

On the Value of Certain Plankton Animals as Indicators of Water Movements in the English Channel and North Sea.

By

F. S. Russell,

Naturalist at the Plymouth Laboratory.

With 6 Figures in the Text.

THE use of plankton animals as "indicators" of water movements has been constantly considered in the past, notably by Cleve, Aurivillius, Gran and Kramp. The distribution of oceanic and neritic species in the English Channel has been fully discussed by Gough (1905, b) and Bygrave (1911). There is a gradual increase in the percentage of oceanic species from east to west. Bygrave distinguished between permanent and periodic oceanic forms, the occurrence of the latter being "probably greatly influenced by purely Hydrographic causes, such as the Ocean Currents and the inflow of Atlantic water into the Channel." He placed in the latter group "such species as *Chaetoceras peruvianum*, *Rhizosolenia hebetata*, *Muggiæa atlantica*, *Euchæta hebes*, and *Limacina retroversa*." There is, however, doubt about the identity of the *Limacina*. Gough (1905, a) showed that *Muggiæa* enters the English Channel from the south-west. Gough (1905, b) has also shown how *Euchæta hebes* and Farran (1911) how *Oithona atlantica* may enter the Channel at times.

But the different plankton associations that can be regarded as indicative of water conditions in the mouth of the Channel have not yet been clearly defined. If plankton animals are to be used as indicators they should be *practical* indicators, and therefore the larger and more easily identifiable they are the better. I hope to show in this report that we have a number of good indicators among the larger plankton animals, whose occurrence or absence off Plymouth is a reflection of water conditions far removed from this area itself.

Since 1930 the weekly ring-trawl collections have been studied with this end in view. A complete list of the numbers of different species taken in the 2-metre stramin ring-trawl off Plymouth in 1930 and the beginning of 1931 was published to act as a basis for comparison for the succeeding years (Russell, 1933, a). In that paper the following species were regarded as characteristic of the year in question, *Aglantha rosea*, *Liriope exigua*, *Stephanomia bijuga*, *Clione limacina*, and *Meganycitiphanes norvegica*.

In 1928 Meek drew attention to the fact that in the North Sea the two species of *Sagitta*, *S. elegans* and *S. setosa*, showed marked differences in their numerical proportions from year to year, and were probably indicative of different water masses. Accordingly, since 1930 special attention has been paid to the life-histories of these two species in the Plymouth region and their occurrence from year to year. A paper has already been published giving the fluctuations in the *Sagitta* populations in the years 1930, 1931, and part of 1932 (Russell, 1933, b). Notes have also been published on the occurrence of certain pelagic tunicates and on the siphonophore *Muggiæa* (Russell and Hastings, 1933; Russell, 1934). In the present paper these results have been brought together and carried on into the first months of 1935.

THE SAGITTA POPULATIONS AND ASSOCIATED FAUNA OF "WESTERN" AND "CHANNEL" WATERS.

The numbers of *S. elegans* and *S. setosa* caught in the half-hour oblique hauls with the 2-metre stramin ring-trawl at a position two miles east of the Eddystone Lighthouse during the period October, 1932, to February, 1935, are shown in Figure 2. I have also reproduced in Figure 1 the diagram that was published in the previous report (Russell, 1933, b) showing the sequence of events from February, 1930, to September, 1932. In these figures the curves for the numbers of the two species are shown in the top halves of the diagrams (*S. elegans*, unbroken line; *S. setosa*, broken line). In the lower halves of these diagrams are given the percentage proportions of the two species in each catch (*S. elegans*, black; *S. setosa*, white). In the previous report it was shown that while *S. elegans* completely predominated in the catches from February to September in 1930, in October, 1930, *S. setosa* started to appear and became dominant in September, 1931. After this there were two slight increases of *S. elegans* in January and in August in 1932 (see Figure 1). Figure 2 shows that the dominance of *S. setosa* has continued up to the present time, February, 1935, with the exception of two short increases of *S. elegans* from March to June in 1933 and in May, 1934, and a further indication at the present date. On no occasion, however, was *S. elegans* seen in anything approaching the very large numbers caught in the earlier period of these observations in 1930 and 1931.

It had at first been thought that these two species might normally always be present together in this area, and that the predominance of one species over the other might be the effect of success or failure in the reproduction of one or other species. That this was probably not so was first indicated by a study of the life-histories of the medusæ occurring off Plymouth. In attempting to link up certain of the medusæ with their

hydroids special attention was given to the species *Cosmetira pilosella*, which is sometimes very abundant here during the summer months and the hydroid of which has not yet been identified. In this study, which was started in 1932, the complete absence of the earliest stages of this medusa was striking. Although examining plankton samples caught with silk tow-nets almost daily I never found a very early stage that could be attached to this species. In fact only one such probable individual has ever been recorded from Plymouth (Browne, 1896, p. 486). The distribution of *Cosmetira* is given by Kramp as British Coasts from Channel to Shetland Islands; North Sea and Kattegat; West Coast of Norway to Bergen (Kramp, 1933, p. 570). In an earlier paper Kramp (1919, p. 63) goes rather fully into the distribution of this species and says "Browne has found quite young specimens at Valencia Harbour both in May and August" (see Browne, 1900, p. 719). The absence of young specimens of *Cosmetira* in the Plymouth waters at once suggests that its hydroid does not live in this region and that the medusæ we catch here have been carried in the water masses from some other region in which the hydroid has its normal habitat. Browne's record of young specimens from Valencia indicates the possibility that the hydroid is to be found in the deeper water along the Atlantic shores of the British Isles.

Now observation of the occurrence of *Cosmetira* in the Plymouth ring-trawl catches during the summer months showed that this species was only to be found when *S. elegans* was also present. If *S. elegans* was present in numbers throughout the summer the period of occurrence of *Cosmetira* was very prolonged, for instance in 1930 it was present from April until September (see Table 1, in Russell, 1933, a). In 1934 *S. elegans* only occurred in numbers in May, in that year *Cosmetira* also appeared in May and then disappeared for the remainder of the summer as did *S. elegans*. A similar agreement between the occurrence of these two species was also shown for the other years (see Figure 4 on page 318). The significance of the decrease in *Cosmetira* in June and July, 1931, is not obvious: it was shown by other plankton animals and also occurs to a lesser extent in 1933.

This then is a definite indication that when *S. elegans* becomes numerous off Plymouth it is being brought here from elsewhere. Owing to the occurrence of young *Cosmetira* at Valencia it was natural to seek for *S. elegans* in the waters south of Ireland. Fortunately that area is worked at intervals each year by the Irish Fishery Department and I was able to enlist the co-operation of Mr. G. P. Farran who very kindly supplied me with samples of *Sagitta* collected in that area in the years 1921, 1930, and 1934; in 1930 and 1934 *S. elegans* and *S. setosa* predominated respectively off Plymouth, while in 1921 both species were common at the Sevenstones. The area covered by the Irish investigations lies between latitudes

