·4	1·02621
	100	33·07	0·4	1·02655
Sect. III, 24. June 17	0	30·31	5·9	1·02389
7.30—7.55 a.m.	10	30·34	5·9	1·02391
N. 47° 12′ W. 61° 20′	15		5·5	
40 m.	25	30·64	4·1	1·02434
	35	31·21	2·45	1·02493

TABLE Ia.—Salinity, Temperature and Density of the water in the Gulf of St. Lawrence during the spring of 1915—*Continued.*

C. G. S. "PRINCESS.

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density	Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°				‰	°	
Sect. III, 25. June 15 11.00 a.m.-12.00 noon N. 46° 45′ W. 61° 27′	0	29·46	7·2	1·02306	Sect. III, 26. June 15 3.00—4.00 p.m. N. 46° 20′ W. 62° 04′	0	28·94	7·0	1·02268
	10	29·50	6·9	1·02313		16	29·00	6·4	1·02280
	15		5·5			15	...	5·3	....
63 m.	18	.	3·2	.	40 m.	20	29·40	3·3	1·02342
	20	30·68	÷0·15	1·02465		25	29·64	2·0	1·02372
	25		÷0·3			35	30·67	÷0·5	1·02466
	30	31·27	÷1·1	1·02515					
	40	31·33	÷1·1	1·02521					
	60	31·41	÷1·5	1·02529					

STEAM DRIFTER "33".

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density	Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
Sect. IV, 21. June 25 7.20 a.m. N. 48° 51′ W. 64° 10′	0	28·67	7·2	1·02244	Sect. IV, 23. June 25 1.00 p.m. N. 49° 03′ W. 63° 58′	0	28·59	8·1	1·02226
	10	30·35	3·65	1·02415		10	28·93	8·0	1·02254
	24	31·28	1·55	1·02506		20	30·78	3·4	1·02451
27 m.					355 m.	30	31·31	2·15	1·02504
						40	.	1·3	......
						50	31·97	0·35	1·02567
Sect. IV, 22. June 25 9.40 a.m. N. 48° 54′ W. 64° 07′	0	28·49	7·8	1·02222		60	....	÷0·2	....
	10	29·42	5·55	1·02322		75	32·51	÷0·8	1·02615
	20	31·01	2·8	1·02474		100	32·84	÷0·3	1·02640
195 m.	30	31·50	1·6	1·02523		150	33·48	1·3	1·02682
	40	...	0·0	...		250	34·22	3·7	1·02721
	50	31·99	÷0·8	1·02573		350	34·62	4·55	1·02745
	75	32·37	÷0·45	1·02602					
	100	33·06	0·35	1·02654	Sect. IV, 24. June 26 5.25 a.m. N. 49° 23′ W. 63° 38′	0	30·83	7·0	1·02416
	125	33·49	1·4	1·02682		15	31·10	6·0	1·02450
	150	33·75	2·35	1·02696		24	31·27	5·2	1·02473
	190	33·87	2·6	1·02703	45 m.	42	32·32	0·1	1·02597

TABLE Ia.—Salinity, Temperature and Density of the water in the Gulf of St. Lawrence during the spring of 1915—*Concluded*.

STEAM DRIFTER "33."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density	Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°				‰	°	
Sect. IV, 25. June 26	0	29·66	8·25	1·02308	Sect. IV, 26. June 26	0	28·83	8·9	1·02223
6.20 a.m. N. 49° 18′ 30″	10	29·68	8·05	1·02312	9.35 a.m. N. 49° 11′ 30″	10	29·05	7·8	1·02267
W. 63° 42′ 00″	20	30·08	7·4	1·02352	W. 63° 50′ 00″	20	30·07	5·55	1·02373
271 m.	30	31·38	1·9	1·02511	389 m.	30	31·59	1·75	1·02529
	40	...	0·35			40	.	0·15	.
	50	31·92	÷0·2	1·02565		50	32·38	÷0·8	1·02604
	65	.....	÷0·4			75	32·66	÷0·7	1·02627
	75	32·48	÷0·55	1·02612		100	32·92	÷0·15	1·02646
	85	.	÷0·4			150	33·37	1·0	1·02676
	100	32·97	÷0·2	1·02650		200	33·91	2·75	1·02714
	150	33·38	1·05	1·02677		250	34·27	3·85	1·02725
	269	34·48	4·15	1·02738		380	34·72	4·5	1·02753

TABLE I*b*.—Salinity, Temperature and Density of the water on the Nova Scotian and Newfoundland banks during the spring of 1915.

C. G. S. "ACADIA".

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. V, 1. May 29 9—10 a.m. N. 44° 35′ 00″ W. 63° 32′ 00″ 25 m.	10	30·73	3·4	1·02447
	20	31·35	2·0	1·02507
Sect. V, 2. May 29 11.05 a.m.–12.05 p.m N. 44° 29′ 00″ W. 63° 22′ 00″ 60 m.	0	31·00	4·75	1·02456
	10	30·91	3·9	1·02456
	20	30·94	3·9	1·02460
	30	31·15	2·1	1·02490
	40	31·44	1·2	1·02520
	55	31·74	0·95	1·02545
Sect. V, 3. May 29 2.30—4.30 p.m. N. 44° 22′ 30″ W. 62° 55′ 00″ 146 m.	0	30·92	4·45	1·02453
	10	30·93	4·25	1·02455
	20	31·06	4·15	1·02467
	30	31·65	1·9	1·02534
	40	31·93	0·0	1·02566
	50	32·09	÷0·25	1·02579
	60	32·14	÷0·1	1·02582
	75	32·29	0·0	1·02594
	90	32·54	0·45	1·02612
	110	32·82	2·4	1·02622
Sect. V, 4. May 29 7.30 p.m. N. 44° 07′ 14″ W. 62° 11′ 36″ 173 m.	0	31·48	4·4	1·02497
	10	31·49	4·85	1·02497
	25	31·56	4·2	1·02506
	40	31·76	2·3	1·02539
	50	31·93	0·85	1·02561
	60	32·33	1·1	1·02592
	75	....	1·95	....
	100	33·14	3·0	1·02643
	120	33·66	5·0	1·02663
	160	34·29	6·7	1·02692

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. V, 5. May 30 1—2.30 a.m. N. 43° 56′ 00″ W. 61° 32′ 00″ 73 m.	0	32·36	5·2	1·02559
	10	32·43	5·1	1·02566
	25	32·68	5·2	1·02584
	50	32·79	4·0	1·02606
	70	33·08	3·85	1·02630
Sect. V, 6. May 30 5.30—6.30 a.m. N. 43° 47′ 00″ W. 60° 52′ 00″ 45 m.	0	32·06	4·35	1·02544
	10	32·06	4·3	1·02544
	20	32·05	4·2	1·02544
	30	32·05	4·0	1·02546
	40	32·15	3·6	1·02556
Sect. V, 7. May 30 10.15—11.15 a.m. N. 43° 35′ 30″ W. 60° 13′ 30″ 109 m.	0	31·90	4·0	1·02535
	10	....	3·9	....
	25	32·05	3·8	1·02549
	50	33·01	2·05	1·02639
	75	33·22	2·6	1·02639
	100	33·80	4·9	1·02683
Sect. V, 8. May 30 12.50 p.m. N. 43° 50′ 30″ W. 60° 04′ 30″ 51 m.	0	31·94	5·4	1·02523
	10	31·94	5·3	1·02524
	20	31·98	4·2	1·02539
	30	32·07	3·4	1·02554
	40	32·08	3·4	1·02555
	50	32·14	2·85	1·02563
Sect. V, 9. May 30 5—6 p.m. N. 43° 44′ 00″ W. 59° 24′ 00″ 106 m.	0	....	3·8	....
	25	32·19	3·3	1·02563
	40	32·82	1·3	1·02630
	50	33·03	1·25	1·02647
	60	....	1·7	....
	75	33·09	1·9	1·02647
	100	33·42	2·75	1·02668

TABLE I*b*.—Salinity, Temperature and Density of the water on the Nova Scotian and Newfoundland banks during the spring of 1915—*Continued.*

C. G. S. "ACADIA."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density	Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°				‰	°	
Sect. V, 10. May 30	0	32·48	4·4	1·02577	Sect. V, 12—*Con.*	150	33·79	3·1	1·02694
7.15 p.m.	25	32·61	4·25	1·02589		175	34·42	6·3	1·02707
N. 43° 41′ 30″ W. 59° 02′ 00″	50	32·74	2·2	1·02616		200		6·6	
740 m.	60	32·83	2·0	1·02626		300	34·49	5·2	1·02727
	75	32·86	0·8	1·02636		400	34·45	3·7	1·02740
	90	33·58	3·1	1·02677	Sect. V, 13. May 31	0	32·19	4·1	1·02556
	100	33·69	3·5	1·02682	4.45—9.45 a.m.	25	32·89	4·65	1·02697
	150	34·40	5·85	1·02712	N. 43° 27′ 35″ W. 27° 18′ 25″	50	33·56	4·0	1·02667
	200		5·1–		over 500 m.	75	33·85	4·6	1·02683
	300	34·49	3·9	1·02741		100	34·43	6·6	1·02705
	400	34·67	3·8	1·02756		150	34·59	6·0	1·02725
						200	34·61	5·3	1·02736
Sect. V, 11. May 30	0	.....	5·2	.....	Sect. V, 14. May 31	0	33·57	8·1	1·02616
10.50 p.m.-12.50 a.m.	25	32·79	5·0	1·02595	12.55—2.30 p.m.	25	33·58	7·65	1·02624
N. 43° 38′ 00″ W. 58° 35′ 00″	50	32·86	3·85	1·02612	N. 43° 20′ 00″ W. 56° 28′ 30″	50	33·60	6·75	1·02638
Over 500 m.	75	33·81	5·3	1·02672	Over 500 m.	75	33·74	7·5	1·02638
	100	34·34	7·0	1·02693		85	34·72	8·35	1·02702
	125	34·49	6·9	1·02705		100	34·77	8·4	1·02705
	150	34·39	4·8	1·02724		125	34·69	7·0	1·02719
	200	.....	3·8			150	34·70	6·75	1·02724
	300	34·33	3·2	1·02735		200		6·35	
	400	34·42	2·9	1·02745		300	34·67	4·7	1·02746
						400	34·75	4·7	1·02753
Sect. V, 12. May 31	0	32·61	4·55	1·02586	Sect. V, 15. May 31	0	33·30	8·1	1·02594
4.30—6.35 a.m.	10	32·63	4·5	1·02588	7.15—9 p.m.	25	33·30	7·95	1·02596
N. 43° 31′ 00″ W. 57° 46′ 00″	15	.....	4·55		N. 43° 07′ 50″ W. 55° 17′ 55″	50	33·55	6·65	1·02635
Over 500 m.	20		÷0·3		Over 500 m.	75	33·44	5·8	1·02636
	25	32·81	÷0·3	1·02637		100	34·02	5·8	1·02682
	50	32·82	÷1·15	1·02641		150	34·43	6·2	1·02710
	75	32·94	÷1·7	1·02651		200		6·7	
	100	33·08	÷0·65	1·02661		300	34·68	5·6	1·02736
	125	33·24	0·4	1·02669		400	34·61	1·25	1·02748

TABLE Ib.—Salinity, Temperature and Density of the water on the Nova Scotian and Newfoundland banks during the spring of 1915—*Continued.*

C. G. S. "ACADIA."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. V & VI, 16. June 1 1.45—3.15 a.m. N. 42° 53′ 00″ W. 54° 09′ 00″ Over 500 m.	0	35·01	12·2	1·02658
	25	35·25	13·05	1·02660
	50	....	12·9	....
	75	35·58	13·75	1·02671
	100	35·33	12·35	1·02679
	150	....	12·25	....
	200	35·05	10·2	1·02696
	300	35·24	10·2	1·02711
	400	35·21	9·3	1·02726
Sect. VI, 17. June 1 9—10.15 a.m. N. 43° 30′ 50″ W. 54° 12′ 50″ Over 500 m.	0	......	11·5	....
	25	34·90	11·55	1·02664
	50	35·11	11·8	1·02673
	75	....	12·1	....
	100	35·39	12·8	1·02675
	150	35·25	11·3	1·02692
	200	....	10·9	....
	300	35·31	10·8	1·02707
	400	35·02	8·8	1·02720
Sect. VI, 17*a*. June 1 1.10—1.25 p.m. N. 43° 56′ 00″ W. 54° 16′ 00″ Over 500 m.	0	33·90	8·8	1·02631
	50	....	12·2	....
	75	35·34	12·0	1·02687
	100	35·38	12·05	1·02690
Sect. VI, 18. June 1 4.30 p.m. N. 44° 11′ 30″ W. 54° 13′ 00″ Over 500 m.	0	32·89	4·8	1·02606
	25	32·88	4·1	1·02612
	40	....	2·9	....
	50	32·84	2·8	1·02621
	60	....	8·25	....
	75	34·16	7·3	1·02674
Sect. VI, 18—*Con*	100	33·82	4·0	1·02687
	150	34·21	4·75	1·02710
	200	....	5·2	....
	300	34·56	4·0	1·02746
	400	34·68	3·8	1·02757
Sect. VI, 19. June 1 8.15—10 p.m. N. 44° 35′ 00″ W. 54° 15′ 00″ Over 500 m.	0	32·91	5·0	1·02604
	25	32·91	5·0	1·02604
	50	32·84	3·7	1·02613
	75	34·22	6·1	1·02694
	100	34·47	7·4	1·02695
	150	34·40	6·4	1·02705
	200	....	6·4	....
	300	34·54	5·1	1·02733
	400	34·61	5·5	1·02734
Sect. VI, 20. June 2 1 a.m. N. 44° 59′ 00″ W. 54° 17′ 00″ 91 m.	0	32·77	3·9	1·02605
	25	32·78	3·9	1·02606
	50	32·82	2·4	1·02622
	75	33·12	1·45	1·02653
Sect. VI, 21. June 2 3.45—4.45 a.m. N. 45° 28′ 00″ W. 54° 28′ 00″ 116 m.	0	32·71	2·2	1·02614
	35	32·87	1·1	1·02635
	50	32·87	1·05	1·02636
	65	33·06	÷0·9	1·02660
	100	33·24	÷1·3	1·02676
Sect. VI & VII, 22. June 2 7.25—7.50 a.m. N. 45° 50′ 30″ W. 54° 20′ 00″ 73 m.	0	32·74	3·4	1·02606
	20	32·75	3·0	1·02612
	40	32·74	1·4	1·02622
	50	32·88	÷0·25	1·02643
	60	33·03	÷1·2	1·02658

TABLE Ib.—Salinity, Temperature and Density of the water on the Nova Scotian and Newfoundland banks during the spring of 1915—*Continued.*

C. G. S. "ACADIA."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		°/₀₀	°	
Sect. VII, 23. June 2	0	32·74	3·3	1·02607
10.35 a.m.	25	32·74	3·0	1·02610
N. 45° 39′ 00″ W. 55° 03′ 00″	50	32·82	0·85	1·02633
100 m.	60	32·93	÷0·4	1·02647
	75	32·92	÷0·5	1·02647
Sect. VII, 24. June 2	0	32·67	3·5	1·02601
2.15—3.50 p.m.	25	....	1·9	....
N. 45° 16′ 30″ W. 55° 29′ 50″	50	32·73	÷0·6	1·02631
120 m.	75	32·95	÷1·35	1·02653
	100	32·96	÷1·4	1·02654
Sect. VII, 25. June 2	0	32·77	3·4	1·02609
5.40—6.30 p.m.	25	32·83	2·45	1·02622
N. 44° 56′ 00″ W. 55° 54′ 00″	50	33·05	0·9	1·02651
124 m.	75	....	÷0·6	
	100	33·17	0·05	1·02665
	120	33·36	0·35	1·02679
Sect. VII, 26. June 2	0	32·11	3·5	1·02557
10—11.15 p.m.	25	32·48	2·6	1·02593
N. 44° 31′ 00″ W. 56° 25′ 30″	50	32·55	1·1	1·02609
Over 500 m.	75	....	0·9	....
	100	33·44	1·4	1·02679
	110	....	3·7	
	125	34·47	6·6	1·02708
	150	34·58	5·9	1·02726
	200	....	5·9	....
	300	34·72	4·65	1·02752
	400	34·80	4·4	1·02761

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		°/₀₀	°	
Sect. VII & VIII, 27. June 3	0	....	4·15	....
2.10—3.30 a.m.	25	32·57	3·4	1·02602
N. 44° 06′ 00″ W. 56° 54′ 00″	50	32·90	3·2	1·02629
Over 500 m.	75	33·29	1·9	1·02663
	100	33·88	4·7	1·02684
	100bis	34·42	7·1	1·02695
	150	34·01	4·0	1·02702
	200	....	5·6	
	300	34·62	4·5	1·02746
	400	34·77	4·3	1·02759
Sect. VIII, 28. June 3	0	31·73	4·1	1·02520
6.15—7.45 a.m.	25	31·89	2·1	1·02550
N. 44° 12′ 00″ W. 57° 24′ 00″	50	32·00	0·4	1·02569
Over 500 m.	75	32·59	0·35	1·02617
	100	32·97	0·85	1·02645
	125	....	3·25	....
	150	34·16	5·4	1·02698
	200	....	5·85	....
	300	34·58	5·35	1·02733
	400	34·73	3·9	1·02760
Sect. VIII, 29. June 3	0	31·69	4·6	1·02512
10.55 a.m.—12 noon.	20	....	4·0	....
N. 44° 21′ 36″ W. 58° 08′ 00″	30	....	2·25	....
58 m.	40	31·79	2·2	1·02541
	55	32·23	0·0	1·02590
Sect. VIII, 30. June 3	0	31·51	4·6	1·02498
3—3.45 p.m.	25	31·63	3·25	1·02520
N. 44° 40′ 50″ W. 58° 42′ 00″	50	32·10	0·65	1·02575
127 m.	75	32·11	0·35	1·02578
	100	32·30	0·2	1·02594
	125	32·53	0·15	1·02613

TABLE Ib.—Salinity, Temperature and Density of the water on the Nova Scotian and Newfoundland banks during the spring of 1915—*Concluded.*

C. G. S. "ACADIA."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. VIII, 31. June 3	0	31·24	4·75	1·02476
7.30—8.30 p.m.	25	31·35	3·1	1·02498
N. 45° 13′ 00″ W. 58° 59′ 00″	50	31·99	÷0·2	1·02571
85 m.	75	32·15	÷0·3	1·02584
	85	....	÷0·3	....
Sect. VIII, 32. June 3	0	31·37	4·5	1·02488
11.15 p.m.-12.15 a.m.	25	31·68	2·55	1·02531
N. 45° 48′ 30″ W. 59° 13′ 00″	50	31·83	1·9	1·02546
155 m.	75	.....	0·0	......
	100	32·48	÷0·35	1·02611
	150	32·99	0·45	1·02649
Sect. VIII & IX, 33. June 4	0	30·55	4·0	1·02428
3.50—4.50 a.m.	10	......	4·0	...
N. 46° 16′ 30″ W. 59° 33′ 00″	15	30·56	3·35	1·02434
Ca. 73 m.	20	...	2·3	...
	25	31·07	1·25	1·02490
	40	31·49	÷0·15	1·02531
	50	31·68	÷0·5	1·02547
	75	32·29	÷0·55	1·02596
Sect. IX, 34. June 4	0	31·97	4·0	1·02541
7.45—8.45 a.m.	15	......	3·9	......
N. 46° 40′ 00″ W. 59° 00′ 00″	25	32·01	1·1	1·02566
Ca. 350 m.	35	.....	0·0	....
Sect. IX, 34—*Con.*	50	32·30	÷0·4	1·02597
	75	....	÷0·5	....
	100	32·51	÷0·45	1·02614
	200	33·45	1·85	1·02676
	300	34·43	4·2	1·02734
Sect. IX, 35. June 4	0	32·15	4·5	1·02549
11.55 a.m.—12.55 p.m	15	32·21	4·2	1·02557
N. 47° 04′ 00″ W. 58° 26′ 00″	30	32·24	2·7	1·02573
Ca. 450 m.	50	32·49	0·45	1·02604
	75	32·83	0·25	1·02637
	100	33·05	0·7	1·02652
	150	33·66	2·1	1·02690
	200	....	3·6	....
	300	34·56	4·2	1·02744
	400	34·66	4·05	1·02753
Sect. IX, 36. June 4	0	32·02	4·3	1·02542
3.30—4.30 p.m.	15	......	3·35	....
N. 47° 26′ 00″ W. 57° 57′ 00″	25	32·17	1·9	1·02573
230 m.	50	32·49	0·45	1·02608
	60	....	÷0·2	....
	75	32·61	÷0·45	1·02622
	100	....	÷0·35	....
	135	33·16	0·4	1·02663
	200	33·81	2·3	1·02702

TABLE Ic.—Salinity, Temperature and Density of the water in the Gulf of St. Lawrence during the summer of 1915.

C. G. S. "PRINCESS".

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Stat. 27. Aug. 3	0	27·86	16·4	1·02021
5.30—6.30 p.m.	10	28·19	16·5	1·02044
N. 46° 02′ W. 63° 24′	20	29·69	8·4	1·02308
23 m.				
Stat. 28. Aug. 3	0	27·63	18·5	1·01955
11.45 p.m.-1.30 a.m.	10	27·72	17·1	1·01995
N. 46° 31′ W. 64° 20′	15	....	17·0	......
23 m.	20	27·85	17·0	1·02007
Sect. X, 29. Aug. 4	0	26·63	17·0	1·01914
6.10—7.15 a.m.	10	27·45	15·6	1·02007
N. 47° 13′ W. 64° 36′	15	28·24	10·7	1·02161
32 m.	20	28·91	9·3	1·02234
	25	29·08	8·1	1·02265
Sect. X, 30. Aug. 4	0	27·85	16·1	1·02027
10.15—11.05 a.m.	10	27·83	15·7	1·02033
N. 47° 31′ W. 64° 09′	25	28·67	10·5	1·02197
66 m.	40	29·49	7·9	1·02299
	50	30·37	5·65	1·02397
	60	31·64	0·45	1·02540
Sect. X, 31. Aug. 4	0	27·37	16·55	1·01970
1.35—2.40 p.m.	10	27·44	13·9	1·02041
N. 47° 47′ W. 63° 45′	25	29·16	8·45	1·02266
65 m.	40	30·57	7·5	1·02389
	50	31·47	1·4	1·02527
	60	31·94	÷0·35	1·02567
Sect. X, 32. Aug. 4	0	28·55	17·0	1·02060
4.55—5.50 p.m.	10	29·49	14·95	1·02277
N. 48° 00′ W. 63° 25′	25	31·04	5·45	1·02452
87 m.	40	...	1·4	
	50	31·76	0·55	1·02549
	75	32·05	÷0·25	1·02576
	85	32·13	÷0·3	1·02583
Sect. X, 33. Aug. 4	0	29·80	15·55	1·02089
8.55—9.50 p.m.	10	29·97	10·35	1·02300
N. 48° 17′ W. 62° 54′	25	31·23	2·5	1·02494
78 m.	50	32·04	÷0·95	1·02578
	75	32·69	÷0·5	1·02629
Sect. X, 34. Aug. 4	0	30·11	15·15	1·02220
11.55 p.m.-2.25 a.m.	10	30·90	11·75	1·02348
N. 48° 27′ W. 62° 37′	25	31·17	7·8	1·02432
405 m.	50	32·05	÷0·55	1·02577
	75	32·47	÷1·15	1·02613
	100	32·89	÷0·3	1·02644
	150	33·51	1·0	1·02687
	200	33·96	3·0	1·02708
	300	34·59	4·45	1·02741
	350	34·72	4·45	1·02753
Sect. X, 35. Aug. 5	0	30·24	12·85	1·02276
4.40—6.35 a.m.	10	30·51	12·9	1·02296
N. 48° 41′ W. 62° 15′	25	31·44	3·4	1·02493
Ca. 400 m.	50	32·25	÷0·6	1·02595
	75	32·55	÷0·75	1·02618

TABLE Ic.—Salinity, Temperature and Density of the water in the Gulf of St. Lawrence during the summer of 1915—*Continued.*

C. G. S. "PRINCESS."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		°/00	°	
Sect. X, 35—*Con.*	100	32·84	÷0·3	1·02640
	150	33·26	÷0·4	1·02674
	200	33·89	2·8	1·02704
	300	34·56	4·35	1·02742
	350	34·65	4·45	1·02748
Sect. X, 36. Aug. 5	0	29·91	14·3	1·02221
9.30—10.20 a.m. N. 48° 58′ W. 61° 48′	10	29·90	14·2	1·02222
	25	30·62	7·6	1·02389
53 m.	35	31·71	1·3	1·02540
	50	31·96	0·3	1·02567
Sect. X, 37. Aug. 5	0	30·14	13·05	1·02265
12.45—1.35 p.m. N. 49° 06′ W. 61° 21′	10	30·15	12·5	1·02277
	15	....	8·65	....
75 m.	25	31·46	2·35	1·02513
	40	....	÷0·4	....
	50	32·21	÷0·85	1·02591
	70	32·60	÷1·1	1·02624
Sect. X, 38. Aug. 5	0	29·96	13·95	1·02233
4.00—5,00 p.m. N. 49° 28′ W. 61° 22′	10	29·97	13·0	1·02253
	25	31·74	1·9	1·02540
180 m.	50	32·36	÷0·95	1·02604
	75	32·73	÷1·1	1·02634
	100	32·95	÷0·95	1·02652
	150	33·31	÷0·2	1·02678
	175	33·41	1·3	1·02678

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		°/00	°	
Sect. X, 39. Aug. 5	0	30·15	13·9	1·02249
7.00—8.35 p.m. N. 49° 45′ W. 61° 19′	10	30·24	13·65	1·02260
	25	31·76	2·6	1·02536
284 m.	50	32·36	÷1·0	1·02604
	75	32·68	÷1·1	1·02630
	100	32·96	÷0·8	1·02652
	150	33·18	÷0·75	1·02669
	200	33·48	0·9	1·02685
	275	34·29	3·95	1·02735
Sect. X & XI, 40. Aug. 5	0	29·43	11·65	1·02199
11.30 p.m.–12.25 a.m. N. 50° 05′ W. 61° 16′	10	31·18	7·05	1·02443
	25	31·72	1·3	1·02541
68 m.	40	32·09	÷0·2	1·02579
	50	32·30	÷0·6	1·02597
	65	32·30	÷0·7	1·02598
Sect. XI, 41. Aug. 6	0	30·32	13·25	1·02275
3.30—4.55 a.m. N. 49° 54′ W. 60° 37′	10	30·35	13·35	1·02276
	25	31·13	5·2	1·02462
189 m.	50	31·89	0·4	1·02560
	75	32·46	÷1·1	1·02612
	100	32·77	÷0·95	1·02637
	150	33·05	÷0·65	1·02658
	180	33·51	1·25	1·02685
Sect. XI, 42. Aug. 6	0	30·53	12·65	1·02303
4.25—8.00 a.m. N. 49° 45′ W. 60° 07′	10	30·54	12·65	1·02304
	25	31·23	7·35	1·02443
90 m.	40	......	5·4	....
	50	32·01	0·65	1·02568
	75	32·68	÷1·0	1·02630
	85	32·70	÷1·0	1·02631

TABLE Ic.—Salinity, Temperature and Density of the water in the Gulf of St. Lawrence during the summer of 1915—*Continued*.

C. G. S. "PRINCESS."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. XI, 43. Aug. 6 11.00 a.m.-12.00 noon N. 49° 33′ W. 59° 28′ 265 m.	0	30·72	13·4	1·02303
	10	30·73	13·4	1·02304
	25	31·39	7·05	1·02458
	50	31·97	0·05	1·02568
	75	32·59	÷0·85	1·02622
	100	32·83	÷0·8	1·02641
	150	33·17	÷0·55	1·02667
	200	33·71	1·85	1·02697
	250	34·27	3·75	1·02726
Sect. XI, 44. Aug. 6 2.30—3.10 p.m. N. 49° 24′ W. 58° 55′ 157 m.	0	30·68	13·45	1·02299
	10	30·69	13·4	1·02301
	25	31·29	5·5	1·02471
	50	32·10	÷0·3	1·02580
	75	32·52	÷0·75	1·02616
	100	32·79	÷0·65	1·02638
	150	33·20	0·0	1·02668
Sect. XII, 45. Aug. 12 2.05—3.50 a.m. N. 47° 53′ W. 59° 38′ 380 m.	0	31·71	12·45	1·02396
	25	31·92	11·35	1·02434
	50	32·32	5·7	1·02550
	75	32·57	2·8	1·02599
	100	32·60	1·2	1·02613
	150	32·75	0·2	1·02631
	200	33·30	0·7	1·02672
	300	34·45	1·15	1·02761
	375	34·66	4·0	1·02764
Sect. XII, 46. Aug. 12 5.25—6.35 a.m. N. 47° 41′ W. 59° 52′ Ca. 455 m.	0	31·37	12·75	1·02365
	25	31·60	8·3	1·02459
	50	32·52	3·55	1·02588
	75	32·57	0·8	1·02613
	100	32·72	÷0·1	1·02629
	150	33·30	0·8	1·02671
	200	33·91	2·8	1·02706
	300	34·52	4·2	1·02741
	400	34·70	4·15	1·02754
Sect. XII, 47. Aug. 12 8.35—10.00 a.m. N. 47° 25′ W. 60° 10′ 410 m.	0	29·82	14·35	1·02215
	25	31·13	12·15	1·02358
	50	31·84	5·95	1·02509
	75	32·41	2·95	1·02584
	100	32·60	0·65	1·02616
	125		0·0	
	150	33·22	0·55	1·02667
	175		1·5	
	200	33·65	1·7	1·02693
	300	34·36	3·9	1·02731
	400	34·71	4·4	1·02753
Sect. XII, 48. Aug. 12 12.40—2.00 p.m. N. 47° 08′ W. 60° 31′ 175 m.	0	29·72	16·2	1·02168
	25	31·29	8·9	1·02426
	50	31·97	0·5	1·02566
	75	32·65	0·35	1·02621
	100	32·88	0·2	1·02641
	125	33·58	1·8	1·02687
	170	33·91	2·65	1·02707

TABLE Ic.—Salinity, Temperature and Density of the water in the Gulf of St. Lawrence during the summer of 1915—*Concluded.*

C. G. S. "PRINCESS."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density	Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°				‰	°	
Sect. XII, 49. Aug. 12	0	28·55	17·05	1·02051	Sect. XII, 50. Aug. 12	0	28·60	16·15	1·02084
6.25—7.05 p.m. N. 46° 40′	10	28·59	16·9	1·02083	11.25 p.m.-12.20 a.m. N. 46° 18′	10	28·62	16·2	1·02086
W. 61° 14′	25	30·43	5·25	1·02405	W. 61° 59′	25	29·23	10·65	1·02238
75 m.	35	31·43	÷0·5	1·02527	42 m.	30	....	4·9	....
	50	31·56	÷1·1	1·02540		40	30·81	0·2	1·02474
	60	31·82	÷1·05	1·02560					
	70	32·38	0·4	1·02599					

STEAM DRIFTER "33".

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density	Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
Stat. 54. Aug. 7	0	22·45	15·2	1·01633	Stat. 59. Aug. 10	0	29·22	14·75	1·02260
9.15 a.m.	10	30·59	10·75	1·02340	12.50 p.m. Inside South Head	10	31·00	12·0	1·02352
South Arm, Bay of Islands,	25	31·55	4·2	1·02504	Bay of Islands.	25	31·67	4·7	1·02510
Newfoundland.	50	31·83	2·25	1·02544	275 m.	50	32·01	1·0	1·02577
110 m.	75	32·27	0·1	1·02593		75	32·29	0·15	1·02594
	100	32·37	÷0·2	1·02601		100	32·42	÷0·25	1·02606
	108	....	÷0·25	....		150	32·61	÷0·3	1·02621
						200	32·63	÷0·35	1·02623
Stat. 58. Aug. 10	0	30·32	13·7	1·02266		270	32·65	÷0·4	1·02625
11.10 a.m. Off South Head,	10	30·95	12·3	1·02342					
Bay of Islands.	25	31·60	5·4	1·02497					
50 m.	45	31·98	1·2	1·02563					

Table I*d*.—Salinity, Temperature and Density of the water on the Nova Scotian and Newfoundland banks during the summer of 1915.

C. G. S. "ACADIA."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. XIII, 37. July 21 5.30 p.m. N. 43° 33′ 00″ W. 65° 12′ 50″ 62 m.	0	31·16	9·7	1·02402
	20	31·47	5·85	1·02481
	40	31·77	2·5	1·02538
	60	31·93	1·95	1·02557
Sect. XIII, 38. July 21 7.50 p.m. N. 43° 14′ 00″ W. 65° 02′ 00″ 170 m.	0	31·02	12·4	1·02347
	25	31·70	10·75	1·02427
	50	31·64	5·1	1·02503
	75	32·01	1·9	1·02563
	100	32·92	4·15	1·02614
	125	33·04	3·9	1·02627
	150	33·22	3·85	1·02641
Sect. XIII, 39. July 21 10.55 p.m. N. 42° 55′ 00″ W. 64° 51′ 00″ 95 m.	0	31·24	12·5	1·02361
	25	31·27	9·5	1·02415
	40	31·43	7·7	1·02455
	50	31·95	3·8	1·02541
	75	32·39	3·15	1·02582
	90	32·43	3·2	1·02584
Sect. XIII, 40. July 22 2.00 a.m. N. 42° 36′ 00″ W. 64° 41′ 00″ 134 m.	0	30·90	13·5	1·02314
	25	33·02	10·65	1·02532
	50	33·46	8·6	1·02599
	60	. . .	7·05	. . .
	75	33·66	6·6	1·02645
	100	33·81	6·4	1·02659
	125	34·05	6·1	1·02681
Sect. XIII, 41. July 22 5.25 a.m. N. 42° 17′ 00″ W. 64° 30′ 30″ 420 m.	0	34·27	18·35	1·02465
	25	35·07	18·95	1·02510
	40	. . .	15·6	. . .
	50	35·33	13·9	1·02647
	75	35·25	13·05	1·02659
	100	35·35	12·5	1·02678
	150	35·42	11·85	1·02695
	200	35·40	11·3	1·02705
	300	35·14	8·95	1·02727
	400	35·08	7·2	1·02747
Sect. XIII, 42. July 22 9.00 a.m. N. 41° 58′ 00″ W. 64° 20′ 00″ Over 1,000 m.	0	34·33	18·7	1·02469
	25	35·11	19·2	1·02507
	50	35·21	14·35	1·02630
	75	35·38	13·15	1·02667
	100	35·33	12·2	1·02682
	150	35·43	11·65	1·02700
	200	35·40	10·85	1·02713
	300	35·12	8·8	1·02727
	400	35·09	7·4	1·02745
Sect. XIII, 43. July 22 11.50 a.m. N. 41° 38′ 30″ W. 64° 10′ 00″ Over 1,000 m.	0	33·69	17·1	1·02450
	25	34·59	18·0	1·02498
	50	34·62	15·75	1·02554
	75	35·82	16·05	1·02638
	100	35·82	15·8	1·02644
	150	35·62	13·75	1·02674
	200	35·47	12·95	1·02679
	300	35·42	11·2	1·02709
	400	35·12	8·4	1·02733

TABLE I*d*.—Salinity, Temperature and Density of the water on the Nova Scotian and Newfoundland banks during the summer of 1915—*Continued.*

C. G. S. "ACADIA."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. XIII & XIV, 44. July 22	0	33·99	19·7	1·02411
3 10 p.m.	25	35·25	21·9	1·02445
N. 41° 19′ 00″ W. 63° 59′ 00″	50	35·90	19·9	1·02549
Over 1,000 m.	75	35·99	17·3	1·02622
	100	35·57	13·9	1·02667
	150	35·35	11·95	1·02691
	200	35·44	11·6	1·02702
	300	35·25	9·45	1·02724
	400	35·11	7·5	1·02749
Sect. XIV, 45. July 22	0	33·73	16·3	1·02472
8.10 p.m.	25	34·28	17·65	1·02483
N. 42° 02′ 00″ W. 63° 43′ 00″	50	34·74	15·2	1·02575
Over 1,000 m.	75	34·60	11·75	1·02634
	100	35·23	13·0	1·02659
	150	35·40	12·2	1·02688
	200	35·34	11·3	1·02702
	300	35·08	7·7	1·02745
	400	35·04	6·2	1·02758
Sect. XIV, 46. July 23	0	32·46	17·0	1·02359
12.50 a.m.	25	32·05	10·5	1·02459
N. 42° 31′ 00″ W. 63° 31′ 30″	50	33·58	7·5	1·02625
Over 1,000 m.	75	33·96	7·8	1·02651
	100	33·99	7·3	1·02660
	150	35·15	10·7	1·02696
	200	34·92	9·4	1·02700
	300	35·23	8·45	1·02740
	400	34·94	6·9	1·02741

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. XIV, 47. July 23	0	31·31	13·35	1·02449
6.30 a.m.	25	31·42	12·25	1·02478
N. 43° 15′ 00″ W. 63° 13′ 30″	50	32·69	6·7	1·02566
144 m.	75	33·47	5·2	1·02656
	100	34·36	8·35	1·02674
	125	34·52	8·05	1·02691
Sect. XIV, 48. July 23	0	30·99	13·1	1·02329
11.00 a.m.	25	31·62	10·5	1·02425
N. 43° 53′ 30″ W. 62° 58′ 30″	50	32·56	2·75	1·02598
264 m.	75	32·94	2·75	1·02628
	100	33·70	5·4	1·02662
	125	34·40	7·3	1·02693
	150	34·67	8·1	1·02702
	200	34·87	8·2	1·02716
	250	34·82	7·55	1·02723
Sect. XIV & XV, 49. July 23	0	30·62	13·05	1·02302
3.35 p.m.	25	31·80	9·2	1·02461
N. 44° 30′ 30″ W. 62° 43′ 00″	40	31·98	3·35	1·02547
135 m.	50	32·13	3·3	1·02560
	75	32·21	0·95	1·92583
	100	32·35	1·0	1·02594
	125	32·59	1·15	1·02613
Sect. XV, 50. July 23	0	31·18	13·3	1·02340
7.30 p.m.	25	31·90	8·9	1·02473
N. 44° 12′ 15″ W. 62° 35′ 00″	40	....	3·25	....
155 m.	50	32·63	3·3	1·02599

TABLE I*d*.—Salinity, Temperature and Density of the water on the Nova Scotian and Newfoundland banks during the summer of 1915—*Continued.*

C. G. S. "ACADIA."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. XV, 50—*Con.*	75	33·03	3·35	1·02631
	100	33·64	5·05	1·02661
	125	33·99	6·05	1·02677
	150	34·23	6·9	1·02684
Sect. XV, 51. July 23	0	31·44	12·95	1·02367
10.25 p.m.	25	32·01	10·35	1·02458
N. 43° 52′ 00″ W. 62° 18′ 00″	40	32·81	5·05	1·02595
133 m.	50	32·94	4·45	1·02612
	75	33·46	4·6	1·02652
	100	33·99	6·2	1·02675
	125	34·22	7·05	1·02681
Sect. XV, 52. July 24	0	31·97	12·7	1·02412
1.45 a.m.	25	32·23	9·4	1·02492
N. 43° 31′ 00″ W. 62° 01′ 00″	40	32·59	4·4	1·02583
95 m.	50	32·76	3·4	1·02609
	60	33·01	2·95	1·02630
	75	33·03	2·55	1·02638
	90	33·56	4·15	1·02665
Sect. XV, 53. July 24	0	32·20	12·2	1·02440
4.45 a.m.	25	32·26	6·65	1·02533
N. 43° 14′ 30″ W. 61° 48′ 00″	40	32·68	1·8	1·02615
99 m.	50	32·77	1·8	1·02622
	60		1·85	
	75	33·00	1·9	1·02640
	95	33·13	2·1	1·02649
Sect. XV, 54. July 24	0	31·94	13·9	1·02386
7.30 a.m.	25	32·66	11·0	1·02498
N. 42° 57′ 30″ W. 61° 34′ 00″	40		5·1	
Over 1,000 m.	50	33·45	5·05	1·02646
	75	33·87	4·7	1·02683
	100	33·93	4·95	1·02685
	150	34·69	7·3	1·02715
	200	34·96	8·5	1·02719
	300	34·89	5·3	1·02757
	400	34·93	4·9	1·02765
Sect. XV, 55. July 24	0	32·03	16·35	1·02342
10.25 a.m.	25	32·67	9·4	1·02526
N. 42° 41′ 15″ W. 61° 21′ 00″	50	33·46	6·35	1·02630
Over 1,000 m.	75	34·69	9·85	1·02675
	100	34·31	7·85	1·02677
	150	35·20	10·1	1·02711
	200	35·01	8·95	1·02717
	300	34·88	7·3	1·02727
	400	34·95	5·95	1·02754
Sect. XV & XVI, 56. July 24	0	31·65	17·6	1·02283
2.15 p.m.	25	32·72	9·45	1·02529
N. 42° 16′ 00″ W. 61° 01′ 00″	50	35·59	15·45	1·02634
Over 1,000 m.	75		14·05	
	100	35·42	13·05	1·02672
	150	35·37	11·55	1·02699
	200	35·35	11·35	1·02700
	300	35·21	9·2	1·02728
	400	35·01	7·8	1·02734

