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* Publication was delayed through the two authors being away on war service.

LIST OF PERSONNEL OF THE DEPARTMENT OF OCEANOGRAPHY, UNIVERSITY COLLEGE OF HULL, 1931–1942

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(In 1942, on being appointed Regius Professor of Natural History in the University of Aberdeen, he was made Honorary Director of Oceanographical Investigations at Hull, and Dr. C. E. Lucas became Head of the Department, now separated from that of Zoology as a special research department.)

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(Officer in charge of the Leith Laboratory since its foundation in1937, and became Head of Department in 1942 ; see note above.)

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J. Scrivener, 1935–†

F. H. Dewing, 1937–§

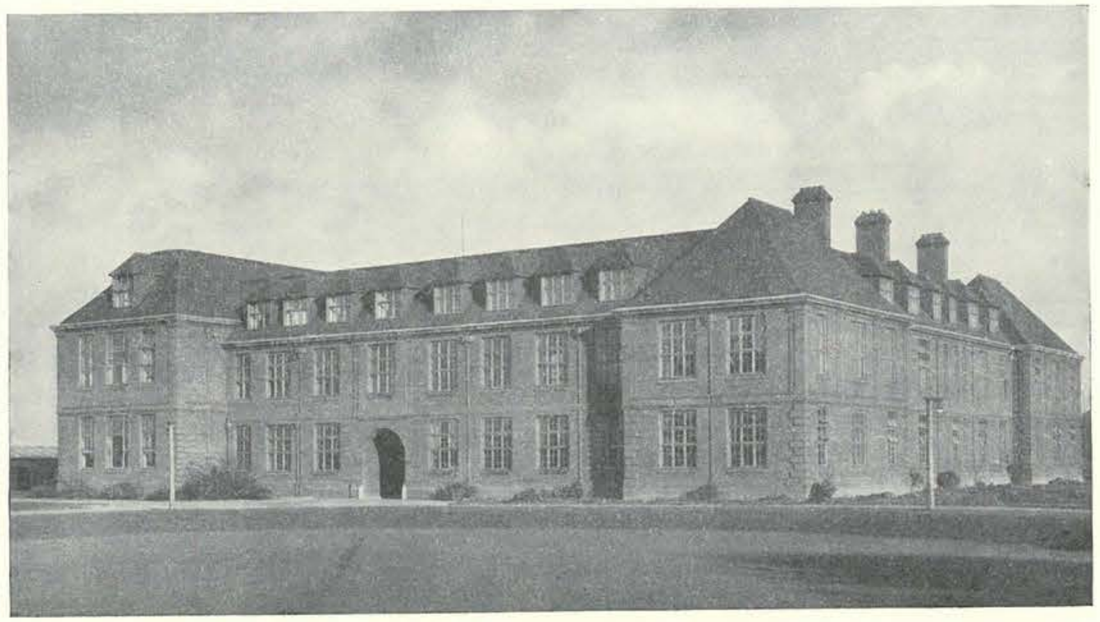
Laboratory Boys :

A. Robinson, 1931–35†

R. R. Warriner, 1935–41†

* Now engaged in scientific war research.
† Now serving in H.M. Forces.
‡ Was serving in H.M. Forces, but invalided out.
§ Now in war-time industry.

Names in italics indicate those members of Staff who have left the service of the Department.



The Science Building, University College of Hull.

PREFACE

The ' Hull Bulletins of Marine Ecology ' are reports on investigations carried out by the Department of Oceanography in the University College of Hull. The College is supported in this work by grants from His Majesty's Treasury, made on the recommendation of the Development Commissioners, and from the Leverhulme Trustees, the Hull Fishing Vessel Owners' Association and the Fishmongers' Company (see acknowledgments in ' Bulletin ' No. 1, p. 53).

The researches are being carried out in close co-operation with the Ministry of Agriculture and Fisheries and the Fisheries Division, Scottish Home Department (late Fishery Board for Scotland). They are not intended to be isolated investigations ; it is hoped that they will be of service to the Fishery Departments, fitting in with their various research programmes and linking up with the general investigations of the International Council for the Exploration of the Sea. In order to maintain a close liaison a Joint Advisory Board, consisting of Dr. E. S. Russell, O.B.E., Director of Fishery Investigations, Ministry of Agriculture and Fisheries, Dr. R. S. Clark, Scientific Superintendent, Fisheries Division, Scottish Home Department, and Professor A. C. Hardy, was set up at the invitation of the

College in 1936 to advise on the future planning and development of the plankton recorder survey, which at present forms the main part of this Department's programme.

When the College was first planned it was intended that a research department should be established to be of service to the great fishing industry which is so well represented on the Humber at Hull and Grimsby. Oceanographic researches must often appear to members of the industry to be remotely removed from their immediate interests. Since reports such as the present 'Bulletins,' which are intended primarily as contributions to the scientific literature of the subject, will necessarily be too detailed and technical to be read by the layman, each volume will be accompanied by an explanation of its contents: a non-technical account pointing out its bearing on the future welfare of the industry.

The 'Bulletins' are not issued at regular intervals, but new numbers are published from time to time as the work develops. While it is hoped that the researches may be developed in several directions for a long period into the future, no guarantee of their continuation can be given; in the event of their coming to an end, the 'Bulletins' would be completed as a work of two or three volumes describing these particular investigations. Since work has been suspended for the war the future must be still more problematical; but sufficient funds have been put on one side to ensure the completion of at least two volumes. The first three 'Bulletins' were in the press and a further three were in an advanced state of preparation before the actual declaration of war.

Acknowledgments of all the kind help we have received in our work from so many people is given in a special section of 'Bulletin' No. 1. As Editor, I would here like to express our appreciation of the trouble the printers, Messrs. Adlard & Son, Ltd., of the Bartholomew Press, Dorking, have taken in the production of the volume, and of the skill of Miss E. C. Humphreys, who has converted all our pencil charts into the finished drawings of the plates which form so large a part of the book.

EXPLANATION

A non-technical account of the contents of the volume for the general reader, intended to show the bearing of the work upon the future welfare of the fishing industry

BY

A. C. HARDY, D.Sc., F.R.S., *Editor*

Pages vii to xv are an introduction to marine ecology in general.
Pages xvi to xlii describe the work at Hull and its relation to the fisheries.

It is not usual for a scientific journal to give space to what may be termed an essay in "popular science." As a reason I may quote from a lecture given at the University College, Hull, in the autumn of 1929 and published under the title of "Science and the Fishing Industry." In it I regretted that sometimes little interest was taken by the industry in scientific investigations but expressed the view that the blame lay as much with the scientist:

> "The results of these researches are published in 'blue books,' often quite unreadable by the layman. We scientists usually write for our colleagues who are working on similar problems, often working in other countries, and we write in a technical jargon of our own, often with a welter of statistics. Some of the plankton papers published look more like fantastic railway guides than accounts of life in the sea; and even scientists have been known to sigh as they turn their pages. How can we expect the industry to understand and sympathize? I think it would be a great service if the Government or the industry employed a trained person to summarize these papers in plain English. Again, and happily this is becoming more common, the scientist and the industry should come together. They both have their contributions to make to the sum of the knowledge of the sea. The fisherman with his life-long experience has much to tell the scientist."

This is an attempt at such an interpretation of the contents of this volume—a simple statement of what we are driving at. Since it introduces the first of our series, it must also be to some extent a short explanation of marine ecology in general.

Marine Ecology.

To begin with, what do we mean by "ecology"? It is often misunderstood. We may define it as the branch of science which studies the relations between living things, both animals and plants, and their surroundings; these include not only the physical world of air, water or soil, in which they live, but also all the other creatures which live round about them. Thus marine ecology not only deals with the kind of water in which we may expect to find, say, a particular kind of fish—warmer or colder water, coastal or oceanic water—but also deals with the relations between such a fish and a host of other forms of life: its enemies which prey upon it, the rival competitors for its food, and the food itself.

Many people on being given such an explanation would reply, "Surely this 'Ecology' is nothing more than a new-fangled name for what we have always known as Natural History?" No—simple natural history describes natural events as history does; it does not *measure* them as does a science, and we defined Ecology as a branch of science. When a naturalist records that a fish feeds upon various kinds of shrimps, that is a fact of natural history. When, after a prolonged investigation, involving the post-mortem examination of thousands of fish of different ages and at different seasons of the year, he can begin to deal in actual numbers, then he is making a contribution to Ecology: when, for example, he can say that this kind of fish takes ten times as much food in summer as it does in winter, or that its food on an average consists of 60 per cent. of one kind, 20 per cent. of another, and so on; or again that these proportions change with the seasons and with the age of the fish. The little bit of ecology, for instance, which concerns the quantities and kinds of food the herring feeds on in different areas is at present based upon the study of more than 50,000 fish by different workers. Ecology is establishing the relationships between a creature and its surroundings in terms of quantity. We shall see the great advantage of this as the discussion proceeds. It is not just the satisfying of scientific curiosity; it is the building of a framework of measurable fact which will in time be turned to practical ends.

But in singing the praises of modern ecology we must not underestimate the value of the older natural history. The naturalists are the pioneers, the advance guard; they describe the different animals and plants, and how they live. The ecologist follows up with instruments of experiment and various methods of analysis.

Ecology deals with the natural "economy" of the world of life. Let us consider that of the sea in its simplest terms. We have the sunlight shining down into the water and we have all the chemicals essential for plant growth—carbon dioxide and oxygen dissolved into the water from the atmosphere, and the no less important mineral salts derived from the land and spread throughout the sea. All plants need sunlight, so in the upper layers of the water, where the sunlight is strong enough, we find the plants of the open sea. They are not large, like the seaweeds of the shore, but are as a living dust scattered through the water: specks of life in countless myriads, so small that they can be seen only through a microscope. In a shaft of sunlight slanting into a shaded room we have all watched the motes of dust floating in the air, floating because they are so small and light; these tiny plants remain suspended in the water in just the same way, many of them being provided with little spine-like projections like thistle-down. The large seaweeds form a very small part of the vegetation of the sea: they are but a shallow fringe along the coasts.

Feeding upon these tiny floating plants, and also like them scattered through the sea in teeming millions, are little animals. Shrimp-like creatures of many different kinds predominate, mostly varying in size from that of a pin's head to that of a grain of rice, but some are larger. There are hosts of other kinds as well—small worm-like forms, miniature snails with flapping fins to keep them up, little jellyfish, and many more which surprise us with their strange and beautiful shapes when first we see them through the microscope.

All these, *both the animals and the plants*, which are floating and drifting with the flow of tides and ocean currents, are spoken of under the general name of *plankton*. It is a Greek word meaning simply *that which is drifted*. It is useful to have one word to distinguish all this passive drifting life from the creatures, such as fish and whales, which are strong enough to swim and migrate through the moving waters. Actually, when they are very young, the baby fish are strictly speaking part of the plankton, for they too are carried along at the mercy of the currents until they can swim against them.

A simple sketch in Fig. 1 shows the general economy of the sea in diagram form. Figs. 2 and 3 show photographs taken through a microscope of the plant and animal plankton which have been caught by drawing a net of fine silk gauze through the water.

Many fish, such as the herring, sprat and mackerel, feed upon these little plankton animals; so also do the huge whales, which form the object of such an important fishery in the far south (they feed upon slightly larger, but still quite small, prawn-like animals which swarm in the polar seas). Even the fish living on the sea bottom fed on the plankton in their babyhood; it is important to remember this.

From this world of planktonic life, dead and dying material is continually sinking to the bottom; here, on the sea bed, we find a profusion of strange animals equipped with all manner of devices for collecting it. Upon these animals in turn feed voracious crawling creatures. Then all of these, worms, starfish, crab and lobster-like crustaceans, bivalve shellfish and many other less familiar kinds of life, form the food of fish which roam the sea-floor in search of them—the cod, haddock, plaice and the like.

Finally comes Man; catching the herring and mackerel with his fleets of drift nets near the surface, hunting the great whales with explosive harpoons, and sweeping the sea bed with his trawl for the bottom-living fish.

We see how all-important the plankton is. All the life of the sea depends, for its ultimate supply of food, upon the meadows of floating microscopic plants—the plant plankton or *phytoplankton* as the scientist calls it. In the sea, just as on the land, it is the plants which are the producers and the animals the consumers. One animal may feed upon another, which has in turn been feeding upon other animals and so on; but ultimately they are all supported by those which feed upon the plants. The plant alone can live upon the simple mineral chemicals, building itself up and growing by using the energy of sunlight.

