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CONTINUOUS PLANKTON RECORDS:

PHYTOPLANKTON IN THE NORTH SEA, 1938-39

PART I.—DIATOMS

BY

C. E. LUCAS, B.Sc.

(Assisted by W. MACNAE, B.Sc.)

CONTENTS

INTRODUCTION: MATERIAL AND METHODS.

The Plankton Recorder survey was extended at the beginning of 1938 to cover the northern as well as the southern North Sea. In addition to those forming the 1932–37 survey (see Lucas, 1940, ' Bulletin ' No. 3) an extra line ran from Hull towards Oslo, three ran from Leith to Hamburg, Copenhagen and Lerwick, and two from the Pentland Firth to Hamburg and Norway. That from Hull towards Oslo was discontinued at the end of 1938 so that the gear could be used in 1939 on an experimental line across the opening to the Faroe–Shetland Channel, described in a later ' Bulletin.' The war suspended all work at sea after August, 1939, and since it was uncertain when it could be resumed, we have thought it desirable to publish at once the data for 1938 and the part of 1939. The present paper deals only with the Diatoms. The account of the Dinoflagellates and Phaeo-

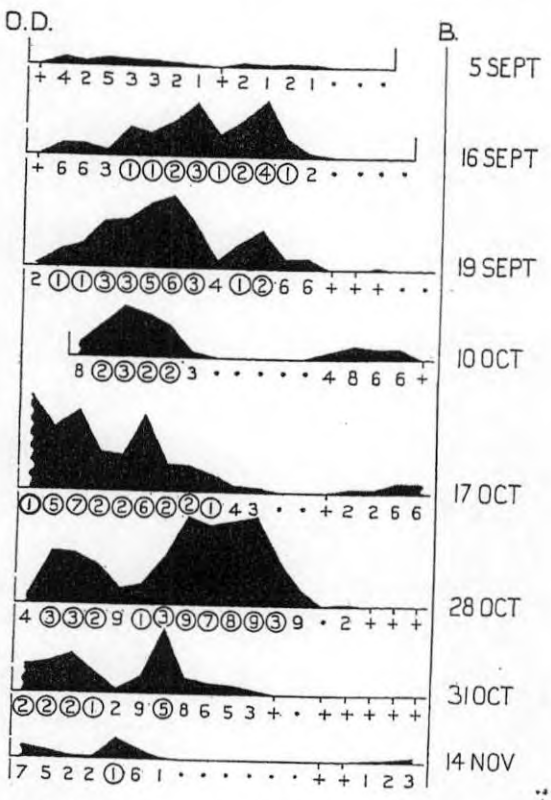
cystis has been postponed for reasons of economy; all the data has been prepared for publication, and we hope to present it in the next 'Bulletin.' The relevant zooplankton data should appear in the two subsequent numbers.

Full details concerning the shooting and hauling of the Recorders during the two years appears in 'Bulletin' No. 7 (Plates I to V and Record List). As in the earlier series there are rather more records for the phytoplankton than for the zooplankton, mainly due to the extended autumn programme in the Southern Bight. It will be seen that occasionally (*e. g.* July, 1938) records at the beginning or end of a month have been allocated to the previous or subsequent month for convenience, usually to provide the most valuable combination of dates for illustrating the changing time picture. On the other hand, although the calendar month has not been strictly adhered to, it was clearly a convenient unit, and in no case is the record more than a few days displaced *nor* has a period of more than 31 days been used. In all some 48,000 miles of record were obtained.

As before, mechanical defects have occurred sometimes, although the new developments in the machine (Hardy, 1939, 'Bulletin' No. 1) led to an appreciable decrease after June, 1938. General principles outlined in 'Bulletins' Nos. 1, 2 and 7 are followed here, certain defective records being rejected, some discarded in part, and a few being utilized with the knowledge that a part of the plankton may have been lost (details of such defective and "qualitative" records are also in 'Bulletin' No. 7). Unfortunately it has not been possible to obtain adequate sampling in every month (March, 1938, being a particular example), but in most months a set of traverses is available which should indicate the principal features of the phytoplankton in the North Sea for that period. Since these are usually the same for each month they provide standards for comparison and reference in so far as they are suitably placed. Whilst they are grouped in periods of approximately one month, we should remember that there may be a considerable time lag between the first and the last of a set, and give this due regard when necessary (see Plates I to V of 'Bulletin' No. 7). Sometimes there is more than one record on a line during the month (*e. g.* the Leith–Lerwick route during the summer and the Hull–Bremen route in the autumn). In the series of maps these have been arranged where possible "in parallel" (the earlier record above) and bracketed. When this was not possible, the extra data have been recorded in the margin (*e. g.* Plate IX); the numerals I, II or III for the Bremen route and I or II for the Lerwick route give the order in which the records were obtained.

There have been no important changes in the methods of analysis since the introduction in 1937 of the system for providing estimates of organisms per mile in blocks of ten miles ('Bulletin' No. 3, Vol. I, p. 75). The lengths of silk equivalent to the ten-mile blocks are calculated for each roll and representative portions of each examined for phytoplankton: the pieces are then cut off and passed to the zooplankton workers. Thereafter they are stored for any future use: where Phaeocystis is present in quantity, one-half is scraped for an estimate of the volume before being stored.

There has necessarily been a change in the method of presentation. For reasons of economy we can no longer consider results from each route separately, as in ' Bulletin ' No. 3 ; the records have been arranged on maps, and in this form will provide the main basis for reference. With the complex network of lines it was impossible any longer to continue with the simple graphical methods of the earlier ' Bulletins ' ; in its place we have adopted a system of symbols to represent the



TEXT-FIG. 1.—Graphs and symbols showing the abundance of *Rhizosolenia styliformis* between the Outer Dowsing (O.D.) and the Borkum (B.) light-vessels in the autumn of 1937 according to the earlier (graphical) and the present (symbolical) systems. For scales see ' Bulletin ' No. 3, Vol. I, Text-fig. 4, and Plate IX in the present paper.

numbers per mile found on each block. *Rhizosolenia styliformis* and *Biddulphia sinensis* are shown on large maps at six to the page (*e. g.* Plate VIII) ; sets of symbols show the general distribution, whilst the numerical values denote the varying quantities with more precision. The two methods may be compared by reference to Text-fig. 1, in which several records of *R. styliformis* on the Bremen Line have been reproduced for the period September–November, 1937, in both methods. For scales see Text-fig. 4 in ' Bulletin ' No. 3, and Plate IX here. (Note that for convenience the graphs in the former were limited in height.)

Symbols only have been used for the other diatoms and the different diagrams consist of the following types :

(1) All the data are shown on monthly maps at twelve to the page, so that the two years are seen facing one another (*e.g.* Plates XVI and XVII). For comparison between these symbols and those used in ' Bulletin ' No. 3, see p. 40.

(2) Twelve or six selected months have been taken to illustrate the principal features of the development (*e. g.* Plates XXXIV and XXXV). Any essential remarks about the other data are given in the text, but otherwise they are arranged as in (1).

(3) Some species which have been scarcer, or which at present seem to have less significance, have been illustrated in periods usually longer than one month (*e. g.* Plate XXXVII). The overall distribution is shown for each of these, together with the Roman numerals for the months in which the principal patches appeared. Additional remarks may be in the text.

(4) Only the overall distribution on the normal lines is shown for each year, or the years combined (*e. g.* Plate XV). It should be remembered that 1939 was incompletely sampled, so that for species which are normally abundant in the autumn it is impossible to show satisfactory comparisons over the two years. (It is important to emphasize this in relation to the whole survey, since even the omission of the data from one or two records may seriously affect the resulting picture.) For the two diatoms *Rhizosolenia calcar-avis* and Dactyliosolen, so few traces were found that they could conveniently be referred to the months.

Clearly, when working on the ten-mile block system, one will meet with sections at the beginning or the end of the record which are of less than ten miles. For the phytoplankton we have normally used such as are over five miles as representative of that block, and have rejected the others.

Throughout the programme we have attempted to obtain more precise data than was possible in the earlier work ; there remain certain groups for which it has still been impracticable to find the time required for detailed analysis, and these will be shown as groups (*e. g.* the group Hyalochaeta excluding *Chaetoceros decipiens* and the " Naviculoid " diatoms). There are necessarily a number of features rendering the approximations involved in this work greater than those normally made (mainly due to the difficulties of analysis within dense concentrations of mixed diatoms). On the other hand, the broad scale methods of presentation of the data and the continuous method of survey reduce the significance of such deficiencies. We are at present concerned more with the large differences which can be (and are) found within relatively short distances : these greatly exceed such errors as we have reason to expect exist in the individual data.[1] One other

[1] It is important to remember that the silk used in this work, 60 meshes to the inch, is much coarser than that normally used for collecting phytoplankton. Consequently the quantities of many of the diatoms are much smaller than those usually obtained with such nets, although we believe the differences in the quantities found *within* this method to be significant of real differences in the conditions of the sea (*cf.* discussion in ' Bulletin ' No. 3, Vol. I, p. 77).

point concerns the depth at which the samples were obtained. For many organisms it is clear that sampling at ten metres may be even less reliable in the deeper northern waters than in the Southern Bight. Although we have been unable to investigate this further, we have reason to believe that since the phytoplankton flourishes only at relatively shallow depths, the differences will be less serious here (*cf.* Gran, 1915 ; Marshall and Orr, 1930). The general problem of relation between depth and the significance of the sample was discussed in ' Bulletin ' No. 3, and we consider that many of the conclusions made there will apply also to the deeper waters of the northern North Sea.

The northern material has been analysed by C. E. L., and that for the south by W.M. Owing to Mr. Macnae's resignation from the Department to take up other work, he has been unable to assist in working up the results.

The Distribution of the Diatoms.

As far as possible the maps have been left to speak for themselves, whilst the usual descriptive section of the text will be limited to a few additional remarks concerning material which has had to be omitted (see above) and certain points to which attention should be drawn. In addition to the series of plates reference should also be made to Text-figs. 2–5, in which the data for most of the diatoms on the southern lines has been presented in an appropriate form for comparison with ' Bulletin ' No. 3. A few results will then be reviewed briefly in the discussion at the end of the paper, when some comparisons will be made between the data for the two years, and between these and the earlier years for the southern routes. We hope that it will be possible to deal more fully in later Bulletins with some matters which have had to be omitted here or mentioned only very briefly.

As before, reference has normally been made to Lebour (1930) for identification and the names used there have been adopted. When in the text reference is made to " traces " or " patches " the former term indicates those small numbers of any diatom which are denoted by the symbol " + " on the series of maps ; the term " patches " is used for the larger concentrations denoted by the various other symbols on the scales provided.

Paralia sulcata (Ehr.). (Plate VI shows the main concentrations.)

This is not a truly planktonic diatom, but is liable to be carried into the upper layers at times of extensive disturbance. Although seldom numerous in comparison with some other diatoms, its variations should be useful in connection with water movements. Plate VI shows the marked seasonal variations together with the great decrease in 1939, particularly in the Southern Bight. We may note its general scarcity in the north-central North Sea, except in the winter months, this being in agreement with the findings of Ostenfeld (1913). The various species of Gyrosigma, shown alongside, have often a similar distribution, and were also

much scarcer in 1939. In these records both were very scarce round the west coast of Norway.

Coscinodiscus spp. (Plate XXXVIII shows the main features in selected maps.)

It was impracticable to separate the species of this genus, but the large ones (mainly *C. concinnus*) have been separated from the smaller ones, which have been much scarcer on the whole ; the larger ones only are shown in the Plate, whilst in Text-fig. 4 the whole data has been used for comparison with the 1932–37 results. In addition to those shown, a few traces were found on the Leith–Copenhagen line in May, 1939. The diffuse, and more northern, distribution of 1939 should be noted. The only patches found were in the winter rather than the spring quarter. It remains possible that some of the diatoms identified here as *Thalassiosira decipiens* were in fact small Coscinodiscus, in view of well-known difficulties of identification.

Thalassiosira spp. (Including Coscinosira spp.) (Plates XXII and XXIII.)

When these were dense we did not feel that the time would justify the labour of separating Coscinosira from the main group (or the different species of Thalassiosira). *Th. decipiens* has been a common form in the earlier stages of the spring growth[1] and thereafter *Th. gravida* and *Th. Nordenskiöldii* have been the commonest species. The arrangement of patches in the north in relation to the possible entry of external waters should be noted, and also the apparent mixing of such patches in the spring of 1939. In general the group was more abundant in 1939. The persistence of patches off the north-east coast of Scotland (even up to October in 1938) is of interest in view of Ostenfeld recording (for both *Th. gravida* and *Th. Nordenskiöldii*) their large numbers off the coast of Scotland in August when they were scarce elsewhere.

Lauderia borealis Gran. (Plate XXXVIII shows the main features in selected maps.)

In addition to those shown, one or two traces appeared in December, 1938, and January, 1939. Note the much earlier north-western growth of 1939. The general contrast between the autumn-winter distribution of the southern North Sea and the spring-summer one in the north agrees well with Ostenfeld's findings, although the August–September patches off Heligoland in 1938 are apparently an exception.

Skeletonema costatum (Greville). (Plate XXXI shows the main features in selected maps.)

Other traces were found in May, November and December, 1938. It has been very spasmodic in the records and is clearly more easily lost than most diatoms

[1] *Cf.*, however, the note on Coscinodiscus spp. Whilst these appeared to us to be *Th. decipiens*, it remains possible that some of the isolated cells were, in fact, small Consinodiscus of the types forming the " Disco " plankton of earlier writers.

(note the modified scale). Once again autumn patches were scarce ; the recording of patches near the Skagerrak in October, 1938, is so far the only instance in these records strictly in accordance with Ostenfeld's observation of a secondary maximum.

Stephanopyxis turris (Greville). (Plate XXIX shows the overall distribution.)

It was absent from June to August inclusive in 1938, whilst the sole traces in 1939 were in April ; thus it was much scarcer in the spring of that year. Its scarcity in the northern waters is interesting in view of Ostenfeld's suggestion that it may enter " the North Sea *via* the North of Scotland " (1913, p. 419).

Dactyliosolen spp. (Plate XI shows all the records.)

A few cells were first seen on the Bergen line early in October, 1938, followed a fortnight later by a few more a little to the east. Another trace was also found off the Skagerrak in November. It is probable that the species was *D. mediterraneus*. Ostenfeld notes (1913, p. 508) that it " is carried by the current through the Faroe–Shetland Channel into the North Sea."

Leptocylindrus danicus Cleve. (Plate XXXVII shows all the records.)

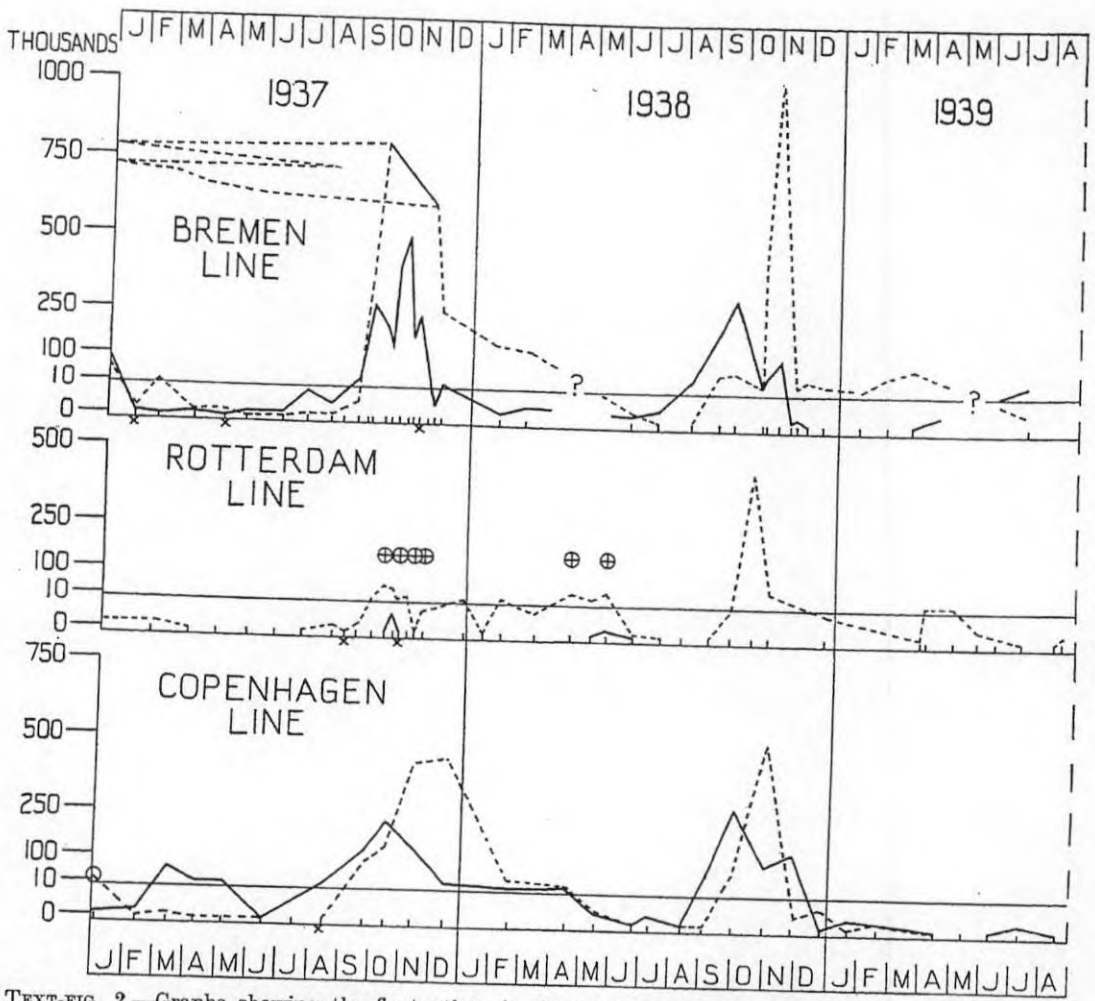
Note its generally more northern distribution in 1939. Like Skeletonema it has been very patchy in these records, probably owing to its small size.

Guinardia flaccida Castr. (Plate XXIX shows the overall distribution for each year.)

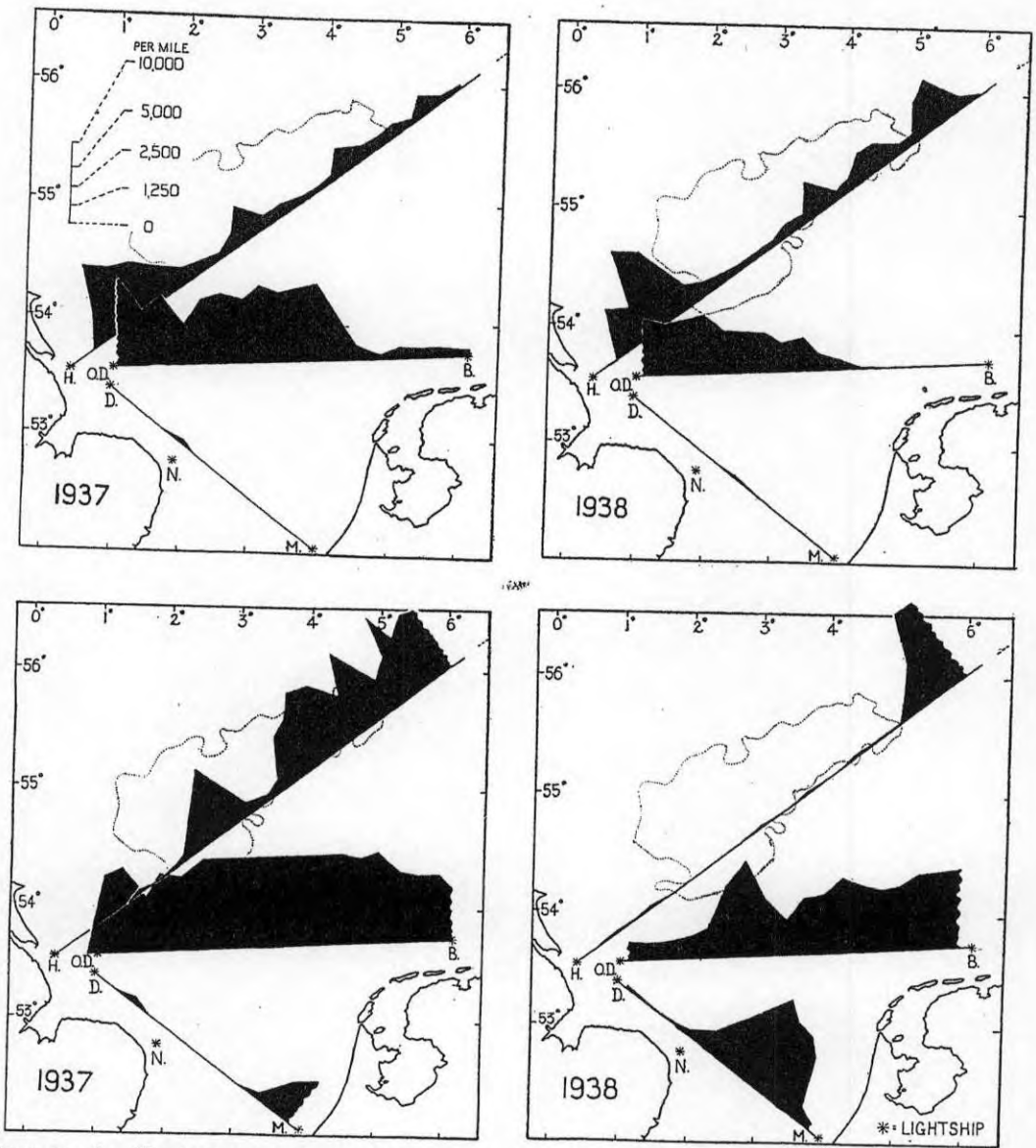
One small patch occurred near the junction of the Esbjerg and the Leith–Hamburg lines in July, 1938 ; only traces were found on other occasions. The north-western traces of 1939 appeared in July and August. We have already remarked (' Bulletin ' No. 3) that a tendency to live in deeper waters more than other forms may account for its unusual scarcity in our records.

Corethron criophilum Castr. (Plate XV shows the overall distribution for each year.)

The largest numbers were found on the Lerwick line in August, 1939, but it was not a dense patch. Previously, fair numbers had been found at the eastern end of the Faeroe line (July, 1939). In view of Ostenfeld's remarks, the few occurrences off the Skagerrak in 1938 (occurring in October) are interesting. He says " it may undoubtedly be considered an indicator of Atlantic water." Similarly the few occurrences on the Hull–Bremen and Hull–Rotterdam lines in 1932 and 1933 may prove to be important.



TEXT-FIG. 2.—Graphs showing the fluctuations in the total numbers of *Rhizosolenia styliformis* (continuous line) and *Biddulphia sinensis* (broken line) recorded between January, 1937, and August, 1939, for comparison with Text-fig. 5 of ' Bulletin ' No. 3 (1932–37). The records for the Bremen line (between Outer Dowsing and Borkum light-vessels), the Rotterdam line (between E. Dudgeon and Maas light-vessels) and the Copenhagen line (from Humber light-vessel for 250 miles towards the Hanstholm) are shown separately. Above and below are time scales in months : J., F., M., A., etc. Each point on a graph represents the total number of cells of the particular diatom found on one record ; the exact position of each record in relation to the time scale is shown as a small vertical line against the base-line of the graphs. The scale of numbers is in thousands of cells per record ; it should be noted that the vertical scale has been exaggerated below the 10,000 point in order to magnify the small, but often significant changes which occur when these diatoms are scarcer. The true base line, however, is also shown (*i. e.* just below point " 10 " on the scale). Records covering less than half the standard distance (see above) have been omitted except where indicated by an open circle ; records covering less than 80 per cent. are indicated by an ×. The few traces of *R. styliformis* on the Rotterdam line are indicated by a + sign within a circle. (The high peaks of the *Biddulphia* graph for 1937 are folded over to the left for space economy.)



TEXT-FIG. 3.—Charts showing the maximal quantities of *Rhizosolenia styliformis* (above) and *Biddulphia sinensis* (below) in numbers per mile (scale inset) recorded in the years 1937 and 1938 at different points along the three lines from Hull to Bremen, Rotterdam and Copenhagen. These should be compared with similar charts for 1932–37 in Text-fig. 6 of ' Bulletin ' No. 3. Note that, as in those charts, the graphs are limited in height for convenience, and some patches, *e. g.* that on the Copenhagen line in 1938, were denser than is apparent.

Bacteriastrum spp. (Plate XXV shows the main features in selected maps.)

All the records were along the Dutch-German-Danish coasts, and so it is probable that they were restricted to *B. hyalinum* Lauder as in previous years.

In addition to those shown a trace appeared near Borkum in June and November, 1938, and a small patch off the Skagerrak in August, 1939.

Rhizosolenia alata Brightw. (Plates XVI and XVII.)

The great difference between the growths of the two years should be noted. Not until June did a significant flowering appear in 1939, and even by August no cells had been seen south of the latitude of the Forth estuary. Even off the Skagerrak and in the north-west the numbers were lower in 1939. The forma *gracillima* has been undoubtedly the most abundant in these as in earlier records, but the typical form may also be common. Although the forma *indica* was seen in 1938, it was not as numerous as in 1937.

Rhizosolenia faeröense Ostenf. and *R. fragillima* Bergon. (Plate XXIII shows the important patches of July and August, 1939.)

A number of traces and one or two small patches were found at other times (mainly in the south). It seems probable that the southern ones were largely *R. fragillima*, whilst *R. faeröense* was dominant in the north-west, although identification is well known to be uncertain. In contrast to the patches shown for 1939 only one north-western trace was found in 1938 (in June).

Rhizosolenia Stolterfothii H. Pérag. (Plate XXXIV shows the main features in selected maps.)

In addition to those shown a few traces were found in April and May, 1938, and May and August, 1939. The limitation of the main patches to the Forth and the Tay estuaries and the Heligoland and Southern Bights, is a point of interest.

Rhizosolenia Shrubsolei Cleve. (Plates XVIII and XIX.)

Although this species was generally scarcer in 1939 than in 1938 (with the possible exception of May) there were significant resemblances between the two years, *e. g.* the small north-western patches in May, the larger ones off the Forth in July, and the much larger south-eastern ones from May onwards.

Rhizosolenia setigera Brightw.

A few traces, mainly along the Hull–Copenhagen line, were recorded in September and October, 1938.

Rhizosolenia styliformis Brightw. (Plates VII to XI.)

Undoubtedly this species is given undue prominence in these records as the result of its great size, but it is difficult to avoid the impression of its importance (and certainly of its significance) in understanding the North Sea cycle. The southern growths of 1938 are similar on the whole to those outlined in ' Bulletin ' No. 3 for the years 1935–37, although the quantities are smaller and it was unusually

scarce in October and the succeeding months. In fact, after January, 1939, no cells were found south of Lat. 55° N., and very few south of 56° N., until the small central patch appeared on the Hull–Bremen line in July. On the other hand, the recent survey gives us information about the life of *R. styliformis* outside the old area, and for the first time it is possible to follow its development over the greater part of the North Sea. What we may term the south-eastern growth in 1938 clearly extended well beyond the southern North Sea proper, but in addition we find that quite large flowerings may occur also in the waters of the north-west (particularly in the autumn). Such northern North Sea patches seem to have received little attention in the past (*cf.* Ostenfeld, 1913), and there is reason to believe that their investigation may be useful. Examination of the cell sizes (see p. 43 and Plate VII) suggests that the diatoms of the two regions may be distinguishable since those of the north-west are generally smaller than the south-eastern ones. We have further found that when, as in the autumn of 1938, the distribution of *R. styliformis* was more or less continuous over the area, it was still possible to separate the two types by this means and so to obtain some idea of the degree of mixing of the waters. The absence of the autumn data for 1939 prevents full comparison with the 1938 results, but we should compare and contrast the appreciable north-western patch of April and May. We may also note the persistent, though small, patch on the Leith–Copenhagen line which appears to carry over from the previous winter until May. Such apparently persistent centres are likely to be important, though in this case we are unable to say whether there was a similarly persistent one in 1938.

