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REPORT BY THE NORTH SEA ROUNDFISH WORKING GROUP ON NORTH SEA COD

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INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA

Report by the North Sea Roundfish Working Group on North Sea Cod

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Introduction

The Working Group was set up at the 1969 ICES Meeting (C.Res.1969/2:6), the resolution passed by ICES being that, in the first instance, the Group should study the interrelationships between the cod in different parts of the North Sea, with a view to reconsidering on a regional basis, the assessments made by the "Working Group on Assessment of Demersal Stocks in the North Sea", for the North Sea cod stocks as a whole.

The Group has reviewed what is known of the spawning and nursery grounds of the cod and, from the returns of tagging experiments, has attempted to assess the interrelationships between groups of cod in different parts of the North Sea.

The first meeting was convened at Charlottenlund from April 14 to 17, 1970, and the Group then reviewed what was known of the spawning and nursery grounds of the cod and carried out a preliminary analysis of the very extensive cod tagging data available. The results of the survey of the spawning and nursery grounds were presented to the 1970 ICES Meeting (Anon 1970), and it was then recommended (C.Res.1970/2:7) that there should be a second meeting to complete the analysis of the tagging data. This second meeting took place at Charlottenlund from January 18 to 20, 1971.

The spawning areas were reviewed on the basis of egg and larval data, and on the distribution of large, mature, cod during the spawning season.

Distribution of Eggs and Larvae

Spawning occurs from the beginning of January to April, with small variations in the time of peak of spawning in the different areas. According to Meek (1924), the eggs, which are pelagic, hatch in about 12 days at an average temperature of 5.5°C, although Wise (1961) gives 17 days at 5°C. Some recent observations concerning the hatching time of cod eggs in different temperatures and salinities, are given by Westernhagen (1970), using Baltic cod.

A difficulty of using egg distribution data to determine the positions of the main spawning grounds is that cod eggs are virtually indistinguishable from haddock eggs until pigmentation develops just before hatching (Graham, 1934). Thus in the northern North Sea where cod and haddock eggs are liable to be taken together, only the distribution of the late stage eggs can be used to provide information about the spawning regions of cod. In the southern North Sea this problem does not normally arise.

In division IVB, results obtained by earlier workers and in particular those of Damas (1909) and Schmidt (1909) show the occurrence of larvae over a wide area of the eastern North Sea between latitudes 54^{o} and 57^{o}N, densities increasing from west to east. Larvae were found from March to August, maximum numbers being taken in April and May. Graham (1934) gives a similar account and also refers to the occurrence of larvae at Flamborough and south of the Fisher Bank.

In the southern North Sea, Aurich (1941) and Buckmann et al.(1955) found concentrations of cod eggs in the White Bank area but very few in the Southern Bight. More recently, however, egg surveys carried out by Daan in January 1970 indicated considerable numbers of cod eggs in coastal waters near Texel, and also near the French coast (Fig. 1).

Off the Danish North Sea coast, larvae have also been observed, although there the typical situation is less certain. Poulsen (1931) found larvae around the Danish coast in March-April 1923 both in the North Sea and round into the Kattegat but with negative hauls in the northern Kattegat. In 1924, however, he found no larvae off the Danish North Sea coast and in 1925 only a few were taken. Bagge (unpublished data) found larvae in April 1952 and 1953 in the North Sea (Fig. 2) and in the Kattegat in March-May 1960 (Fig. 3). Lindquist (1970) states that there were no cod in vertical Hensen net hauls off the Danish North Sea coast and in the north Skagerak in May.

Off the Scottish north and north-west coasts, cod larvae have been recorded by Schmidt (1909). More recently, Raitt (1967) has described the occurrence of larvae in Scottish waters from surveys made in the years 1953-1956. Larvae were found around the Scottish coasts and over most of division IVA. Maximum larval concentrations in March and April were distributed in patches extending north-easterly from the Butt of Lewis and Scottish north coast (XX16 to ZZ17) to the north of the Shetlands (D20). Concentrations of larvae were also observed in the vicinity of the Moray Firth (B15). In May and June the larvae were mainly concentrated to the east of the Greenwich meridian and south of latitude 59^{o}N, although small patches of larvae were also found north and west of this region.