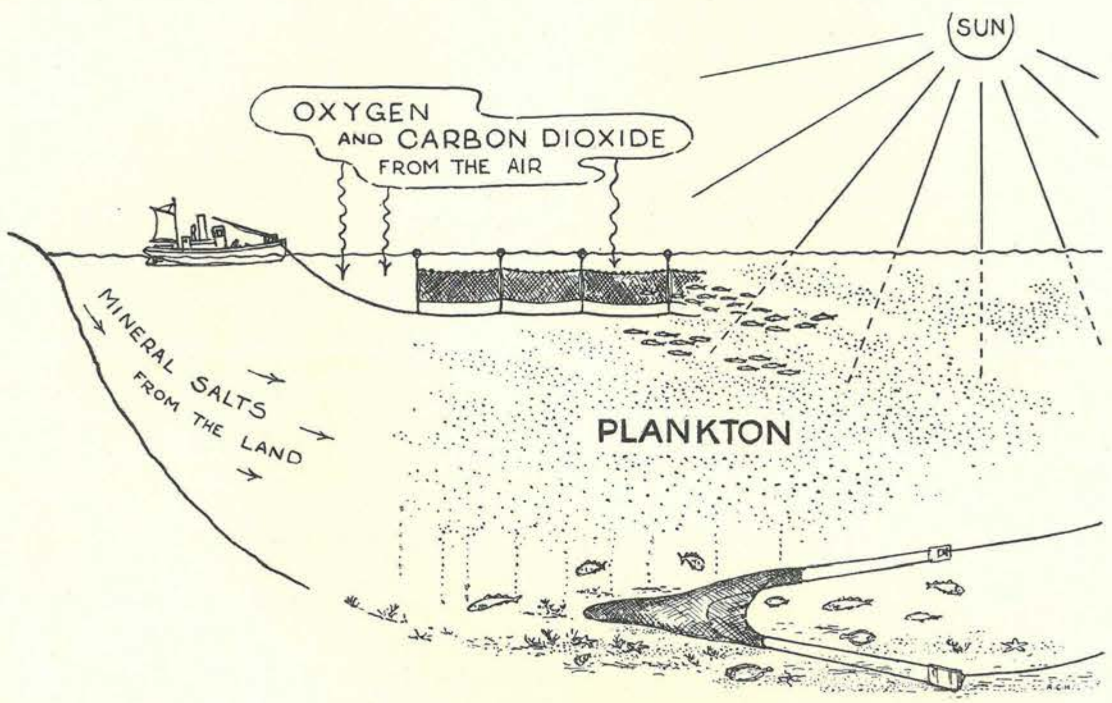


FIG. 1.—Simple sketch of the natural economy of the sea, showing how the fisheries, both drift-net and trawl, are dependent upon the plankton which in turn subsists through the tiny plants upon the chemicals of the sea and the energy of sunlight. Plankton is the food of fish like the herring; it also feeds the animals on the sea-bed which are the food of trawl caught fish.

It is not surprising that at last we are beginning to realize the economic importance of studying these factors which underly this great production of fish and whale oil. The beginning of this century saw the formation of the International Council for the Exploration of the Sea; scientists of government (or government supported) institutions of the different nations of Europe began a series of investigations to form part of one great plan. Not only are they inquiring into the lives of the fish themselves, their life-histories, food and feeding habits, migration, growth, birth-rates and so forth; but, with continually improving equipment, they are studying the distribution of the different plankton forms, the conditions

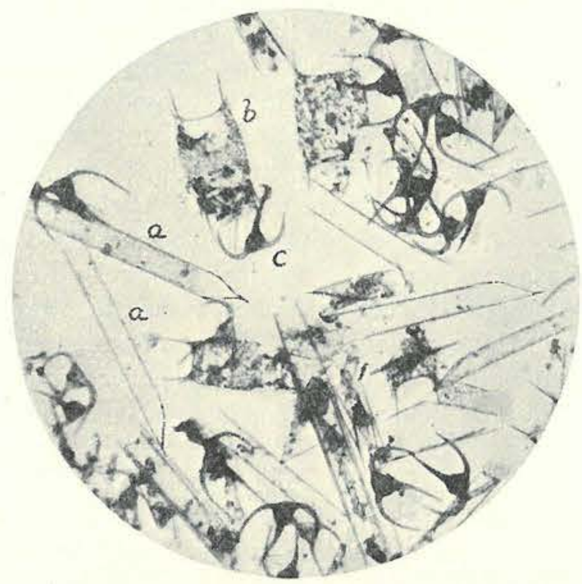


FIG. 2.—Some of the tiny plants (phytoplankton) as seen through a microscope magnifying them some 60 times (*i.e.* × 60 diam.). This sample shows (a) *Rhizosolenia styliformis* and (b) *Biddulphia sinensis*, both, when abundant, having an adverse influence on the herring fisheries (see p. xvi); also (c) *Ceratium* (one of the Dinoflagellates).

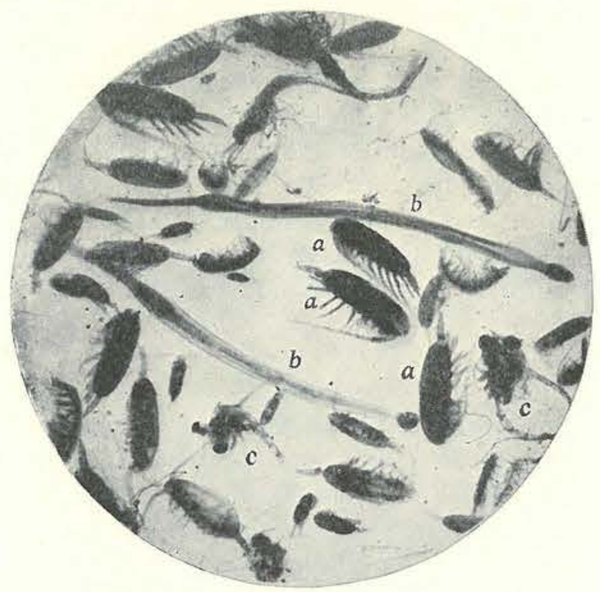


FIG. 3.—A sample of animal plankton (zooplankton) magnified about six times (i.e. × 6 diam.), showing among other forms: (a) *Calanus*, the principal food of the herring, (b) the arrow-worm *Sagitta*, and (c) young planktonic stages of the crab.

under which they live, the flow of ocean currents, the chemistry of the sea and the varying nature of the sea bottom and its life. The aim of all this work, set before it by the International Council, is "*the rational exploitation of the sea.*"

This science of marine ecology is working to provide answers to such questions as the following: Why do fisheries fluctuate—fish sometimes being plentiful, sometimes scarce? Why do fish vary in quality; sometimes there being a shortage of the size most desired by the trade? Can forecasts be made of the future state of a fishery? Can science provide the means to enable fishermen to locate the fish more easily with a saving in time, labour and fuel? Is this or that area being over-fished, and if so what is the best remedy?

Some of these questions have already been answered in part, but progress cannot be rapid. On the land we can watch the harvest in the making; but in the sea all is hidden from us beneath the surface. Everything the scientist must find out about the fish, and the conditions under which they live, he must grope for in an unseen world; and the sea is a big place. He lets down his instruments on ropes and wires—some to take the sea's varying temperature and to collect samples of the water from different regions and depths for chemical analysis, others to measure the amount of light reaching different levels, and others again to record the speed and direction of ocean currents. He sweeps the waters with all kinds of nets to sample the small forms of life which we have seen are so important to the fish. Building up a picture of life in the sea is like putting together a huge jigsaw puzzle made up of tiny pieces, when not only have we a very imperfect idea of the kind of picture which will emerge, but all the pieces to be fitted together are not on the table before us, but somewhere under the table in the darkness. It is a fascinating pursuit, but full of disappointments. Some bits of the puzzle can only be found during a short period of the year; before they can be picked up stormy weather may intervene, so that the instruments cannot be used, and we must wait a whole year before another chance will come. Experiment and observation must be made in the open sea as well as in the shelter of the laboratory.

Yes, progress is slow; but this picture of life in the sea is growing and becoming clearer and clearer. The pioneers have already built up a great body of knowledge, and every year this information and its value will increase.

Early Work.

Marine ecology, this study of life in the sea in terms of measurable relationships, is a very young science. It is a modern development of Oceanography, which began very little earlier as a general descriptive science of the sea. This is not the place to write its history; nevertheless the briefest outline of the more important phases of its development may not be out of place, if for no other reason than that of showing how the work described in this volume is dependent upon the discoveries made by the pioneers of the past and also by our contemporaries working in other institutions. Those who are familiar with this history can skip

and pass at once to the next subsection, which deals with the beginnings of our work at Hull.

There are still nearly thirty years to go before we can celebrate the centenary of the real birth of Oceanography—the sailing of the *Challenger* Expedition in 1872. Before that time there were only very sketchy ideas of the physical conditions in the sea and of its life. It is just a hundred years ago since Johannes Müller first used what we have come to call the tow-net—a small conical net of fine silk gauze or muslin with a little collecting jar at the end of it. By towing it behind a boat he was the first to reveal this teeming world of tiny plants and animals which we call the plankton. About this time, too, Edward Forbes, in addition to being the first naturalist in this country to follow Müller in the use of the tow-net, was carrying out pioneer dredging in the coastal waters, and declaring that it would be impossible for life to exist below some 300 fathoms. He believed there was a great region in the depths entirely devoid of life. This was the generally accepted view until the late 'sixties, when Wyville Thomson and Carpenter on the *Lightning* and *Porcupine* expeditions dredged to depths of over a thousand fathoms and showed, as far as they went, a wealth of life new to science on the ocean floor. It was their exciting discoveries together with the interest being taken in the new projects of submarine cables which led to the dispatch of H.M.S. *Challenger*, under the directorship of Sir Wyville Thomson, on its epoch-making five years' voyage to explore all the oceans of the world.

The end of the last century and the beginning of this was the descriptive period of marine natural history. The results of the *Challenger* Expedition filled more than fifty massive volumes, and a number of other important series of reports were published as other nations followed in sending similar expeditions to explore the depths of the seas and describe their life. The Prince of Monaco was one of the pioneers and patrons of this new science. This period, too, saw the founding of the famous marine stations, the first at Naples, then Plymouth in this country, and Wood's Hole in America; in these laboratories researches into the structure, development, life and habits of marine creatures of all kinds have been continued to the present day.

The eighteen-nineties saw the birth of true ecology when the German naturalist, Victor Hensen, began his studies. It was he who first introduced the term *plankton*. He and his fellow workers at Kiel developed their elaborate painstaking process of estimating the actual numbers of these little specks of life in known quantities of water from different parts of the sea. They attempted to calculate the total productivity of the sea under different conditions. They showed that there were sometimes millions of these living forms in one cubic yard of water. At this time, too, Cleve, the Swedish oceanographer, produced his charts of plankton distribution, showing that different ocean currents carried with them different communities of life.

Then came the investigations of the International Council already referred to—a unique and splendid example of what may be achieved by wide international co-operation. From 1902 to 1908 the research ships of the different nations, each being allotted different parts of the sea, undertook quarterly cruises to investigate the varying abundance of the plankton at many different points scattered over the whole of the waters off the north-west of Europe. Elaborate records were kept of the landings of different kinds of fish at the different ports, and a staff of fish measurers was employed to collect a mass of information as to the sizes of different fishes in different areas. The migrations of fish were discovered by attaching little numbered labels to them, letting them go and offering rewards for information about their recapture. The fish were measured before being released and measured again when recaught, so by this method not only could their movements be studied, but their rates of growth in different parts of the sea. Young fish were marked and transplanted from one part of the sea to another which was richer in food, and their increased growth compared with that of similar fish left behind—the first experiment in the farming of the sea. The spawning grounds were charted, and the drift of the baby fish followed as they hatched out to feed on the plankton and to be carried along by the currents to the regions where they settle down and begin to grow up. In the early days of the century these pioneer fishery investigations were developing in a number of countries, particularly under the leadership of C. G. J. Petersen in Denmark, Johan Hjort in Norway, and Walter Garstang in this country. At the same time our knowledge of the changing areas of warmer and colder waters, of more salt or less salt water, was advancing with the working out of the complex systems of ocean currents. Petersen began his work of estimating the quantities of animal life on the sea bed by using a special "grab," which could bring up measured samples of the sand or gravel, together with all the animals in it. All these investigations have been continued to the present day. The great body of knowledge that has been built up about the lives of fish, such as the plaice, cod, haddock, herring and hake, cannot be summarized here, and we can but mention the amount of work that has been done on the subject of mesh regulation and the problem of over-fishing generally.[1] The object here is just to place the investigations about to be described against the general background of work that has been developing in this science of the sea.

Our research deals essentially with the plankton, and a little more must be said about the course of plankton investigations in particular. The earlier work was descriptive; the quarterly cruises made under the International Council told us what kinds of planktonic animals and plants were usually found in different areas in the different seasons. Many special plankton cruises have been made in relation to fisheries work, charting the distribution of the plankton in great detail by using Hensen's methods of estimating the actual numbers found in a definite body of water filtered by nets of a known size. The research ship steams backwards and forwards across the sea on definite lines, stopping at intervals, perhaps 20 miles apart, to take its samples.

[1] See the recent books: 'The Overfishing Problem,' by E. S. Russell (1942), and 'The Fish Gate,' by Michael Graham (1943).

Many such cruises have also been made to estimate the quantities and distribution of fish eggs and young fish. The discovery that nearly all bottom-living fish lay floating eggs was one of the first economic contributions of marine research. Towards the end of last century, when the trawl was increasing in size, there was an outcry by certain sections of the industry demanding a limit to the size of the trawl, which they thought must be destroying the spawn on the sea bed. There was a Royal Commission to investigate the matter. But in the meantime the tow-net had given the answer: G. O. Sars, the great Norwegian naturalist, had shown that the cod and other bottom-living fish lay floating eggs, so that these fears, like the eggs, were groundless. The eggs float as little spheres, hatching out into baby fish, which live for an important period of their life as part of the plankton. The herring, which spends so much of its adult life feeding on plankton near the surface, is curiously an exception in laying its eggs on the sea bed, although its young come up into the plankton as soon as they are hatched.