For comparison of the monthly "totals" and the "maximal" quantities with the data for 1932–37 graphs may be used which have been prepared for the three southern lines (Text-figs. 2 and 3). The general decrease in abundance in 1938 is clearly shown here. We may say that the results as a whole agree very well with the unpublished data very kindly shown to us in advance by Mr. R. S. Wimpenny, of the Ministry of Agriculture and Fisheries Laboratory, Lowestoft.

Rhizosolenia calcar-avis Schultze. (Plate XI shows all the records.)

These traces are the first recordings of this species since the survey began in 1932. Note the apparent translation in position between the findings in the two months.

Rhizosolenia hebetata semispina (Hensen). (Plates XX and XXI.)

With the exception of July, it was scarcer in the south in 1939 than in 1938. Otherwise many of the features are similar. We may note in particular the double patches on the Bergen line in the spring of both years (*cf.* several other species of diatoms) and the summer patches off the Scottish coast. The latter patches (in close association with *R. Stolterfothii*) and the very southerly patches of May, 1938, should be considered in conjunction with Ostenfeld's suggestion that this

is an oceanic species which " penetrates into the North Sea by the access north of Scotland " (1913, p. 441).

Only a few cells of *R. h. hiemalis* Gran have been seen during the two years.

Chaetoceros.

Since 1935 we have separated the two subgenera Phaeoceros and Hyalochaete. The difficulties of further subdivision when diatoms are numerous (the occasions when precise identifications would be most desirable) do not justify the time required, but we have found it possible to separate *Ch. decipiens* from the Hyalochaetes, and so will present the data in three sets.

Chaetoceros s.g. Phaeoceros. (Plates XXIV and XXV.)

These have consisted largely of *Ch. borealis* and its varieties. The numbers in the two years seem to have been rather similar, 1939 being perhaps a little thinner in the south. In this group may be noted a particular tendency which is shown more or less by several forms: after a fairly widespread distribution the central region becomes empty and the patches are mainly coastal. The northern patches developed later each year than in the south.

Chaetoceros decipiens Cleve. (Plates XXVI and XXVII.)

Here again the northern patches were about a month later than in the rest of the area. On the whole it was a little scarcer in the south in 1939 than in 1938, and rather more abundant in the north. The occurrence is in general agreement with that found by Ostenfeld. In Text-fig. 4 these are included in the group for comparison with 1932–37.

Chaetoceros s.g. Hyalochaete (excluding *Ch. decipiens*). (Plates XXVIII and XXIX.)

Again the southern patches were rather weaker in 1939 and the northern ones stronger. In this group we can see that the northern patches may, as in 1939, develop even earlier than the southern ones (note, however, how heterogeneous is the group). The persistent patches off the Orkneys and Shetlands, particularly in 1939, should be noted. The group was particularly scarce on the southern lines in comparison with the dense patches found in the year 1937 (*cf.* also Text-fig. 4, in which this group and *Ch. decipiens* are combined as Total Hyalochaetes).

Biddulphia aurita (Lyngb.). (Plate XXXVI.)

In addition to those shown a few traces were also seen in March, 1938, and January, 1939. The limited coastal distribution is clearly seen (*cf.* Ostenfeld, 1913). It is unfortunate that the omission or failure of some records in April, 1938, and March, 1939, should have prevented effective comparison with the large quantities found along the Danish coast in April, 1939.

Biddulphia mobiliensis (Bail.) Grun. in Van Heurck and *B. granulata* Roper. (Plate XV shows the overall distribution for each year.)

Certain doubts regarding identity suggest that it is still advisable to combine the data for these two species. *B. mobiliensis* is definitely the more abundant of the two. No large patches were found, but in 1938 the most widespread distribution occurred in February. The few occurrences in the north-west should be compared with those for *B. regia* (with which this data is combined in Text-fig. 5 for comparison with 1932–37).

Biddulphia regia M. Schultze. (Plate XVII shows the overall distribution for each year and the large patches of 1939.)

This has been scarce at most times, and although in 1938 it was most abundant in the spring, yet only one small patch was found then (near the Maas in February). The greater numbers were in 1939 (note the occurrences in the north-west then). It is striking that for at least eight years (according to these records) it has remained relatively inconspicuous in comparison with *B. sinensis*, although it used to be regarded as an important feature of the plankton. In Text-fig. 5 this species has been combined with *B. mobiliensis* and *B. granulata* for comparison with 1932–37.

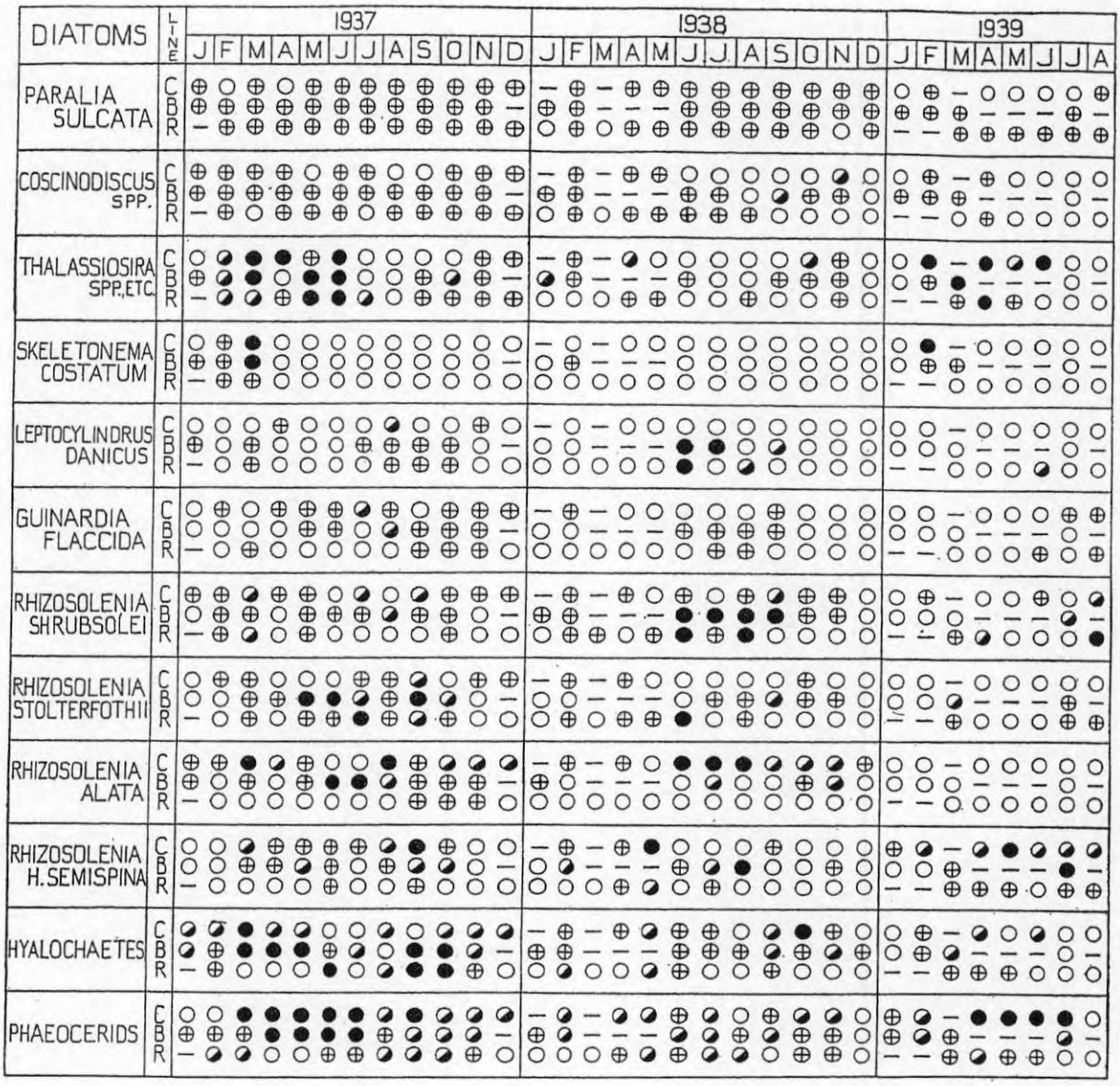
Biddulphia sinensis Grev. (Plates XII to XV.)

As with *R. styliformis* the southern distribution resembles that of the previous years fairly closely, although the numbers in the autumn of 1938 were lower than in 1937. We should note also that dense patches were never found so near to the Outer Dowsing Light as in that year, and that the occurrence on the Hull–Copenhagen line was once again limited to the water east of the Dogger Bank. On the other hand the quantities on the Rotterdam line for a brief period were the greatest found in these records: note, however, their more central position. These points are shown clearly in Text-figs. 2 and 3, where the "total" and the "maximal" distributions in time and space are given for the three southern lines.[1] The extended survey enables us to see the limited distribution in the autumn of 1938, probably a typical one (*cf.* Ostenfeld, 1908 and 1913). In view of this the appearance of small patches in the north-west in the spring of 1939 may be important; it may be compared with that for several other diatoms (*B. regia*, Ditylium and Bacillaria, etc.). Not since 1930 has the Scottish Fishery Board recorded *B. sinensis* in abundance for this region (Rep. Fish. Bd. Scot. for 1930 to 1938).

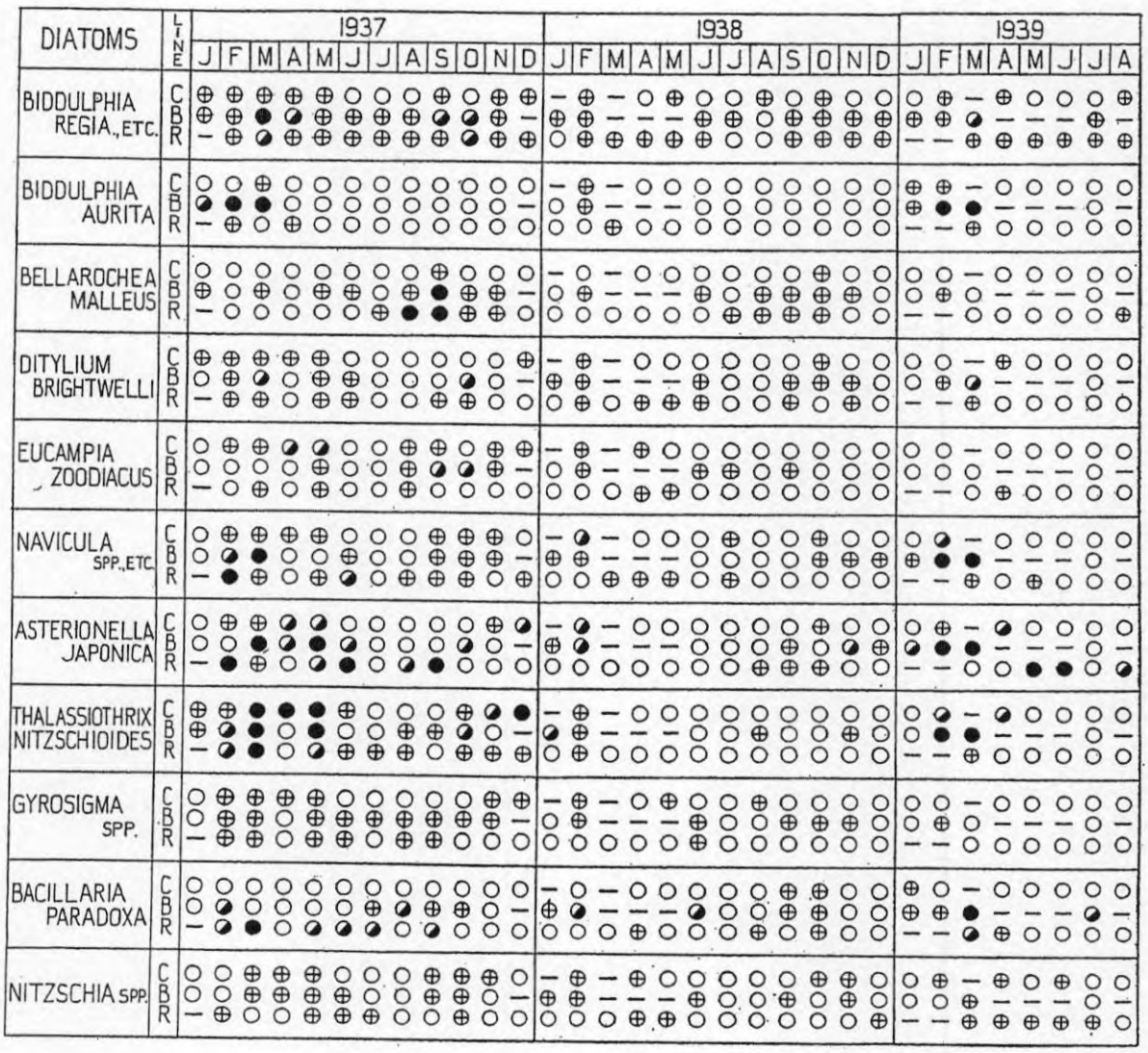
Biddulphia rhombus (Ehr.) W. Smith. (Plate XV shows the overall distribution for each year.)

Traces only were found, and their very limited occurrence in this survey amply confirms the apparent limitation which we found in the earlier work. In 1939 it seems to have been even more limited than in 1938.

[1] Note that the patch on the Copenhagen Line in 1938 was much denser than those in 1937, although this is not apparent in Text-fig. 3, owing to the abridged scale adopted for convenience (*cf.* also Text-fig. 2).



TEXT-FIG. 4.—Diagrammatic tables, for comparison with Text-figs. 8 and 9 of ' Bulletin ' No. 3 (1932–37), showing the varying densities attained by the more important diatoms other than *Rhizosolenia styliformis* and *Biddulphia sinensis* on the three lines from Hull to Bremen, Rotterdam and Copenhagen, month by month from January, 1937, to August, 1939. The months are indicated by the letters J., F., M., etc. One observation is given for each month in which a record was taken: ○ = none found, ⊕ = presence, ◪ = medium patch, = ● major patch, and — = no record taken (see p. 40). Reference to the serial maps in Plates VI to XXXVIII will indicate both the extent of the patches and which lines were sampled in any month. The tables are further continued in Text-fig. 5.



TEXT-FIG. 5.—Continuation of Text-fig. 4.

Biddulphia alternans (Bail.) Van Heurck. (Plate XIX shows the patches of September and October, 1938.)

In addition a trace was also found in May, 1938, on the Rotterdam line, and several in the Southern Bight in November. None were seen in 1939 up to the end of the survey. There was a close association with Bacteriastrum spp. during these months, and the two sets of data suggest the possibility of a movement from the German coast northwards, to which we shall later refer.

Bellarochia malleus (Brightw.) Van Heurck. (Plate XV shows the overall distribution in each year.)

Note the limited distribution. No large patches were found, but in 1938 the bulk occurred in the autumn as usual. Differences between the two years are not really significant since we could not obtain samples in the autumn of 1939, but the more northerly samples found in the earlier months of that year are of interest in view of possible movements after the autumn of 1938.

Cerataulina Bergonii H. Pérag. (Plate XXI shows the large patches of May and June, 1939.)

In addition traces and a few very small patches occurred centrally at other times in both years. There are no comparable patches for May and June, 1938 (*cf.* also *Rhizosolenia faeröense*).

Ditylium Brightwelli (West). (Plate XXXV shows the main features in selected maps.)

Other traces were found in the south-east in May, June and September to November, 1938, and January, February, May and June, 1939, but there were none in the north-west other than those shown. The general distribution should be compared with that for *Biddulphia sinensis* (*cf.* Ostenfeld, 1913, who compared it with his group *B. mobiliensis sens. lat.*).

Eucampia zoodiacus Ehr. (Plate XXXV shows the main features in selected maps.)

There were only scattered traces from June to August, 1938, and October, 1938, to March, 1939, whilst none appeared after May, 1939. Note the decrease on the southern lines after 1936 and 1937 (*cf.* Plates XLI–XLIV in 'Bulletin' No. 3).

"Naviculoids." (Plate XXXVI shows the main features in selected maps.)

This comprises the same group of chain forms (Navicula, Fragillaria, etc.) which appeared in 'Bulletin' No. 3. There were only occasional traces at times other than those shown. They appear to have been more abundant in 1939 as far as the evidence goes.

Asterionella japonica Cleve & Möller. (Plate XXX shows the main features in selected maps.)

In addition to those shown there were small patches during the incompletely recorded March, 1938 and to the south of Aberdeen in June. Other traces and very small patches were found in August, October and December; the last, being off the Outer Dowsing Light, is part of a continuous series from November through to the extensive growth there in February and March, 1939. Those patches found in the Southern Bight in the spring and early summer of 1939 may be related to

the earlier series of records ; a small one was still there in August. Note also the persistent patches off the Forth-Tay estuaries. The later appearance of the northern patches is seen in each year. Whilst the general distribution is coastal, the distribution in April, 1939, is of interest since Ostenfeld found that " it is only found in quantities near the land " (1913, p. 410).

Thalassiothrix longissima Cleve & Grun. (Plate XXXIII shows the main features in selected maps.)

Note the unusual scale adopted here for convenience. In addition to those shown, extensive patches were found on the Pentland–Hamburg line in March, 1938. Apparently it was much scarcer in the centre of the area in the spring of 1939, and perhaps more abundant in the north-east. The apparent south-eastern movement in the autumn of 1938 should be noted.

Thalassiothrix Nitzschioides Grun., Van Heurck. (Plate XXXII shows the main features in selected maps.)

It is possible that in the north small quantities of unidentified *Thx. Frauenfeldii* have been included in these samples. Very few traces were found after June in each year. In the north by far the larger quantities appeared in 1939, the widespread patches of March and April being very striking.

Gyrosigma spp. (Plate VI shows all the occurrences along with the data for *Paralia sulcata*.)

This includes all the sigmoid diatoms. Their close association at times with the patches of Paralia may be observed and probably, like Paralia, they are only carried into the upper layers at times of extensive disturbance. They were very scarce in the south after September, 1938, and even earlier in 1938 they were much rarer than in 1937.

Bacillaria paradoxa Gmel., Van Heurck. (Plate XXXVII shows the main features in selected maps.)

Other small patches appeared in the Southern Bight in February and April, 1938, and off the Friesian Is. in May and July, 1939. The appearance of traces in the north-west in 1939 may be associated with a similar occurrence of several other diatoms there in that year. There was a marked decrease in 1938 (and possibly 1939) when compared with 1937 (*cf.* Plates XLIII–XLIV in ' Bulletin ' No. 3).

Nitzschia closterium (Ehr.). (Plate XXIX shows the overall distribution.)

Again (see ' Bulletin ' No. 3) this was most common in the presence of Phaeocystis, both in the south and the north-west (probably due to the clogging effect of the flagellate). It is also found at other times, although clearly there is more

chance that it will not be recorded when Phaeocystis is absent. The overall distribution is found to be very extensive both in time and space (it was found in every month except December). It is probable that a proportion of *N. delicatissima* has been included at times with the slenderer types of this species, but this should be small.

Nitzschia seriata Cleve. (Plate XXVII shows the date and position of all the main patches, together with all other records.)

Note its rarity in the southern area and the general changes in position between the first and second parts of 1938.

Other species.

Other species recorded were *Streptotheca thamensis* Shrubs., *Hyalodiscus steliger* Bailey, *Melosira Borreri* Greville, Licmophora spp., *Biddulphia favus* (Ehr.), *Actinoptychus undulatus* (Bail.), and Grammatophora spp. There have been no records during 1938–39 of those other species in Table I of ' Bulletin ' No. 3, which are not mentioned above, but which occurred from time to time during 1932–37. On the other hand we should remember that these were usually only isolated recordings, whilst the scale of working has been decreased during the recent years with the adoption of the ten-mile block system.

Discussion.

Although we hope to deal more fully with the various points reviewed below in a later paper, the present circumstances make it desirable to present some tentative suggestions regarding the more obvious features of the data at this date.

The Data for 1938.

It is evident that we cannot regard the year 1938 as providing a full survey ; unfortunately it was not possible to cover anything like the whole area in some months (*e. g.* March), and so important information has been missed. Similarly although the period July, 1938, to June, 1939, for example, was fairly well sampled, there are good reasons for believing that it could hardly be representative in view of various signs that it was a transition period. Yet since this is the first attempt to show monthly pictures of the varying diatom flowerings over the greater part of the North Sea, it may be useful to try to sketch an outline of the general development, and for this purpose it is best to study 1938 as far as the evidence goes.

All the records for January and some for February show the phytoplankton to be very scarce, although a few species show residues of the previous year's growth (*e. g. B. sinensis* and some of the Ceratium spp.). Some however, in February, appear to be initiating a spring flowering ; such were the early diatoms Thalassiosira spp. (at first mainly *Th. decipiens*), Asterionella, some Phaeocerids,

Skeletonema and *Thx. longissima*. Appearing first as scattered patches over the Dogger Bank and to the north of it, most of them seem to have developed rapidly in March, giving rise in April to quite extensive patches in the centre of the area. These are dominated by Thalassiosira spp. (now mainly *Th. gravida* and *Th. Nordenskiöldii* along with Coscinosira spp.), chaetocerids of all three groups, *Thx. Nitzschioides* and smaller numbers of Asterionella and Skeletonema. Meanwhile *Thx. longissima* decreased whilst Eucampia, *R. semispina* and *R. alata* had been developing in the central region (just as in the Heligoland Bight the earlier patch of Coscinodiscus spp. had given place to *B. aurita*, and *B. sinensis* showed further growth in the Southern Bight). As far as the incomplete evidence goes there is reason to believe that a similar process went on in the north about one month later, to include a significant patch of *R. styliformis* in May, although apparently not including Eucampia and *B. aurita* or Coscinodiscus spp.

To anticipate a later report we should note here that in April the southern growths of the flagellate Phaeocystis had begun (culminating in May and June), whilst the Dinoflagellates began to appear in appreciable numbers, attaining a maximum much later. There were two initial centres for the production of both groups, as with the diatoms, broadly speaking in the south-east and the north-west. Once again, it seemed, the northern one was about a month behind the southern.

It is necessary to bear in mind the growths of the flagellates, since they play their part in the rapid changes occurring after April. In May the diatoms were generally scarcer in the south (we should note the temporary maximum of *B. sinensis*), although it is likely that they attained their northern maximum then. It is striking that on the whole they were more on the periphery of a central zone which many of them had been occupying before. Just as May shows the rapid development of the flagellate (and, indeed, the animal) plankton, so it proved to be in the nature of a transition month for the diatoms. Few of the earlier ones were left in June, and these were mainly restricted in extent. We may note particularly that whilst *R. styliformis* and *R. semispina* had been decreasing, *R. alata* had become much more prominent, and well-defined patches of *R. Shrubsolei* had appeared in the south-east along with *R. Stolterfothii*. These three last, as well as local patches of *R. semispina*, chaetocerids, Thalassiosira and Skeletonema form a background to the conditions up to September (amongst other details there were relatively large patches of Leptocylindrus). Whilst *R. alata* was most prominent in the northern and central waters, the other two were mainly south-eastern, and in September we see them giving place to the now familiar patches of *B. sinensis*, which have appeared there during each autumn of this survey (in association with various smaller diatoms). At the same time *R. styliformis* appeared over the western patch of the Dogger Bank. In the north-west we find the smaller Rhizosolenias persisting until October, until *styliformis* began to develop there too (though not in association with *B. sinensis*). Other diatoms of the southern autumnal flowering were usually in smaller numbers as far as these records are concerned ; Chaetocerids were prominent, whilst there were smaller

patches of Thalassiosira, Leptocylindrus and Skeletonema with fair growths of Coscinodiscus in November. Although in small numbers, it is useful to remember the patches of *B. alternans*, *R. calcar-avis* and Bacteriastrum off the Dutch-German-Danish coasts at this time, and their apparent movements. We should also note the apparent movement of diatoms away from the Scottish coast during the last three months, along with a similar translation shown by the southern patches of *R. styliformis* and *B. sinensis* towards the north-east. By December there was little but *B. sinensis* and small numbers of *C. concinnus* to be found.

The Data for 1939.

In the broadest sense the development in 1939 may be said to have been similar. In fact, the process outlined above is a familiar one, apart from some details which are now available from monthly surveys. On the other hand there are many important differences. Once again the north-western flora tended to be about a month later, and the more numerous spring records for this year enable us to be more certain of this. Very few diatoms were seen in January, but in February early spring forms again appeared, although with a difference in distribution (*e. g. B. sinensis* was restricted to the Borkum region in February instead of near the Outer Dowsing Light, and it had a more northerly position in March and April). It is impossible to compare adequately the conditions in March, although the data for 1939 tend to confirm our earlier suggestion that there had been little growth in the north-west then, when elsewhere the diatoms may be quite abundant. In particular we should note the good growth in the north-east at this time. In April, on the other hand, they were well advanced in the north-west and the data for the spring period show many differences from 1938. Whilst the general background was the same, we may note the general scarcity of, *e. g.*, Eucampia, *R. alata* and *R. Shrubsolei* in 1939, and the lower numbers of *Thx. longissima*, whilst *Thx. Nitzschioides*, Thalassiosira spp., Bacillaria, "Naviculoids," Ditylium and *B. regia* are much more abundant. A number of diatoms appear to be much more northerly this year (or at least scarcer in the south), and amongst these *Thx. longissima* is striking. In particular we must note the patches of *B. sinensis* (along with *B. regia*, Lauderia and traces of Ditylium and Coscinodiscus) in the north-west, and the subsequent patches of Cerataulina and *R. faeröense* (also the slightly more southerly and later traces of Bacillaria), all of which were scarcely (or not) apparent in 1938. In general the northern and north-western complex was much denser, and even in August showed differences from the previous year's growth (*cf.* the patch of Corethron). There were also differences in the distribution of the Ceratia, which will be referred to in a later paper.

There are other differences in the Southern Bight. Whilst a few of the earlier forms were quite abundant at first (*e. g.* Thalassiosira spp.), many were much scarcer (*cf. R. alata*, which was both scarcer and later this year), and on the whole the chief concentrations were more northern (*e. g. R. styliformis*, *R. Shrubsolei*,

R. semispina and the Phaeocerids). Not until August did *R. alata* attain anything like the densities of the previous year, and along with this we see the general scarcity of *R. Stolterfothii* and Leptocylindrus. Yet a few diatoms, amongst which Asterionella, *B. regia*, Ditylium and Bacillaria stand out, were particularly abundant or persistent. The general impression appears that although the " residual " crop south of the Dogger Bank may at first have been of the order of that in 1938, it became progressively thinner and, indeed, the area affected in this way became larger. In association we may anticipate the flagellate data to say that whilst Phaeocystis was perhaps even denser than in 1938, all the species of Ceratium were fewer in the southern half of the area.

During the year 1938 and the incompletely sampled 1939 it is worthy of note that, after a period in which the diatoms were fairly widespread over the central waters of the North Sea, they became progressively scarcer there from May onwards, the summer patches being on the whole much more coastal and, of course, thinner. This is more striking in 1938 than 1939, perhaps owing to the smaller numbers in the south for the latter year, and we see that it was not until October and November that they became relatively significant in the central waters again.

Comparison with the Data for 1932–37.

The differences seen here could be understood better in relation to a longer period. Unfortunately there are no adequate data for the northern area, but the more southern data may be compared with that in ' Bulletin ' No. 3. There we came to the conclusion that over the period 1932 (or 1931) to 1937 there had been a general increase in the densities of the residual crops of diatoms and Dinoflagellates, culminating variously in 1935, 1936 or 1937, although mainly the last. In several ways 1934 and 1936 showed deviations from this trend, and in some species it probably began after 1933, rather than in 1932. By no means all showed the trend, but most did so, and some which did not show the change in numbers still showed changes in distribution which might have been related.