Distribution of Large Cod and Spawning Areas

The distribution of large, mature cod at spawning time during the early months of the year, gives a further guide to the possible positions of the spawning grounds.

In the central North Sea, Graham (1924, 1934) identified four major spawning areas from the distribution of high landings per unit effort of mature cod (over 70 cm in length) from English statistics for the period 1920-1930. These, the Ling Bank, Fisher Bank, Forties and Flamborough areas, are shown in Figure 4. The members of the Group confirmed the importance of these as spawning grounds, as well as other grounds, including the Silver Pit (E7, G7), the Clay Deep (H7,8 and J7,8) and the Tail End (J9) which Graham also referred to but considered of less importance at the time. In addition to these grounds, spawning in the Southern Bight has been reported as long ago as 1902-1906 by Redeke (1909). More recent statistics (Bannister, personal communication) are given in Figures 5-10 showing the landings of large cod by English vessels during the spring. The landings are expressed as cwt per 10 hours' fishing and are given separately for various statistical rectangles, mainly in division IVB. These confirm the importance of the area to the south-east of the Dogger Bank during February. They also indicate a tendency for the regions of greatest importance to move north and north-east during the period from February to April.

There is evidence, too, of spawning as far south as Bassurelle at least until 1965. After 1967, French and Belgian observations suggest that spawning in this region may have occurred further north off the Belgian coast. These conclusions were based partly on the relatively high landings per unit effort by French vessels working off the Belgian coast from Janurary to May 1968, when many mature fish were captured. Also, the Belgian data show that from 1967 to 1969, the percentage of cod over 70 cm in landings from this region was 8.4% in the winter and spring compared with 1.5% in the summer.

Off the Danish Skagerak coast, there is no evidence of spawning. It was considered that larvae observed in the Kattegat were the products of spawning in the southern Kattegat and Belt Sea and formed part of a stock that was separate from that in the North Sea.

Spawning is known to occur on the Norwegian Skagerak coast, but the stock there is considered to be independent of that on the Danish side of the Skagerak (Dahl 1906, Løversen 1946 and Ruud 1939).

Off the Scottish north and east coasts, maximum landings per unit effort of large cod from January to April were observed as long ago as 1901-6 by D'Arcy Thompson (1909). More recent statistics (West 1970) are given in Figures 11-18, showing the landings per unit effort of cod over 50 cm in length by Scottish vessels. Cod in Scottish waters begin to mature at about this length and it is considered that a large proportion of cod over 50 cm taken in the spring would be maturing fish. The data show peak landings per unit effort off the Scottish north-west, north and east coasts, including the Moray Firth. Subsidiary concentrations were noted in G18, F18, E19 and E20 and north-west of the Shetlands. Concentrations were also noted in G13 and H13, G14, F14, corresponding with Graham's Ling Bank area.

According to West (1970), spawning grounds in Scottish waters, although widely distributed, are very localised, generally, in inshore waters at depths of less than 100 m.

Nursery Grounds

According to Russell (1922), cod become demersal at an age of 2 to $2\frac{1}{2}$ months and an average length of 2.5 cm, but observations by members of the Group suggested that this was probably the minimum length at which codling took to the bottom and that cod spawned over deeper water were liable to take to the bottom after a longer period at a larger size. German catches of 0-group cod in the German Bight shrimp fishery showed that the smallest cod were 4 cm with a mean of 5-6 cm. Scottish records of 0-group cod taken pelagically in division IVA in June 1969 showed that their lengths ranged from 2 to 10 cm (Hislop 1970).