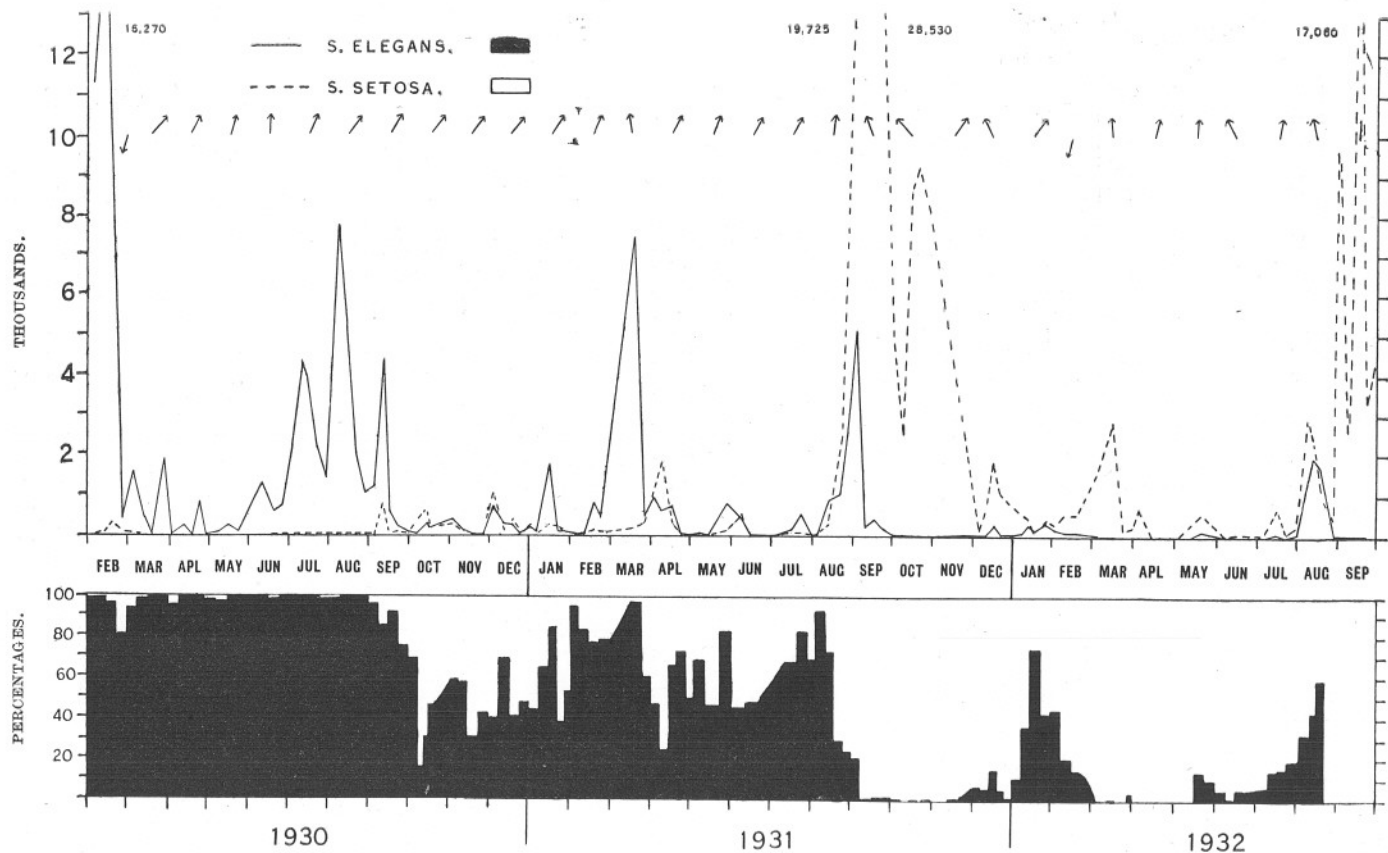


FIG. 1.—Above, curves showing the actual abundance of *S. elegans* (—) and *S. setosa* (---) in half-hour oblique hauls with the 2-metre ring-trawl made usually at weekly intervals during the period February, 1930, to September, 1932. (The numbers are in thousands.) Below, the percentage composition of the Sagitta populations during the same period; *S. elegans*, black; *S. setosa*, white.

At the top of the diagram the arrows indicate the mean direction (true) of flow of water through the Straits of Dover for each month as indicated by the Carruthers Current Meter working from the Varne Lightship.

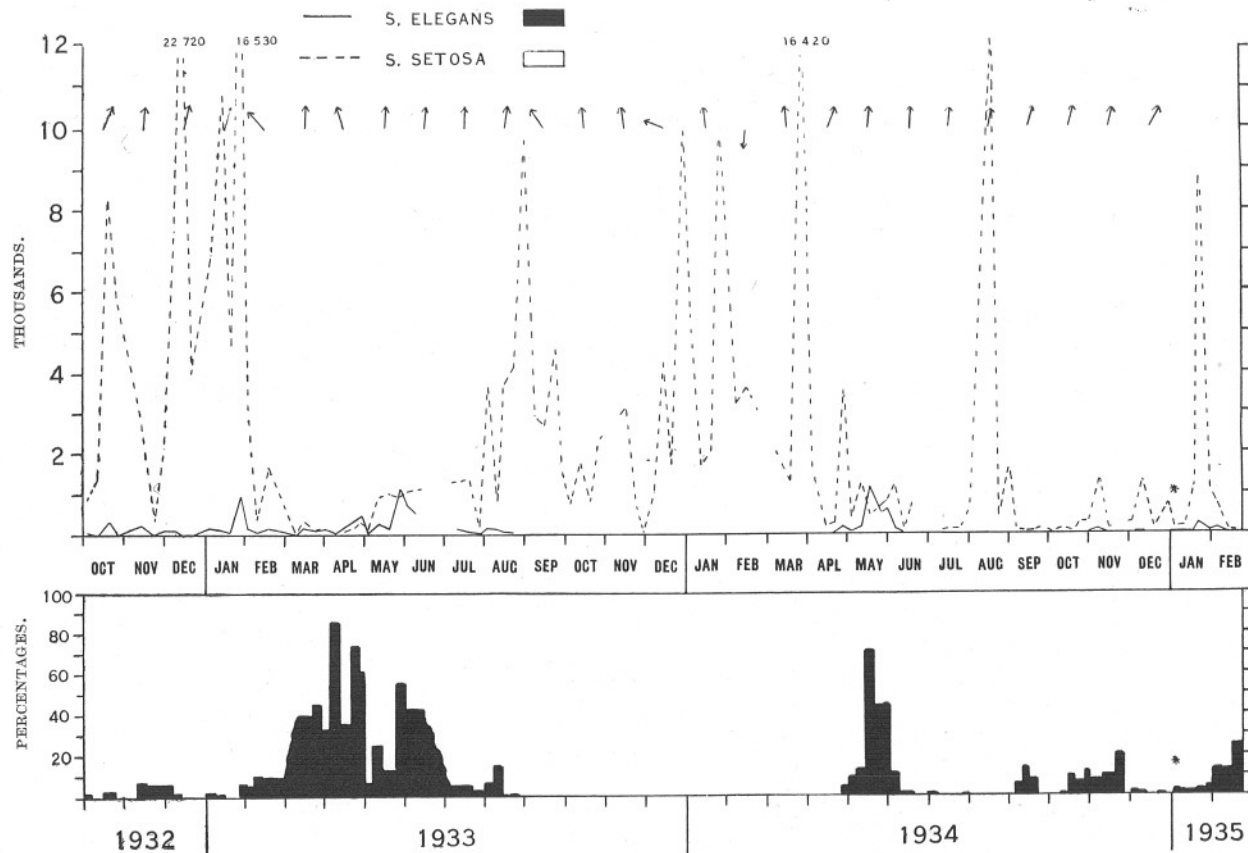


FIG. 2.—Above, curves showing the actual abundance of *S. elegans* (—) and *S. setosa* (---) in half-hour oblique hauls with the 2-metre ring-trawl made usually at weekly intervals during the period October, 1932 to February, 1935. “*” denotes that the collection was made at night. (The numbers are in thousands.) Below, the percentage composition of the Sagitta populations during the same period; *S. elegans*, black; *S. setosa*, white.

At the top of the diagram the arrows indicate the mean direction (true) of flow of water through the Straits of Dover for each month as indicated by the Carruthers Current Meter working from the Varne Lightship.

50°54'N. to 49°20'N. and longitudes 6°21'W. to 11°17'W. (see Figure 3). Examination of the Sagitta material collected in that area at different times of the year showed that in the years 1921, 1930, and 1934 *S. elegans* alone was present and no *S. setosa* were seen.* It is evident therefore that *S. elegans* lives in a body of water quite distinct from that in which *S. setosa* lives.

This was further confirmed by the examination of plankton samples taken from the Sevenstones Lightship in the years 1913 to 1928. In these samples *S. elegans* was always present and only at certain times did *S. setosa* appear in any numbers, notably in 1921. Clearly the boundary between the populations of these two species of Sagitta lies somewhere about Land's End. Following this up an attempt was made in January, 1934, to define more exactly the regions occupied by the two species. Unfortunately this cruise in S.S. *Salpa* was cut short by weather conditions, and it was only possible to make collections on a line between Plymouth and the Lizard. Even so, the results were quite definite and showed a gradual change over from a population off Plymouth in which *S. setosa* predominated to one in which *S. elegans* was becoming the most abundant species. The actual proportions of the two species were as follows.