In view of this we awaited the data for the later years with great interest in order to see whether any return to the earlier conditions might be found. Text-fig. 2 shows the total numbers of *R. styliformis* and *B. sinensis* for each record in 1938–39, arranged as in Text-fig. 5 of ' Bulletin ' No. 3 ; for effective comparison the totals are for the shorter lines of the old period (180 miles of the Hull–Bremen route, from the Outer Dowsing Light to Borkum, and for 250 miles from the Humber Light on the Hull–Copenhagen route). *R. styliformis* was much scarcer on the Bremen route in 1938 (and also on the Rotterdam, as far as the slight evidence goes), although it was slightly more abundant on the Copenhagen route for a short period. *B. sinensis* decreased even more extensively on the first and, although along the Copenhagen route it reached a similar quantity, it persisted for a shorter time than in 1938. In association we must note that it extended far less towards the Outer Dowsing Light this year than it had done since 1933 ; consequently the mixing

with *R. styliformis* was slighter. Similarly its extension along the Copenhagen line was limited to the waters east of the Dogger Bank in contrast to the unusual (in these records) extension in 1937. On the other hand the total on the Rotterdam line was much higher than before, and both spring totals were rather higher than before. These points are brought out in Text-fig. 3, which shows the maximal quantities found on the different parts of each line throughout 1937 and 1938; they may be compared with Text-figs. 6 and 7 of ' Bulletin ' No. 3. The lack of samples in 1939 prevents the useful comparison we should have wished to make for another year, but we should note the patch of *R. styliformis* and the traces of *B. sinensis* in July and August which may be the precursors of new autumn patches. As far as the evidence goes, both diatoms appear to have been scarcer in the spring of 1939 than in that of 1938.

So far there is some evidence of a decrease in these forms to which we have paid more attention; this is confirmed by many other diatoms. Owing to the approximations used in some of the earlier work it is not possible to provide strict comparison between the new and the earlier data. However, the patches represented by the larger open circles in Plates XVI to XXXVIII approximately compare with the " medium " patches of earlier years, the higher values comparing with the " major " patches of 1932–37 (it is evident, as we suggested, that we could also have allowed for a " very dense " grade in ' Bulletin ' No. 3 : similarly it is now found useful to have the lower grade of the smaller open circles). On this basis Text-figs. 4 and 5 have been prepared to show the data for 1938–39 in comparison with that for 1937, as in Text-figs. 8 and 9 of ' Bulletin ' No. 3. Most of the diatoms provided smaller numbers (viewed thus) in 1938 and/or 1939 than in 1937, the year in which so many had been apparently at their highest. In some the reductions are such that they approach the values of the very scanty early years (*e. g.* Eucampia, *Thx. Nitzschioides*, Bacillaria, *R. Stolterfothii*). The absence of important spring records on the Hull–Bremen line prevents the best comparison, but even allowing for this it appears that only *R. semispina* attained high densities for a significantly longer period in 1939 than in 1937 or 1938. Such a method gives a biased view, and the spatial distribution must also be considered. The absence of certain records (or their incompleteness at times) prevents full comparison, but when this is possible, we see again that most species were scarcer on the whole in the last two years, only the Thalassiosira group and the " Naviculoids " showing significantly more widespread distributions on these lines in 1939. Although much of the present work goes to show how near patches may be to these three lines without actually appearing on them (and so detracting from their value as standards), we should also note that the Esbjerg line (which crosses two of them) was also particularly thinly populated in 1939.

At this stage we may refer once again to the data for the Ceratium spp. Whilst on the Bremen and Rotterdam lines the 1938 totals were even higher than in 1937 (the highest so far on these lines), there was a big reduction on the Copenhagen line. Even more striking were the conditions in 1939, when all the species showed marked

reductions for each month in which there were samples. Even on the Rotterdam line the patch of *C. fusus*, which had been so abundant in 1937 and 1938, was insignificant until August, and then was much less than in 1938. The totals for the two northern lines were more of the order of the low values found in the earlier part of the survey. On the other hand, we have found that Phaeocystis, which was abundant in the first years and then scarcer until an increase occurred in 1937, was even more abundant in the last two years.

One more point of comparison is noteworthy. In 'Bulletin' No. 3 (p. 132, and Text-fig. 10) we showed how in the earlier years the diatoms tended to be towards the edges of the Dogger Bank, whereas later they became relatively more abundant in the central and western regions of the Copenhagen line. Similarly on the Bremen and Rotterdam lines they tended to become more western in distribution. In 1938, however, the patches were on the whole much scarcer in the western waters (particularly those round the Humber mouth and on the western half of the Rotterdam line). Once again we see that, although the 1938–39 diatoms were often more abundant than in the earliest years, yet in still another feature they resembled these rather more than 1936 and 1937.

In comparison with Ostenfeld's Plankton Resumé (1931) it is evident that, in general, both these results and those of the quarterly surveys of the International Council are in agreement for the southern and the northern North Sea. On the other hand the monthly data usually available here enables one to denote the periods of maximum with much greater precision than before. As a point of disagreement we may note that *Rhizosolenia h. semispina* is omitted from Ostenfeld's list of common spring forms in the southern and the northern North Sea; it is also surprising that *Thalassiosira* spp. does not appear there as a spring form for the southern North Sea and *Biddulphia sinensis* in the autumn. The last may well be due to the fact that *B. sinensis* was only then (1902–08) beginning to develop in the area, but throughout this work all three have appeared as important diatoms in the phytoplankton, even after allowing for their various sizes in relation to those of the other species.

We cannot make similar comparisons for the northern waters, except to emphasize the changes from 1938 to 1939, the general increase in the last year providing a complement to the reductions in the south. It seems important to emphasize also the occurrence of a number of forms there in 1939 which we did not find so abundantly (or at all) in 1938, some being more (or entirely) restricted to the southern waters in 1938. Although in March and April there is unfortunately a shortage of records here in 1938, wherever comparison can be made the difference is quite sharp (*cf.* the later differences for May–August, in which most of the records are available). There seems to have been a distinct addition to the flora, since most of those present in 1938 were also there in 1939. We may note that for one of the diatoms, *B. sinensis*, the Scottish records suggest that not since 1930 has it been so abundant there (p. 31). It seems very unfortunate that owing to the war the records should have ceased; there is reason to believe

that data even for one or two more months might have added largely to our knowledge of the apparent cycle of events in the North Sea during the last few years—particularly regarding the autumnal flowerings of *R. styliformis* and *B. sinensis* in the Southern Bight.

General Remarks.

Whilst we had to limit our work at first to three divergent lines from Hull, we had the difficulty of being uncertain how applicable the data might be to the problems for solution. The Esbjerg line immediately gave some checks on this, and we could see how on the whole the data from the intersecting lines was confirmatory. Yet we often had evidence that the absence of an organism from the Bremen line, for example, could be misleading, since it might be found in fair numbers on the other (see ' Bulletin ' No. 3, p. 100). Now that we have had ten lines, each normally intersecting with another at least once in each month, it is clear that the individual lines can only be used with qualification. There are still large gaps in the network in which important processes may go on undetected (the results from the unusual recording of a Lerwick–Hamburg line in July, 1939, may be noted here). The whole set of records must be associated and full allowance made for the gaps in observation, both in time and space, and the varying times of recording.

In this connection the new work has provided even more evidence of the importance of patchiness (and more reliable data for its study in some species). Whilst the more general remarks of the earlier survey will still apply, they require qualification. When we consider the diatoms as a group, we see at first very marked patches with sharp boundaries, yet within these general patches are equally sharply defined sub-patches of the individual species (or even varieties). Data for the Dinoflagellates present similar features. In general (and this applies by no means only to the phytoplankton) we see that there are regions which are productive for one of the main groups, which may yet yield very different analyses within their boundaries ; the time factor shows this to be a dynamic problem, and one which concerns the inter-relationships of different organisms, both physical and biological (see also Lucas, 1938). It seems likely that many of the details, and perhaps some of the broader features, of annual and even longer cycles will be bound up with this problem.

The data from this and the earlier survey are already being studied in relation to the hydrology of the North Sea and water movements ; certain features can only be understood in this light. Both 1938 and 1939 have shown further evidence of the type of movement suggested for the south in earlier years, although 1939 shows also some obvious differences. However, the extension which has enabled us to link the old area to a much wider field is likely, through the information gained in the north, to produce a better understanding of the southern events. Examples are seen in the apparent translation of many forms (*Thx. longissima*, *R. styliformis*, Dactyliosolen and the Chaetocerids) away from the Scottish coast

eastwards and southwards in the autumn of 1938 ; with this we may associate the more familiar movements in the south-east as *R. styliformis* and *B. sinensis* recede towards and along the Dogger Bank (although the latter does not, as in 1937, spread over the western half of the Dogger Bank). Patches of Chaetocerids and the smaller Rhizosolenia spp. appear to be moving in the same manner, whilst some zooplankton species show similar changes. On the other hand the relative stability of some patches in time suggests, not so much a lack of movement, as the persistence of suitable conditions (perhaps from swirls or upwelling) in that region. Such are found, for example, near the western and eastern ends of the Dogger Bank, particularly in the autumn, and off the coast of Scotland on a number of occasions (in particular the possibly continuous occurrence of a patch of Asterionella in the Southern Bight from November, 1938, to August, 1939, may be the results of some such swirl (see p. 34). The more or less regular occurrence of such concentrations of diatoms and their detailed variations in position must be of great significance in consideration of the bottom communities of these regions (*cf.* Orton, 1937, on the relations between swirls or eddies and the local ground fauna).

In addition to such hydrological evidence as is provided by the movements or persistence of " bodies " of diatoms (relatively persistent communities which can be identified from time to time), we have also been using the method of identification adopted by Wimpenny (1936)—that of measuring cell sizes. As well as measuring the sizes of cells of suitable *R. styliformis* patches in 1932–37, at least some measurements have been made in all the patches of 1938–39. These will provide material for a paper to follow, but we may anticipate results to say that the data suggest a ready means of separating the northern and the southern crops during these years. On the whole the northern cells were much smaller, and the general difference might seem to imply a mixing of the two crops in the central North Sea towards the end of 1938. Plate VII provides a summary of the data for 1938 by showing symbolically the sizes of the *smallest* cells found throughout the whole year on each pair of blocks (" double " blocks of twenty miles). In this way the black symbols (denoting the larger " smallest " cells) show clearly a south-eastern region in which cells similar to the even smaller ones of the north-west were rarely recorded. Along the northern edge of this area there appears to be a region in which the two smallest sizes are mixed. The relationships between these are complex and will be discussed in the later paper. Meanwhile the problem is also being investigated by Mr. R. S. Wimpenny (of the Ministry of Agriculture and Fisheries' Laboratory at Lowestoft), with whom the writer is in touch ; it is hoped that through these different approaches a sound solution will be found for this interesting distribution. It seems likely that such work might profitably be extended to some other species, and since the Recorder material has certain advantages for this purpose (as well as some disadvantages), we are continuing the investigation by means of analyses of the sizes of *B. sinensis* which are likely to have a rather different relevance.

A few concluding remarks should be made regarding the incomplete cycle of events which we have postulated for the period 1932–39. Full consideration must be deferred until the data for the zooplankton can be reviewed as well as the associated conditions in the sea, although we may say that some similar trends have also been found in the zooplankton. However, it is suggested that the "residual stock" of many phytoplankton species appeared to increase for some years (variously from 1931–33 to 1935–37), and that thereafter they decreased to various extents. In association one or two species appeared to do the reverse, or showed more or less cyclic changes in time and space. We referred in 'Bulletin' No. 3, p. 164, to other changes which were observed by other writers in the earlier period : *e. g.* the occurrence of Sagitta spp., young fish, phosphates and phytoplankton in the English Channel and the varying northern influences on the North Sea. Very tentatively it was suggested that the increased phytoplankton in the southern North Sea might be due to increased phosphate supplies arising from the unusual water movements there (with perhaps some lag period between them, *cf.* Russell, 1939, p. 184), just as off Plymouth the reverse seems to have occurred. On such a suggestion the recent decreases might well be due to a decrease in phosphate as the "abnormal" conditions disappeared, probably with a lag period.

Whilst this possibility will be more fully examined later, it is important to mention some evidence which offers partial confirmation for the suggestion. Dr. Carruthers has examined the varying rates of water-flow past the Varne Lightvessel since 1926, and found fairly strong rates of flow into the North Sea on the whole up to 1931. Then he found a varying amount of "hold-up" or "reversal" (Carruthers' terms) of the flow up to and including 1937 (Carruthers, 1935, and Min. of Agric. and Fish., Reports on Sea Fisheries for 1935–37). We are greatly indebted to him for permission to make use of his latest unpublished data. This shows that after the beginning of 1938 a strong flow to the North Sea again set in, and persisted with little interruption until the end of these observations in August, 1939. Such a persistent flow had not been recorded since 1930, and even before that there had been none of such a steady nature. During these years there has been, in fact, a cycle (more or less irregular) in the pressure balance between the North Sea and the English Channel.

The links between these different events are by no means clear as yet, though the data for the last two years help to carry us a step further. It will be unwise to look too deeply without the necessary zoological and hydrological evidence, but it seems fair to point out that if, after a long period when the Channel waters were deficient in phosphate, they begin to flow again into the Southern North Sea in (relatively) unusual quantity, then it is not so surprising that the phytoplankton resulting in that area should be poorer. It will be remembered that whilst some of the earlier species of 1938 and 1939 were fairly abundant, the greater decreases were seen in the autumn of 1938 and the later spring and summer of 1939, as if the available phosphates were being used up, *or being swept out of the area.* Judging from the biological evidence it seems possible that the processes in the southern

North Sea may be returning to conditions not so dissimilar from ones seen in the earlier years of the survey. Such a return would have important corollaries for other events in that area, and it is also tempting to wonder if the trends which have occurred in the English Channel region will soon be directed back towards earlier conditions. Up to date Russell (1939) has not been able to report any sign of such a return. On the other hand, the Report of the Scottish Fishery Board for 1938 mentions that " the sea water conditions . . . would appear to have become more or less normal after a long period cycle of abnormalities in the northern North Sea." The various pointers seem to be directed towards the same conclusions, and it is greatly to be hoped that the war will not result in the cessation of all means of recording whereby we might have some knowledge of the contemporary changes.

Summary.

1. The present 'Bulletin' concerns an extension of the earlier survey of the southern North Sea with the Continuous Plankton Recorder to include the central and northern waters. It deals with the changes in composition and distribution of the diatom plankton month by month from January, 1938, to August, 1939. Data for the Dinoflagellates and Phaeocystis will appear later.

2. Six extra steamship lines were run monthly : from Hull to Oslo, from Leith to Hamburg, Copenhagen and Lerwick and from the Pentland Firth to Hamburg and Bergen. The material and methods are described on pp. 19 to 23.

3. Whilst particular attention is still being paid to the diatoms *Rhizosolenia styliformis* and *Biddulphia sinensis* (pp. 28 and 31), a number of other species have been examined and illustrated in more detail than before (pp. 23 to 36).

4. Variations occur in time and space which essentially resemble those of the earlier 'Bulletin'; they are shown in a series of monthly maps for the different species (Plates VI–XXXVIII). From them arise further evidence of " patchiness," " inter-relationships " and of water movements.

5. Standing out from these details are certain general tendencies. The northern diatoms were more abundant in 1939 and the southern ones in 1938. On the whole the southern crops have decreased since the period 1935–37 (pp. 36 to 42).

6. This apparent decrease in the southern North Sea follows the general increase suggested to have occurred between 1932–33 and 1935–37. There appears to have been a cycle of growth in the area, probably in association with certain hydrological changes to which attention is tentatively drawn (pp. 42 to 45). Owing to the onset of the war it has been impossible to obtain further records after August, 1939, and so further stages in this " cycle " cannot now be followed out.

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EXPLANATION OF PLATES VI TO XXXVIII.

PLATE VI.

Maps showing the distribution of *Paralia sulcata* (in line) and Gyrosigma spp. (×) month by month in 1938 and 1939. The thick line denotes that Paralia was common and the thin one that it was scarce or absent. The distribution of Paralia and Gyrosigma is referred to on pp. 23 and 35 respectively.

PLATE VII.

Showing the sizes (in μ) of the "smallest" cells of *Rhizosolenia styliformis* recorded for each block of twenty miles on the normal routes during 1938. Those "smallest" cells per block which were larger than 40μ are denoted by white figures on black. See discussion on p. 43.

PLATES VIII–X.

Maps showing the distribution of *Rhizosolenia styliformis* (p. 28) month by month from January, 1938, to June, 1939. Numerals and symbols are used to denote the varying numbers per mile in each ten-mile block (for scale see inset on Plate IX). Where more than one record has been obtained within any month, they have usually been shown "in parallel" (the earlier one above) and bracketed together. Where this has not been possible, one representative record has been shown in the usual manner and the other(s) have been shown in the margin (as in November, 1938), the symbols I and III denoting the first or the third of the series (for dates see 'Bulletin' No. 8).

PLATE XI.

Maps showing the continuation of *Rhizosolenia styliformis* for July and August, 1939; also the overall distribution of *Rhizosolenia calcar-avis* (p. 29) and Dactyliosolen spp. (p. 25) in 1938; neither of the latter were recorded in 1939.

PLATES XII–XIV.

Maps showing the distribution of *Biddulphia sinensis* (p. 31) month by month from January, 1938, to June, 1939, arranged in the same manner as those of *R. styliformis* (see explanation of Plates VIII–X above).

PLATE XV.

Maps showing the continuation of *Biddulphia sinensis* for July and August, 1939; also the overall distribution of *Biddulphia mobiliensis* + *B. granulata* (p. 31), *Biddulphia rhombus* (p. 31), *Bellarochia malleus* (p. 34) and *Corethron criophilum* (p. 25) in 1938 and 1939.

PLATES XVI AND XVII.

Maps showing the distribution of *Rhizosolenia alata* (p. 28) month by month from January, 1938, to August, 1939. Symbols are used to denote the varying numbers per mile in each ten-mile block (for scale see inset on Plate XVI). Where more than one record has been obtained in any month, they have usually been shown " in parallel " (the earlier one above) and bracketed together. Where this has not been possible, one representative record has been shown in the usual manner and the other(s) have been shown in the margin (as in August, 1938), the symbol AI denoting the first of the pair (for dates, see ' Bulletin ' No. 8).

The inset on Plate XVII shows the distribution of *Biddulphia regia* (p. 31) in March and April, 1939 (scale, etc., as above), and also the overall distribution in 1938 and 1939.

PLATES XVIII AND XIX.

Maps showing the distribution of *Rhizosolenia shrubsolei* (p. 28) month by month from January, 1939, to August, 1939, arranged in the same manner as those of *R. alata* (see explanation of Plates XVI and XVII above).

The inset on Plate XIX shows the distribution of *Biddulphia alternans* (p. 33) in September and October, 1938 (scale, etc., as above).

PLATES XX AND XXI.

Maps showing the distribution of *Rhizosolenia hebetata semispina* (p. 29) month by month from January, 1938, to August, 1939, arranged in the same manner as those of *R. alata* (see explanation to Plates XVI and XVII above).

The inset on Plate XXI shows the distribution of *Cerataulina Bergonii* (p. 34) in May and June, 1939 (scale, etc., as above).

PLATES XXII AND XXIII.

Maps showing the distribution of Thalassiosira spp. (including Coscinosira spp., p. 24) month by month from January, 1938, to August, 1939, arranged in the same manner as those for *R. alata* (see explanation to Plates XVI and XVII above).

The inset on Plate XXIII shows the distribution of *Rhizosolenia faeröense* and *R. fragillima* (p. 28) in July and August, 1939 (scale, etc., as above).

PLATES XXIV AND XXV.

Maps showing the distribution of Chaetoceros spp. (s.g. Phaeoceros, p. 30) month by month from January, 1938, to August, 1939, arranged in the same manner as those for *R. alata* (see explanation to Plates XVI and XVII above).

The inset on Plate XXV shows the distribution of Bacteriastrum spp. (p. 27) from August to October, 1938 (scale, etc., as above).

PLATES XXVI AND XXVII.

Maps showing the distribution of *Chaetoceros decipiens* (p. 30) month by month from January, 1938, to August, 1939, arranged in the same manner as those for *R. alata* (see explanation to Plates XVI and XVII above).

The inset on Plate XXVII shows the distribution of *Nitzschia seriata* (p. 36) during the periods January to July, 1938, August to December, 1938, and January to August, 1939 (scale, etc., as above). The Roman numerals denote the months in which the patches occurred.

PLATES XXVIII AND XXIX.

Maps showing the distribution of Chaetoceros spp. (s.g. Hyalochaete less *Ch. decipiens*, p. 30) month by month from January, 1938, to August, 1939, arranged in the same manner as those for *R. alata* (see explanation to Plates XVI and XVII above).

The inset on Plate XXIX shows the overall distribution of *Nitzschia closterium* (p. 35), *Stephanopyxis turris* (p. 25) and *Guinardia flaccida* (p. 25) during 1938 and 1939.

PLATE XXX.

Maps showing the distribution of *Asterionella japonica* (p. 34) in 12 selected months during 1938 and 1939, arranged in the same manner as those for *R. alata* (see explanation to Plates XVI and XVII above).

PLATE XXXI.

Maps showing the distribution of *Skeletonema costatum* (p. 24) in 12 selected months during 1938 and 1939, arranged in the same manner as those for *R. alata* except that the scale is slightly modified as shown (see explanation for Plates XVI and XVII above.)

PLATE XXXII.

Maps showing the distribution of *Thalassiothrix Nitzschioides* (p. 35) in 12 selected months during 1938 and 1939, arranged in the same manner as those for *R. alata* (see explanation for Plates XVI and XVII above).

PLATE XXXIII.

Maps showing the distribution of *Thalassiothrix longissima* (p. 35) in 12 selected months during 1938 and 1939, arranged in the same manner as those for *R. alata* except that the scale is modified as shown (see explanation for Plates XVI and XVII above).

PLATE XXXIV.

Maps showing the distribution of *Rhizosolenia Stolterfothii* (p. 28) in 12 selected months during 1938 and 1939, arranged in the same manner as those for *R. alata* (see explanation for Plates XVI and XVII above).

PLATE XXXV.

Maps showing the distribution of *Ditylium Brightwelli* (p. 34) and *Eucampia zoodiacus* (p. 34) in selected months during 1938 and 939, arranged in the same manner as those for *R. alata* (see explanation for Plates XVI and XVII above).

PLATE XXXVI.

Maps showing the distribution of *Biddulphia aurita* (p. 30) and the " Naviculoid " diatoms (p. 34) in 6 selected months during 1938 and 1939, arranged in the same manner ast hose for *R. alata* (see explanation for Plates XVI and XVII above).

PLATE XXXVII.

Maps showing the distribution of *Bacillaria paradoxa* (p. 35) and *Leptocylindrus danicus* (p. 25) during 6 selected periods in 1938 and 1939 (scale, etc., as in Plate XXXVI). The Roman numerals denote the months in which the patches occurred.

PLATE XXXVIII.

Maps showing the distribution of *Lauderia borealis* (p. 24) and the larger Coscinodiscus spp. (p. 24) during 6 selected periods in 1938 and 1939 (scale, etc., as in Plate XXXVI). The Roman numerals denote the months in which the patches occurred.

Corrigendum.

As the result of an oversight the data for the Pentland–Bergen record of October 22, 1938, has been slightly mis-plotted on each occasion on which it has been used. Instead of being in the direct line, as in the previous record, the direction was changed during the voyage, the true route being as in Plate II of ' Bulletin ' No. 7. For most purposes the error may be regarded as a slight one.