According to Hjort and Petersen (1905), 0-group cod were taken in quantities in the central North Sea, along the coasts in the neighbourhood of large estuaries, and on banks as far north as the Great Fisher Bank. Further north, in deeper water, only single individuals were encountered. More recently, Dutch and German data for 1966, 1968 and 1969 show that small numbers of O-group cod are found in the Silver Pit and considerable considerable numbers, up to 2,400 per $10^5 m^2$ fished, along the Dutch, German and Danish coasts. O-group cod were also recorded in the mouths of the Schelde (20 per $10^5 m^2$ fished) and in the Wadden Sea (up to 1,400 per $10^5 m^2$ fished) and the occurrence and distribution of young cod in the latter area have been described by Daan (1969) (Fig. 19). In the autumn of 1969, a small number of O-group cod were taken by otter trawl in Aberdeen Bay (Jones, unpublished communication).

The probability that many of the O-group cod north and east of the Dogger Bank come from the main spawning regions in division IVB as a result of larval drift is argued by Graham, Carruthers and Goodchild (1926). Along the Norwegian Skagerak coast, Norwegian sampling in September/October with a beach seine has yielded numbers of O-group cod, 4-12 cm in length, but, as already mentioned, these are not thought to belong to the North Sea stock (Danielssen, unpublished communication).

The results of the International Young Herring Surveys carried out in February and March 1965-70 describe the occurrence of I-group cod in the central North Sea. Concentrations are again most marked along the Dutch and Danish coasts, but there are nevertheless some years when I-group cod are distributed over most of division IVB to a depth of 80 m as far north as latitude 58°N. For example, in February 1970 (Fig. 20) there were clearly secondary concentrations in the Clay Deep (J9,10), the North West Rough (F9, G9, G8), the Norfolk Banks (F5) off Whitby and over a wide area from south of the Fladen to the Fisher Bank.

Data from the catches in a small meshed codend during recent English trawl surveys gave similar results (Bannister, unpublished communication).

The Group noted incidentally, the coincidence between the distribution of young cod and herring in the neighbourhood of the Dutch, German and Danish coasts.

Between 1965 and 1967, I-group cod were found along the French and Belgian coasts (Lefranc and Lybaert, unpublished communications).

In Scottish waters, small numbers of I-group cod are landed by commercial vessels (Raitt and Symonds 1967). The largest numbers of these come from the Scottish north and east coasts, including the Moray Firth whereas from the more offshore grounds in division IVA the numbers of I-group fish are relatively small. To summarise, therefore, I-group cod can be found all over the North Sea.

Young codling, mainly 2 years of age, are taken extensively in the commercial bottom fisheries throughout the entire North Sea and off the Scottish north coast. Graham (1934) indicates a wide distribution of 'small' cod (mainly 2 years of age) in the central North Sea, an interesting feature of his observations being that comparatively few 'small' cod were taken off the Belgian and Dutch coasts where the greatest density of I-group fish had been observed. Similarly, German data showing that II-group cod are absent from the Wadden Sea suggest that cod emigrate from that area before they become II-group. The emigration of I-group cod from the coast has been noted by Daan (1969) in the case of the Dutch coast, and Lefranc (1970) in the case of the English Channel French coast.

Spawning Grounds

The data described above, suggest the overall picture of the major spawning grounds shown in Figure 21. Spawning grounds can be grouped into three main regions, centred as follows:

(a) in the central North Sea between latitudes 54° and 58°30'N and west of longitude 5°E,

(b) off the Dutch and Belgian coasts where spawning seems to have become relatively more important during the 1960s,

and (c) around the Scottish east and north coasts, in inshore waters, less than 100 m in depth. Though widely distributed, the grounds are more localised (West 1970) than might be supposed from the intensity of the shading in Figure 21.

Meristic Characters

Variations in the mean number of vertebrae of cod from different regions were examined to see if these could be of any value for stock separation. It was concluded, however, that insufficient data were available to enable valid conclusions to be drawn.

Tagging Data

The interrelationships between the cod in different parts of the North Sea were studied using the returns of cod tagged in various regions. Data were available from 6 countries and details of the liberation areas and seasons of the year in which tagging experiments have been carried out in various parts of the North Sea and Skagerak are shown in Figure 22. The data were first examined by plotting returns on a rectangle basis following Bedford (1966). Returns were plotted separately according to season and year of recapture. The seasons adopted were winter (January-April), summer (May-August) and autumn (September-December). For each of the main experiments, contour lines were then drawn, showing:

(a) the limits within which tagged fish were recaptured during the first year after liberation, and

(b) the limits within which tagged fish were recaptured during all subsequent years.