		<i>S. elegans.</i>	<i>S. setosa.</i>
Jan. 21, 1935.	2 m. East of Eddystone	2.3%	97.7%
„ 24, 1935.	14 m. W.S.W. of Rame Head†	4.3%	95.7%
„ 24, 1935.	22 m. „ „ „	28.3%	71.7%
„ 24, 1935.	33 m. „ „ „	49.3%	50.7%
„ 24, 1935.	Off Lizard	53.6%‡	46.4%
„ 29, 1935.	2 m. East of Eddystone	4.1%	95.9%

Having established that the two species of Sagitta occupy different water masses it remained to examine the results of the ring-trawl collections off Plymouth over the period of years 1930 to 1935 to see whether the occurrence of other plankton animals could be linked with either one or other species of Sagitta.

Examination showed that the following species occurred only when *S. elegans* was present in numbers in the catches,|| *Aglantha rosea*, *Stephanomia bijuga*, *Cosmetira pilosella* (in spring and summer only), *Clione limacina*, *Meganyctiphanes norvegica*, *Thysanoessa inermis*, and three specimens of *Sagitta serratodentata*.

Only in 1930 did all these species occur together and it can be assumed that the large quantities of *S. elegans* present in that year, to the exclusion

* Two badly preserved specimens in 1921 were identified as ? *S. setosa*, but it is doubtful if they were.

† Haul taken in the dark.

‡ *Aglantha* also present.

|| All names of species in this report are those used in the Plymouth Marine Fauna, 1931.

of *S. setosa*, indicated that a considerable body of water had moved into the Channel from the south of Ireland carrying its planktonic fauna with it. In future in this report the water which carries these indicators will be alluded to as "western" water. In the other years when *S. elegans* only appeared spasmodically in small numbers it may be regarded as indicating that there were only minor influxes of "western" water, since the next most abundant species, *Aglantha*, *Cosmetira*, and *Stephanomia*, alone appeared in small numbers with *S. elegans*.

All the above species are boreal or arctic boreal species whose occurrence off the south of Ireland is well known and has been shown by the plankton investigations of the International Council. The breeding and distribution of *Meganyctiphanes* has been worked out in detail for that area by Frost (1932) and the species is shown to occur all over the region investigated. Its presence on the Smalls and Cockburn Bank has also been indicated by Hickling (1925). *Sagitta serratodentata* is a pure oceanic species, and its occurrence may be taken as an indication that the "western" water flowing past Plymouth in 1930 was drawn from well out towards the Atlantic.

In the International plankton investigations *Meganyctiphanes* was recorded for the English Channel as a species "which has never been taken, except at one station in the Western part in November 1907" (Kramp, 1913, p. 540). It is significant that exactly the same is said of *Clione limacina* and that this species also was only recorded from the Channel in 1907 (Paulsen, 1911, p. 53).

In 1924 Lebour (1924) recorded both *Meganyctiphanes* and *Thysanoessa* off Plymouth. We have no records of *Sagitta* throughout that year, but in June at any rate *S. elegans* predominated.

The positions of the stations from which the catches of *Sagitta* were examined from the south of Ireland in 1921, 1930, and 1934, are shown in Figure 3. In this figure the area that has been shown to be populated by *S. elegans* is indicated by diagonal shading. We do not know how much further this area extends to the south. It may perhaps stretch right across the mouth of the Channel, or it may be reasonably expected that the area changes and lies in fact in the region of cyclonic circulation known to exist at the mouth of the Channel south of Ireland (see p. 321)*. A small area well to the south, in the Bay of Biscay, was studied by Fowler's "Research" Expedition. This area has been indicated in Figure 3. *Aglantha*, *Meganyctiphanes* and *Sagitta serratodentata* were caught in that area. Browne (1906) recorded that 42% of the medusæ were *Aglantha rosea* and 27% *Aglaura hemistoma*. It might be supposed that if the "western" water came from as far south as the "Research" area *Aglaura* would have been noticed here with *Aglantha*. But it has never been seen in the Channel. It is in fact a warm water species,

and probably its northern limit of distribution slightly overlaps the southern boundary for *Aglantha*. A further indication that "western" water does not come from so far south is that no *Clione limacina* were found in the "Research" collections (Pelseneer, 1906). Paulsen (1910,

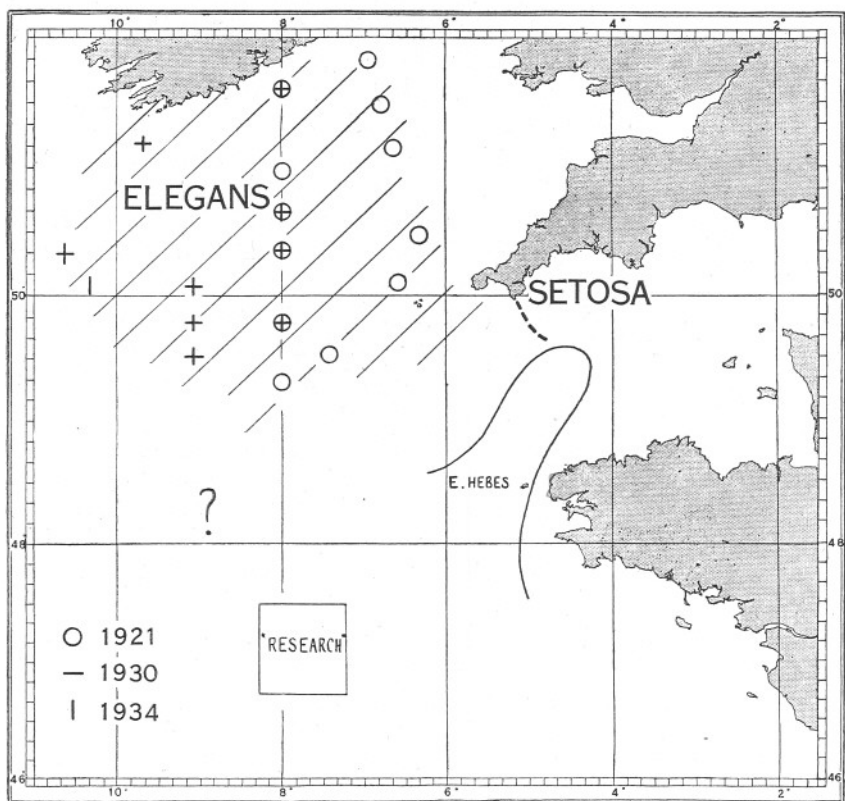


FIG. 3.—Chart showing the positions of the stations south of Ireland from which collections were examined for 1921, 1930 and 1934. Only *S. elegans* were found and the shaded area indicates "western" water. The position of the boundary between "western" water as indicated by *S. elegans* and "Channel" water as indicated by *S. setosa* is shown for 1934.

The small rectangle indicates the region in which the "Research" Expedition worked.

The distribution of *Euchata hebes* is indicated after Farran (1911, Plate XIV). This is the limit within which the species occurred on at least 20% of the occasions on which observations were made.

p. 52) also says of *Clione*, "Here, south of Ireland, I found *Clione* repeatedly from the 'Thor' in 1906, but only north and east of the steep slope towards the deep Atlantic. In the Bay of Biscay proper I have not found a single specimen, although in search of *Clione*. Thus it is likely that we have the southern limit of its distribution here." This

species was caught further south on the "Michael Sars" North Atlantic Expedition but only in the deeper layers in the open Atlantic (see Bonnevie, 1933, p. 60). However, "during the Southern crossing it was found to belong to a water-layer with a temperature as low as from 4° to 10° C."

It has been shown above that there are a certain number of plankton animals that can be regarded as indicators of "western" water. So far, however, in the ring-trawl catches it has not been possible to find any species that can be linked alone to *S. setosa*. The distribution of this species is gone into fully below (see p. 322) and it is concluded that it is a purely neritic species. If this be so it is at present the sole indicator we know of what I shall henceforth call "Channel" water.* It is, however, not possible to fix the other indicators, if they exist, without a similar close survey of the plankton population of the "western" water to see which species, commonly present in "Channel" water in association with *S. setosa*, are at the same time absent in "western" water.

In another paper in this Journal (Russell, 1935, p. 170) I have drawn attention to the agreement shown between the abundance of the young of summer spawning fish and the phosphate content of the water in the previous winter. The occurrence of low phosphate values coincides with the periods in which *S. setosa* predominates and it seems likely that this low phosphate content is a characteristic of "Channel" water. The abundance of plankton animals as shown by the ring-trawl catches in the summer months is certainly much less when "Channel" water predominates off Plymouth than when "western" water predominates.