PLATE VI

PARALIA SULCATA

COMMON
RARE OR ABSENT
AND

GYROSIGMA SPP

SHOWN THUS
X = PRESENT

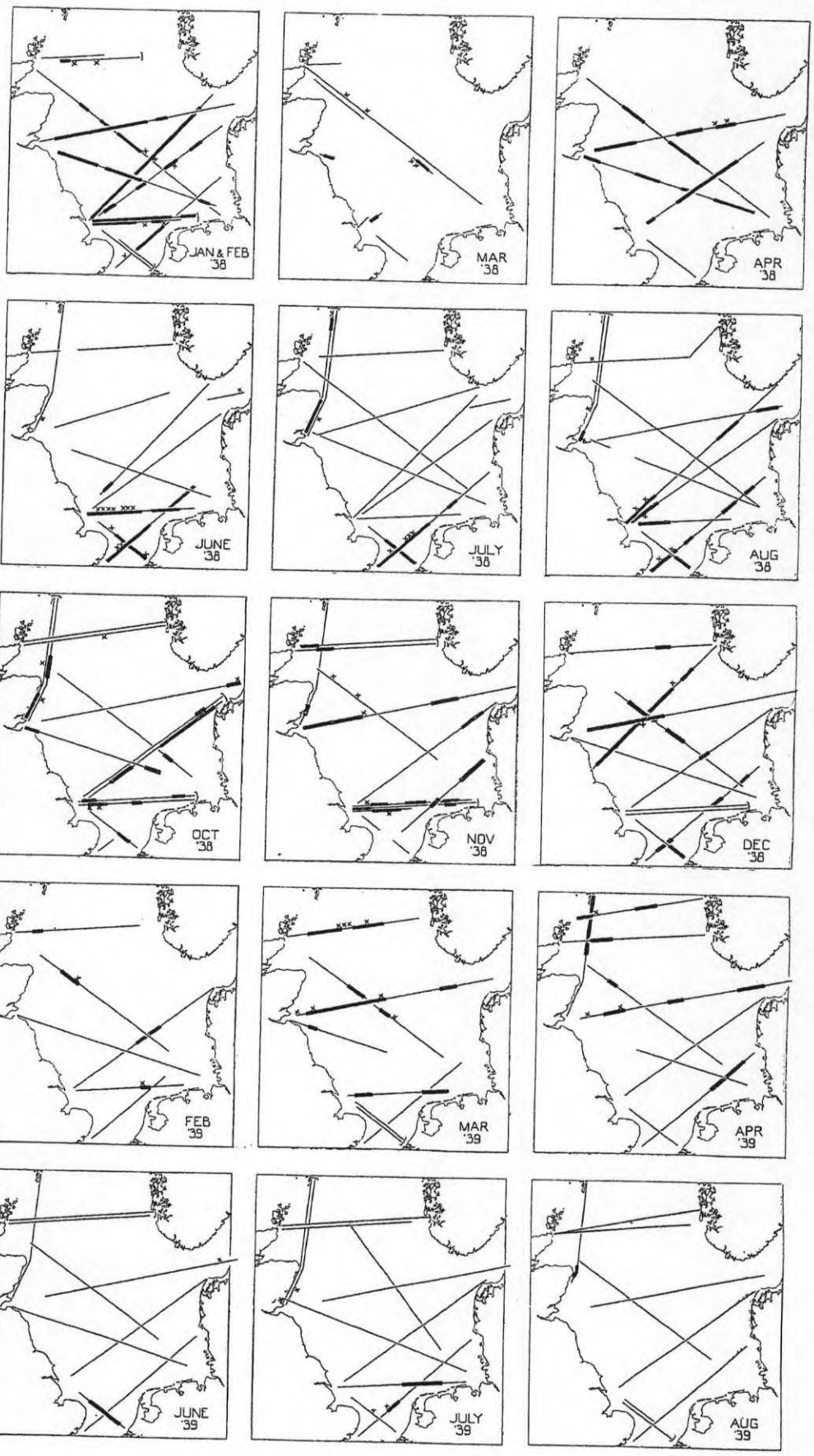
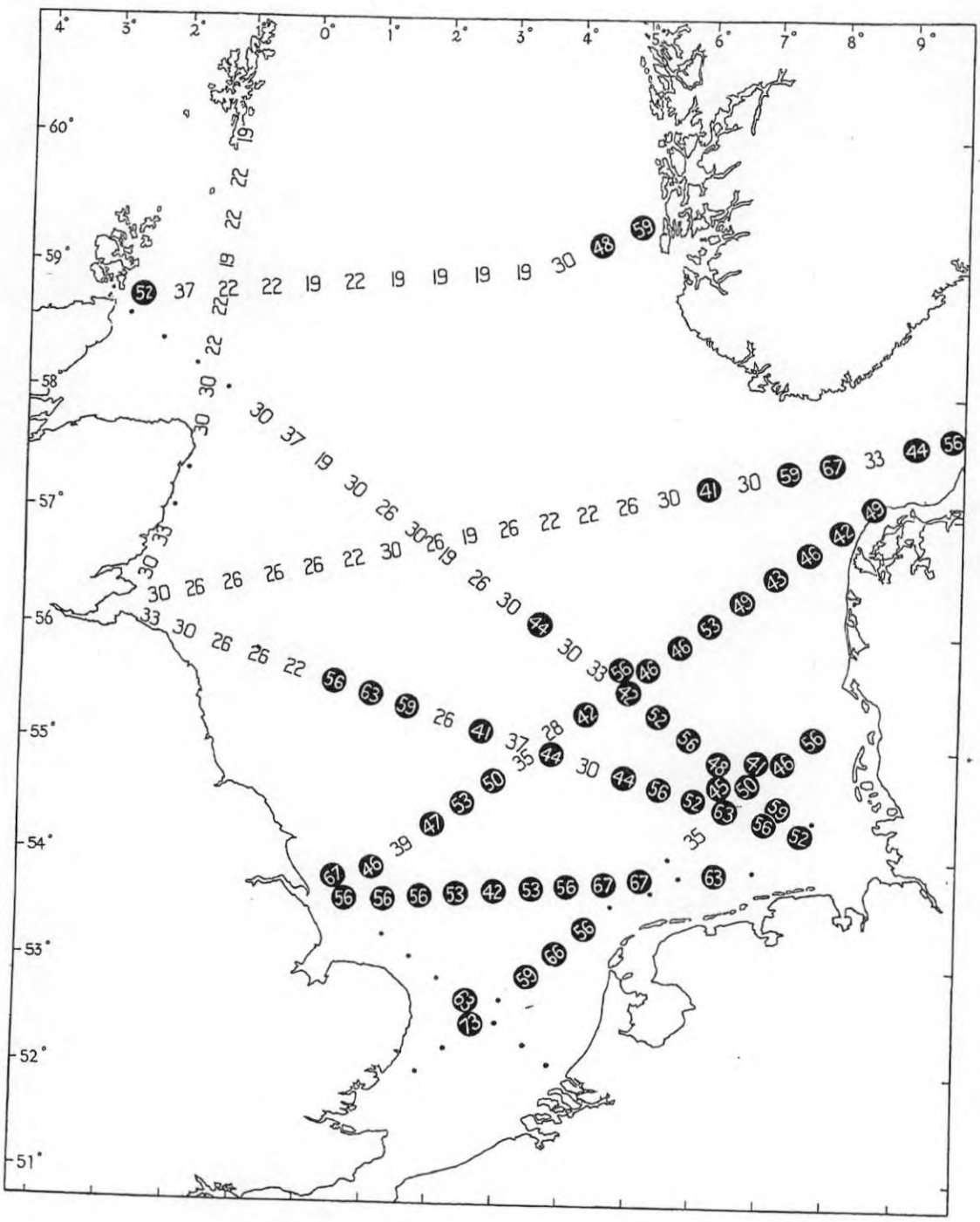
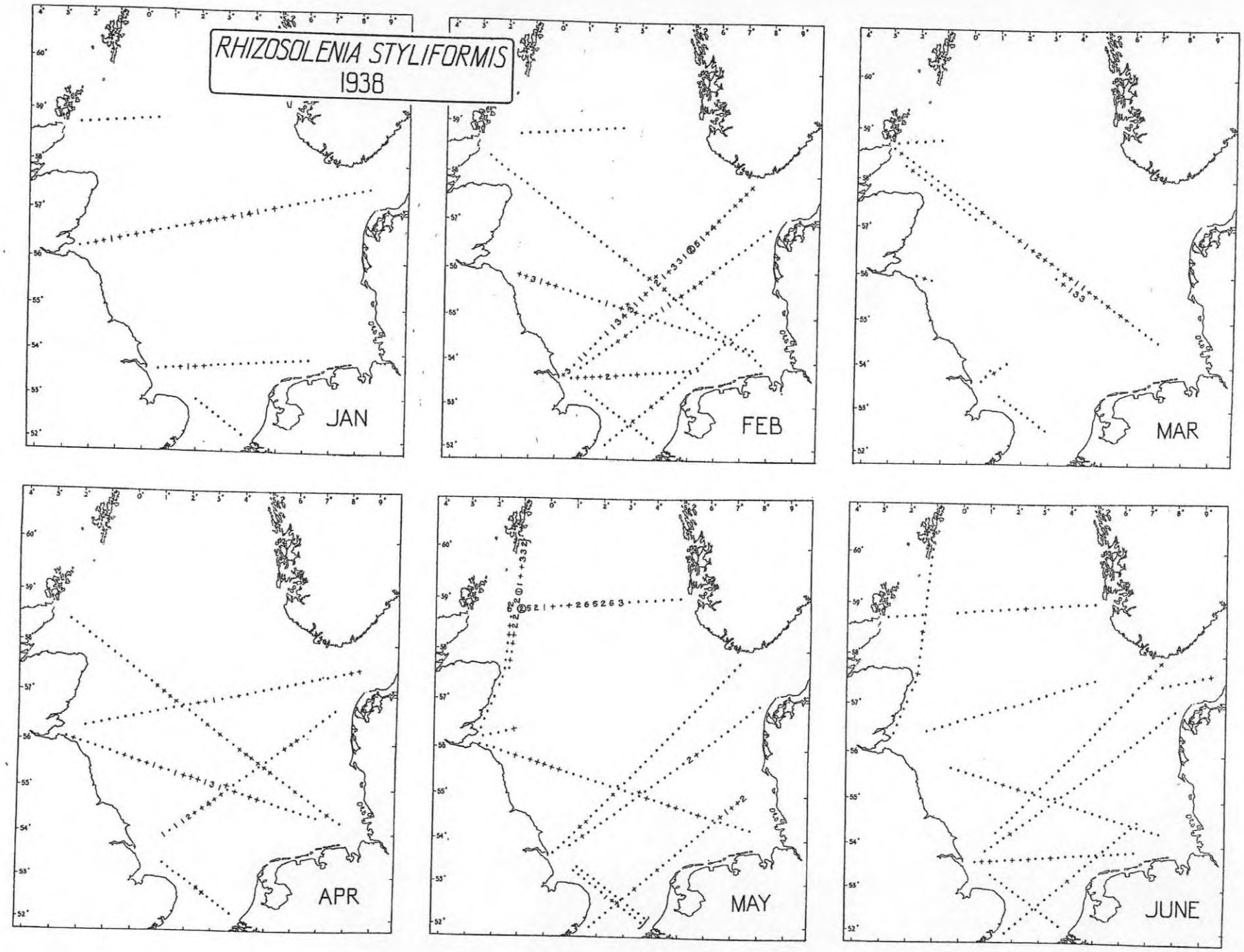


PLATE VII



Showing the sizes [in μ] of the smallest cells of *Rhizosolenia styliformis* recorded for each block of twenty miles on the normal routes during 1938. Those larger than 40μ are denoted by white figures on black.

PLATE VIII



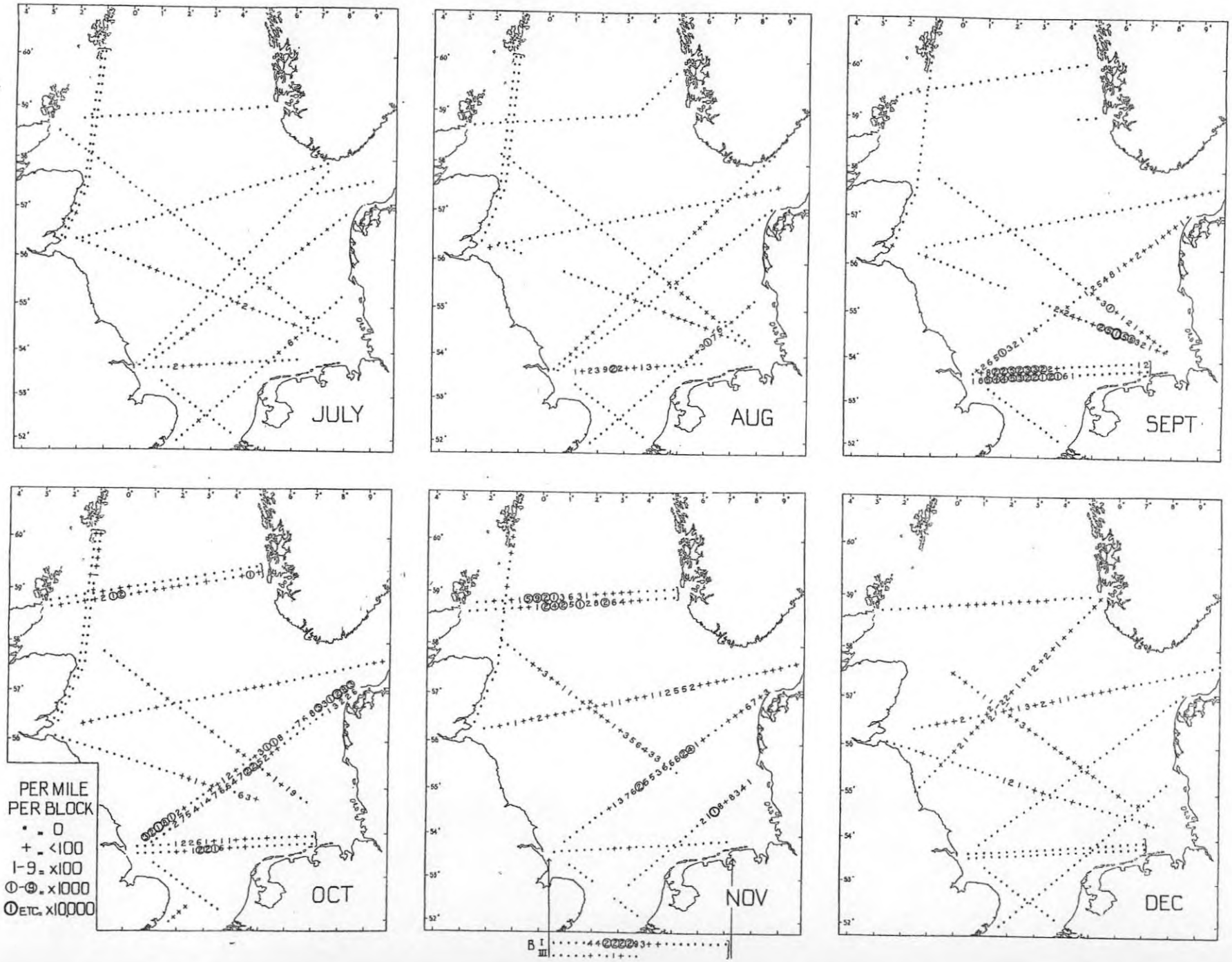
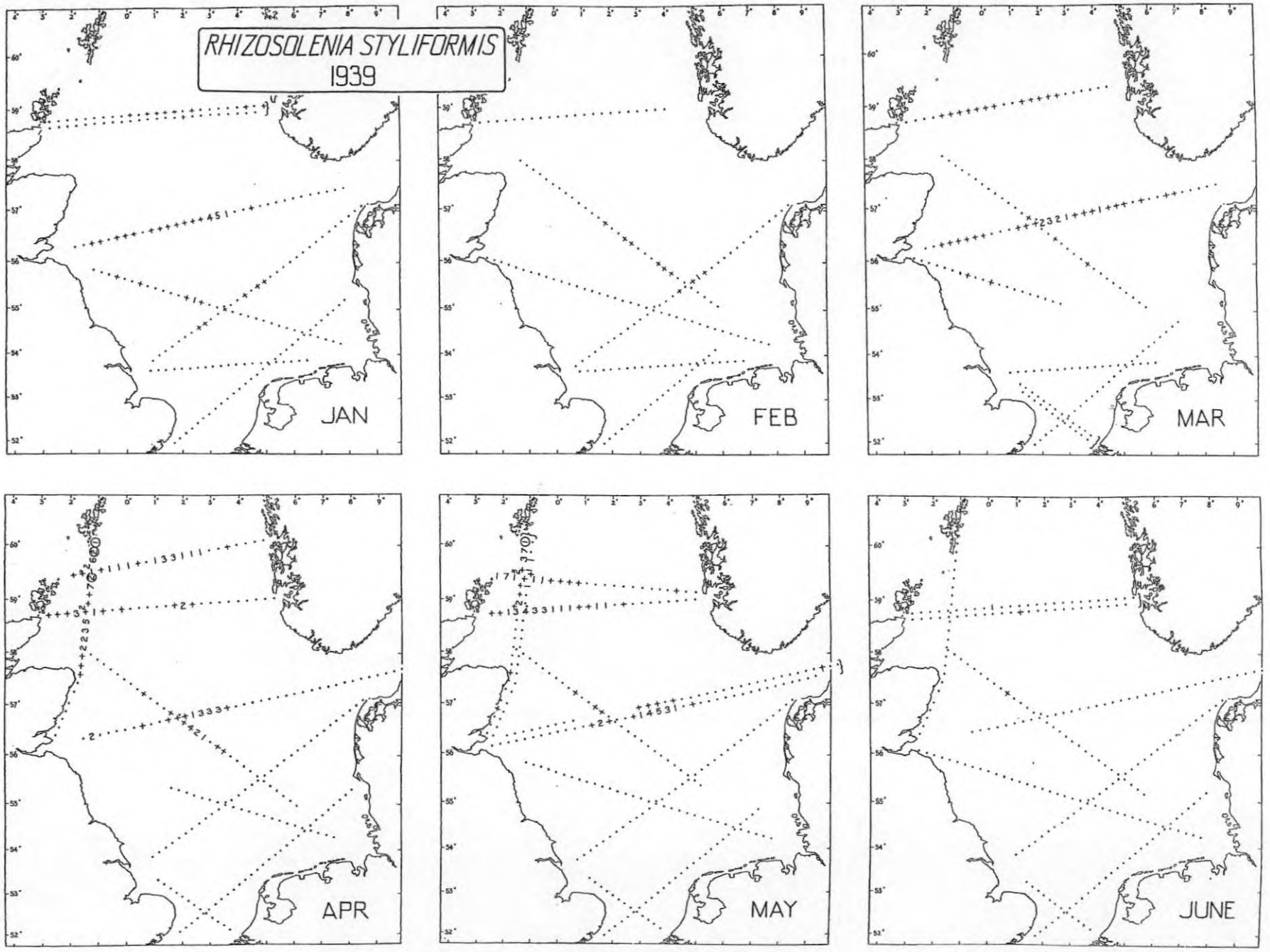
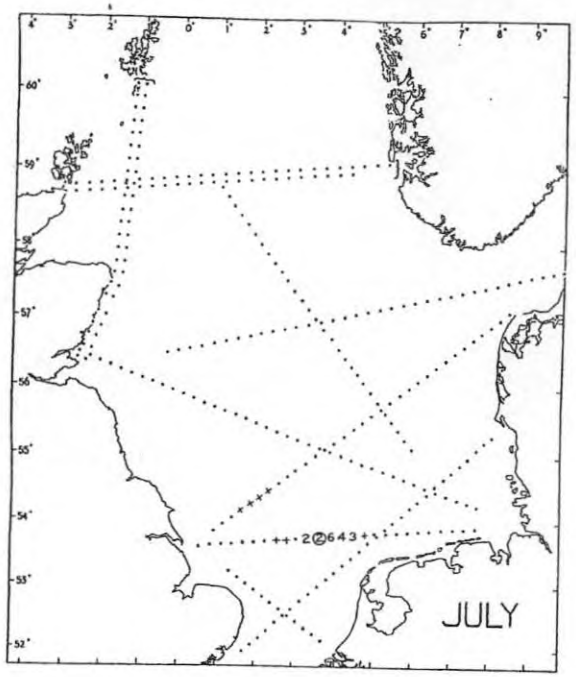
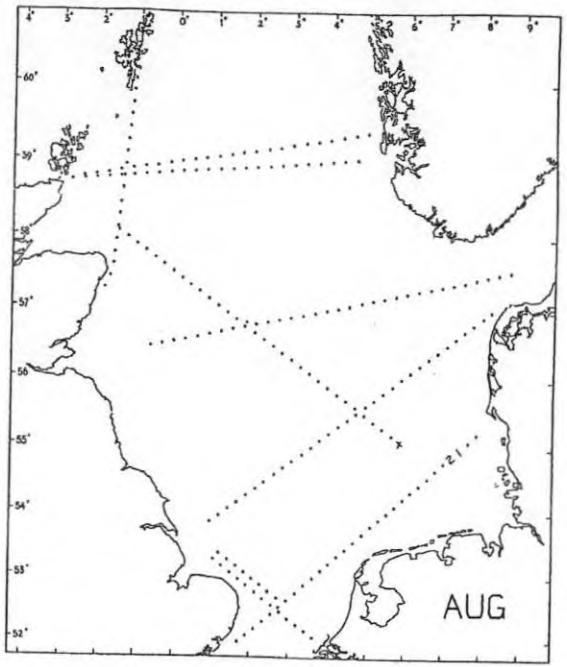

JULY
AUG
SEPT
OCT
NOV
DEC
PER MILE
PER BLOCK
• = 0
+ = <100
1-9 = x100
①-⑨ = x1000
① ETC. x10,000
B I
III

PLATE IX

PLATE X

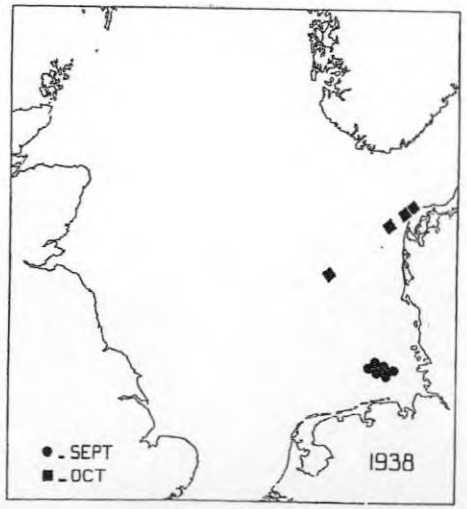






RHIZOSOLENIA STYLIFORMIS
1939 CONTD.

RHIZOSOLENIA CALCAR-AVIS
All records :



DACTYLIOSOLEN SPP.
All records :

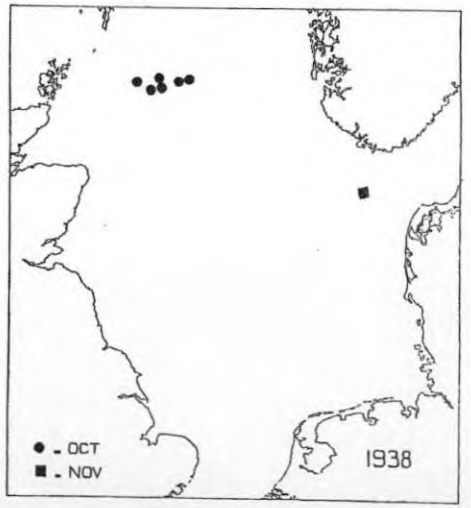
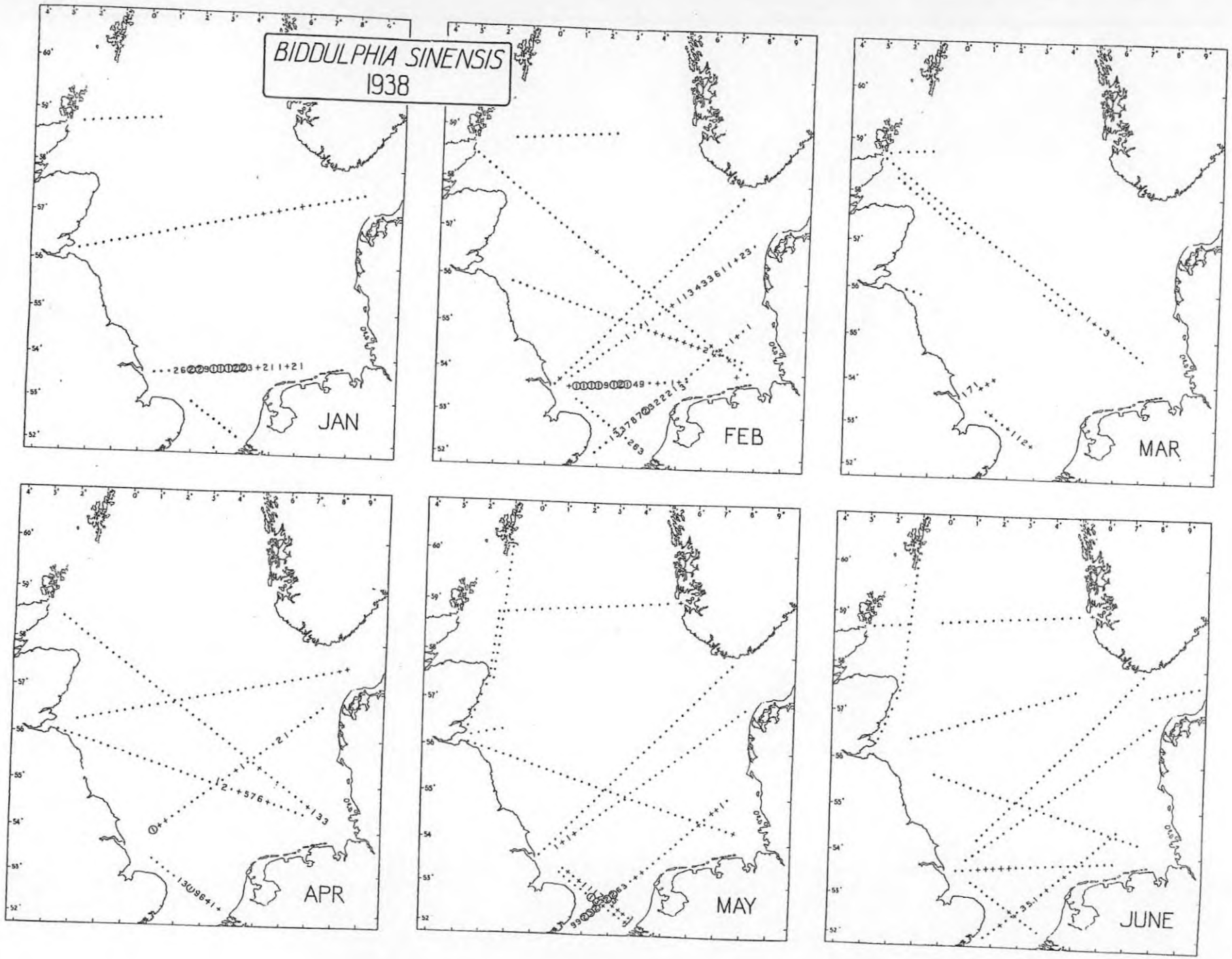
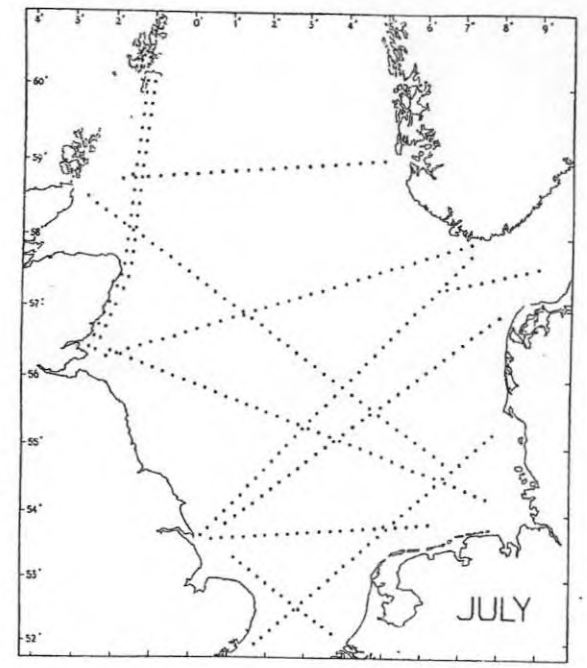
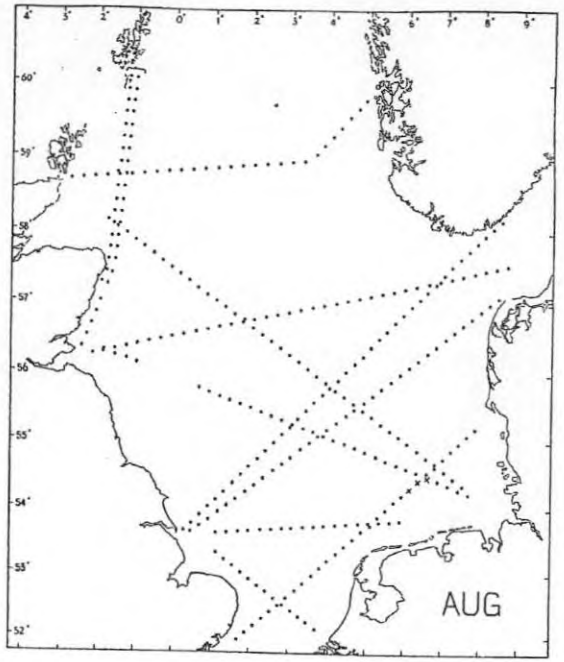