The results for recaptures during the winter are shown in Figures 23-26 and for recaptures during the summer in Figures 27-30. Examination of the limits of the winter returns shows that:

Fish released in the Southern Bight are rarely recaptured north of latitude 54°N (Fig. 25);

Fish released close to the Scottish north and east coasts and the English east coast north of Flamborough, are rarely recaptured more than 30 miles offshore (Figs. 23 and 24);

Fish released off the Danish Skagerak coast are recaptured on the Danish side of the Skagerak or in the North Sea (Fig. 23);

Fish released in the central North Sea are mainly returned from one of two regions:

(a) between the Straits of Dover and latitude $54^\circ 30'$N (for example the G7 experiment in Fig. 26),

(b) between latitude $53^\circ 30'$N and 59°N and between longitudes 1°E and 7°E (Fig. 26).

Examination of the limits of the summer returns shows that:

For the Danish and UK coast releases, the limits of the summer returns were similar to those of the winter returns (Figs. 27 and 28);

For the Southern Bight releases, few summer returns were found further north than latitude 56°N (Fig. 29);

For the central North Sea releases, the summer returns mainly recaptured from an area bounded by latitudes $53^\circ 30'$N and 60°N and longitudes 1°W and 8°E (Figs. 30-35).

The limits of the summer and winter returns are therefore similar except that in certain regions dispersal is greater in the summer than in the winter.

An important feature of Figures 23-30 is that in both the first and subsequent years, the regions within which tagged fish were recaptured were very similar. In other words, no matter where fish have been released, there is no evidence of dispersion without limit throughout the North Sea. This result was further investigated by calculating coefficients of dispersion following Jones 1965. The parameters estimated were:

a^2 the daily coefficient of dispersion of fish about their centre of density,

$\bar{t}$ the mean number of days' absence, and

$a^2\bar{t}$ the coefficient of dispersion of fish about their centre of density after a mean time, $\bar{t}$.

Estimates of these, and other parameters required for the analysis of seasonal movements in the centre of density, are given in Table 1. There, the data are related to size of fish, liberation area and period of liberation. Generally the lengths of the fish have been grouped as follows: 30-49 cm, 50-69 cm and >69 cm but in one case they have been grouped into ≤70 and >70 cm. In Table 2 the data have also been grouped successively according to the following periods of recapture: January-April (winter), May-August (summer) and September-December (autumn) successively.

Analysis of the Dispersion Parameters

Seasonal mean values of the coefficients a^2 and $a^2\bar{t}$ are summarised in Tables 3 and 4 for various parts of the North Sea and Skagerak, and in Figures 31-33.

Consider first the values of a^2, summarised in Table 3 and in Figures 31 and 32. For fish tagged off the Scottish coast, the central North Sea, the Southern Bight and the English Channel, values of a^2 decline with period of absence. The rate of decline is particularly marked during the first year after liberation but slows down during the third year of liberation. Off the Scottish coast, initial values of 10-15 miles^2/day decline to less than 1 mile^2/day by the third year of liberation. In the central North Sea, Southern Bight and English Channel experiments, initial values of a^2 of 60-100 miles^2/day decline to 10-20 miles^2/day by the third year after liberation. In the case of the experiments off the English NE coast and in the Skagerak, the tendency for a^2 to decline with time is masked by large seasonal fluctuations around an average of about 12 miles^2/day (Fig. 32).

Values of $a^2\bar{t}$ are summarised in Table 4. In the Scottish experiments, values of $a^2\bar{t}$ tended to remain constant at about 400. For all other areas, $a^2\bar{t}$ increases. However, the increase is not in direct proportion to the time of absence, while for two areas, the Southern Bight and English Channel (Fig. 33), values of $a^2\bar{t}$ were at a maximum from May to August and at a minimum from September to April each year, i.e. there are pronounced seasonal fluctuations, so that the overall upward trend in the mean value of $a^2\bar{t}$ is comparatively small.