TABLE I*d*.—Salinity, Temperature and Density of the water on the Nova Scotian and Newfoundland banks during the summer of 1915—*Continued.*

C. G. S. "ACADIA."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		°/oo	°	
Sect. XVI, 57. July 24	0	32·84	17·5	1·02376
7.18 p.m. N. 42° 57′ 30″ W. 60° 56′ 00″	25	32·67	10·45	1·02508
	50	33·30	6·6	1·02615
Over 1,000 m.	75	33·63	4·75	1·02664
	100	33·96	5·2	1·02684
	150	34·56	6·45	1·02716
	200	34·61	5·75	1·02731
	300	35·06	6·8	1·02752
	400	34·98	5·5	1·02763
Sect. XVI, 58. July 24	0	32·28	14·65	1·02398
10.35 p.m. N. 43° 23′ 00″ W. 60° 53′ 00″	25	32·74	10·5	1·02512
	50	33·20	5·5	1·02622
187 m.	75	33·30	5·4	1·02630
	100	33·64	3·5	1·02677
	125	34·20	6·1	1·02693
	150	34·36	6·2	1·02704
	175	34·76	7·85	1·02713
Sect. XVI, 59. July 25	0	31·73	11·55	1·02415
12.00 noon. N. 43° 48′ 30″ W. 60° 50′ 00″	15	31·75	11·3	1·02422
	30	31·92	8·45	1·02496
45 m.	45	32·21	4·55	1·02554
Sect. XVI, 60. July 25	0	31·80	13·3	1·02388
5.53 a.m. N. 44° 13′ 30″ W. 61° 14′ 00″	25	32·22	9·6	1·02487
	50	32·73	4·35	1·02597
98 m.	75	33·17	3·5	1·02641
	95	33·46	4·3	1·02655
Sect. XVI, 62. July 25	0	31·08	11·6	1·02364
10.05 a.m. N. 44° 34′ 30″ W. 60° 47′ 00″	25	31·31	9·35	1·02420
	40	31·67	3·9	1·02518
62 m.	50	31·96	2·5	1·02552
	60	32·08	1·8	1·02567
Sect. XVI, 63. July 25	0	31·04	11·8	1·02361
11.55 a.m. N. 44° 43′ 30″ W. 60° 46′ 00″	25	31·54	6·7	1·02476
55 m.	50	32·13	2·1	1·02568
Sect. XVI, 64. July 25	0	30·39	12·3	1·02298
2.30 p.m. N. 45° 04′ 00″ W. 60° 46′ 00″	25	31·15	9·65	1·02403
	50	31·74	5·1	1·02511
120 m.	75	32·24	0·35	1·02589
	110	32·52	0·4	1·02613
Sect. XVI & XVII, 65. July 25	0	29·85	12·3	1·02257
5.15 p.m. N. 45° 17′ 00″ W. 60° 42′ 30″	10	30·35	11·8	1·02305
	25	30·92	5·7	1·02440
105 m.	50	31·88	1·25	1·02555
	75	32·00	0·75	1·02567
	100	32·21	0·45	1·02585
Sect. XVII, 66. July 25	0	30·58	11·85	1·02321
7.55 p.m. N. 45° 08′ 00″ W. 60° 23′ 00″	10	30·61	11·7	1·02325
	25	30·59	11·6	1·02327
64 m.	40	31·09	5·9	1·02451
	50	31·67	1·8	1·02535
	60	32·06	0·35	1·02574

Table Id.—Salinity, Temperature and Density of the water on the Nova Scotian and Newfoundland banks during the summer of 1915—*Continued.*

C. G. S. "ACADIA."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. XVII, 67. July 25 11.55 p.m. N. 44° 49′ 00″ W. 59° 40′ 00″ 205 m.	0	31·05	11·95	1·02355
	10	31·05	11·9	1·02356
	25	31·52	8·65	1·02447
	40		4·55	....
	50	32·21	1·45	1·02579
	75	32·47	0·55	1·02606
	100	32·53	0·45	1·02611
	150	32·75	0·65	1·02629
	200	32·89	0·8	1·02639
Sect. XVII, 68. July 26 3.55 a.m. N. 44° 32′ 00″ W. 59° 04′ 00″ 54 m.	0	31·32	11·65	1·02382
	10	31·38	10·8	1·02401
	25	32·01	3·85	1·02545
	40	32·12	2·4	1·02566
	50	32·26	1·95	1·02580
Sect. XVII, 69.* July 26 8.05 a.m. N. 44° 19′ 15″ W. 58° 36′ 00″ 64 m.	0	30·90	10·95	1·02361
	10	30·89	10·8	1·02363
	25	31·37 31·83	9·9 6·3	1·02416 1·02503
	40	32·18 32·26	2·25 1·95	1·02571 1·02580
	50	32·27	1·95	1·02581
	60	32·20	4·45	1·02554
Sect. XVII, 70. July 26 11.40 a.m. N. 44° 05′ 00″ W. 58° 05′ 00″ Over 1,000 m.	0	31·91	13·9	1·02397
	25	32·57	8·25	1·02535
	50	33·08	4·2	1·02626
	75	33·49	3·2	1·02668
	100	34·15	5·55	1·02696
	150	34·57	6·25	1·02720
	200	34·77	6·3	1·02735
	300	34·62	4·3	1·02748
	400	34·76	4·15	1·02759
Sect. XVII, 71. July 26 2.30 p.m. N. 43° 57′ 00″ W. 57° 46′ 30″ Over 1,000 m.	0	32·01	15·15	1·02397
	25	32·65	9·8	1·02517
	50	33·00	4·3	1·02619
	75	33·64	3·9	1·02674
	100	34·19	5·6	1·02698
Sect. XVIII, 72. July 26 3.45 p.m. N. 43° 51′ 30″ W. 57° 33′ 00″ Over 1,000 m.	0	32·01	16·1	1·02346
	10		12·55	
	25	32·83	9·1	1·02542
	50	33·04	2·6	1·02638
	75	33·26	0·85	1·02668
	100	33·95	4·7	1·02689
	150	35·01	9·3	1·02710
	200	35·04	8·9	1·02719
	300	34·49	4·0	1·02740
	400	34·88	5·6	1·02753
Sect. XVII, 73. July 26 5.45 p.m. N. 43° 46′ 00″ W. 57° 21′ 00″ Over 1,000 m.	0	32·54	17·6	1·02351
	25	32·72	9·8	1·02523
	50	32·99	1·35	1·02644
	75	33·84	5·2	1·02676
	100	34·59	8·4	1·02692
Sect. XVII, 74. July 26 7.00 p.m. N. 43° 41′ 00″ W. 57° 08′ 00″ Over 1,000 m.	0	32·90	18·45	1·02357
	10		13·4	
	25	34·79	16·65	1·02546
	50	34·31	10·2	1·02639
	75	35·39	13·25	1·02666
	100	35·42	12·8	1·02678
	150	35·37	11·7	1·02696
	200	35·28	10·95	1·02702
	300	35·05	8·45	1·02726
	400	34·83	6·0	1·02744

* The figures for this station are not reliable, owing to some fault in taking the observations.

TABLE I*d*.—Salinity, Temperature and Density of the water on the Nova Scotian and Newfoundland banks during the summer of 1915—*Continued.*

C. G. S. "ACADIA."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. XVII & XVIII, 75. July 26	0	32·81	16·0	1·02408
10.55 p.m.	10	33·06	16·4	1·02418
N. 43° 30′ 00″ W. 56° 43′ 00″	25	34·63	17·45	1·02514
Over 1,000 m.	50	34·78	16·1	1·02558
	75	35·59	14·5	1·02656
	100	35·51	13·2	1·02676
	150	35·41	12·2	1·02689
	200	35·35	11·2	1·02704
	300	35·15	8·9	1·02728
	400	34·63	4·7	1·02744
Sect. XVIII, 76. July 27	0	30·49	13·85	1·02276
2.45 a.m.	10	.....	13·6	....
N. 43° 55′ 30″ W. 56° 13′ 00″	25	31·33	8·65	1·02432
Over 1,000 m.	50	32·68	1·75	1·02616
	75	33·00	0·0	1·02652
	100	33·98	5·65	1·02681
	150	34·43	6·2	1·02709
	200	34·58	5·45	1·02732
	300	34·67	4·2	1·02752
	400	34·84	4·65	1·02760
Sect. XVIII, 77. July 27	0	31·27	15·3	1·02305
7.25 a.m.	10	31·92	13·55	1·02389
N. 44° 21′ 15″ W. 55° 42′ 30″	25	33·35	11·65	1·02540
Over 1,000 m.	50	33·17	4·0	1·02635
	75	33·40	3·15	1·02662
	100	33·86	5·0	1·02679
	150	34·37	5·8	1·02710
	200	34·53	5·3	1·02729
	300	34·70	4·9	1·02747
	400	34·75	4·3	1·02757

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. XVIII, 78. July 27	0	32·38	15·35	1·02389
10.15 a.m.	25	....	....	....
N. 44° 33′ 00″ W. 55° 29′ 00″	50	33·36	4·0	1·02651
Over 1,000 m.	75	33·48	2·35	1·02675
	100	34·41	6·75	1·02701
Sect. XVIII & XIX, 79. July 27	0	32·42	13·05	1·02441
12.05 p.m.	10	32·53	11·1	1·02486
N. 44° 47′ 00″ W. 55° 13′ 00″	25	32·85	9·5	1·02538
410 m.	50	33·06	5·5	1·02610
	75	33·33	2·5	1·02662
	100	33·97	4·9	1·02689
	150	34·40	5·9	1·02711
	200	34·60	6·2	1·02722
	300	34·61	4·65	1·02743
	400	34·72	4·15	1·02756
Sect. XIX, 80. July 27	0	31·97	12·3	1·02420
3.40 p.m.	10	32·00	11·2	1·02442
N. 45° 17′ 00″ W. 55° 27′ 00″	25	32·21	8·7	1·02500
155 m.	40	32·57	4·1	1·02587
	50	32·72	1·25	1·02622
	75	33·02	÷1·05	1·02657
	100	33·07	÷1·3	1·02662
	125	33·10	÷1·2	1·02663
	150	33·10	÷1·2	1·02663
Sect. XIX, 81. July 27	0	32·17	11·65	1·02448
7.20 p.m.	10	32·16	10·85	1·02462
N. 45° 48′ 30″ W. 55° 43′ 00″	25	32·50	6·3	1·02556
56 m.	40	32·64	3·05	1·02602
	54	32·65	2·5	1·02607

TABLE I*d*.—Salinity, Temperature and Density of the water on the Nova Scotian and Newfoundland banks during the summer of 1915—*Continued.*

C. G. S. "ACADIA."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°	
Sect. XIX, 82. July 27	0	32·20	12·15	1·02442
10.00 p.m.	10	32·20	12·15	1·02442
N. 46° 11′ 00″ W. 55° 54′ 00″	25	32·38	8·8	1·02511
58 m.	40	32·42	5·9	1·02555
	50	32·70	0·95	1·02622
Sect. XIX & XX, 83. July 28	0	31·89	11·3	1·02433
12.45 a.m.	10		10·75	
N. 46° 32′ 00″ W. 56° 04′ 00″	25	31·96	8·75	1·02480
172 m.	50	32·56	1·3	1·02609
	75	32·73	÷0·05	1·02630
	100	32·82	÷0·8	1·02640
	125	32·91	÷1·2	1·02648
	150	33·00	÷1·45	1·02656
	170	33·04	÷1·4	1·02660
Sect. XX, 84. July 28	0	32·24	11·9	1·02449
4.35 a.m.	10	32·23	11·75	1·02452
N. 46° 17′ 00″ W. 56° 37′ 00″	25	32·51	9·45	1·02512
60 m.	40	32·54	4·9	1·02576
	50	32·74	0·3	1·02629
Sect. XX, 85. July 28	0	30·93	12·9	1·02329
8.05 a.m.	20	31·54	7·3	1·02467
N. 46° 02′ 45″ W. 57° 09′ 00″	40	32·56	4·9	1·02578
492 m.	50	33·39	7·15	1·02615
	75	33·26	3·25	1·02650
	100	33·42	1·8	1·02675
	150	34·17	5·1	1·02703
	200	34·46	5·35	1·02725
	300	34·62	4·1	1·02750
	400	34·78	4·0	1·02763
Sect. XX, 86. July 28	0	31·14	13·8	1·02327
11.10 a.m.	25	32·86	8·9	1·02548
N. 45° 47′ 00″ W. 57° 34′ 00″	40	......	5·4	.
455 m.	50	32·92	2·6	1·02628
	75	33·17	÷0·4	1·02667
	100	33·33	1·4	1·02670
	150	34·16	4·5	1·02709
	200	34·36	4·85	1·02720
	300	34·58	4·1	1·02747
	400	34·78	4·0	1·02763
Sect. XX, 87. July 28	0	31·36	14·65	1·02327
2.15 p.m.	15	32·16	10·9	1·02461
N. 45° 38′ 30″ W. 57° 59′ 30″	25	32·73	7·95	1·02552
330 m.	50	32·94	2·0	1·02634
	75	33·10	÷0·4	1·02661
	100	33·31	1·15	1·02670
	150	34·07	4·75	1·02699
	200	34·23	3·95	1·02720
	300	34·63	4·3	1·02749
Sect. XX, 88. July 28	0	30·27	13·9	1·02258
5.45 p.m.	25	31·34	4·25	1·02487
N. 45° 26′ 00″ W. 58° 34′ 30″	40	31·68	1·2	1·02539
130 m.	50	31·86	1·7	1·02551
	75	32·15	0·2	1·02582
	100	32·50	0·15	1·02610
	125	33·04	0·55	1·02652

TABLE I*d*.—Salinity, Temperature and Density of the water on the Nova Scotian and Newfoundland banks during the summer of 1915—*Concluded.*

C. G. S. "ACADIA."

Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density	Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		‰	°				‰	°	
Sect. XX, 89. July 28	0	30·52	13·95	1·02276	Stat. 91. July 29	0	29·07	12·05	1·02201
8.35 p.m. N. 45° 16′ 00″	25	30·90	9·1	1·02391	12.30 p.m.	10	29·21	12·0	1·02212
W. 59° 04′ 00″	50	31·92	0·75	1·02561	Canso Strait, off Hawkesbury	20	29·14	11·7	1·02213
130 m.	75	32·13	0·15	1·02581	50 m.	30	29·14	11·5	1·02216
	100	32·13	0·15	1·02581		45	29·14	11·45	1·02217
	125	32·24	0·05	1·02590					

TABLE Ic.—Salinity, Temperature and Density of the water along the Coast from Halifax to Newfoundland (Cabot Strait) during the autumn of 1915.

C. G. S. "ACADIA."

Station, time, position and depth.	Depth m.	Salinity ‰	Temp. C. °	Density
Stat. 92. Nov. 14 5.45—6.45 p.m. N. 44° 23′ 00″ W. 62° 54′ 30″ 158 m.	0	30·40	8·2	1·02366
	10	30·41	8·4	1·02364
	20	30·42	8·4	1·02364
	30	30·43	8·4	1·02365
	40	30·77	8·3	1·02397
	50	31·60	6·85	1·02480
	60	31·88	5·3	1·02519
	75	32·21	3·3	1·02566
	90	32·53	2·2	1·02599
	110	32·84	1·9	1·02628
Sect. XXI, 93. Nov. 14 10.00—10.50 p.m. N. 44° 09′ 00″ W. 62° 13′ 00″ 175 m.	0	31·73	9·15	1·02446
	10	31·74	9·3	1·02444
	25	31·72	9·3	1·02448
	40	31·74	9·3	1·02444
	50	32·86	5·2	1·02598
	60	33·12	4·15	1·02629
	75	33·24	3·9	1·02643
	100	33·60	4·85	1·02661
	120	33·91	5·95	1·02672
	160	34·39	7·4	1·02691
Sect. XXI, 94. Nov. 15 2.40—3.20 a.m. N. 44° 30′ 00″ W. 61° 39′ 00″ 172 m.	0	*31·05	8·4	1·02414
	10	32·14	9·2	1·02488
	25	31·55	9·85	1·02430
	40	31·03	8·9	1·02405
	50	30·95	8·75	1·02402
	60	32·97	5·55	1·02602
	75	33·27	4·55	1·02637
	100	33·60	4·6	1·02664
	150	34·04	6·1	1·02680
Sect. XXI, 95. Nov. 15 6.45—7.25 a.m. N. 44° 50′ 00″ W. 61° 03′ 00″ 90 m.	0	30·52	7·75	1·02381
	10	30·52	7·85	1·02380
	25	30·56	7·9	1·02382
	40	31·86	5·35	1·02518
	50	32·11	3·65	1·02555
	60	32·34	2·65	1·02581
	75	32·47	1·85	1·02598
Sect. XXI, 96. Nov. 15 10.50—11.10 a.m. N. 45° 11′ 00″ W. 60° 29′ 00″ 75 m.	0	30·61	6·95	1·02399
	10	30·63	7·2	1·02398
	25	30·72	7·3	1·02404
	40	30·86	7·3	1·02415
	50	32·16	3·5	1·02560
	60	32·41	1·95	1·02588
Sect. XXI, 97. Nov. 15 2.45—3.15 p.m. N. 45° 32′ 00″ W. 59° 53′ 00″ 190 m.	0	30·42	6·4	1·02391
	10	30·44	6·7	1·02391
	25	30·54	6·65	1·02400
	40	30·61	6·6	1·02404
	50	30·67	6·1	1·02415
	60	31·23	5·75	1·02464
	75	31·96	4·5	1·02535
	100	32·62	1·6	1·02612
	125	33·03	0·9	1·02649
	150	33·21	0·8	1·02664
	175	33·23	0·8	1·02666
Sect. XXI, 98. Nov. 15 6.50—7.20 p.m. N. 45° 54′ 00″ W. 59° 17′ 00″ 83 m.	0	30·61	6·15	1·02409
	10	30·96	6·3	1·02435
	25	30·97	6·3	1·02436
	40	31·00	6·3	1·02439

* Some errors in the labelling of the water samples must have occurred at this station in a depth of o to 50 m. (see p. . .).

Table Ie.—Salinity, Temperature and Density of the water along the Coats from Halifax to Newfoundland (Cabot Strait) during the autumn of 1915—*Continued.*

C. G. S. "ACADIA."

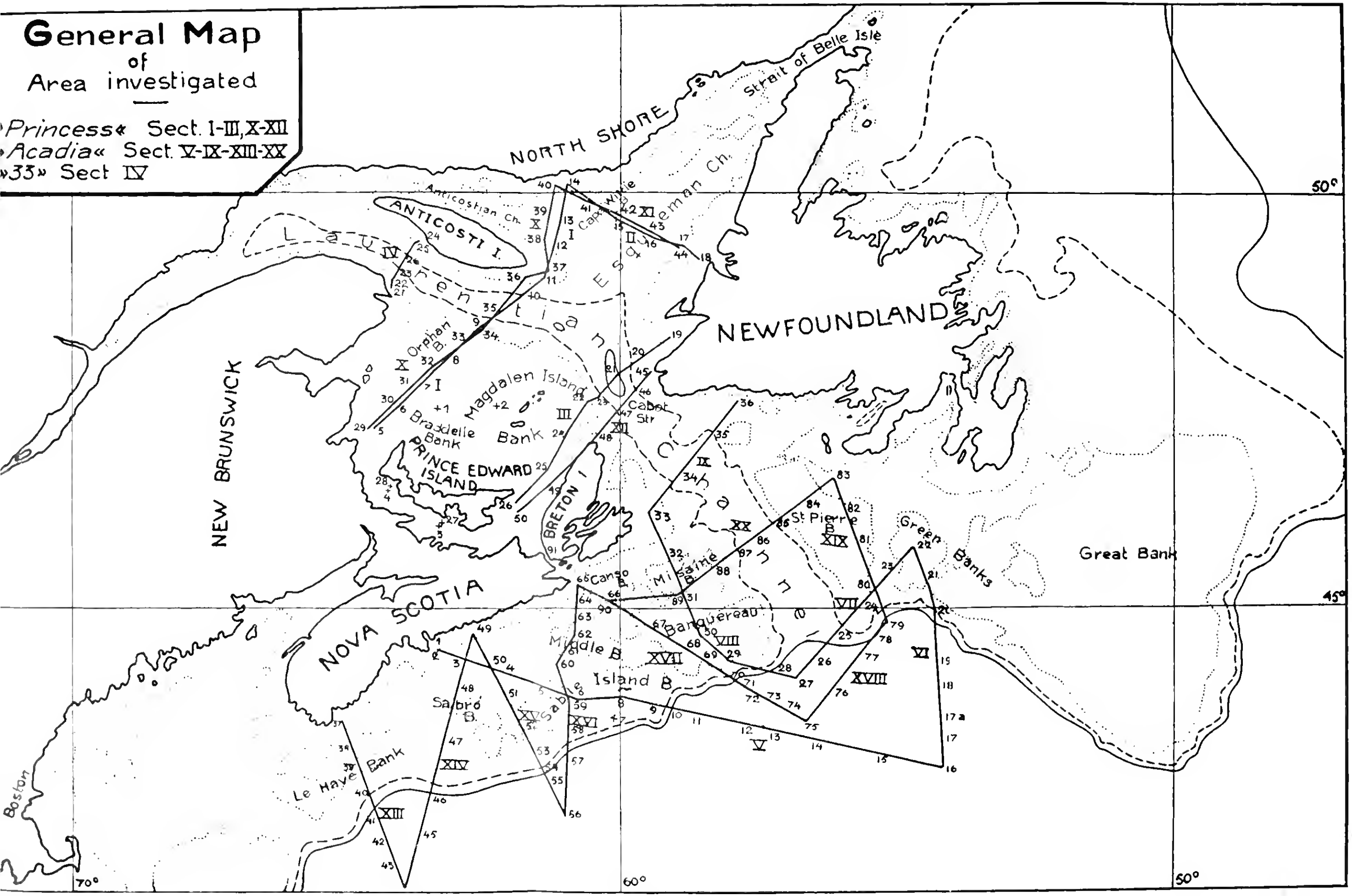
Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		⁰/₀₀	°	
Sect. XXI, 98—*Con.*	50	31·21	5·65	1·02463
	60	31·74	4·5	1·02517
	75	32·15	3·2	1·02562
Sect. XXII, 99. Nov. 15 10.15 p.m. N. 46° 17′ 00″ W. 59° 33′ 00″ 73 m.	0	29·97	7·45	1·02343
	10	30·06	7·5	1·02348
	25	30·09	7·5	1·02351
	40	30·11	7·45	1·02354
	50	30·16	7·4	1·02358
	60	30·32	7·35	1·02372
Sect. XXII, 100. Nov. 23 1 p.m. N. 46° 39′ 00″ W. 58° 52′ 00″ Over 400 m.	0	32·24	4·8	1·02553
	25	32·15	4·65	1·02548
	50	32·23	4·7	1·02554
	75	32·28	4·45	1·02559
	100	32·85	0·75	1·02636
	125	33·12	0·0	1·02661
	150	33·40	0·65	1·02681
	200	33·86	2·8	1·02701
	300	34·42	4·2	1·02732
	400	34·70	3·95	1·02748
Sect. XXII, 101. Nov. 23 9 a.m. N. 47° 03′ 00″ W. 58° 24′ 00″ Over 400 m.	0	32·20	4·9	1·02549
	25	32·20	5·0	1·02548
	50	32·38	4·55	1·02569
	75	32·94	0·6	1·02643
	100	32·98	0·3	1·02648
	125	33·21	0·05	1·02668
	150	33·51	0·35	1·02691
	200	34·06	3·4	1·02712
	300	34·61	4·2	1·02749
	400	34·80	4·1	1·02765
Sect. XXII & XXIII, 102. Nov. 23 5 a.m. N. 47° 26′ 00″ W. 57° 54′ 00″ 231 m.	0	32·11	4·45	1·02546
	25	32·14	3·8	1·02556
	50	32·31	3·45	1·02572
	75	32·60	1·8	1·02609
	100	32·85	0·65	1·02636
	110	33·035	0·3	1·02653
	125	33·07	0·2	1·02656
	135	33·17	0·65	1·02662
	150	33·21	0·5	1·02665
	200	33·61	1·95	1·02688
Sect. XXIII, 103. Nov. 23 1.45 a.m. N. 47° 24′ 00″ W. 58° 28′ 00″ 185 m.	0	32·11	4·85	1·02542
	25	32·13	4·75	1·02545
	50	32·23	3·35	1·02557
	75	32·77	1·35	1·02626
	110	32·85	0·65	1·02636
	125	32·945	0·25	1·02646
	150	33·12	0·1	1·02660
	175	33·51	1·35	1·02685
Sect. XXIII, 104. Nov. 22 10.35—11.15 p.m. N. 47° 21′ 30″ W. 59° 08′ 30″ Over 400 m.	0	32·205	4·55	1·02553
	25	32·20	4·5	1·02553
	50	32·48	2·95	1·02590
	75	32·70	1·5	1·02618
	100	32·87	0·5	1·02638
	125	33·14	0·05	1·02663
	150	33·37	0·2	1·02680
	200	33·77	2·75	1·02694
	300	34·45	4·2	1·02735
	400	34·74	4·0	1·02758

TABLE Ie.—Salinity, Temperature and Density of the water along the Coast from Halifax to Newfoundland (Cabot Strait) during the autumn of 1915—*Concluded.*

C. G. S. "ACADIA."

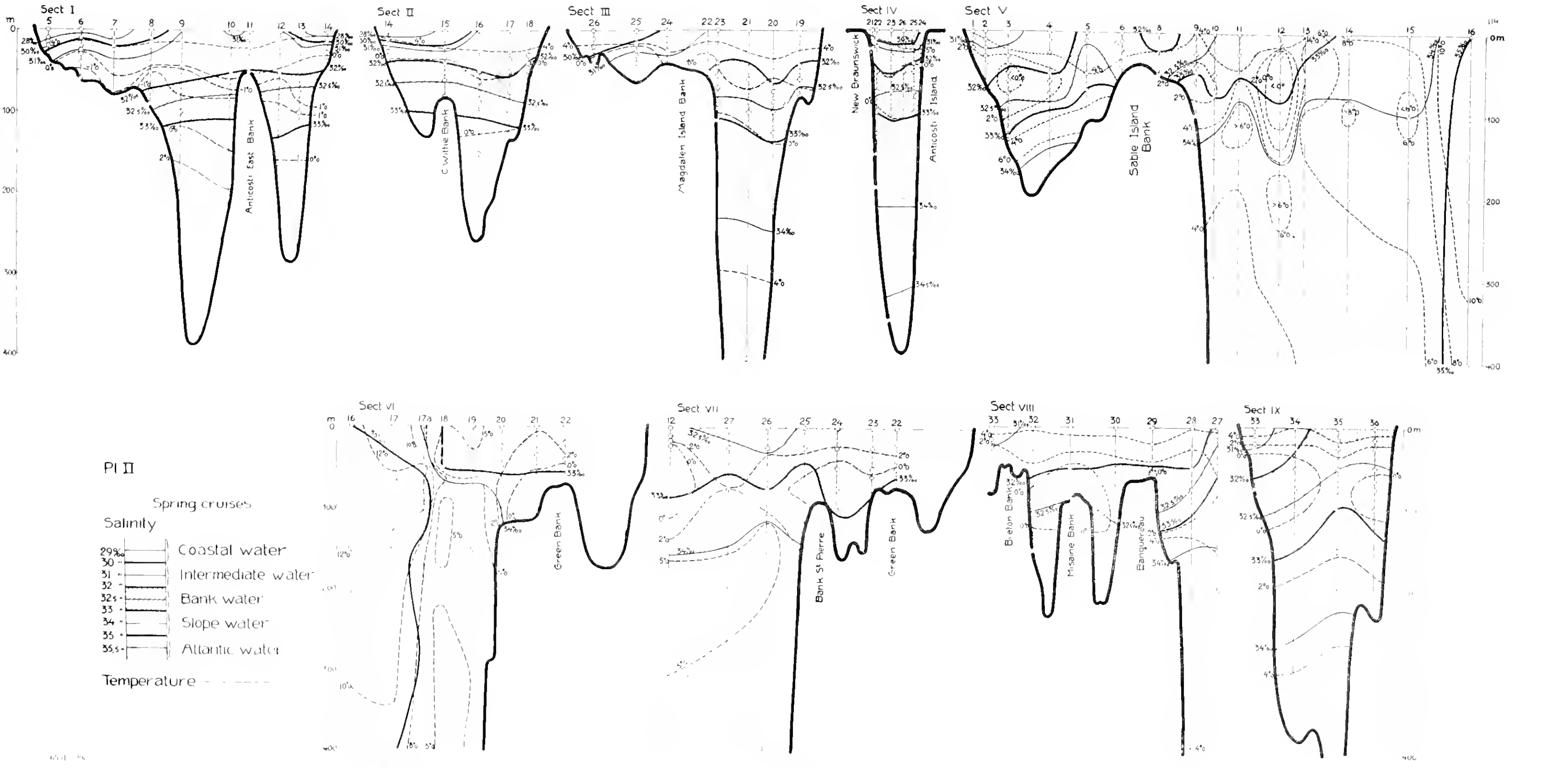
Station, time, position and depth.	Depth m.	Salinity	Temp. C.	Density
		°/₀₀	°	
Sect. XXIII, 105. Nov. 22	0	32·15	5·6	1·02537
7.50—8.30 p.m.	25	32·10	5·55	1·02533
N. 47° 06′ 00″ W. 59° 28′ 30″	50	32·10	5·4	1·02535
	75	32·565	2·65	1·02599
Over 400 m.	100	32·78	1·1	1·02628
	125	32·95	0·35	1·02645
	150	33·33	0·8	1·02674
	200	33·96	2·95	1·02708
	300	34·59	4·3	1·02745
	400	34·785	4·25	1·02761
Sect. XXIII, 106. Nov. 22	0	30·70	5·1	1·02428
5—5.40 p.m.	25	31·89	4·7	1·02527
N. 46° 51′ 00″ W. 59° 47′ 00″	50	32·21	4·55	1·02553
	75	32·65	2·9	1·02604
235 m.	90	33·00	0·05	1·02651
Sect. XXIII, 106—*Con.*	100	33·06	0·75	1·02652
	110	33·13	0·3	1·02660
	125	32·27	3·05	1·02573
	150	31·34	4·65	1·02484
	200	32·12	4·15	1·02550
	225	32·385	2·2	1·02571
Sect. XXIII, 107. Nov. 22	0	30·28	5·95	1,02387
3 p.m.	10	30·27	5·8	1·02389
N. 46° 40′ 00″ W. 60° 01′ 00″	25	30·30	5·75	1·02390
	40	30·31	5·7	1·02391
128 m.	50	30·44	5·35	1·02406
	60	30·71	4·85	1·02431
	75	31·17	4·3	1·02474
	100	32·65	1·9	1·02612
	125	33·17	1·5	1·02656

Pl. 1

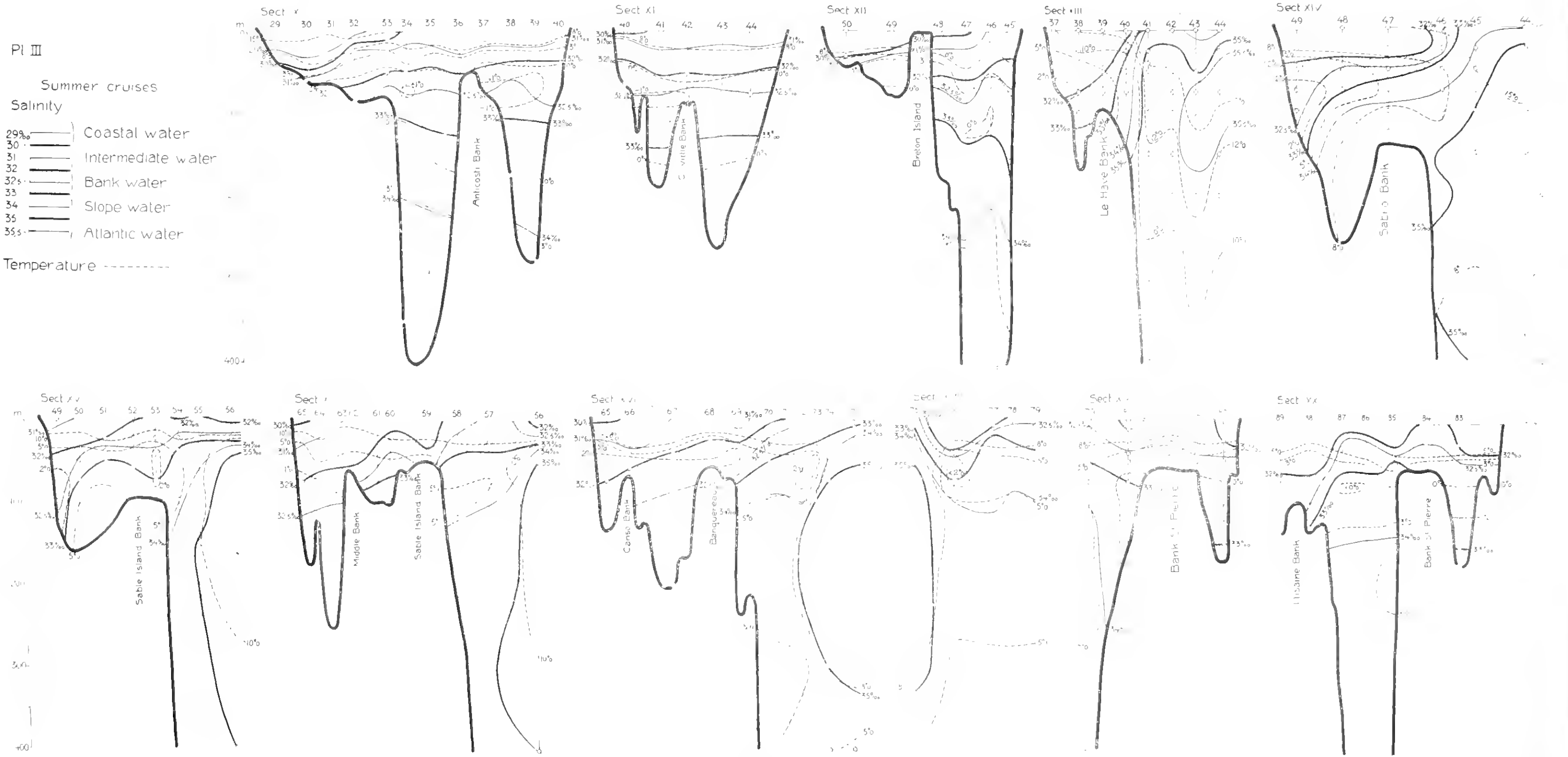


Errata.—Read "C. Breton Island" for "Breton I." and "Sambro" for "Sabro." Also "Acadia Sect. V-IX, XIII-XX" for "Acadia Sect. V-IX-XIII-XX."

6551—29b.


Sect I
Anticosti East Bank
Sect II
C Wittie Bank
Sect III
Magdalen Island Bank
Sect IV
New Braunswick
Anticosti Island
Sect V
Sable Island Bank
Sect VI
Green Bank
Sect VII
Bank St Pierre
Green Bank
Sect VIII
Brelon Bank
Misaine Bank
Banquereau
Sect IX
Pl II
Spring cruises
Salinity
Coastal water
Intermediate water
Bank water
Slope water
Atlantic water
Temperature

Pl III



Summer cruises
Salinity
29‰ 30 Coastal water
31 32 Intermediate water
32.5 33 Bank water
34 35 Slope water
35.5 Atlantic water
Temperature
Sect X
Sect XI
Sect XII
Sect XIII
Sect XIV
Sect XV
Anticosti Bank
Breton Island
Le Have Bank
Sable Island Bank
Middle Bank
Canso Bank
Banquereau
Bank St Pierre

CANADIAN FISHERIES EXPEDITION, 1914-15.

BIOLOGY OF ATLANTIC WATERS OF CANADA.

SOME QUANTITATIVE AND QUALITATIVE PLANKTON STUDIES OF THE EASTERN CANADIAN PLANKTON.

BY

A. G. HUNTSMAN, B.A., M.B.,

University of Toronto, Curator of the Atlantic Biological Station, St. Andrews, New Brunswick.

1.—Introduction.

2.—Quantity of Plankton.

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PREFATORY NOTE.

By Prof. E. E. Prince, Dominion Commissioner of Fisheries, and Chairman of the Biological Board of Canada.

A note of explanation appears desirable respecting the series of papers by Dr. Huntsman which are here brought together. They are separate reports upon his work during the season of 1915 (under Dr. Hjort's Canadian Fisheries Expedition); but, in subject and treatment, they form practically one research, the first short paper being of the nature of an introduction; the second paper has a general character, the quantitative phase being emphasized in it, and demonstrating that in colder and deeper water the plankton content is more abundant than in warmer, more superficial, strata, while the plankton as a whole seeks during the night a deeper level than during the day. The third paper embodies a detailed study of the distribution of *Sagitta*, or rather of the Chaetognaths, of which Dr. Huntsman determines ten species in our eastern coastal waters, seven species of *Sagitta*, and one species each of *Pterosagitta*, *Eukrohnia*, and *Khronitta*. These delicate, actively swimming creatures, of a glassy translucency and needlelike in form, are typical pelagic forms, at one time included amongst sea-worms; but now regarded as an aberrant group. They proved to be very abundant, and must form an important element of food for fishes, especially in the younger stages of the latter. These Chaetognaths vary in length from half an inch to two inches (50mm.) in length, and Dr. Huntsman's elaborate study is of special interest and importance, and illustrated by twelve figures, four of them being drawings of the creatures themselves, and eight of them charts showing the details of their distribution in the sea.

INTRODUCTION.

By A. G. Huntsman, B.A., M.B., University of Toronto, Curator of the Atlantic Biological Station, St. Andrews, N.B.

In undertaking a study of certain groups of animals from the plankton, as proposed by Dr. Johan Hjort, I have been obliged to limit it to certain forms that could be identified with reasonable ease. Not having a special knowledge of these groups, it has been necessary for me to repeatedly alter the scope and method of work during the progress of the investigation. This has resulted in a lack of uniformity in the records that would have been avoided if it had been possible to formulate a definite plan at the beginning.

This collection of plankton has been of the greatest interest, not only because it came from localities representative of the greater part of our Atlantic waters and permitted a survey of the whole region, but also because it came from waters of such diverse nature. It has afforded an unequalled opportunity for an introduction to, if not a solution of, the problem of the factors that are concerned in the distribution of our planktonic species. The subject has been considered from that standpoint, namely, to determine, if possible, the distribution, both vertical and horizontal, and the relative abundance, of each species.

The time was too short for taking many closing-net hauls, which are so essential in determining the vertical distribution. It was also unavoidable that the hauls were not perfectly reliable for quantitative comparison of the regions covered. Some of the factors to which this was due are: the well-known irregularity in the local distribution of species (their occurrence in streaks or shoals which may be taken or missed in successive hauls at the same locality); the hauls not having been taken uniformly either from the bottom, from a certain depth, or to the surface (at certain stations no vertical hauls were made); the hauls not having been always strictly vertical owing to the drifting of the ship before the wind; the variations in the coefficient of filtration of the net, depending upon its condition, the character of the plankton and the rate of hauling; the individual factor, the hauls having been taken by different persons; occasionally incomplete or faulty preservation; the difficulty in recognizing small specimens in large quantities of plankton; the unsuitability of the method of capture for large species (capturing too few) and for small species (their passage through or retention in the net depending upon the other elements in the plankton).

For these reasons the results as to distribution must be accepted with reserve and considered as tentative merely. It has been necessary, however, to take the results as they stand and, notwithstanding the large element of doubt, to put forth general views which future investigation may either confirm or refute. Where possible, account has been taken of these factors. Knowing the irregularities in the method of obtaining the plankton, I have been frequently astonished at the apparent completeness of the picture presented in the distribution of many of the species.

The charts of distribution have been made graphic by lining in the supposed areas of distribution, the positions of the stations from which data were obtained being indicated by circles. This method is objectionable in that it shows perhaps more than the facts warrant, but, since all the data are published, false impressions may be corrected by reference to them.

In some instances the hauls that were taken were not of the proper kind to show definitely the presence or the absence of a species. Such stations have not been considered in plotting the charts, although many of them have been indicated on the charts. For example, no vertical hauls were taken at Acadia Stations 10, 18-22, 27, 33, 43, 61, 77, and 90; the vertical hauls of the cruises of the *Princess* were not deep enough to explore the peculiar bottom water of the deeper portions of the gulf. It has not been thought necessary to refer in every instance to these evident imperfections in the material.

The tow hauls are the most unreliable, owing to lack of information in the records as to the manner in which they were taken. The depths given are in most instances merely presumptions from the scanty data available. The tow hauls were taken in a great variety of ways.

There has been a possibility of considerable error arising in counting the specimens, for, owing to the large amount of plankton and the short time available for the work, it was necessary in many cases to take only a portion of the catch for examination and for the determination of the number of individuals. A varying portion was taken, depending largely upon the quantity of the plankton and the number and the range of size of each species. The figures indicate the manner in which the determination was made: 15-10 meaning that 15 individuals were counted in approximately one-tenth of the entire haul. With many of the tow hauls arbitrary signs have been used to indicate roughly the relative number of individuals: × meaning that the species occurred or that only a few specimens could be seen; ×× meaning that there were more numerous; + meaning that there were many; and ++ meaning that there were very many.