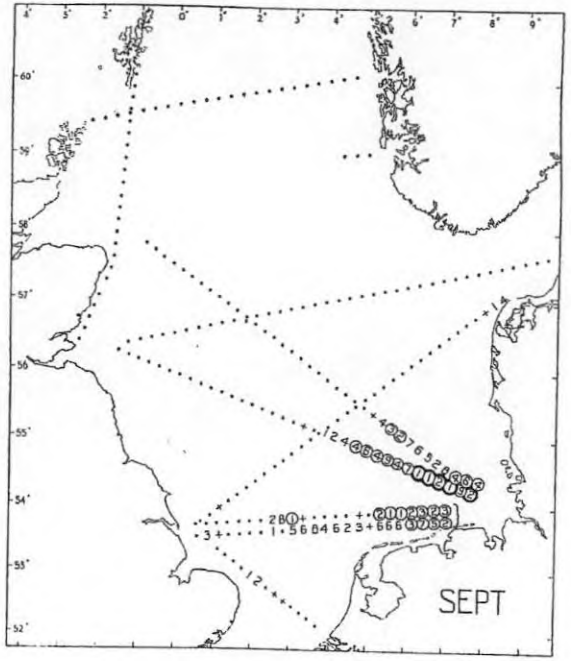
PLATE XI

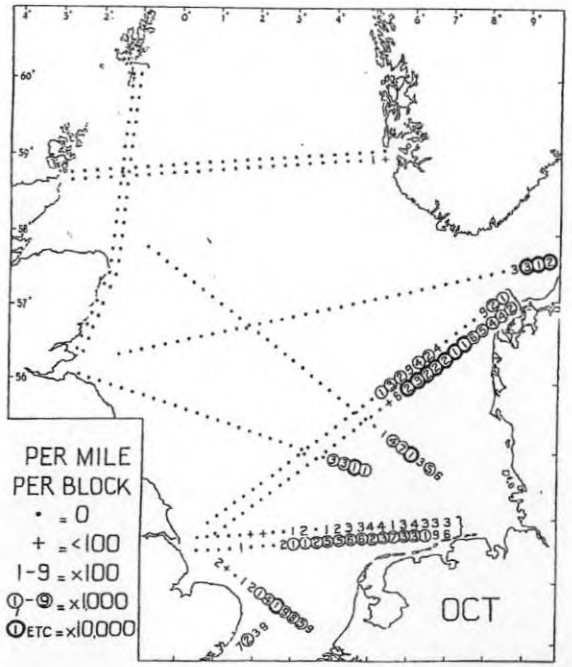
PLATE XII

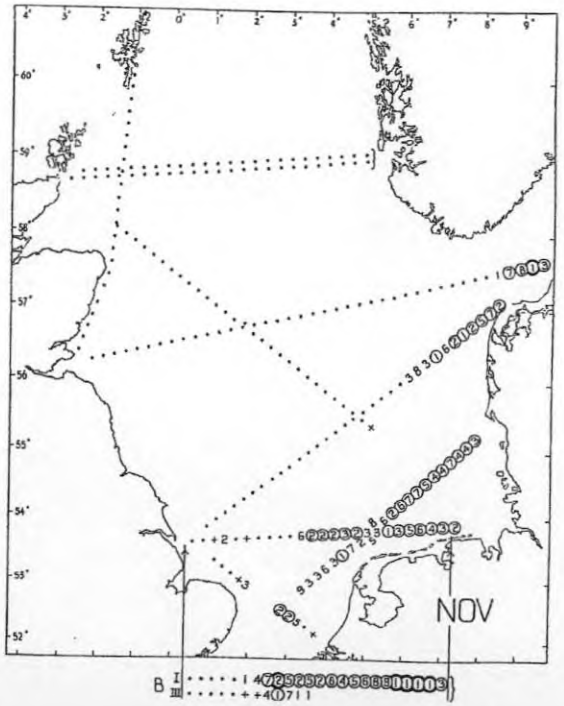



JULY


AUG


SEPT


PER MILE
PER BLOCK
• = 0
+ = <100
1-9 = x100
⓪-⑨ = x1000
① ETC = x10,000
OCT


NOV

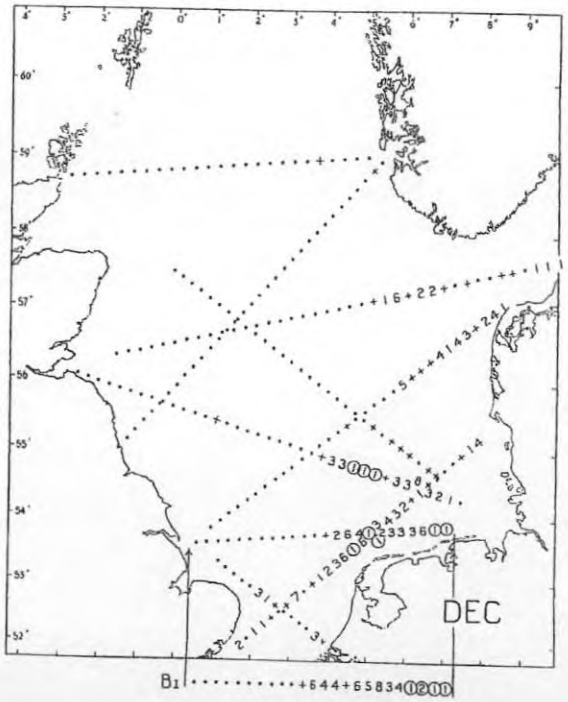
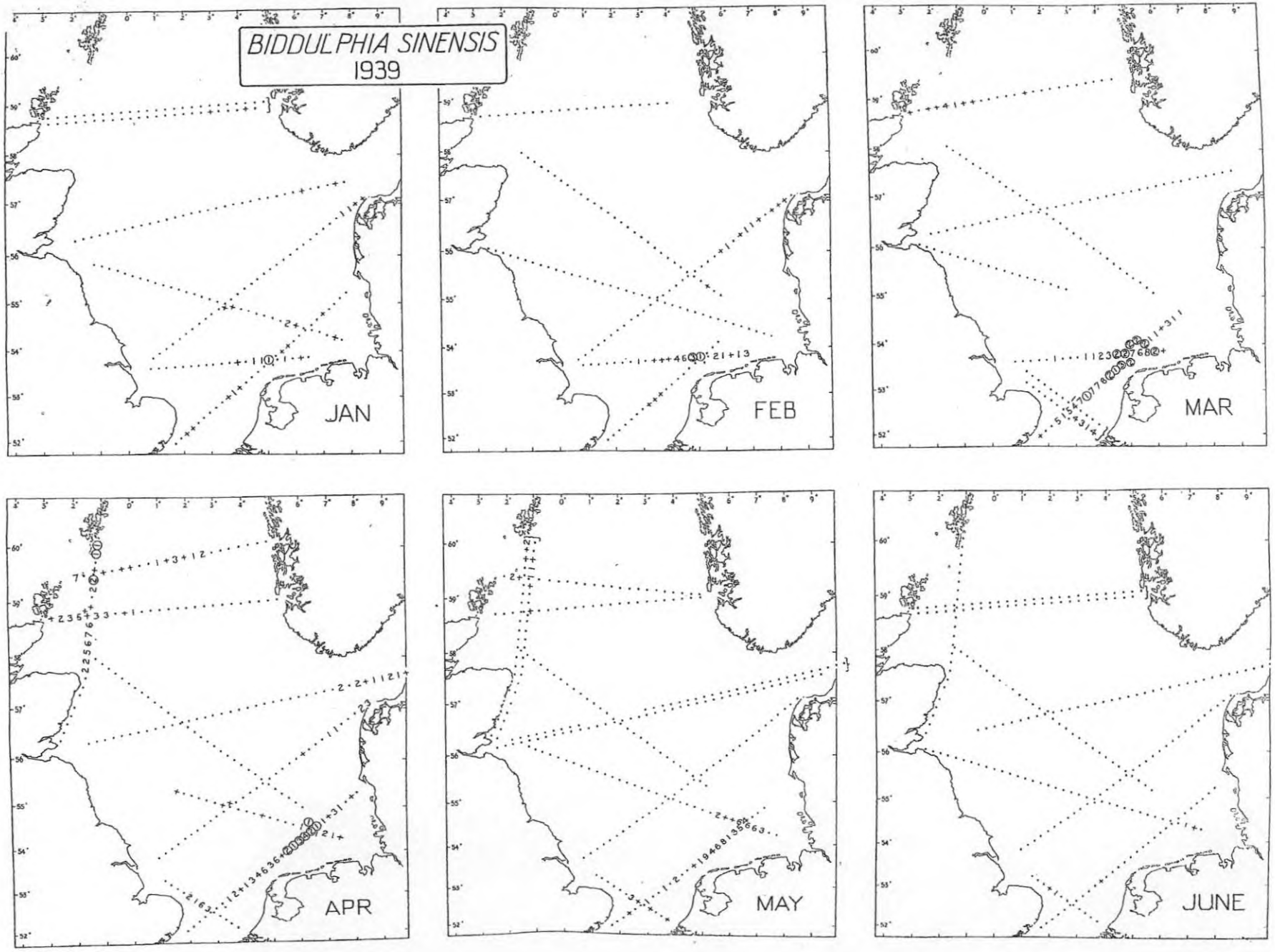
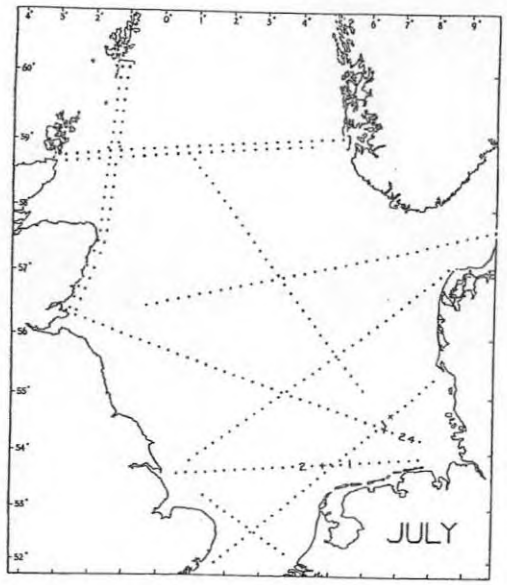
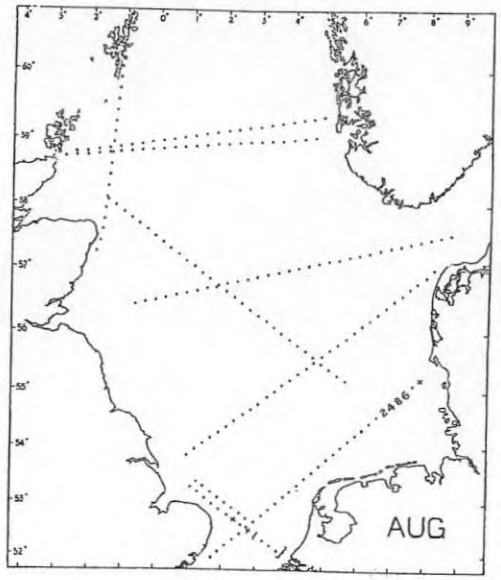

DEC

PLATE XIII

PLATE XIV



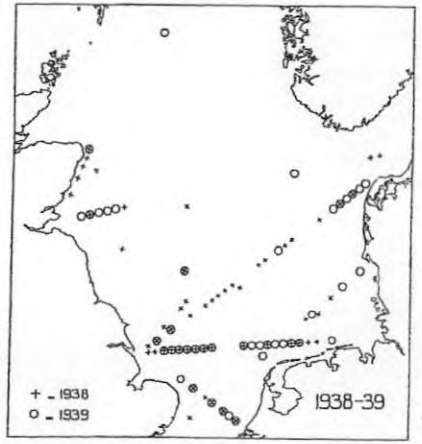




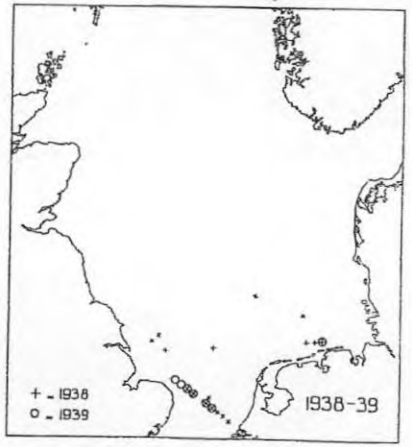
BIDDULPHIA SINENSIS
1939 CONTD.

Single maps showing the overall distribution of four other species.

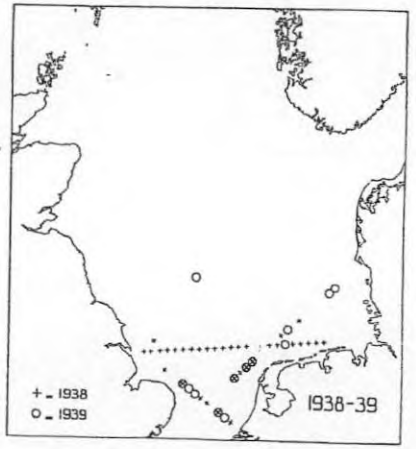
B.MOBILIENSIS



B. RHOMBUS



BELLAROCHIA



CORETHRON

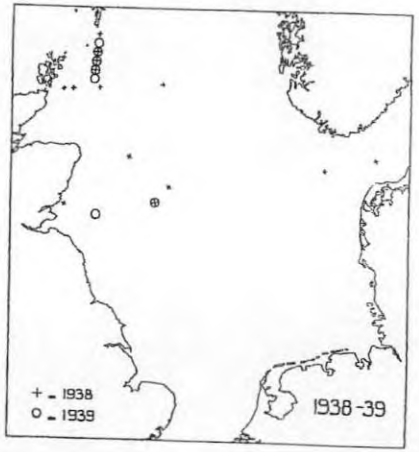


PLATE XV

PLATE XVI

RHIZOSOLENIA ALATA

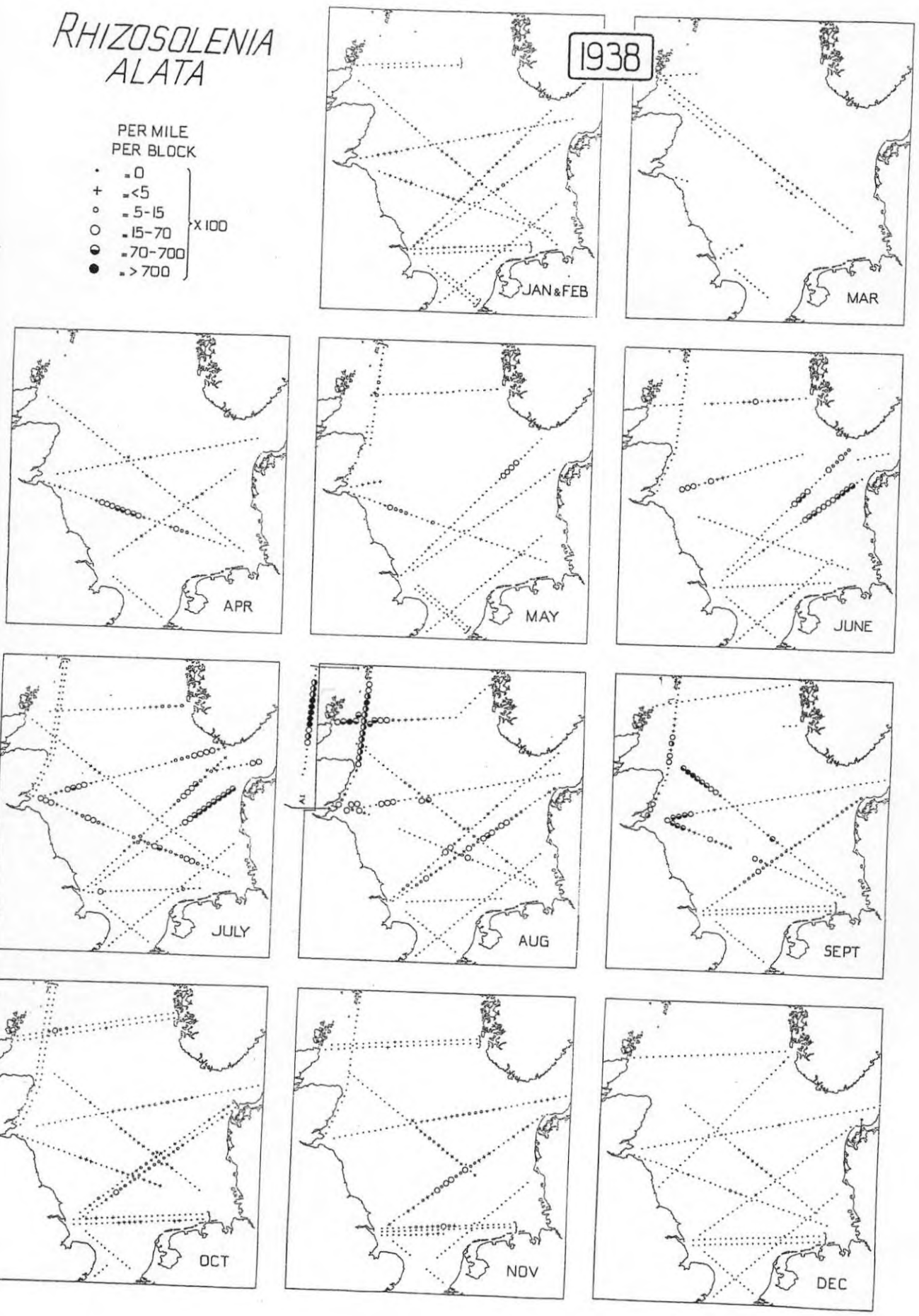
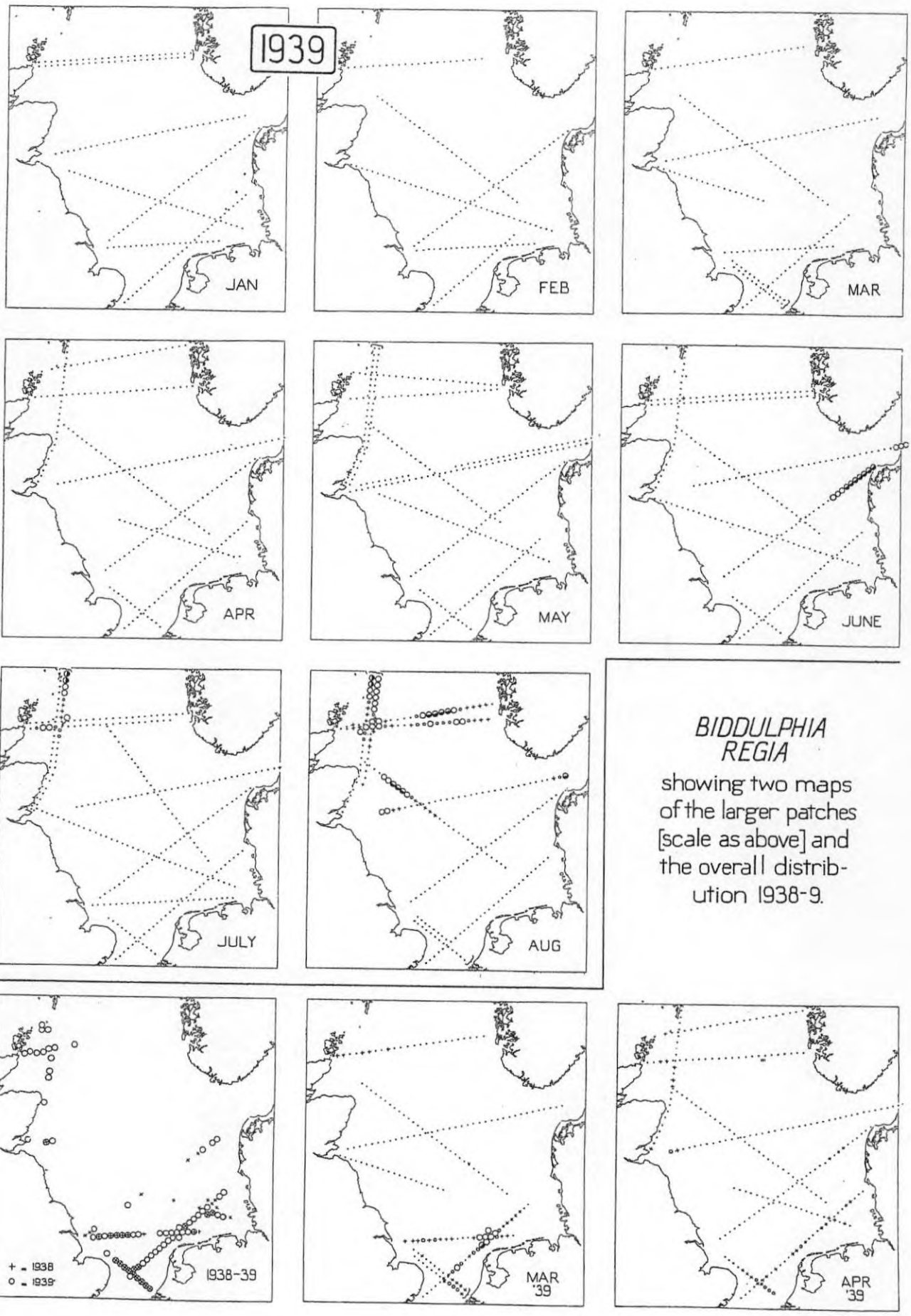


PLATE XVII



BIDDULPHIA REGIA

showing two maps of the larger patches [scale as above] and the overall distribution 1938-9.

PLATE XVIII

RHIZOSOLENIA SHRUBSOLEI

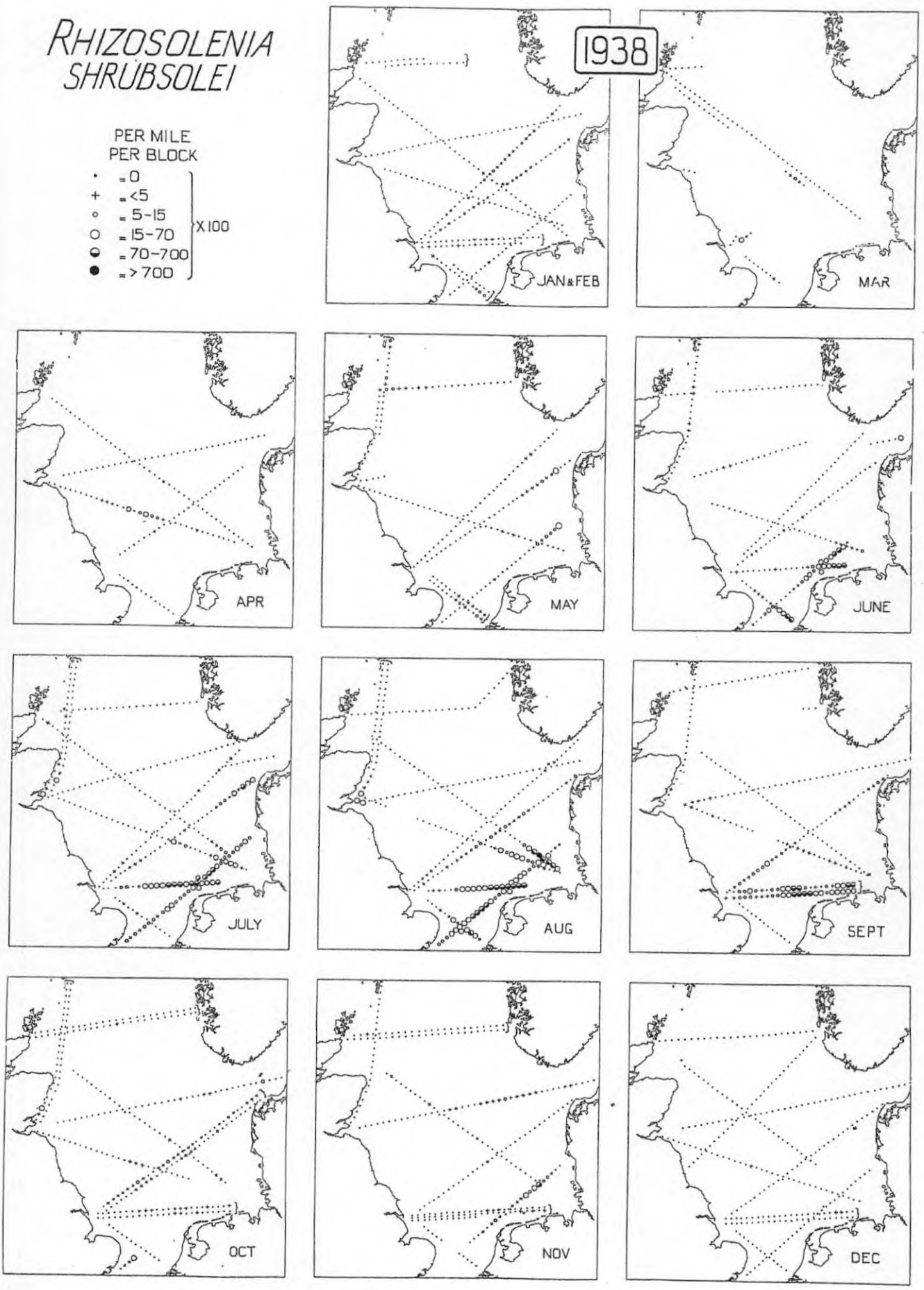
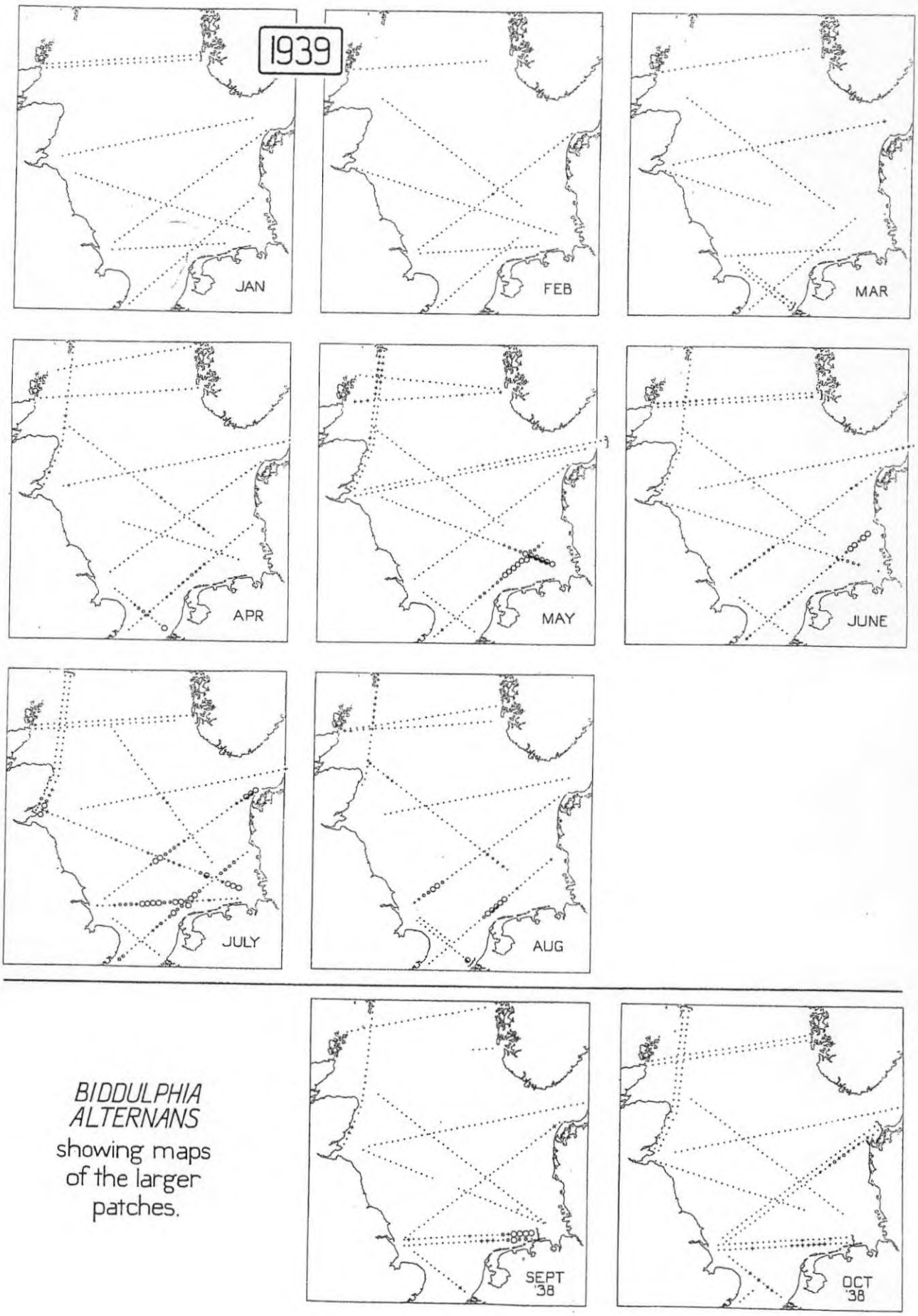


PLATE XIX



BIDDULPHIA ALTERNANS
showing maps of the larger patches.