Another series of investigations was begun in 1907 by the late Sir William Herdman. Week after week, year by year, he had tow-nettings taken across the bay at Port Erin, Isle of Man, to study the seasonal changes in the plankton, and to compare the amount found in one year with that found in another. They were continued until 1920, and gave a great deal of information about the succession of different kinds of plankton throughout the year. The plankton is not only made up of those forms which spend all their life in this drifting, floating state; in addition there are numbers of young forms, *larvae* as they are called by scientists, of animals such as starfish, sea urchins, worms and shellfish, which live on the sea bottom. They send up these young floating larvae to spread their kind far and wide over the sea.[1] Such investigations as these show how at various seasons larvae of different kinds come into the plankton and make up an important part of it.

This was the trend of plankton research up to the last war—mainly a descriptive phase. Then came a new line of investigation at the coastal laboratories, as at Plymouth and Millport in this country, into the physical and chemical conditions of the sea that control the plankton production. This revealed the part played by sunlight and the all-important salts, the phosphates and nitrates, in the growth of the little plants, and the effect of plankton animals keeping them in check by grazing them down. This work was making great advances when it was interrupted by the present conflict.

During this inter-war period, at the other end of the world, began the *Discovery* investigations carried out by the Colonial Office on behalf of the Falkland Islands Government; they relate to the same fundamental problems as those studied by the International Council, but are concerned directly with the ecological factors underlying the great whale fisheries in Antarctic waters. It was whilst serving on the first of this series of *Discovery* Expeditions under the leadership of Dr. Stanley Kemp, F.R.S., that I experimented with the first continuous plankton

[1] Some of these are shown in Fig. 14, p. xli.

recorder. The work presently to be described owes much to his kind encouragement in those early days, when the machine was being developed and so often went wrong.

The Beginning of Work at Hull and its First Practical Outcome.

We must now come to what this volume is about. Our work at Hull is at present concerned with the plankton and its influence on the fisheries. Its most immediate application is to the herring side of the industry, but we believe in time it will also contribute to a better understanding of trawl fishery problems. It is the direct outcome of work begun when I was serving on the scientific staff of the Fisheries Laboratory of the Ministry of Agriculture and Fisheries at Lowestoft under the directorship of Dr. E. S. Russell. I like to feel that it is still part of that work. As stated in the Preface, our researches are carried out in close co-operation with the Fishery Departments of both the Ministry and the Scottish Home Department; they are not intended to be isolated investigations, but to fit in with their research programmes and link up with the work of the International Council.

At Lowestoft in 1921 I began to work on the ecology of the herring—its food and its relations to the plankton in general. It was a poor autumn herring season that year; the fish were not being taken in their usual quantities. When out on a herring drifter I took plankton samples with a tow-net and found the water was thick with one of the small plants—one known to science by the long name *Rhizosolenia*, which I must mention because I want to refer to it again and it has no other name. It is shown in Fig. 2. So abundant was it that the meshes of the fine silk net were clogged with it. The skipper said they called this water "weedy water," or sometimes "Dutchman's baccy juice," because the nets came up slimy and brown and he said they were unlikely to catch fish in it.

I then started experimenting with a little instrument I have called the plankton indicator, a little torpedo-shaped device, hollow, and open at each end to allow the water to flow through it. It was designed to be taken down by a weighted rope when towed behind a drifter. Before being thrown out, a small gauze disc was placed across the water tunnel so that it sieved out the plankton as it was towed along. Fishermen were asked to use this instrument to take a sample of the plankton where they fished, and then to wrap up the disc after they had used it and drop it into a tin containing the preservative formalin. Then, after they had shot their nets and hauled them again, they filled in a printed label giving the date, position, and the number of herring caught. The idea was to get a series of plankton samples together with records of the catch of fish, so as to obtain definite experimental evidence as to whether the fisherman's belief in the poor catches to be expected in this so-called "weedy water" was actually based on fact or not. It was first tried out in the autumn of 1922, but only twelve records were obtained with it that season. The number was very low, but the results were highly significant. In six of those twelve hauls the indicator discs were quite clean; in the other six they were coloured a distinct green by the presence of quantities of the tiny plants, this time not *Rhizosolenia*, but another little plant called *Phaeocystis*. The six herring catches corresponding to the clean discs were 15, 15, 17, 30, 30 and 45 crans (a cran is a measure for roughly a thousand fish). The catches corresponding to the six green discs were ½, 2, 3, 3, 3 and 6 crans. We see that all the catches which were in *clear* water were from 15 to 45 crans, with an *average of 25*, whereas none of the catches with a green disc was greater than *6* crans, with an *average of 3*. The odds against such a clear-cut result being just due to chance are millions to one.

It was not until I had been working for some little time on these lines that I came across the very interesting observations which Mr. Pearcey made in 1884 and recorded in a paper in the 'Proceedings of the Royal Physical Society of Edinburgh' for 1885. He made a voyage in one of the old sailing luggers from Leith round the Shetland Isles, taking with him a tow-net. He, too, was studying the plankton in relation to the herring, sixty years ago, and it is surprising that his results were not better known to fishery investigators. He came across dense zones of the little plants, so thick, he writes, "that little heaps of the algae were formed on the deck as it dropped from the nets," and in each of these areas he caught hardly any herring. In the clear regions between, the herring catches were high.

It seemed likely that the dense patches of plant-plankton, produced in the autumn in the southern North Sea, might play an important part in the success or failure of the East Anglian herring fisheries, which extend from the end of September to the beginning of December. With Mr. Savage, of the Ministry of Fisheries, I therefore started in 1922 a series of annual cruises in the research ship *George Bligh* to chart the extent of such patches during each autumn fishery. When I left to join the first of the present series of *Discovery* expeditions to investigate the biology of the whales in the Antarctic, Mr. Savage continued these autumn cruises. The patches were shown to vary enormously in both size and position from year to year. Sometimes there were patches of *Rhizosolenia*, sometimes of *Phaeocystis*, and at other times yet another tiny plant, *Biddulphia*, or sometimes areas of *Rhizosolenia* and *Biddulphia* partly mixing one with the other. Considerable evidence was obtained that when these patches occurred near to the main shoaling grounds the arrival of the herring there was delayed, or sometimes the fish were deflected from the normal grounds.

On returning from the Antarctic I was appointed Professor of Zoology at our new University College of Hull when it opened in 1928. From the beginning it was intended that a Fishery Research Department should be developed, and in 1931 my Department was enlarged to that of Zoology and Oceanography. The new laboratories were opened by the late Sir John D. Marsden, Bart., then President of the British Trawlers' Federation. The appointment of the research staff (see p. iv) and the financing of the Department are described in 'Bulletin' No. 1.

We had two programmes of work. The first was completed in 1934 and described in reports by Drs. Lucas, Henderson and Fraser and myself, published in 1936 in the 'Journal of the Marine Biological Association,' vol. xxi, pp. 147–291; the second and larger programme is the subject of the present series of 'Bulletins.' The first has a distinct bearing upon the second, so that a short account of it must be given; all details will be found in the reports just referred to.

First I was anxious to try out again the small plankton indicator which I had begun to use at Lowestoft. In addition to its trial in the autumn fishery, when the unfavourable *plant* plankton is common, I had made fairly extensive trials of it in the summer Shields fishery in an attempt to establish whether or not any relation

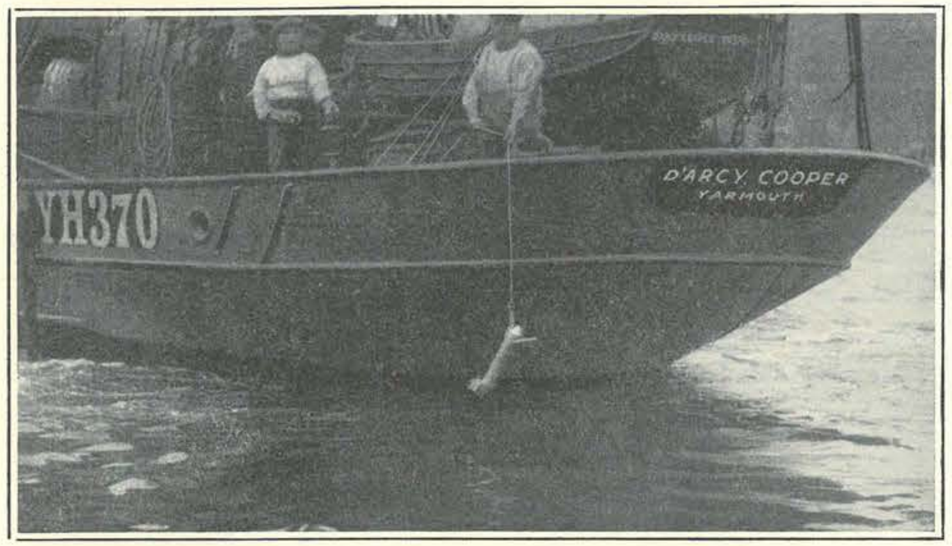


FIG. 4.—The Plankton Indicator in use on a drifter; it is normally used without stopping the vessel (see also more detailed illustration on p. 240).

could be found between the catches of the feeding shoals and the abundance of the *animal plankton* which was their food. Plankton is patchy; it is known often to vary enormously in quantity and kind at points even quite short distances apart. No relation was then established, but I realized that the instrument, while efficient in the capture of the plant plankton, was by no means so well adapted to the collection of the animal forms. Very often the weight failed to take it down properly below the surface. We therefore started the experiments all over again with a newly-designed indicator on the lines of a paravane, fitted with diving planes and stabilizing tail, so that it automatically dived below the surface and took up a position at about the depth that the herring nets are used. The instrument is shown in Fig. 4 (see also p. 240). The experiments were carried out on a large scale; we received the willing help of 32 drifter skippers, and in

addition officers of the Royal Navy in command of Fishery Protection gunboats and commanding officers of fishery cruisers of the Fishery Board for Scotland kindly took records alongside drifters fishing.

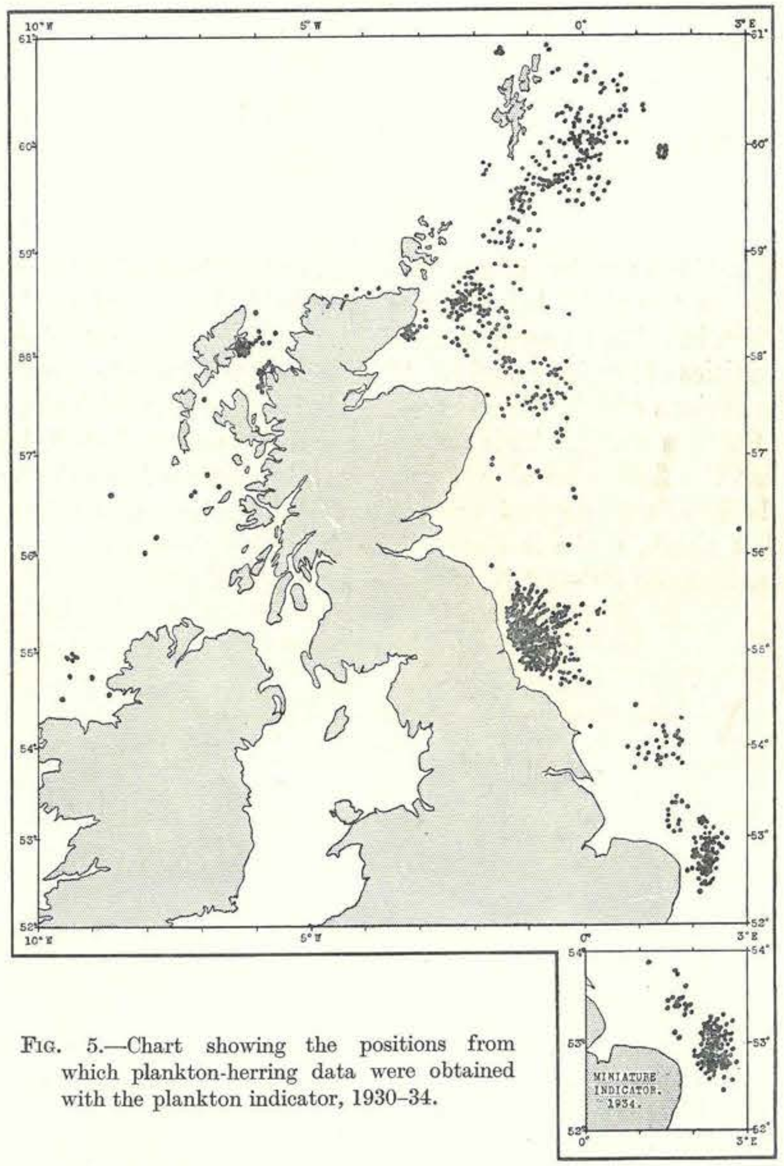


FIG. 5.—Chart showing the positions from which plankton-herring data were obtained with the plankton indicator, 1930–34.