There is also a doubt as to proper identification when large numbers are examined rapidly. Errors from these causes have been detected and corrected in a number of instances. Naturally, the larger the individuals the less likelihood is there for such errors to arise.

2.—ON THE QUANTITY OF PLANKTON OBTAINED AT ONE HUNDRED AND SEVENTY-NINE STATIONS DURING THE CANADIAN FISHERIES EXPEDITION, 1915.

(By A. G. Huntsman, B.A., M.B., Curator of the Atlantic Biological Station, St. Andrews, New Brunswick.)

At Dr. Hjort's request, I have determined roughly the amount of plankton taken in the various hauls during the cruises of C.G.S. *Acadia*, C.G.S. *Princess*, and C.G.S. *No. 33*. For a number of reasons the data are far from being accurate. The plankton was not measured at the time it was obtained. In most cases all of the plankton was preserved, but at times only a portion was retained and the rest thrown away. In some of these cases (but not all) an estimate was made of the total amount at the time it was taken. In other cases the plankton was partially sorted or a portion taken out before being measured. As a result, some of the larger quantities should be still larger, but the smaller quantities are approximately correct.

The table given below is self-explanatory, but some comment may be advisable. Under "hour" are given the times of commencement and finish of the station as far as the records were kept. When only one time is given, it is the time at which the station was begun. The depth of water is given in metres. When no sounding in metres was made, the sounding in fathoms has been converted into metres for uniformity.

The hauls of plankton were made in three ways: (1) *Vertical hauls* (vert.) in which the net was lowered to a certain depth and then hauled to the surface; (2) *vertical closing hauls* (vert. clos.), similar but closed some distance before the surface was reached; and (3) *tow hauls* (tow), in which the net was towed at a variable distance from the surface. The vertical hauls were not always vertical owing to the drifting of the ships, which in some cases was considerable. The numbers given for the depths of the hauls indicate the amount of wire out, which was occasionally more than the actual depth at the station. In *Acadia* stations 44 to 91 the vertical hauls were made in fathoms. These have been converted to round numbers in metres. No time has been given for the tow hauls. The records are not complete in this respect. In many of these hauls the net was towed by the drifting of the ship before the wind. Sometimes it was part drift and part steam towing. The rate at which the net was towed varied within such wide limits that the time could not well be used for purposes of comparison. This does not apply to the tows made by C.G.S. *No. 33*. The letter "c" (*circa*) before the depth indicates that the depth has been presumed only.

With two exceptions all the hauls were made with a net having a mouth with a diameter of one metre and made of silk bolting cloth with from fifteen to sixteen meshes to the centimetre. Certain hauls made at *Princess* stations 1 and 2 were made with a net of finer mesh (gear 20).

When two hauls were made at the same depth at the same station, these have been distinguished by the Roman numerals I and II.

The plankton was measured after settling in the bottles in which it was preserved. Similar bottles were graduated and the amount of plankton determined by comparing the bottle containing the plankton with the graduated bottle of the same kind. This was a quick but rough method of determining the amount.

The measurements confirm the observations made during the cruises that: (1) there is more plankton in colder water, (2) there is more plankton where the water is deeper, and (3) the plankton as a whole is at a deeper level during the day.

PLANKTON.—HAULS AND QUANTITY.

C. G. S. "ACADIA."

No. of Station	Date.	Hour.	Depth (metres).	Depth of Haul (metres).	Quantity (in c.c.)
2	May 29 ..	11.05 a.m.–12.05 p.m.	60	50– 25 (vert. clos.).....	15
				20– 0 (vert.).........	2
3	May 29 .	2.30–4.30 p.m	99–144	100– 50 (vert. clos.).....	35
				30– 0 (vert.)..........	10
				0 (tow)...........	30
4	May 29..	7.30 p.m	171	150–100 (vert. clos.).....	70
				80– 40 (vert. clos.).....	15
				30– 0 (vert.)..........	25
5	May 30 .	1.00–2.30 a.m..........	72	60– 0 (vert.).........	25
				0 (tow)...........	170
6	May 30 ...	5.30–6.30 a.m	45	40– 0 (vert.)..........	35
				0 (tow)...........	35
7	May 30..	10.15–11.15 a.m	108	0 (tow).........	5
8	May 30...	12.55 p.m...	50	50(?)– 0 (vert.)..........	5
				0 (tow)...........	25
9	May 30	5.00–6.00 p.m..	104	25– 0 (vert.)..........	5
				0 (tow)...........	20
10	May 30...	7.15–9.00 p.m	732	0 (tow)...........	800

PLANKTON.—HAULS AND QUANTITY—*Continued.*

C. G. S. "ACADIA"—*Continued.*

No. of Station	Date.	Hour.	Depth (metres).	Depth of Haul (metres).	Quantity in c.c.
11	May 30-31	10.50 p.m.-12.50 a.m	over 2,000	70- 0 (vert.)	70
				0 (tow)	800
12	May 31	4.30-6.35a.m	over 2,000	100- 0 (vert.)	70
				0 (tow)	250
13	May 31	8.45-9.45 a.m	over 2,000	70- 0 (vert.)	30
14	May 31	12.55-2.30 p.m.	over 2,000	200- 0 (vert.)	70
				0 (tow)	5
15	May 31	7.15-9.00 p.m	over 2,000	100- 0 (vert.)	175
				0 (tow)	550
16	June 1	1.45-3.15 a.m	over 2,000	200- 0 (vert.)	90
				0 (tow)	160
17	June 1	9.00-10.15 a.m	over 2,000	200- 0 (vert.)	50
				0 (tow)	20
18	June 1	4.30 p.m	over 2,000	0 (tow)	60
19	June 1	8.15-10.00 p.m	over 2,000	0 (tow)	100
20	June 2	1.00 a.m	90	0 (tow)	45
21	June 2	3.45-4.45 a.m	115	0 (tow)	45
22	June 2	7.25-7.50 a.m	75	0 (tow)	25
23	June 2	10.35 a.m	99	70- 0 (vert.)	10
				0 (tow)	7
24	June 2	2.15-3.00 p.m.	118	100- 0 (vert.)	25
				0 (tow)	25
25	June 2	5.40-6.30 p.m	122	120- 0 (vert.)	60
				10(?)-0 (tow)	15
26	June 2	10.00-11.15 p.m	over 400	100- 0 (vert.)	55
				0 (tow)	400
27	June 3	2.10-3.30 a.m	over 400	0 (tow)	400
28	June 3	6.15-7.45 a.m	over 400	100- 25 (vert. clos.)	65
				0 (tow)	80
29	June 3	10.55 a.m.-12 noon	57	55- 0 (vert.)	10
				0 (tow)	5
30	June 3	3.00-3.45 p.m	126	120 ? -0 (vert.)	25
				0 (tow)	25

PLANKTON.—HAULS AND QUANTITY—*Continued.*

C. G. S. "ACADIA."—*Continued.*

No. of Station.	Date.	Hour.	Depth (metres).	Depth of Haul (metres).	Quantity (in c.c.)
31	June 3	7.30–8.30 p.m.	82	75(?)–0 (vert.)	70
				0 (tow)	75
32	June 3–4	11.15 p.m.–12.15 a.m.	153	100– 25 (vert. clos.)	125
				0 (tow)	115
33	June 4	3.50–4.50 a.m.	70	0 (tow)	?
34	June 4	7.45–8.45 a.m.	c. 360	100– 0 (vert.)	90
				0 (tow)	32
35	June 4	11.55 a.m.–12.55 p.m.	c. 450	125– 25 (vert. clos.)	70
				0 (tow)	20
36	June 4	3.30–4.30 p.m.	226	100– 15 (vert. clos.)	20
				0 (tow)	30
37	July 21	5.00 p.m.	62	60– 20 (vert. clos.)	15
				60– 0 (vert.)	15
				20– 0 (vert.)	1 (?)
				0 (tow)	100
38	July 21	8.00 p.m.	170	150– 0 (vert.)	60
				100– 0 (vert.)	75
				0 (tow)	110
39	July 21	11.00 p.m.	95	100– 0 (vert.)	50
				25– ? (vert.)	50
				0 (tow)	75
40	July 22	2.00 a.m.	134	125– 0 (vert.) I	25
				125– 0 (vert.) II	25
				0 (tow)	12
41	July 22	5.30–6.30 a.m.	360	200– 0 (vert.)	5 (?)
				100– 0 (vert.)	2 (?)
				0 (tow)	10 (?)
42	July 22	9.00 a.m.	over 1,000	200– 0 (vert.)	5
				0 (tow)	5
43	July 22	11.50 a.m.	over 1,000	0 (tow)	5
44	July 22	3.00 p.m.	over 1,000	270– 0 (vert.)	25
				0 (tow)	40

PLANKTON.—HAULS AND QUANTITY—*Continued.*

C. G. S. "ACADIA"—*Continued.*

No. of Station	Date.	Hour.	Depth (metres).	Depth of Haul (metres).	Quantity (in c.c.)
45	July 22	8.10 p.m.	over 1,000	270– 0 (vert.)	50
				90– 0 (vert.)	5
				0 (tow)	50
46	July 23	1.00 a.m.	over 1,000	270– 0 (vert.)	130
				0 (tow)	25
47	July 23	6.30 a.m.	140	125– 0 (vert.)	25
				90– 0 (vert.)	15
				0 (tow)	10
48	July 23	11.00 a.m.	248	70–2 0 (vert.)	70
				45– 0 (vert.)	2
				0 (tow)	25
49	July 23	3.35 p.m.	126	125– 0 (vert.) I	35
				125– 0 (vert.) II	35
				0 (tow)	100
50	July 23	7.30 p.m.	151	145– 55 (vert. clos.)	80
				145– 0 (vert.)	55
				55– 0 (vert.)	25
				0 (tow)	45
51	July 23	10.25 p.m.	131	125– 55 (vert. clos.)	60
				125– 0 (vert.)	60
				0 (tow)	100
52	July 24	1.45 a.m.	99	90– 0 (vert.) I	40
				90– 0 (vert.) II	45
				0 (tow)	25
53	July 24	4.45 a.m.	95	90– 0 (vert.)	40
				0 (tow)	120
54	July 24	7.30 a.m.	over 1,000	270– 0 (vert.)	10
				125– 0 (vert.)	5
				0 (tow)	5
55	July 24	10.25 p.m.	over 1,000	270– 0 (vert.)	15
				90– 0 (vert.)	5
				0 (tow)	5
56	July 24	2.15 p.m.	over 1,000	375–250 (vert. clos.)	15
				250– 0 (vert.)	10

PLANKTON.—HAULS AND QUANTITY—*Continued.*

C. G. S. "ACADIA"—*Continued.*

No. of Station	Date.	Hour.	Depth (metres).	Depth of Haul (metres).	Quantity (in c.c.)
57	July 24	7.18 p.m.	over 1,000	270– 90 (vert. clos.)	50
				90– 0 (vert.)	35
				0 (tow)	25
58	July 24	10.35 p.m.	187	180– 55 (vert. clos.)	30
				155– 0 (vert.)	50
				55– 0 (vert.)	25
				0 (tow)	10
59	July 25	12.00 a.m.	45	45– 0 (vert.)	25
				0 (tow)	500
60	July 25	6.53 a.m.	99	90– 0 (vert.)	65
				0 (tow)	20
61	July 25	7.30 a.m.	72	0 (tow)	45
62	July 25	10.05 a.m.	61	55– 0 (vert.) I	40
				55– 0 (vert.) II	75
				0 (tow)	over 65
63	July 25	11.55 p.m.	53	55– 0 (vert.)	60
				0 (tow)	50
65	July 25	5.15 p.m.	90	110– 0 (vert.)	10
				90– 0 (vert.)	10
				0 (tow)	25
66	July 25	7.55–8.30 p.m.	63	55– 0 (vert.) II	15
				55– 0 (vert.) II	12
				0 (tow)	150
67	July 26	11.55–12.30 a.m.	198	190– 0 (vert.)	150
67	July 26	11.55–12.30 a.m.	198	90– 0 (vert.)	50
				0 (tow)	230
68	July 26	3.55 a.m.	53	45– 0 (vert.) I	5
				45– 0 (vert.) II	8
				0 (tow)	50
				5– 0 (tow)	20
				c. 20– 10 (tow)	100

PLANKTON.—HAULS AND QUANTITY—Continued.

C. G. S. "ACADIA"—Continued.

No. of Station	Date.	Hour.	Depth (metres).	Depth of Haul (metres).	Quantity (in c.c.)
69	July 26	8.05 a.m.	68	60– 0 (vert.) I	20
				60– 0 (vert.) II	5
				5– 0 (tow)	1 (?)
				c. 20– 10 (tow)	10
70	July 26	11.40–1.00 p.m.	over 1,000	325– 0 (vert.)	5
				55– 0 (vert.)	1 (?)
				c. 20– 10 (tow)	4
72	July 26	3.45 p.m.	over 1,000	325– 0 (vert.)	20
				55– 0 (vert.)	2
				c. 20– 10 (tow)	5
74	July 26	7.00 p.m.	over 1,000	325– 0 (vert.)	10
				55– 0 (vert.)	2
				c. 20– 10 (tow)	15
75	July 26	10.55 p.m.	over 1,000	325– 0 (vert.)	25
				55– 0 (vert.)	5
				c. 20– 10 (tow)	50
76	July 27	2.45 a.m.	over 1,000	270– 0 (vert.)	40
				c. 20– 10 (tow)	75
77	July 27	7.25 a.m.	over 1,000	c. 20– 10 (tow)	8
79	July 27	12.05 p.m.	360	325– 0 (vert.)	20
				55– 0 (vert.)	35
80	July 27	3.40–4.15 p.m.	168	145– 0 (vert.)	45
				55– 0 (vert.)	25
				c. 20– 10 (tow)	50+
81	July 27	7.20 p.m.	60	55– 0 (vert.)	25
				c. 20– 10 (tow)	85
82	July 27	10.00 p.m.	69	55– 0 (vert.) I	15
				55– 0 (vert.) II	20
				c. 20– 10 (tow)	55 + c. 25,000 (Aurelia)
83	July 28	12.45 a.m.	172	160– 0 (vert.)	70
				55–100 (vert.)	45
				c. 20– 10 (tow)	400

PLANKTON.—HAULS AND QUANTITY—*Continued.*

C. G. S. "ACADIA"—*Concluded.*

No. of Station.	Date.	Hour.	Depth (metres).	Depth of Haul (metres).	Quantity (in c.c.)
84	July 28 ..	4.35 a.m.	60	55– 0 (vert.) I	35
				55– 0 (vert.) II	50
				c. 20– 10 (tow)	230
85	July 28 ..	8.05 a.m.	over 400	270– 0 (vert.)	65
				55– 0 (vert.)	20
				c. 20– 10 (tow)	150
86	July 28 ..	11.10 a.m.–12.30 p.m.	over 400	270– 0 (vert.)	60
				55– 0 (vert.)	40
				c. 20– 10 (tow)	60
87	July 28	2.15 p.m.	331	290– 0 (vert.)	50
				55– 0 (vert.)	20
				c. 20– 10 (tow)	125
88	July 28 .	5.45 p.m.	130	110– 0 (vert.)	15
				55– 0 (vert.)	5
				c. 20– 10 (tow)	20
89	July 28 ..	8.35 p.m.	132	115– 0 (vert.)	80
				55– 0 (vert.)	55
				c. 20– 10 (tow)	235
90	July 29	c. 2.00 a.m.	c. 60	c. 20– 10 (tow)	200+
91	July 29 .	c. 12.30 p.m.	c. 45	45– 0 (vert.)	5

C. G. S. "PRINCESS."

No. of Station.	Date.	Hour.	Depth (metres).	Depth of Haul (metres).	Quantity (in c.c.)
1	May 11 ..	9.00 a.m.	68	?	100
				?	10 (gear 20)
2	May 11 ..	3.20–4.30 p.m.	45	?	90
				?	10 (gear 20)
3	June 9	11.00 a.m.–12.00 noon	20	20– 0 (vert.)	5
				0 (tow)	50
4	June 9 .	5.10 p.m.	22	20– 0 (vert.)	15
5	June 10 ..	8.50–9.35 a.m.	32	30– 0 (vert.)	25
				0 (tow)	120+
6	June 10	12.30 p.m.	57	60– 0 (vert.)	20
				0 (tow)	50

PLANKTON.—HAULS AND QUANTITY—*Continued.*

C. G. S. "PRINCESS"—*Continued.*

No. of Station.	Date.	Hour.	Depth (metres).	Depth of Haul (metres).	Quantity in c.c.)
7	June 10	3.40-4.30 p.m.	80	80– 0 (vert.)	15
				0 (tow)	90
8	June 10	8.15-10.00 p.m.	80	80 0 (vert.)	90
				40– 0 (vert.)	50
				0 (tow.)	180
				0 (tow)	10 (gear 20)
9	June 11	12.15-1.00 a.m.	over 200	100– 0 (vert.)	55
				80– 0 (vert.)	50
				0 (tow)	50
10	June 11	7.00 a.m.	over 200	100– 0 (vert.)	50+
				0 (tow)	45
11	June 11	9.30 a.m.	48	50– 0 (vert.)	20
				0 (tow)	20
12	June 11	12.30-1.30 p.m.	135	100– 0 (vert.)	30
				0 (tow)	55
13	June 11	4.00 p.m.	over 200	100– 0 (vert.)	10
14	June 11	7.00 p.m.	39	35– 0 (vert.)	3
				0 (tow)	5
15	June 12	9.00-10.00 a.m.	90	80– 0 (vert.)	25
				0 (tow)	15
16	June 12	1.15 p.m.	over 250	100– 0 (vert.) I	40
				100– 0 (vert.) II	45
				0 (tow)	20
17	June 12	4.30 p.m.	130	100– 0 (vert.) I	35
				100– 0 (vert.) II	35
				0 (tow)	40
18	June 12	7.30 p.m.	63	50– 0 (vert.)	15
				0 (tow)	2
19	June 13	2.45 a.m.	81	80– 0 (vert.)	30
				0 (tow)	50
20	June 13	6.00 a.m.	over 200	100– 0 (vert.)	50
				0 (tow)	65
21	June 13	9.45 a.m.	over 400	100– 0 (vert.)	60
				0 (tow)	15

PLANKTON.—HAULS AND QUANTITY—*Continued.*

C. G. S. "PRINCESS"—*Continued.*

No. of Station.	Date.	Hour.	Depth (metres).	Depth of Haul (metres).	Quantity (in c.c.)
22	June 13	1.30 p.m.	52	50– 0 (vert.)	20
23	June 13	4.00 p.m.	115	100– 0 (vert.)	80
24	June 15	7.30–7.55 a.m.	40	35– 0 (vert.) I	5
				35– 0 (vert.) II	8
				0 (tow)	30
25	June 15	11.00 a.m.–12 noon	63	60– 25 (vert. clos.) I	5
				60– 25 (vert. clos.) II	10
				60– 0 (vert.) I	25
				60– 0 (vert.) II	40
				0 (tow)	50
26	June 15	3.00–4.00 p.m.	39	40– 0 (vert.) I	5
				40– 0 (vert.) II	10
				0 (tow)	20
27	Aug. 3	5.30–6.30 p.m.	23	20– 0 (vert.)	1
				20– 0 (tow)	(plankton + bottom material)
28	Aug. 3–4	11.45 p.m.–1.30 a.m.	19	20– 0 (vert.) I	8
				20– 0 (vert.) II	1
				20– 0 (tow)	(plankton + bottom material)
29	Aug. 4	6.10–7.15 a.m.	32	20– 0 (vert.)	12
				c. 20– 10 (tow)	25
30	Aug. 4	10.15–11.05 a.m.	66	60– 0 (vert.)	20
				30– 0 (vert.)	10
				c. 20– 10 (tow)	150
31	Aug. 4	1.35–2.40 p.m.	65	60– 0 (vert.)	30
				30– 0 (vert.)	5
				c. 40– 0 (tow)	30
32	Aug. 4	4.55–5.50 p.m.	87	80– 0 (vert.)	50
				30– 0 (vert.)	25
				c. 40– 0 (tow)	120
33	Aug. 4	8.55–9.50 p.m.	78	80– 0 (vert.)	30
				30– 0 (vert.)	25
				c. 40– 0 (tow)	260

PLANKTON.—HAULS AND QUANTITY—*Continued.*

C. G. S. "PRINCESS"—*Continued.*

No. of Station	Date.	Hour.	Depth (metres).	Depth of Haul (metres).	Quantity (in c.c.)
34	Aug. 4-5..	11.55 p.m.-2.25 a.m.........	405	130- 0 (vert.).........	45
				30- 0 (vert.)......	10
				c. 40- 0 (tow)........	150
35	Aug. 5....	4.40-6.35 a.m...............	over 350	130- 0 (vert.)......	20?
				30- 0 (vert.)......	30?
				c. 40- 0 (tow)......	140
36	Aug. 5...	9.30-10.20 a.m..............	48	60- 0 (vert.).........	20
				c. 40- 0 (tow)..........	75
37	Aug. 5....	12.45-1.35 p.m..............	75	80- 0 (vert.)..........	10
				30- 0 (vert.)..........	5
				c. 40- 0 (tow)..........	50
38	Aug. 5 ..	4.00-5.00 p.m..............	180	130- 0 (vert.).........	20
				40- 0 (vert.).......	5
				c. 40- 0 (tow)..........	30
39	Aug. 5...	7.00-8.35 p.m.........	284	130- 0 (vert.)..........	25
				40- 0 (vert.).........	5
				c. 40- 0 (tow)..........	25
40	Aug. 5-6	11.30 p.m.-12.25 a.m....	68	70- 0 (vert.).........	15
				30- 0 (vert.)......	15
				c. 40- 0 (tow)........	55
41	Aug. 6...	3.30-4.55 a.m........	189	130- 0 (vert.)......	10
				30- 0 (vert.)......	5
				c. 40- 0 (tow)......	25
42	Aug. 6...	7.25-8.00 a.m.	90	100- 0 (vert.)	10
				30- 0 (vert.) ...	2
				c. 40- 0 (tow)......	10
43	Aug. 6....	11.00 a.m.-12 noon	265	130- 0 (vert.) I	10
				130- 0 (vert.) II	8
				30- 0 (vert.) I	2
				30- 0 (vert.) II	1
				c. 40- 0 (tow)	30
44	Aug. 6	2.30-3.10 p.m.	157	130- 0 (vert.)	25
				30- 0 (vert.)	10

PLANKTON.—HAULS AND QUANTITY—*Continued.*

C. G. S. "PRINCESS"—*Concluded.*

No. of Station.	Date.	Hour.	Depth (metres).	Depth of Haul (metres).	Quantity (in c.c.)
45	Aug. 12...	2.05–3.50 a.m.	375	130– 0 (vert.)	35
				30– 0 (vert.)	20
				c. 40– 0 (vert.)	300
46	Aug. 12...	5.25–6.35 a.m.	over 400	130– 0 (vert.)	20
				30– 0 (vert.)	15
				c. 40– 0 (tow)	210
47	Aug. 12...	8.35–10.00 a.m.	over 400	130– 0 (vert.) I	15
				130– 0 (vert.) II	10
				30– 0 (vert.)	3
				c. 40– 0 (tow)	30
48	Aug. 12...	12.40–2.00 p.m.	171	130– 0 (vert.)	30
				30– 0 (vert.)	20
				c. 40– 0 (tow)	130
49	Aug. 12...	6.25–7.05 p.m.	70	70– 0 (vert.)	40
				30– 0 (vert.)	15
				c. 40– 0 (tow)	70
50	Aug. 12–13	11.25 p.m.–12.20 a.m.	52	40– 0 (vert.) I	10
				40– 0 (vert.) II	10
				c. 40– 0 (tow)	100

PLANKTON.—HAULS AND QUANTITY—*Continued.*

C. G. S. "No. 33".

No. of Station.	Date.	Hour.	Depth (metres).	Depth of Haul (metres).	Time.	Quantity in c.c.
3	June 2	10.30 a.m	40	2– 0 (tow)	5 min	3
		11.00 a.m		20– 15 (tow)	10 min	40
4	June 2	2.30 p.m	45	2– 0 (tow)	15 min	15
5	June 3	10.55 a.m.	23	1– 0 (tow)	5 min	2
6b	June 8	3.00 p.m	c. 30	2– 0 (tow)	10 min	10
7	June 9	10.30 a.m	20	2– 0 (tow)	5 min	7
8	June 9	11.25 a.m	37	2– 0 (tow)	5 min	3
9	June 9	12.50 p.m	10	2– 0 (tow)	10 min.	10
10	June 9	2.00 p.m	39	2– 0 (tow)	5 min	5
				35– 25 (vert. clos.).		10
				25– 10 (vert. clos.).		7
				10– 0 (vert.).		5
11	June 9	5.25 p.m	59	2– 0 (tow)	5 min	20
12	June 9	7.50 p.m	67	2– 0 (tow)	5 min	70
13	June 9	9.45 p.m.	39	3– 0 (tow)	5 min.	20
14	June 10	1.15 a.m	58	3– 0 (tow)	5 min	50
15	June 10	4.35 a.m	38	2– 0 (tow)	5 min	5
16	June 10	7.30 a.m.	?	2– 0 (tow)	5 min	3
17	June 11	8.20 a.m	39–37	2– 0 (tow)	5 min	35
				2– 0 (tow)	20 min	55
19a	June 24	4.30 p.m	90	2– 0 (tow)	5 min	30
19b	June 24	5.45 p.m		2– 0 (tow)	20 min	40
21	June 25	7.50 a.m	27	5– 0 (tow)	10 min	25
22	June 25	11.00 a.m	195	3– 0 (tow)	15 min	10
23	June 25	1.00 p.m	355	340–145 (vert. clos.).		100
				100– 60 (vert. clos.).		25
				45– 0 (vert.)		20
				0 (tow)	5 min	10
24	June 26	5.25 a.m	45	2– 0 (tow)	5 min	65
25	June 26	6.20 a.m	271	2– 0 (tow).	5 min	15
26	June 26	9.35 a.m.	389	30– 15 (tow).	40 min	65
				2– 0 (tow)	5 min	2
29	June 30	6.00 p.m	41	3– 2 (tow)	5 min	75

PLANKTON.—HAULS AND QUANTITY—*Continued.*

C. G. S. No. "33"—*Concluded.*

No. of Station.	Date.	Hour.	Depth (metres).	Depth of Haul (metres).	Time.	Quantity (in c.c).
35	July 7...	11.00 a.m..........	25	15– 6 (tow)........	? min......	50
36	July 8...	5.00 p.m...........	60	20– 8 (tow)........	45 min......	110
40	July 13....	? p.m...........	38	c. 9 (tow).........	? min......	95
48	July 26 ..	5.00 p.m..........	?	40– 0 (tow).........	? min......	90
49	July 27...	5.00 p.m..........	?	15– 0 (tow).........	? min......	145
54	Aug. 7...	9.15 a.m..........	110	70– 34 (tow)........	1½ hours....	2,000+
				25– 5 (tow)........	1½ hours....	2,000+
57	Aug. 9 .	3.15 p.m	210	200– 0 (vert.).......	....	75
58	Aug. 10 ..	11.10 a.m.........	50	c. 40– 0 (tow)........	20 min......	50
59	Aug. 10 .	12.50 p.m.	275	270– 0 (vert.).. ...	....	130
62	Aug. 11	?	?	30– 0 (tow).. ...	....	8
64	Aug. 13..	9.30 a.m.	?	80– 20 (tow)........	80 min......	75+
67	Aug. 17. .	?	?	30– 0 (tow)	75 min......	8
68	Aug. 17. .	7.00 p.m.	?	70– 20 (tow)........	35 min......	350
69	Aug. 18 .	4.00 a.m	?	100– 20 (tow)	45 min......	320
70	Aug. 18	2.30 p.m.	?	8– 2 (tow)........	75 min......	100

BIOLOGICAL LAUNCH "PRINCE."

No. of Station	Date.	Hour.	Depth (metres).	Depth of Haul (metres).	Quantity in (c.c.).
1	Sept. 14 .	3.45 p.m..........	c. 38	c. 35– 0 (vert.) I	18
				c. 35– 0 (vert.) II......	12
				c. 20– 10 (tow)..........	230
				0 (tow)..........	40
2	Sept. 14 .	4.30–5.00 p.m.........	c. 100	100– 0 (vert.)	30
				c. 4– 2 (tow)..........	20
3	Sept. 15 .	10.00–11.00 a.m...........	180	180– 0 (vert.).........	220
				20– 10 (tow)..........	40
				2– 0 (tow)..........	25
4	Sept. 15	5.30 p.m	c. 35	c. 35– 0 (vert.).........	10
				15– 5 (tow)..........	10

3. A SPECIAL STUDY OF THE CANADIAN CHÆTOGNATHS, THEIR DISTRIBUTION, ETC., IN THE WATERS OF THE EASTERN COAST.

By A. G. Huntsman, B.A., M.B., University of Toronto.

(With 12 Figures.)

The transparent worm-like animals of this group were very prominent in the catches, sometimes forming more than half of the entire catch. In comparatively few instances were they lacking. The method employed was therefore a suitable one for studying their distribution, and they are as valuable as any group as an index of the character and origin of the water. They are free-living in all stages and therefore independent of the presence of banks *per se*. Their distribution will depend upon temperature, salinity, light, oxygen, currents, and food.

The measurements given are of the total length. In determining the tail percentage the tail fin was not included in the measurements. The number of jaws at first increases and later may decrease with age.

KEY TO THE SPECIES.

A_1. Two pairs of lateral fins. (Sagitta.)
  B_1. Fins (lateral) adjacent or connected.
    C_1. Anterior fin not extending to ventral ganglion.

S. lyra. Rather soft and stout. Transparent. Fins with anterior end and inner zone free from rays. 8-10-3 jaws. Tail percentage, 21-14. No collarette. Ovary rodlike. Up to 38mm.
    C_2. Anterior fin extending to ganglion.

S. maxima. Rather soft and stout. Transparent. Fins with anterior end and inner zone free from rays. 10-11-4 jaws. Tail percentage, 32-19. No collarette. Ovary rodlike. Up to 87mm.
  B_2. Fins separated.
    D_1. Fins completely traversed by rays.
      E_1. Anterior fin extending to ventral ganglion.

S. bipunctata. Stiff and slender. Rather opaque. 8-10-7 jaws. Tail percentage. 28-21. Short collarette. Ovary rodlike. Up to 25mm.
      E_2. Anterior fin not exteeding to ventral ganglion.

S. elegans. Stiff and moderately slender. 8-13-8 jaws. Tail percentage, 27-10. Short collarette. Ovary rodlike. Up to 52mm.
    D_2. Fins not completely traversed by rays (anterior end and inner zone free).
      F_1. Anterior fin extending to ventral ganglion.

S. serratodentata. Stiff and slender. Rather opaque. 5-10 jaws, tips turned inwards and inner edges serrate. Tail percentage, 32-20. Short collarette. Up to 24mm.
      F_2. Anterior fin not extending to ventral ganglion.
        G_1. Anterior teeth few (3-5), long and diverging.

S. hexaptera. Stout. Transparent. 7-10-4 jaws. Tail percentage, 26-16. No collarette. Ovary rodlike. Up to 70mm.
        G_2. Anterior teeth many (5-11), short and overlapping.

S. enflata. Soft and stout. Transparent. 7-10-7 jaws. Tail percentage, 23-14. Short collarette. Ovary sausage-shaped. Up to 30 mm.

A_2. One pair of lateral fins.
        H_1. Lateral fins on tail only. Two rows of teeth on each side.

Pterosagitta draco. Stiff. Rather opaque. Fins completely traversed by rays. 7-10-8 jaws. Tail percentage, 46-38. Collarette very thick and over whole of trunk. Ovary rodlike. Up to 11mm.

H_2. Lateral fins on both trunk and tail. One row of teeth on each side.

J_1. Fins extending to ventral ganglion and largely without rays.

Eukrohnia hamata. Stiff and moderately slender. 8-11-9 jaws. Tail percentage, 22-32. No collarette. Up to 43mm.

J_2. Fins well behind ventral ganglion, with small inner zone free from rays.

Krohnitta subtilis. Stiff and slender. 7-10 jaws. Tail percentage, 29-38. No collarette. Up to 16mm.

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(*a*) **Sagitta hexaptera** d'Orbigny.

1911. Ritter-Zahony, p. 12.

The specimens varied in size from 11-50mm. in length.

DISTRIBUTION.

C. G. S. "ACADIA."

Station No.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
16	over 2,000	200– 0 (V.)......	32 & 50	2
		0 (T.).....		0
17	over 2,000	200– 0 (V.).....	13, 21 & 36	3
		0 (T.)...........		0
44	over 1,000	270– 0 (V.).....	17 & 20	2
		0 (T.).		0
56	over 1,000	375–250 (C.)..		0
		250– 0 (V.)	50	1
74	over 1,000	325– 0 (V.)	21	1
		55– 0 (V.)..		0
		c. 20– 10 (T.)	11 & 12	2
75	over 1,000	325– 0 (V.)	30	1
		55– 0 (V.)		0
		c. 20– 10 (T.).		0

VERTICAL.—With one exception this species was obtained only in deep open net hauls, down to 200 metres or over, and did not occur in the shallower hauls (55 metres up). The exception was in a tow haul taken about 20 metres below the surface at station 74. The two individuals obtained were the smallest taken (11 and 12mm.).

The small number of individuals found is quite inadequate for determining the distribution, but the hauls made at stations where the species was found show its absence below 250 metres, its rarity above 55 metres (and then only small individuals), and its uniform presence in hauls made through intermediate depths. This agrees with the finding of Michael (1913, p. 34) who suggests its maximum abundance as existing between 50 and 100 fathoms, based upon twenty-eight specimens taken in fourteen hauls. The presence of two small individuals near the surface in station 74 on the edge of the Gulf Stream, is explained by the fact that in warm waters this species occurs quite to the surface in its younger stages.

HORIZONTAL.—*Sagitta hexaptera* is a cosmopolitan oceanic form occurring in tropical regions, but large individuals have been found far into the polar regions.

It was found only in the outermost warm water stations of the *Acadia's* cruises, and it occurred in every one. As it is a form characteristic of intermediate depths, from 100 to 200 metres, its distribution is an indication of the extent to which this intermediate water has pressed in toward our shores from the open Atlantic. The inner limit of its distribution would appear to be well outside the continental shelf, perhaps sixty or more miles in May and June, and rather closer, from twenty to forty miles, in July and August. Its distribution (shown for July-August by the vertical interrupted lines in fig. 1) does not indicate that there has been any movement of this intermediate water of the Gulf Stream in over the banks or up the gully leading to the gulf of St. Lawrence.

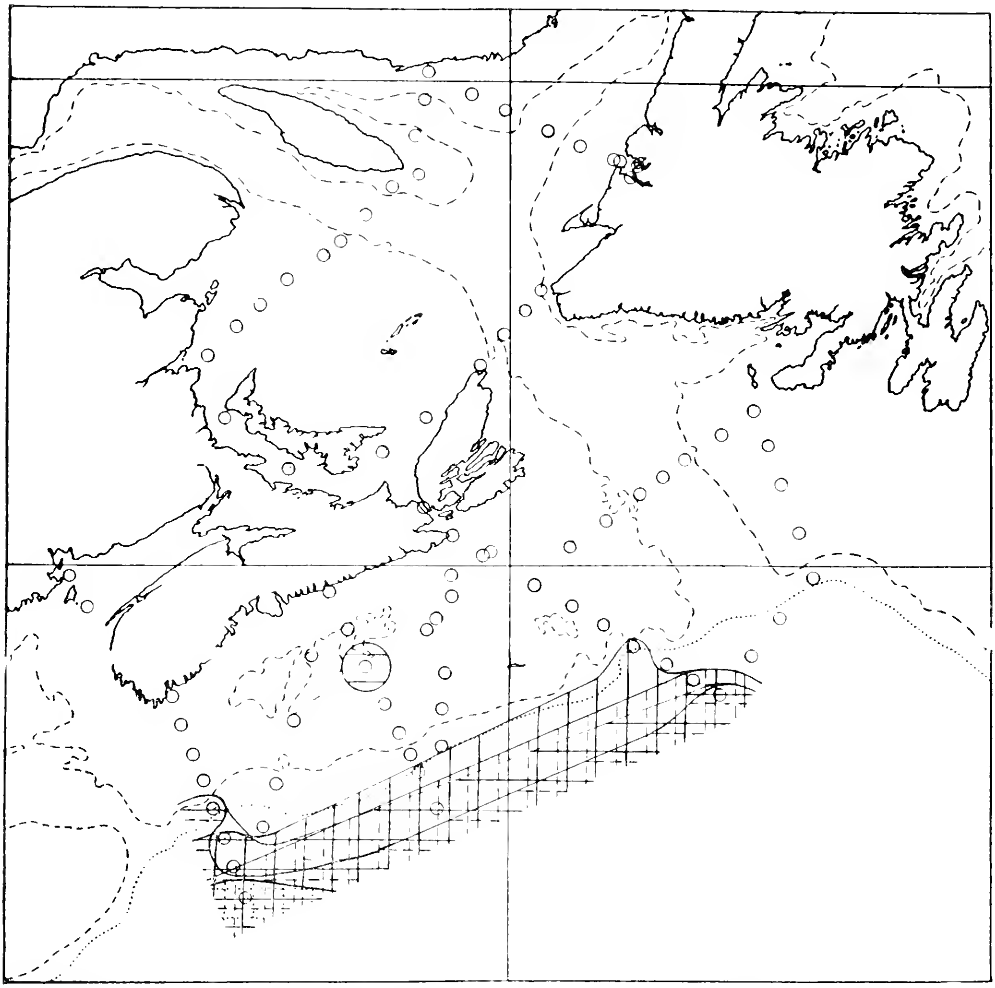

Fig. 1—Distribution of Gulf Stream Chaetognaths, July-August 1915. *S. enflata* ——— *P. draco* — — — *S. bipunctata* .... *S. lyra* |, *S. hexaptera* ¦, *K. subtilis* ⁞ .

Bigelow (1915, p. 298) obtained it in the July-August cruise (1913) of the *Grampus* only in the outermost stations, apparently from 10 to 20 miles outside the continental shelf, and in the more northern of the outer stations not at all, as these were apparently not far enough out for it. We may perhaps deduce from these facts that this species comes nearer to the coast as the summer progresses, that its distance off the coast increases as we go northward from Chesapeake bay to the Grand Banks, and that along our shores it belongs to the Gulf Stream water coming up from the south, and not to the cold boreal water coming down from the north. The occurrence of this species in the far north (74° N. according to Michael, 1913, p. 26) and in the far south (77° S., Fowler, 1907, p. 3) would lead one to expect it in our boreal oceanic water. As it belongs typically to lower latitudes, its absence may mean that older individuals when carried toward the poles survive, but do not have any progeny (owing to the absence of the warm salt surface water frequented by the young) and as a result the cold water that passes toward low latitudes is devoid of this species, the old individuals having all died off.

There is, however, some doubt as to how far it is carried toward the poles. Ritter-Zahony considers that Fowler's Antarctic specimens belong to *S. gazellae* and not to this species, and he gives the usual distribution as between the fortieth parallels north and south.

(*b*) **Sagitta enflata** Grassi.

1911. Ritter-Zahony, p. 16.

The range in size of the specimens obtained is from 7-23mm. The larger individuals were all sexually mature. This species is easily recognized by the short tail and the short sausage-shaped ovaries.

DISTRIBUTION.

C. G. S. "ACADIA."

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
41	6 a.m.	369	200– 0 (V.)		0
			100– 0 (V.)		0
			0 (T.)	11	1
42	9 a.m.	over 1,000	200– 0 (V.)	8	2
			0 (T.)		0
44	3 p.m.	over 1,000	270– 0 (V.)	7–23	39
			0 (T.)	7–20	170
50	9 p.m.	151	145–55 (C.)		0
			145– 0 (V.)	18	1
			55– 0 (V.)		0
			0 (T.)		0
56	3 p.m.	over 1,000	375–250 (C.)	(fragment)	1
			250– 0 (V.)		0
75	9 p.m.	over 1,000	325– 0 (V.)	13	1
			55– 0 (V.)	6–13	4
			c. 20– 10 (T.)		0

VERTICAL.—All the specimens obtained came from open-net vertical hauls or from horizontal surface hauls. This species is a typical surface form belonging to the upper epiplankton. The majority of the specimens were taken in a surface haul at 3 p.m.

HORIZONTAL.

HORIZONTAL.—*Sagitta enflata* is a tropical form ranging north to the fortieth parallel. The present records appear to be more northern than any hitherto recorded for this species. Two specimens were obtained at *Acadia* station 75, the position of which was 43° 30′ N., 56° 43′ W. It belongs to the surface water of the Gulf Stream. It was not found on the first cruise of the *Acadia*. On the second cruise of the *Acadia* it occurred in abundance only at the southernmost station (station 44), where 209 specimens were obtained. At each of five other stations, one to five specimens were taken (stations 41, 42, 50, 56 and 75). Its occurrence at station 50 is interesting as indicating the movement as far as that point of the surface Gulf Stream water. Its distribution is shown by the horizontal continuous lines in fig. 1.