PLATE XX

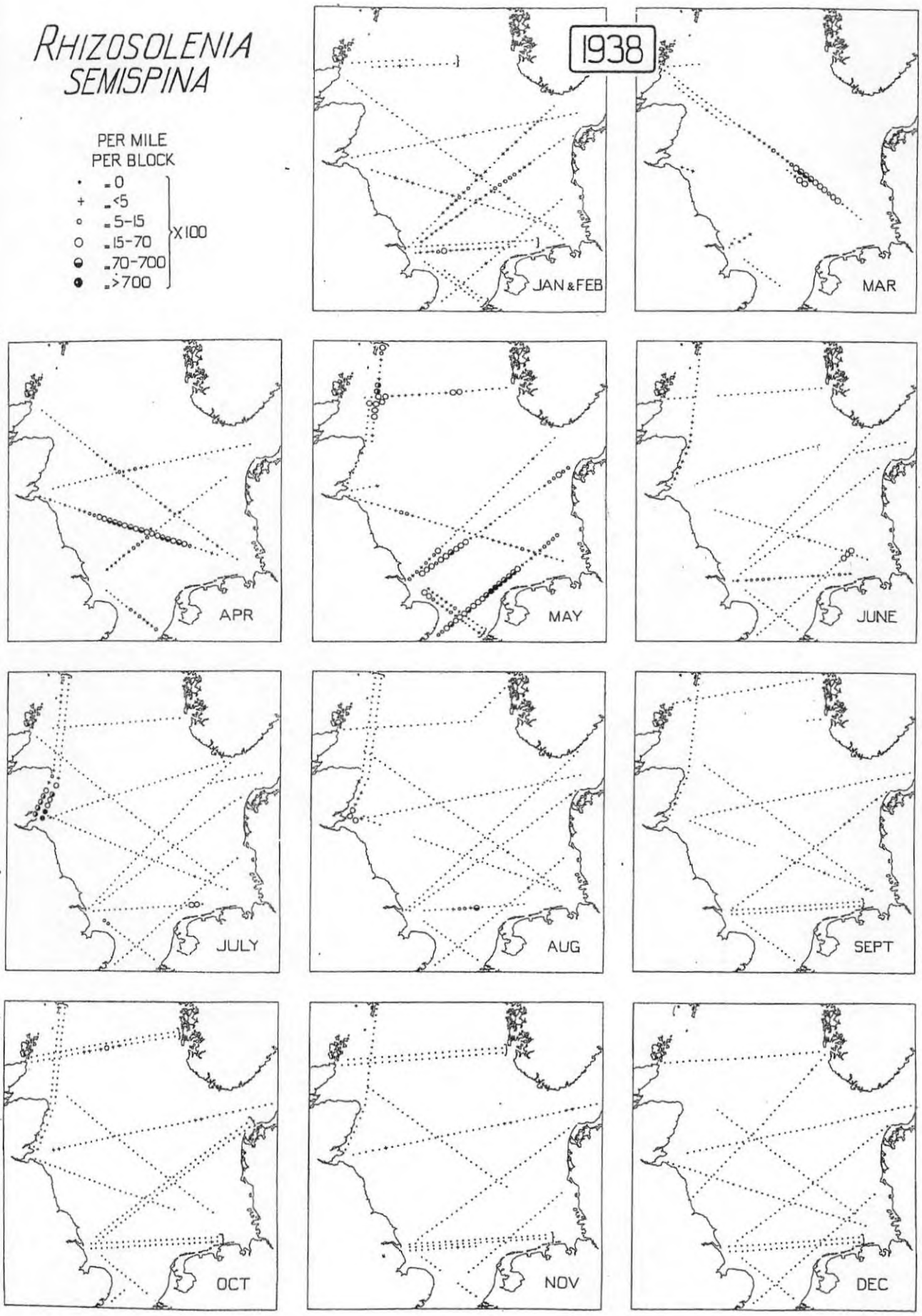
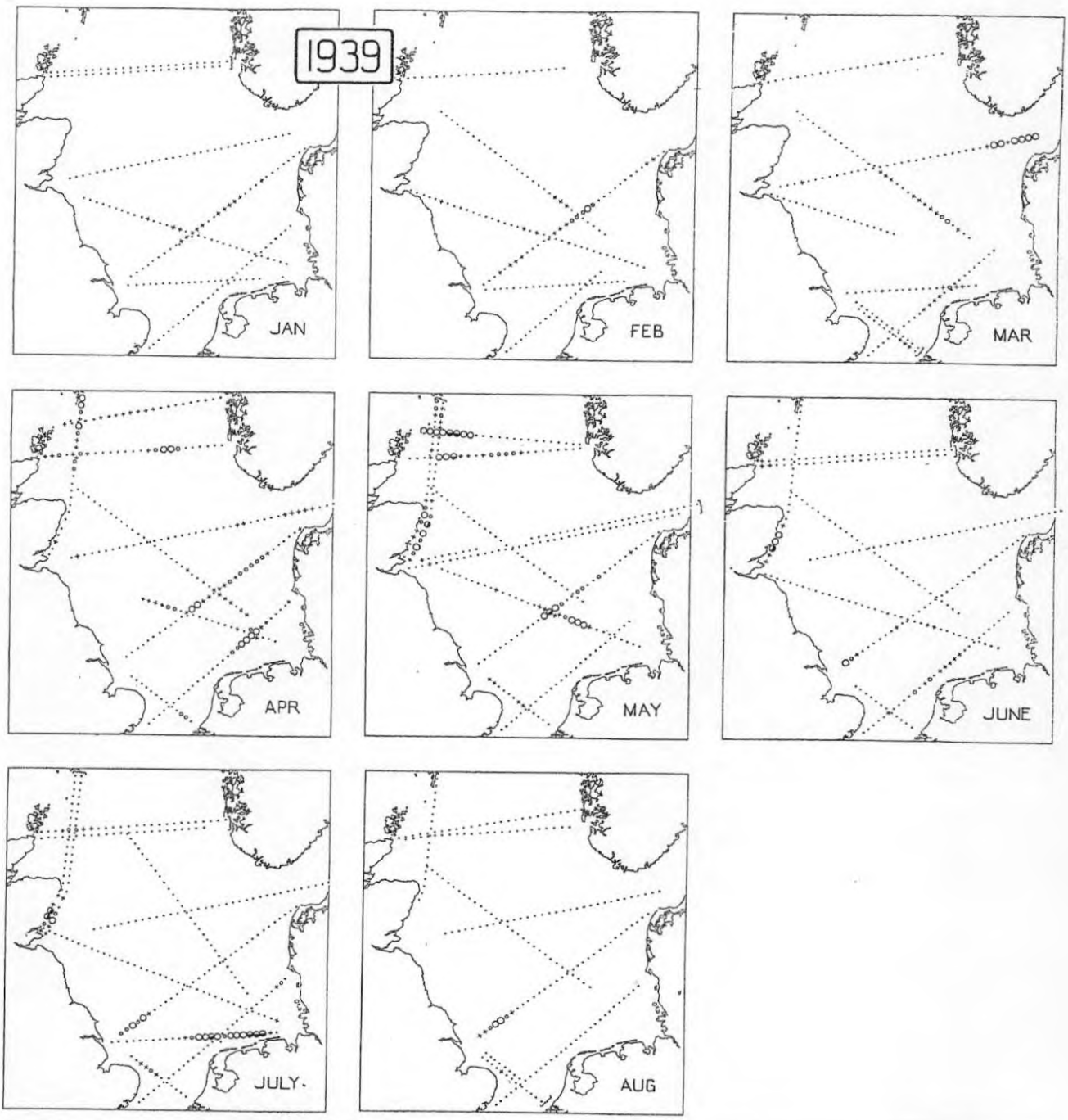

RHIZOSOLENIA SEMISPINA
PER MILE PER BLOCK
· = 0
+ = <5
○ = 5-15
○ = 15-70
◒ = 70-700
● = >700
X100
1938
JAN & FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC

PLATE XXI



CERATAULINA BERGONII

showing maps of the larger patches of 1939

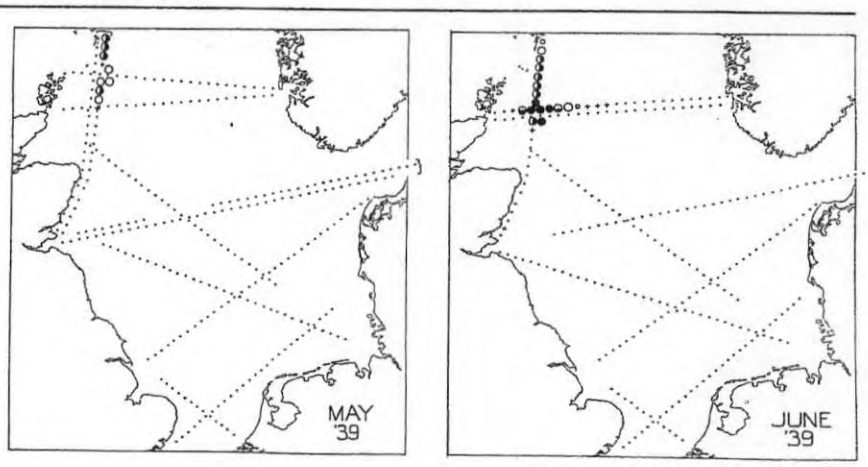
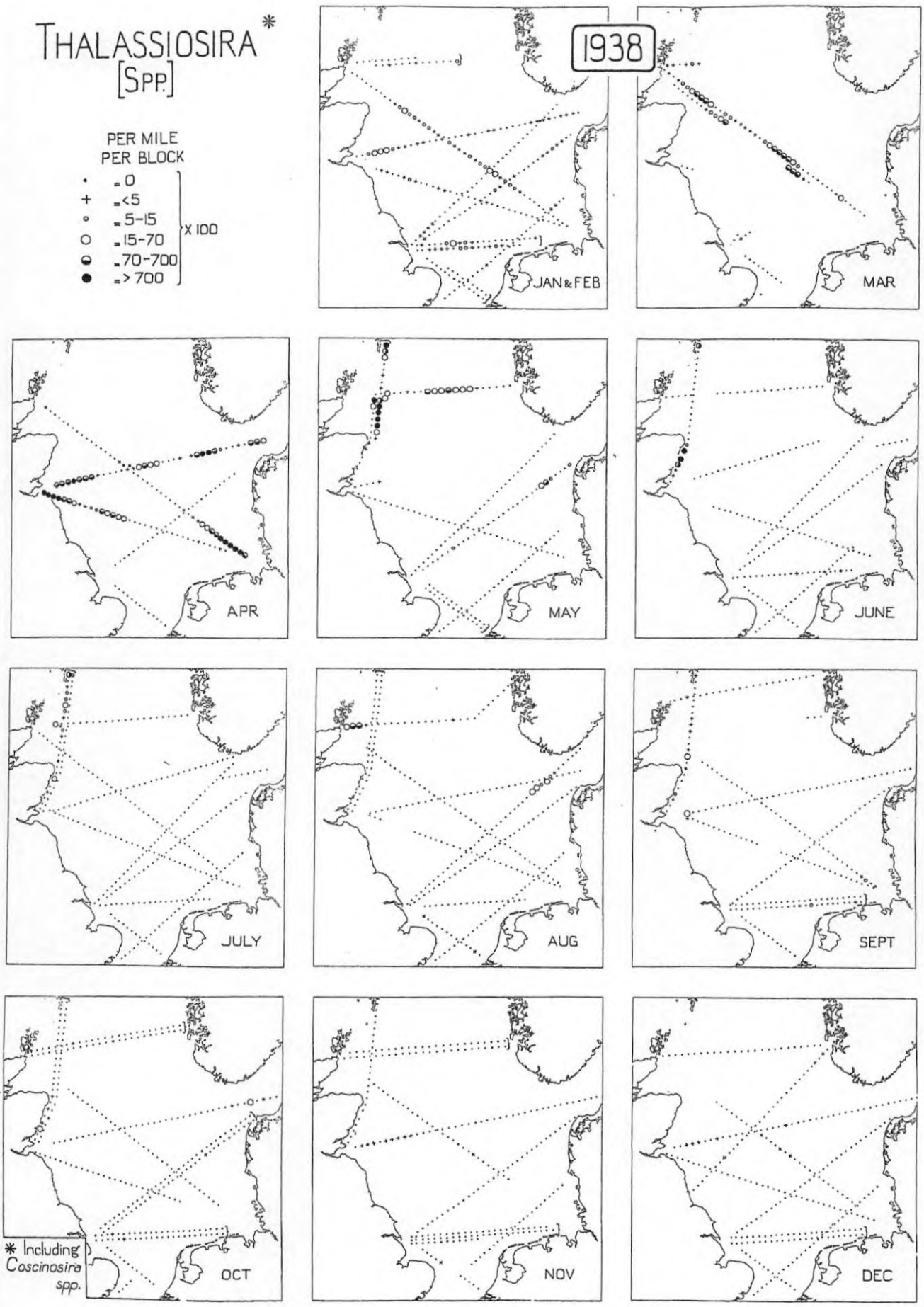


PLATE XXII

THALASSIOSIRA* [SPP.]

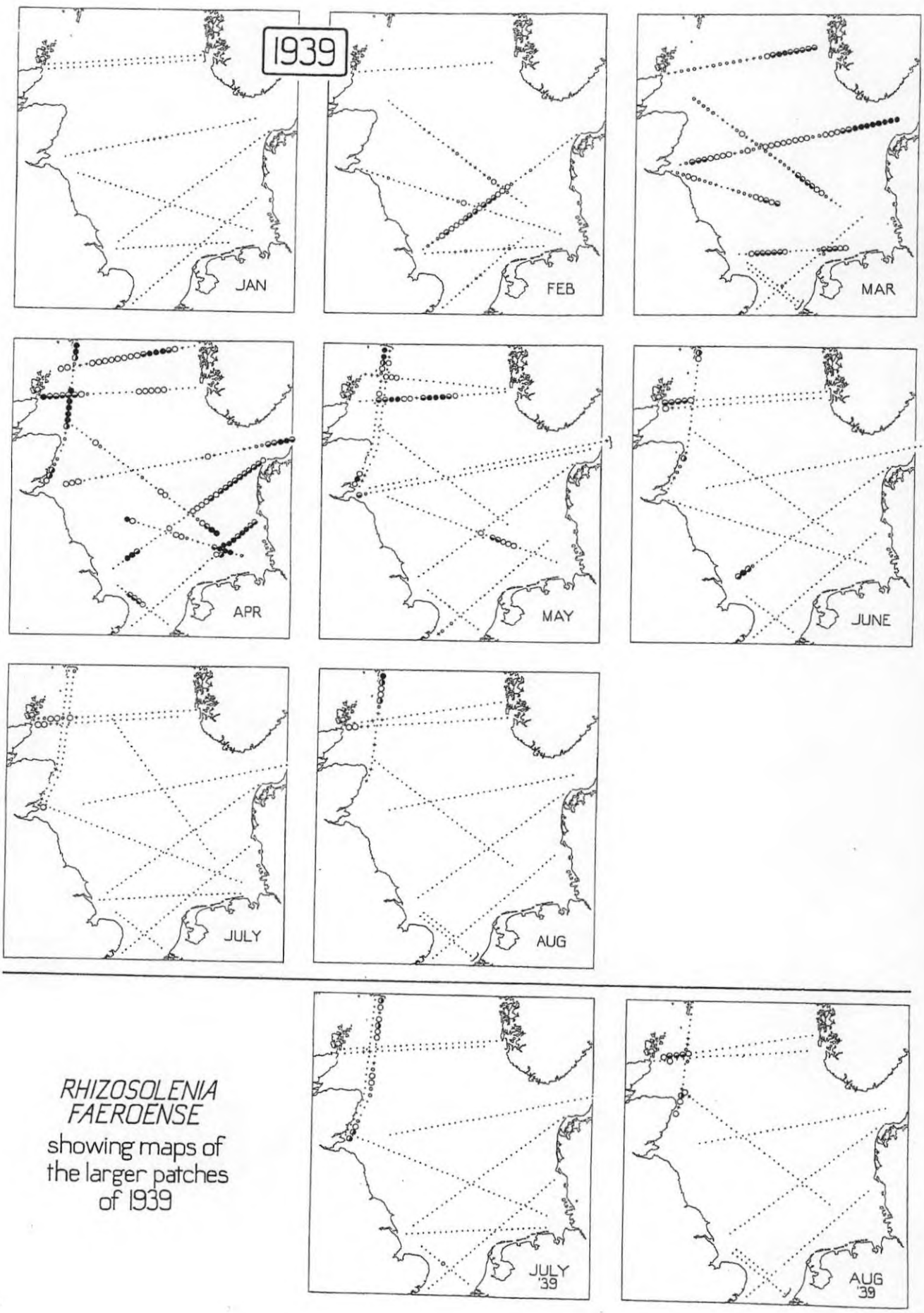
PER MILE PER BLOCK

·	= 0	X 100
+	= <5	
∘	= 5-15	
○	= 15-70	
◒	= 70-700	
●	= > 700	



* Including *Coscinosira* spp.

PLATE XXIII



RHIZOSOLENIA FAEROENSE
showing maps of the larger patches of 1939

PLATE XXIV

CHAETOCEROS [PHAEOCERIDS]

PER MILE PER BLOCK

- · = 0
- + = <5
- ∘ = 5-15
- O = 15-70
- ◒ = 70-700
- ● = >700

} X100

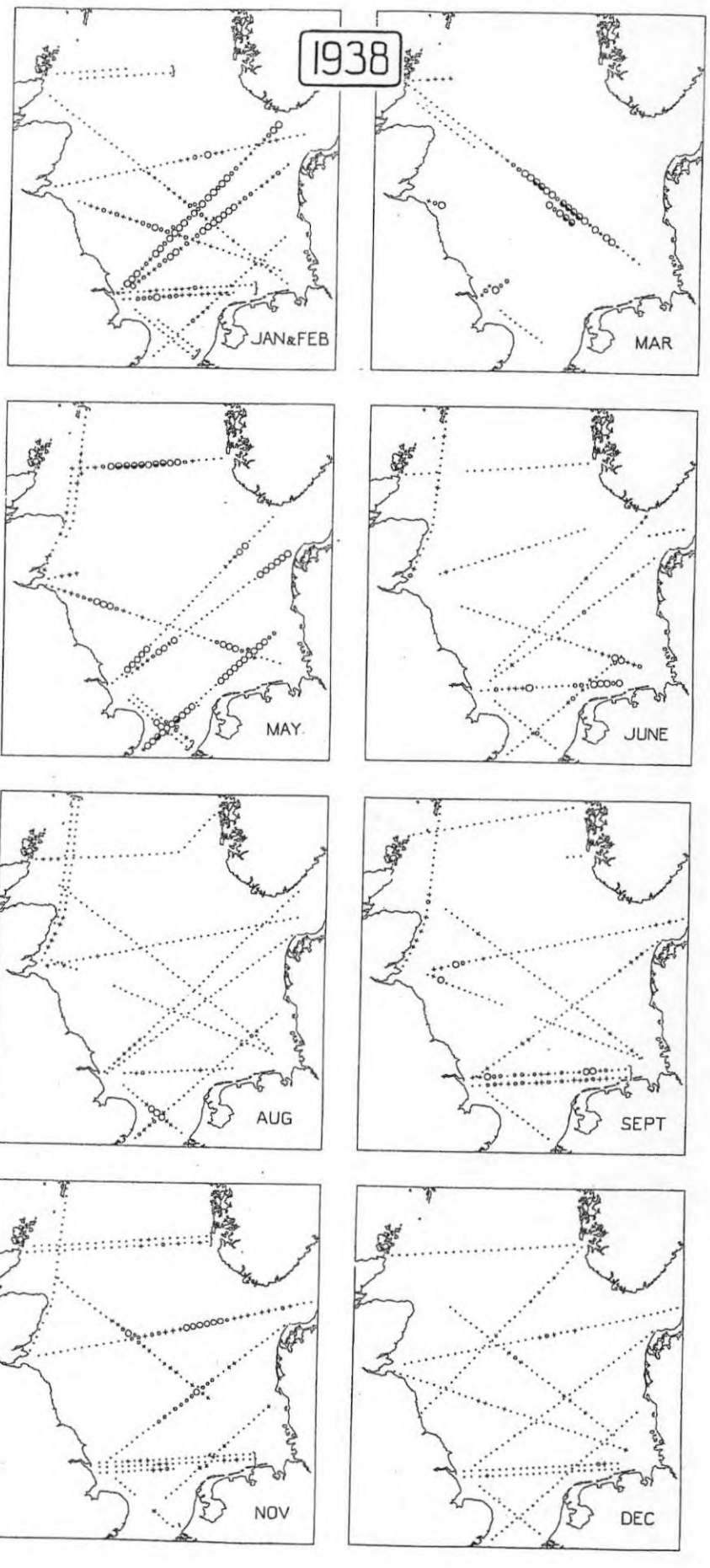
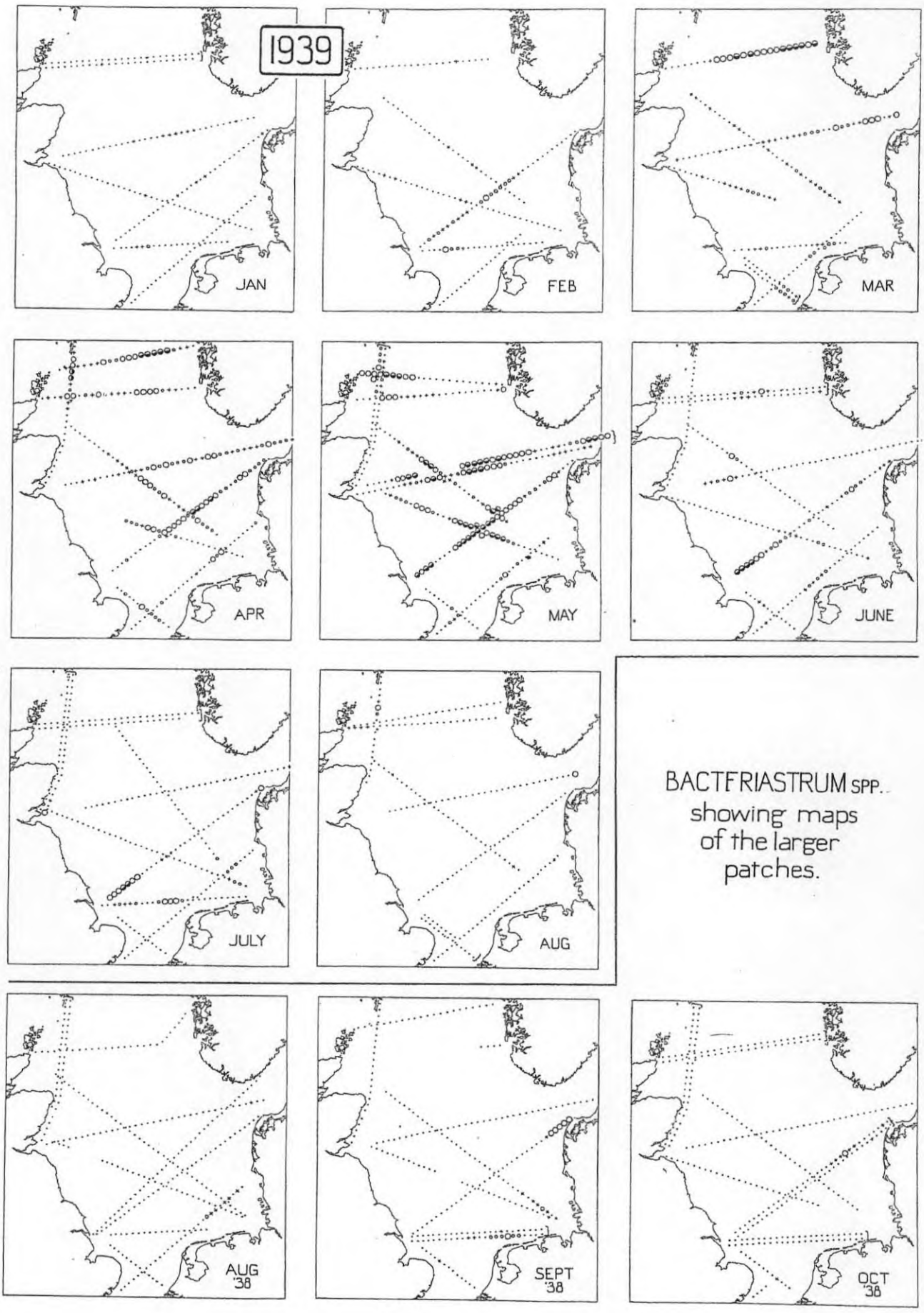


PLATE XXV



BACTERIASTRUM SPP. showing maps of the larger patches.