THE PLANKTON FAUNA OF "SOUTH-WESTERN" WATER.

From time to time certain plankton animals appear off Plymouth whose normal habitat is undoubtedly in warmer waters. Among the most obvious of these are the pelagic tunicates, Salps, and Doliolids, the siphonophores, Muggiæa, and the medusa, *Liriope exigua*. Gough (1905) has shown how in 1904 *Muggiæa atlantica* penetrated the Channel from the south-west and gradually extended its distribution over the neighbouring waters. As a result of the International plankton investigations the occurrence of a warm water copepod, *Euchaeta hebes*, was shown by Gough (1905, b). Farran (1911) has indicated graphically how the distribution of this species may extend into the mouth of the Channel as a tongue stretching from the south-west past Ushant (see Figure 3).

Farran points out "the connection between the distribution of this species and the presence of a tongue of highly saline water running across

* Künne (Wulff, Bückmann and Künne, 1934) says of Channel water that the lack of indicators is especially characteristic.

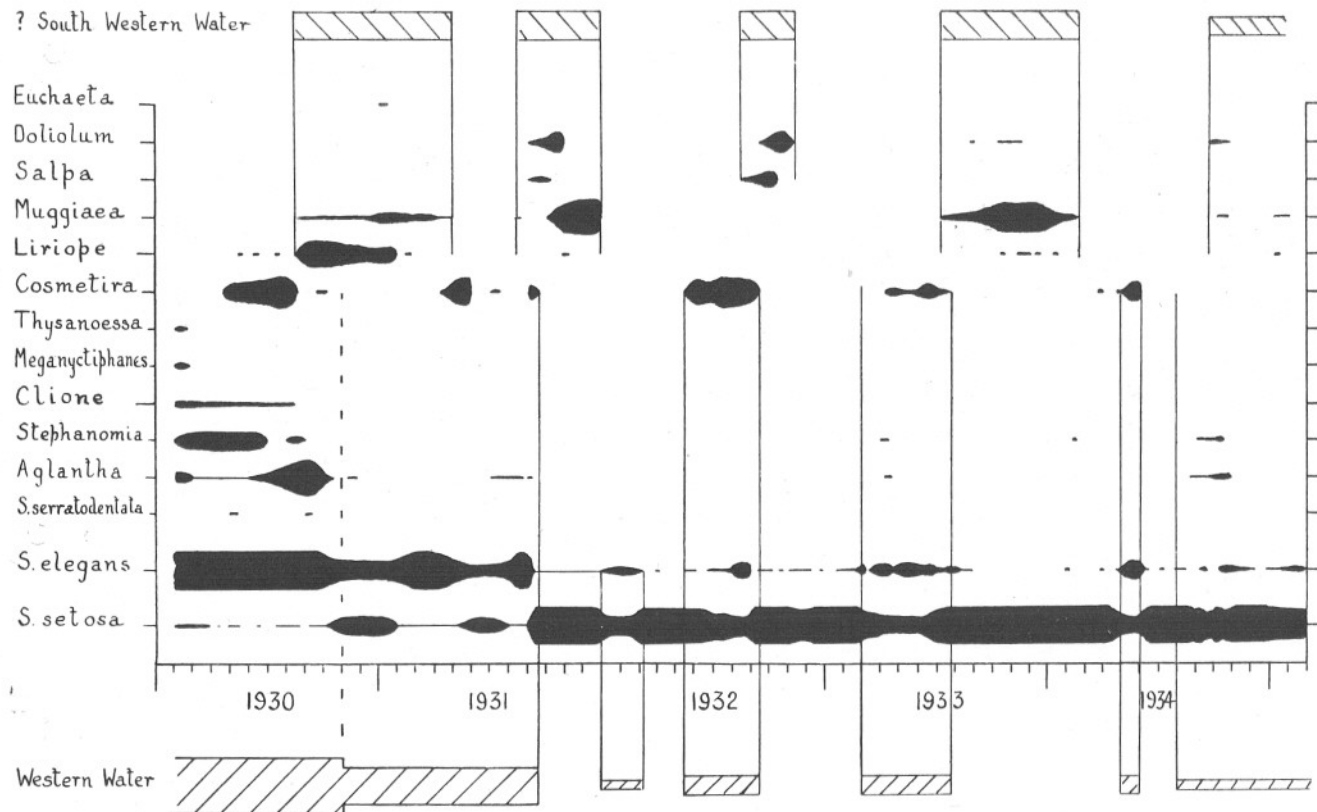


FIG. 4.—Diagram showing the occurrence of the various planktonic indicators in collections off Plymouth during the period February, 1930, to February, 1935.

The species shown are *Sagitta setosa*, *S. elegans*, *S. serratodentata*, *Aglantha rosea*, *Stephanomia bijuga*, *Clione limacina*, *Meganyctiphanes norvegica*, *Thysanoessa inermis*, *Cosmetira pilosella*, *Liriope exigua*, *Muggia kochi*, *Salpa democratica* (1931), *Salpa fusiformis* (1932), *Dolium nationalis* (1931 and 1932), *Dolium gegenbauri* (1931), and *Euchaeta hebes*.

the mouth of the Channel." He remarks that the most frequent occurrence of this species coincides with the area of mean salinity of 33.4‰. He also comments on the fact that this species had never been met with in the course of the Irish Investigations on the south and west coasts of Ireland, that is in "western" water.

The occurrence of the pelagic tunicates and of *Muggiæa* off Plymouth in recent years has already been noted (Russell and Hastings, 1933; Russell, 1934). The occurrence of these animals and of *Liriope* in the ring-trawl catches off Plymouth since 1930 is shown graphically in Figure 4. It can be seen that these species show no association with *S. elegans* and they are here regarded as possible indicators of "south-western" water. That this may be true is strengthened by the record of the occurrence of *Euchæta hebes* in 1931 when *Muggiæa* was abundant. At that time the complete contents of the ring-trawl catches were examined; in the later years only the easily observed "indicators" alluded to have been picked out. If *Euchæta* occurred at other times in association with the "south-western" fauna it will have been overlooked. It is surely significant also that in the International plankton investigations from 1902 to 1908 the only year in which this species was not seen was 1907, that is the only year in which *Clione* and *Meganyctiphanes* were recorded in the Channel (see above, p. 315, and Farran, 1911, p. 94). In addition Farran (1911, p. 104) records that the deeper living and more northerly copepod, *Oithona atlantica*, which is distinctly oceanic, spread up the Channel to an unusual distance in 1907.

In regarding the pelagic tunicates and *Muggiæa* as indicators of "south-western" water caution is needed. These are species which can reproduce asexually, and it is possible that at times their numbers will thus be increased so rapidly as to give the false impression that there has been a movement of a large body of water. This might especially be so if the water were unusually warm. In this connexion, therefore, *Liriope* may possibly be regarded as the better indicator. In Figure 4 it is noticeable that the "south-western" water indicators seem usually to follow the disappearance of the "western" water. It appears almost as though this might indicate that we have here a seasonal phenomenon rather than an indication of water movement, the warm water species increasing when the water is sufficiently warmed. But if this were so the disappearance of *S. elegans* is hard to explain; and the absence of *E. hebes* in 1907 indicates that in that year water may not have come from the south-west, but from the west as shown by the presence of *Clione*, *Meganyctiphanes*, and *Oithona atlantica* (see also p. 315). It should perhaps also be mentioned that whereas such animals as *Cosmetira*, *S. elegans* (except July to September), and the Euphausiids live in the daytime in the deeper water layers (Russell, 1927), Salps, Doliolids, and *Muggiæa* are not

so bound to the depths and strong southerly winds might carry them along in the surface layers in sufficient numbers to seed the area. The occurrence of floating organisms such as *Velella* and *Ianthina* in 1932 (Russell and Kemp, 1932) was an indication of this.

The full sequence of events showing the occurrence of the indicators representative of the three bodies of water—"western," "Channel," and "south-western"—since 1930 is shown diagrammatically in Figure 4.

THE RELATION BETWEEN THE PLANKTON "INDICATORS" AND THE HYDROGRAPHIC CONDITIONS.