Bigelow in his July-August cruise of 1913 obtained it south of cape Cod up to a latitude of nearly 40°.

(*c*) **Sagitta lyra** Krohn.

1911, Ritter-Zahony, p. 13.

The specimens obtained varied in size from 15-38mm. in length. The individuals obtained at *Acadia* stations 16 and 17 on June 1 were not sexually mature, seminal vesicles and ovaries not being easily seen, although the tests were distinct. Those obtained on the later cruise were more mature, the ovaries being moderately long but narrow, and the seminal vesicles appearing. This species and the next are easily separated from the other species by the very evident connection between the anterior and posterior fins.

DISTRIBUTION.

C. G. S. "ACADIA."

Station No.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
16	over 2,000	200– 0 (V.)	13–30	8
		0 (T.)		0
17	over 2,000	200– 0 (V.)	25–30	4
			15, 16 & 19	3
		0 (T.)		0
42	over 1,000	200– 0 (V.)	(fragment)	1
		0 (T.)		0
44	over 1,000	270– 0 (V.)	15–25	5
		0 (T.)		0
55	over 1,000	270– 0 (V.)	24 & 27	2
		90– 0 (V.)		0
		0 (T.)		0
56	over 1,000	375–250 (C.)	26–32	7
		250– 0 (V.)	25–32	4
70	over 1,000	325– 0 (V.)	38	1
		55– 0 (V.)		0
		c. 20– 10 (T.)		0
74	over 1,000	325– 0 (V.)	18–33	4
		55– 0 (V.)		0
		c. 20– 10 (T.)		0
75	over 1,000	325– 0 (V.)	29–33	10
		55– 0 (V.)		0
		c. 20– 10 (T.)		0

VERTICAL.—This species was obtained only in deep open-net hauls down to 200 metres or more, and in one closing-net haul below 250 metres. It was therefore distributed from above 200 metres to below 250 metres. All the hauls from 90 metres up, and shallower, were negative. Michael (1913, p. 31) found it very rarely above 25 fathoms, and attaining its maximum abundance below 250 fathoms. He does not, however, distinguish *S. maxima* from this species. Ritter-Zahony (1911, p. 14) gives its distribution as from 100-200 metres downwards. It is thus typically in the deeper layers of water.

HORIZONTAL.—This species is cosmopolitan and extends well to the north in the Atlantic. It is oceanic, being confined to deep water. In our waters its distribution is very similar to that of *S. hexaptera*, it was found only in the outer stations. But it occurred in more of these than did *hexaptera*, pressing farther in towards the continental shelf. In the May-June cruise it was found at the same stations as *hexaptera*, and did not occur at *Acadia* station 14, where a suitable haul was made. It would seem to have been at that time about sixty miles off the continental shelf, but the data are quite insufficient. In the July-August cruise (its distribution is shown by the vertical continuous lines in fig. 1) it was found in moderate abundance (about half-a-dozen specimens) at the outermost stations (44, 56, 74, 75) with *hexaptera*, and as well in some of the neighbouring stations (42, 55, 70), but only one or two specimens in each case. Thus it virtually came to the edge of the continental shelf. It might have been expected at stations 45, 72 and 76. Station 45 was peculiar in giving only one Chaetognath, *S. serratodentata*. Stations 72 and 76 appear to have had too great an amount of coastal water (witness the presence of *S. elegans*). It is perhaps worthy of note that at only one station (*Acadia* 16) were *S. lyra* and *S. elegans* found together, and at only four stations were they both absent. The inner limit in distribution of *S. lyra* almost corresponds with the outer limit of *S. elegans*. Although coming very close in, *Sagitta lyra* does not appear to be carried over the banks or up the gullies between the banks or up into the gulf of St. Lawrence.

It belongs to the deeper part of the bank of Gulf Stream water, and is carried in small numbers into the " cold wall " of boreal water that Hjort (1912, p. 10) has shown to exist along the southern side of the Grand Banks between the Gulf Stream and the continental shelf, and that Bigelow (1915) has shown to become narrower as we pass southward along the coast. We may take arbitrarily a salinity of 35 per thousand as forming the boundary line between the two. It is present in this boreal water only south of the angle where the Gulf Stream is deflected to the south by proximity to the Grand Banks, as if some mixing of the two waters occurred there.

The passage of this species from the Gulf Stream into the boreal oceanic water, and the failure of *S. hexaptera* to pass in a similar direction is perhaps to be explained by the fact that *S. lyra* occurs in deeper, colder water than *S. hexaptera*, and is therefore more apt to pass through the bottom of the Gulf Stream. The rarity of *S. hexaptera* may also be responsible for our failure to get it in the boreal oceanic water.

Dr. Bigelow (1915, p. 297) lists *S. lyra* from each of his four stations taken just outside the continental shelf south of cape Cod in July-August, 1913, and not from those inside, except for two specimens from the gulf of Maine.

(*d*) **Sagitta maxima.** (Conant.) Fig. 2.

1911. Ritter-Zahony, p. 15.

The range in size is from 7 to 55mm. in length.

Fig. 2.—Sagitta maxima × 2.

With one exception all the individuals were quite immature. Those obtained on the first cruise had no evident gonads. The larger ones of the second cruise had the ovaries of moderate size, but not mature, and the seminal vesicles distinct. Michael (1911, p. 37) has considered this form identical with *S. lyra,* but by following Ritter-Zahony's account I have experienced no difficulty in separating the two species, except with damaged specimens. The points relied upon have been: relation of anterior ends of anterior fins to ventral ganglion and proportionate length of the tail. This species reaches and matures at a much larger size than *Sagitta lyra.*

It is interesting to note that the specimens of this species described by Conant (1896, p. 84) were obtained by the *Albatross* at station 2428, 42° 48′ N. and 50° 55′ 30″ W., just inside the southern tip of the Grand Banks, and therefore in the "cold wall" of boreal water. They were brought up in the trawl wings.

DISTRIBUTION.

C. G. S. "ACADIA."

Station No.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
14	over 2,000	200– 0 (V.)	15–32	14
		0 (T.)	..	0
16	over 2,000	200– 0 (V.)	15–25	16
		0 (T.)	..	0
17	over 2,000	200– 0 (V.)	7–13	3 / 10
			15–30	98
		0 (T.)	..	0
44	over 1,000	270– 0 (V.)	14–19	4
		0 (T.)	..	0
46	over 1,000	270– 0 (V.)	24	1
		0 (T.)	..	0
48	248	270– 0 (V.)	..	0
		45– 0 (V.)	23	1
		0 (T.)	..	0
54	over 1,000	270– 0 (V.)	19–25	4
		125– 0 (V.)	20 & 22	2
		0 (T.)	..	0
55	over 1,000	270– 0 (V.)	17–28	6
		90– 0 (V.)	..	0
		0 (T.)	..	0
56	over 1,000	375–250 (C.)	20–25	3
		250– 0 (V.)	13–21	5
57	over 1,000	270– 90 (C.)	13–42	7
		90– 0 (V.)	..	0
		0 (T.)	..	0
70	over 1,000	325– 0 (V.)	20–30	9
			55	1
		55– 0 (V.)	..	0
		c. 20– 10 (T.)	..	0
72	over 1,000	325– 0 (V.)	23–40	8
		55– 0 (V.)	25	1
		c. 20– 10 (T.)	..	0

"ACADIA" Concluded.

Station No.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
74	over 1,000	325– 0 (V.)......................	10–16	5
		55– 0 (V.)......................	....	0
		c. 20– 10 (T.)......................	....	0
75	over 1,000	325– 0 (V.)......................	15–24	7
		55– 0 (V.)......................	....	0
		c. 20– 10 (T.)......................	....	0
76	over 1,000	270– 0 (V.)......................	13–36	14
		c. 20– 10 (T.)......................	....	0
79	360	325– 0 (V.)......................	12–40	14
		55– 0 (V.)......................	....	0
85	over 400	270– 0 (V.)......................	10–16	6
		55– 0 (V.)......................	....	0
		c. 20– 10 (T.)......................	....	0
86	over 400	270– 0 (V.)......................	15–17	5
		55– 0 (V.)......................	....	0
		c. 20– 10 (T.)......................	....	0
87	331	290– 0 (V.)......................	15 & 23	2
		55– 0 (V.)......................	....	0
		c. 20– 10 (T.)......................	....	0

VERTICAL.—Except in three instances, this species was obtained only in hauls taken from a depth of 200 metres or more. The exceptions are small individuals, 25 m m.or less in length, and were obtained at *Acadia* stations 48, 54 and 72. The conditions at these stations were peculiar. The surface oceanic species *S. serratodentata*, the coastal species *S. elegans*, and two deep-water boreal species, the present one and *Eukrohnia hamata*, all occurred together. These are undoubtedly places where mixing of the different kinds of water occurs and where vertical currents might be expected to bring temporarily nearer to the surface forms that are ordinarily to be found only in deeper water. The number of individuals in each case was small (1, 2, 1).

On the first cruise of the *Acadia*, numerous specimens were obtained in all the hauls made from 200 metres to the surface (stations 14, 16 and 17) outside the continental edge and none in the hauls made from 100 metres to the surface (stations 12, 15, 26 and 27). On the second cruise (with the exceptions noted above) again only the deeper hauls were productive. The shallower hauls were not very deep (90 metres or less). At station 56, three individuals were obtained in the closing net from below 250 metres. These facts show an ordinary distribution of this species in our waters from above 200 metres (but not above 100) to below 250 metres. Michael (1913, p. 32) gives for *S. lyra* (in which he includes *S. maxima*) a maximum abundance below 250 fathoms and a decreasing frequency toward the surface (above 25 fathoms it was extremely rare) for the San Diego region. Fowler (1896, p. 992 as *S. whartoni*) in his investigations of the Faeroe channel found it only on one occasion above 100 fathoms, and Ritter-Zahony for the coasts of Ireland found it regularly only below 100 fathoms.

In the Gulf Stream stations of the second cruise a gradation in depth according to size is evident. At the southernmost station (station 44), the haul from 270 metres up yielded no specimen longer than 19mm. At station 56, the next station north, the haul from 250 metres up gave specimenes up to 21mm., and the haul from 375 to 250 metres, specimens up to 25 (?) mm. The northern Gulf Stream stations (stations 74 and 75) from a depth of 325 metres to the surface gave specimens up to 16 mm. and 24mm. respectively. The boreal stations yielded much larger specimens from similar depths (e.g. up to 25, 28, 42, 55, 40, 36, and 40mm. at stations 54, 55, 57, 70, 72, 76, and 79 respectively). Therefore, as we pass into warmer water the larger specimens go deeper and deeper down and only the smallest specimens occur near the upper limit of distribution. It is worthy of note that at the Gulf Stream stations of the second cruise (stations 44, 56, 74 and 75) in each of the hauls, the average size of *S. maxima* (the larger species) was less than the average size of *S. lyra* (the smaller species). This seems to indicate that *S. lyra* attains its maturity and perhaps also its maximum abundance in the upper part of the mesoplankton and *S. maxima* its maturity and maximum abundance in the lower part of the mesoplankton. These two closely related species, though having to a great extent a coincident horizontal distribution would be rather sharply separated in their vertical distribution, as Michael (1913) has shown to be the case for other couplets of species in this group. Data as to the lower limit of distribution *S. lyra* are lacking, although Ritter-Zahony (1910) appears to have obtained it in quantity below 700 fathoms.

HORIZONTAL.—This species is cosmopolitan, extending to the far north in the Atlantic, so that it may be considered a cold-water species, distributed in all oceans in the depths. In our waters in the depths that we have examined (down to from 200 to 300 metres) it occurs in greatest abundance outside the continental shelf and inside the outermost stations, that is, inside the Gulf Stream. Little can be stated as to its distribution during the first cruise of the *Acadia*, owing to the fact that only three deep hauls were made. At station 17 an extraordinary number were obtained, 128 in the one open-net haul from 200 metres to the surface. Larger individuals were obtained at the innermost of the thre stations, 30 and 32mm. at stations 17 and 14, respectively, as opposed to 25mm. at station 16. The records indicate that it was present in maximum abundance between station 16 and the Newfoundland banks, and decreased in abundance toward the west and south. Its distribution in July-August is shown in fig. 3. It occurred in moderate abundance at the outermost stations (7, 5, 8 and 4 specimens at stations 75, 74, 56 and 44 respectively). At the remaining stations outside the continental shelf, it occurred in maximum abundance at the northeast, and decreased in abundance with almost perfect regularity, passing to the southwest, until it disappeared altogether (14, 14, 8, 10, 7, 6, 4, 1, 0, 0 and 0 specimens at station 79, 76, 72, 70, 57, 55, 54, 46, 45, 42 and 41, respectively) considering in each case only the deep open-net haul. It also occurred in fair abundance up the gully leading to the Gulf of St. Lawrence. In the gully it was present in greater amount on the north side, the numbers obtained in the deep vertical hauls being 6, 5 and 2 specimens, respectively, at stations 85, 86 and 87. Inside the Gulf of St. Lawrence, on the cruises of the *Princess*, it was not found, perhaps because the hauls were not deep enough (not over 130 metres). The only other place where it was found was at station 48 in the deep water inside the outer banks off Halifax, where a solitary specimen was obtained. Its distribution (fig. 3) suggests (1) that this species belongs typically to the deep boreal water that is found against the side of the continent; (2) that this water disappears as we pass southwest along the continent, doubtless seeking a lower level, unexplored by our nets; (3) that some of it passes up over the banks south of Sable island to mix with the shallow coastal water; and (4) that another portion passes up the gully leading to the St. Lawrence gulf but keeping mainly to the north side of the gully.

Its centre of abundance (fig. 3, closely placed lines) is then the deeper part of the northern oceanic (boreal) water which flows to the south around the Newfoundland banks. It is carried by the latter into the coastal water and beneath the Gulf Stream. In the coastal water it must speedily perish, but in the Gulf Stream, the smaller individuals at least find suitable conditions. The Gulf Stream on its way to the north would seem to receive fresh additions of this species from the boreal water beneath. The numbers obtained in the open vertical hauls from the south to the north

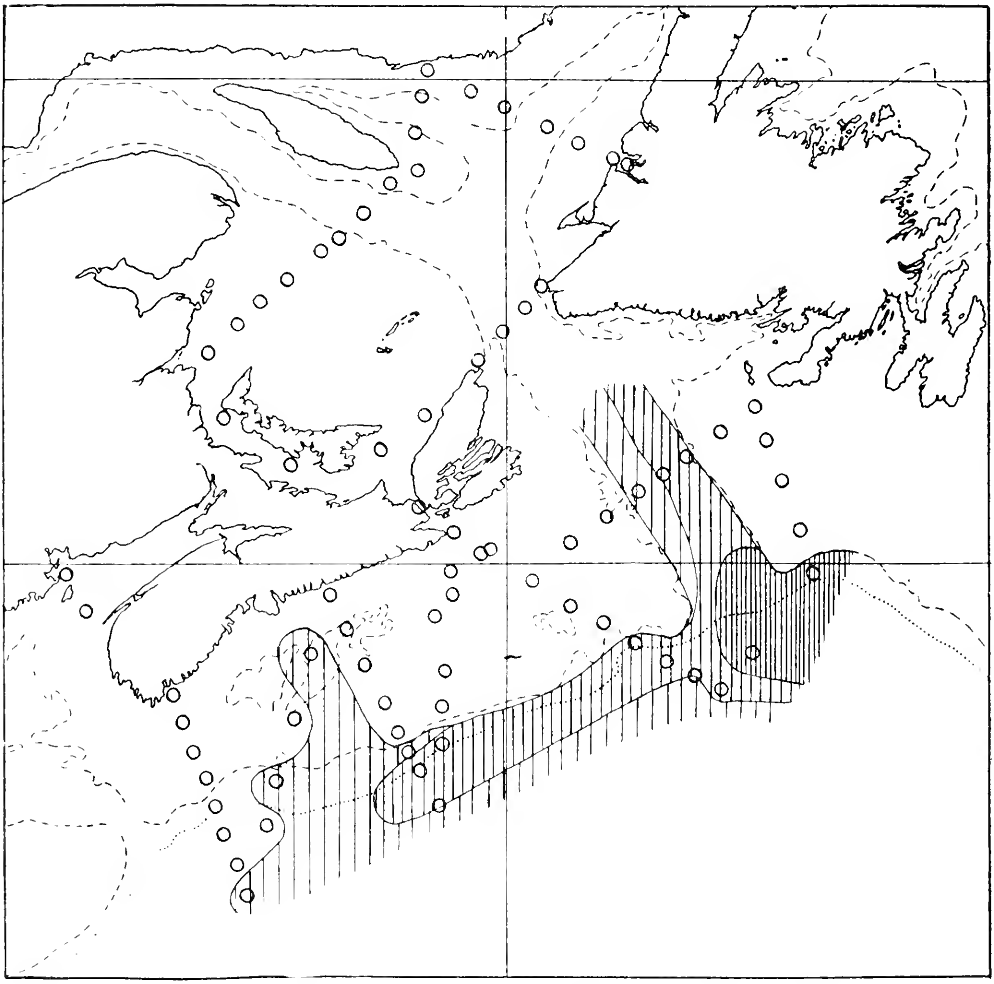

Fig. 3.—Distribution of *S. maxima*, July-August 1915. Zones show frequencies of 1 to 5, 6 to 10 and 10 and over per station.

are 4, 5, 5, 7 at stations 44, 56, 74 and 75, respectively, showing an increase in the number at the north. This may explain how the fauna of the Gulf Stream, as it passes to the north, changes from tropical to boreal, the change in temperature killing the tropical forms which are replaced by the boreal forms that enter the stream as young individuals from the boreal water below. The growth of the boreal forms proceeds *pari passu* with the change in temperature, and they find themselves constantly in water of suitable temperature for their continued existence.

Hjort (1912, p. 640) considers that this species (as *S. gigantea*) is arctic to boreal in its distribution, and has found it as a typical inhabitant of the deep cold water of the Norwegian sea. Apstein (1911, p. 173) records its distribution in European waters as being restricted to the Atlantic and the Norwegian sea, but in one year at least coming down the Norwegian gully to the western part of the Skager-Rack. It was strictly limited to the deep water, remaining below 100 metres. This is very similar to what we have found, the species tending to enter the St. Lawrence gulf along the submerged Laurentian valley. It will probably be found at times well inside the gulf in the deep water.

The distribution of this species may be contrasted with that of *S. lyra*, its closest ally. *S. lyra* belongs to the Gulf Stream, but large individuals wander into the northern oceanic water *S. maxima* belongs to the northern oceanic water, but small individuals wander into the Gulf Stream. Both species are apparently unfitted for life in water of low salinity like the coastal water, regardless of temperature.

(*e*) **Sagitta serratodentata** Krohn. Fig. 4.

1911. Ritter-Zahony, p. 22.

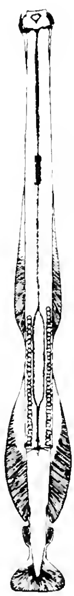

Fig. 4.—Sagitta serratodentata.

The range in size is from 6 to 24mm. in length. All the larger individuals were sexually mature. The slender build of this species and the early appearance of the seminal vesicles on either side of the tail, make it easily distinguishable from our other Chaetognaths. A character to which attention does not appear to have been called is the presence in the young of a distinct bridge between the anterior and posterior fins on each side. This tends to disappear with age. In young individuals the serrations on the hooks are seen with difficulty, if at all. The variations in the descriptions of this species, as taken in different localities, make one question whether several species have not been confounded. The great differences in the conditions throughout our waters give us almost the extremes of these variations. In the warm water at *Acadia* station 44, the largest individuals were only 12mm. long. Both their male and female gonads were mature. The jaws were few (5-8), the tail proportion small (23-27 per cent) and the body relatively stout. At *Acadia* station 38, individuals as long as 22mm. were obtained, and those as long as 15mm. were immature. The jaws were more numerous in these (7-10), the tail proportion larger (25-32 per cent), and the body more slender. If these are one species, the differences in structure will be due to the differences in the conditions under which they have developed. These hifferences are similar to those seen in the varieties of *S. elegans* (see under that species) occurring in localities where different climatic conditions prevail. In both the cold water develops a type of larger size, with more jaws, and a higher tail percentage. The number of jaws increases with age (there may be latterly a decrease) and the maximum number in the cold-water type is higher than is found in the warm-water type (though the difference is not great). The following are the numbers of jaws found in the two types:—

TROPICAL WATER. ("ACADIA" STATION 75).

Length (mm.).	7	8	9	10	11	12	13
Number of jaws	6	6	6	6	5	7	6
	7	6	6	6	6	7	7
		6	6	6	6	7	7
		6	6	6	6	7	7
		6	6	6	7	8	7
		7	7	6	7	8	7
		7	7	7	7	8	8
			7	7	7	8	8
			7	7	7	......	8
				7	7	......	8
				7	8	......	......
				8	8	....	.....
				...	8	....	......
					8	.....	.....
	....				8	.....	.....

BOREAL WATER. ("ACADIA" STATIONS 17, 38, AND 85).

Length (mm.).	10	11	12	13	14	15	16	17	18	19	20
Number of jaws........	7	7	.....	7	7	7	8	8	8	7	8
	7	7	..	8	8	8	8	8	8	8	9
	7	7	.....	..	8	8	8	8	8	8	9
	8	8	.....	..	8	8	9	8	9	8	......
	....		..		8	8	....	8	9	......	......
	.....		....	..	9	8	......	8	9	......	......
	.....	...			9	..	......	9	......	......	......

The comparative variability in the number of jaws in individuals of the same size makes it necessary to examine larger numbers of individuals than would otherwise be the case. Although the number is not very large, it is fairly evident from the figures given that there is a very gradual but steady increase in the number of jaws, and this is irrespective of the type, individuals of the same length in the two types having equal numbers of jaws (or slightly more in the larger type).

In the case of the tail percentage there is a decrease with age. The following are the results of measurements of the percentages in the two types of *S. serratodentata.*

Boreal Water. ("Acadia" Station 38.)

Length (mm.).	10	11	12	13	14	15	16	17
Tail percentages..........	29	28	27	26	26	25	26	25
	30	29	28	27	27	25	26	27
	30	30	28	28	28	26	27	
	32	30	28	28	28	27	27	
	32	30	29	30	28	28		

For the larger sizes it was necessary to examine specimens from another point.

Boreal Water. ("Acadia" Station 85.)

Length (mm.).	17	18	19	20
Tail percentages...	24	23	23	23
		23		
		24		
		24		

Tropical Water. ("Acadia" Station 75.)

Length (mm.).	8	9	10	11	12
Tail percentages.........	26	26	24	24	23
	26	26	24	24	23
	27	26	25	24	23
	28	27	25	25	24
	28		25	26	24

For the smallest sizes specimens from another station were taken.

TROPICAL WATER. ("ACADIA" STATION 41.)

Length (mm.).	6	7	8
Tail percentages	30	28	29
	......	30	......
	......	30	......
	......	32	......

The range in percentage is the same for the two types (32-23), but for any given length it is very different, for example, for 12mm., 23-24 per cent and 27-29 per cent. If we consider 20mm. the ordinary upper limit for the boreal water and 12mm. that for the tropical water, we find that for corresponding sizes the percentages are as nearly the same as could be expected. Half-grown individuals show percentages of 30 and 27-29, respectively; two-thirds grown individuals of 26-28 and 25-28; fully-grown individuals of 23-24 and 23.

It is probable that we have not to do with two races, but that the tropical form is constantly brought to the boreal water, keeping the strain uniform. The differences may be confidently be referred purely to the environmental factors. Cold may be said in this species to increase the length, delay maturity till a much greater length is attained, delay the decrease in tail percentage correlative to maturity, and increase the number of jaws. We have the number of jaws correlated with size and the tail percentage corrleated with maturity (attainment of maximum size and also maturity of sexual organs).

DISTRIBUTION.

"ACADIA."

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
5	3 a.m.	72	60– 0 (V.)	19	1
			0 (T.)	10–15	35
				15–20	43
6	6 a.m.	45	40– 0 (V.)	14	3
			0 (T.)	13	2
12	6 a.m.	over 2,000	100– 0 (V.)	13–15	3+1×10
				16–17	3
			0 (T.)	......	0
13	9 a.m.	over 2,000	70– 0 (V.)	14	1
14	3 p.m.	over 2,000	200– 0 (V.)	14–15	3
				16–24	18+1×10
			0 (T.)		0

"ACADIA"—*Continued.*

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
15	9 p.m........	over 2,000	100– 0 (V.)...........	16–18	9
			0 (T.)........	13–15	5×2
				16–20	19×2
16	3 a.m.......	over 2,000	200– 0 (V.)...........	6–7	58×10
				13–15	3×10
				15–20	27×10
			0 (T.)......	9–21	+ +
17	9 a.m........	over 2,000	200– 0 (V.)....	4–12	43+19×10
				15–21	16+13×10
			0 (T.)....	11–20	c. 30
18	6 p.m........	over 2,000	0 (T.)..— ..	17–18	2
19	9 p.m........	over 2,000	0 (T.)........	15–19	c. 20
25	6 p.m........	122	120– 0 (V.)........	13	1
			10(?)– 0 (T.)........		0
26	12 m. n. ...	over 400	100– 0 (V.)....	15–17	3
			0 (T.)....	.	0
27	3 a.m.....	over 400	0 (T.).....	c. 17	×
28	3 a.m.....	over 400	100– 25 (C.).......		0
			0 (T.)......	16	1 seen
38	9 p.m.....	170	150– 0 (V.)......	10–15	10+20×10
				15–16	4
			100– 0 (V.)......	7–15	30+25×10
				15–22	19+3×10
			0 (T.).....	9–14	× ×
39	12 m. n......	95	100– 0 (V.)......	12–15	12×10
				15	4
			25– ? (V.)..	12–15	5×5
				15–17	14
			0 (T.)..	10–17·5	× ×
40	3 a.m........	134	125– 0 (V.) 1	12	2
			125– 0 (V.) 11	10	1
			100– 0 (V.).		0
			0 (T.) .	shrivelled specimens	×

"Acadia"—*Continued.*

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
41	6 a.m........	360	200– 0 (V.)..........	6–9	25
			100– 0 (V.)........	10–12	3
			0 (T.).........	10	1
42	9 a.m........	over 1,000	200– 0 (V.).......	7–11	67
			0 (T.).........	....	0
44	3 p.m........	over 1,000	270– 0 (V.)........	7–11	26
			0 (T.).........	7–12	58
45	9 p.m........	over 1,000	270– 0 (V.)......	6–11	8×4
			90– 0 (V.)......	7–15	21
			0 (T.).........	....	0
46	12 m.n........	over 1,000	270– 0 (V.).......	5–13	14+4×5
				5–16	2
			0	5–14	+
				16–20	×
47	6 a.m........	40	125– 0 (V.)......	9–14	13+2×10
				15 & 17	2
			90 –0 (V.)......		×
			0 (T.)......	5–12	+
48	12 m.n	250	270– 0 (V.)......	....	0
			45– 0 (V.)......	11	1
			0 (T.).........	....	0
50	9 p.m........	151	145– 0 (V.)........	12·5	2×5
				12–14	12
				16–20	5
			145– 55 (C.)........	16	1
			55– 0 (V.).........	10–14	5+1×5
				17	1
			0 (T.).......	10–16	++
51	12 m.n	131	125– 55 (C.)..........	9 & 15	2×5
			125– 0 (V.)...........	14–15	3+1×5
				15–19	4
			0 (T.)...........	11–16	+

"ACADIA"—*Continued.*

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.)	Number.
52	3 a.m. ..	99	90– 0 (V.) II . .	17	1
			0 (T.) . .	13 & 14	2
				16–18	2
53	6 a.m. .	95	90– 0 (V.) .	9	1×5
				11–12	3
				15–19	3
			0 (T.).	19	×
54	9 a.m.	over 1,000	270– 0 (V.)	13–14	3
			125– 9 (V.) . .		0
			0 (T.).	7–12	c. 12
55	12 m. .	over 1,000	270– 0 (V.). .	8	2
				17	1
			90– 0 (V.)	16	2
			0 (T.). .	9–15	7
56	3 p.m.	over 1,000	375–250 (C.). .	c. 8	2
			250– 0 (V.)	7–9	42
57	9 p.m. .	over 1,000	270– 90 (C.).	8	1
			90– 0 (V.) .	9 & 12	2
			0 (T.). . . .	9–12	15
58	12 m.n	187	180– 55 (C.). . .	10 & 12	2
			55– 0 (V.). .	9–10	4
			0 (T.). . .	8–13	c. 15
				18–20	2
60	6 a.m	99	90– 0 (V.) . .	7·5–9	3×5
				15	1×5
			0 (T.) .	small	×
70	12 m. . .	over 1,000	325– 0 (V.) .		0
			55– 0 (V.). .		0
			c. 20– 10 (T.) .	13–14	4
72	3 p.m .	over 1,000	325– 0 (V.) .		0
			55– 0 (V.). .	. .	0
			c. 20– 10 (T.)	9–13	7
				16	1

"ACADIA"—*Concluded.*

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
74	6 p.m.......	over 1,000	325– 0 (V.)............	8–11	52
			55– 0 (V.)...........	7–13	21
			c. 20– 10 (T.)...........	7–12	+
75	9 p.m........	over 1,000	325– 0 (V.)...........	6–12	25×4
			55– 0 (V.)..........	6–12	50×5
			c. 20– 10 (T.)...........	8–14	++
77	9 a.m........	over 1,000	c. 20– 10 (T.)...........	10–14	c. 12
				18 & 19	2
85	9 a.m........	over 400	270– 0 (V.)........	15–21	8
			55– 0 (V.).........	11 & 21	2
			c. 20– 10 (T.)...	17	××
86	12 m	over 400	270– 0 (V.)........	15–20	4
			55– 0 (V.)..........	19	1
			c. 20– 10 (T.).......	19	1 seen
87	3 p.m.......	331	290– 0 (V.).......	19	2
			55– 0 (V.).	......	0
			c. 20– 10 (T.).......	13 & 14	2 seen
				17–20	5 seen

"PRINCE."

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
3	12 m.....	200	180– 0 (V.)..	19·5	1
			c. 20– 10 (T.).......	5·5	1 seen
			2– 0 (T.).......	......	0

In discussing the distribution of this species, it has been thought advisable to distinguish between small and large individuals.

Ritter-Zahony states that in warm water this species rarely reaches more than 15mm. in length. As we have both warm and cold water in the area explored, those under 15mm. may show a different distribution from those over 15mm. In the table given above in most cases these two groups have been separated. It must be remembered, however, that this division is quite arbitrary, warm water individuals being occasionally longer than 15mm. and cold-water individuals being of all sizes.

VERTICAL.—Fowler and Ritter-Zahony regard this species as typically epiplanktonic, but extending int othe mesoplankton. Michael, on the contrary, for the San Diego region, states that the species reaches its maximum abundance below 150 fathoms, and that only the immature were taken above 100 fathoms except at night when the larger specimens came up as far as 50 fathoms (1911, p. 150). This contradiction would indicate that different species have been confounded.

The small individuals of the Gulf Stream stations were taken in abundance at or near the surface at 3 p.m. (station 44), 6 p.m. (station 74), and 9 p.m. (station 75), and these hauls contained mature individuals, though small. At station 56, two specimens were obtained in the deep closing-net haul below 250 metres, and forty-two from 250 metres to the surface. The records at station 74 and 75 show that nearly as many (21 as opposed to 35) or more (50 × 5 as opposed to 25 × 4) were obtained from the shallow vertical haul (55 — 0m.) as from the deep vertical haul (325 — 0m.). These facts indicate that the warm-water variety of the Gulf Stream occurs chiefly near the surface, even during the day.

The large individuals of the colder water are to be found in the intermediate water (between Gulf Stream and coastal water) where mixing may be supposed to be going on. The vertical currents that are doubtless present here would tend to bring them nearer to the surface, and so influence the vertical distribution.

The mixing would also tend to give the opposite result, namely, fewer at the surface, when the surface water comes from the cold shallow coastal water, in which *S. serratodentata* does not occur. However, the records show fairly conclusively that these large individuals do come to the surface at least during the night, numbers having been taken near the surface at 9 p.m. (*Acadia* Stations 19, 38, 50), at 12 midnight (*Acadia* stations 39, 46, 51) at 3 a.m. (*Acadia* stations 5 and 16), at 6 a.m. (*Acadia* station 47), and at 9 a.m. (*Acadia* stations 17 and 85). At no stations taken about the middle of the day were large individuals obtained in numbers, yet specimens were taken near the surface at 12 m. (*Acadia* station 86) and at 3 p.m. (*Acadia* stations 72 and 87). At *Acadia* station 50, twenty-seven specimens were caught in the vertical open net from 145 metres to the surface, one in the closing net from 145 to 55 metres, eleven in the open vertical net from 55 metres to the surface, and very many at the surface. This would indicate that at 9 p.m. the bulk of the individuals were above 55 metres. On the other hand, at station 51 almost as many were obtained from 125 to 55 metres as from 125 metres to the surface, so that the data are inconclusive.

In the Laurentian channel at *Acadia* stations 85, 86, and 87, the vertical hauls indicate that it came very near the surface, but was as abundant in the depths as at the surface, or perhaps more abundant. The three stations gave fourteen in the deep hauls, as compared with three in the shallow hauls. This suggests that it is forced into deeper water by the presence near the surface of water of too low a salinity. If it comes to the surface is spite of the unsuitability of the surface water, it will doubtless perish and thus fail to penetrate as far into the St. Lawrence gulf at does *E. hamata*.

Individuals above 15mm. in length were obtained at or near the surface at practically every hour of the day. Taking the stations at which these large individuals were obtained, we have the following positive and negative results for the near surface hauls:—

—	6 a.m.	9 a.m.	12 m.	3 p.m.	6 p.m.	9 p.m.	12 m.n.	3 a.m.
Positive	1	3	1	2	1	3	4	5
Negative	2	0	2	1	0	1	1	0

There can be no doubt that this species is truly epiplanktonic in both cold and warm water, though whether or not it is driven below the surface to any extent by the light during the day is an open question.

HORIZONTAL.—*S. serratodentata* is cosmopolitan, occurring in all oceans except in the far north and the far south. Its most northerly record is 60° 2′ N. and 22° 56′ W.

It extends farther to the north than any of the other epiplanktonic warm water forms. In our area, too, it extends farther inshore than any of the others, being able to withstand the lower temperature and salinity better. It seems to be equally at home in the Gulf Stream and in the cold boreal water next the banks. It grows to a much larger size in the latter, but this difference can scarcely be used for dividing the species into two groups. The presence of individuals above 15mm. in length is indicative of the presence of boreal water, but the presence of small individuals is not necessarily indicative of the presence of Gulf Stream water. Small sexually mature individuals might be indicative of Gulf Stream water, but I have not correlated

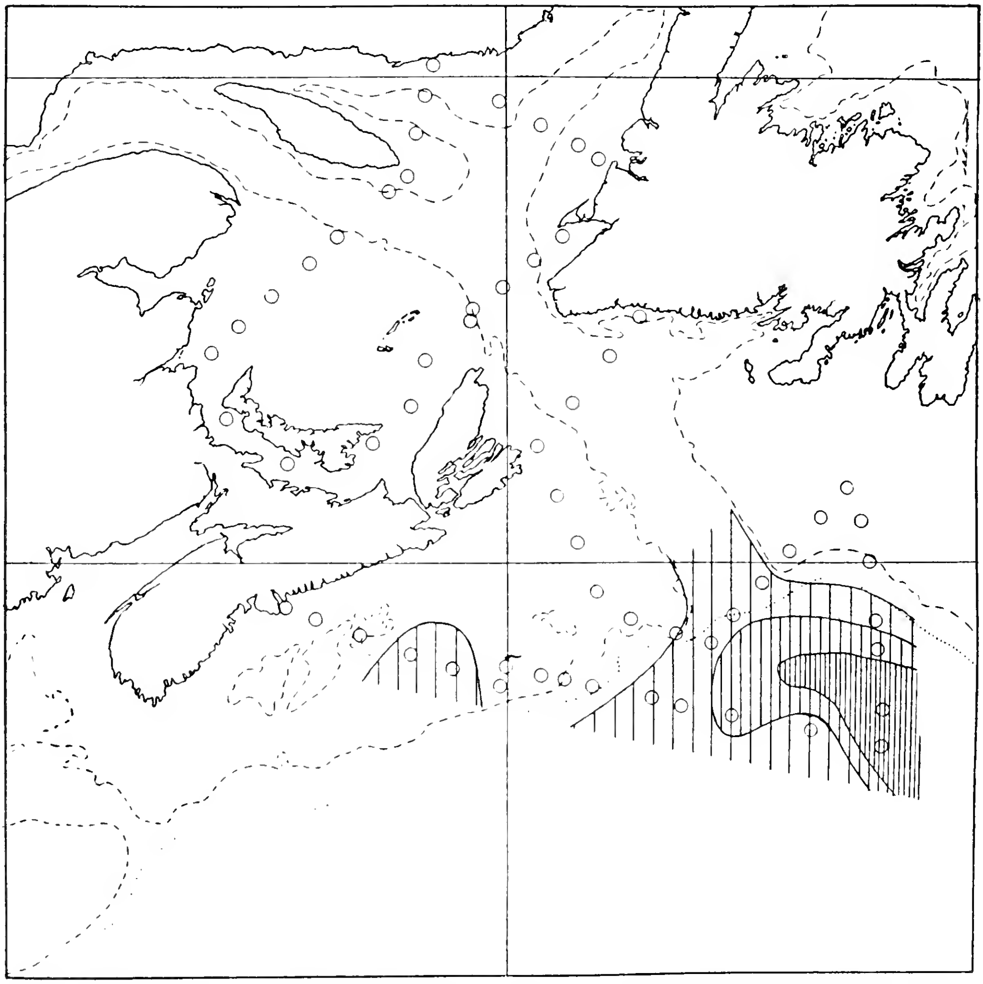

Fig. 5.—Distribution of *S. serratodentata*, May-June 1915. The zones indicate frequencies of 1 to 25, 26 to 100 and 100 and over per station.

distinct from the cold bank water. Fig. 5 shows its distribution during the first cruise of the *Acadia*. It is virtually confined to the deep water off the continental shelf, passing upwards over the banks only at stations 5 and 6 on the lower part of Sable sexual maturity with size in my records. Taken as a whole the species is indicative of the extent to which oceanic water (either Gulf Stream or boreal) extends, as

Island bank. The deep water between Sable Island bank and Halifax seems to have been free from it. It can only be considered to have been abundant at the two outer stations (16 and 17), although the lack of uniformity in the hauls renders the point uncertain.

Fig. 6 shows its distribution during the second cruise of the *Acadia*. Owing to the route of the second cruise being different from that of the first, a strict comparison is difficult.

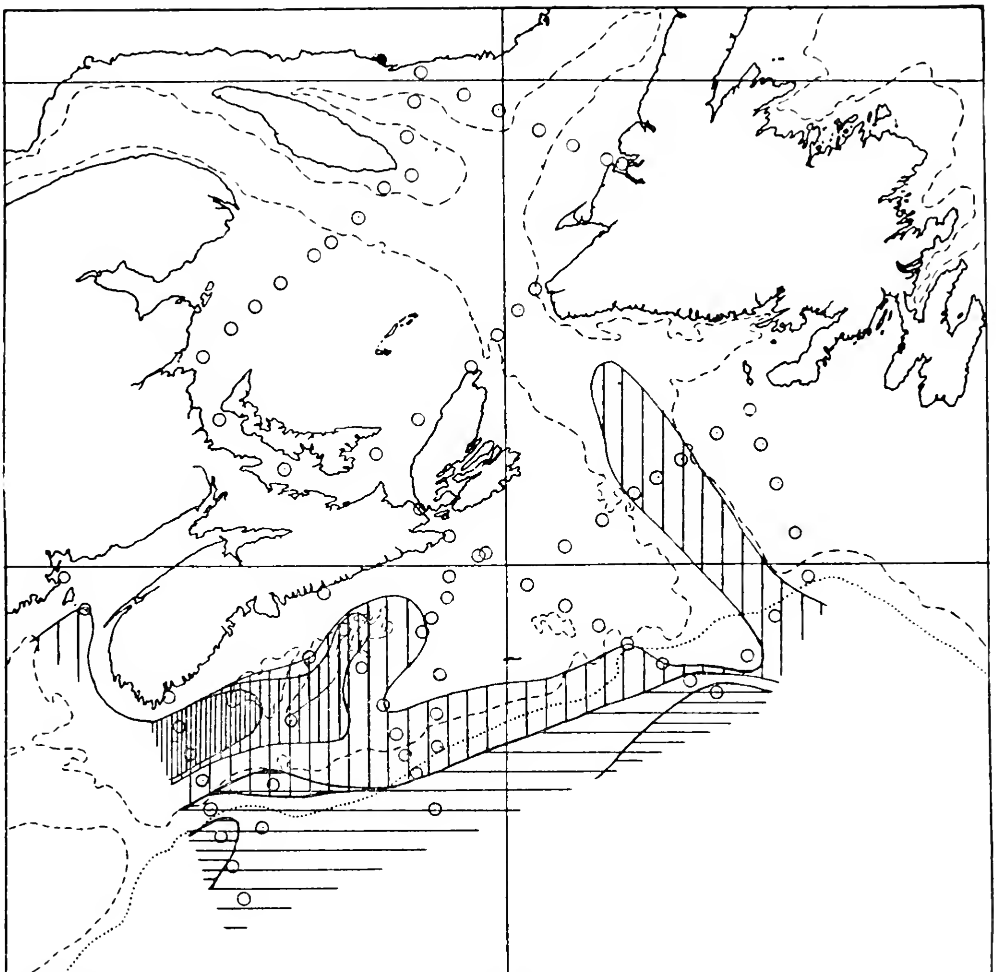

Fig. 6.—Distribution of *S. serratodentata*, July-August 1915. Vertical lines indicate the boreal form with zones showing frequencies of 1 to 25, 26 to 100 and 101 to 300. Horizontal lines indicate the Gulf Stream form with zones showing frequencies of 1 to 50 and 51 to 300.

