Oceanography and the Fluctuations in the Abundance of Marine Animals*

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A MOST important feature of animal life in the sea is the constant occurrence of large variations in abundance, and these, though they may not be greater, appear to be more general in their incidence than in land animals. One year may be exceptionally favourable, with production far above normal, to be followed perhaps by several years of scarcity; and it is not uncommon to find that fish belonging to one year-class are fifty times as numerous as those of another. It is on these great variations in abundance that fishery prediction is based.

Some very valuable information on fluctuations in year-classes of fish has recently been collected by the International Council for the Exploration of the Sea. The object of the Council was to summarize data on good and bad survival years in some of the principal food fishes, and the reports from the specialists who were appointed to undertake the work are of particular interest. For some fish the available information was found insufficient; but for cod, haddock, herring and plaice the data are adequate, at least for some areas. The results show that in different parts of the north-east Atlantic there are with rare exceptions no coincidences in good or bad spawning seasons, even if one species only is considered, and the evidence thus is that the fluctuations which are observed are regional in their incidence.

Of recent years, however, it has become increasingly apparent that in addition to the annual fluctuations, there are other over-riding influences at work, which not only affect the abundance of marine animals, but also may bring about great changes in their distribution. For the past thirteen years, Mr. F. S. Russell has been studying the young fish taken in the plankton at Plymouth and has made regular collections by standard methods in the neighbourhood of the Eddystone. He finds that from 1931 onwards there has been an alarming decrease in the abundance of larval fish. At first this decrease occurred in the comparatively small number of summer spawning fish; but it has now extended to the spring spawning fish also. If we compare the average numbers for the four-year

period 1934-37, with those for the same period ten years ago, 1924-27, we find that the larvæ of summer spawning fish have now been reduced to little more than one fifth of their former abundance, while the numbers of the young of spring spawning fish have dropped to one third. It is particularly to be noted that all species of fish are similarly affected, and bearing in mind the evidence I have already mentioned on good and bad survival years, this fact alone is sufficient to show that the decrease is not due to a chance coincidence in annual fluctuations.

This change which has come about in recent years is unfortunately apparent also in the Plymouth herring fishery, which has declined to such an extent that it is now virtually non-existent. As with herring fisheries elsewhere, the catch has shown marked fluctuations—the seasons 1924-25, 1927-28 and 1929-30 were much above the average. These, however, are normal annual fluctuations and they are due, as Mr. Ford has shown, to the great abundance of five-year old fish: there were specially successful spawning seasons in 1920, 1923 and 1925.

The significant feature is, however, the marked change in the composition of the catch which began in 1931-32—that is to say, in the winter of the year in which the summer spawning fish larvæ showed their first signs of decline. Prior to 1931-32, the younger herring, not more than six years old, always formed at least two thirds of the catch. In that season the younger fish were only 52 per cent of the total, and from then on there has been a rapid deterioration, until to-day there are less than 20 per cent of the younger and more than 80 per cent of the older.

The change found by Mr. Ford in the constitution of the herring shoals was not immediately reflected in the size of the catches, which for some years were maintained at a good level by the considerable stocks of older fish. But as these passed out, they were not replaced by any adequate numbers of the younger year classes, and in recent years the fishery has been profoundly affected. Formerly the number of Lowestoft drifters which visited Plymouth for the herring season rarely fell below 75 and was sometimes well over 100; during the past season only one came.

*From the presidential address to Section D (Zoology) of the British Association, delivered at Cambridge on August 18. The complete address contains several tables of data upon which the argument is based.

It is interesting and perhaps significant to note that, as Mr. G. P. Farran has shown, the stock of herring on the north coast of Donegal has shown a pronounced decline in recent years. The decline began in 1930, some eighteen months before the change in the constitution of the Plymouth shoals was first seen, and the industry based on this fishery has suffered greatly. Mr. Farran tells me, however, that the shortage of herring in recent years has been accompanied, just as at Plymouth, by a great reduction in the numbers of the earlier year classes, and it is thus possible that the same long-period fluctuation is affecting both areas.

FACTORS IN LONG-PERIOD FLUCTUATIONS

Since 1931, when the depression in the Plymouth area began, there has been a marked change in the amount of phosphate in the offshore waters. Records made by Dr. W. R. G. Atkins and Dr. L. H. N. Cooper show that the phosphate is at its maximum in the winter, in December and January, and since the phytoplankton crop is limited by the amount of phosphate in the water, the winter records give a good indication of the quantity of food which will be available for fish larvæ. The records show a heavy decrease in phosphate beginning in 1931. If the average values for the two four-year periods 1924-27 and 1934-37 are compared, we find that the decrease has been about 35 per cent. The fact that the larvæ of summer spawning fish were the first to feel the adverse conditions, and that those of the spring spawning fish were not seriously affected until 1935, can in theory at least be explained in terms of nutrient salts; a reduced crop of phytoplankton will mean a smaller supply of zooplankton, and this will mostly be consumed by the spring larvæ, leaving little or none for those that come later in the year.

Renewal of the phosphate in the Channel appears to be largely dependent on an inflow of mixed Atlantic water, which is rich in phosphate because it contains water that has upwelled at the edge of the continental shelf; and it seems probable that the normal water movements off the mouth of the Channel have undergone marked alteration in recent years. Direct proof of this is lacking, for we have no observations in the waters to the west of the Channel, but evidence of it is afforded by the very interesting discovery which Mr. Russell has made that certain planktonic species may be used as indicators of water-masses. A relation of this kind has been found in a number of plankton species, but it is here only necessary to refer to those belonging to the genus *Sagitta*, and these owing to their abundance are the most useful.