Since the conclusions arrived at in this report have been based on observations in only a single locality it is not possible to draw any close comparison between the presence of the plankton indicators and the hydrographic data collected over the whole of the western half and mouth of the English Channel. Furthermore, it is doubtful if the hydrographic observations are sufficiently closely spaced in time and space to indicate for certain the direction from which water is entering the Channel. In an area where several water bodies mix, also, the plankton animals alone can give the clue as to the water's origin unless the salinity differences are marked.

Such outlines of the hydrographic conditions as can be obtained from the data have been given by Harvey (1930 and 1934). A comparison with these and later unpublished data shows at most that there is no considerable discrepancy between such deductions as can be drawn from the sequence of events shown in Figure 4 and the hydrographic data. Especially is it noticeable that *S. elegans* is generally to be found off Plymouth when water of high salinity has entered the Channel, and that *S. setosa* predominates during periods of low salinities.

It has been shown by Harvey (1934, p. 739) that the distribution of salinity in the western half and mouth of the Channel reflected the nature of the movements of water through the Straits of Dover as shown by Carruthers' (1928) current measurements from the Varne Lightship. It seemed, therefore, of interest to compare the fluctuations in the *Sagitta* population off Plymouth with the conditions of passage of water through the Straits of Dover. I am greatly indebted to Dr. J. N. Carruthers for supplying me with data on the flow of water past the Varne Lightship for the whole period of my observations. He has kindly allowed me to publish the data given in Figures 1 and 2.* In a recent publication Carruthers†

* Since the above was written these data have appeared in print (Carruthers, 1935). Table II in this new report by Carruthers presents the data used in this present paper. His Appendix 6 gives the substance of his British Association paper quoted under Carruthers (1934).

† See also Ministry of Agriculture and Fisheries Report on Sea Fisheries for the year 1933 (1934, pp. 47-49).

(1934) says, "The results of the last three years are of especial interest, for, instead of the residual current heading boldly into the North Sea (as it most frequently has done in the previous three years) it has displayed less and less easting with the passage of time. During 1933 the current headed about half a point west of north."

I have inserted at the tops of Figures 1 and 2 the idealized directions (true) of the daily flow for each month of the residual current through the Straits of Dover. The decrease in the easting alluded to above is very obvious and it is significant that the change has taken place at the time when *S. elegans* gave way to *S. setosa* in 1931. On the whole there is agreement also in that the periods when *S. elegans* is most abundant off Plymouth tend to coincide with the periods of strongest flow through from the Channel to the North Sea. Under these circumstances apparently "western" water flows past Plymouth.

It is not expected that agreement can be shown at this stage in every detail between plankton indicators and hydrographic data, but at any rate sufficient relation has been indicated to prove that a study of these organisms, in conjunction with the hydrographic observations, over the whole area might prove a valuable aid to the elucidation of the water movements. Indeed the following on of the occurrence of "south-western" water after the disappearance of "western" water alluded to on page 319 is quite in accord with previous ideas on the water circulation off the mouth of the Channel (see Matthews, 1914, and Lumby, 1925). The "western" water probably arises from the cyclonic circulation to the south of Ireland. This cyclonic circulation "whose southern limit in winter is approximately in the latitude of the Scilly Islands, extends as far south as Ushant in summer" (Lumby, 1925, p. 12). The mouth of the Channel thus becomes partially blocked and water can only enter from the south-west bringing with it the "south-western" fauna. There is thus an indication from the plankton observations of a pulse of "western" water entering the Channel with its maximum about May. This pulse retreats as the pulse of Atlantic water entering the North Sea from the north increases; and this is followed by a pulse of "south-western" water into the Channel.

It has already been remarked (p. 317) that there is an indication that the "western" water is richer in phosphate than the Channel water. It is therefore interesting to read the following quotation from Matthews (1914, p. 22): "This circulation may prove to be of considerable biological importance. The water off the south-east coast of Ireland, and in the southern edge of the cyclonic circulation off the fairway to the English Channel, has travelled a long distance since it last left the open ocean, and if, as seems probable, there is any difference, other than temperature and salinity, between oceanic and shore waters, then this water might be

poorer in the minute constituents of oceanic water and richer in those of coastal water than would be expected on the ground of its distance from the open sea." Actually the indications are that relatively the coastal water is poorer in nutrient salts, and it seems likely that the enrichment of the "western" water is due to upwelling along the Atlantic slope (see also Thomsen, 1933, for the North Sea).

THE GEOGRAPHICAL DISTRIBUTION OF *Sagitta setosa*.

Sagitta setosa appears to be a plankton animal with a rather limited distribution. It has only been recorded from the English Channel, the North Sea, Skagerak and Kattegat. Meek (1928, p. 756), in commenting on the occurrence of this species off the Northumberland coast in such years as 1921, when the flow of Atlantic water into the North Sea from the north was strong, has suggested that the species may be brought there from the Atlantic. This species together with *S. elegans* has been consistently confused with the warm-water species *S. bipunctata* and it is possible that future investigations may show that its area of distribution actually stretches further than that given above. There are, however, a few points worthy of mention that indicate that this may not be the case.

We owe the first full descriptions for distinguishing between the above three species of *Sagitta* to Ritter-Záhony. These descriptions were published by him in his report on the Chætognatha of the Plankton Expedition (1911). In this report Ritter-Záhony deals with collections made in the Atlantic both off the mouth of the English Channel and round the north of Scotland. Yet he makes a point of mentioning (1911, p. 11) that *S. setosa* had then only been found in the North Sea, Skagerak, and Kattegat, and English Channel. If the species had occurred in collections from the open Atlantic he at any rate is not likely to have overlooked them.

Almost all the holoplanktonic animals occurring in the northern waters on the eastern side of the Atlantic have been shown to live also on the American side. Yet *S. setosa* has never been recorded from the western Atlantic and if it occurs there it is not likely to have been overlooked by Huntsman who has studied the variations of *S. elegans* in such detail (1919).

In 1933 I had the opportunity of cruising in more northern waters in Col. E. T. Peel's yacht, *St. George*. A sample of plankton taken off the Yorkshire coast on August 2nd, 1933, (54°31'N. : 0°0½'W.) yielded large numbers of *S. setosa* with only one or two *S. elegans*. But in samples that I took in the Shetland Isles, in Balta Sound (13.vii.33) and in Luning Sound (14.vii.33), there were no *S. setosa*, but only *S. elegans* together with

Aglantha. Similarly only *S. elegans* and Aglantha appeared in a collection made in Loch Eriboll (25.vii.33) on the north coast of Scotland, while these two species with large numbers of *Cosmetira* were present in collections made north of the Fair Isle Channel (9.vii.33; 59°42'N.; 2°10'W.). There was therefore no evidence that *S. setosa* was living in the Atlantic waters in the north.

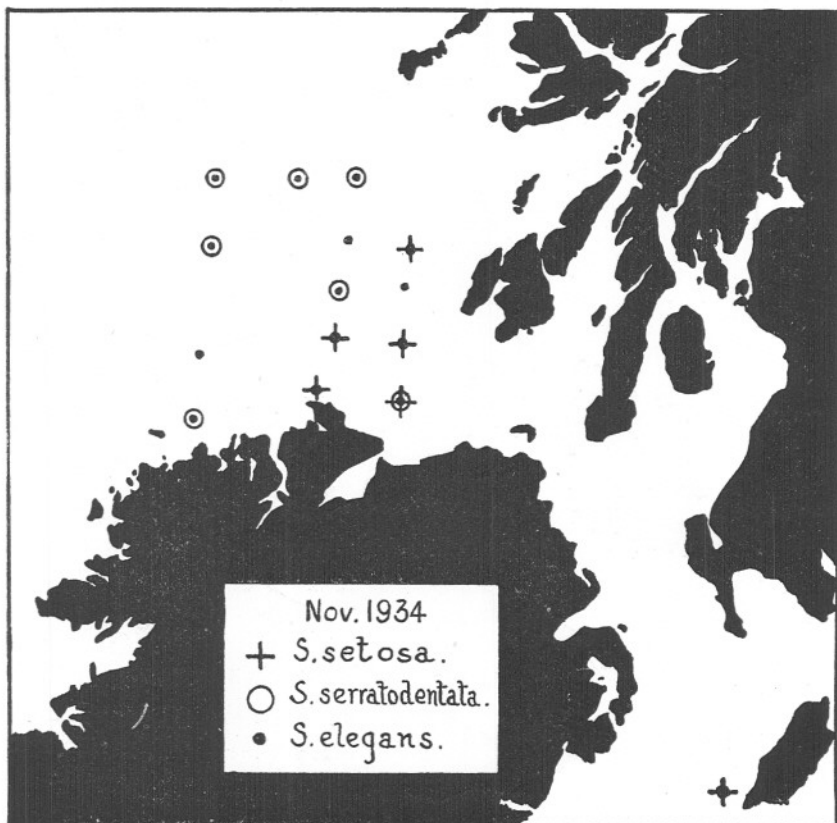


FIG. 5.—Chart indicating the positions of occurrence of the three species of *Sagitta* off the north coast of Ireland and at Port Erin in November, 1934.