Several points are noteworthy: first, its presence in quantity in the deep water between Sable Island bank and Halifax; second, its absence on Sable island bank at station 59, where it was present on the first cruise (station 6); and third, its absence at station 76 well out in deep water off the centre of the mouth of the Laurentian channel. The sinuosities in the inner limit of its distribution are much the same in the two cruises, except that they have been shifted toward the west in the second cruise. The species does not seem to have pressed farther in to any appreciable extent during the intervening two months. With *S. maxima* it extends well up the Laurentian channel as shown at stations 85, 86, and 87 and, like that species it is most abundant on the north side of the channel. The decrease in abundance from north to south across the channel is very evident, for the deep vertical hauls eight, four, and two specimens were obtained at stations 85, 86, and 87, respectively, and for the shallow vertical hauls two, one, and zero specimens for the same stations.

It was not obtained at any of the stations of the *Princess* cruises and, being a surface form, it could scarcely have been missed. It does not therefore extend into the St. Lawrence gulf, doubtless being killed by the cold brackish surface water. Its absence over the banks south of Newfoundland (St. Pierre and Green banks), and over those north of Sable island (Banquereau, Misaine, etc.) and along the Nova Scotia shore is noteworthy as denoting the absence here of oceanic water.

Bigelow has shown that it extends well up into the gulf of Maine, keeping to the deep water near the centre, in July and August of both 1912 and 1913 (1914, p. 121, and 1915, p. 299). Our record of September, 1915, at *Princess* station 3, in the deep water between Grand Manan and Nova Scotia, shows that it extends at least up into the mouth of the Bay of Fundy. It was absent at *Prince* station 2 off Campobello island, farther up the bay. The small number of specimens obtained at *Prince* station 3, and the lateness in the season, indicates that this is its northern limit in the bay.

It may perhaps be possible to delimit pure Gulf Stream conditions as exhibited by this species, when we take note of both size and abundance. This is shown in fig. 6, horizontal lines representing the small variety and vertical lines the large.

The outermost stations gave in the vertical hauls comparatively large numbers of individuals, whose upper limit in length was 13mm. Taking these together with the stations that show similar results and we have the following list of "Gulf Stream" stations: Station 41, 200-0m., 6-9mm., twenty-five specimens; station 42, 250-0m., 7-11mm., sixty-seven specimens; station 44, 270-0m., 7-11mm., twenty-six specimens; station 45, 270-0m., 6-11mm., thirty-two specimens; station 56, 250-0m., 7-9mm., forty-two specimens; station 74, 325-0m., 8-11mm., thirty-five specimens; station 75, 325-0m., 6-12mm., 25 × 4 specimens. The line separating these stations from the others nearly coincides with the outer limit of specimens over 15mm. in length.

There are several stations at which a few small individuals were obtained (station 40, 54, 57, and 70), but the degree of sexual maturity shown by them indicates that they belong to the larger cold water form. A line drawn just inside stations 41, 45, 56, 74, and 75 would separate the warm water form from the cold water form. It must be emphasized, however, that this line cannot be sharp, as there is a transition from one form to the other. A study of the specimens from stations 44, 45, and 46 shows this. At station 44 a maximum size of 12mm. is attained; at station 45, of 15mm.; and at station 46 of 20mm. There is the same gradation in the change from a stout to a slender body and from early to late maturity.

Its absence at *Acadia* stations 59 and 76, where numbers of *S. elegans* were obtained indicates that at these points definite tongues of coastal water extend out into the boreal or mixed water, which doubtless come from the mass of coastal water present over and between the banks north of Sable island. These two tongues are shown in fig. 6. On the earlier cruise of the *Acadia* these two tongues are fused as shown in fig. 5, this species not ocurring at *Acadia* stations 6 to 10. The distribution of *S. elegans* during the same cruise (fig. 8) shows the two tongues but they are close together.

On neither cruise is there any indication that the cold coastal water of the Newfoundland banks (where *S. serratodentata* was not found) has to any extent flowed out from the banks into the water outside the continental shelf, but it does appear that the water north of Sable island has done so.

Though the quantitative data as to the distribution of this species are incomplete, the centre of abundance during the first cruise of the *Acadia*, as shown in fig. 5, was definitely at the outermost stations (16 and 17). It decreased in abundance to the north and to the west (perhaps also to the south). This perhaps indicates that surface boreal water was at that time coming around the southern side of the Newfoundland banks.

This area was not explored during the second cruise. The distribution at that time, as shown in fig. 6, would indicate the presence of very little surface boreal water south of the Newfoundland banks, probably owning to the pressing in of the surface Gulf Stream water. The centre of abundance at this time was off the lower end of Nova Scotia, where no stations were taken on the first cruise. Whether the animals were transported to this point from the north during the intervening two months or not must remain problematical, although the direction of the known surface currents in these waters would support such a view.

The rarity of *S. serratodentata* in north European waters as recorded by Ritter-Zahony (1910, p. 2) and Apstein (1911, p. 174) is remarkable. It is rare even in the open Atlantic off Ireland. Its occurrence on one occasion in the deep water of the Skager-Rock, and only at a depth of 150 metres or more (Apstein) indicates a restriction to the deep salt water on the rare occasions when it is carried into the North sea.

(*f*) **Sagitta bipunctata,** Quoy et Gaimard.

1911. Ritter-Zahony, p. 19.

"ACADIA."

Station No.	Hour.	Depth (metres)	Depth of Haul (metres).	Length (mm.).	Number.
44	3 p.m.	Over 1,000	270-0 (V.).	12 & 15	2
			(O. T.)	12-15	5

This species was obtained only at the southernmost station of the second cruise of the *Acadia*, at station 44 (fig. 1, horizontal dotted lines). It occurred in both surface and open-net vertical hauls. It is a tropical surface form, but extends well north in the Atlantic. Owing to its confusion with other species the records of its occurrence are untrustworthy.

It was obtained by Bigelow in July-August, 1913, only in his more southern and outer stations south of cape Cod.

(*g*) **Sagitta elegans** Verrill. Fig. 7.

1911. Ritter-Zahony, p. 17 and figs. 1-3.

This is the characteristic *Sagitta* of our Atlantic waters, from its general occurrence in the shallow water all along the coast.

The range in size is from 2 to 52mm. in length. Ritter-Zahony divides the species into three subspecies, of which two, *elegans* and *arctica*, would be represented here. As these are not distinct but are connected by intermediates, I have not thought it worth while to consider them separately. The differences between the two are similar to the differences between the two types of *S. serratodentata* and are no doubt due to the same cause, namely, difference in temperature during development. It is interesting to note that the only place where individuals longer than 36mm. were found, was in the Bay of Islands. In that place there is an extensive layer of water below the freezing point, from about 50 fathoms to as much as 150 fathoms deep. Such an extreme condition was not found elsewhere, and approaches the conditions in the Arctic regions.

Ritter-Zahony gives the upper limit of *S. elegans* as 30mm. and of *S. elegans arctica* as 44mm. Our measurements would indicate that *S. elegans* reaches a length of 36mm. (an individual from the Bay of Fundy, which is almost in the region from which the species was first described, measured 35mm.), and *S. elegans arctica* a length of 52mm.

The majority of the larger specimens are sexually mature, but even some of the largest are immature. The size at which maturity is attained apparently varies with the region. No measurements of the sexual organs were made, but on examining material from a number of points and observing the state of the ovaries and seminal

Fig. 7.—Sagitta elegans. x 4.

vesicles it was seen that in the Bay of Islands *No. 33* station 57), the sexual organs were maturing only when a length of 30mm. was reached (but even as low as 22mm. in a catch by the young fish trawl); northern part of gulf (*Princess* station 16), 23mm.; middle part of gulf (*Princess* station 33), 23mm.; southern part of gulf (*Princess* station 25), 20 mm.; southern coast of Newfoundland (*Acadia* stations 20, 35, 83), 24mm.; off northern end of Nova Scotia (*Acadia* stations 67 and 90), 25 mm.; off southern part of Nova Scotia (*Acadia* station 38), 24mm.; in the Bay of Fundy, (*Prince* station 1), 22mm. At *Prince* station 3 at the mouth of the Bay of Fundy, the specimens even as large as 35mm. had immature ovaries. Other factors are doubtless involved.

The subject demands much more extensive investigation than the present opportunity affords, but from the cursory examination made, it would appear that in warmer water the species matures at a smaller size, as is seen very definitely to be the case with *S. serratodentata.*

The southern gulf specimens in early maturity approach the Baltic subspecies, *S. elegans baltica.* It is rather difficult to say what is the upper limit in size in this area, owing to the currents bringing outside individuals into the area. As the chief current sweeps across this part of the gulf from west to east, the individuals of the eastern side are perhaps most representative. In June, at *Princess* station 26 the largest individual was 25mm. long, at station 25, farther north, 32mm. long. In August at *Princess* station 50, the largest was 20mm. long; at station 49, 20mm. long, and at station 48, 26mm. long. In June, at *No. 33* stations 4-15 (all in this same area between Prince Edward, Cape Breton, and Magdalen Islands) the largest individuals were 26mm. long. This (26) may be considered as the maximum size for individuals that have grown up in the area (the larger ones at *Princess* station 25 may well have been carried in from without. In the Bay of Fundy at *Prince* station 3 the maximum size was 35mm. In the Bay of Islands at *No. 33* stations 57 and 59 the maximum was 45mm. (at station 57 a very large number were obtained with the young fish trawl, and among these one individual 52mm. long was seen).

The maximum size therefore varies with the temperature, being higher in colder water.

S. elegans baltica, according to Ritter-Zahony, has from eight to ten jaws on each side, the number being largest in specimens of medium size (about 16mm.). In *S. elegans elegans,* the number is from eight to eleven, with probably no decrease in older individuals. In *S. elegans arctica,* the number is from eight to twelve, with apparently no decrease in older individuals.

Counts were made to determine whether a difference could be detected in this respect between the Bay of Islands specimens and those from the Lower Gulf.

BAY OF ISLANDS (No. 33 STATION 57.)

Length (mm.).	No. of Jaws.	Length (mm.)	No. of Jaws.
20	11-12	39	11-11
21	10-11	40	12-12
22	12-12	40	12-12
24	10-10	40	12-12
24	11-11	40	13-13
25	12-12	42	12-12
25	12-12	43	12-12
26	12-12	44	12-12
28	12-12	46	13-13
29	11-11	49	9-10
35	13-13	52	10-11

BAY OF ISLANDS (No. 33 STATION 54.)

Length mm.).	No. of Jaws.	Length (mm.)	No. of Jaws.
13	9–9	15	8–9
14	10–10	15	10–11
14	10–11		

LOWER GULF. (PRINCESS STATION 25.)

Length (mm.).	No. of Jaws.	Length (mm.)	No. of Jaws.
22	11–11	26	12–12
24	11–11	27	11–11
24	12–12	27	11–11
25	11–11	30	12–12

LOWER GULF. (PRINCESS STATION 50.)

Length (mm.).	No. of Jaws.	Length (mm.)	No. of Jaws.
9	9–9	14	10–10
11	9–10	15	10 11
14	10–10		

So far as can be seen, the number of jaws is dependent upon the size, irrespective of the degree of maturity. Only in the very largest individuals is there any indication of the decrease in number that is so characteristic of certain other species.

The number of jaws is therefore proportional to the size, and becomes greater in the colder water.

The subspecies *S. elegans baltica* Ritter-Zahony (1911, p. 18) differs from both the typical and arctic subspecies in having a relatively shorter tail, that is, its tail percentage (the percentage of the length of the tail in the total length) is less. It seemed likely that this character would show differences characteristic for each region and that the Lower Gulf specimens would approach the Baltic type. To test this, in the first place a series of small individuals from 11 to 16.5 mm. long, taken in July and August at different poins, were studied. There were none available from the Bay of Fundy. The results were as follows:—

BAY OF ISLANDS (No. 33 STATION 54).

Length (mm.).	12	12·5	13	13·5	14	15	15·5	16
Tail percentages	19	19	18	19	19	19	18	19
	19	20	19	19	21	....	....	....
	21	....	20	20	....	....	....	....

SOUTH COAST OF NEWFOUNDLAND ("ACADIA" STATION 83.)

Length (mm.).	12·5	13	13·5	14	15	15·5	16·5	
Tail percentages..................	....	19	18	18	20	19	17	18
		20	18	....	..	.	....	......
		21	18	.	...	..	.	.....

OUTER COAST OF NOVA SCOTIA ("ACADIA" STATION 37).

Length mm.).	11	11·5	12·5	13	15	16	16·5
Tail percentages..........................	20	20	18	19	19	19	18
	....	....	.....	.....	19		18
	—...	.....	.....	...	....	.	19

SOUTHERN PART OF GULF. ("PRINCESS" STATION 48).

Length mm.).	11	12·5	14·5	15	15·5	16	16·5
Tail percentages..........................	18	18	17	17	18	18	17
	......	20	18	18	19	18	17
	.....	..	19	....	...	.	18

The differences shown in the above tables are very slight. The Bay of Islands specimens have, on the whole, the highest tail percentage, and the southern gulf specimens the lowest. Larger individuals show more marked differences. A series from 21 to 27mm. were taken from three localities: (1) Bay of Islands (*No. 33* station 57) with icy cold bottom water doubtless throughout the year; (2) Bay of Fundy (*Prince* station 3) with moderately cool water throughout the year; and (3) the southern part of the gulf (*Princess* station 25) with water very warm in summer and very cold in winter.

The tail percentages for the different sizes are given in the following tables:—

BAY OF ISLANDS (NO. 33 STATION 57).

Length (mm.).	21	22	23	24	25	26	27
Tail percentages..	20	20	22	19	20	20	19
	20	.	22	21	20	19	20
			20	20	20	19	20
	...		..	21	20		20
	...	.	...	.	19	.	.
	..		.		21		.
	.	.	.	..	20		..

Bay of Fundy. (Prince Station 3).

Length (mm.).	21	22	23	24	25	26	27
Tail percentages	17	16	17	17	17	18	17
	18	18	17	17	19	19	19
	17	16	...	18	18	17	17
	18	17	......	......	19	17	17
	17	16	......	......	16	18	17
	...	18	......	......	19	18	17
	.....	......	......	......	17	17	19
	.....	.....	......	......	......	20	19
	....	...	....	......	......	18	......
	.....	.....	......	....	......	17	......
	.....	...	......	.....	......	17	......
	....	...	....	......	......	18	......
	.	.	...	...	......	19	......

Southern Part of Gulf. (Princess Station 25).

Length (mm.).	21	22	23	24	25	26	27
Tail percentages	16	15	17	15	16	16	16
	16	15	16	16	16	18	16
	17	15	17	14	......	17	......
	16	16	19	15	.....	16	......
	.	17	18	18	.....	19	......
	...	15	....	16	......	18	......
	...	16	.	...	......	15	......
	.....	....	..	...	......	18	......

The general result is that for the Bay of Islands the percentage varies from 19 to 22, with the greatest number at 20; for the Bay of Fundy, from 16 to 20, with the greatest number at 17; and for the lower part of the gulf from 14 to 19, with the greatest number at 16. The individual sizes show similar gradations.

We have very little knowledge as to the conditions under which these forms grow, and as to their life-histories, but the greater differences in tail percentages shown by the larger individuals is, I think significant.

As will be shown farther on, the young individuals occur much nearer the surface than do the older ones. This surface water becomes quite warm in the summer throughout the region (except in the Bay of Fundy, from which we have no specimens) so that conditions are much the same for the young in all the regions and as a result, the tail percentages do not greatly differ. The older individuals seek the deeper water and have lived long enough to experience the totality of conditions characteristic of the several regions, and consequently exhibit greater differences.

The next point is: do the cold-water individuals ever attain as low a tail percentage as those of warm water? Large individuals from the Bay of Islands show the following:—

Bay of Islands. (No. 33 station 57).

Length (mm.).	Tail percentage.	Length (mm.).	Tail percentage
30	20		
31	18	44	17, 17
39	18, 20	46	17
40	18, 18, 19, 19, 19	49	17
42	19	52	19

Above 40mm. in length the Bay of Islands specimens reach a tail percentage (17) equal to that of specimens between 20 and 30mm. in length from the Bay of Fundy. They would appear never to reach as low a tail percentage as do those of the lower gulf.

The tail percentage is seen to be a function of the degree of maturity, although the cold water seems to delay the decrease in tail percentage more than maturity.

The general result is definite. The Bay of Islands provides conditions suitable for the Arctic type, the lower part of the St. Lawrence gulf furnishes a type approaching that found in the Baltic sea, and the remainder of the region shows the intermediate type or the typical *S. elegans*.

Distribution.

"Acadia."

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
2	12 m	60	50–25 (C.)	15-31	28
			20–0 (V.)	25	1
3	3 p.m	99–144	100–50 (C.)	15	1
				19-31	62
			30–0 (V.)	22–29	4
			0 (T.)		0
4	9 p.m	171	150–100 (C.)	12–30	46
			80–40 (C.)	20–27	20
			30–0 (V.)	15–30	15
	3 a.m	72	60–0 (V.)	10	1
			0 (T.)	13–24	6+7×2

"ACADIA"—*Continued.*

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.)	Number.
6	6 a.m.......	45	40–0 (V.).........	12–26	8
			0 (T.)........	10–23	9
7	12 m.....	108	0 (T.)......	c. 15	2
8	12 m.....	50	50 (?)–0 (V.).........	6	1
				12	1
				17–25	11
			0 (T.)	25	1
9	6 p.m....	104	25–0 (V.)...	16	1
			0 (T.).	....	0
10	9 p.m......	732	0 (T.)....	17 & 20	2
11	12 m.n....	over 2,000	70–0 (V.).	12 & 13	2
				15–20	6
			0 (T.).	21	1
12	6 a.m	over 2,000	100–0 (V.)..	14	1
				19	3
				20–30	41
			0 (T.)	27	1
13	9 a.m...	over 2,000	70–0 (V.)	11–24	6
14	3 p.m..	over 2,000	200–0 (V.)...	20	1
			0 (T.)..	.....	0
15	9 p.m....	over 2,000	100–0 (V.).	20	1
			0 (T.).	...	0
16	3 a.m.....	over 2,000	200–0 (V.)..	30	1
			0 (T.)..	15 & 19	2 seen
20	12 m. n.	90	0 (T.).	11–26	35
? 23	12 m.....	99	70–0 (V.).	4	2
			0 (T.).	......	0
25	6 p.m...	122	120–0 (V.).....	11–30	30
			10(?)–0 (T.)...	......	0
26	12 m. n.	over 400	100–0 (V.).....	11	1
				18–30	107
			0 (T.)..	17–32	+ +
27	3 a.m.	over 400	0 (T.)......	15–30	+

"ACADIA"—*Continued.*

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.)	Number.
28	6 a.m. ...	over 400	100–25 (C.)	14–28	100
			0 (T.)...	15–25	×
29	12 m...	57	55–0 (V.)	17 & 22	2
			0 (T.)		0
30	3 p.m ...	126	120(?)–0 (V.).........	21	1
			0 (T.)...		0
31	9 p.m ...	82	75(?)–0 (V.)	12–31	28
			0 (T.).	c. 20	×
32	12 m. n	153	100–25 (C.)...	14–30	130
			0 (T.)...	15–32	c. 50
34	9 a.m	circa 360	100–0 (V.)...	16–34	28×5
			0 (T.)..	..	0
35	12 m	circa 450	125–25 (C.)..	14–32	102×2
			0 (T.)....	15–24	c. 15
36	3 p.m	226	100–15 (C.).	26	1
			0 (T.).....	18	1
37	6 p.m. ..	62	60–20 (C.)....	8–17	12
				20–30	120
			60–0 (V.)......	4–10	31×5
				8–16	120
				20–30	190
			20–0 (V.)....	8·5 & 14	
				20–27	5
			0 (T.)...	5–19	+ +
				20–23	×
38	9 p.m.	170	150–0 (V.)..	7–19	22+15×10
				20–30	115
			100–0 (V.)	5–19	70+63×10
				20–31	104
			0 (T.).	5–16	+
				21–22	×

"ACADIA"—*Continued.*

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.)	Number.
39	12 m. n.......	95	100–0 (V.)............	7–18	28×10
				20–30	35
			25–? (V.)............	6–12	30×5
				7–15	18
				20–26	7
			0 (T.)............	7–14	+
				20–30	×
40	3 a.m........	134	125–0 (V.) I..........	12–16	4
				20–25	12
			125–0 (V.) II.........	15	2
				20–30	11
			0 (T.)...........	small	?
47	6 a.m........	140	125–0 (V.)...........	8–19	122+2×10
				20 & 22	2
			90–0 (V.)............	8–19	c. 100
			0 (T.)............	....	0
48	12 m..........	248	270–0 (V.)...........	20–30	7
			45–0 (V.)............	....	0
			0 (T.)............	....	0
49	3 p.m........	126	125–0 (V.) I..........	7–12	82×5
				9–20	175
				23–31	6
			0 (T.)............	6–13	+
50	9 p.m........	151	145–55 (C.)............	11–13	3×5
				12–20	225
				21–26	9
			145–0 (V.)...........	9–17	35×5
				9–20	124×3
				21–28	8
			55–0 (V.)............	9–14	27×5
				7·5–20	164
			0 (T.)............	7–15	+
51	12 m. n.......	131	125–55 (C.)............	5–14	76×5
			125–55 (C.)............	11–19	257
				21–25	3

"ACADIA"—Continued.

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.)	Number.
			125-0 (V.)...........	10-17	86×5
				9-19	96
				28	1
			0 (T.)...........	8-20	++
52	3 a.m........	99	90-0 (V.) II..........	13-20	9
			0 (T.)...........	13-18	14
53	6 a.m.......	95	90-0 (V.)...........	8-13	7×5
				13-15	13
			0 (T.)...........	10-11	×
54	9 a.m........	over 1,000	270-0 (V.)...........	30	2
			125-0 (V.)...........	....	0
			0 (T.)...........	....	0
59	3 a.m........	45	45-0 (V.)...........	6-12·5	21×10
			0 (T.)...........	10-14	+
60	6 a.m........	99	90-0 (V.)...........	13	1×5
			0 (T.)...........	small	×
61	9 a.m........	72	0 (T.)...........	4-10	×
62	12 m..........	61	55-0 (V.) II	7-9	18×10+8×40
				10-19	137
			0 (T.)...........	7-9	××
63	12 m..........	53	55-0 (V.)....	8-16	44+31×15
				20-25	4
			0 (T.)...........	6	×
65	6 p.m......	90	110-0 (V.)...........	5-17	30+41×4
				18-19	3
				21-33	50
			90-0 (V.)	5-15	75+50×5
				19	1
				22-36	16
			0 (T.)..	6-11	++
				12-14	×
66	9 p.m........	63	55-0 (V.) II	6-14	90×4
				25-29	3
			0 (T.)..	7-14	++

"ACADIA"—*Continued.*

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.)	Number.
67	12 m.n.	198	190–0 (V.)	8–15	109×10
				20–34	20
			90–0 (V.)	8–14	c. 100+184×5
				21–28	10+2×5
			0 (T.)	8–15	++
68	3 a.m.	53	45–0 (V.) II	8–20	63
			0 (T.)	10–13	6
			5–0 (T.)	10–12	6
69	9 a.m	68	60–0 (V.) I	11–14	4
			5–0 (T.)	.....	0
			c. 20–10 (T.)	.....	0
72	3 p.m.	over 1,000	325–0 (V.)	11	1
				18–20	3
			55–0 (V.)	.....	0
			c. 20–10 (T.)	.....	0
76	3 a.m.	over 1,000	270–0 (V.)	11–18	8+4×4
				20–24	12
			c. 20–10 (T.)	13–16	××
79	12 m.	360	325–0 (V.)	6–11	33×10
				8–15	16
				21	1
			55–0 (V.)	6–9	18
80	3 p.m	168	145–0 (V.)	8–11	29×20
				9–18	82×4
				21–30	15
			55–0 (V.)	7·5–18	131×4
				20 & 22	2
			c. 20–10 (T.)	8–15	++
				17	×
81	9 p.m.	60	55–0 (V.)	6–13	44×10
				10–16	201
				22	1
			c. 20–10 (T.)	10–15	++
82	9 p.m.	60	55–0 (V.) I	9–14	7×4
			c. 20–10 (T.)	12	1

"ACADIA"—*Continued.*

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.)	Number.
83	12 m.n	172	160-0 (V.)	8-15	14×10
				17	1
				20-29	8
			55-0 (V.)..	7-15	90×4
				17 & 19	2
				21-24	3
			c. 20-10 (T.)...	7-15	+
84	6 a.m	60	55-0 (V.) I	9-15	21×5
			c. 20-10 (T.)..	8-14	++
85	9 a.m.......	over 400	270-0 (V.)..	8-14	12
				19 & 20	2
				25-30	9
			55-0 (V.)..	8-16	11
			c. 20-10 (T.)..	15	×
				20-30	×
86	12 m..........	over 400	270-0 (V.)....	7-11	24×10
				12-19	100
				21-26	9
			55-0 (V.)..	6-16	9×10
			c. 20-10 (T.)..	7-15	× ×
87	3 p.m.......	331	290-0 (V.)..	7-10	6×10
				12-19	29
				23-27	8
			55-0 (V.)..	6-9	5×5
				6·5-17	43
			c. 20-10 (T.)	6-15	+
				17	×
88	6 p.m.......	130	110-0 (V.)	6-15	92
			55-0 (V.)..	6-14	86
			c. 20-10 (T.)..	6-15	+ +
89	9 p.m.	132	115-0 (V.)..	6-14	19+107×5
				22-34	124
			55-0 (V.)	6-14	113×5
				20-29	61
			c. 20-10 (T.)	6-14	+
				20-29	+

"ACADIA"—*Concluded.*

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
90	12 m.n.......	c. 60	c. 20–10 (T.)...	11·2	×
				20–30	c. 100
91	(?)..........	c. 45	45–0 (V.)..	7–13	17×20

"PRINCESS."

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
1	9 a.m........	68	(?)	14	1
				11–22	22
			(?)	11–22	c. 25
2	3 p.m........	45	(?)	c. 15	×
3	12 m	20	20–0 (V.)...	16	1
			0 (T.)..... ..	....	0
5	9 a.m........	32	30–0 (V.).. .	4–6	7×5
			0 (T.)...	....	0
6	12 m..........	57	60–0 (V.)... ..	6	2
			0 (T.)	4–5	5×6
7	3 p.m........	80	80–0 (V.)..	6	2×3·5
			0 (T.)	c. 6	×
8	9 p.m.......	80	80–0 (V.)....	17–27	13
			40–0 (V.)....	28	1
			0 (T.)....	10	1 seen
				15–26	c. 40
9	12 m.n	over 200	100–0 (V.)...	15–30	21
			80–0 (V.)...	15–30	23
			0 (T.).....	15–30	c. 30
10	6 a.m........	over 200	100–0 (V.)... ...	25–33	30
			0 (T.)......	15–18	3 seen
11	9 a.m.. .	48	50–0 (V.).....	25–30	9
			0 (T.)... . ..	....	0
15	9 a.m....	90	80–0 (V.)... ..	11–14	4
			0 (T.)..	....	0
16	12 m......	over 250	100–0 (V.) II	16–31	26
			0 (T.)..	28	1
17	6 p.m	130	100–0 (V.) I......	21	1
			100–0 (V.) II	....	0
			0 (T.)..	... .	0

"PRINCESS"—*Continued.*

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
18	9 p.m.......	63	50-0 (V.)..	23	1
			0 (T.)..	.....	0
19	3 a.m	81	80-0 (V.)..	19-32	55×4
			0 (T.)....	....	0
20	6 a.m	over 200	100-0 (V.)	15-32	67
			0 (T.)..	17 & 22	2 seen
21	9 a.m.	over 400	100-0 (V.)......	15-32	176
			0 (T.)......	16	1
23	3 p.m.......	115	100-0 (V.)..... ..	20-31	14
24	9 a.m.....	40	35-0 (V.) I.	16	1
			35-0 (V.) II........	c. 4	4
			0 (T.).......	......	0
25	12 m.....	68 (?)	60-25 (C.) I ..	20-30	14
			60-25 (C.) II	20-30	24
			60-0 (V.) I	......	22
			60-0 (V.) II	20-32	35
			0 (T.).. ..	7	1
26	3 p.m	39	40-0 (V.) I ..	17-20	5
			40-0 (V.) II .	15-25	12
			0 (T.) .	..	0
29	6 a.m.....	32	20-0 (V.)..	5-13	23×5
			c. 20- 10 (V.).. ..		0
30	12 m.........	66	60-0 (V.) ...	10-21	15
				small	9×5
			30-0 (V.) .	6-15	3×5
			c. 20-10 (T.)..	small	×
31	3 p.m.....	65	60-0 (V.)..	3-11	23×5
			30-0 (V.) .	6-9	11
			c. 40-0 (T.) .	2-8	×
32	6 p.m........	87	80-0 (V.)	5	2×10
				10 & 15	2
			30-0 (V.).	6-8	16
			c. 40-0 (T.) .		×

"PRINCESS"—*Continued.*

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.)	Number.
33	9 p.m.......	78	80–0 (V.)...........	10–18	26×10
				20–30	17
			30–0 (V.)...........	7–26	164
			c. 40–0 (T.).........	....	+
34	12 m. n......	405	130–0 (V.).........	8	1×10
				12–19	6
				20–29	13
			30–0 (V.).........	9–28	17
			c. 40–0 (T.)........	20–30	c. 50
35	6 a.m ...	over 350	130–0 (V.).........	8–20	19
				20–26	23
			30–0 (V.).........	10–20	12+4×4
			c. 40–0 (T.)........	10–17	+ +
36	9 a.m	48	60–0 (V.).........	6–16	28+39×4
			c. 40–0 (T.)........	6–16	+
				30	1
37	12 m ...	75	80–0 (V.).........	6–12	10×4
				8–20	32
				25 & 29	2
			30–0 (V.).........	6–17	42
			c. 40–0 (T.)........	6–21	+
38	6 p.m.....	180	130–0 (V.).........	6–16	120+12×4
			40–0 (V.).........	6–15	64
			c. 40–0 (T.)........	6–16	+
39	9 p.m	284	130–0 (V.).........	6–15	108+13×4
				20–26	7
			40–0 (V.).........	6–14	24
			c. 40–0 (T.)........	6–16	+
40	12 m. n	68	70–0 (V.).........	6–15	59
				26	1
			30–0 (V.).........	small	76
				10–23	22
			c. 40–0 (T.)........	....	+

"PRINCESS"—*Continued.*

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.)	Number.
41	3 a.m	189	130-0 (V.)..	6-15	155
			30-0 (V.).......	7-15	116
			c. 40-0 (T.)..	6-15	+ +
42	9 a.m.....	90	100-0 (V.)	7-10	18
			30-0 (V.)..	6-12	26
			c. 40-0 (T.)..	6-14	+ +
43	12 m..	265	130-0 (V.) I	6-13	49
			30-0 (V.) I.......	5-9	5
			30-0 (V.) II	7	1
			c. 40-0 (T.) .	7	11
44	3 p.m.....	157	130-0 (V.)..	6-17	192×4
			30-0 (V.).. ..	6-16	61×4
45	3 a.m.....	375	130- 0(V.)..	12-21	170×8
				24-30	8
			30-0 (V.)	6-20	110×8
				26	2
			c. 40-0 (T.)...		+ +
46	6 a.m..	over 400	130-0 (V.)...........	8-20	90×5
				21-32	13
			30-0 (V.)...	8-17	60×4
			c. 40-0 (T.).. ..	c. 13	× ×
47	9 a.m.....	over 400	130-0 (V.) I	5-18	110×4
				23 & 26	2
			30-0 (V.).. .	6-15	102
			c. 40-0 (T.) . .	c. 12	+ +
48	12 m.......	171	130-0 (V.)........	6-18	80
				22-26	4
			30-0 (V.)......	6-18	50×4
			c. 40-0 (T.).. .	c. 15	+
49	6 p.m......	70	70-0 (V.).....	6-16	42×10
			30-0 (V.)..	6-20	52×4
			c. 40-0 (T.)...	c. 12	+
	12 m. n . .	52	40-0 (V.) I	6-20	148×4
			c. 40-0 (T.)	c. 15	+ +

"PRINCESS"—*Continued.*

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
4	3 p.m........	45	2–0 (T.)..........	12	1
6b	3 p.m........	c·30	2–0 (T.)..........	22	1
9	12 m..........	10	2–0 (T.)..........	19–24	5
10	3 p.m........	39	2–0 (T.)..........	....	0
			35–25 (C.)..........	16–26	32
			25–10 (C.)..........	14	1
			10–0 (V.)..........	....	0
11	6 p.m........	59	2–0 (T.)..........	5	1
12	9 p.m........	67	2–0 (T.)..........	3–6	6
				13	1
13	9 p.m........	39	3–0 (T.)..........	10–22	c·50
14	12 m.n........	58	3–0 (T.)..........	10–26	++
15	6 a.m........	38	2–0 (T.)..........	15	1
19b	6 p.m........	90	2–0 (T.)..........	6	1
23	12 m..........	355	340–145 (C.)..........	....	0
			100–60 (C.)..........	20	1
				23–32	29
			45–0 (V.)..........	15–22	5
			0 (T.)..........	....	0
26	9 a.m........	389	30–15 (T.)..........	6	1
				16	1
			2–0 (T.)..........	....	0
29	6 p.m........	41	3–2 (T.)..........	6	×
36	6 p.m......	60	20–8 (T.)..........	6–10	×
40	?	38	c·9 (T.)..........	6–10	×
48	6 p.m........	?	40–0 (T.)..........	10–19	c. 100
49	6 p.m.......	?	15–0 (T.)..........	5	1
54	9 a.m........	110	70–35 (T.)..........	11–16	++
			25–5 (T.)..........	11–16	++
57	3 p.m......	210	200–0 (V.)..........	9–15	12+51×10
				27–33	31
				42	1
58	12 m.	50	40–0 (T.)..........	10–12	+

"PRINCESS" *Concluded*

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.)	Number.
59	12 m.........	275	270–0 (V.)...........	10–16	106×10
				17–45	70
64	8 a.m.......	?	80–20 (T.)...........	11–16	1×2
67	?	?	30–0 (T.)...........	11	+
68	6 p.m........	?	70–20 (T.)...........	10–30	++
69	3 a.m	?	100–20 (T.)..	10–30	+
70	3 p.m........	?	8–2 (T.)...........	13–15	c. 6

"PRINCE."

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.)	Number.
1	3 p.m........	c. 38	c. 35–0 (V.) I........	....	0
			c. 35–0 (V.) II........	....	0
			c. 20–10 (T.)..........	18–30	41
			0 (T.)......		5
2	6 p.m........	c. 100	100–0 (V.)...........	22–28	9
			4–2 (?) (T.)..	....	0
3	12 m..........	180	180–0 (V.)....... .	18–35	98
			c. 20–10 (T.)	9	1 seen
			2–0 (T.)..........	....	0
4	6 p.m.......	c. 35	c. 35–0 (V.)..........	23 & 27	2
			15–5 (T.)...........	26	1

Vertical.—So many factors are involved in the vertical distribution of this species that a discussion of particular stations is necessary. At *No. 33* station 23 in the deep water off Anticosti island no specimens were obtained in the closing-net haul between 340 and 145 metres. Between 100 and 60 metres, one specimen 20mm. long and twenty-nine over 23mm. long were obtained. Between 45 and 0 metres there were five specimens all 22 mm. or under in length, and at the surface none were obtained. These hauls were made about midday (1-2p.m.). The larger specimens were all below 45 metres, the intermediate specimens above 60 metres but not at the surface. No specimens were in the deep saline water. No small specimens were present.

At *No. 33* station 10 off the eastern side of Prince Edward Island in shallow water, the closing haul from 35 to 25 metres gave thirty-two specimens over 16mm. in length. The haul from 25 to 10 metres one specimen 14mm. long; and the hauls from 10 to 0 metres and at the surface, none. These hauls were made about 3 p.m. The larger were in the cold bottom water below 25 metres, and there were none above 10 metres.

In the Bay of Islands at *No. 33* station 54 the tow hauls which were presumed to go as deep as 70 metres brought up an abundance of this species, but all the individuals were 16mm. or less in length. At practically the same spot at *No. 33* station 55, the young-fish trawl brought up from the bottom (about 110 metres deep) an abundance of large individuals (23 to 43mm. in length.) Here again the larger individuals were wholly confined to the cold bottom water below 70 metres, and there was an abundance of small individuals above 25 metres. The time of day was between 9 and 10 a.m.

At *No. 33* station 57 in the Bay of Islands where the depth was 210 metres with moderately saline water below the freezing point quite to the bottom, the young-fish trawl, which was towed along the bottom, brought up an abundance of large individuals between 21 and 52mm. long. These were thoroughly mixed with typical bottom forms (shrimps and Amphipods) so that there can be little doubt but that they were near the bottom. It is at least probable that in the Bay of Islands the larger individuals go down into the deepest water, for example, 270 metres at *No. 33* station 59. More definite information is desirable on this point. There would thus be a marked difference in the vertical distribution depending upon the character of the water. Where proper conditions of salinity and temperature obtained, the species goes far into the depths, but if not, it is restricted to the suitable intermediate layers.

As in the case of *Eukrohnia hamata*, the hauls made in the Bay of Fundy at *Prince* stations 1, 2 and 3 showed the effect of the vertical currents due to the tides. At station 1 where the species was so rare as not to be taken in either of two vertical hauls, the tows taken near or at the surface yielded 46 large specimens. At stations 2 and 3 it was obtained in numbers in the vertical hauls, but failed to occur in the tows, except one small individual in the deep tow at station 3.

Vertical currents doubtless explain many of the irregularities appearing in the vertical distribution elsewhere.

Owing to differences due to this and other factors, it is very difficult to determine what effect light has on the vertical distribution of this species. If we divide the twenty-four hours into three-hour intervals, and designate these by their mid-points, 6 a.m. representing from 4.30 to 7.30 a.m., and others similarly, and then put together the records for each three-hour period, we can to some extent overcome the influence of the other factors. The stations on the first cruise of the *Acadia,* at which this species was obtained, give the following result as to its presence or absence in the surface hauls: 9 a.m., one negative; 12 m., two negative, 3 positive; 3 p.m., three negative, one positive; 6 p.m., two negative; 9 p.m., one negative, two positive; 12 midnight, four positive; 3 a.m., three positive; 6 a.m., two positive. It is noteworthy that large numbers were obtained in the surface hauls only for 12 midnight and 3 a.m. From this we conclude that *S. elegans* comes to the surface from 9 p.m. to 3 a.m., occurring there in numbers about the middle of that period. From 9 a.m. to 6 p.m. it seeks a lower level. The individuals obtained on this cruise were of large size.

The *Princess cruise* (stations 3 to 26) gives similar results, but the figures require analysis: 9 p.m. and 12 midnight show many large individuals at the surface (stations 8 and 9; 6 a.m. shows several only (stations 10 and 20). For some reason the single 3 a.m. station (19) is negative. From 9 a.m. to 6 p.m. the stations are negative or show only small individuals (9 a.m., 16mm.; 12 midnight, 5-7mm.; 3 p.m., 6mm.); but there is a single exception at station 16, where one large individual was obtained.

The specimens from the second cruise of the *Acadia* (stations 37 to 90) have been divided into two groups, those under and those over 20mm. in length. The larger group is represented in surface hauls in only three instances. A few specimens were obtained in the surface hauls of the first three stations, at 6 p.m., 9 p.m., and 12 midnight. The largest individuals were obtained at the midnight station. In the deeper tow hauls of the latter part of the cruise, they were obtained in only three instances; occasional in one at 9 a.m., abundant in one at 9 p.m., and one at 12 midnight.

Those under 20 mm. show a different distribution. Surface hauls: 9 a.m., two negative, one positive (occasional specimens up to 10 mm. long); 12 m., one negative, two positive (occasional specimens up to 9mm.); 3 p.m., one positive (many specimens up to 13mm.); 6 p.m., two positive (very many specimens up to 19mm); 9 p.m., three positive (very many specimens up to 16mm.); 12 midnight, three positive (many specimens up to 20mm.); 3 a.m., four positive (several specimens up to 18mm.); 6 a.m., one negative, two positive (occasional specimens up to 11mm.). Deeper tow hauls: 9 a.m., one negative, one positive (occasional specimens); 12 m., one negative, one positive (occasional specimens); 3 p.m., one negative, two positive (many specimens); 6 p.m., one positive (very many specimens); 9 p.m., three positive (very many specimens); 12 midnight, one positive (many specimens); 3 a.m., one positive (occasional specimen); 6 a.m., one positive (very many specimens). There is little evidence of any daily migration of the larger individuals at these stations. They remain almost constantly in the depths. The smaller individuals come nearer to the surface. They are less abundant and smaller or entirely absent from 6 a.m. to 3 p.m.