Of the species of *Sagitta*, *S. serratodentata* is typical of the open Atlantic, *S. elegans* of the mixed Atlantic water and *S. setosa* of the Channel water. The first of these is only to be found on rare occasions off Plymouth when the inflow of Atlantic water is exceptional. Mr. Russell's data only began in 1930, and the records are therefore not as complete as could be desired. It is, however, known that for some years prior to this date the offshore plankton in the neighbourhood of Plymouth was of the kind characteristic of the mixed Atlantic water: it was a very rich plankton with such forms as *Meganyctiphanes* and *Agathia*. It was this type of plankton which was found in 1930, and in the regular series of tow-net hauls made in that year, Mr. Russell found that there was 94 per cent of *S. elegans* and only 6 per cent of *S. setosa*. In the following year, when the deficiency of phosphate and of summer spawning fish larvæ first became manifest, there was a conspicuous change in the *Sagitta* population: of *S. elegans* there was only 17 per cent, while there was 83 per cent of *S. setosa*. Since then *S. setosa* has always greatly preponderated in the catches, with a percentage of 93 or more, with the single exception of 1936, when there was 60 per cent of *S. setosa* and 40 per cent of *S. elegans*. There is no doubt there was a small incursion of mixed Atlantic water in the Channel in this year, but it was apparently insufficient to alter the trend of events.

We thus have evidence from four separate sources of the changed conditions which have prevailed in the Channel since 1930-31. These sources are (i) the winter phosphate maximum; (ii) the numbers of fish larvæ; (iii) the constitution of the spawning herring shoals; and (iv) the predominance of one or other species of *Sagitta*. The picture, to my mind at least, is convincing: one gains the impression that if only we had fuller knowledge, corroborative data from many biological sources would be forthcoming.

We may suppose that this long-period fluctuation at the mouth of the Channel will end in due course, but we have no means of knowing when this will happen. When the change comes it will be heralded, we believe, by the return of *Sagitta elegans* in large numbers, and by a marked increase in the winter phosphate maximum. The fisherman will presumably not find any immediate improvement in the bottom fish. As yet he has perhaps scarcely realized the full extent of the depression which started some years ago, and when there is a return to better conditions, he must wait until the increased numbers of larvæ grow to fish of marketable size. It is possible, however, that bottom-living fish have been migrating into the area and that he may thus in some measure escape the worst

effects of the depression. If the younger herring have forsaken their spawning grounds and gone elsewhere, we may hope that they will at once return in force when conditions improve, and that the Plymouth fishery will rapidly be re-established. If, however, they have throughout held to their

former migration routes, and the present dearth is due to lack of suitable conditions for the larvæ, they are in the same position as the bottom fish, and a number of years must elapse before the fishery can be resumed.

(To be continued.)

Luminescence

AN important series of discussions arranged by the Faraday Society took place in the Biochemical Theatre of the University of Oxford on September 15-17 on the subject of "Luminescence". A more appropriate time for the discussion of work in this field could scarcely have been chosen, and in spite of recent events, a surprisingly large number of visitors from overseas was present. The discussions were formally divided into three parts: luminescence of vapours, liquids, and solutions; luminescence of solids; chemiluminescence. The subject of luminescence is of particular interest at the present time for two reasons. First, it forms an excellent testing ground for some of the more recent theories, particularly with respect to the physical properties of solids, and the nature of chemical reactions. Secondly, a good deal of stimulation has been given by the technical interest in the subject. The use of fluorescent solids in discharge tubes as a means of modifying the colour of the light or increasing the efficiency of such devices is undoubtedly leading up to new work of interest, and contributions to the meeting were made by more than half a dozen industrial laboratories.

The first two parts of the discussion dealt essentially with the absorption of radiation by matter and its emission in the form of light; the final section was concerned, however, with the radiations emitted as a result of chemical reactions. The now classical experiments of Polanyi and his collaborators on the characteristics of the reaction between streams of halogen and sodium vapour at low pressure are a specially interesting example of chemiluminescence, in that they are providing the basis for theoretical work in this field.

A valuable feature of the earlier parts of the meeting was the way in which ideas concerning the precise meaning of the terms 'fluorescence' and 'phosphorescence' were brought out. If a luminescent compound is first illuminated at *O* (see accompanying graph) with radiation of constant intensity, an appreciable time may elapse before the luminescence reaches a constant value, as along

AB. If the exciting radiation (for example, ultra-violet) is removed at a time corresponding to *B*, a rapidly falling curve of intensity *BC* follows. Many, and in fact most, of those engaged in experimental work in this field have usually referred to the part *AB* as 'fluorescence' and the part *BC* as 'phosphorescence'. This usage is undoubtedly convenient from the experimenter's point of view, since the time constant of the luminescence has usually been measured during the period *BC*. It has of course been realized that the electrons returning to the ground-state during the equilibrium period *AB* do so only after a finite and possibly considerable time after the absorption process. It was suggested in the course of the discussion that definitions based on the type of electron transition would be more fundamental than those already described. On this basis the term 'fluorescence'

should be reserved for all processes in which electrons are returning from *excited* energy states of parent atoms, and the term 'phosphorescence' used only in those cases where the luminescence is dependent on temperature, and is a result of electrons being involved in metastable states or completely removed from the parent atoms. It is likely that the older definitions will continue to be used on account of their convenience, and because of insufficient data concerning processes. Further progress along these lines can only be made by a study of the time-dependent effects of luminescence, and the corresponding photo-conductivity properties.

Very many substances, both liquid and solid, are capable of absorbing some part of the ultra-violet spectrum, but comparatively few are luminescent. It is to be assumed that the