The same system of providing drifter skippers with labels and tins of formalin, as described for the earlier experiment, was adopted. They were asked to use the instrument just before they reached the position at which they intended to shoot their nets, and to tow it for one mile up to their position for fishing. Over fourteen hundred records were obtained: records of catches of fish with corresponding samples of plankton for analysis. Fig. 5 shows the positions in which they were taken. We divided the areas of fishing into regions separated by degrees of latitude and dealt with the samples from each region in half-monthly periods. We now examined the samples to see if there was any connection between the numbers of herring caught and the numbers of the special little animals, which they prefer for food, found in the sea at the same time and place. Earlier work had shown that the herring's favourite food is the little shrimp-like animal called *Calanus* (see Fig. 3). Having analysed the plankton samples we wrote down the number of Calanus found in each and then arranged them in ascending order from the lowest to the highest numbers, and we put them down in two columns, that on the left being half the number of samples and having those with the *lower* Calanus numbers, that on the right being the other half, having the *higher* Calanus numbers. Then in columns against the Calanus figures we wrote down the corresponding quantities of herring caught. Thus we can total up the number of herring caught in the regions of *poor* Calanus water and compare it with the total caught in the *richer* Calanus water. This may appear a little complicated, but it is most important that the fisherman should understand what we have done; his future benefit, we believe, will depend upon his understanding this relationship. An example will, I think, make it clear. The following figures are for the Eastern Scottish Area, latitude 59°–60° N., for the second half of July, 1932:

	In poorer Calanus water.		In richer Calanus water.	
	Calanus numbers.	Herring (in crans).	Calanus numbers.	Herring (in crans).
	1	0	120	36
	1	24	125	47
	20	20	165	2
	25	4¾	180	9½
	40	0	204	61
	42	4½	245	37½
	68	¾	280	63
	88	72	330	59½
	96	30	332	10¾
	101	1	480	19
	105	0	1420	0
Totals	587	157	3881	345¼
Averages	53	14¼	353	31½

We see that while some good herring catches were made in the poorer Calanus water, and some poor catches were made in the richer Calanus water, the *total catch* in the richer Calanus water was *more than double* that in the poorer water: an average catch of 31½ crans as against 14¼ crans. This example is shown in diagram form in Fig. 6. For the eastern Scottish fisheries, from the Shetlands southwards, the catches in the richer Calanus water exceeded those in the poorer Calanus water for fourteen out of eighteen such periods of experiment. The increased catch in the richer Calanus water was usually very considerable.

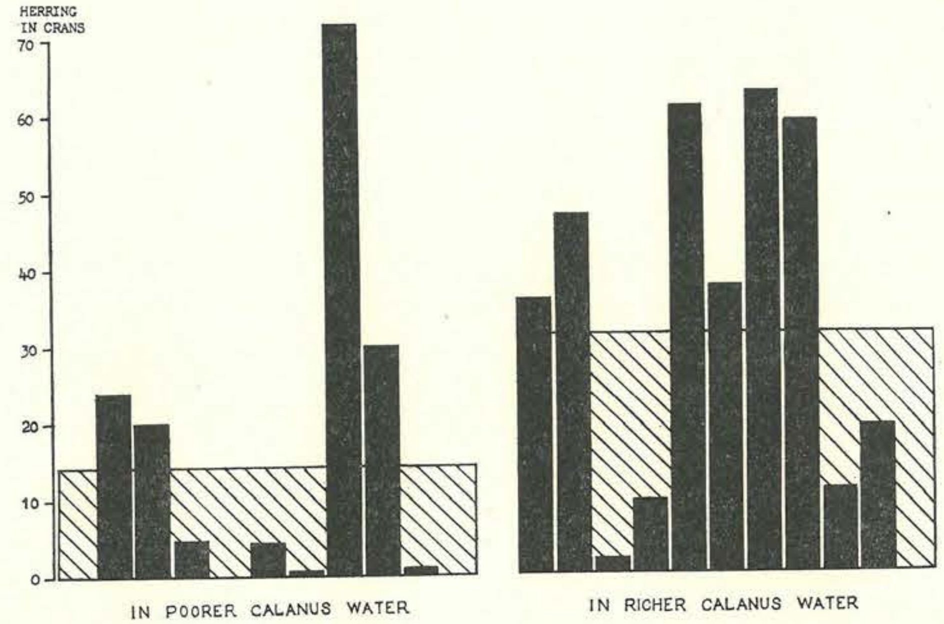


FIG. 6.—A graphical comparison of the individual herring catches (black columns) and the average catches (shaded blocks) in the poorer and richer *Calanus* water off the north-east of Scotland (59°–60° N.) in the second half of July, 1932.

We then wanted to find out what would be the advantage if a drifter skipper actually used the indicator to guide him towards the richer feeding-grounds. In our example the total catch of herring during the period was 502¼ crans (157 plus 345¼): that is what the skipper got by fishing sometimes in poorer and sometimes in richer Calanus water. If he used the indicator to test the water as he steamed out from port, taking samples every few miles and fishing at the place where he got the most Calanus, he should easily have come into water that was distinctly above the average Calanus content *each* time he fished, instead of only sometimes. Now, if all the catches had been in the richer Calanus water instead of only half, he should have caught 345¼ crans twice over, which comes to 690½ crans, instead of 345¼ in rich and 157 in poor water, which was only 502¼ crans; he would have got a gain of 188¼ crans, or 37½ per cent. This is of course only an *estimated* gain, and reliance must not be placed on just one such example ; but if we take the whole series of eighteen periods, including the four in which the catch of herrings was actually less in the richer Calanus water, we get an average gain for the whole of the eastern Scottish fisheries of $24\frac{1}{2}$ per cent. This means that by a regular use of the instrument (although it would fail on occasions because of irregularities in the movements of the fish, which are sometimes swimming in search of food, and sometimes collecting for spawning), the fishermen would increase their average yield per boat by nearly 25 per cent. In the Shields fisheries the results were not so good, but still they gave an average gain of 12·7 per cent. or 21·2 per cent. if we omit the results of 1931, which were exceptional for reasons which we now understand.[1] We also had abundant evidence to confirm the opposite relation between the herring and dense zones of plant plankton, which would give the fishermen a clear indication by a green coloured disc ; they should always steer clear of such water. Without the indicator they do not usually know they are in this " weedy water " until they have hauled their nets and found them all slimy —by that time their night's fishing has been wasted. The instrument has thus become a commercial possibility. A green indication is seen at a glance (Fig. 7) ; but to see the Calanus the fisherman drops the disc into a little frame carrying a lens powerful enough to give a good magnification (Fig. 8). He cannot mistake Calanus for anything else : photographs and discs with preserved Calanus on them are provided for comparison ; he soon learns to distinguish it (Fig. 9).

Several of the more progressive skippers have taken it up and been very pleased with the results. As examples of just how it works in practice I will quote from two accounts written by drifter skippers and published in *The Fishing News* (24th February and 16th June, 1934) ; the first is by Mr. Ronald Balls, master of the S.D. *Violet and Rose*, YH757 :

" Calanus is very easily recognized on the disc, and any boats that could do most of their fishing in water containing it could certainly expect a considerable increase in their catches. . . .

" First of all, it is most important that the Indicator should be used as consistently as possible over at least a whole summer season for a real test of its usefulness, because, although there are cases where when good feed is found an excellent catch results, this is not always the case, and occasionally the opposite happens. It is only by continuous use over a period of weeks that the benefits of the instrument become apparent.

" Nevertheless, I have found during the summer that at any time when a small belt of Calanus has been found, with the surrounding waters devoid of feed, a superior catch has always been the result of shooting in the feed. Naturally, one cannot expect this to happen very often, and when Calanus is very widespread choice of position for fishing is unnecessary unless, as sometimes happens, there are also patches of unfavourable plankton about, when the Indicator can be used in its other capacity.

" As an illustration of this I can quote from my own experience on Monday, July 10, of last year. On this day, steering north by east from Rattray Point, we found Calanus fairly

[1] Those specially interested will find these reasons given on p. xl of this " Explanation " in an account of the work in ' Bulletin ' No. 5.

FIG. 7.—Examining the disc for a green (plant plankton) indication.

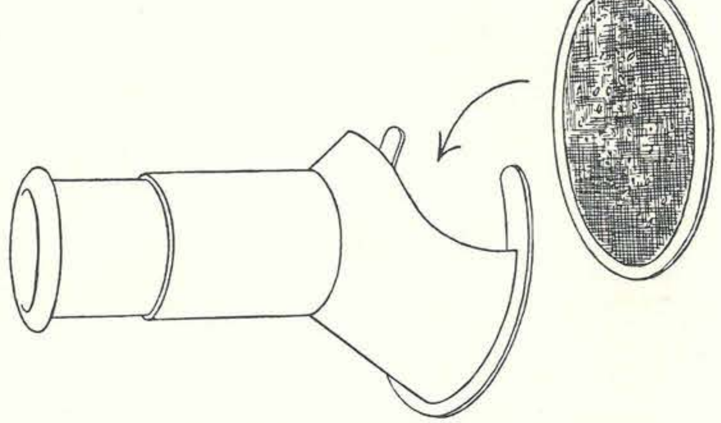


FIG. 8.—The lens holder used for viewing the disc for *Calanus* indications ; it is simply held up to the light.

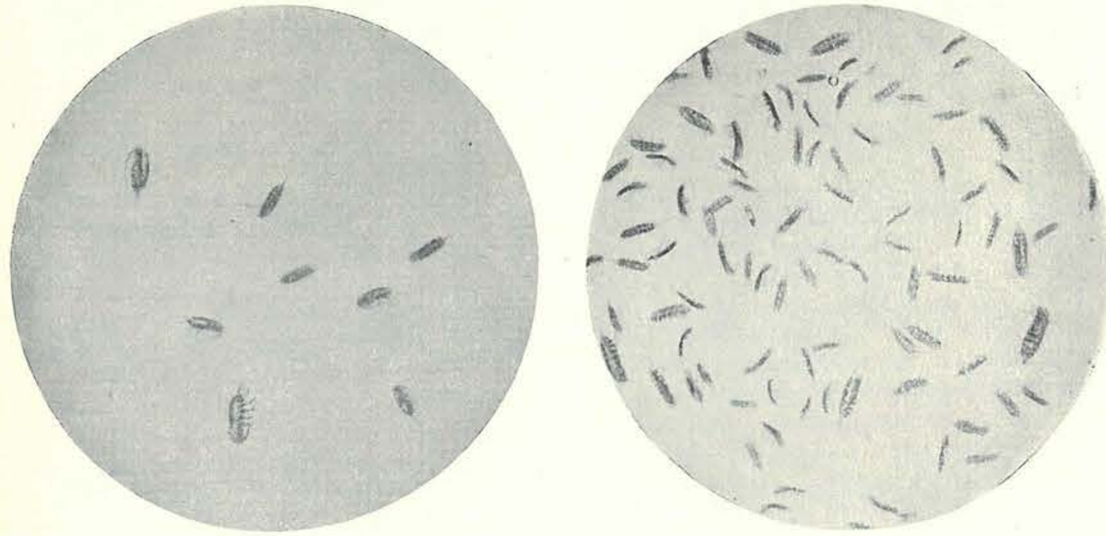


FIG. 9.—Poor and good *Calanus* discs as seen through the examination lens.

good from 30 miles onward to 50 miles, but although each disc we towed was seemingly good enough to shoot on, I noticed that every one was clogged with a fine jelly-like substance. Continuing on our course, at 54 miles we obtained a good disc of Calanus, which was also quite free from the jelly; in fact, the remarkable liveliness of the Calanus here was noticeable after their lifeless condition when amongst the jelly on the earlier discs.

"Thus, although we had found good feed for over 20 miles, there was also the unfavourable organism present until we were 54 miles from Rattray. We shot exactly where we had towed this good disc, and our catch of 70 crans next morning was well above the average at Peterhead or Fraserburgh.

"I have also found that when there is no Calanus about but only wide patches of weedy or unfavourable water, the same procedure of steaming until clean water is found usually has a beneficial result. . . .

"From May 1 to July 30 we shot 69 times—40 shots were in water with little or no Calanus, and the average catch for these was 3 crans; 29 shots were in water containing good or fairly good Calanus, and the average for these 29 shots was 9·5 crans. Thus, when Calanus was present there was an increase of 216% in the average catch."

The second account is by Mr. H. K. George, master of the S.D. *Ocean Spray*, YH264:

"I feel sure that other skippers amongst your readers will be interested in hearing of further practical results obtained with the Indicator, as if properly worked and studied it will greatly assist a skipper in finding the best fishing grounds in the spring and summer fishing. As examples I will quote two instances which stand out vividly in my mind.

"Herrings were very scarce and dear at Shields on this particular day, and the only boat to have any was the motor boat *Twilight* with 12 crans from N.E. by N. 20 miles, so that was where we started for that day. After we had steamed 8 miles I put the Indicator over and pulled it up every mile until we were 13 miles without seeing the slightest signs of Calanus.

"Between 13 and 14 miles there were a few on the disc; from 14 to 15 miles it was a very good disc; from 15 to 16 miles it was only moderate again, and from then on to where the *Twilight* was shooting her nets at 20 miles there was nothing on the disc, so we steamed back to where we found the Calanus, and we found it again.

"We shot our nets and got 16 crans of herrings, which was a good night's work, and not one of the other boats got any, they all being three miles and more to the north of us.

"The next instance was one day we had 40 crans from 22 miles E.N.E. and steaming off that day I put the Indicator over and the best disc I got was between 17 and 18 miles, but I carried on the 22 miles and could not find any Calanus, so I steamed back to where I got the good disc and found it again.