Taking the shallow vertical hauls (30 to 0 metres) of the second *Princess* cruise (station 27 to 50), we have the following upper limits in size for the individuals obtained in the several three-hour periods: 9 a.m., 15mm.; 12m., 18mm.; 3 p.m., 16mm.; 6 p.m., 20mm.; 9 p.m., 26mm.; 12 midnight, 28mm.; 3 a.m., 20mm.; 6 a.m., 20mm. There would seem to be a definite movement of the larger individuals across the 30-metre line during the twenty-four hours.

As to the effect of temperature on the vertical distribution, we may compare the early and late cruises both outside and inside the gulf. On the earlier cruises the surface water was decidedly colder than on the later ones. The *Acadia's* cruises show that outside the gulf in May-June large individuals came in numbers to the surface during the night, while in July-August they were virtually absent. The *Princess'* cruises show that inside the gulf in June larger individuals came to the surface than came above 30 metres in August, for 9 a.m., 12m., 9 p.m., 12 midnight and 6 a.m. This decrease in the daily vertical migration is doubtless due to the warming of the surface water.

The facts point to the following conclusions *Sagitta elegans* is confined to water of comparatively low salinity, being stopped in its migration into the depths by water of high salinity. It is affected by light, coming nearer the surface at night. It is affected by temperature, keeping to the colder water. The young behave differently from the adults, living in the lighter, warmer surface water. With increasing age it becomes gradually restricted to the darker, colder water, which is deeper.

HORIZONTAL.—This species belongs to the subarctic and arctic regions. Along our coast it is typical of the cold coastal water and is found over practically the whole of the continental shelf. Its distribution in May-June is shown in fig. 8. Of the entire area covered, it was absent at only three places; western part of Northumberland straits (*Princess* station 4), north of Anitcosti island (*Princess* stations 12 to 14) and out in

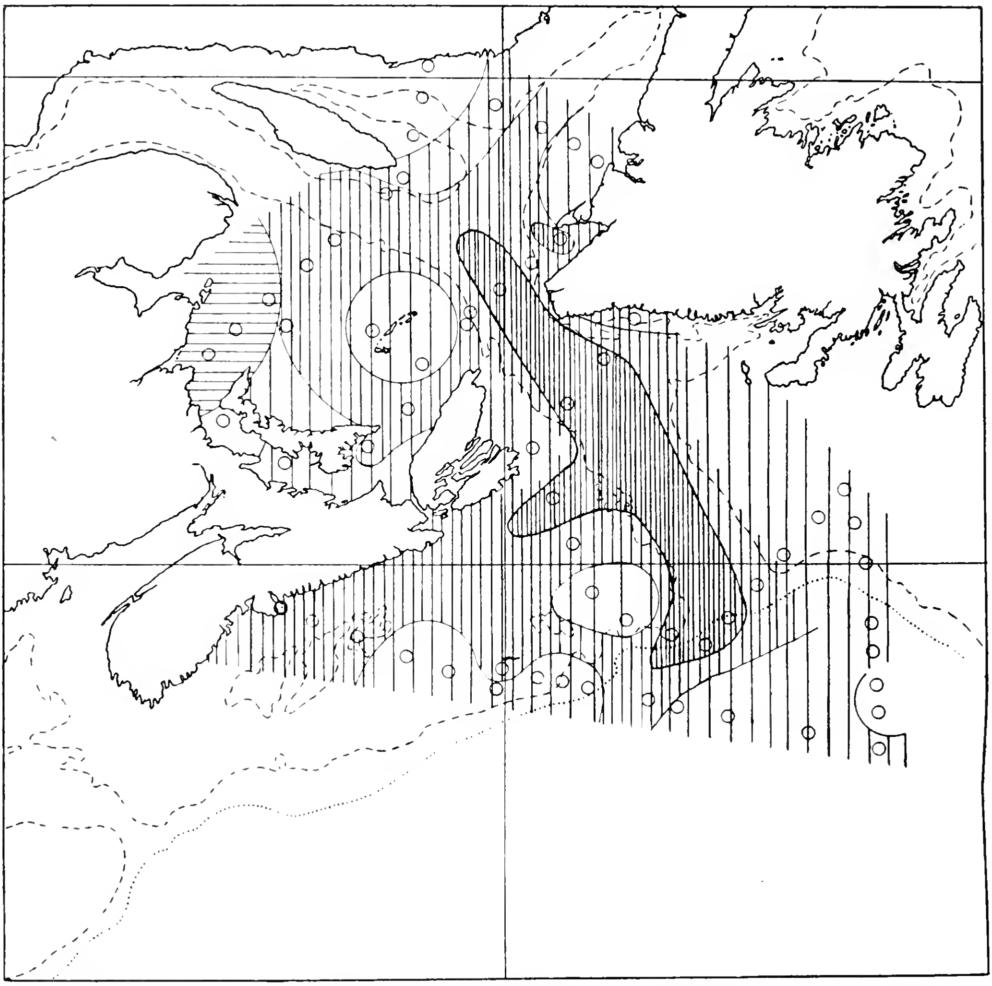

Fig. 8.—Distribution of *S. elegans*, May-June 1915. Zones showing frequencies of 1 to 10, 11 to 100 and 100 and over. Horizontal lines indicate a zone containing none over 10^{mm} in length.

the open Atlantic at one of the outermost (*Acadia* station 17). Its area of abundance corresponded closely with the deeper parts of the coast water, the shallow southern part of the gulf an dthe shallow banks elsewhere showing only a few or small individuals. Its great abundance at the mouth of the Laurentian channel and off Banquereau at *Acadia* stations 12, 13, 26, 27, and 28 would indicate the presence there of a large amount of cold coastal water. At the remainder of the stations off the continental shelf, it was present in small numbers or altogether absent.

The distribution in July-August is represented in fig. 9. The large individuals (those above 20mm. in length are represented by vertical lines) are more restricted to the deeper parts of the coastal water, and in the northern part of the gulf they are few in number or altogether lacking even in the deep water. We again see them abundant off the mouth of the Laurentian channel on the southern side, at *Acadia* station 76, indicating the presence there of coastal water, that

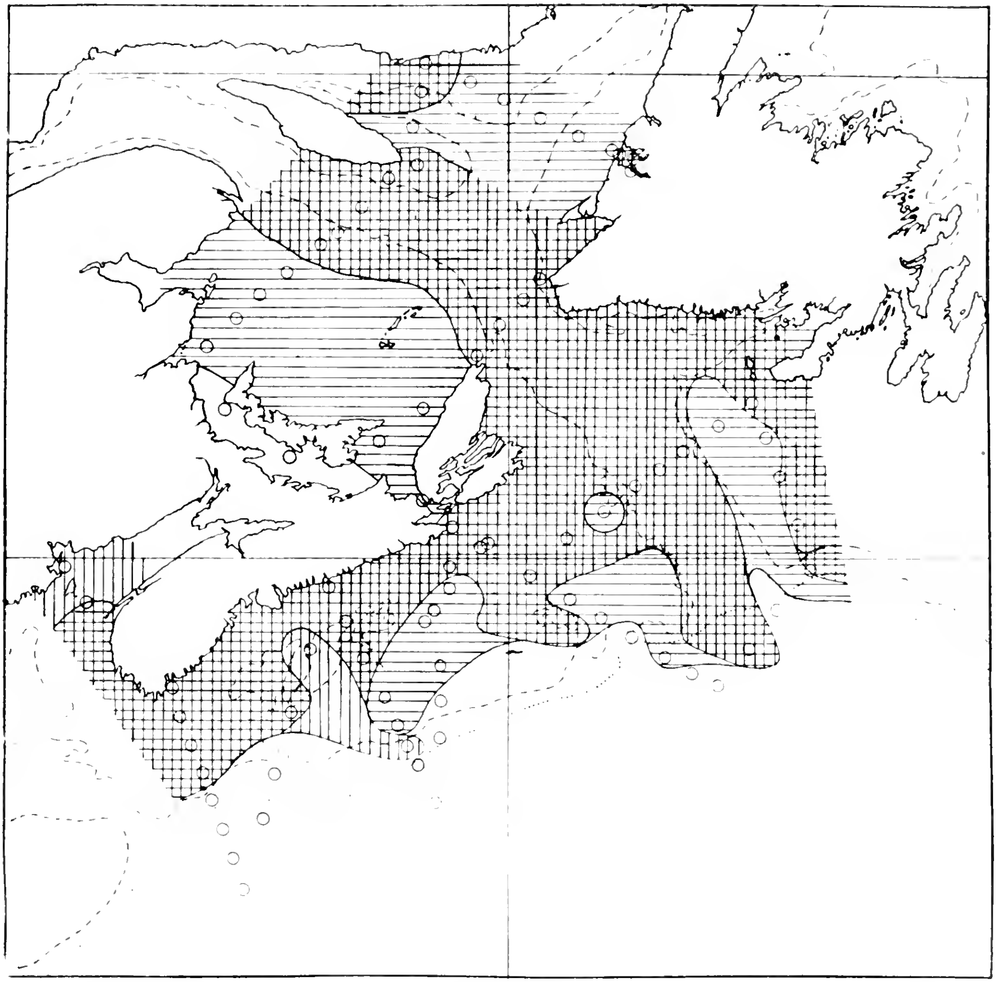

Fig. 9—Distribution of *S. elegans*, July-August 1915. Horizontal lines indicate individuals under 20 mm. in length and vertical lines those over 20 mm.

has doubtless come from inside Banquereau. The absence of large individuals on the banks where warmer water conditions prevail than in the spring is important. The small individuals (represented by horizontal lines) are generally present over the whole of the continental shelf, and pass out with the coastal water from the mouth of the Laurentian channel. In two places they are absent, and for different reasons. In Northumberland straits there were none, perhaps because this area is too far from the places where the adults occur. In the Bay of Fundy, among 156 specimens there was only one individual under 18mm. in length, and that at *Prince* station 3 in the mouth of the Bay. There can be no doubt that the absence of warm, brackish surface water in this part has prevented their development, the Bay of Fundy being a distinctly unfavourable breeding place, although quite suitable for the adults, as large numbers of them were found. In the Bay of Islands fjord the conditions appear to be ideal for both the old and the young, the icy bottom water containing an abundance of the adults and the warm brackish surface water an abundance of the young. There is therefore a sharp contrast between the conditions in: (1) the Bay of Islands, (2) the lower part of the gulf, and (3) the Bay of Fundy. In the first the conditions are suitable for both adults and young, in the second suitable only for the young and in the third suitable only for the adults.

The virtual absence of small individuals in the Bay of Fundy is important, as indicating the lack of suitable conditions for the breeding of species that require quite warm water of comparatively low salinity for at least the early stages of development. Many fish of economic importance have eggs and young larvæ at the surface that would be affected by this. Further investigation of the Bay of Fundy is needed.

The hauls lacking young *Sagitta elegans* were made in September. Prof. J. P. McMurrich informs me that in a series of tow-nettings taken regularly in Passamaquoddy bay from October, 1914, to May, 1915, only two small *Sagittæ* were obtained, and these at the mouth of the St. Croix river on October 29, 1914. This is a spot with strong tidal currents, where forms brought in from without would appear, if they did appear anywhere. The nets used were more suitable for taking young *Sagittæ* than older ones, and yet ten large individuals from 22·5 to 32·5 mm. in length were taken in a haul on January 1, 1915.

The centre of abundance during the earlier cruises (May-June) is shown in fig. 8. Stations at which more than 100 individuals were obtained in the deep vertical haul occur in an area represented by the most closely placed lines. This area occupies the Laurentian channel from the centre of the gulf outwards to slightly beyond the mouth. Two tongues extend from it to the southwest. One just outside Cape Breton island and the other just outside Banquereau. These may signify the directions in which the currents are carrying the abundant schools. On the later cruises the centre of abundance of the larger individuals is at the lower end of Nova Scotia (as shown in fig. 10). This part of the region was not investigated on the first cruise, but it is at least probable that the currents have during the intervening two months carried large numbers from the Laurentian channel down along the coast, and thus depopulated the northern part of the area. This is all the more probable because the conditions at the lower end of Nova Scotia do not appear to be as suitable for the large individuals as those of the intermediate water in the Laurentian channel.

Another centre of abundance is seen among the banks north of Sable island at *Acadia* station 89 where 124 specimens were obtained in the vertical haul. Their presence near the surface was demonstrated by the taking of sixty-one in the haul from 55 metres to the surface, and by the large number obtained in the tow. This zone apparently extended to station 90, where many were obtained in the tow, but where no vertical haul was made. The neighbouring station (66) showed very few large individuals, but at station 65 off Cape Canso, fifty were obtained in the deepest haul. The distribution suggests that the pressing-in of the boreal water over the banks south of Sable island has tended to separate the zone of abundant *S. elegans* into two parts, one north of Sable island and the other at the lower end of Nova Scotia.

At *Acadia* station 77 at the mouth of the Laurentian channel no vertical haul was made, but since the deep-water form *Eukrohnia hamata* was obtained in the tow haul and no *S. elegans*, it is practically certain that the latter species was absent. This is significant, indicating almost pure boreal water at that point between two stations where coastal water was present. This boreal tongue extends into the Laurentian channel on the north side. Farther up the channel it is covered with coastal water (stations 85 and 86).

The distribution of the large individuals in July-August shows that they have retreated from the shallower banks, also from the lower part of the gulf and curiously enough also from the deep northern part of the gulf. Between Anticosti island and the north shore they were entirely absent in June but present in August. The general circulation in the gulf has doubtless been responsible for this, carrying them around and then out through Cabot strait.

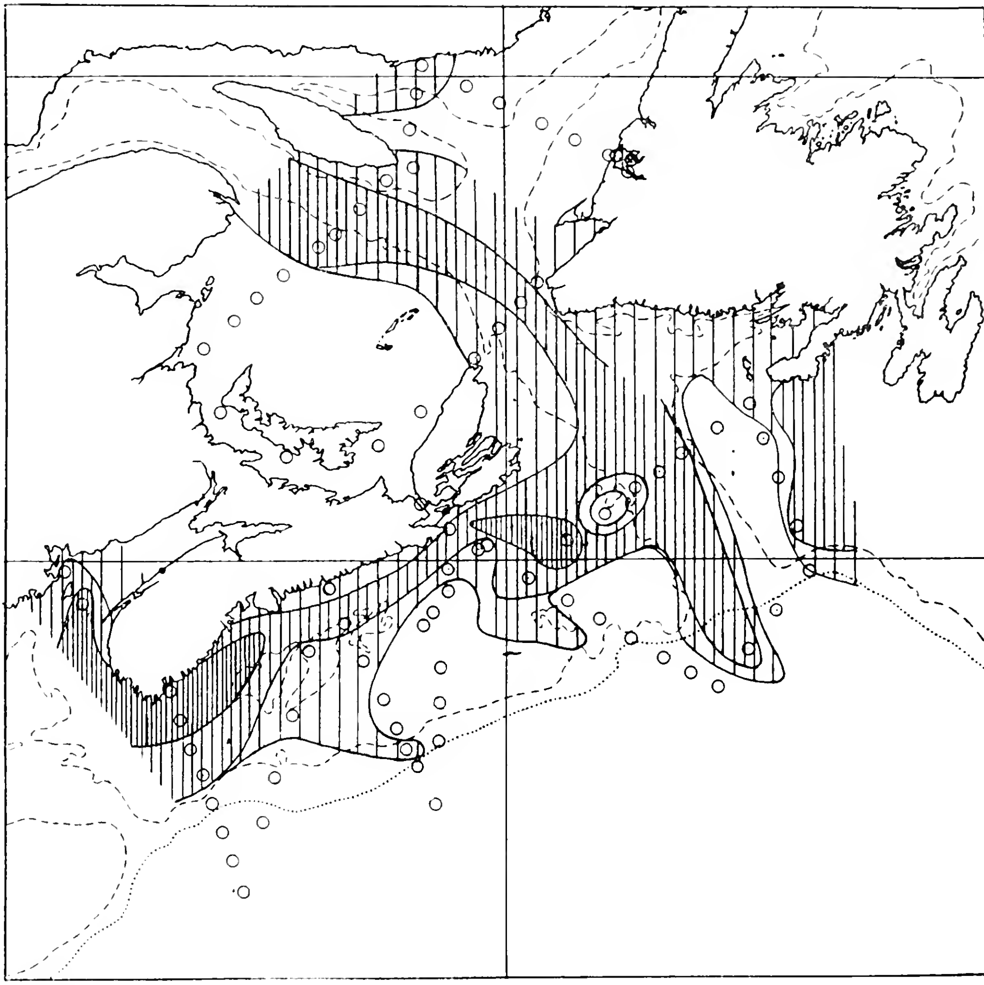

Fig. 10. Distribution of *S. elegans* (those over 20 mm in length). July-August 1915. Zones showing frequencies of 1 to 8, 9 to 90 and 90 and over per station.

The retreat inshore of the species during the summer from the open Atlantic is shown by its absence beyond the continental shelf during the late cruise, except at the mouth of the Laurentian channel, while during the early cruise it occurred at the outermost stations (except *Acadia* station 17), though in small numbers. In some places on the late cruise it was pushed well back from the edge of the shelf, particularly in the southern part.

During the June cruise the western side of the lower part of the gulf contained only small individuals, 6mm. or less in length. This is shown by the horizontal lines in fig. 8. This is the beginning of the condition that in the August cruise was found over practically the whole of the lower part of the gulf. It is interesting that this change has spread from west to east in the direction of the Gaspé current.

The presence of two large individuals of this species in the boreal oceanic water at *Acadia* station 54 does not, I think, indicate that there has been an outflow of coastal water at this point, but rather that individuals carried into the boreal water by the tongue of coastal water that comes out of the southern side of the Laurentian channel, have been transported in the boreal water along the side of the continent past Sable island along the course shown by the distribution of *E. hamata* (fig. 12). During May-June the tongue of coastal water actually extended from the channel mouth to the southwest for a considerable distance, as found at *Acadia* station 12 (see fig. 8), with boreal water on either side. We can readily believe that early in the year such a tongue extended as far to the south as *Acadia* station 54 at least, and from that point passed up over the banks to connect with the coastal water off Halifax. In July-August this connection of the coastal water outside Sable island had been severed in the middle and only the ends left.

The large amount of boreal water occurring on the shelf off Halifax accounts for the few large *S. elegans* found at stations 47, 48, and 51.

On the New England coast, Bigelow (1915, p. 299) has found the species extending in the coast water as far south as Long island.

In making a comparison of the distribution of this species on the two sides of the Atlantic, there arises a doubt as to the identification of the European specimens. According to Ritter-Zahony this species has been confused with *S. bipunctata.* If the European records of the latter species are referable to *S. elegans,* we have the latter species confined to the epiplankton and occurring down to 100 fathoms off the Irish coast (Ritter-Zahony, 1910, p. 2) with the younger stages in the upper layers, and the older stages in the lower. Its outer limit of distribution is not indicated.

Apstein (1911, p. 171) describes its occurrence throughout the North sea and neighbouring waters, going below 300 metres in depth in the Skager-Rack, and in the Baltic not usually occurring near the surface but only in the deeper water where more saline conditions prevailed; sometimes only on the bottom below 85 metres (Danziger Bucht). The Arctic form occurred only in the Kattegat and Skager-Rack, and was confined to the deeper layers, coming near the surface only in winter.

There is a definite agreement between the distribution on the two sides of the Atlantic—its general occurrence in the coastal waters and usually confined strictly to the epiplankton; its rarity and restriction to the deeper layers in areas where low salinity and high summer temperatures prevail, as in the lower St. Lawrence gulf region and in the Baltic; and the development of a small type in an extensive shallow enclosed area and of a very large type where the true coastal water is deep. One difference is worthy of note: it has (at least in summer) a sharp outer limit on the American coast, where as on the European coast none has been shown, indicating that there is not there the sharp distinction between oceanic and coastal water that is met with on this side of the Atlantic.

(*h*) **Pterosagilla draco** (Krohn).

"ACADIA."

Station No.	Hour.	Depth (metres).	Depth of Haul (metres).	Length (mm.)	Number
41	6 a.m	360	200–0 (V.)	7	1
			100–0 (V.)		1
			0 (T.)		0
44	3 p.m	over 1,000	270–0 (V.)		0
			0 (T.)	5·9·5	4
75	9 p.m	over 1,000	325–0 (V.)		0
			55–0 (V.)	7·5	1
			c 20–10 (T.)		0

Only six specimens were obtained, four of which were in the surface haul at station 44. Its distribution is shown by the horizontal interrupted lines in fig. 1. It is a tropical surface form. Bigelow obtained it in July-August, 1913, at his outermost southern stations south of cape Cod. It is noteworthy that it occurred at three of the five stations at which *Sagitta enflata* was found, and that four of the six specimens came from the only station where *S. enflata* was abundant. Fowler notices this agreement in the general distribution of the two species (1906, p. 76).

Fowler gives its most northerly record as 41° 36′ N, 56° 18′ W. (Strodtmann). Its occurrence at *Acadia* station 75 (43° 30′ N., 56° 43′ W.) extends its known northern limit. These two tropical species (for both of which new northerly records are now given and for our waters, their previous northerly records having also been from our waters) come much farther north on this side of the Atlantic than on the European side, where they only reach the latitude of the Mediterranean, thus harmonizing in a general way with the distribution of salinities and temperatures (see Helland-Hansen in Murray and Hjort, 1912, pp. 227 and 297). Strodtmann, who studied the Chaetognaths obtained by the Plankton-Expedition in the North Atlantic, which included a series of stations both north and south of the Newfoundland banks, considers that these two species characterize the true region of the Gulf Stream (1892, p. 369) as opposed to the Labrador current and the northeastern branch of the Gulf Stream.

Their distribution indicates that the surface water of the Gulf Stream presses in much nearer the continental shelf at the lower (southern) end of our range than elsewhere.

(*i*) **Eukrohnia hamata** (Möbius). Fig. 11.

1911. Ritter-Zahony, p. 30.

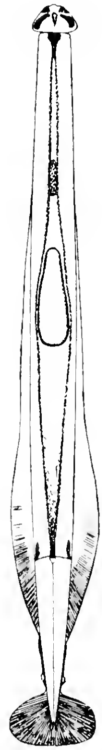

Fig. 11.—Eukrohnia hamata. x 4.

The range in size is from 7 to 35mm. long. The latter is near the upper limit of its length, and yet in none were the ovaries mature, although in some of the larger individuals the seminal vesicles were distinct. It may be doubted whether it breeds in our area, unless in the deeper parts of the outer waters, which we did not investigate. As it is typically a deep-water species, except in polar waters, the absence of mature individuals is not to be wondered at.

DISTRIBUTION.

"ACADIA."

Station No.	Depth (metres).	Depth of Haul (metres).	Lenght (mm.)	Number.
5	72	60–0 (V.)	10	1
		0 (T.)		0
11	over 2,000	70–0 (V.)	12	1
		0 (T.)		0
13	over 2,000	70–0 (V.)	10–14	5
14	over 2,000	200–0 (V.)	9–20	10 × 10
		0 (T.)		0
15	over 2,000	100–0 (V.)	20	1
		0 (T.)	20	1 × 2
16	over 2,000	200–0	c. 15	1
		0 (T.)	21	1 seen
17	over 2,000	200–0 (V.)	8–13	36 × 10
		0 (T.)		0
25	122	120–0 (V.)	10–12	3
		0 (T.)		1
26	over 400	100–0 (V.)	10–22	12
		0 (T.)		
27	over 400	0 (T.)	c. 20	
28	over 400	100–25 (C.)	10–16	6
		0 (T.)		0
35	c. 450	125–25 (C.)	15–19	3[illegible] × 2
		0 (T.)		0
47	140	125–0 (V.)	8–14	8
		90–0 (V.)		8
		0 (T.)		0
48	248	270–0 (V.)	14	1
		45–0 (V.)		0
		0 (T.)		0
50	151	145–55 (C.)	10	2 × 5
			15	2
		145–0 (V.)	10–14	2 × 5
			18 & 21	2
		55–0 (V.)		0
		0 (T.)		0

"ACADIA"—*Continued.*

Station No.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
52	99	90–0 (V.) II	12	1
		0 (T.)		0
54	over 1,000	270–0 (V.)	9–16	29
		125–0 (V.)		0
		0 (T.)		0
55	over 1,000	270–0 (V.)	9–11	5
		90–0 (V.)		0
		0 (T.)		0
57	over 1,000	270–90 (C.)	10–13	22
		90–0 (V.)		0
		0 (T.)		0
58	187	180–55 (C.)	12	1
		150–0 (V.)		0
		55–0 (V.)		0
		0 (T.)		0
67	198	190–0 (V.)	24	1
		90–0 (V.)		0
		0 (T.)		0
70	over 1,000	325–0 (V.)	7–15	54
		55–0 (V.)		0
		c. 20–10 (T.)		0
72	over 1,000	325–0 (V.)	7–13	60
			17–23	12
		55–0 (V.)	11–13	3
		c. 20–10 (T.)		0
74	over 1,000	325–0 (V.)	8–12	31
			15–21	2
		55–0 (V.)		0
		c. 20–10 (T.)		0
76	over 1,000	270–0 (V.)	12	11×4
			14–20	9
		c. 20–10 (T.)		0
77	over 1,000	c. 20–10 (T.)	17	1
			24	1

"ACADIA"—*Continued.*

Station No.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
79	360	325–0 (V.)..	5–14	10×10
			10–23	43
		55–0 (V.)..	12	1
85	over 400	270–0 (V.)....	7·5–10	4×40
			10–19·5	27
		55–0 (V.)...	10–20	17
		c. 20–10 (T.)......	10–17	[illegible]
86	over 400	270–0 (V.)......	8–10	14×10
			13–23	28
		55–0 (V.)...	10–13	5×10
		c. 20–10 (T.)...	c. 12	1 seen
87	331	290–0 (V.)....	8–11	3×10
			11–22	19
		55–0 (V.)...	12–19	5
		c. 20–10 (T.)...........	14 & 15	2 seen

"PRINCESS".

Station No.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
34	405	130–0 (V.)..	18–28	5
		30–0 (V.)....		0
		c. 40–0 (T.)...		0

"No. 33".

Station No.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
23	355	340–145 (C.)....	10–13	3
			22 & 35	2
		100–60 (C.).....		0
		45–0 (V.)....		0
		0 (T.).....		0

"PRINCE".

Station No.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
1	c. 38	c. 35–0 (V.) I.....		0
		c. 35–0 (V.) II ..		0
		c. 20–10 (T.)...	19–21	3
		0 (T.)...		1
3	180	180–0 (V.)...	24 & 26	2
		c. 20–10 (T.)...		0
		2–0 (T.) .		0

VERTICAL.—At station 23 of the cruises of the trawler *No. 33*, three vertical hauls were made from various depths with the closing net. This station is well up in the gulf of St. Lawrence, and so well away from places, where mixing is going on which might through vertical currents vitiate the results. Six specimens of this species were obtained between 340 and 145 metres, and none between 100 and 60 metres and from 45 metres to the surface. On the cruises of the *Princess* in the gulf, numerous hauls were made in the deeper parts with open vertical nets from 100 or 130 metres, and at only one station was this species obtained. Its vertical distribution for the gulf may be considered to lie below 130 metres.

In the Bay of Fundy at station 3 of the *Prince*, two specimens were obtained in the open vertical net from 180 metres and none in the tows above 20 metres in depth. Yet at station 1, although none were obtained in two open vertical hauls from the bottom (showing the rarity of the species there), three specimens were obtained in the tow haul about 20 metres in depth and one in a haul made at the surface. This latter station was in the Friar Roads between Eastport and Campobello island. The tides here are of such magnitude that the water forms whirlpools and the "boiling" up of the deep water to the surface can be seen constantly. These vertical currents are certainly responsible for bringing this deep-water species to the surface at this point. Just outside Campobello island at station 2, both the vertical haul from about 100 metres up and the tow hauls failed to secure any specimens of this form, showing that it was some distance down.

Its presence at or near the surface at *Acadia* stations 15, 16, 25, 26 and 27 indicates that there were strong vertical currents at the mouth of the Laurentian channel on the first cruise of the *Acadia*. On the second cruise it was at or near the surface only at stations 77, 85, 86, and 87 at the mouth and some distance up the Laurentian channel showing strong vertical currents in about the same area. The data from the last three stations are interesting. At stations 85 on the north side of the channel, where *S. serratodentata* and *S. maxima* were most abundant, we find this species coming near the surface in fair numbers (20-10? metres, rather many) and many obtained in both the shallow and deep vertical hauls. At 86 in the middle of the channel, while very many were obtained from both vertical hauls, only one was seen in the material taken by the tow haul. At station 87 on the south side of the channel, while a fair number came up in the deep vertical haul, the shallow vertical haul yielded five only, and a solitary specimen was observed in the tow. This species comes nearer to the surface as we pass to the north across the channel, indicating greater vertical currents on the north side or a greater influx of the cold deep boreal water, from which the vertical currents may bring the species to the surface. There is, of course, the possibility of the species coming to the surface of itself under changed conditions, perhaps of salinity and temperature, as it does in polar regions.

The vertical distribution seems to vary with the region, but these details may more appropriately be considered in connection with the horizontal distribution. Suffice it now to say that it did not appear in the outer and southern stations (stations 41 to 46, 56, 75), the hauls, one of which was from a depth of 375 metres, apparently being too shallow, the cosmopolitan distribution of the species making it fairly certain that it was present but at lower levels. Fowler (1906, p. 73) refers it to the epiplankton (usually young specimens) north of 47° N., and to the mesoplankton in tropical and sub-tropical waters. Michael (1913, p. 35) states that his data suggest "that the region of maximum abundance is in the neighbourhood of 250 fathoms for the San Diego region."

The records are too fragmentary to show whether or not daylight affects the vertical distribution.

HORIZONTAL.—This species is cosmopolitan, being found in all seas, and it extends to both the farthest north and the farthest south. As it is a deep-water form in low latitudes, if we consider only the proper layers of the sea (the part explored by our nets), this species is characteristic of arctic and antarctic seas. In our region it may be considered the typical form of the deep boreal water next the banks. On the first cruises during May and June it occurred at *Acadia* station 5, inside Sable island, generally in the deep water examined off the mouth of the Laurentian channel, up the channel in Cabot strait (*Acadia* station 35) and far up the channel in the deep water between Anticosti and Gaspé (*No. 33* station 23). It is doubtless present in all the central deep parts of the St. Lawrence gulf. Our other hauls in this area were too shallow to obtain it. The distribution in July and August, as shown in fig. 12, was similar, with the gulf hauls again too shallow except at one station (*Princess* station 34). It is again present in the Laurentian channel and at its mouth, as well as along the outer side of Sable island bank and in the deep water between that bank and Halifax and in the Bay of Fundy. In both cruises it is definitely absent over the banks south of Newfoundland, over the banks north of Sable island (rare in the gullies or fjords—*Acadia* station 67, one specimen), as well as in the shallow parts of the gulf and close along the Nova Scotia shore. It is therefore absent from the cold coastal water. This is well shown by its absence in the Bay of Islands (*No. 33* stations 57 and 59), where there is a depth of as much as 150 fathoms, but with water of low salinity and low temperature all the way to the bottom.

Its outer limit of distribution was not reached on the May-June cruises, (though it was rare at stations 15 and 16) but in the July-August cruises it was plainly demonstrated. It failed entirely at the typical Gulf Stream stations (*Acadia* stations 41-45, 56, and 75) except the most northerly one (74), as well as at some of the intermediate southern stations (*Acadia* stations 38-40 and 46). The hauls of the *Prince* in September show that it occurs in all the deeper parts of the Bay of Fundy. Bigelow found it in July-August, 1913, in all the deeper parts of the gulf of Maine and under the edge of the Gulf Stream, but never at the surface.

The absence of any connection being shown between its distribution off the Nova Scotia coast and in the gulf of Maine is apparently owing to the pressing in of the Gulf Stream close against the continental shelf (*Acadia* station 41), and also owing to the hauls at this point not being deep enough to get below the Gulf Stream. This phenomenon of the sinking of the species to lower levels as we pass out into the Gulf Stream is very well shown in the records. At *Acadia* station 72, three individuals were obtained in the shallow vertical haul (55-0 metres), and 72 in the deep vertical haul (325-0 metres). At station 74 there were none in the shallow haul, but thirty-three in the deep haul. At station 75 there were none in either haul. At stations 52 and 58 on the continental shelf it was obtained in hauls from 90 and 180 metres, respectively. At stations 54, 55 and 57 it occurred in fair numbers in the vertical hauls from 270 metres, but not in the vertical hauls from 125 and 90 metres. And at station 56 it was not present even in the deep haul from 375 metres. The gradation in size as we pass into warm water is equally distinct. For the same depth, the individuals become distinctly smaller as we pass to warm water. At station 72 the proportion of small to large (those under and those over 15mm.) was 5 to 1. At station 74 for a similar haul it was 15·5 to 1, and at the same time the maximum size changed from 23mm. to 21mm. Off Sable Island bank the stations taken in order of their nearness to the continental shelf show the following for similar hauls (270-0 metres): Station 54, twenty-nine specimens with a maximum size of 16 mm.; station 57, twenty with a maximum of 13 mm.; station 55, five with a maximum of 11 mm.; and station 56, none. There is a decrease in maximum size as well as in the number taken. Although the records are framentary this species is seen to resemble others in that the younger individuals are to be found in the upper, warmer water, as described by Broch and Fowler for this species.

The records are too incomplete to show where the centre of abundance was during the earlier cruises, but it must have been north of *Acadia* station 16, between that point and the continental shelf, as shown by the numbers at stations 14 and 17, the only two where deep hauls were made. On the later cruises the centre of abundance (as shown by the closely placed lines in fig. 12) was definitely in the northern oceanic water just south of the Newfoundland banks. It decreased in quantity to the north,

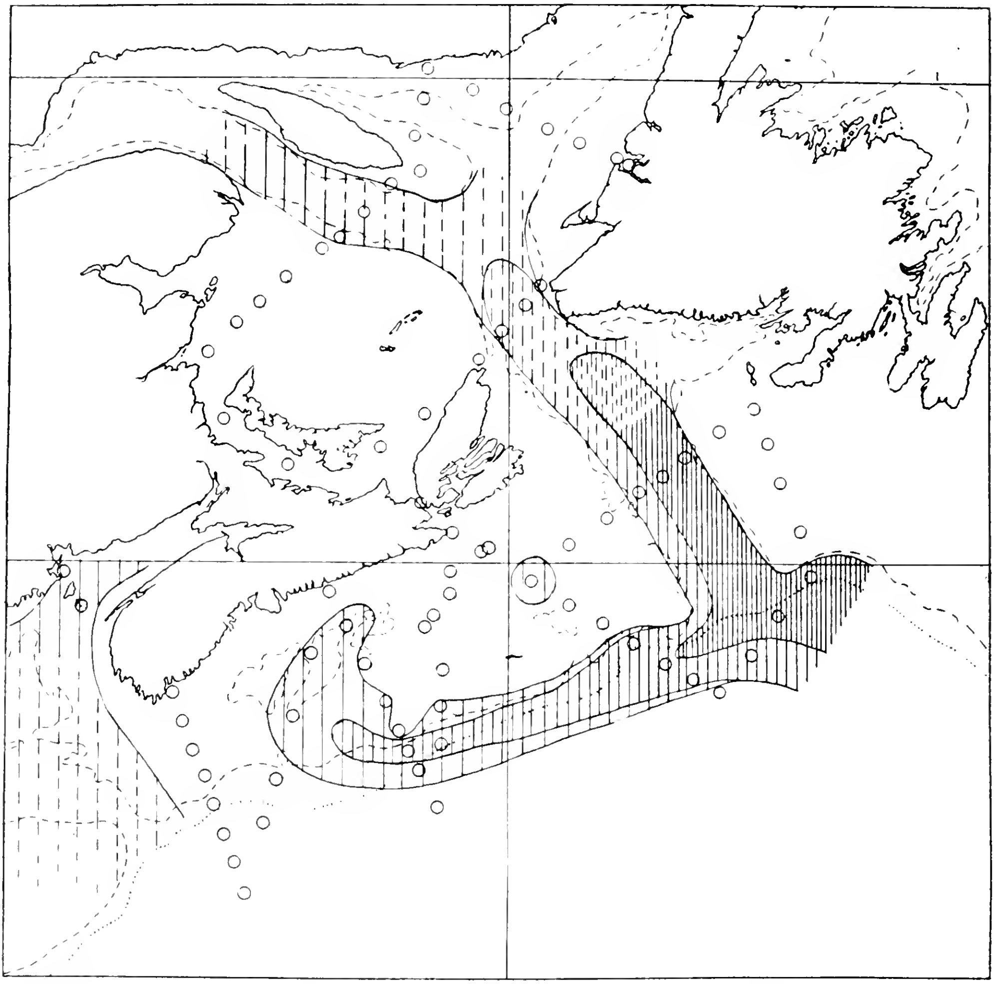

Fig. 12.—Distribution of *E. hamata*, July-August 1915. Zones showing frequencies of 1 to 20, 21 to 75 and 75 and over per station.

west, and south. The agreement with the distribution of *S. maxima* is very evident. They both belong to the deeper part of the boreal oceanic water and show its extension up the Laurentian channel and to the south along the outer side of the continental shelf and to some extent over the banks, but diminishing in amount in each direction. The two species differ in that *S. maxima* can not endure as much of a decrease in salinity as can *E. hamata,* and does not extend as far up the Laurentian channel or over the banks as the latter species. It can, however, endure an increase in salinity better than *E. hamata,* as it occurs in the outer Gulf Stream stations, where the latter is absent on the later cruise though present on the earlier. High temperature may, however, be as potent a factor in excluding *E. hamata* from the Gulf Stream as high salinity.

The absence of this species generally in the hauls from 130 metres to the surface in the gulf on the August cruise of the *Princess* and its occurrence in such a haul at *Princess* station 34 indicates an upwelling of the deep boreal oceanic water at that point.

The definite separation of this species from *S. elegans* in vertical distribution as seen at *No. 33*, station 23, shows that they belong to waters of different salinities. Where they occur together in mixed water, as south of Sable island or in the Bay of Fundy, *E. hamata* is to be found only in small numbers, showing that this mixed water is not suitable for it.

To the south of our area, Bigelow, (1915, p. 297) has found this species in the deeper parts of the gulf of Maine and along the edge of the continental shelf as far south as Chesapeake bay in July-August, 1913. Its outer limit was, however, not determined. It decreased in quantity to the south.

Apstein (1911, p. 174) for European waters gives its distribution as similar to that of *S. maxima*, but occurring regularly in the Norwegian channel; and in the Skager-Rack, where it was abundant, it occurred at the surface, but was most abundant in the depths. This is quite similar to the conditions on our coast, where it passes landward up the deep gullies, and much farther than does *S. maxima*.

(*j*) **Krohnitta subtilis** (Grassi).

1911. Ritter-Zahony, p. 32.

"ACADIA".

Station No.	Depth (metres).	Depth of Haul (metres).	Length (mm.).	Number.
44	over 1,000	270– 0 (V.)	13·5	1
		0 (T.)	...	0

A single specimen of this species was obtained at station 44, the southernmost station of the second cruise of the *Acadia*, in an open-net vertical haul from 270 metres (fig. 1, vertical dotted lines). It is a tropical species occurring chiefly in the mesoplankton; according to Ritter-Zahony, chiefly in the lower epiplankton and upper mesoplankton; according to Fowler (1906, p. 74), and according to Michael (1913, p. 35), chiefly between 200 and 250 fathoms (none above 50 fathoms). Fowler gives its most northerly record in the Atlantic as 60° 12′ N., 22° 56′ W.

GENERAL SUMMARY OF DISTRIBUTION.

In summarizing the distribution of the Chaetognaths it will be well to review briefly the principal features of the region covered.

The general topography as shown in the charts is too well known to require description. The submarine physiography has been described by J. W. Spencer (see chapter ix of Sub-Oceanic Physiography of the North Atlantic Ocean, by E. Hull, London, 1912; and Bull. Geol. Soc. Amer., vol. xiv, 1903, p. 207). The main feature is the submerged Laurentian valley cutting across the middle of the St. Lawrence gulf and passing out to the open ocean through Cabot strait and between St. Pierre bank and Banquereau. We have referred to this as the Laurentian channel. Another channel, the Cansan, cuts through between Sable Island bank and Banquereau. Farther to the south is the Fundian channel passing out from the Bay of Fundy and through the gulf of Maine. These three channels delimit two portions of the continental shelf off Nova Scotia. That to the north between the Laurentian and Cansan channels includes the Banquereau, Misaine, and Cansan banks, and may be called the Breton portion of the shelf, or the Breton bank, since it lies off Cape Breton island. The southern part lies between the Cansan and Fundian channels and includes La Have and Sable Island banks. It may be called the Scotian bank since it lies against the main portion of the province of Nova Scotia.