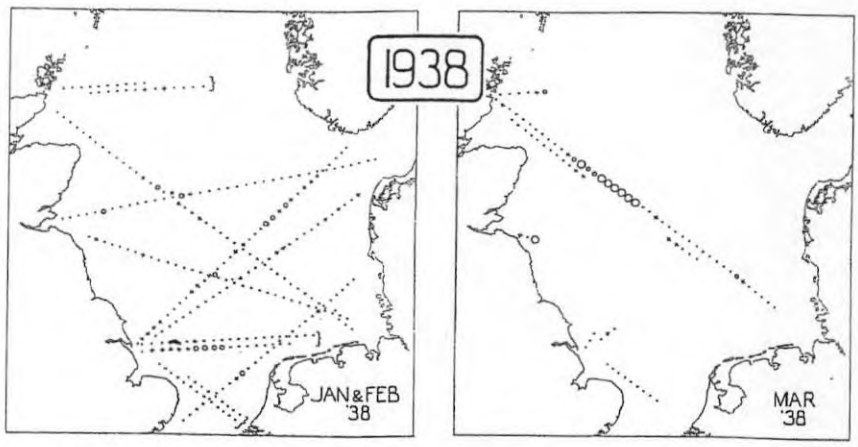
PLATE XXVI

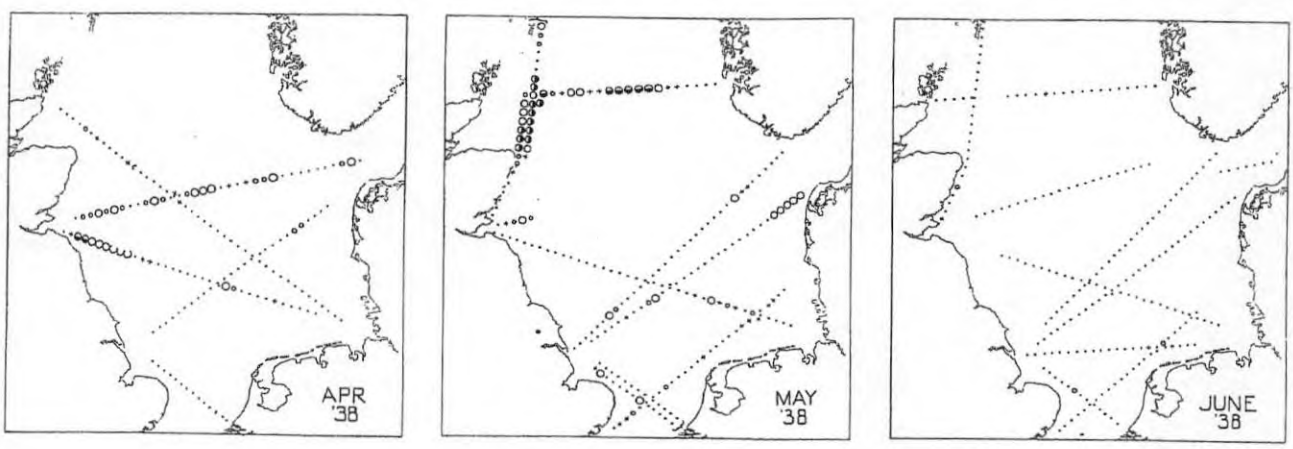
CHAETOCEROS DECIPIENS

PER MILE
PER BLOCK

- • = 0
- + = <5
- ○ = 5-15
- ○ = 15-70
- ◒ = 70-700

} X 100





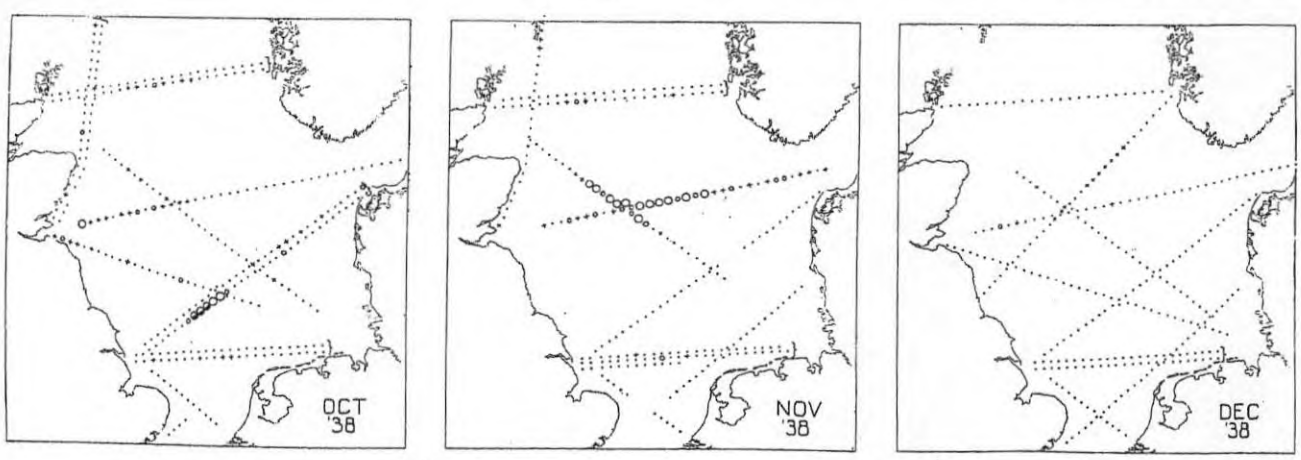
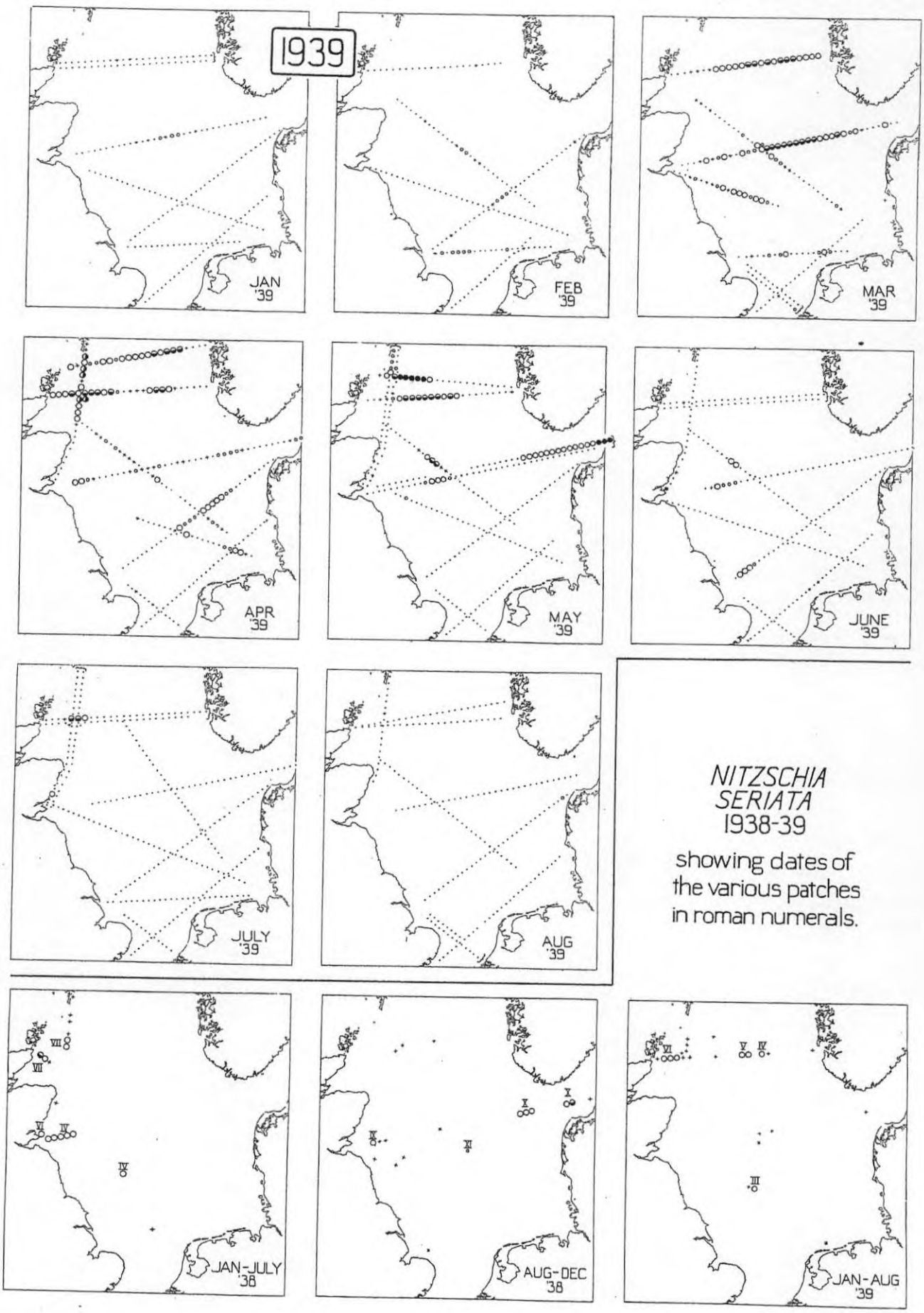


PLATE XXVII



NITZSCHIA SERIATA
1938-39

showing dates of the various patches in roman numerals.

PLATE XXVIII

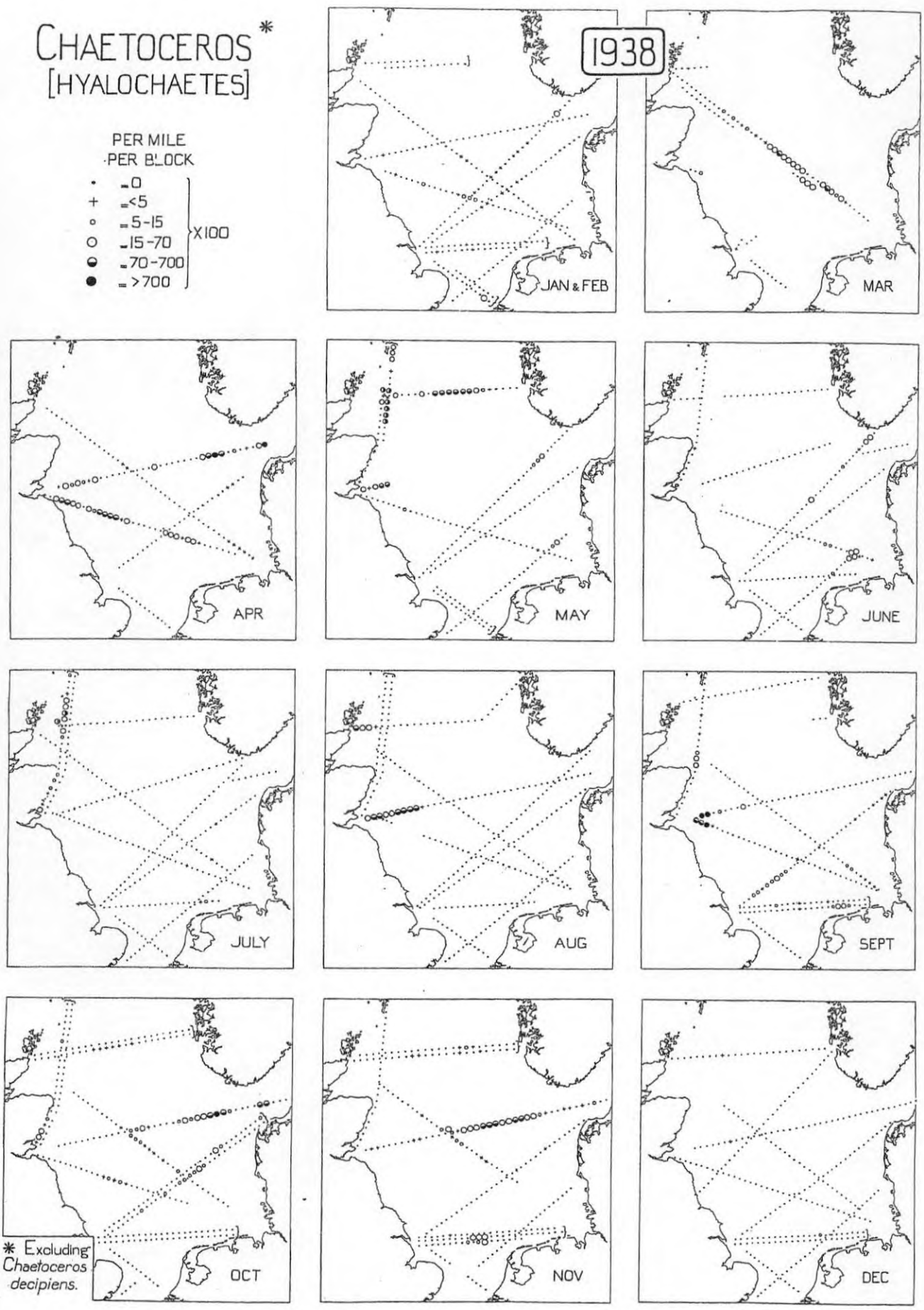


PLATE XXIX

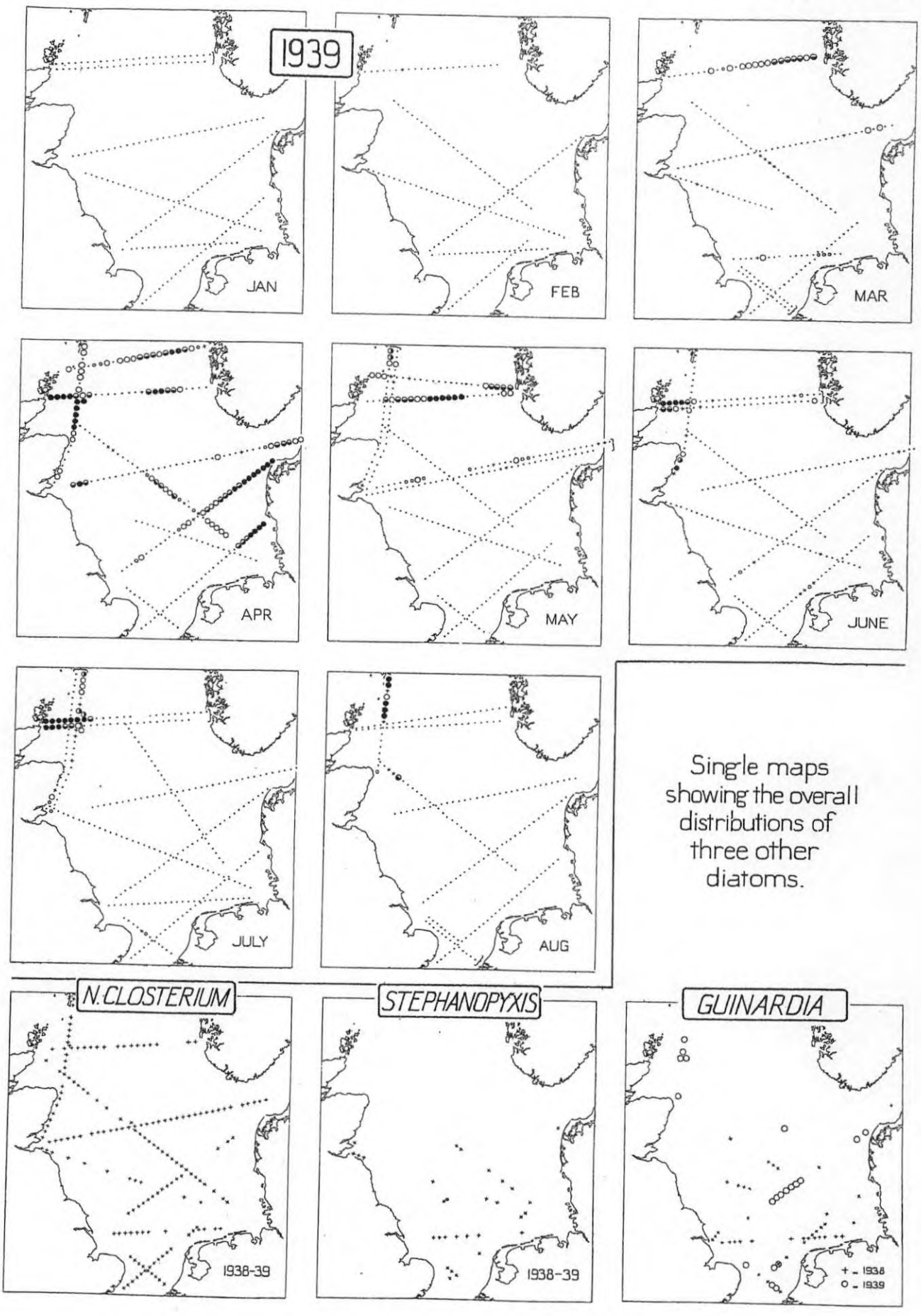
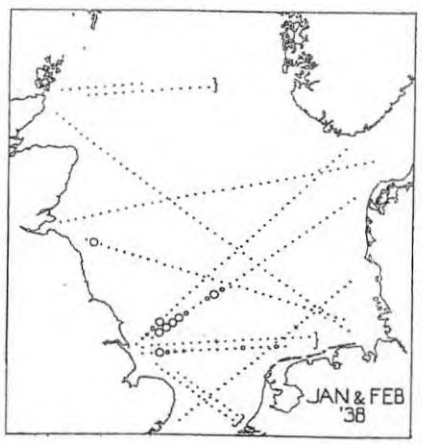

1939
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
Single maps showing the overall distributions of three other diatoms.
N. CLOSTERIUM
1938-39
STEPHANOPYXIS
1938-39
GUINARDIA
+ - 1938
○ - 1939

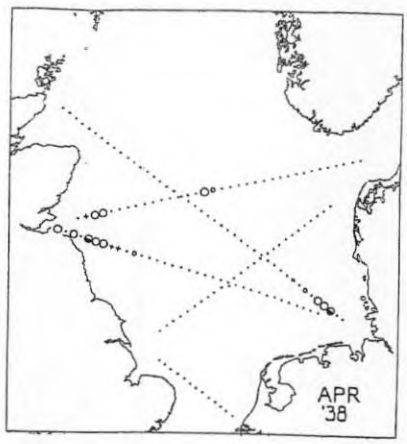
PLATE XXX

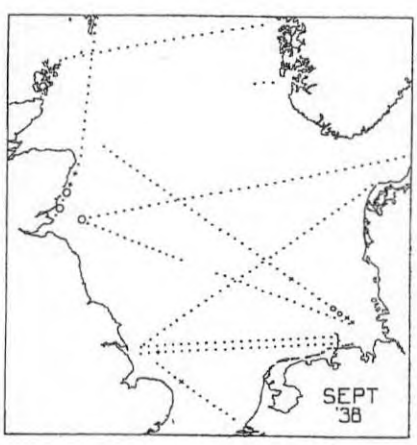
ASTERIONELLA JAPONICA

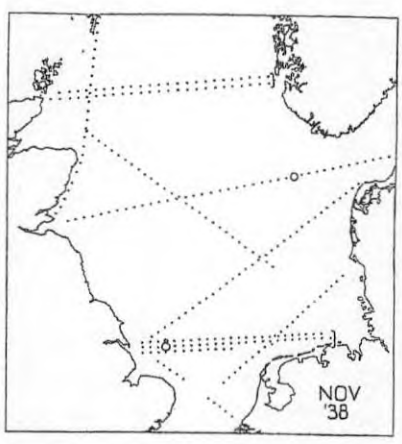
PER MILE
PER BLOCK

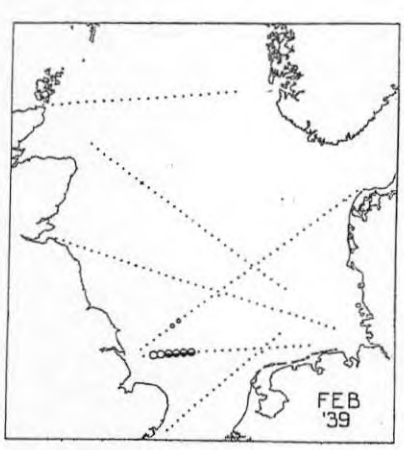
•	= 0	X 100
+	= <5	
○	= 5-15	
○	= 15-70	
◒	= 70-700	
●	= >700	

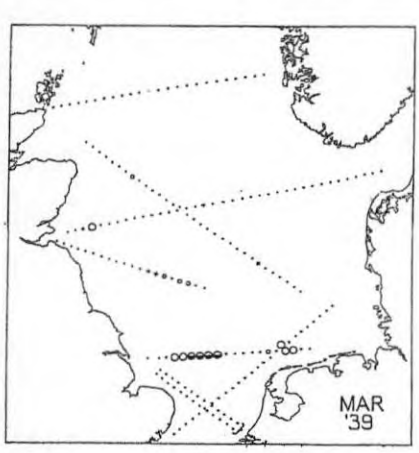


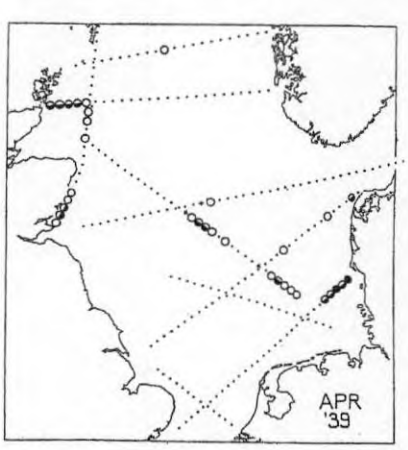


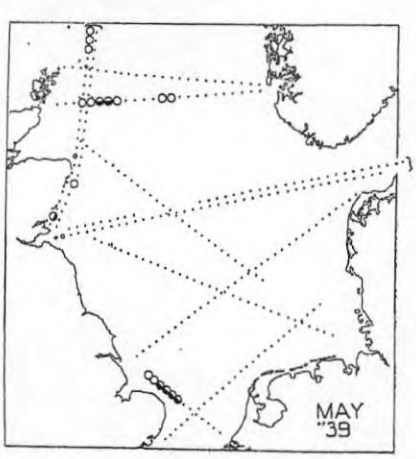


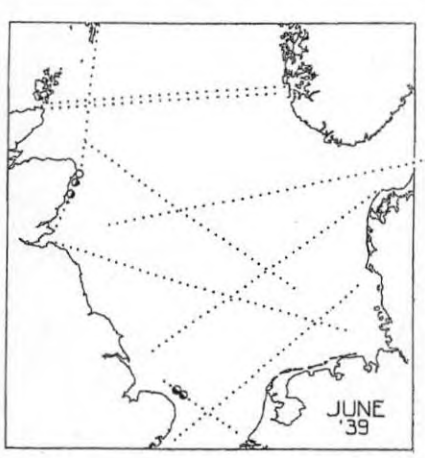












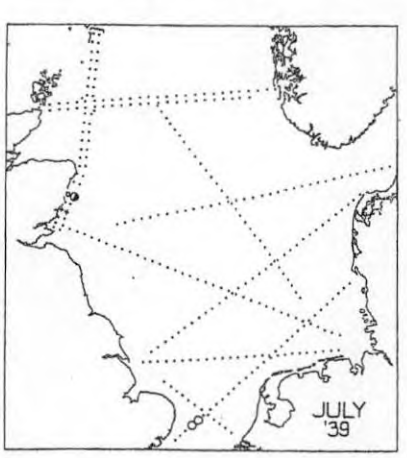


PLATE XXXI

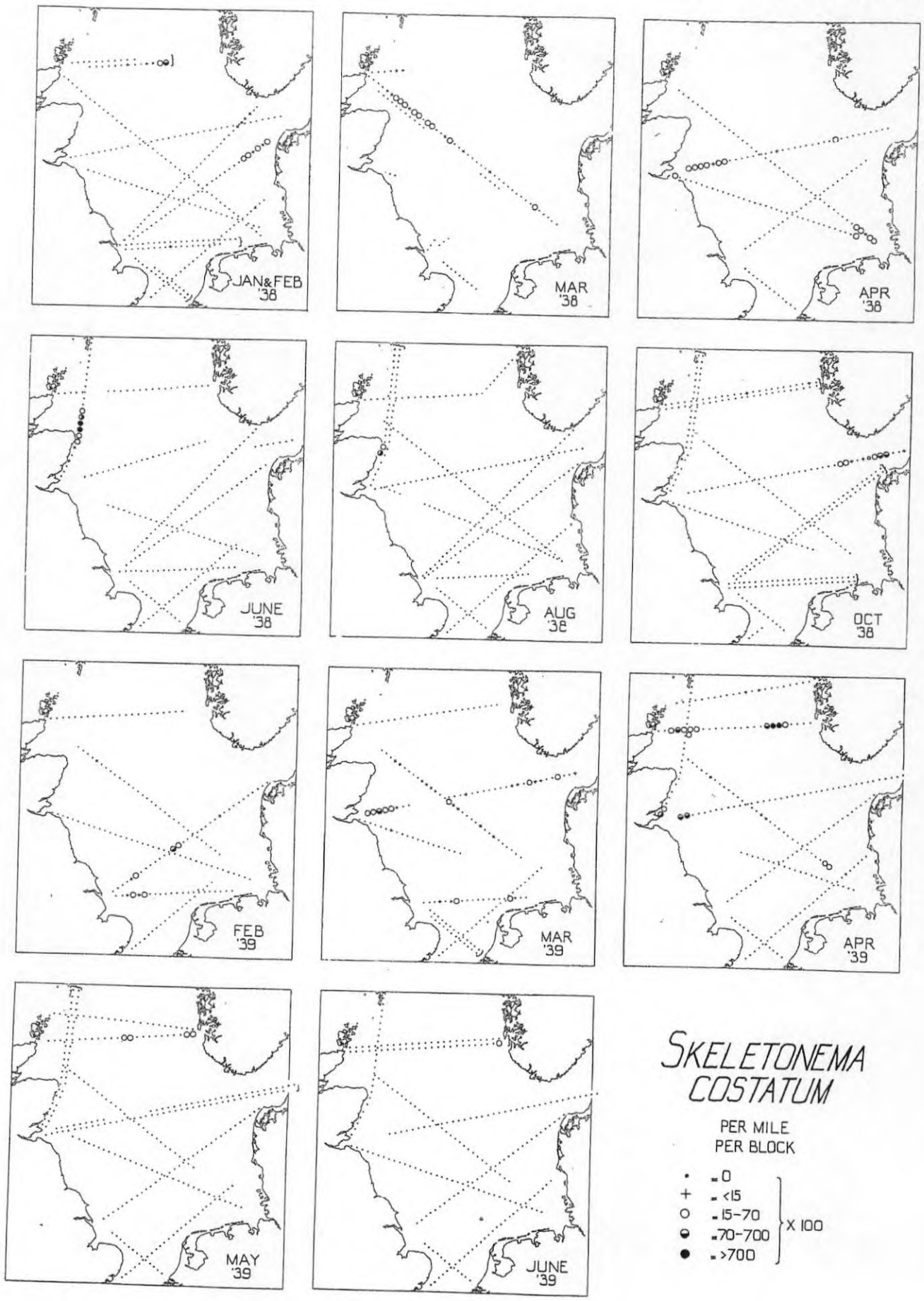

JAN&FEB '38
MAR '38
APR '38
JUNE '38
AUG '38
OCT '38
FEB '39
MAR '39
APR '39
MAY '39
JUNE '39
SKELETONEMA COSTATUM
PER MILE PER BLOCK
• = 0
+ = <15
○ = 15-70
◒ = 70-700
● = >700
X 100