"The same thing happened as before, and with that and many other instances when it happened it gave me complete confidence, though I don't pretend to think it is infallible, as at times we have found feed and got very few herrings, and at others we have not found any feed and yet we have got a few herrings, though not many.

"I also noticed that the week when herrings were plentiful at Shields the sea where the herrings were was full of Calanus, but it didn't last long in so widespread a nature, neither did the herrings. I have had several chats with other skippers who I know take a great interest in this work, and I am sure we were unanimous on the point that the skipper who has an Indicator and takes interest in it will be streets ahead of them who just trust to pot luck.

"Some of the older skippers don't believe in it though I think in a very short time they will have to admit."

Confirmation of our results comes also from Iceland, where Mr. A. Fridriksson tried out one of our indicators with success and published his results in 1935.[1]

In spite of these favourable reports and our published statistics, it had not come into general use by the beginning of the war. No doubt it will in time—but it is not easy to convince a skipper who does not keep careful records that it is really benefiting him. It does *not* work *every time*. In the period tabulated, which is typical, we see, as already pointed out, a number of good herring catches in the poor Calanus water and a number of poor catches in the good Calanus water; it is only when we take the *average* of a number of occasions that the benefit is realized. In our example we see that in the very best Calanus water no herring were taken at all. A skipper getting such a result might well say, "This is a fraud! Its no use at all," or more likely something stronger, and give it up. Again, if he realizes that he *has* increased his catch on an average by some 25 per cent. since he took up using the indicator, is he convinced that this is due to the extra trouble he has taken in using it and not just luck? Often he will get a spell of good luck and a spell of bad luck; and the use of the indicator does entail a certain amount of extra trouble. It is easier to trust to luck than to follow science; but there is no doubt from our published figures which really pays. It will take time and a good deal of instruction to get the indicator into regular use. The development of our second and larger programme took up all our time and energy, so that we were not able to do this educational work in the use of the indicator; it is a task we must undertake after the war.

The Plankton Recorder Survey.

The second and, ultimately we believe, more important line of work which has occupied us and which forms the subject of this volume has been the study of the large scale changes in the abundance and distribution of the plankton over wide stretches of the North Sea month by month and year by year. The plankton varies from season to season and in no two years is it alike. The strength and course of ocean currents alter, as do the climatic and water conditions which may favour or discourage the growth and multiplication of this or that kind of little animal or plant.

We are studying these major planktonic changes over wide areas, much as the weather expert studies the changes in the distribution of centres of high and low pressure in the atmosphere with a view to forecasting; but we are dealing with changing centres of *high and low production of plankton*—and of plankton of many different kinds. We are building up series of monthly charts, and just as weather maps could never be constructed from observations made at a single station, even if that observatory moved about, so such charts of the *changing plankton* over wide areas cannot be constructed from the observations made by a single research ship. We are employing other means: *automatic* sampling machines which take

[1] 'Fiskirannsoknir, Fiskifelags Islands,' iv, pp. 50 and 67. Reykjavik, 1935.

continuous records of the plankton as they are towed at a standard depth behind steamships on regular lines across the area to be studied. We call these machines continuous plankton recorders; we will see how they work a little later. It is our intention to attempt to relate these planktonic changes, on the one hand, to the changing climatic and water conditions which are their cause, and, on the other, to the changes in the fortunes of the fisheries, both herring and trawl fisheries, which are their effect. It is hoped that, when we have advanced beyond the period of initial trial and experiment, we may gradually build up sufficient evidence of cause and effect to render forecasts possible. Apart from forecasts, an increased knowledge of the relationships of the changing plankton to the lives of fish will be a contribution towards the solution of a number of fishery problems.

How can all this benefit the fisheries? The industry is divided into its two great and distinct sections with their different interests: the trawl fisheries for bottom-living "white fish" and the drift-net fisheries for herring. Because the relation of this survey to the herring fisheries is the more direct, we will deal with that side of the industry first.

We have seen, from our indicator work already described, what a marked effect the changes in the plankton may have upon the successful fishing of individual drifters. The importance of this indicator work lies not only in its providing a practical guide to the fisherman in his daily working; by showing how the movements of the herring are closely linked up with the distribution of the plankton, it also shows how dependent the fishery as a whole must be on the changes which are taking place in the plankton over wide areas from season to season. It is for this reason that we have dealt at some length with the results of this earlier work. The main areas of food may sometimes be against the coast, and at other times many miles away from it; again, sometimes the path of the shoaling herring may be blocked by dense areas of the plant plankton, which they avoid.

In industry it is not always possible to assist the interests of the individual and at the same time benefit the industry as a whole; but here is a case in point. The drifters tend to work together in a fleet over a particular area; they work to supply a market which is largely concerned with cured fish for export, not fish for immediate consumption. It would be of great value to the fleet to know whether, during the coming month, one area on the whole was likely to be more profitable than another area. It is just such information that we expect the plankton recorder survey will in time be able to provide. It will not give detailed information for the day-to-day fishing of individual boats; that is the work of the small indicator. While one large area will on the whole be more favourable for the herring than another for some particular period, *within* that area the plankton is usually by no means evenly spread; the Calanus they seek and the plant plankton they avoid may differ markedly in quantity at points only a few miles apart. *Both recorder and indicator may be of service together.*

Now let us turn to the trawl fisheries. Do the major planktonic changes over the wider areas have an influence upon them as well? We have seen that the baby fry of the bottom-living trawl-caught fish live for a time in the upper layers of water, feeding upon the plankton; they are themselves actually part of the plankton, drifting with the currents of the sea. An important part of fishery research, not mentioned in our earlier brief review, is recording the age of fish; this is usually done by examining their scales, which are seen to have rings on them like those found in a cross-section of the trunk of a tree, each ring, like that in a tree, indicating a year's growth. Thus the age of cod, haddock and herring can be read; that of the plaice is read in the same way but from the "ear stones" (otoliths), which have similar rings. The stocks of fish have been studied in detail by many different investigators so as to reveal the numbers of fish of different ages making up a population at any particular time. Such a study may show that for one kind of fish there may in one year be, let us say, far more of those which are four years old than of those which are three or five years old; this tells us that the brood hatched out four years before was far more successful than that of its preceding or following year. Work of this kind, carried out from the laboratory of the Fishery Board for Scotland at Aberdeen, revealed marked fluctuations in the haddock stock. By *fluctuations* we mean differences in the numbers from year to year; in some years there were very many more haddock than in others. Dr. Harold Thompson found that these corresponded closely with the fluctuations in the numbers of baby haddock found in earlier years by the sampling nets of the research ship. He showed that it is now possible to forecast to the industry a year or two in advance the relative success or failure of the Scottish haddock fisheries. All the evidence pointed, as Dr. Thompson showed, to these fluctuations in the numbers of baby fish being due, not usually to differences in the quantities of eggs spawned, but to the varying mortality and survival of the young fish in the early stages of their development in different years. This varying death-rate of young fish is most likely due to there being varying quantities of *suitable planktonic food* available in different years; there may be either differences in actual plankton production—and we know these may be very great—or else changes in its distribution brought about by changes in the strength and direction of ocean currents, such as the varying inflow of Atlantic water into the northern North Sea. It is clear that a study of the changing plankton has in this way a direct and important bearing on the trawl fisheries. This is not just an interesting fact; it is, as we shall see, one which can be of economic value to the industry.

The tiny fish fry, both the young of the bottom-living trawl-caught fish and of the herring, are sampled by our continuous plankton recorders, as well as the plankton amongst which they are living. We have just seen how the strength of future stocks of fish can be related to the success or failure of the young broods. A report by Dr. Stubbings, dealing with the fish eggs and young fish taken in our survey, will be published in our second volume. This side of the work is only in its infancy; but already striking differences in the number of young fish are seen in different years. Our machines are designed so that they can easily be adjusted to capture more of the young fish (and larger plankton animals), and less of the smaller forms, than they do at present. The results of these first surveys clearly show the desirability of making additional runs, with the recorders so adjusted, at just those periods of the year when a knowledge of the coming broods is particularly important to the fisheries. If the industry knows in advance that the fishing of a certain stock of fish is likely to be less profitable than usual in the coming year, *companies will have the opportunity of diverting some of their vessels to other regions until such time when they will again know in advance that this stock is improving in strength.*

Again, the animal life on the sea bed is, as we have seen, fed by the supply of plankton from above; we may therefore expect areas of rich plankton to give rise a little later to areas of more abundant life below—food for trawl-caught fish. Changes in the distribution of these fish—and we know that their concentrations do change considerably quite apart from their normal yearly migrations—may in time be shown to follow *earlier* changes in the distribution and abundance of the plankton. Those of their irregular movements which are not linked with the changing abundance of their food will most likely be related to changes in the water conditions—changes in the extent and position of regions of oceanic or coastal waters and their mixture. Such movements of different water masses may often be shown by the changes in the areas of distribution of particular plankton animals which are characteristic of such waters. Examples of the plankton being used to show water movement will be given in our second volume.

The possibility just outlined is clearly more remote than the forecasting of the future state of a stock of fish from the numbers of fry in the plankton in preceding years—a forecast which Dr. Thompson, as we have seen, has already shown to be feasible in the case of the haddock. It is not only more remote, but it may even be undesirable under present conditions. Members of the trawling community compete for a market for fresh fish, so the industry is much more individualistic than the herring drift-net fishery; they are in truth rival hunters, and the more enterprising are the more successful. If we should *in time* be able to announce that more trawl-fish were likely to be caught in one area than another, all the vessels might flock there and then there would be a glut on the market with falling prices. Such forecasting, if it should be possible, could only be of value to an industry working on less competitive lines. But if the movements of trawl-fish can be shown in part to be dependent upon movements of different kinds of water, then it should be possible to devise other types of indicators that would help the *individual* trawler skipper just as the plankton indicator helps the herring drifter skipper. (We must not forget that at times the cod are collecting to feed on the herring; in time use may be made of this fact.) Such an application lies in the future and we can only slowly feel our way towards it. Our science is still very young; new discoveries will be made which will open up fresh possibilities. We are as yet but exploring the ground.

Our friends in the industry at Hull and Grimsby may be impatient that we are carrying out our survey in the North Sea, and not proceeding at once to an investigation of the far northern waters in which they are so much more interested. There is good reason for our beginning in the North Sea. Far more is known of the water conditions of this area than is known of the far north; we have all the records of varying saltness and temperature compiled from year to year by the International Council to refer to. Likewise there are all the weather maps and records of sunshine and rainfall available. There are also the detailed statistics of the progress of the fisheries prepared by the Ministry of Agriculture and Fisheries; the whole of the North Sea is divided up into more than a hundred squares, and monthly charts are prepared to show the quantities of different kinds of fish landed from each square for every 100 hours' fishing. It is only in the North Sea, where we have all this other information available, that we can begin to link the changes in the plankton, as shown by such a survey, either with the fluctuations in the fisheries, or again with the basic climatic and water conditions at the back of it all. The North Sea can be used almost as a laboratory in which to work out relationships with known factors, and to establish principles which in time may come to be applied to the more distant regions about which we know at present too little. (Actually we have begun some preparatory work on the food of the arctic cod at Bear Island and Iceland, and a report on this will be published in a later volume; but it is not yet part of our main programme.)

For the first five and a half years, from June, 1932, to the end of 1937, our plankton survey was confined to the southern part of the North Sea. This was definitely a pioneer period of trial; it is the phase which forms the subject of this, our first volume. In 1938 the survey was extended to cover the whole of the North Sea, and in the spring of 1939 the first monthly line of observations towards Iceland was begun; these later developments will be dealt with in our second volume.

I have been stressing the bearing of this work on the better understanding of fishery problems; it is the purpose of this explanation to show our aims in relation to the industry. But now a note of caution. Our programme is admittedly an ambitious one. We are just at the beginning; we have a very long way to go before the goals we are working towards can be realized. They must be approached slowly, making sure of the ground step by step; there will be many temptations to jump to conclusions on too slender evidence. The limitations of the methods we are employing must be carefully weighed and a good deal of space in the coming 'Bulletins' will be concerned with these. Direct economic results must not be expected quickly, although the work of the early years has already been of value in providing advance information of the areas of dense plant plankton which have such an adverse effect upon the East Anglian autumn herring fishery (see the Report of the Development Commissioners quoted on p. 8 of 'Bulletin' No. 1). The more immediate outcome will be a better understanding of the nature of the changes taking place in the North Sea plankton community as a whole; any steps, however, towards a better knowledge of the biology of the North Sea is a step towards ultimate economic advantage. It is with these contributions that the present volume is concerned.

Our course towards the practical ends we have suggested will not be taken alone. The short excursion into the history of our science made at the beginning of this essay was intended to show how much we are indebted in the initiation of this work to the pioneers of the past; any progress in the directions in which we are hoping to go will be made with the help of the findings of our colleagues working at kindred problems in other marine laboratories. Ours is but one line of attack among many others. It aims at providing a background to all the important investigations being carried out by other departments into the lives of the fish, their growth rates, migrations and feeding habits, into the fluctuations in their stocks and many other problems. It is not suggested that our survey replaces the need for plankton cruises by research ships for special purposes; there are many aspects of plankton research which cannot be undertaken by our methods. It is only by co-operation and the fitting together of the different lines of approach that progress can be made.