In the St. Lawrence gulf we have to the north of Anticosti island, the Anticostian channel, and running north towards the straits of Belle Isle the Esquiman channel. To the south of the Laurentian channel in the gulf is an extensive submarine plateau with, for the most part, less than 30 fathoms of water covering it. Cropping up from it are the Magdalen islands and Prince Edward island. This area is peculiar in its biological and hydrographical characters. We have referred to it as the Lower Gulf region. It might be called the Magdalen bay.

The currents of the region have been thoroughly investigated by Dr. W. Bell Dawson, and his results published in the reports of the Tidal and Current Survey of Canada from 1894 to 1913, including special reports on the currents. In the gulf of St. Lawrence he finds that the general circulation is in a left-handed direction and chiefly confined to the deep central portions. A current enters the gulf through Cabot strait off cape Ray and spreads out to the north and northeast. Part runs up the Esquiman channel on the east side and returns on the west. Similarly a current runs up the Anticostian channel on the north side and returns on the south, and up the Laurentian channel between Anticosti island and the Gaspé coast on the north side and returns on the south. The last of these, the Gaspé current, is very strong and spreads to the southeast over the Magdalen bay, passing to either side of the Magdalen islands, and finally as a single stream of constant strong character, the Cape Breton current, it emerges from the gulf on the south side of Cabot strait.

Dr. Dawson has shown by density determinations that the inflowing water is more saline than the outflowing and, as a result, the northern part of the gulf is constantly more saline than the southern, a line of division passing from East cape, Anticosti island, to the middle of Cabot strait.

The shallower channels of the gulf show the same circulation but to only a slight degree. Through the straits of Belle Isle and the Mingan channel on the north there is a general inward or westward tendency, and through the Northumberland strait (and perhaps also the Gut of Canso[1]) on the south a general outward or eastward tendency.

Outside the gulf there is a slight westward tendency on the southern coast of Newfoundland and a southwestward drift along the outer coast of Nova Scotia. In the gulf of Maine, Bigelow has found a general left-handed circulation, entering the gulf on the north and leaving it on the south. In the Bay of Fundy there is doubtless a similar circulation, although so masked by the heavy tides that Dawson has been unable to determine it by current measurements.

Farther out we have two well-known strong currents, the Polar or Labrador current coming down from the north along the outer coast of Newfoundland, flooding the Grand Banks and then turning to the east at their southern border; and the Gulf Stream coming from the southwest along the coast of the United States and being deflected to the east and south just south of the Grand Banks.

As a basis for our knowledge of the different kinds of water occurring in the region we may take the three sharply marked zones found by Hjort off our coasts in 1910 (Murray and Hjort, 1912, p. 109) in his section from the Azores to Newfoundland. There are the following: (1) a Northern Coastal zone (Arctic?) on the Newfoundland

[1] I have just received from Dr. Dawson a proof sheet of a forthcoming report in which he describes a preponderance of outflow to the south through the Gut of Canso.

banks, with water of low salinity (under 33‰) and very low temperature (down to 1·5° C.) except at the surface in summer; (2) a Northern Oceanic zone (boreal) along the southern side of the Grand Banks, with water of moderately high salinity (33-35‰) and moderately low temperature (3°-8° C.), which connects with the bottom water of the Atlantic; and (3) a Southern Oceanic zone (tropical) farther to the south in the Gulf Stream, with water of high salinity (over 35‰) and high temperature (10°-25° C.).

The northern coastal water owes its low salinity to the fresh water poured in by the rivers and to the melting of the icebergs from the north, and its low temperature to the cooling effect of the rigorous winters and to floating ice.

The southern oceanic water is brought up from the tropics by the Gulf Stream. This accounts for its high temperature and salinity.

The northern oceanic water may be derived in part from a mixture of the two preceding kinds. It is essentially an intermediate water, and in its circulation will, on the one hand, have its temperature and salinity reduced by mixture with the coast water and, on the other hand, have its temperature and salinity increased by mixture with the Gulf Stream water. As it is heavier than they, it will be found beneath them and, particularly toward the south, where it is less extensive, it will permit of their mixing together above it. It is continuous around the south side of the Grand Banks with the open water of the northwestern Atlantic, where is found the Labrador current. The latter doubtless contributes along this course (around the banks) to our northern oceanic water, but for the most part only at some depth and not on the surface.

To these may be added a fourth, the Southern Coastal zone existing in the Magdalen bay, to which certain southern coastal forms, e.g., the oyster, are restricted. It is characterized by water of very low salinity and very high summer temeprature, and is therefore similar to the upper layers of the northern coastal water. Its low salinity is due to the large amount of fresh water poured into it by the St. Lawrence and other rivers. Its high summer temperature is due to the same cause and to the shallowness of this part of the gulf. In a negative way the absence of heavy tides contributes to both the low salinity and the high temperature.

In the Southern Oceanic zone we have at the surface *Sagitta enflata*, *S. bipunctata*, small *S. serratodentata*, and *Pterosagitta draco*. In the depths there are *S. hexaptera*, *S. lyra*, and *Khronitta subtilis*. The extent of this zone in July-August is shown in fig. 1. Surface species are indicated by horizontal lines, deep-water species by vertical lines. The further extension landwards of the surface forms in the southwest part of the region and of the deep-water forms in the northern part is noteworthy. This is corroborated by the distribution of small *S. serratodentata* as shown in fig. 6. The nearness of the zone to the continental shelf on the south as compared with the north is also important, indicating a turning of the Gulf Stream to the east.

On the May-June cruise only the northern part of the area was investigated. Only deep-water species were obtained. The records show that the surface Gulf Stream forms, which were not found, must have been farther out than the deep-water forms, and that both were at that time farther from the continental shelf than in July-August.

There is the question as to what part the Gulf Stream plays in mixing with either the coastal or the boreal oceanic waters. The sharp inner margins of the areas of distribution of most of the Gulf Stream species is against the view that the Gulf Stream by any back eddies remains as a distinguishable part of our waters. In the upper layers the most abundant species (*S. enflata*) decreases in abundance toward the inner side of the stream, and may even be lacking, showing that this inner margin is mixed water going with the stream. A solitary individual was found inside the stream, far in on the Scotian bank off Halifax. Its ability to survive in the water of intermediate salinity and temperature indicates that there can be little water of Gulf Stream origin in the intermediate boreal oceanic zone, otherwise individuals of this species would have been obtained at some of the nine intervening stations. *S. serra-*

todentata is a Gulf Stream form, but its occurrence in the boreal water is not indicative of a recent Gulf Stream origin, since it is of a decidedly different type in the boreal water. Its abundance in our boreal water and its rarity on the European coast may be due to its ability to live and grow to maturity but not to reproduce successfully in boreal water. With this interpretation our boreal water would have a very slight but constant contribution from the Gulf Stream.

Of the deep-living species, *S. hexaptera* is absent from the boreal water, but *S. lyra* was found at two of the boreal stations. One of these stations was, however, really on the edge of the Gulf Stream, and the single specimen found at the other station (*Acadia* station 70) was much larger than any others obtained. This individual may have passed through the bottom of the Gulf Stream, since the species goes into very deep water and is a constant inhabitant of the depths of the Atlantic; or if it has entered the boreal water by the mixture of the latter with the Gulf Stream, its size precludes a recent entrance.

We have therefore no certain evidence of any deep contribution of Gulf Stream water to the boreal zone in our region, and evidence of only a slight surface contribution.

Of movement in the opposite direction, from the boreal water to the Gulf Stream, since there is no peculiar surface boreal form, we have merely the negative evidence of rarity of the surface tropical species at the northern Gulf Stream stations. The deep-living boreal species, *S. maxima*, was regularly found at the Gulf Stream stations except at the extreme southwest, and it was more abundant at the north, while *Eukrohnia hamata* was found at only one of the stations, the most northerly (*Acadia* station 74). There is therefore evidence that the boreal water does contribute to the Gulf Stream in the deeper part, and perhaps also at the surface. The latter contribution will tend to be indistinguishable from coastal water.

In the Northern Oceanic zone we have large *S. serratodentata* at the surface, and in the depth, *S. maxima* and *E. hamata*. For its extent in July-August see figs. 3, 6 (vertical lines), and 12. There is to be seen an extension of the surface water over the Scotian bank to the south, and of the deep water up the Laurentian channel to the north. The deep water is present in small amount over the Scotian bank, the surface water in the Laurentian channel, and both in the gulf of Maine and Bay of Fundy. The virtual absence of this water over the Newfoundland banks is worthy of note, it being held off by the coastal water. Its centre is seen to be a narrow zone close against the continental shelf, decreasing in width to the southwest. The vertical distribution of *S. maxima* and *E. hamata* shows that it passes to a deeper level below the coastal water up the Laurentian channel and below the Gulf Stream to the south and southwest.

On the May-June cruise the small area explored showed a similar distribution, but extending farther out from the continental shelf.

The absence of any continuation of the deeper part of this water (as indicated by *E. hamata* and *S. maxima*) along the continental shelf off Shelburne in July-August as shown by our most southern section, indicates the abruptness of the transition from Gulf Stream to coastal water at this point, the boreal water having been squeezed out by the pressing in of the Gulf Stream close to the continent. This is doubtless temporary. At another time, perhaps earlier in the season, the boreal water would be much more extensive and pass continuously down the coast and up into the gulf of Maine.

Dawson has shown that in the deep parts of the St. Lawrence gulf there is water with the characters which we have given above for boreal oceanic. The *Albatross*, as reported by Townshend, found in July, 1885, very low temperatures at the bottom which would indicate no boreal water on the bottom on the banks just south of Newfoundland, on the Breton bank, nor close along the shore of Nova Scotia; but in the mouth of the Laurentian channel and off Shelburne near La Have bank the bottom temperatures were higher (37·5°—40° F.), indicating boreal water. For the banks just south of Newfoundland, Dawson's investigations did not go deep enough, but Hjort failed to find it at the bottom, or only in very small amount at the north. The *Challenger*, on May 20, 1873, found, just east of La Have bank, water at the bottom with too low salinity and temperature to be boreal. For the early part of the year the boreal water may be absent from the Scotian bank. Bigelow has found boreal water at the mouth of the Bay of Fundy. With the exception of the *Challenger* record, for which the season of the year may be responsible, the distribution of the Chaetognaths agrees with what has been found as to the extent of the boreal oceanic water.

As to its origin and movements, we have seen that there is little reason to suppose that the Gulf Stream contributes appreciably to it. It must therefore come either from the deeper part of the Polar current around the outer side of the Grand Banks (its comparative purity at the north as shown by the quantitative distribution of *S. maxima* and *E. hamata* support this view) or by upwelling from the depths of the Atlantic, since it is being constantly dissipated by mixture with the coastal water. That it is actually moving toward the southwest seems to be shown by the movement of the centre of abundance of *S. serratodentata* to the southwest during the summer, and also by the rarity of the boreal species over the Scotian bank, which is an indication that boreal water is passing in that direction and being dissipated.

The greater abundance of the boreal species on the northern side of the Laurentian channel is an evidence that the boreal water forms part of the current entering the gulf. On its way it must be mixing with the coastal water, as is witnessed by the presence of *E. hamata* near the surface. This doubtless explains the failure of two of the species to enter the gulf. The third species certainly passes up the Laurentian channel as far as the Gaspé coast, although it is unlikely that it reproduces there.

The boreal oceanic water may be considered as coming from the northeast, and in our region disappearing partly by mixing with the coastal water, particularly in the Laurentian channel, on the Scotian bank and in the gulf of Maine, partly by mixing with the Gulf Stream and returning to the northeast and partly by sinking beneath the Gulf Stream to pass into the Atlantic bottom water.

In the Northern Coastal zone there is only a single species, *S. elegans*. Young individuals characterize the upper layers, large individuals the lower layers, and very large ones the deepest parts. Fig. 9 shows the distribution in July-August, horizontal lines representing individuals under 20mm., and vertical lines those over 20mm. The general extent of the zone corresponds with the continental shelf, but passes beyond it to some extent in the north, particularly at the mouth of the Laurentian channel. The only parts of the shelf not in the zone are the Northumberland strait and the extreme outer part of the Scotian bank. The former is occupied by the southern coastal water, and the latter by the boreal oceanic water. If we exclude the smaller individuals, considering that they belong properly to the southern coastal water, the zone is more restricted, the shallower banks and particularly the Magdalen bay being excluded. This intermediate water containing chiefly the large individuals over 20mm. in length has a salinity of from 31‰ to 33‰ and temperature ranging from about 10° C. down to —1·5° C. Its apparent absence in the northern part of the gulf will be explained later. Its full development as indicated by the largest individuals of *S. elegans* occurs in deep fjords like the Bay of Islands, and to a less extent over the Breton bank. The May-June cruises show less difference between the upper and lower layers, large *S. elegans* being nearer the surface, and therefore in shallower water and more generally distributed. The zone as a whole was at that time more extensive, covering parctically the whole area investigated, extending into Northumberland strait and out to the outermost station in the Atlantic. The species was, however, not abundant near these limits nor over the shallower banks.

The effect of the currents on the coastal water and this coastal species would seem to be the following: The circular motion around the gulf acts as a huge whirlpool and tends to collect *S. elegans* in the central portions. Wherever data are available they show that more individuals were in the middle in the various channels, where Dawson has shown that the water is comparatively stationary, than along the sides. Four of the channel sections show this.

The outflowing Cape Breton current depopulates the gulf to a considerable extent, the older individuals being much less numerous during the second cruise. They are carried by the current along the southern side of the Laurentian channel out into the open Atlantic off the continental shelf for some distance and also into the deeper water on the Breton bank. Such a course for the coastal water is indicated imperfectly by Dickson's charts for surface temperature and salinity for the North Atlantic for the years 1896 and 1897 (Phil. Trans., A, vol. 196, pls. 1-4, 1901), in which can be seen a tongue of water of low salinity, warm in summer and autumn and cold in winter and spring, extending along this course from Cabot strait. This is evidently a very permanent condition. The continuation of this tongue toward the southwest along the outer side of the continental shelf, as appears in fig. 8 at *Acadia* station 12, may well be a regular course for a part of the coastal water in the colder part of the year. It will connect south of Sable island over the Scotian bank with the band of coastal water along the Nova Scotia shore. This view is supported by the finding of coastal water at the bottom near La Have bank by the *Challenger* in May, 1873, and by the presence of *S. elegans* at *Acadia* station 54 (see fig. 10) which would be a last remmant for the summer of this current. This current and the more constant one close to the Nova Scotia coast carry the species to the southern end of Nova Scotia and heap it up there as is seen in fig. 10. During the two months between cruises the currents have transferred the centre of abundance from the Laurentian channel to the lower end of Nova Scotia, only a part being left on the Breton bank.

The current along the southern coast of Newfoundland may carry coastal water and with it this species to Cabot strait and possibly into the gulf. That it does not enter to any great extent into the current running in past cape Ray will appear from the following considerations. The stations in the northern half of the gulf during both cruises showed few or no large *S. elegans*. The cold intermediate water in which it lives is present in this part of the gulf but will have been formed by the mixture of the inflowing boreal water with the surface water, neither of which contain large *S. elegans*. Consequently, few or no large individuals are to be expected in the first part of the water's course, that is in the northern half of the gulf. If it were derived from the coastal water south of Newfoundland, this would not be the case.

The loss of large individuals from the gulf through Cabot strait being greater than the gain, the gulf would be depopulated were it not for the yearly swarms of young individuals growing up in the surface layers. These will likewise be carried out, but since they are several times as numerous as the adults, enough will be left to keep up the stock. The more or less stagnant areas in the gulf, for example the Bay of Islands fjord, will aid in repopulating the whole area. The conditions in that fjord are most suitable for this species. The bar at the mouth prevents the egress of the large individuals during the summer at least and yet permits of many of the young escaping. We found only the latter at the mouth in August. In the deepest haul in the bay, where there was over 200 metres of suitable water, seventy large individuals were obtained. This may be considered the upper limit for the number that is normal to an area. More than this would certainly be due to concentration, as for example the areas of abundance shown in figs. 8 and 10. The numerical relation between the adults and young is interesting. At both stations in the Bay of Islands where vertical hauls were made (*No 33* stations 57 and 59) the young were about fifteen times as numerous as the adults ($^{522}/_{32}$ and $^{1060}/_{70}$). This provides a very considerable surplus to overflow into the neighbouring depopulated part of the gulf.

The areas of distribution of the boreal oceanic and northern coastal waters overlap to a great extent. In the gulf of St. Lawrence where conditions are moderately static they are separated vertically, the boreal water being below. Elsewhere the separation is not so complete, more or less active vertical mixing going on, as is evidenced by the two groups of species being mixed and the deep forms found near the surface. The chief large areas of this kind are along the Laurentian channel from Cabot strait out to some distance beyond the edge of the continental shelf, the central portion of the Scotian bank, and the Bay of Fundy.

The typical northern coastal water, as we have described it, has been found by Dawson generally in the gulf of St. Lawrence, along the outer coast of Nova Scotia and around the southeastern corner of Newfoundland. The *Albatross* records show that it was present in July, 1885, on the banks off cape Race, on the Breton bank and along the Nova Scotia shore. Bigelow's results show it in the mouth of the Bay of Fundy, and Copeland's account demonstrates its presence at the bottom in Passamaquoddy bay, as at *Prince* station 4. This is in entire accord with the distribution of *S. elegans*.

In the Southern Coastal zone there are no Chaetognaths or merely small *S. elegans*. It is scarcely distinct from the northern coastal and might be taken to include the surface layers of the latter. This would give it a salinity of less than 31‰ and a summer temperature of from 10° to 20° C., although a somewhat higher salinity would not be excluded. It occurs typically in the Magdalen bay, particularly toward the south. Elsewhere it is not so typical and grades into the northern coastal water. The surface waters generally over the continental shelf approximate to the southern coastal type, except in the Bay of Fundy where the heavy tides increase the surface salinity and lower the temperature. As a result of this there is a virtual absence of small *S. elegans* in the Bay of Fundy.

The movements of this water are not indicated by the Chaetognaths, but it will be carried out of the gulf by the Cape Breton current, and perhaps also to a slight extent through the Gut of Canso. It arises by a mixture of the river water with the northern coastal, and is dissipated by mixture with the latter and with the boreal oceanic.

CANADIAN FISHERIES EXPEDITION, 1914-15.

QUANTITATIVE INVESTIGATIONS AS TO PHYTOPLANKTON AND PELAGIC PROTOZOA IN THE GULF OF ST. LAWRENCE AND OUTSIDE THE SAME.

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QUANTITATIVE INVESTIGATIONS AS TO PHYTOPLANKTON AND PELAGIC PROTOZOA IN THE GULF OF ST. LAWRENCE AND OUTSIDE THE SAME.

By H. H. Gran.

The plankton investigations which have been carried out in North European waters since P. T. Cleve and Aurivillius, in the nineties of the past century, made their pioneer researches on the plankton of the Skagerak, and which from 1901 have been under the guidance of the International Council for the Exploration of the Sea, have, as a first general result, given us a very close knowledge of the distribution of the different species and their relative frequency at the various seasons of the year. A survey of the data thus acquired has been issued by the Council in a series of papers, edited by Dr. C. H. Ostenfeld.[1]

The next aim of the investigations is to enable us to determine the quantitative occurrence of the plankton as a measure of the production in the different areas of sea. The question was already raised by Hensen, and his methods of operation, by vertical hauls made with "quantitative" nets and countings of individuals in certain fractions of the catch—or simple determinations of volume for the whole—made the first steps towards a solution of this great and many-sided problem. With the fundamental work of Lohmann in this field, a great advance was made in regard to the methods employed, and we are now able to determine the quantity of plankton in relatively small water samples, by means of the centrifuge. In seeking to ascertain the relation of plankton production to various external conditions, such as light, temperature, salinity and food, it will not be enough to work merely with samples taken in vertical hauls, as the conditions in question are by no means uniform throughout the entire column of water filtered by the net. A series of water samples, on the other hand, taken at the same locality, but at different depths, will show how the quantity of the plankton varies with the depth, so that we can, with a sufficient quantity of material, ascertain the dependence of the production upon the different factors, which vary in a horizontal as well as in a vertical direction, throughout the sea.

A further improvement of the method, and adaptation of the same to particular purposes, was made when I succeeded in finding a means of preserving water samples by means of Flemming's liquid, added in the proportion of 1–25; this rendered it possible to collect a greater quantity of material in a short time, and store it for subsequent thorough investigation. The method was employed for research work throughout the whole of the year in the Norwegian coastal waters, as also in extensive investigations of the North sea and North Atlantic, carried out in May-June, 1912, by the North Sea countries acting in concert.[2]

The large amount of material and observations collected in the course of these investigations presents various points of difficulty in regard to judging the results, as it is distinctly seen that the conditions in the sea are rarely, if ever, so stationary that we can immediately presume the existence of causal relation between the quantities of plankton found at any spot and the conditions of life there prevailing at the time. The plankton moves, not only with the currents in a horizontal and a vertical direction, but sinks to a great extent, and rises also, though in a lesser degree, actively, within the water mass in which it has developed. We often find, for instance, considerable quantities of pelagic algæ at depths far beyond the level at which they can have developed; so far down, indeed, that their assimilation of carbonic acid

[1] Bull. Trimestriel....Resumé des Observations sur le Plankton, Parts 1-3, 1910-1913.

[2] H. H. Gran. The Plankton Production of the North European Waters in the spring of 1912. Bulletin Planktonique pour l'annee 1912, publie par le bureau du Conseil Permanent International pour l'exploration de la mer. Copenhague 1915.

must be far less than their respiration; there can hardly be any possibility of continued propagation here. Thus even the comparatively simple question as to the limit of depth at which assimilation predominates over the destructive metabolism of chlorophylliferous organisms offers in itself considerable difficulty, and can hardly be solved by mere investigation of the vertical distribution of the organisms concerned.

The investigations in question did, however, furnish various important results which could serve as basis for further research; among these, the following may be particularly mentioned:—

(1) The diatoms, which appear to be the most rapidly growing of all producers in the sea, develop in great quantities in the coastal waters of Northern Europe during the later winter months (February-April) while the temperature of the surface layers is still at or slightly above the minimum for the year. They are restricted to a cold surface layer with comparatively low salinity, lying above water layers of considerably higher temperature. The greatest quantities are found in places where there is a continual inflow of water either from the land, e.g. from the Baltic, and from the rivers of Northern Europe, or from the ice limit of the Arctic ocean, but where the fresh water has nevertheless become so mixed with salt that there is a certain degree of stability in regard to osmotic pressure. The supply of foodstuffs brought down by the river water seems to play an essential part in this production.

(2) The great production of diatoms in the coastal waters ceases in May-June, when the surface layers become warmer. At this time of year, there may be a secondary minimum in the total quantity of phytoplankton, until the mobile algæ, chiefly *Ceratium,* propagating in the warmest season of the year, have reached such numbers as to replace the diatoms. Local and temporary maxima of diatoms may, however, occur also in summer, especially in the vicinity of the coast after a rainy spell, when a rich supply of foodstuff in solution has been carried down from the land. In summer, then, the conditions of life must be unfavourable to diatoms, the marked isolation between the warm, light surface layer and the waters below preventing any introduction of nutritive matter by vertical circulation or mechanical mixture, and also because they are ill able to keep floating in the water layers of low specific gravity, which are also, owing to their high temperature, of comparatively slight viscosity. These obstacles can be surmounted by the mobile *Ceratium*, though these also exhibit a distinct tendency to sink down towards the limit of the surface layer—but not by the diatoms, save where circumstances are particularly favourable with regard to nourishment, as by abundant supply of food from the land. In the autumn, when cooling begins, when the autumn gales and also the purely mechanical equilibrium of the water layers drives the surface water towards land, so that both vertical circulation and a stronger mechanical mixture can take place, then the conditions are more favourable. At this season, in October-November, we find a new maximum, and the diatoms can then, at any rate, in some years, again occur in quantity.

The characteristic feature, then, of North European waters, considered as feeding grounds for pelagic plant life, is the rich supply of river water, which in a mixed state flows over the surface in thick layers in the vicinity of the coasts. This supply is probably the most important source of the great productivity of the entire area of sea, but it is just in the hottest season, when the surface layer is most markedly isolated from the remaining water masses, that it offers the least favourable conditions for production.

The waters about the east coast of Canada present numerous points of resemblance in oceanographical respects to what we find off Northwestern Europe, and it may therefore be interesting to try how far the working hypotheses above set forth may be applicable to conditions on the coast of America. I was therefore happy to avail myself of Dr. Hjort's kind offer to collect a series of water samples in and outside the gulf of St. Lawrence, according to the same method as we have followed in Europe. The method is, it must be admitted, not without certain limitations, and these become more than usually apparent when dealing with a water whose phytoplankton is less known, or where, at any rate, the annual periodicity of the species, a point with which we are here especially concerned, is very little known indeed. The comparatively small samples offer no occasion for critical consideration of the species from a systematic point of view, or for description of the rarer forms. All species of common occurrence are, however, well known from the North-European waters, so that this is only of minor importance. A more serious difficulty is the fact that an investigation such as the present can naturally give widely different results at different seasons of the year, and it will consequently be impossible to determine at what season the samples should preferably be collected, when seeking to obtain, from a limited quantity of material, a view of the characteristic features in the production of the water concerned.

The present material was collected at two different seasons, in early summer (May 29 to June 15) and, later on, in August. The former period would, on first consideration, appear very favourable, provided that the conditions prevailing were anything like those of Northern Europe; we should at this time expect to encounter the transition between the rich spring plankton and the incipient development of the summer plankton; in August, on the other hand, the summer plankton should be nearing its culmination, though this would probably not be actually reached until September.

The results show us a plankton essentially consisting of the same species as are also found on the other side of the Atlantic, but which is both qualitatively and quantitatively poorer than that of the European waters. We must doubtless reckon with the possibility that the greatest maxima are found at other seasons of the year than those covered by the present investigations; this is, indeed, more than likely to be the case. In the North-European waters, the diatoms have their maximum in March-April, when the surface temperature is at the annual minimum; this mass development of diatoms is here composed chiefly of northern, and to some extent of Arctic species with low temperature optimum, and the Arctic character becomes more and more pronounced farther to the north. Such a maximum was encountered in the gulf of St. Lawrence on the 11th of May, when no plankton samples were taken for quantitative investigation, but only qualitative samples, taken in the ordinary nets. These samples were very rich, and consisted of markedly Arctic species, a community such as we find in May-June off the coasts of Greenland or in the Barents sea, or, to a less pronounced degree, off the northwest coast of Norway in April. It also exhibits great resemblances to the plankton described by P. T. Cleve from the water about Disco island in May, 1894.[1]

[1] P. T. Cleve, Diatoms from Baffins Bay and Davis Strait, collected by M. E. Nilsson, 1896, Bihang till K. Svenska Vet. Akad. Handlinger Bd. 22 Afd. III, No. 4.

The following species were found:—

Achnanthes tæniata Grun., abundant, with resting spores.
Amphiprora hyperborea (Grun.)
Bacterosira fragilis Gran.
Biddulphia aurita. (Lyngb.)
Chætoceras atlanticum. Cleve.
compressum. Lander.
criophilum. Castr.
debile. Cleve.
decipiens. Cleve
diadema. (Ehrbg.) Gran.
scolopendra. Cleve.
teres. Cleve.
Detonula confervacea. Cleve.
Eucampia groenlandica. Cleve.
Fragilaria cylindrus. Grun.
oceanica. Cleve, predominating, with resting spores.
Navicula pelagica. Cleve.
septentrionalis. Oestrup, abundan.
Vanhœffeni. Gran.
Nitzschia closterium. W. Smith.
frigida. Grun.
Pleurosigma Stuxbergi. Cleve et Gran.
Rhizosolenia hebetata (Bail.) f. semispina, Hensen.
Thalassiosira bioculata. (Grun.)
gravida. Cleve, with resting spores.
hyalina. (Grun.)
Nordenskiöldi. Cleve, predominating.
Thalassiothrix longissima. Cleve et Grun.
Dinophysis granulata. Cleve.

No such quantities of diatoms were found in any of the quantitative samples from June to August, and the species of diatoms which characterize the rich spring plankton are only found at some few stations in the gulf of St. Lawrence (stations 10 and 12, on the 11th of June) and even there in minor quantities, and restricted to the ice-cold water layers at 50 to 75 m. depth. From this we may presumably conclude that the characteristic Arctic spring plankton has already disappeared by the middle of June, or has sunk down to deeper water layers, where remains of it are found, for the most part with resting spores.

Cruise of the "Princess" June 9 to 15 (Table 1 (*a*), (*b*), and (*c*).

The plankton samples from the cruise of the *Princess*, June 9 to 15, 1915, distinctly show that the development of the pelagic diatoms at this season has passed its annual maximum. In the first place the markedly Arctic species, mentioned above, have sunk down to the deeper water layers, where we may certainly presume that they will no longer find conditions suitable for their further development, and have to a considerable extent formed resting spores. But in addition to this, we find that a community of somewhat more thermophile forms, especially *Chætoceras compressum* and *Ch. laciniosum*, which somewhat later must have replaced the Arctic species, is now already declining. These species we find more particularly at the stations nearest to land, (stations 3, 5, 10, 12 and 25). These forms are likewise not found in quantity in the surface layers, but they have not sunk so deep down as the Arctic species. Their maxima lie, as the table shows:—

At station 3, at 20 m.
" 5, at 10 m.
" 10, at 0–25 m.
" 12, at surface, but small quantities.
" 25, at 30 m., but sparsely.

The stations where they are found nearest the surface (stations 10, 12) have lower surface temperature than the places where the diatoms had almost or entirely disappeared from the surface layers (stations 3, 5). Resting spore formation has commenced in these species also.

The species which in June predominate in the surface layers are, on the one hand, the brown Cilioflagellates *Dinophysis norvegica* and *D. acuminata* (especially at stations 5, 6, and 8); and, on the other hand, infusoria. Foremost among these we find the remarkable *Mesodinium rubrum*, and species of the genus *Laboea*, the distribution of which is, up to the present, but little known, as all previously known methods of collection and preservation render them unrecognizable. Of the *Laboea* species, two in particular are found to predominate, viz., *L. conica* Lohmann, and *L. vestita* Leegaard. Both the *Mesodinium* and these two *Laboea* species are distinguished by the presence of chlorophyll (covered by a brown colouring matter) and thus belong to the producers of the plankton. *Mesodinium* is, according to Lohmann's investigations, doubtless colourless in itself, but lives symbiotically with small brown algæ, which fill the whole of its cell. The two *Laboea* species—in contrast to several others of the same genus—are brown, which fact I have been able to convince myself of by investigation of living material; up to the present, however, I have not been able to ascertain exactly whether the colour is due to captured algal cells or belongs to organs in the cells of the infusoria themselves. In any case, these three species appear to have been the most important CO_2-assimilating organisms in the gulf of St. Lawrence in June, 1915. *Laboea conica* has hardly been found before at any place in such great quantities as here (over 3,000 per liter at stations 6 and 8, over 5,000 at station 16).

It may appear remarkable that just these interesting organisms which unite the nutritive power of the plants with the lively movement of the animals, should be the first to populate the surface layers after the conclusion of the diatoms' period of development, but as their development otherwise is at present little known, we cannot decide whether the feature in question is characteristic of the gulf of St. Lawrence.

A further noteworthy point is the comparatively large quantities of colourless *Gymnodinium* species, especially *G. Lohmanni*. This Cilioflagellate subsists by absorbing solid bodies into its interior; whether it is also capable of absorbing dissolved organic matter from its surroundings has not yet been determined. An occurrance of 5,000 per liter (station 8) or 5 per cc. is a very considerable quantity for so large an organism, obliged to live upon organic food, and may be taken as a certain sign that it finds particularly favourable conditions for development.

Cruise of the "Acadia" May 29 to 31, 1915 (Table 2).

The samples from the *Princess* are supplemented in an interesting manner by the series taken somewhat more than a week earlier by the *Acadia* in the sea outside the Gulf of St. Lawrence. Most of the stations have, however, a plankton surprisingly poor in quantitative respects; this applies especially to stations 2, 4, 10, and 12. The quantities found are in reality so small that we must presume that the conditions for development cannot have been favourable to the phytoplankton. Of producers, only quite small quantities were found of colourless Cilioflagellates (*Gymnodinium Lohmanni*), with infusoria (*Laboea* species) somewhat more numerous. The method of preservation leaves it an open question whether Coccolithophoridæ, whose calcareous shells would have been dissolved by the acid employed, or small flagellates, which are difficult to find in a preserved state, were or were not present. If no such sources of nutrition occur it will be difficult to explain the finding of so rich a stock of organisms unable to assimilate carbonic acid for themselves. At station 10, however, we find at the surface a quite rich stock of the assimilating *Laboea conica*.

An exception is formed by the two stations 6 and 8, which have a rich diatom plankton, with *Leptocylindrus danicus*, and at station 8 also *Chætoceras debile*. This plankton resembles both in quantity and quality that which may be found on the coasts of Northern Europe in May. Both the composition in regard to species, and the abundance, point to a distinct coastal influence; the species are neritic, and the rich development is most probably due to dissolved nutritive matter from the coastal sea. The vertical distribution is peculiar; at station 6 we find *Leptocylindrus danicus* almost evenly distributed from surface to bottom, though with a certain increase in numbers toward the lower levels. We may be justified in concluding that this even distribution is a result of vertical movements, either of the water masses or of the diatoms themselves, which, after a rich development at the surface, have then sunk down to deeper layers. At station 8, this development is somewhat further advanced; the rich diatom plankton has almost disappeared from the warmer and somewhat less saline surface layer, and is first met with at 30 m. and thence down to the bottom.

Leptocylindrus danicus represents, on the coasts of Northern Europe, the last phase in the development of the spring diatom plankton, and the same appears to be the case in the waters here investigated, where the development already seems to be nearing its conclusion in the last week of May. Here, however, we do not find, as we do in Europe, any rich plankton of Cilioflagellates ready to replace the diatoms; these organisms have their optimum at higher temperatures. The most northerly of these species, *Ceratium arcticum,* is found, it is true, especially at station 10, but in small quantities compared with the numbers of *Ceratium* found in the coastal waters of Europe. Only at station 14, where the surface layer has attained a temperature of 8·1°C, do we find any considerable quantity, especially of *Ceratium longipes.*

CRUISE OF THE "PRINCESS" AUGUST 4 TO 5, 1915 (TABLE 3).

On investigating the gulf of St. Lawrence in the first days of August we might expect to find the results of the summer influence upon the plankton development typically represented. The present investigation, however, reveals a remarkably poor plankton. From what we know of the European waters, we should hardly expect, at this season, to find any considerable quantity of diatoms; and they are also but very sparsely represented in our samples. August should, however, be the right time for Cilioflagellates, especially *Ceratium* and *Dinophysis* species. Of these, we find *Ceratium fusus* and *longipes* quite abundant at the two first stations (29 and 30); otherwise, however, they are somewhat scarce. The genus *Dinophysis* is represented by *Dinophysis norvegica,* the occurrance of which corresponds to that of the *Ceratium* species. *Ceratium tripos,* which, with *C. fusus,* is distinctly euryhaline on the coasts of Europe, is here altogether lacking, as also *C. furca.* Of infusoria, we find the interesting *Laboea strobila* abundant at station 29; otherwise all species occur but sparsely. As, however, these samples were preserved with formalin, which is far less calculated to preserve the more delicate forms than Flemming's liquid, the result may be somewhat misleading in the case of the infusoria; with Diatoms and Cilioflagellates, on the other hand, this method also is thoroughly efficacious.

As a general result, then, we may say that the phytoplankton of the area investigated appears to be in quantitative respects considerably poorer than at the corresponding season in the North sea; on the coasts of Europe, we find a secondary maximum in September-October, when the surface layers are driven in towards the shores; and we might expect to find something similar also on the other side of the Atlantic. The present investigations seem to show that the general character of the plankton has an annual periodicity similar to that noted on the coasts of Europe, though commencing somewhat later, with the psychrophile species more predominant, while a number of the thermophile forms of Northern Europe are lacking, or occur but sparsely. The relative poverty in an area such as the gulf of St. Lawrence, which with its rich supply of fresh water, should offer, for the diatoms especially, good conditions of nourishment, is somewhat surprising; possibly it may be connected with the rapid alterations in hydrographical conditions. On the coast of Norway, the development of the diatoms commences in February, and not until May is the rise of temperature in the surface layers so perceptible that the development is arrested; in the gulf of St. Lawrence, the development can hardly be supposed to begin before early May, and at the close of this month the rise of temperature in the surface layers of the coastal water is distinctly apparent. On the other hand, the summer temperature is not sufficiently high to favour the development of a rich *Ceratium* plankton answering to the European plankton community called by Cleve the "Triposplankton."

More than this we can hardly say on the basis of the present observations; they represent a first commencement. As a necessary foundation for further studies, we must first have observations carried out throughout the entire year from a number of selected stations, so that we can obtain a clear view of the annual periodicity. In this connection, it will be of great interest to have investigations similar in plan to the present ones, repeated over a wider area at various seasons, but a continuous investigation series covering the whole of the year should first be made, in order that it may be possible to choose, for the more extensive investigations, the seasons at which the most important plankton communities are in course of development. Even now we may say that it would be particularly interesting to have quantitative investigations of the plankton in the gulf of St. Lawrence and environs for the beginning of May, so that we could determine the distribution of the rich spring plankton; the investigations should preferably be combined with determinations of oxygen content according to Winkler's method, as this would enable us to gauge the quantities of organic matter produced by the phytoplankton during this rich period of development.

I have not considered it necessary at the present stage to give a list of the species found and their synonyms. It will here suffice to refer to "Nordisches Plankton," where the great majority of the species are described; to my paper on the plankton production of the North European waters in May, 1912[3]; and to Caroline Leegard's work published at the same time (Untersuchungen ueber einige Planktonciliaten des Meeres." Kristiania, 1915. Nyt Magazin for Naturbidenskaberne, Bd. 53), with a description of the *Laboea* species and some related forms.

[3] *loc. cit.*

Table 1 (a).—Diatoms, "Princess," June, 1915.

TABLE 1 (a). DIATOMS, "PRINCESS," JUNE, 1915.	St. 3, June 9, N 46° 02', W 63° 25'			St. 5, June 10, N 47° 11', W 64° 15'				St. 6, June 10, N 47° 30', W 64° 08'				St. 8, June 10, N 48° 11', W 65° 04'				
Depth, Meters	0	10	20	0	10	20	30	0	10	30	60	0	10	20	40	60
Temperature, C.	11.5	4.8	3.15	10.1	8.6	4.15	2.4	9.6	4.4	0.77	1.15	9.1	7.75	1.85	0.2	0.6
Salinity	27.83	28.14	28.52	27.46	27.82	29.11	30.82	27.71	29.83	31.13	31.54	29.00	29.62	30.82	31.2	31.81
Density, σt	21.15	22.51	22.74	21.09	21.70	23.10	24.22	21.36	23.67	25.0	25.38	22.47	23.12	24.06	25.08	25.58
1 Actinocyclus Ehrenbergii, Ralfs	20		400													
2 Actinoptychus undulatus, Ralfs																
3 Achnanthes taeniata, Grun.																
4 Asterionella sp.			200													
5 Biddulphia aurita, Bréb.																
6 Chaetoceros atlanticum, Cl.	100		31400		6910	320										
7 " compressum, Lauder					40											
8 " " spore																
9 " convolutum, Castr.						80	20									
10 " criophilum, Castr.					720	180	80		200				60			
11 " debile, Cl.	100	1240	6000		160	20		180								
12 " decipiens, Cl.					160											
13 " diadema (Ehrbg.)																
14 " " spore			9100	180	11880	520										
15 " laciniosum, Schütt					1000	40										
16 " " spore																
17 " scolopendra, Cl.																
18 " sociale, Lauder																
19 " " spore				160	80											
20 " teres, Cl.					1140								20			
21 " sp.																
22 Coscinodiscus concinnus, W. Smith												80	40			
23 " subbulliens, Jørg.	10		300				20									
24 Diploneis sp.																
25 Fragilaria oceanica, Cl.											820					
26 " sp.																
27 Lauderia glacialis (Grun.)	220		600								40	40				
28 " sp.		150	2000													
29 Leptocylindrus danicus, Cl.		80	1500													
30 " minimus, Gran	10		1900													
31 Navicula distans, W. Smith																
32 " sp.			80													
33 Nitzschia closterium (Ehrbg.)				540	380	120										
34 " seriata, Cl.	0							20	20							
35 " sp.	30		18700				20				200					
36 Paralia sulcata (Ehrbg.)			1500				20									
37 Pleurosigma sp.																
38 Rhizosolenia alata, Brightw.		80	100													
39 " faeroense, Ostenf.	40		4150			20	160	90					10			
40 " semispina, Hensen	10		200													
41 " styliformis, Brightw.			1100													
42 Thalassiosira bioculata (Grun.)												40	60		20	40
43 " gravida, Cl.			900		140	880	540				20					
44 " Nordenskioldii, Cl.																
45 Thalassiothrix longissima, Cl. & Grun.																