I am indebted to Mr. W. C. Smith, the curator of the Port Erin Laboratory, for allowing me to see samples of plankton taken off the Isle of Man in the Irish Sea in 1934. In November a number of *S. setosa* were found although *S. elegans* had predominated earlier in the year. Samples of *Sagitta* caught off the North Coast of Ireland in the same year, 1934, have also been kindly sent me by Mr. G. P. Farran. *S. setosa* only occurred there in November, and then only in small numbers at the stations nearest to the entrance to the North Channel into the Irish Sea (see

Figure 5). It is likely that these had filtered out from the Irish Sea where they were numerous at that time of year. These *S. setosa* in the Irish Sea may have been a local race, or may have drifted up from the English Channel round Land's End and through the St. George's Channel. Examination of a number of samples taken in different localities in the

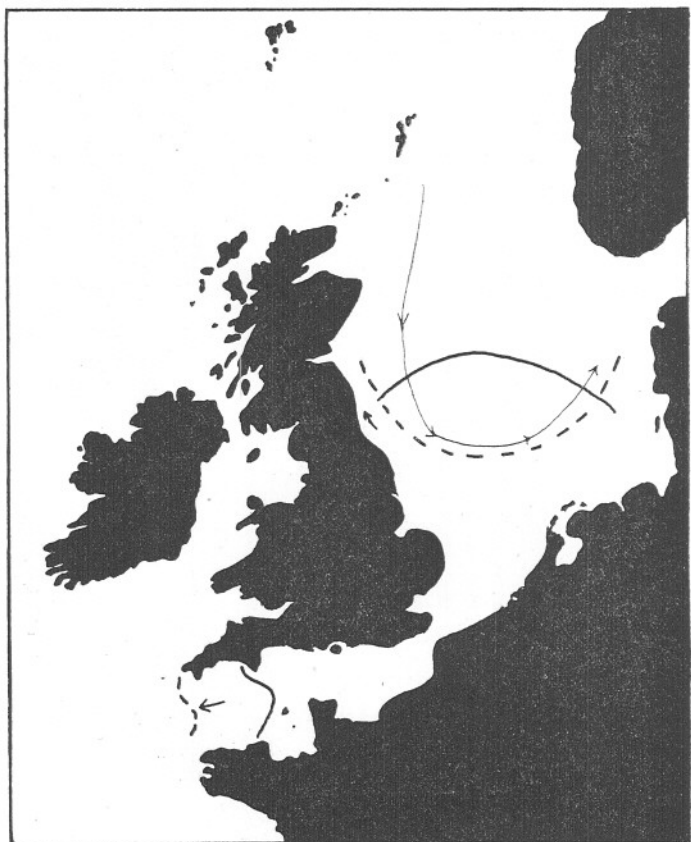


FIG. 6.—Chart showing the hypothetical centre of distribution of *Sagitta setosa* in the North Sea and English Channel (unbroken line boundaries) and the change in distribution effected by an increase of flow of Atlantic water from the north into the North Sea (broken line boundaries).

Irish Sea in the years 1909, 1913, and 1925, showed an almost entire preponderance of *S. elegans*.

In the area sampled north of Ireland *S. elegans* was found at all stations, while at the outermost stations to the west and north the more oceanic *S. serratodentata* was common (Figure 5).

The above evidence seems to indicate very strongly that *S. setosa* is a purely neritic species, with its main centre of distribution in the southern North Sea and English Channel. As such it may be expected to have

rather a similar distribution to that of the neritic copepod *Centropages hamatus*. If this be so the fluctuations in the numbers of *S. elegans* and *S. setosa* off Plymouth would appear to give a striking confirmation to the theory put forward by Carruthers (1934) that "the Dover Straits current waxes and wanes through the year in a sort of buffer relationship with the current from the north—that there exists a sort of see-saw conflict between the two." In Figure 6 I have drawn a hypothetical distribution for *S. setosa*, based on that of *C. hamatus* (Scott, 1911, Plate XVIII), showing how an increased flow of Atlantic water from the north into the North Sea would tend to push the *S. setosa* population, or "Channel" water towards the mouth of the Channel, while an increased flow from the Channel through the Straits of Dover into the North Sea would tend to bring the "western" water with *S. elegans* past Plymouth. At the same time an increased flow of water into the northern North Sea would bank up the southern North Sea water and some might tend to flow up the east coast of England thus carrying *S. setosa* further north than usual. This would account for the predominance of *S. setosa* on the Northumberland coast in 1921 as shown by Meek; it is significant also that in 1921 *S. setosa* was unusually abundant at the Sevenstones.

It is evident that we are greatly in debt to Professor Meek for drawing attention to the value that these two *Sagitta* species may have as indicators of the origins of water masses.

In conclusion it should be pointed out that at this stage it is unsafe to attempt to draw definite deductions. At most we have a somewhat hazy picture; yet the indications are clear enough to show that the problem is worth following up in greater detail. It is especially desirable that the limits of the distribution of the different species concerned should be more closely defined over the whole area.

THE POSSIBLE VALUE OF SAGITTA AS AN INDICATOR OF CONDITIONS IN AREAS FAR REMOVED FROM PLYMOUTH.

Since all the species in association with *S. elegans* are boreal or arctic boreal species it is likely that they will also prove of value as indicators of Atlantic water entering the northern North Sea, as indeed is already indicated by Künne* (in Wulff, Bückmann and Künne, 1934, p. 334).

* I did not see the data given by Künne (1934) until after this report was finished. Künne gives as indicators for the south-west Dogger Bank swirl *Cosmetira megalotis*, *Aglantha digitalis*, *Nyctiphanes couchi*, *Agalma elegans*, *Clione limacina*, *Limacina retro-versa*, the larvæ of *Luidia sarsi*, and *Oikopleura labradoriensis*. Of these *C. megalotis* is very closely allied to *C. pilosella*; and *A. rosea* recorded in this paper is regarded by some as a variety of *A. digitalis*. It is interesting also that Künne should regard the larvæ of *Luidia* as indicators, since off Plymouth in the late summer of 1930 *Luidia* larvæ were very abundant; both *L. sarsi* and *L. ciliaris* young were recorded (see Plymouth Marine Fauna, 1931, pp. 291–292). Although *N. couchi* occurred in large numbers in 1930 with *M. norvegica* it is doubtful whether it can be regarded as a reliable indicator of "western" water as it is the least oceanic of the Euphausiids occurring here. At any rate its presence should only be regarded as significant if it is unusually numerous.

Mention has been made in the Annual Reports of the Fishery Board for Scotland for the years 1930 to 1933 of certain organisms that have characterised the waters rounding the North of Scotland from year to year. *Stephanomia* was recorded (as *Agalmopsis*) in 1930; in that year it was especially abundant off Plymouth. Amongst other species of medusæ *Cosmetira* and *Laodicea* are mentioned for 1931; although no reasons have been found as yet for regarding *Laodicea* as an indicator in the Channel region it is interesting that in the summer of 1931 *Laodicea* was very much more abundant off Plymouth than in any of the other years under review. In 1932 *Cyclosalpa bakeri* was recorded from the North of Scotland; in that year salps occurred off Plymouth although a different species, *Salps fusiformis*.

In 1931 *Doliolum gegenbauri* was recorded for the first time off Plymouth; in 1933 this species appeared in the North Sea (Lucas, 1933).