We will now pass to a brief account of the contents of the six 'Bulletins' which complete our first volume.

'Bulletin' No. 1.

The first paper (pp. 1–57) deals with the object, plan and methods of our survey. The structure and working of the continuous plankton recorder is described. It is stream-lined, like a torpedo, but is square in cross-section to fit the internal mechanism better; like the smaller plankton indicator already described, it is fitted with planes to make it dive below the surface and swim at a depth which may be regulated by the amount of towing cable veered out. As it is towed along it continually samples the plankton from the sea by means of a long gauze banding, which is slowly wound across a water tunnel by the action of a propeller turned by the passing water. A water tunnel opens at the very front of the machine and passes through its body to the back; the front opening is quite small, but the cross-section of the tunnel enlarges very much as it reaches the gauze, so that the filtration area is many times larger than the entrance—an arrangement which both slows down the speed of the water and allows an unobstructed flow through the gauze. The gauze banding is ruled with numbered transverse lines at 2-inch intervals. For every mile of sea through which the machine is towed fresh gauze strains off the plankton from the water and is then wound on into a storage chamber filled with preservative fluid (formalin), where it is rolled up for future examination.

The gauze banding is wound off a spool just like the film of a camera and enters and leaves the water tunnel through narrow slits; as it leaves the tunnel it is joined by another similar banding, which is wound with it on to a larger spool in the storage tank, so imprisoning the plankton between the two and preventing it spreading from one section of the roll to another. The two bandings form, in fact, a long sandwich with the plankton as the jam and it is wound up rather like

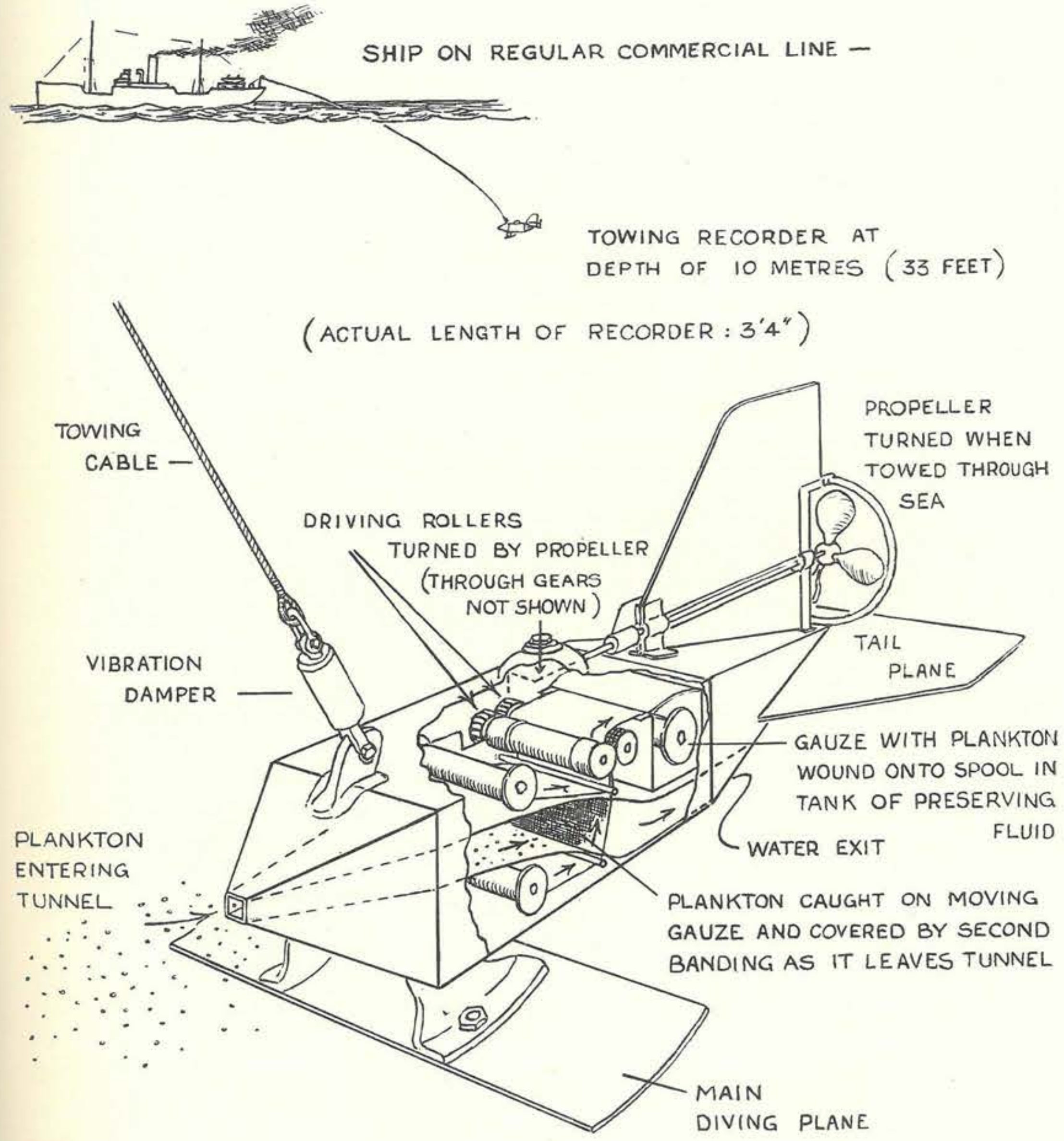


Fig. 10.—A simplified diagram to show the working of the continuous plankton recorder; part of the outer casing has been cut away to show the internal mechanism. The catching gauze is actually ruled in transverse numbered divisions (not shown in drawing) each of which may represent one or more miles of sea according to the setting of the propeller blades.

a swiss roll (only double); the edges of the covering gauze are turned over so as to separate the two fabrics slightly and prevent undue pressure on the plankton. (This is an improvement made in the course of the work: in the early days of the survey the plankton suffered much from crushing.) The gauze bandings are driven on between two rollers like those of a mangle, but as they only grip the "sandwich" at the edges they do not mangle the plankton. The driving rollers turn very slowly, being themselves driven through a reduction gear from the propeller shaft. A simple diagrammatic sketch of the machine is shown here in Fig. 10, and a photograph on p. 3 of the 'Bulletin' shows that the internal mechanism may be taken out to be loaded with the gauze bandings before use, just as a camera is loaded with a new film.

At the end of a run the spool is taken out of the storage tank and mounted on a stage beneath a special traversing microscope (illustrated on pp. 32 and 34); the "swiss roll" is then unwound and the two sides of the "sandwich" separated for examination. The numbers of the different plankton animals and plants can now be counted or estimated section by section along the band, representing on a small scale the miles of sea traversed. The actual scale of working can be changed by altering the pitch of the propeller blades, which are adjustable to give a range of speed of rotation, so that each section of gauze may be made to represent one, two or more miles of sea as desired. Thus we are able to study the varying composition of the plankton mile by mile all the way across the sea—not just at isolated intervals, as by former research ship methods using tow-nets. The results can be shown as graphs representing the relative abundance of the different animals and plants along the route as shown in the example on p. 35.

The machine is made all ready for working before being taken to the ship which is to use it. The ship is provided with a special winch and davit for lowering and hauling it to and from the water. It is put out as the ship passes some definite point, usually a light-ship, on leaving one coast, and hauled up again on reaching some similar point on the opposite side of the North Sea. Throughout the survey the recorder has been towed at a standard depth of 10 metres ($5\frac{1}{2}$ fathoms), the cable being marked to show when this depth is reached. The machine is only just over 3 ft. in length and does not interfere at all with the speed of the ship. At the end of each run it is brought back to our laboratories for examination.

This first 'Bulletin' describes the planning of the survey and the kind help we have received from the various shipping companies co-operating in the scheme. At first, as already pointed out, the survey was confined to the southern part of the North Sea (1932–37). The recorders were run monthly along lines from Hull towards the Skagerrak (Copenhagen line), Hull to Bremen and Hull to Rotterdam, a line from London to Esbjerg being added in 1936. In 1938 the survey was enlarged to cover the whole of the North Sea (see Fig. 11), but this extended survey forms the subject of our second volume.

There is an account of the development of the recorder and the many difficulties that had to be overcome before it reached its present state of efficiency.

A great deal of the paper is taken up with discussions on such matters as the interpretation of results, the catching power of the machine, the scale of working and the limitations to the method, all of which are of too technical a nature to find a place in this general account.

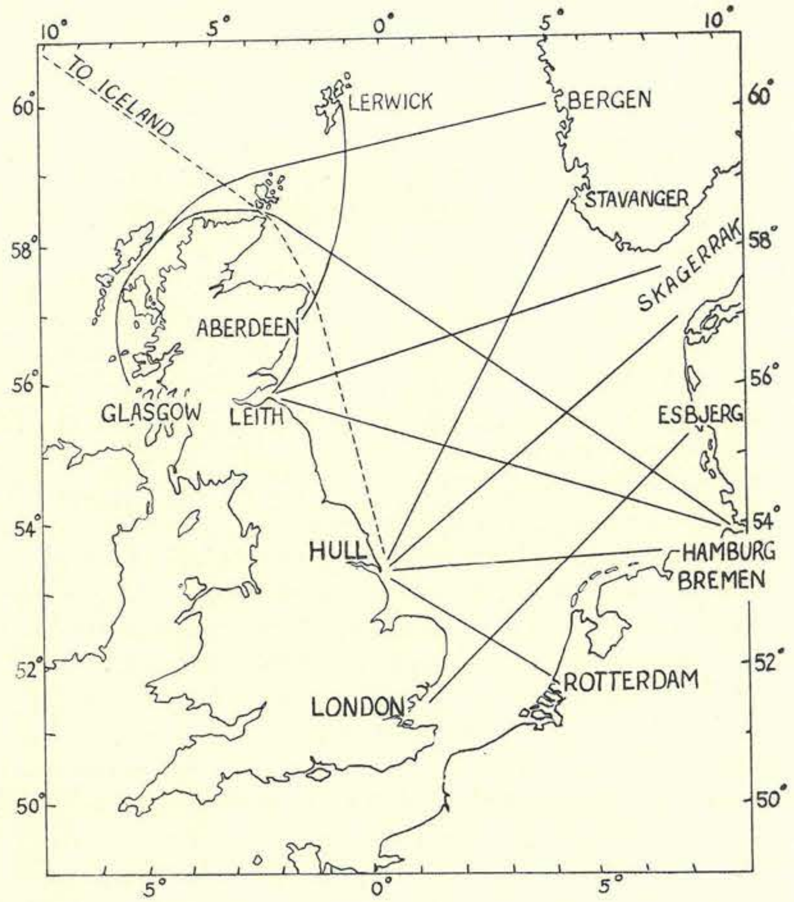


FIG. 11.—Chart of the extended monthly plankton recorder survey of 1938–39. The lines between Hull and the Skagerrak, Bremen and Rotterdam were begun in 1932, London to Esbjerg in 1936, and the remainder in 1938. For modifications in 1939 regarding the Stavanger and Iceland lines see 'Bulletin' No. 1, p. 56.

'BULLETIN' NO. 2.

The second 'Bulletin' (pp. 59–71) is a summary list giving all the particulars of dates, times, distances, weather and sea conditions, etc., for all the records made from 1932 to 1937. The total distance successfully recorded during this period was 44,246 miles.

'BULLETIN' No. 3.

Dr. Lucas here gives an account of the changing distribution and abundance of the little plants of the plankton (the *phytoplankton*) over the southern North Sea from June, 1932, to the end of 1937. There are a great many different kinds. Many are classed together as Diatoms; each is a little bit of living plant matter enclosed between two thin shells of natural glass (silica), which fit together as do the bottom and lid of a pill-box. Some are indeed shaped just like a pill-box, but others are of all manner of designs, as seen in Fig. 12. Next in importance of numbers come the Dinoflagellates; so called because they are provided with two little whip-like organs ("flagella"), which help to keep them up in the water. Then there is Phaeocystis—vast numbers of tiny plant cells held together in a little mass of floating jelly.

Special attention has been given to the two diatoms *Rhizosolenia styliformis* and *Biddulphia sinensis* (to give them their full names), which, as we have seen, are so important in relation to the herring fisheries in that often they densely cover large areas in the autumn and so, because herring avoid such water, delay the arrival or alter the position of the main shoals. On Plates XXII–XXXVI Dr. Lucas shows their varying abundance along the lines of our survey month by month through the different years. They are clearly most abundant in the autumn: but see how their production varies in different years: compare, for example, the latter half of 1934 (Plate XXVII) with that of 1935 (Plate XXIX).