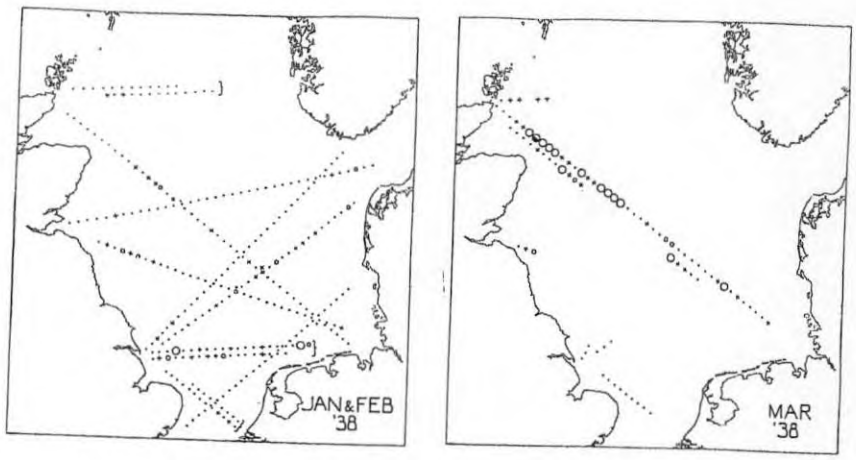
PLATE XXXII

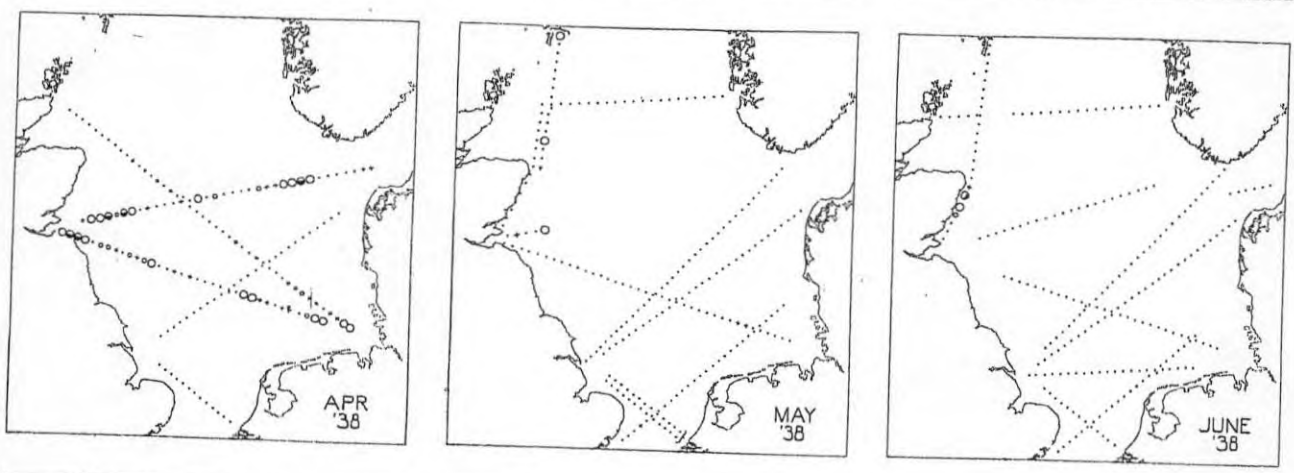
THALASSIOTHRIX NITZSCHIOIDES

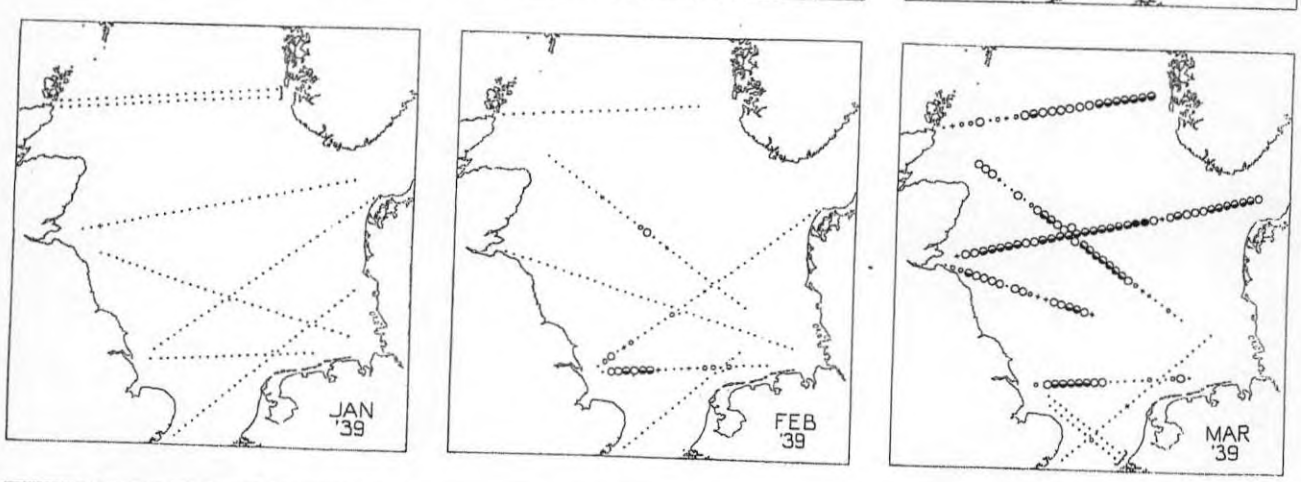
PER MILE
PER BLOCK

- · = 0
- \+ = <5
- ○ = 5-15
- ○ = 15-70
- ◒ = 70-700
- ● = >700

} X 100







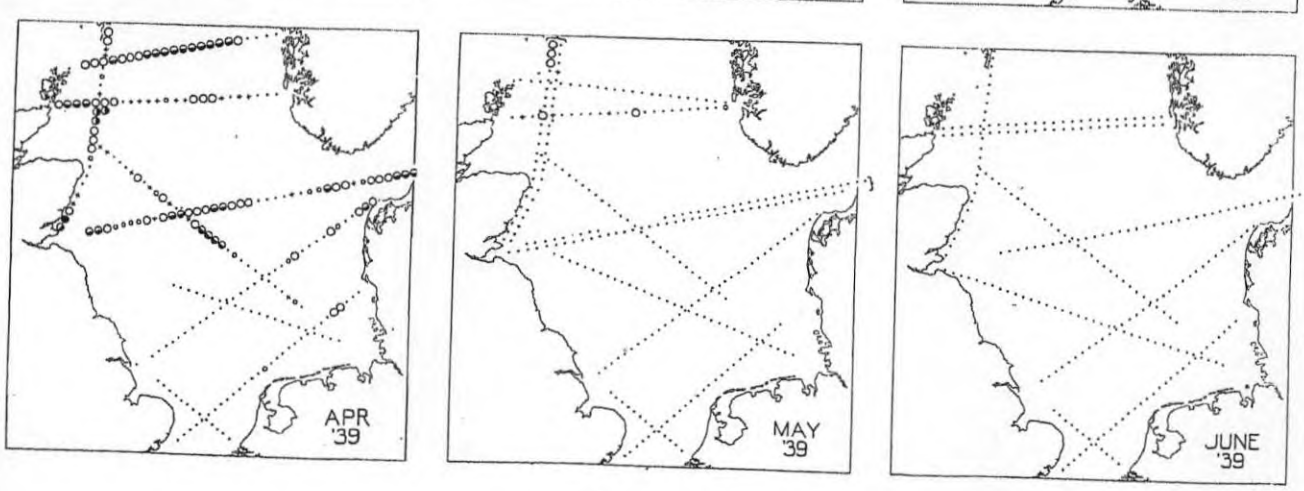
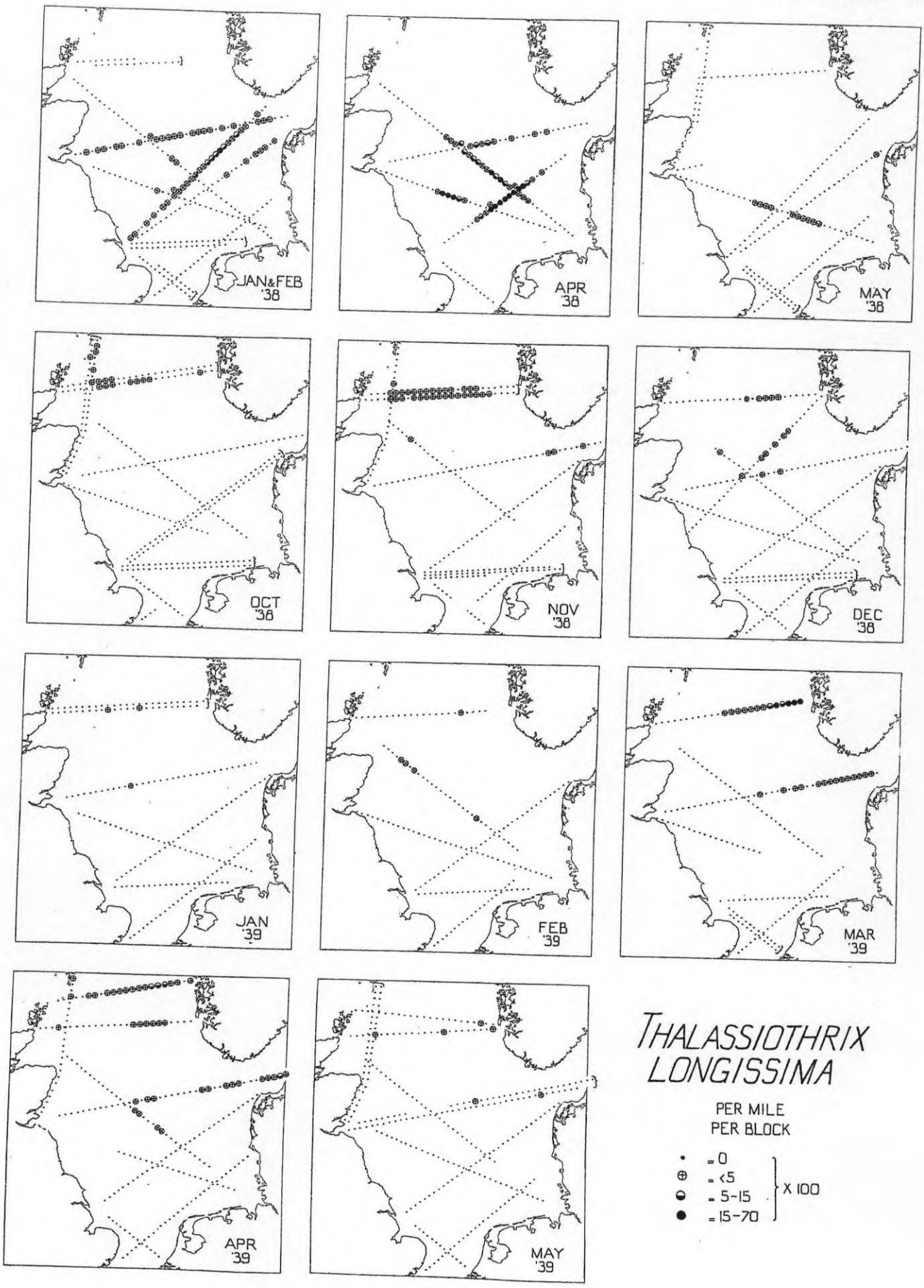


PLATE XXXIII



THALASSIOTHRIX LONGISSIMA

PER MILE
PER BLOCK

- = 0
- ⊕ = <5
- ◒ = 5-15
- ● = 15-70

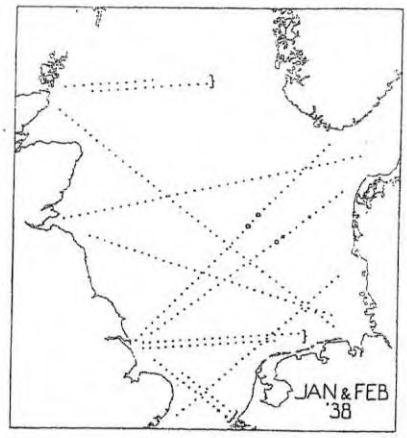
} X 100

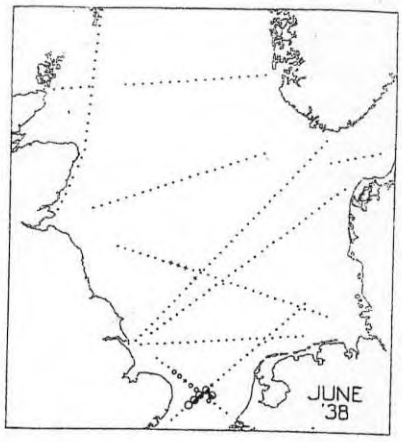
PLATE XXXIV

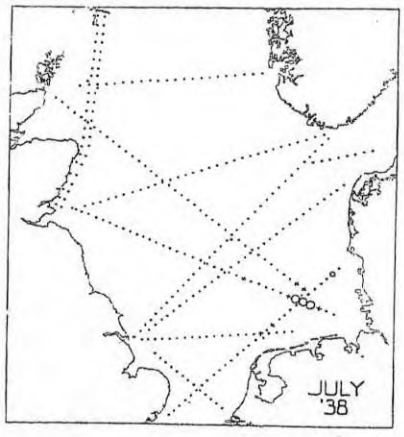
RHIZOSOLENIA STOLTERFOTHII

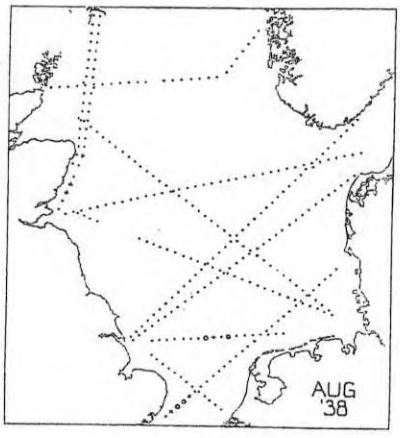
PER MILE
PER BLOCK

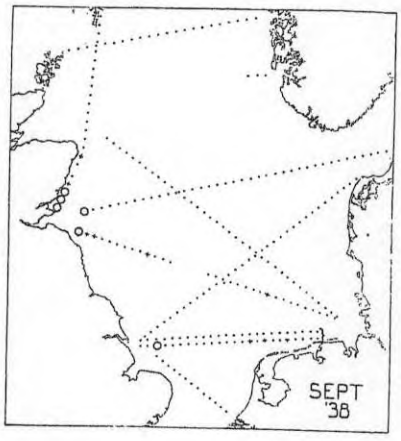
· = 0
+ = <5
o = 5-15
O = 15-70
◒ = 70-700
● = >700
} X 100

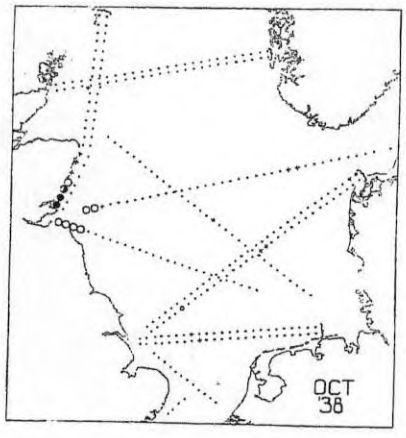


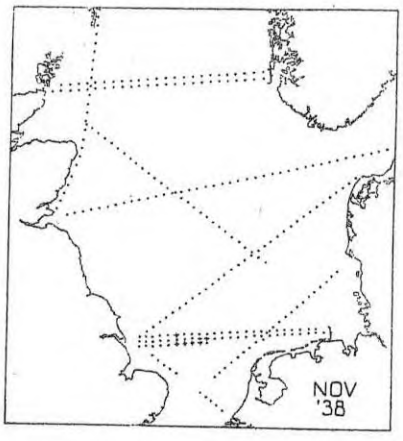


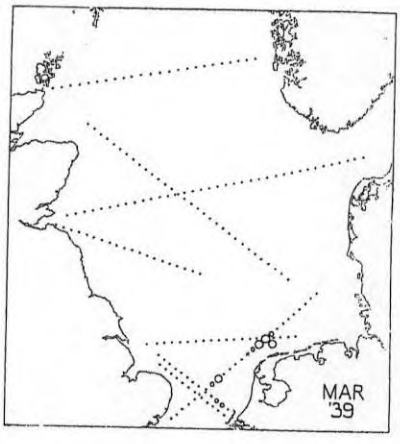


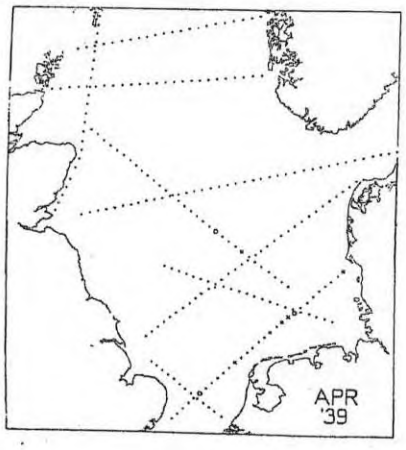


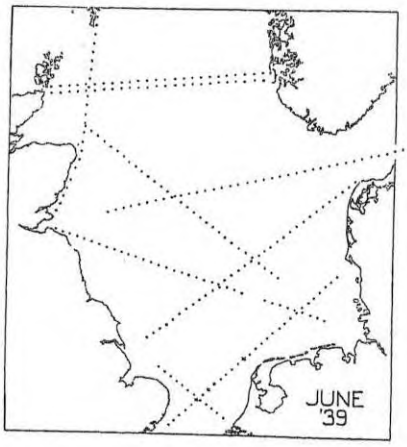












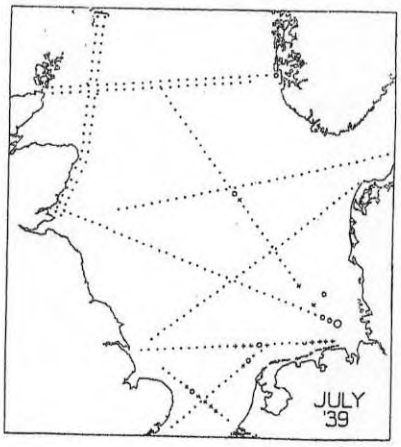


PLATE XXXV

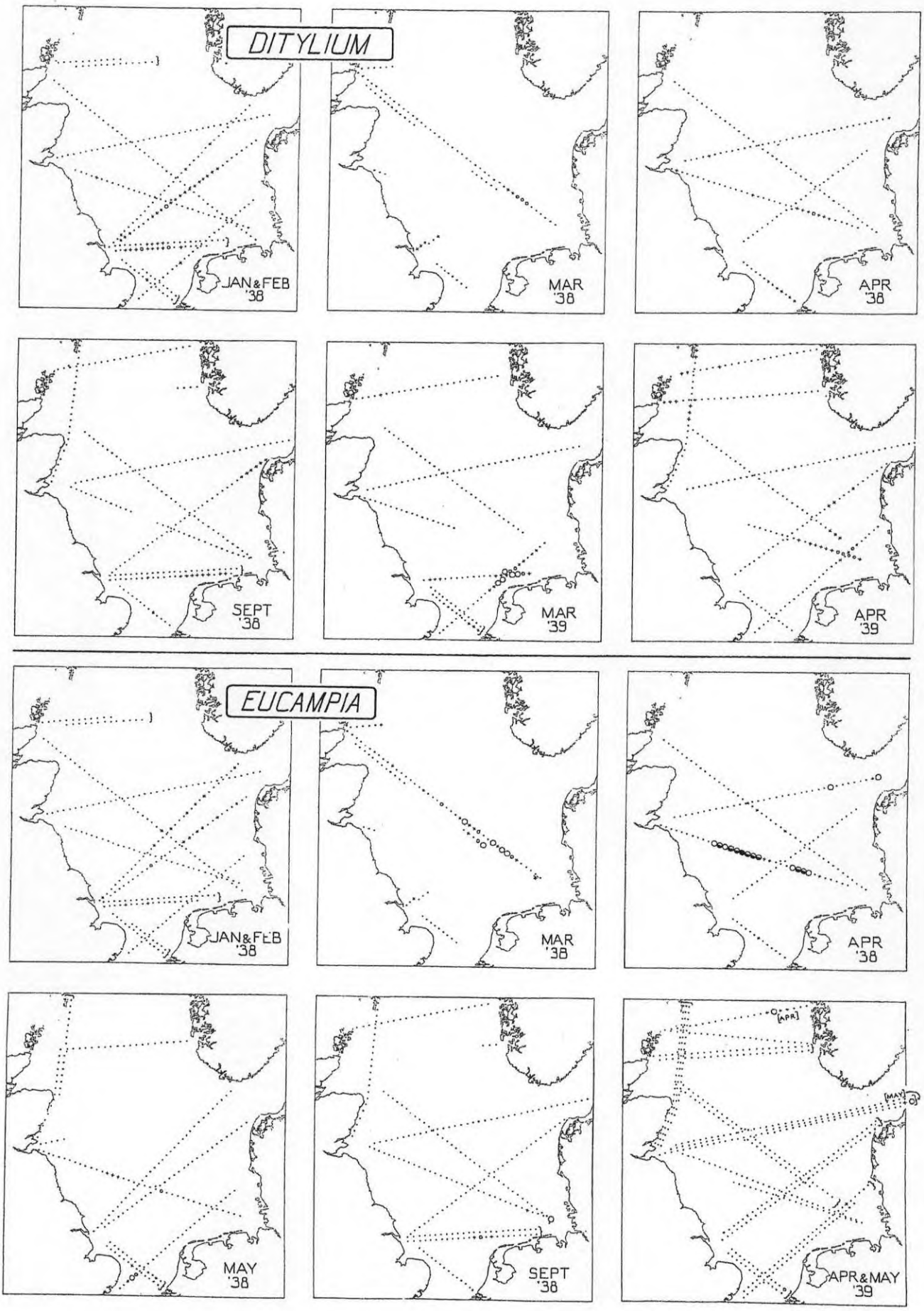

DITYLIUM
JAN&FEB '38
MAR '38
APR '38
SEPT '38
MAR '39
APR '39
EUCAMPIA
JAN&FEB '38
MAR '38
APR '38
MAY '38
SEPT '38
[APR]
[MAY]
APR&MAY '39

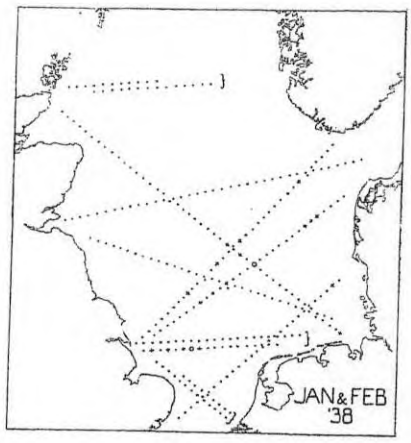
PLATE XXX VI

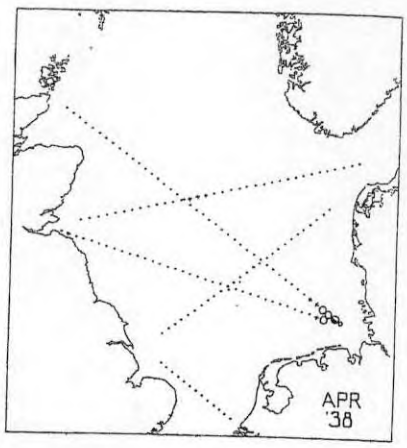
BIDDULPHIA AURITA

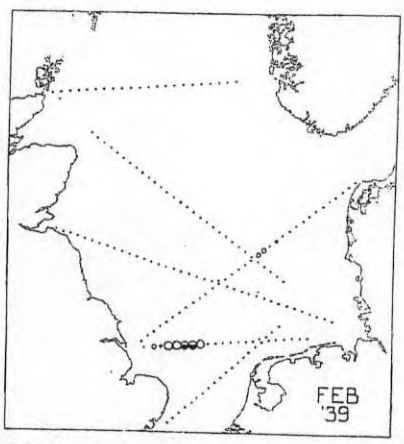
PER MILE
PER BLOCK

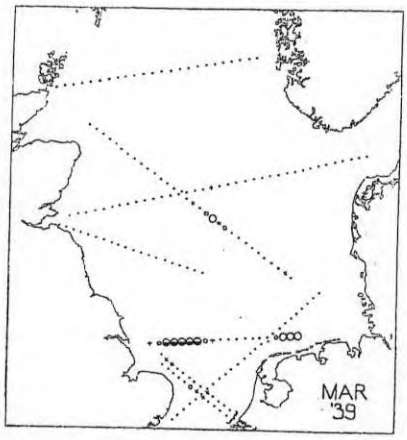
· = 0
+ = <5
∘ = 5-15
○ = 15-70
◒ = 70-700
● = >700

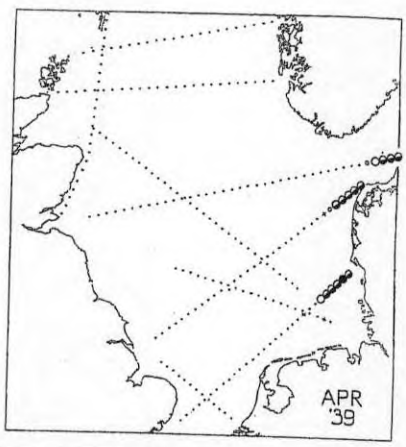
} X 100









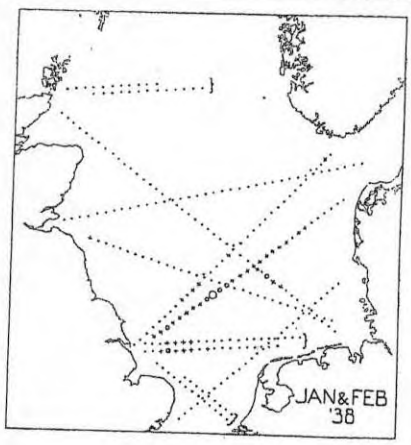


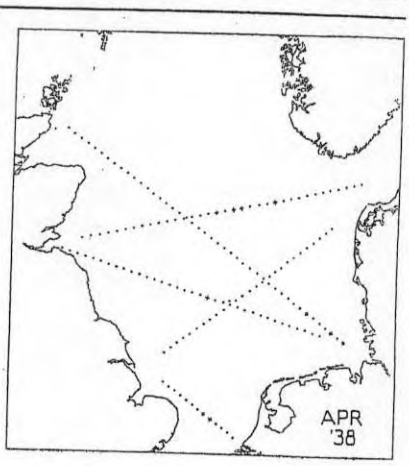
"NAVICULOID" DIATOMS

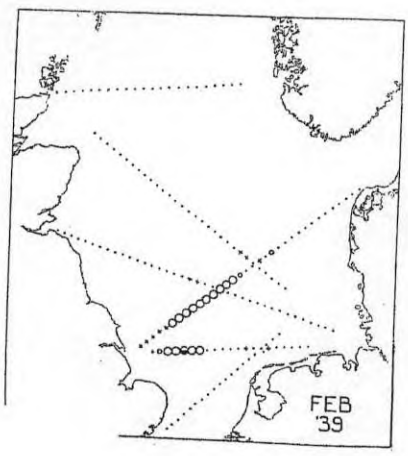
PER MILE
PER BLOCK

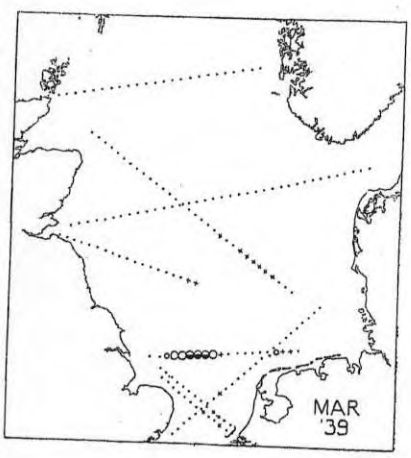
∘ = 0
+ = <5
∘ = 5-15
○ = 15-70
◒ = 70-700

} X 100









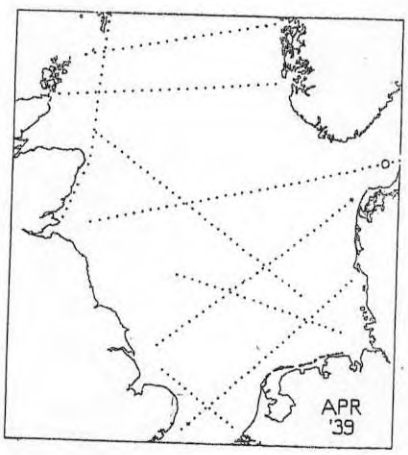


PLATE XXXVII

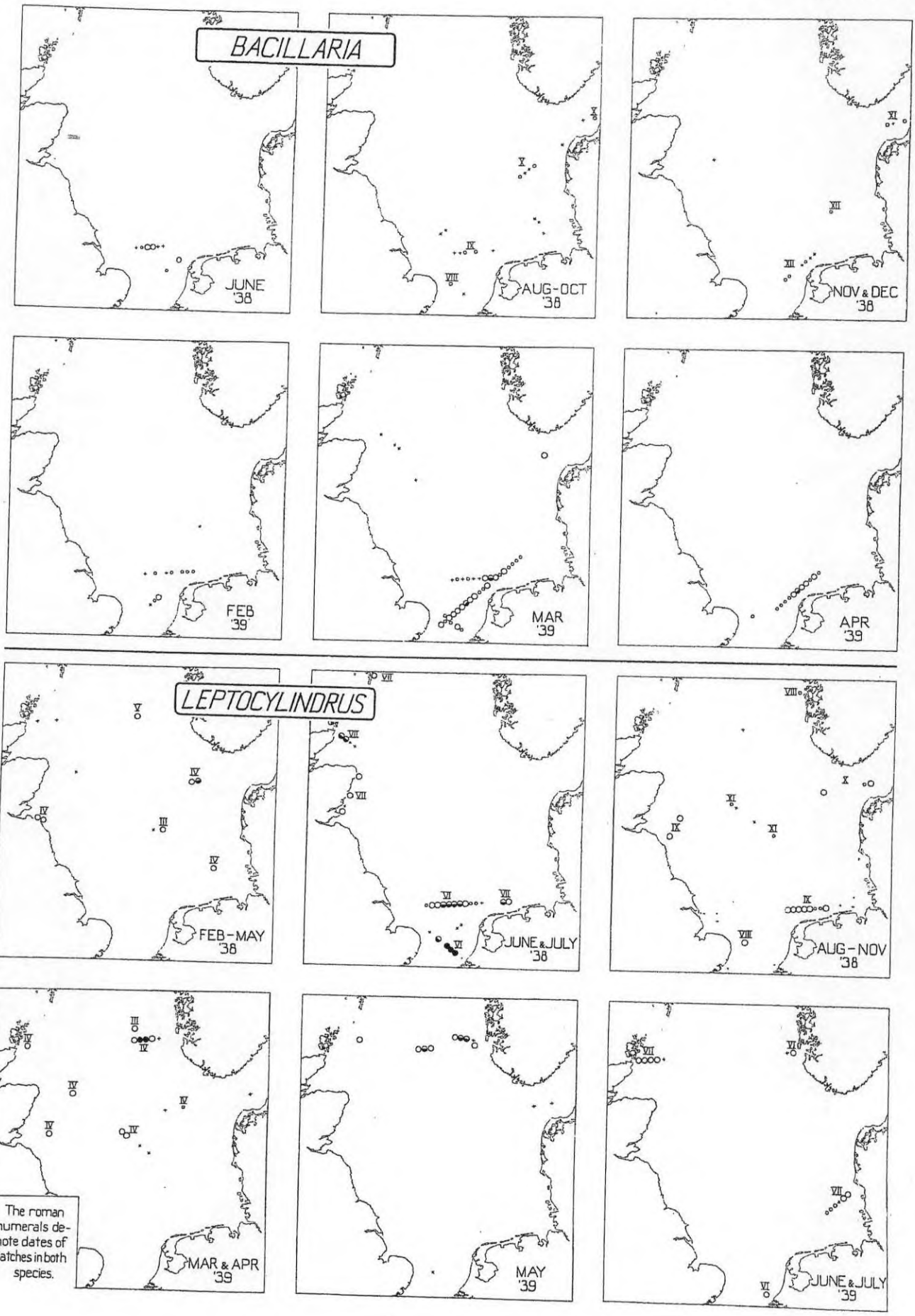


PLATE XXXVIII