Savage and Hardy (1935) have for a number of years been studying the occurrence and distribution of large concentrations of the diatom *Rhizosolenia styliformis* in the southern North Sea. This diatom has been regarded as an indicator of Atlantic water. If the presence or absence of large patches of *Rhizosolenia* in the southern North Sea be compared with the variations in the *Sagitta* population off Plymouth a certain amount of agreement is shown. For instance, in the years 1930 and 1931 when *S. elegans* was predominating at Plymouth there were no concentrations of *Rhizosolenia* in the area studied in the North Sea. In 1932, when *S. setosa* predominated off Plymouth, *Rhizosolenia* was abundant in the North Sea. Although for previous years full data are not available for Plymouth, what evidence we have strongly supports the above indication. In 1921, when *S. setosa* was very abundant at the Sevenstones, *Rhizosolenia* occurred in the North Sea. In 1924, when *Meganyctiphanes* occurred off Plymouth and in which year *S. elegans* was at any rate predominating in July, an absence of phytoplankton was recorded in the North Sea. This is further evidence that the two populations of *Sagitta* swing to and fro off Plymouth according to the strength of the flow of Atlantic water into the North Sea from the north. When this flow is strong *Rhizosolenia* is carried in the Atlantic water, rich in phosphates (Thomsen, 1933), to seed the region of the south-west Dogger Bank swirl, and in the Channel *S. elegans* becomes pushed away to the westward so that *S. setosa* is brought into the neighbourhood of Plymouth.

Examination of the *Sagitta* results for 1933 and 1934 shows that with the predominance of *S. setosa* off Plymouth *Rhizosolenia* is likely to have occurred in the southern North Sea in both years. Furthermore seeing that *S. elegans* was entirely absent off Plymouth in the autumn of 1933, but present in small numbers in 1934, it seemed likely that a greater volume of Atlantic water passed into the North Sea from the north in

1933 than in 1934. Thus it would be expected that the conditions were suitable for producing a bigger flowering of *Rhizosolenia* in 1933 than in 1934. Actually the *Rhizosolenia* concentration was very dense in 1933 (see Min. Agric. Fish. Report on Sea Fisheries for the year 1933 (1934, p. 46)), and Mr. R. E. Savage has confirmed by letter that *Rhizosolenia* occurred in smaller quantities in 1934. If this agreement should be confirmed in the future we shall be in the position of being able to predict from the composition of the *Sagitta* population off Plymouth what are the chances that there will be concentrations of *Rhizosolenia* in the southern North Sea in the autumn. Savage and Hardy have further shown that the movements of the Herring shoals are apparently influenced by the occurrence and distribution of these phytoplankton concentrations, and the landings of Herring at Lowestoft and Yarmouth are affected in consequence.

The possible value of *Sagitta* as an indicator of Herring movements off Plymouth should also be borne in mind. It can now be realised that the Herring spawning in the neighbourhood of Plymouth and along the south Cornish coast visit a region in which either "Channel" water or "western" water may predominate. It is probable that at the spawning period a fish is most susceptible to the physical and chemical conditions of the water. Close watch should therefore be kept to see whether the shoals visiting Plymouth when *S. setosa* predominates are of the same composition and origin as those spawning here when *S. elegans* predominates.

SUMMARY.

The possibility that certain plankton organisms retained by a stramin net may prove of value as indicators in elucidating the water movements at the mouth of the English Channel is shown.

The water populated by *Sagitta setosa* is shown to be clearly demarked from that in which *S. elegans* lives, the latter living to the west of the Channel mouth south of Ireland. The water in which *S. elegans* lives has here been called "western" water.

It is shown that the planktonic indicators for "western" water are *Sagitta elegans*, *Sagitta serratodentata*, *Aglantha rosea*, *Stephanomia bijuga*, *Clione limacina*, *Meganyctiphanes norvegica*, *Thysanoessa inermis*, and *Cosmetira pilosella* (in spring and summer only). *Sagitta setosa* is regarded as an indicator of "Channel" water. Muggiæa, Salps, Doliolids, *Liriope exigua* and *Euchæta hebes* are regarded as indicators of "south-western" water.

The geographical distribution of *S. setosa* is discussed. It is shown that

it is probably a neritic species mainly confined to the English Channel and North Sea.

S. setosa predominates off Plymouth when the easterly element in the Dover Straits current is suppressed and the flow of Atlantic water into the North Sea from the north is strong (Carruthers' Theory). The two Sagitta populations swing to and fro off Plymouth so that, with a strong flow of Atlantic water into the North Sea from the north, the *S. elegans* population is pushed westward to the mouth of the Channel and *S. setosa* occurs off Plymouth.

During the course of the five years, 1930 to 1934, an agreement has been found between the occurrence or absence of concentrations of the diatom *Rhizosolenia styliformis* in the southern North Sea and the variations in the composition of the Sagitta population off Plymouth. In the years in which *Rhizosolenia*, an indicator of Atlantic water, was abundant in the southern North Sea *S. setosa* predominated off Plymouth; when *Rhizosolenia* was absent *S. elegans* predominated.

These diatom concentrations have been shown by Savage and Hardy to have an apparent influence on the movements of the Herring which is reflected in the landings at Yarmouth and Lowestoft.

REFERENCES.

- BONNEVIE, KR. 1913. Pteropoda from the "Michael Sars" North Atlantic Deep-Sea Expedition, 1910. Rep. Sci. Res. M. Sars N. Atl. Exped., 1910, Vol. III, Part I, 1913 (reprinted 1933), pp. 1-69.
- BROWNE, EDWARD T. 1896. On British Hydroids and Medusæ. Proc. Zool. Soc. London, pp. 459-500.
- 1900. The Fauna and Flora of Valencia Harbour on the West Coast of Ireland. II. Report on the Medusæ (1895-98), pp. 694-736.
- 1906. Biscayan Plankton collected during a cruise of H.M.S. "Research," 1900. Pt. IX. The Medusæ. Trans. Linn. Soc. London. 2nd Ser. Zool. Vol. X, Pt. 6, pp. 163-187.
- BYGRAVE, W. 1911. Report on the Plankton of the English Channel in 1906. Mar. Biol. Assoc. Internat. Fish. Invest. 3rd Report (Southern Area), 1906-1908, pp. 235-267.
- CARRUTHERS, J. N. 1928. The Flow of water through the Straits of Dover as gauged by continuous current meter observations at the Varne Lightvessel (50°56'N.-1°17'E.). Min. Agric. Fish., Fish. Invest., Ser. II, Vol. XI, No. 1, pp. 1-109.

- 1934. Certain Fishery Applications of the results of researches on marine currents carried out from the Lowestoft Fisheries Laboratory. British Association Rep. Annual Meeting, 1934, Section D, pp. 325–326.
- 1935. The Flow of water through the Straits of Dover as gauged by continuous Current-Meter Observations at the Varne Lightvessel ($50^{\circ} 56' \text{ N.} - 1^{\circ} 17' \text{ E.}$). Part II.—Second Report on Results Obtained. Min. Agric. Fish., Fish. Invest., Ser. II, Vol. XIV, No. 4, pp. 1–67.
- FARRAN, G. P. 1911. Copepoda. Résumé des observations sur le Plankton des Mers explorées par le Conseil pendant les Années 1902–1908. Bull. Trimest. Cons. Int. Explor. Mer., Pt. II, pp. 81–149.
- FROST, WINIFRED E. 1932. Observations on the Reproduction of *Nyctiphanes couchii* (Bell) and *Meganyciphanes norvegica* (Sars) off the South Coast of Ireland. Proc. Roy. Irish Acad., Vol. XL, Sect. B, No. 14, pp. 194–232.
- GOUGH, LEWIS HENRY. 1905, a. On the Distribution and the Migrations of *Muggicea atlantica*, Cunningham, in the English Channel, the Irish Sea, and off the South and West coasts of Ireland, in 1904. Cons. Perm. Int. Explor. Mer., Publ. Circ. No. 29, pp. 1–13.
- 1905, b. Report on the Plankton of the English Channel in 1903. Mar. Biol. Assoc. Internat. Fish. Invest., 1st Report (Southern Area), 1902–1903, pp. 325–377.
- HARVEY, H. W. 1930. Hydrography of the Mouth of the English Channel, 1925–1928. Journ. Mar. Biol. Assoc., N.S., Vol. XVI, No. 3, pp. 791–820.
- 1934. Hydrography of the Mouth of the English Channel, 1929–1932. *Ibid.* Vol. XIX, No. 2, pp. 737–746.
- HICKLING, C. F. 1925. Notes on Euphausiids. Journ. Mar. Biol. Assoc., N.S., Vol. XIII, No. 3, pp. 735–745.
- HUNTSMAN, A. G. 1919. Some Quantitative and Qualitative Plankton Studies of the Eastern Canadian Plankton. Canadian Fisheries Expedition, 1914–1915, pp. 405–485, Ottawa.
- KRAMP, P. L. 1913. Schizopoda. Résumé des Observations sur le Plankton des Mers explorées par le Conseil pendant les Années 1902–1908. Bull. Trim. Cons. Perm. Int. Explor. Mer., Pt. III, pp. 539–556.
- 1919. The Danish Ingolf Expedition, Vol. V, No. 8, Medusæ. Part I, Leptomedusæ, pp. 1–111.
- 1933. Nordisches Plankton. XXII Lief., XII. Craspedote Medusen. 3 Teil: Leptomedusen, pp. 541–602.