So as to compare more easily the relative production in different years another method of charting has been adopted. As examples let us look at Plates I and II. Here for Rhizosolenia all the records for the central line of the survey (the Hull–Bremen line) are compared together year by year. Down the side are marked twelve divisions labelled J, F, M, etc., to represent a scale of time in months, January, February, March, etc., throughout the year; the horizontal lines represent the Bremen recorder lines, which are put in according to their dates against the scale of months. A scale of miles is given at the foot, and the vertical lines under the letters OD and B (at the top) indicate the positions of the Outer Dowsing and Borkum lightships along the recorder's route (they lie off the Humber and German coasts respectively). The records for the different years are shown side by side under the dates (1932 to 1937) placed at the top. The quantities of Rhizosolenia recorded are shown as blacked-in graphs. It is all a little complicated at first sight, but I think worth a little trouble to understand. Once we have got the hang of the arrangement we can compare the relative abundance of this form which is so important to the herring fisheries, just as we can compare weather charts, for different years. We see how much heavier were the crops in 1935, '36 and '37 when compared with the three earlier years; how much later it was in 1936 than in '35 or '37. In the same way the Copenhagen and Rotterdam lines are shown on other plates. Similar series are shown for *Biddulphia sinensis* and for the Dinoflagellates and Phaeocystis. As another example look at Plates XIII

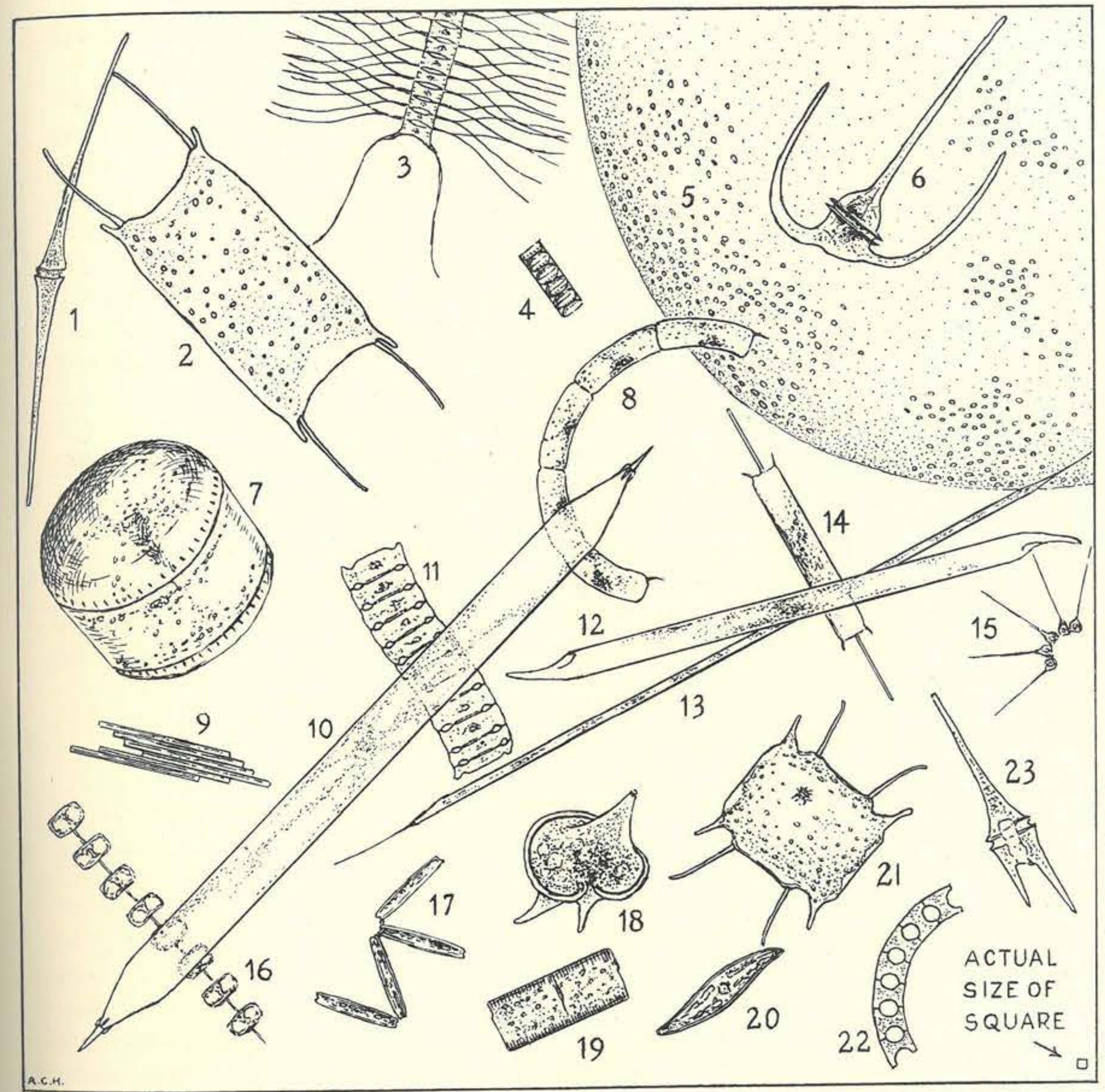


FIG. 12.—Sketches of the tiny plants of the plankton (phytoplankton) dealt with in 'Bulletin' No. 3, seen through a microscope. They are all drawn on the same scale; the actual size of the area shown is 1/20 of an inch square (see bottom right hand corner of figure). Note particularly the important diatoms *Rhizosolenia styliformis* (10) and *Biddulphia sinensis* (2), part of a Phaeocystis colony (5) and examples of Dinoflagellates (1, 6, 18, 23); all the rest are diatoms.

1. *Ceratium fusus.*
2. *Biddulphia sinensis.*
3. *Chaetoceras decipiens.*
4. *Paralia sulcata.*
5. Small part of a *Phaeocystis* colony.
6. *Ceratium tripos.*
7. *Coscinodiscus concinnus.*
8. *Rhizosolenia stolterfothii.*
9. *Bacillaria paradoxa.*
10. *Rhizosolenia styliformis.*
11. *Bellarochia malleus.*
12. *Rhizosolenia alata.*
13. *Rhizosolenia h. semispina.*
14. *Ditylium brightwelli.*
15. *Asterionella japonica.*
16. *Thalassiosira gravida.*
17. *Thalassiothrix nitzschioides.*
18. *Peridinium depressum.*
19. *Guinardia flaccida.*
20. Gyrosigma sp.
21. *Biddulphia regia.*
22. *Eucampia zoodiacus.*
23. *Ceratium furca.*

and XIV, and see the tremendous differences in the crops of Dinoflagellates on the Copenhagen line: production increasing through the years up to 1937.

The object of this " explanation " is not to describe the 'Bulletins' in detail, but just to point out to the general reader the sort of results which have been obtained during this pioneer period. For the first time Dr. Lucas is giving us a comprehensive picture of the changes in abundance of some of the more important elements of the plant plankton over a large area month by month for a period of five and a half years. On pp. 94 and 95 he shows us the changing quantities of Rhizosolenia and Biddulphia on the Bremen line at *weekly* intervals during the more intensive survey in the autumn, which was arranged to keep a close check on the position of the patches of these plants in relation to the autumn herring fishery.

Twenty-one other kinds or groups of diatoms are dealt with in less detail; their relative abundance in different months throughout the years is shown by various symbols in the diagrammatic tables on pp. 118 to 121.

A trend towards a general increase in the plant plankton as a whole is observed over the period of years, although there are some kinds which are exceptions to this trend. In 1938 and '39, as will be recorded in our next volume, we see a return to conditions more like those at the beginning of the period. We have indications here of a long period cycle which, if confirmed by future work, may be of great importance.

'Bulletin' No. 4.

Here Mr. Rae and Dr. Fraser study the varying distribution and abundance of the most important single group of plankton animals, the Copepoda (meaning oar-footed animals), which are little shrimp-like creatures about the size of a pin's head. There are many different kinds, although at first sight they all look much alike. Fig. 13 shows the commoner kinds of the North Sea. *Calanus*, the important food of the herring, is one of them; it is larger than most others, being about the size of a grain of rice. It is not so abundant in the southern part of the North Sea as it is further north, and the Calanus results for this survey are being treated in a later paper, together with the 1938–39 results for the whole of the North Sea, when their significance will be better understood.

Here we see the copepods studied much as Dr. Lucas did the plants. It has long been known from the work of the International Council that there are considerable variations in the numbers of the copepods in the area from season to season. The survey sets out to give some measure of this variation. It seeks to provide answers to such questions as the following: " Is the seasonal sequence of changes in the population of the area broadly the same year after year? How great are the ranges of fluctuation usually encountered? Are phases of exceptionally high or low production usually only of short duration? Do two or more species tend to fluctuate together? Do some species tend to be more evenly

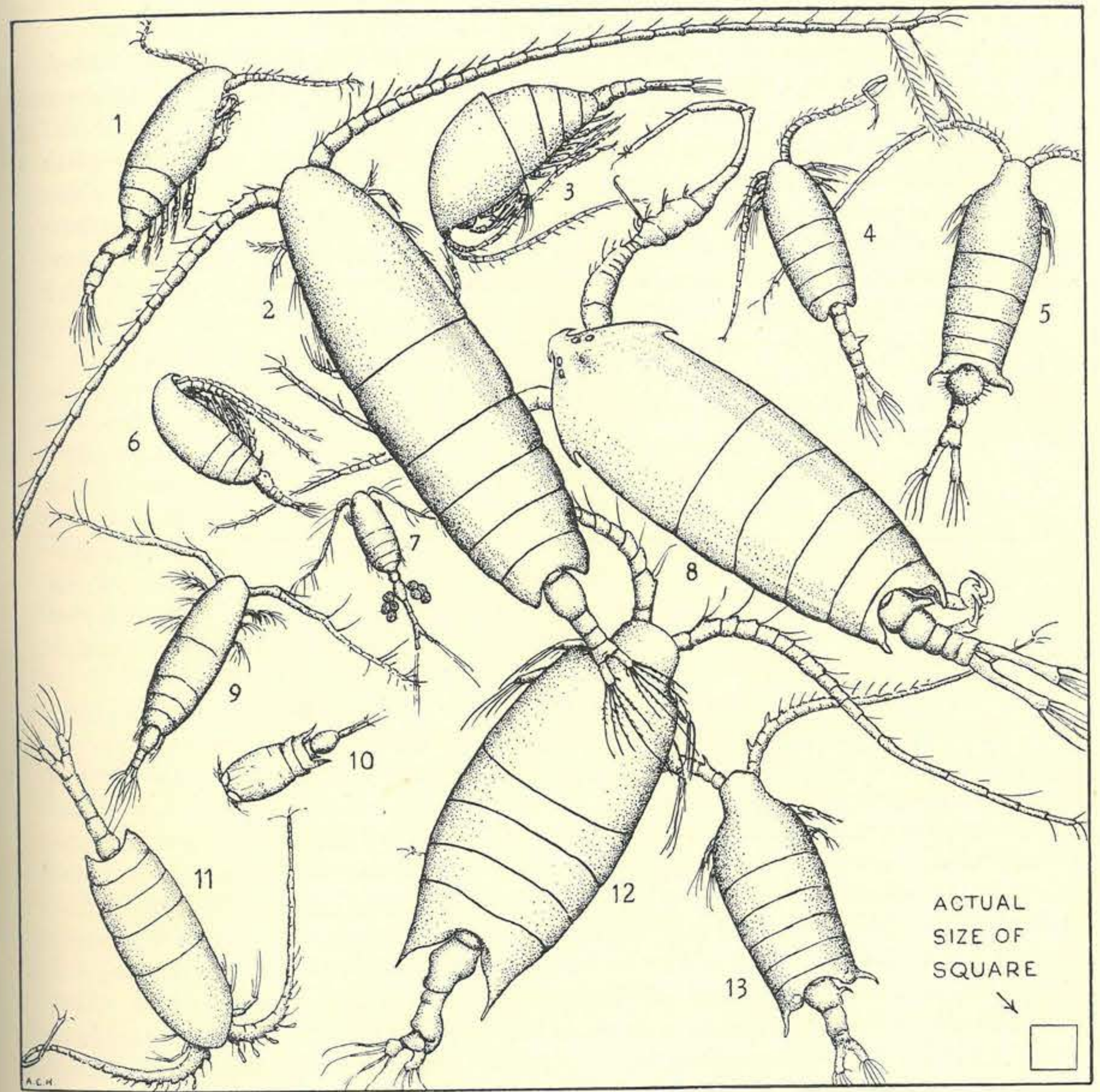


Fig. 13.—Sketches of the more important Copepoda (small shrimp-like animals) of the plankton dealt with in 'Bulletin' No. 4. All are magnified to the same extent and the actual size of the area shown is $\frac{1}{4}$ of an inch square. Examples 4, 8 and 11 are males, the remainder females.

1. *Pseudocalanus elongatus*
2. *Calanus finmarchicus*.
3. *Temora longicornis*.
4. *Isias clavipes*.
5. *Centropages hamatus*.
6. *Paracalanus parvus*.
7. *Oithona similis*.
8. *Anomalocera patersoni*.
9. *Acartia clausi*.
10. *Corycaeus anglicus*.
11. *Metridia lucens*.
12. *Candacia armata*.
13. *Centropages typicus*.

spread throughout the area than others? When we find a markedly uneven distribution in the area, does such a pattern of distribution tend to be repeated at the same season in subsequent years?"

Firstly they treat the varying production of all the Copepoda together. Look at the distribution and abundance in 1935 as shown in Plates C and CI, and compare it with the previous years shown in the preceding plates. On Plates LXVII and LXVIII we see the production on the Bremen line compared month by month in different years in the same way as already explained for Dr. Lucas's plant forms (the curves for 1936 and '37 are not so detailed as in former years because of an alteration in the scale of working). See how the production varies in different years; compare the poor year of 1933 with bumper crops of 1935; see the very good autumn production of 1932. Similar charts are shown for the Rotterdam and Copenhagen lines; on the former compare 1935 with 1936 (Plate LXVI).