	St. 10, June 11, N 48° 55', W 63° 50'				St. 12, June 11, N 49° 27', W 61° 20'					St. 14, June 11, N 50° 07', W 61° 09'			
Depth, Meters	0	25	50	100	0	25	50	75	100	0	10	25	35
Temperature, C.	6.15	2.3	0.8	0.65	7.55	2.15	0.15	-1.05	-0.3	8.1	3.5	1.1	-0.15
Salinity	30.80	31.66	31.92	32.86	31.07	31.75	31.96	32.54	32.83	26.15	29.78		31.95
Density, σt	24.26	25.24	25.61	26.41	24.27	25.37	25.60	26.19	26.41	20.44	23.70		25.68
1 Actinocyclus Ehrenbergii, Ralfs													
2 Actinoptychus undulatus, Ralfs								1740					
3 Achnanthes taeniata, Grun.	20	80	80			40		80	20	120	180	100	
4 Asterionella sp.													
5 Biddulphia aurita, Bréb.	150	100	860		150	180	400	380		20			
6 Chaetoceros atlanticum, Cl.	720	7750			700								
7 " compressum, Lauder													
8 " " spore	10												
9 " convolutum, Castr.		40	440				60	110					
10 " criophilum, Castr.	2160	9400	17800	140	1100		4720	420					
11 " debile, Cl.	80				150		40	60					
12 " decipiens, Cl.	60	980	1080				620	120		200	1140		
13 " diadema (Ehrbg.)								180					
14 " " spore	17680	11400			8100								
15 " laciniosum, Schütt													
16 " " spore		160											
17 " scolopendra, Cl.			1500				600						
18 " sociale, Lauder								1540	100				
19 " " spore		40											
20 " teres, Cl.					80		100						
21 " sp.		20			40	20							
22 Coscinodiscus concinnus, W. Smith													
23 " subbulliens, Jørg.													
24 Diploneis sp.			440				600	2020	140				
25 Fragilaria oceanica, Cl.													
26 " sp.		20	20					20					
27 Lauderia glacialis (Grun.)													
28 " sp.	20	200					500					10	
29 Leptocylindrus danicus, Cl.													
30 " minimus, Gran													
31 Navicula distans, W. Smith							40	20	20				
32 " sp.													
33 Nitzschia closterium (Ehrbg.)	100	1100	20		500	40					60		
34 " seriata, Cl.													
35 " sp.													
36 Paralia sulcata (Ehrbg.)													
37 Pleurosigma sp.	20	190	70		30		150					10	20
38 Rhizosolenia alata, Brightw.		40	100										
39 " faeroense, Ostenf.	720	640	2210	10	530	200	1280	540	30		50		40
40 " semispina, Hensen													
41 " styliformis, Brightw.													
42 Thalassiosira bioculata (Grun.)	180	160	1440	20	20	160	100	120			20		100
43 " gravida, Cl.		100	210	50	120			200	20			20	
44 " Nordenskioldii, Cl.													
45 Thalassiothrix longissima, Cl. & Grun.													

	St. 16, June 12, N 49° 33', W 59° 41'					St. 18, June 12, N 49° 16', W 58° 37'				St. 21, June 13, N 47° 52', W 60° 04'					St. 25, June 15, N 46° 45', W 61° 27'				
Depth, Meters	0	25	50	75	100	0	30	40	50	0	25	50	75	100	0	10	20	30	40
Temperature, C.	6.2	3.0	1.1	-0.7	-0.5	5.95	0.7	0.0	-0.3	4.2	1.0	2.45	0.1	-0.4	7.2	6.9	-0.15	-1.1	-1.1
Salinity	31.50	31.61	32.02	32.66	32.94	31.35	31.70	32.16	32.26	31.73	31.72	32.12	32.36	32.66	29.46	29.50	30.68	31.27	31.33
Density, σt	24.80	25.12	25.67	26.27	26.48	24.70	25.50	25.84	25.93	25.19	25.20	25.65	26.00	26.25	23.06	23.13	24.65	25.15	25.21
1 Actinocyclus Ehrenbergii, Ralfs													20						
2 Actinoptychus undulatus, Ralfs																			
3 Achnanthes taeniata, Grun.							160	80									20	20	60
4 Asterionella sp.																			
5 Biddulphia aurita, Bréb.	60			120			280	120	120					40				200	140
6 Chaetoceros atlanticum, Cl.														180				1000	
7 " compressum, Lauder																		1720	1020
8 " " spore											120							60	
9 " convolutum, Castr.																		280	
10 " criophilum, Castr.									140	240	380	1080	140	320				32700	51200
11 " debile, Cl.																		160	580
12 " decipiens, Cl.																		1180	800
13 " diadema (Ehrbg.)																		140	
14 " " spore										60	80	100						60	
15 " laciniosum, Schütt																			
16 " " spore																			
17 " scolopendra, Cl.																			
18 " sociale, Lauder								+	+										180
19 " " spore								20										40	120
20 " teres, Cl.									80										
21 " sp.							60												
22 Coscinodiscus concinnus, W. Smith																			
23 " subbulliens, Jørg.																			
24 Diploneis sp.																		700	1740
25 Fragilaria oceanica, Cl.																			
26 " sp.				40														220	240
27 Lauderia glacialis (Grun.)																			
28 " sp.							120	40	110			40							
29 Leptocylindrus danicus, Cl.																			
30 " minimus, Gran																			
31 Navicula distans, W. Smith																			
32 " sp.																			
33 Nitzschia closterium (Ehrbg.)						160	180					40							100
34 " seriata, Cl.																			
35 " sp.																			
36 Paralia sulcata (Ehrbg.)																			
37 Pleurosigma sp.							10	10				40							10
38 Rhizosolenia alata, Brightw.											280							160	
39 " faeroense, Ostenf.			80				100	280	110		110							50	
40 " semispina, Hensen																			
41 " styliformis, Brightw.																			
42 Thalassiosira bioculata (Grun.)								160	180										
43 " gravida, Cl.					20													20	20
44 " Nordenskioldii, Cl.					20														20
45 Thalassiothrix longissima, Cl. & Grun.																			

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Table 1 (b). Cilioflagellata. "Prince" June, 1915.

TABLE 1 (b). CILIOFLAGELLATA — "PRINCE" — JUNE 1915

	June 9			St. 5 June 10 N. 47 1. W. 64 55				St. 6 June 10 N. 47 30 W. 64 08			
Depth Meter	0	10	0	0	10	20	30	0	10	30	60
Temperature °	11	3.8	[illegible]	10.1	8.6	3.[illegible]	2.1	9.6	4.1	0.7[illegible]	−1.1[illegible]
Salinity	27.8[illegible]	28.11	28.52	27.46	27.87	29.11	30.8	27.71	29.80	31.1[illegible]	31.54
Density	1.15	[illegible]	22.74	21.09	21.59	23.10	24.22	21.[illegible]6	2[illegible].67	25.0[illegible]	25.[illegible]8
1 Ceratium arcticum Ehrbg.					60					20	
2 " fusus Ehrbg.				20							
3 " longipes (Bail.)				20				10			
4 Dinophysis acuminata Clap. et Lachm.	20			20	140			240	0		
5 " acuta Ehrbg.											
6 " norvegica Clap. et Lachm.	80	60		40	220			20	60		
7 " rotundata Clap. et Lachm.				60		60		10	40	20	
8 Diplopelta bomba Stein											
9 Diplopsalis lenticula Bergh						20		20			
10 Exuviaella baltica Lohm.	100	20									
11 Gonyaulax sp.											
12 " sp.											
13 Gonyaulax spinifera Clap. et Lachm.								20			
14 " triacantha Jörg.									20		
15 " sp.	60										
16 Gymnodinium lohmanni Paul.	0	100		140	200	[illegible]40	180	980	1120	540	20
17 " sp.		0		0	300	0		[illegible]80	100		
18 Peridinium achromaticum Levander				0	0						
19 " conicoides Paul.						[illegible]0					
20 " conicum (Gran)										[illegible]0	
21 " depressum Bailey				0	80	[illegible]0		20	0		
22 " oceanicum Vanhöff.									20		
23 " ovatum Pouchet				0	0	[illegible]0			20		
24 " pallidum Ostenf.									20	20	
25 " sp.											
26 " pellucidum Bergh						20					
27 " sp.											
28 " [illegible]	40								40		
29 Pouchetia sp.				60							
30 [illegible] sp.	[illegible]0	0		160	100	80		680		20	
31 Protoceratium reticulatum Clap. et Lachm.											
32 [illegible] Ehrbg.								20			

	St. 8 June 10 N. 48 11 W. 6[illegible] 04					St. 10 June 11 N. 48 5[illegible] W. 64 50				St. 12 June 11 N. 49 27 W. 64 20				
Depth Meter	0	10	20	40	60	0	25	50	100	0	25	50	75	100
Temperature °	9.1	7.75	1.85	0.[illegible]	0.6[illegible]	6.17	1.[illegible]	0.8	−0.[illegible]	2.55	[illegible].5	0.15	1.[illegible]	0.[illegible]
Salinity	29.04	29.12	30.8	31.[illegible]	31.51	30.86	31.6[illegible]	31.92	32.86	31.07	31.55	31.96	32.54	32.83
Density	22.47	2[illegible].1[illegible]	24.66	25.08	25.38	24.26	25.24	25.61	26.41	24.[illegible]7	25.[illegible]7	25.69	26.19	26.41
1 Ceratium arcticum Ehrbg.	20									20				
2 " fusus Ehrbg.										20				
3 " longipes (Bail.)										20				
4 Dinophysis acuminata Clap. et Lachm.	920	100				10				80				20
5 " acuta Ehrbg.														
6 " norvegica Clap. et Lachm.	980	140				80	10			180				
7 " rotundata Clap. et Lachm.	20	60								20				
8 Diplopelta bomba Stein	20													
9 Diplopsalis lenticula Bergh	60					20	40			60		10		20
10 Exuviaella baltica Lohm.	20													
11 Gonyaulax sp.	700					280				160				
12 " sp.						100				20				
13 Gonyaulax spinifera Clap. et Lachm.														
14 " triacantha Jörg.														
15 " sp.														
16 Gymnodinium lohmanni Paul.	5520	1160	20	20	20	140	220	100		340	260	400		
17 " sp.	980	40			10	200	100			160	40	20		
18 Peridinium achromaticum Levander	[illegible]0	[illegible]0				20			20	80				
19 " conicoides Paul.														
20 " conicum (Gran)											20			
21 " depressum Bailey						40		20		20		20		
22 " oceanicum Vanhöff.														
23 " ovatum Pouchet	80					10				40	[illegible]0		40	20
24 " pallidum Ostenf.	2[illegible]					20		2		20	20			
25 " sp.	1010	[illegible]00				110	20	10		120	20			
26 " pellucidum Bergh	20													
27 " sp.														
28 " [illegible]						20				20				
29 Pouchetia sp.														
30 [illegible] sp.	80	20	20			140		20		100	20		20	
31 Protoceratium reticulatum Clap. et Lachm.	20													
32 [illegible] Ehrbg.														

	St. 14 June 11 N. 50 07 W. 64 00				St. 16 June 12 N. 49 34 W. 59 31					St. 18 June 12 N. 49 16 W. 58 37			
Depth Meter	0	10	25	35	0	25	50	75	100	0	20	40	50
Temperature °	8.1	[illegible].5	1.6	−0.15	6.2	3.[illegible]	1.1	0.7	−0.5	5.95	0.7	0.0	−0.4
Salinity	26.15	29.78		31.95	31.50	31.61	31.0[illegible]	32.6[illegible]	32.94	31.15	31.79	32.16	32.26
Density	20.44	23.70		25.68	24.80	25.12	25.67	26.27	26.48	24.70	25.50	25.84	25.90
1 Ceratium arcticum Ehrbg.	10					20				20			
2 " fusus Ehrbg.													
3 " longipes (Bail.)		40											
4 Dinophysis acuminata Clap. et Lachm.	20				20					40			
5 " acuta Ehrbg.										20			
6 " norvegica Clap. et Lachm.	180	20			20								
7 " rotundata Clap. et Lachm.		20				40				10			
8 Diplopelta bomba Stein													
9 Diplopsalis lenticula Bergh			20										
10 Exuviaella baltica Lohm.													
11 Gonyaulax sp.	40												
12 " sp.													
13 Gonyaulax spinifera Clap. et Lachm.					20								
14 " triacantha Jörg.													
15 " sp.													
16 Gymnodinium lohmanni Paul.	460	480	500	60	320	40	20	20	20	620	100	10	
17 " sp.	80	260	40	20	140	20				120			
18 Peridinium achromaticum Levander	1[illegible]0	40		20	40					80			
19 " conicoides Paul.													
20 " conicum (Gran)											20		
21 " depressum Bailey	60	20			20	20	20			20	20		
22 " oceanicum Vanhöff.										20			
23 " ovatum Pouchet	40	40			20					20	20		
24 " pallidum Ostenf.	20	20								20			
25 " sp.													
26 " pellucidum Bergh						20				20			
27 " sp.													
28 " [illegible]	60												
29 Pouchetia sp.													
30 [illegible] sp.					80		20	20					
31 Protoceratium reticulatum Clap. et Lachm.													
32 [illegible] Ehrbg.													

	St. 21 June 13 N. 47 52 W. 60 01					St. 25 June 15 N. 46 45 W. 61 25				
Depth Meter	0	25	50	75	100	0	10	20	30	40
Temperature °	1.2	1.10	2.15	0.1	−1.4	7.2	6.9	0.15	1.1	1.1
Salinity	31.74	31.71	32.12	32.36	32.66	29.16	29.50	30.68	31.27	31.33
Density	25.19	25.20	25.65	26.00	26.25	23.06	23.13	24.65	25.15	25.23
1 Ceratium arcticum Ehrbg.										0
2 " fusus Ehrbg.										
3 " longipes (Bail.)										
4 Dinophysis acuminata Clap. et Lachm.						20				
5 " acuta Ehrbg.										
6 " norvegica Clap. et Lachm.		10				280	120			
7 " rotundata Clap. et Lachm.										
8 Diplopelta bomba Stein										
9 Diplopsalis lenticula Bergh	20									
10 Exuviaella baltica Lohm.										
11 Gonyaulax sp.										
12 " sp.										
13 Gonyaulax spinifera Clap. et Lachm.										
14 " triacantha Jörg.										
15 " sp.										
16 Gymnodinium lohmanni Paul.	600	900	40	60				1280	60	60
17 " sp.	100	40	10	20						
18 Peridinium achromaticum Levander										
19 " conicoides Paul.										
20 " conicum (Gran)									40	
21 " depressum Bailey	20	10								
22 " oceanicum Vanhöff.										
23 " ovatum Pouchet									20	20
24 " pallidum Ostenf.										
25 " sp.										
26 " pellucidum Bergh								50		
27 " sp.									80	
28 " [illegible]						20	20			
29 Pouchetia sp.										
30 [illegible] sp.	60	20	80			20	20		80	40
31 Protoceratium reticulatum Clap. et Lachm.										
32 [illegible] Ehrbg.										

TABLE I (c).—Infusoria. "Princess," June, 1915.

TABLE I.—INFUSORIA, "PRINCESS," JUNE, 1915.

	St. [illegible], June 9, N. 46° 02′, W. 63° 25′			St. 5, June 10, N. 47° 13′, W. 64° [illegible]				St. 7, June 10, N. 47° 50′, W. 64° 08′			
Depth, Meters	0	10	[illegible]	0	10	20	30	0	10	30	60
Temperature, C.	11.5	4.8	3.15	10.1	5.6	4.35	2.4	9.6	1.4	0.75	1.15
Salinity	27.84	28.41	28.52	27.46	27.82	29.11	30.82	27.71	29.83	31.13	31.54
Density, σt	21.15	22.54	22.71	21.20	21.59	23.10	24.22	21.36	23.67	25.00	25.38
1. Cyttarocylis denticulata Ehrbg.				20					20		
2. " norvegica Clap. et Lachm.											
3. Laboea acuminata Jörg.											
4. " conica Lohm.	20	120		540	280		20	80	660	240	20
5. " constricta Jörg.					80	140			60		
6. " crassula Jörg.	20								140		
7. " cornuta Jörg.											
8. " strobila Lohm.	20			40	80				760	100	
9. " vestita Jörg.	40	40		100	120			40	1380	140	
10. " sp.					20						
11. Lohmanniella [illegible] Leeg.	60	20	100	280	660	220	20	[illegible]	140	220	[illegible]
12. Mesodinium rubrum Lohm.	280		100	1820	720	100	60	180	200	20	40
13. " sp.		40		40	60						
14. Ptychocylis [illegible] Brandt					40						
15. Tintinnopsis sp.	180	20		60				40			
16. Tintinnus acuminatus Clap. et Lachm.					40						
17. Nauplii	20	20		140	30	20		100		20	
18. Oithona		40							20		
19. Acartia											
20. [illegible]											
21. Fritillaria sp.				20							

	St. 8, June 10, N. 48° 11′, W. 63° 04′					St. 10, June 11, N. 48° 5′, W. 61° 50′				St. 12, June 11, N. 49° 27′, W. 61° 20′				
Depth, Meters	0	10	20	40	60	0	25	50	100	0	25	50	75	100
Temperature, C.	9.1	7.75	1.85	0.2	−0.6	6.45	1	0.8	−0.35	7.55	2.35	−0.15	1.5	[illegible]
Salinity	29.04	29.62	30.82	31.2	31.81	30.86	31.66	31.92	32.86	31.07	31.75	31.96	32.53	32.83
Density, σt	22.47	22.42	23.66	25.08	25.58	24.26	25.21	25.61	26.31	24.27	25.37	25.60	26.19	26.31
1. Cyttarocylis denticulata Ehrbg.	80		40			80		20	20	60	40			
2. " norvegica Clap. et Lachm.														
3. Laboea acuminata Jörg.	60					20								
4. " conica Lohm.	620	460	1000			340	180			140	60			
5. " constricta Jörg.		20				90		120	40		60	160		
6. " crassula Jörg.	60	300	220			160	80			80	160			
7. " cornuta Jörg.							20					40		
8. " strobila Lohm.	20	20	120			80	60			40	300	20		
9. " vestita Jörg.	800	920	800	60		80	60	20		100	40			20
10. " sp.														
11. Lohmanniella [illegible] Leeg.	220	200	80	60		140		140			120	100	20	
12. Mesodinium rubrum Lohm.	1120	540	400			540		80		140	20	80		
13. " sp.	120	20				[illegible]				20				
14. Ptychocylis [illegible] Brandt										20		20		
15. Tintinnopsis sp.	20													
16. Tintinnus acuminatus Clap. et Lachm.														20
17. Nauplii	60	40				60				160				
18. Oithona														
19. Acartia			20											
20. [illegible]								20						
21. Fritillaria sp.								600						

	St. 14, June 11, N. 50° 7′, W. 61° 09′				St. 16, June 12, N. 49° 43′, W. 59° 31′				
Depth, Meters	0	10	25	35	0	25	50	75	100
Temperature, C.	8.1	5.5	1.0	−0.15	6.2	3.0	1.1	−0.7	−0.5
Salinity	26.15	29.78		31.95	31.50	31.61	32.02	32.66	32.84
Density, σt	20.44	23.70		25.68	24.80	25.12	25.67	26.27	26.48
1. Cyttarocylis denticulata Ehrbg.	60	20				20	20		
2. " norvegica Clap. et Lachm.			20			20			
3. Laboea acuminata Jörg.									
4. " conica Lohm.	100	60		20	5480				
5. " constricta Jörg.			80	40			20	60	
6. " crassula Jörg.	60	180				100			20
7. " cornuta Jörg.									
8. " strobila Lohm.	20	320			340	1000			
9. " vestita Jörg.	120	60	120		2260			60	
10. " sp.									
11. Lohmanniella [illegible] Leeg.			20	20		80		20	
12. Mesodinium rubrum Lohm.	1840	360		280		20			
13. " sp.	20		40	20					
14. Ptychocylis [illegible] Brandt									
15. Tintinnopsis sp.									20
16. Tintinnus acuminatus Clap. et Lachm.									
17. Nauplii	40	100			20	20			
18. Oithona			20						
19. Acartia					20				
20. [illegible]									
21. Fritillaria sp.									

	St. 18, June 12, N. 49° 16′, W. 58° 37′				St. 21, June 13, N. 47° 52′, W. 60° 04′					St. 25, June 15, N. 46° 45′, W. 61° 27′				
Depth, Meters	0	20	40	50	0	25	50	75	100	0	10	20	30	40
Temperature, C.	5.95	0.5	0.0	[illegible]	4.2	4.0	2.45	0.1	−0.4	7.2	6.9	0.15	1.1	−1.1
Salinity	31.15	31.70	32.16	32.26	31.73	31.72	32.12	32.36	32.66	28.46	29.50	30.68	31.27	31.5[illegible]
Density, σt	24.70	25.50	25.84	25.93	25.19	25.20	25.65	26.00	26.25	23.06	23.33	24.65	25.15	25.21
1. Cyttarocylis denticulata Ehrbg.	120	20			20	20					20	20		
2. " norvegica Clap. et Lachm.														
3. Laboea acuminata Jörg.		60												
4. " conica Lohm.	2380				600	580				20		2480	40	20
5. " constricta Jörg.			120	60										100
6. " crassula Jörg.	20	60	60		140	40	240					10	60	
7. " cornuta Jörg.														
8. " strobila Lohm.	520		40		120	300				40	80	40		
9. " vestita Jörg.	2080				520	140	20			300	20	3000		60
10. " sp.														
11. Lohmanniella [illegible] Leeg.	180	60	60	60	40	20					80		100	220
12. Mesodinium rubrum Lohm.	1920				360	200				160	240	260	60	80
13. " sp.	20													20
14. Ptychocylis [illegible] Brandt	20	20	20								20			
15. Tintinnopsis sp.														20
16. Tintinnus acuminatus Clap. et Lachm.														
17. Nauplii	120					20				40	120	20		
18. Oithona														
19. Acartia														
20. [illegible]	20													
21. Fritillaria sp.	20	40												

[illegible]

TABLE 2.—ACADIA, MAY, 1915.

	St. 2—May 29. N. 44° 29', W. 62° 22'						St. 4—May 29. N. 44° 7' 03", W. 62° 11' 30"							
Depth, Meters	0	10	20	30	40	55	0	10	25	40	50	60	75	100
Temperature C	4.75	3.9	3.9	2.1	1.2	0.95	4.1	4.85	4.2	2.3	0.85	1.1	1.95	[illegible]
Salinity	31.00	30.91	30.94	31.15	31.44	31.74	31.48	31.49	31.56	31.76	31.93	[illegible]		33.14
Density (σ_t)	24.50	24.56	24.60	24.90	25.20	25.45	24.97	24.97	25.06	25.19	25.61	25.42		26.4
1 Asterionella sp.	20	20				40	20		20					
2 Chaetoceras atlanticum Cl.														
3 compressum Lauder														
4 debile Cl.														
5 decipiens Ehrbg.	180													
6 laciniosum Schütt														
7 teres Cl.														
8 sp.														
9 Leptocylindrus danicus Cl.											40		140	
10 Navicula sp.														20
11 Nitzschia closterium (Ehrbg.)														
12 seriata Cl.														
13 Paralia sulcata (Ehrbg.)														
14 Pleurosigma sp.														
15 Fragilaria oceanica														
16 Rhizosolenia alata Brightw.														
17 faeroensis Ostenf.														
18 semispina Hensen														
19 Skeletonema costatum (Grev.)														
20 Thalassiosira [illegible] Grun.														
21 gravida Cl.		20											20	
22 Thalassiothrix longissima Cl. & Grun.														
23 Ceratium arcticum Ehrbg.	20													
24 fusus Ehrbg.			20											
25 longipes (Bail.)									20				20	
26 Dinophysis norvegica Clap. et Lachm.														
27 rotundata Clap. et Lachm.														
28 Diplopsalis lenticula Bergh														
29 Goniaulax sp.			20						20					
30 Goniodoma sp.														
31 [illegible] Pauls.	30	160	180		40	80	80	240	60	160	40		200	
32 sp.	20							20						
33 Peridinium catenatum Levander							40							
34 conicum Gran														
35 depressum Ehrbg.														
36 ovatum Pouch.								20			20			
37 pallidum Ostenf.														
38 pellucidum Bergh														
39 sp.	20												20	
40 Cyttarocylis denticulata Ehrbg.		20			20		40	40						
41 Laboea acuminata Leeg.													40	
42 conica Lohm.		10	10	20			400	80	80	20			100	
43 crassa Leeg.			20											
44 [illegible] Leeg.									20	60	20			
45 strobila Lohm.		20	10	20			900	120	80	120	20		140	
46 delicatissima Leeg.							40	60	10					
47 [illegible] Lohm.		40	160				40		60					
48 [illegible]		160	160		20	20	220	100	20			10	200	
49 Lohmanniella oviformis Leeg.		120	80	20	20	60	300	10	10		80	10	60	
50 spiralis Leeg.			30		20		20				20			
51 Mesodinium rubrum Lohm.	20		60				120	40	60		20		180	
52 sp.														
53 [illegible] Clap. et Lachm.							20	20						
54 [illegible]		20						20						
55 Globigerina bulloides d'Orb.														
56 Nauplii			10	20	10		10	20	20		20		20	
57 [illegible]														
58 Copepoda							20							
59 Appendicularia							20							

	St. 6—May 30. N. 43° 47', W. 60° 52'					St. 8—May 30. N. 43° 50' 00", W. 60° 1' 00"					
Depth, Meters	0	10	20	0	10	0	10	20	0	10	50
Temperature C	4.35	4	4.2	4.0	6	7.4	[illegible]	1.2	3.4	3.4	2.85
Salinity	32.06	32.06	32.05	32.05	32.15	31.91	31.94	31.98	32.07	32.08	32.11
Density (σ_t)	25.44	25.44	25.44	25.46	25.56	[illegible]	25.24	25.39	25.51	25.55	25.63
1 Asterionella sp.		20	80		20						20
2 Chaetoceras atlanticum Cl.			80	140		60			120		
3 compressum Lauder	180		80	320					220	520	
4 debile Cl.	80		160	160			180		2820	5880	20000
5 decipiens Ehrbg.											20
6 laciniosum Schütt		80							100	80	260
7 teres Cl.									40		
8 sp.		180				4080	500				
9 Leptocylindrus danicus Cl.	59400	129770	163600	205290	193600	220	60	40	141080	105880	202600
10 Navicula sp.	20		100	200	10						80
11 Nitzschia closterium (Ehrbg.)	20	120	60	60	80					40	20
12 seriata Cl.	140	120	400	20	60				80	120	80
13 Paralia sulcata (Ehrbg.)	40									200	
14 Pleurosigma sp.	60	100	40	100	60						60
15 Fragilaria oceanica											
16 Rhizosolenia alata Brightw.									10	60	20
17 faeroensis Ostenf.	80	120		20	180				980	1080	900
18 semispina Hensen			40		10		20			10	
19 Skeletonema costatum (Grev.)										400	
20 Thalassiosira [illegible] Grun.						60		40	40		200
21 gravida Cl.		60	20	20	40						200
22 Thalassiothrix longissima Cl. & Grun.						40					20
23 Ceratium arcticum Ehrbg.						20		20			
24 fusus Ehrbg.											
25 longipes (Bail.)		20	20			100					
26 Dinophysis norvegica Clap. et Lachm.							20				
27 rotundata Clap. et Lachm.											
28 Diplopsalis lenticula Bergh		20						20			
29 Goniaulax sp.											
30 Goniodoma sp.											
31 [illegible] Pauls.		40	120	120		160	80	20	120	800	60
32 sp.											
33 Peridinium catenatum Levander						20					
34 conicum Gran									20		
35 depressum Ehrbg.	120	80		20		180	80	20			20
36 ovatum Pouch.											
37 pallidum Ostenf.		20	20				60	20			
38 pellucidum Bergh				20							
39 sp.	20			40		20	80				
40 Cyttarocylis denticulata Ehrbg.			20								
41 Laboea acuminata Leeg.						20				120	
42 conica Lohm.						400		20	20		
43 crassa Leeg.	20								10		
44 [illegible] Leeg.											
45 strobila Lohm.									200	80	
46 delicatissima Leeg.											
47 [illegible] Lohm.	20	60		220		80		20	480	920	
48 [illegible]						20					
49 Lohmanniella oviformis Leeg.							10	40	20		
50 spiralis Leeg.								10	20		
51 Mesodinium rubrum Lohm.	60	60	40	240	60	20	10	10	160	60	
52 sp.		20	20								
53 [illegible] Clap. et Lachm.											
54 [illegible]											
55 Globigerina bulloides d'Orb.											
56 Nauplii		20	10	20		60	20	20			
57 [illegible]						20	20				
58 Copepoda						20					
59 Appendicularia			20								

	St. 10—May 30. N. 43° 41' 20", W. 59° 2'							St. 12—May 31. N. 43° 31', W. 57° 46'						St. 14—May 31. N. 43° 20', W. 56° 28' 30"					
Depth, Meters	0	25	50	60	75	90	100	0	10	25	50	75	100	0	25	50	75	100	150
Temperature C	4.4	4.27	2.2	2.0	0.8	1.1	3.5	4.55	4.5	0.3	1.15	-1.7	0.65	8.1	7.65	6.75	7.5	8.4	6.75
Salinity	32.48	32.61	32.74	32.81	32.86	33.56	33.61	32.61	32.63	32.81	32.82	32.94	33.18	33.57	33.58	33.60	33.74	34.77	34.70
Density (σ_t)	25.77	25.80	26.16	26.20	26.30	26.77	26.82	25.86	25.88	26.37	26.41	26.51	26.61	26.10	26.24	26.38	26.38	27.05	27.24
1 Asterionella sp.	40																		
2 Chaetoceras atlanticum Cl.			60											20					
3 compressum Lauder																			
4 debile Cl.	180																		
5 decipiens Ehrbg.																			
6 laciniosum Schütt																			
7 teres Cl.																			
8 sp.																			
9 Leptocylindrus danicus Cl.														80					
10 Navicula sp.																			
11 Nitzschia closterium (Ehrbg.)																			
12 seriata Cl.											20								
13 Paralia sulcata (Ehrbg.)																			
14 Pleurosigma sp.																			
15 Fragilaria oceanica																			
16 Rhizosolenia alata Brightw.													180						
17 faeroensis Ostenf.											60								
18 semispina Hensen																			
19 Skeletonema costatum (Grev.)																			
20 Thalassiosira [illegible] Grun.																			
21 gravida Cl.							20					20							
22 Thalassiothrix longissima Cl. & Grun.																			
23 Ceratium arcticum Ehrbg.	80	80		20	10			20	20					10	10	10	20		
24 fusus Ehrbg.	20														20				
25 longipes (Bail.)					10			40	20					120	130	90	110		
26 Dinophysis norvegica Clap. et Lachm.								20											
27 rotundata Clap. et Lachm.				20					40										
28 Diplopsalis lenticula Bergh										20									
29 Goniaulax sp.																			
30 Goniodoma sp.	20																		
31 [illegible] Pauls.	20	20		20	20	20		40	20										
32 sp.	120						10												
33 Peridinium catenatum Levander			60					20											
34 conicum Gran																			
35 depressum Ehrbg.	20	60			20			60	40		100	20			100	40	30		
36 ovatum Pouch.			20											10	10				20
37 pallidum Ostenf.																			
38 pellucidum Bergh																			
39 sp.			20	40		20			10			20							
40 Cyttarocylis denticulata Ehrbg.																			
41 Laboea acuminata Leeg.																			
42 conica Lohm.	2580				60			120	60			20		10					
43 crassa Leeg.																			
44 [illegible] Leeg.			460	260						120	20	40							
45 strobila Lohm.	10	10	60		100			60		20	10	20				20			
46 delicatissima Leeg.																			
47 [illegible] Lohm.	2120		60		100			220	30	20	20			10		60		40	
48 [illegible]	1400	20	80	60	130			80	20	20	10	80		160	20			20	
49 Lohmanniella oviformis Leeg.	120		40	10	50	80			60	60	30	10		10					
50 spiralis Leeg.		60	60	80	80			260	220		100			10	10				
51 Mesodinium rubrum Lohm.	180		80	40	120			100	80	100	60	80		60			10		
52 sp.																			
53 [illegible] Clap. et Lachm.				20							20								
54 [illegible]																			
55 Globigerina bulloides d'Orb.															30				
56 Nauplii		10	20	20	10	10	20	10	30		10	40		20	10	60	50		
57 [illegible]														10		10	10		
58 Copepoda																			
59 Appendicularia																			

TABLE 3.—"PRINCESS," JUNE, 1915

Depth Meters	St 29, Aug 4, N 47 1[illegible], W 64 [illegible]6: 0	10	20	St 30, Aug 4, N 47 31, W 64 0[illegible]: 0	10	25	40	[illegible]	60	St 31, Aug 4, N 47 47, W 6[illegible] 47: 0	10	25	30	[illegible]
Temperature C	17.0	15.6	9.[illegible]	18.1	[illegible]	10.5	7.9	[illegible]	0.45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Salinity	26.63	27.45	28.91	27.85	[illegible]	28.67	2[illegible].49	[illegible]	[illegible].64	[illegible]	27.11	[illegible]	[illegible]	[illegible]
Density σt	19.13	20.07	22.[illegible]1	20.27	[illegible]	21.97	22.9[illegible]	2[illegible].97	25.40	19.70	20.11	[illegible]	[illegible]	[illegible]
Diatomaceae														
Actinocyclus Ehrenbergii Ralfs	520	640	20								20	20		
Chaetoceras [illegible] Cl.														
decipiens Cl.														
Coscinodiscus sp.														
Paralia sulcata (Ehrbg.)			120											
Rhizosolenia alata Brightw.														
semispina Hensen	20												10	
setigera Brightw.		100			50									
Thalassiosira Nordenskioldii Cl.														
" [illegible]				80		180	90	80	20					
Thalassiothrix nitzschioides Grun.												10		
Peridiniales														
Ceratium [illegible] Ehrbg.														
fusus Ehrbg.	1030	20	30	110	110					50	50			
longipes (Bail.)	410	1020	80	10	10	100	10			60	150			
Dinophysis acuminata Clap. et Lachm.										20				
granulata Cl.											50			
norvegica Clap. et Lachm.	780	1500	10	190	130	40				10	170			
rotundata Clap. et Lachm.	10	100		40	[illegible]					10				
Diplopsalis lenticula Bergh														
Exuviaella sp.														
Gonyaulax sp.						10				20	[illegible]			
Peridinium achromaticum Levander														
crassipes Kofoid	10	10	30											
depressum Bail.			80											
[illegible] Paul.	140	80	30		50									
oceanicum Vanhöff.														
ovatum (Pouchet)								20						
pallidum Ostenf.														
pyriforme Paul.		10												
Pyrocystis lunula Schütt	10	20												
Tintinnoidea														
Amphorella subulata (Ehrbg.)						40	10					10		
Cyttarocylis denticulata (Ehrbg.)						50		10		50	10	20		
[illegible] conica Lohm.										[illegible]				
[illegible]ta Jörg.		10						[illegible]						
[illegible] Jörg.		60												
[illegible]data Lohm.	400	1170	10	30	[illegible]	10	20			100	10			
[illegible]ta Jörg.	70	240		50	80									
[illegible] Jörg.	10													
[illegible] Jörg.												20		
Mesodinium sp.	140	20	20							80	[illegible]			
Ptychocylis urnula Clap. et Lachm.			20											
Tintinnus acuminatus Clap. et Lachm.			30			50								
Nauplii	[illegible]	100	60	120	[illegible]	50	30	[illegible]		10	50			

Depth Meters	St 32, Aug 4, N 48 00, W 63 25: 0	10	25	40	75	St 33, Aug 4, N 48 17, W 62 53: 0	10	25	50	75	St 34, Aug 4, N 48 27, W 62 37: 0	10	25	50	75
Temperature C	17.0	14.95	5.45	1.4	0.25	15.55	10.[illegible]	[illegible].5	0.9	0.[illegible]	15.15	11.75	7.8	0.55	1.15
Salinity	25.77	27.49	31.04		32.05	2[illegible].80	29.07	31.2	32.04	3[illegible]	30.11	30.90	31.17	32.05	32.47
Density σt	20.10	22.77	24.52		25.76	20.8[illegible]	2[illegible].00	2[illegible]	25.78	26.[illegible]	22.20	2[illegible].18	24.32	25.77	26.1
Diatomaceae															
Actinocyclus Ehrenbergii Ralfs															
Chaetoceras [illegible] Cl.															
decipiens Cl.															
Coscinodiscus sp.			10												
Paralia sulcata (Ehrbg.)															
Rhizosolenia alata Brightw.															
semispina Hensen															20
setigera Brightw.															
Thalassiosira Nordenskioldii Cl.															
" [illegible]				40	20										
Thalassiothrix nitzschioides Grun.															
Peridiniales															
Ceratium [illegible] Ehrbg.											10	100	120		
fusus Ehrbg.	20	20				50	60				20				
longipes (Bail.)	80	150				60	60				60	20	180		
Dinophysis acuminata Clap. et Lachm.															
granulata Cl.															
norvegica Clap. et Lachm.		20										10		20	
rotundata Clap. et Lachm.						10						10			20
Diplopsalis lenticula Bergh														20	20
Exuviaella sp.												30			
Gonyaulax sp.															
Peridinium achromaticum Levander															
crassipes Kofoid			10												
depressum Bail.		10													
[illegible] Paul.															
oceanicum Vanhöff.															20
ovatum (Pouchet)											20				
pallidum Ostenf.			10										10		
pyriforme Paul.															
Pyrocystis lunula Schütt															
Tintinnoidea															
Amphorella subulata (Ehrbg.)															
Cyttarocylis denticulata (Ehrbg.)															
[illegible] conica Lohm.												10			
[illegible]ta Jörg.												[illegible]	10		
[illegible] Jörg.															
[illegible]data Lohm.						[illegible]	20					20	10		
[illegible]ta Jörg.															
[illegible] Jörg.															
[illegible] Jörg.															
Mesodinium sp.									20						
Ptychocylis urnula Clap. et Lachm.													20		
Tintinnus acuminatus Clap. et Lachm.															
Nauplii		50	10			[illegible]					20	[illegible]			

Depth Meters	St 35, Aug 5, N 48 41, W 62 15: 0	10	25	50	St 36, Aug 5, N 48 58, W 61 48: 0	10	25	50	St 37, Aug 5, N 49° 06′, W 61° 21′: 0	10	25	50	St 38, Aug 5, N. 49° 28′, W 61° 22′: 0	10	25	50	75
Temperature C	12.85	12.9	[illegible].4	0.6	11.[illegible]	14.2	7.6	0.3	13.05	12.5	2.35	−0.85	13.95	13.0	1.9	−0.95	−1.1
Salinity	30.24	30.51	31.44	32.25	29.91	29.90	30.62	31.96	30.14	30.15	31.46	32.21	29.96	29.97	31.74	32.36	32.73
Density σt	22.76	22.96	24.93	25.95	22.21	22.22	23.89	25.67	22.65	22.77	25.13	25.91	22.43	22.53	25.40	26.04	26.44
Diatomaceae																	
Actinocyclus Ehrenbergii Ralfs																	
Chaetoceras [illegible] Cl.								60									
decipiens Cl.	[illegible]																
Coscinodiscus sp.								80								20	
Paralia sulcata (Ehrbg.)																	
Rhizosolenia alata Brightw.				10													
semispina Hensen																	
setigera Brightw.																	
Thalassiosira Nordenskioldii Cl.																	
" [illegible]																	20
Thalassiothrix nitzschioides Grun.																	
Peridiniales																	
Ceratium [illegible] Ehrbg.	10	20				10	10			30			10	10	10		
fusus Ehrbg.	[illegible]	20			70	60	10		40	60			30	80			
longipes (Bail.)	100	70			80	10	50		60	80			60	80	10		
Dinophysis acuminata Clap. et Lachm.																	
granulata Cl.																	
norvegica Clap. et Lachm.	50					20			10	10			20	10			
rotundata Clap. et Lachm.			20							20							
Diplopsalis lenticula Bergh						10		[illegible]									
Exuviaella sp.														20			
Gonyaulax sp.																	
Peridinium achromaticum Levander										20							
crassipes Kofoid						10											
depressum Bail.	10																
[illegible] Paul.																	
oceanicum Vanhöff.																	
ovatum (Pouchet)		10	20											10			
pallidum Ostenf.							20										
pyriforme Paul.																	
Pyrocystis lunula Schütt																	
Tintinnoidea																	
Amphorella subulata (Ehrbg.)																	
Cyttarocylis denticulata (Ehrbg.)	[illegible]	10			10	10	10		10	20							
[illegible] conica Lohm.																	
[illegible]ta Jörg.														10			
[illegible] Jörg.																	
[illegible]data Lohm.						10	10							20	20		
[illegible]ta Jörg.										20							
[illegible] Jörg.																	
[illegible] Jörg.																	
Mesodinium sp.																	
Ptychocylis urnula Clap. et Lachm.			20				10								10	20	
Tintinnus acuminatus Clap. et Lachm.																	
Nauplii	[illegible]	10				50			[illegible]	110			10	20			

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DEPARTMENT OF THE NAVAL SERVICE

CANADIAN FISHERIES EXPEDITION, 1914-1915

Investigations in the Gulf of St. Lawrence and Atlantic Waters of Canada

UNDER THE DIRECTION OF

DR. JOHAN HJORT,
Head of the Expedition
Director of Fisheries for Norway

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