- LEBOUR, M. V. 1924. The Euphausiidae in the Neighbourhood of Plymouth and their Importance as Herring Food. Journ. Mar. Biol. Assoc., N.S., Vol. XIII, No. 2, pp. 402-432.
- LUCAS, C. E. 1933. Occurrence of *Doliioletta gegenbauri* (Uljanin) in the North Sea. Nature, Vol. 132, p. 858.
- LUMBY, J. R. 1925. The Salinity and Water Movements in the English Channel and Southern Bight during the Period 1920-1923. Min. Agric. Fish., Fish. Invest., Ser. II, Vol. VII, 1924, pp. 1-37.
- MATTHEWS, DONALD J. 1924. The Salinity and Temperature of the Irish Channel and the Waters south of Ireland. Fisheries, Ireland, Sci. Invest., 1913, IV, pp. 1-26.
- MEEK, ALEXANDER. 1928. On *Sagitta elegans* and *Sagitta setosa* from the Northumbrian Plankton, with a Note on a Trematode Parasite. Proc. Zool. Soc. London, No. 29, pp. 743-746.
- PAULSEN, OVE. 1910. Pteropoda. Résumé des Observations sur le Plankton des Mers explorées par le Conseil pendant les Années 1902-1908. Bull. Trim. Cons. Perm. Int. Explor. Mer., Pt. I, pp. 52-59.
- PELSENEER, PAUL. 1906. Biscayan Plankton collected during a cruise of H.M.S. "Research," 1900. Pt. VII. Mollusca. Trans. Linn. Soc., London, 2nd Ser., Zool., Vol. X, Pt. 5, pp. 137-157.
- RITTER-ZÁHONY, RUDOLF VON. 1911. Die Chätognathen der Plankton-Expedition. Ergeb. d. Plankt. Exped. d. Humboldt-Stiftung, Bd. II, H.e., pp. 1-32.
- RUSSELL, F. S. 1927. The Vertical Distribution of Marine Macroplankton. V. The Distribution of Animals caught in the Daytime in the Plymouth Area. Journ. Mar. Biol. Assoc., N.S., Vol. XIV, No. 3, pp. 557-608.
- 1933, a. The Seasonal Distribution of Macroplankton as shown by Catches in the 2-metre Stramin Ring-trawl in Off-shore Waters off Plymouth. *Ibid.*, Vol. XIX, No. 1, pp. 73-82.
- 1933, b. On the Biology of *Sagitta*. IV. Observations on the Natural History of *Sagitta elegans* Verrill and *Sagitta setosa* J. Müller in the Plymouth Area. *Ibid.*, Vol. XVIII, No. 2, pp. 559-574.
- 1934. On the Occurrence of the Siphonophores *Muggiea atlantica* Cunningham and *Muggiea kochi* (Will) in the English Channel. *Ibid.*, Vol. XIX, No. 2, pp. 555-558.
- 1935. The Seasonal Abundance and Distribution of the Pelagic Young of Teleostean Fishes Caught in the Ring-trawl in Offshore Waters in the Plymouth Area. *Ibid.*, Vol. XX, No. 2, pp. 147-179.

- RUSSELL, F. S., and KEMP, STANLEY. 1932. Pelagic Animals off the South-west coasts of the British Isles. *Nature*, Vol. 130, p. 664.
- RUSSELL, F. S., and HASTINGS, A. B. 1933. On the Occurrence of Pelagic Tunicates (Thaliacea) in the Waters of the English Channel off Plymouth. *Ibid.*, Vol. XVIII, No. 2, pp. 635-640.
- SAVAGE, R. E., and HARDY, A. C. 1935. Phytoplankton and the Herring. Part I. 1921 to 1932. *Min. Agric. Fish. Invest.*, Ser. II, Vol. XIV, No. 2, pp. 1-73.
- SCOTT, THOS. 1911. Copepoda. Résumé des Observations sur le Plankton des Mers explorées par le Conseil pendant les Années 1902-1908. *Bull. Trim. Cons. Int. Explor. Mer.*, Pt. II, pp. 106-149.
- THOMSEN, HELGE. 1933. The Distribution of Phosphate and Nitrate in the North Sea in May, 1932. *Cons. Perm. Int. Explor. Mer.*, Rapp. Proc. Verb., Vol. LXXXV, pp. 42-46.
- WULFF, A., BÜCKMANN, A., and KÜNNE, Cl. 1934. Berichte über die Teilnahme an einer Fischereischuttfahrt der "Weser" zu Untersuchungen über die Verbreitung der Heringslarven in der südlichen Nordsee und dem Kanaleingang. 7 November bis 15 Dezember 1933. *Ber. deutsch. wiss. Komm. f. Meeresforsch. N.F.*, Bd. VII, Heft 3, pp. 328-342.

APPENDIX.

Since the above report was written a number of samples of *Sagitta* have been kindly sent to me by Dr. J. Le Gall, Director of the Marine Laboratory at Boulogne, from catches made during fishery cruises off the mouth of the Channel. Although these samples are too few to show the water movements they confirm the general idea outlined above. Collections were made sometimes further south than the area covered by the Irish investigations and these indicated that the distribution of *S. elegans* might stretch

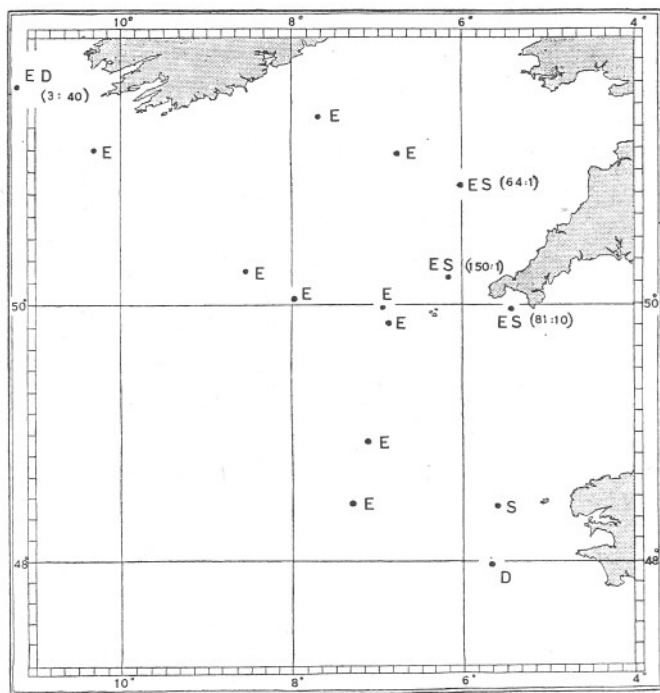


FIG. 7.—Distribution of three species of *Sagitta* shown by collections made in May and June, 1929. E, *S. elegans*; S, *S. setosa*; D, *S. serratodentata*. The figures in brackets show the proportions in which two species occurred together.

right across the mouth of the Channel. The occurrence of the different species of *Sagitta* in May and June, 1929, is shown in Figure 7. This clearly indicates that *S. setosa* was confined to the coastal and Channel water and may be carried northwards round Land's End in small numbers.

These collections enable the following new localities for *S. setosa* to be recorded :

13.vii.25	.	.	47° 46' N. : 4° 13' W.
1.vi.27	.	.	49° 52' N. : 6° 16' W.
16.v.29	.	.	48° 27' N. : 5° 33' W.
29.iv.31	.	.	48° 15' N. : 4° 36' W.