Similar charts are prepared for the more important different kinds of Copepoda which commonly occur (they have no simple English names): *Pseudocalanus* and *Paracalanus*, *Temora longicornis*, *Acartia*, *Centropages hamatus* and *Centropages typicus*; the appearance of rarer forms in just certain seasons and years is also recorded. A study of the charts of the commoner forms, together with those for the total Copepoda, provide the answers to the questions raised in their introduction and quoted above. The information obtained about the time and place of the occurrence of the rarer forms at intervals through the survey is of great interest in relation to water movements, especially the occurrence of the more oceanic forms.

The young herring, when it hatches out from the egg and swims up into the plankton, begins to feed on a number of different small animals and plants. Earlier work has shown that then, for a very important part of its life-history, when it is growing from a length of half an inch to that of an inch and a quarter, it feeds on little else but the copepod *Pseudocalanus*. Mr. Rae and Dr. Fraser show how the numbers of this little animal vary enormously from year to year and from place to place along the recorder lines of observation. Here may well be one of the causes of the fluctuations seen in the stocks of older herring. Similarly in regard to trawl fish Miss Ogilvie, of the Scottish Fishery Department, has shown how up to 90 per cent. of the food of haddock fry consists of young copepods. The relative survival of different broods must in part depend upon the available food supply during this critical period of a fish's life. Step by step the framework of the natural economy of the sea is being filled in.

On p. 234 we see graphs of the monthly production of Copepoda through the year, January to December (J, F, M, . . . D), averaged for 1933–37, as continuous line curves for the Copenhagen route (above) and the Bremen route (below); then superimposed upon each of them is a similar curve in broken line to represent the corresponding production on the more southerly Rotterdam route. Whilst the region of the Copenhagen and Bremen lines have their peaks of production at similar periods, the more southerly region has its maximum peak very much later in the year. Many other interesting points are raised and discussed, but this "interpretation" cannot do more than indicate to the general reader the sort of picture that is emerging from the study of these changing planktonic populations.

'BULLETIN' No. 5.

This does not deal with the plankton recorder survey, but relates to the plankton collected by the small plankton indicator in the Shields herring fishery during the experiments already referred to on p. xviii. Mr. Savage, of the Ministry of Fisheries, was making a study of the food of the herring in the Shields area *at the same time*; his results were published in 1937. Mr. C. Cheng, a graduate of the National Tsing-Hua University, China, who came to this country to study fishery research methods, undertook a comparison of the plankton as collected by our indicators and that found by Mr. Savage in the stomachs of herring taken in the same fishery. Mr. Savage analysed his herring food material into 10-day periods throughout the summers of 1931, '32, and '33; Mr. Cheng separated all the available plankton indicator samples into the corresponding periods to match. Here we have a very interesting study of the plankton looked at from inside and outside the herring by two independent workers over the same period of time. It will help us to answer this question: Does the herring take its food by individual acts of capture, selecting this or that more attractive item from the "menu," or does it blindly swim through the water, sieving out just what comes in its way, as does our plankton recorder? Many naturalists have believed the latter view to be correct; Mr. Cheng's findings, however, support the former. This again is not just an amusing point of natural history; upon it hangs much of consequence to the fishery.

While the proportions of the Copepoda Calanus and Temora in the stomachs may sometimes correspond fairly closely with the those in the plankton, at other times they may be very much higher. Copepoda such as Acartia and Oithona, other little crustacea called Cladocera and the young of bivalve shellfish are always in much larger proportions in the plankton than they are in the stomachs of the fish. In July and August, 1931, Calanus was very scarce in both the plankton and the stomachs, and at that time we find a remarkably close correspondence between the quantities of two other animals in the herring stomachs and the same two animals in the plankton. These animals are the little planktonic snail Limacina and the "arrow worm" Sagitta (see Fig. 14). There is no such correspondence at all in 1932 and '33, *when Calanus is available for the herring in plenty*. This correspondence in the quantity of Limacina and Sagitta in the herring stomachs and plankton of 1931 is worth looking at; it is shown in the form of graphs on p. 252. The plankton curve is the continuous line and the herring stomach curve is the broken line. Is not the correspondence of the two curves for 1931 for both Limacina and Sagitta remarkable? Obtained by two independent workers by quite different methods it gives one confidence in the reality of ecological results. But what significance has all this for the industry? First it shows that the herring is not just blindly taking whatever food is there; it has preferences: it prefers Calanus if it can get it, hence the success of the commercial application of the plankton indicator already described. Let us now return to those commercial trials with the instrument when the Calanus-herring relationship was being tested. We saw on p. xxii that for the Shields area the plankton indicator during 1932 and '33, if properly used, would give an average increased catch of 21·2%, nearly as much as for the Scottish fisheries, but in July and August of 1931 at Shields it was a failure, reducing the average gain for the whole period of investigation to only 12·7% for the Shields area. We now see *why* it failed. The Calanus was so scarce during July and August, '31 (see Text-fig. on p. 250), that the fish were mainly going after Limacina and Sagitta rather than after the much scarcer Calanus. Little bits of the jig-saw puzzle fit together. The fishermen must not expect to get results with the plankton indicator if Calanus is scarce over the whole region. Our knowledge of the correct use of the plankton indicator is increasing. As the work goes on, as other little bits of the puzzle drop into place, its application and efficiency will no doubt be greatly improved.

'Bulletin' No. 6.

The last number of the volume concerns once more the main plankton survey, and deals with the distribution and abundance of the other members of the animal plankton apart from the Copepoda already dealt with in No. 4, and the young fish, which together with those for the **1938–39** survey will form the subject of a report in the next volume.

This paper has been much delayed and curtailed owing to the authors, Dr. Henderson and Mr. Marshall, both being on active service. It is more limited than the former reports for other reasons (see p. 256). It deals with the main general groups of different kinds of animals rather than with distinct species. However, in spite of its limitations this paper completes the picture of the changing plankton community in broad outline, and forms some basis for comparison for the more detailed future work.

Some of the more important members of these animal groups are shown in Fig. 14. Here we see the small planktonic snail Limacina, the arrow-worm Sagitta and the Cladocera all referred to in 'Bulletin' No. 5.

In the plates of this 'Bulletin' the varying quantities of plankton are shown, not as curves, but as numbers and symbols (for better comparison with the methods adopted in the later 'Bulletins'): the higher numbers are enclosed by circles which clearly show up the regions of greater abundance.

The outbursts of young forms (larvae) of bottom-living animals, such as Decapod larvae (the young of crab and lobster-like crustacea), Echinoderm larvae (the young of starfish and sea urchins) and the Lamellibranch larvae (the young

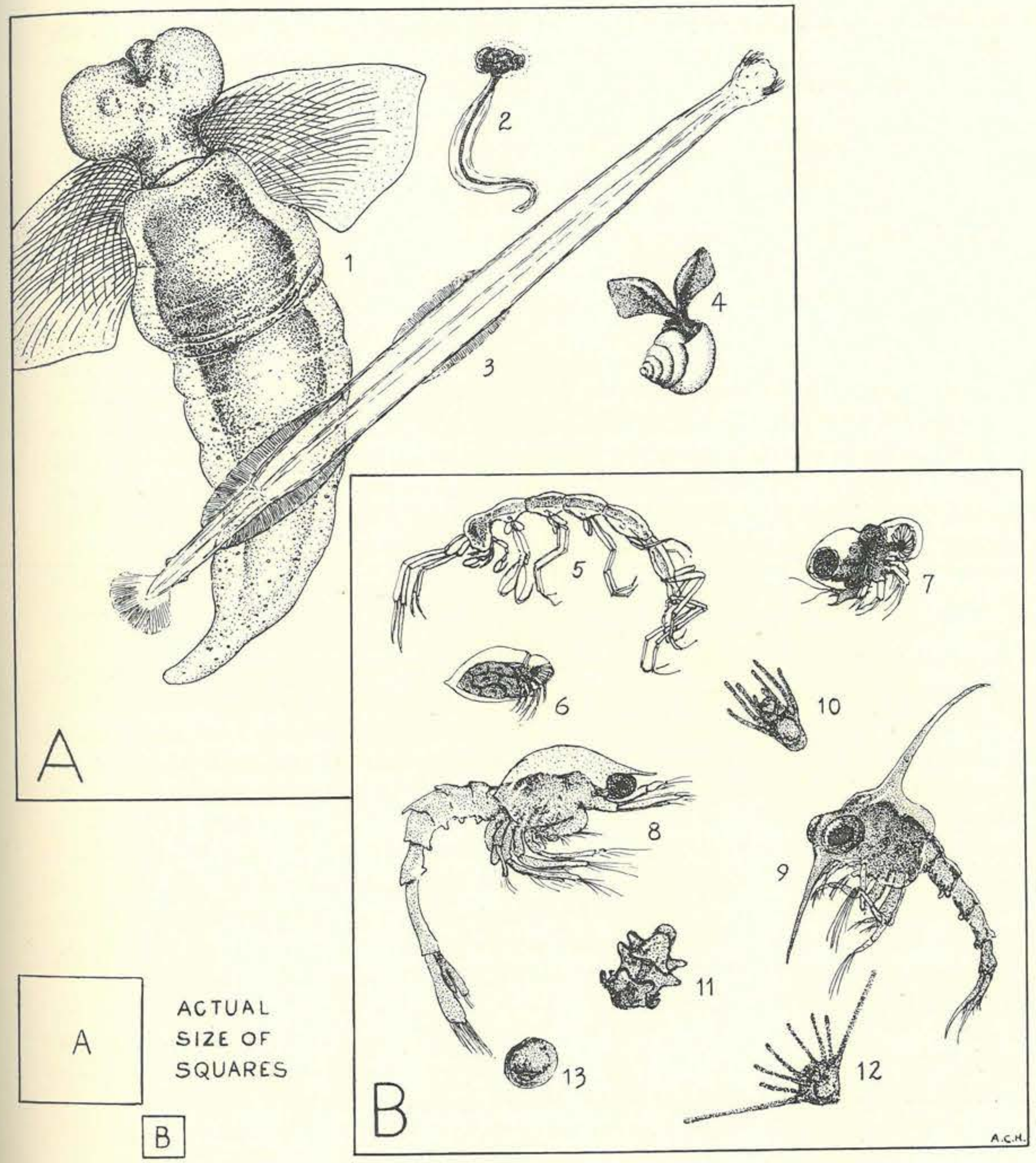


FIG. 14.—Sketches of the more important animals of the plankton (zooplankton) dealt with in 'Bulletin' No. 6. Those in square A are less highly magnified than those in square B, the actual sizes of A and B being $\frac{3}{4}$ and $\frac{1}{4}$ inch squares respectively.

1, *Clione limacina*; 2, *Oikopleura* sp.; 3, *Sagitta elegans*; 4, *Limacina retroversa*; 5, Caprellid Amphipod; 6 and 7, the Cladocera—Evadne and Podon; 8 and 9, Decapod larvae (young planktonic stages of shrimp and crab); 10, 11 and 12, Echinoderm larvae (young planktonic stages of sea urchin, starfish and brittle star); 13, Lamellibranch larva (young planktonic stage of bivalve mollusc).

of bivalve shellfish) are recorded. The bivalves are of great importance as the food of fish such as the plaice, and variations in their abundance over the Dogger Bank are particularly interesting in relation to the trawl fisheries (see pp. 264–266).

Diagrams on pp. 262–265 show in summary form the varying abundance of the more important animals month by month throughout the years for the three lines—Copenhagen, Bremen and Rotterdam. One is struck by the general poverty of the plankton in 1933—we saw that this applied also to the Copepoda discussed in 'Bulletin' No. 4.

The distributional characteristics of the different animals are compared: we see their tendencies to even or patchy production.

The papers of the present volume are just a beginning, a first attempt at showing how the *changing* plankton can be studied over wide areas, just as the changing weather conditions can be studied, with the passage of time. We are studying the plankton community in space and time. In the papers of the next volume, some of which are already published, we shall see similar pictures of changing abundance for the whole of the North Sea. As already indicated, further papers will attempt to relate these planktonic changes to those of the climatic and water conditions on the one hand, and to the fluctuations in the fisheries on the other. The war has interrupted this. Dr. Lucas was engaged on the former task, and had gone a long way towards its completion when he put it aside to take up special scientific work in relation to the war. All the members of the research staff are either serving in His Majesty's Forces or engaged on scientific war work.

I have acknowledged in 'Bulletin' No. 1 our debt of gratitude outside the College, to our financial supporters and many other helpers, and inside the College to our Council and Senate for all the encouragement and support we have received in the development of this work; here I would like to end this general account of the first phase of our investigations with a simple word of thanks to all the members of my staff for their devotion to this work. The labour of all this analysis has been enormous; the many difficulties of this pioneer period have not discouraged them; their enthusiasm has overcome each obstacle. May it not be long before our team is drawn together again to pick up the fallen threads.

I have tried to show how one day, we believe, this work will develop to be of real service to the industry. It is a small beginning now, but were not the first series of weather maps poor things when compared with the forecasts of to-day which are of such service to marine and aerial navigation?