In the case of random dispersion without limit. theory suggests that the values of a^2 should be constant, and that the values of $a^2\bar{t}$ should increase in direct proportion to the time absent. For dispersion within a region with finite limits, however, values of a^2 should decline and values of $a^2\bar{t}$ should tend to an asymptote. The observed results are therefore more consistent with the latter alternative, i.e. that tagged cod disperse relatively rapidly during the first year after liberation, but that dispersal during subsequent years is such that the region occupied does not continue to increase.

Seasonal Movements

Recapture patterns are characterised not only by dispersion, but by seasonal movements in their centre of density. For each liberation area, the positions of the centres of density of the fish returned have been plotted using the mean values of $V\bar{t}$ and ψ shown in Table 2. Each pair of values of $V\bar{t}$ and ψ gives a distance and direction from the relevant position of liberation. These have been plotted for each of the main areas for the winter, summer, and autumn returns separately in Figure 34. In general, it was found that the centres of density either were located close to the position of liberation, or moved within a reasonable distance of the position of liberation. In no case was there a tendency for the centre of density to move progressively away from the position of liberation during successive years. Results for each season of recapture during successive years have been combined therefore, and these results are plotted in Figure 34. A summary for each position of liberation is given below.

Skagerak (reference numbers 1-6 in Tables 1 and 2)

Small cod, under 50 cm in length, showed no pronounced seasonal movements and displacements in their centres of density were mostly less than 20 miles from the position of liberation. Larger cod also showed little seasonal movement in the summer or autumn, but there was a south-westerly movement towards the North Sea in winter. The mean displacement of the centre of density was then about 20 miles, although some individuals had travelled up to 100 miles into the North Sea. Overall, only 5% of the recaptures (mainly of immature fish) came back from the Kattegat, and 14% (mainly of mature fish) were returned from the North Sea (Danielssen 1969).

Scottish Coast (reference numbers 23-33 in Table 1)

Close to the Scottish coast, seasonal movements in the centres of density were small, and mostly less than 20 miles from the positions of liberation. This was so for periods up to 786 days absence, showing that there was very little long-term displacement in the centres of density. Off the Scottish north coast, movements were to the north or west of the position of liberation.

Seasonal movements in the Moray Firth were also small and showed no consistent seasonal pattern. Here also, values of $\bar{Vt}$ tended to remain constant, showing no long-term trend in the displacement of the centre of density with time.

Results for the Scottish east coast were very similar to those for the Moray Firth and the Scottish north coast. Again values of $\bar{Vt}$ were very small, and the maximum value was only 22 miles to the north one winter after 119 days. In summer and autumn there were even smaller displacements around the positions of liberation.

English Coast (reference numbers 52-54 in Tables 1 and 2)

Three experiments described by Bedford (1966) have been analysed. Two were in rectangle C9 in May 1962 and 1963 respectively. The other was in rectangle D7 in November 1963.

The seasonal movements of these fish were similar to those for fish liberated in Scottish coastal waters. Values of $\bar{V}$ averaged less than 0.2 miles per day. There was little tendency for the values of $\bar{Vt}$ to increase with time, indicating that there was no long-term directional displacement of these fish. Bedford recorded that most of the fish released in rectangle C9 were 40-50 cm long and recaptured within 25 miles of the coast. During the autumn, the codling fishery at North Shields (C9) declines but the codling fishery in the region around Flamborough Head (D7) begins, so it is interesting that in the autumn of 1963, some of the fish released in the summer of 1963 in rectangle C9, were recaptured in the Flamborough Head fishery during the same autumn. This suggests that the autumn fishery off Flamborough Head is at least partially dependent on fish arriving from further north during the summer.

Central North Sea (reference numbers 7-11 and 34-45 in Tables 1 and 2)

Experiments in the Central North Sea comprised releases in rectangles G12 (ref. nos. 34, 35), H7 (ref. nos. 38-43), G7 (ref. nos. 7-11), F8 and 9 (ref. nos. 36, 37, 44, 45) (Bedford 1966).

Movements in the centres of density of the fish liberated in each of these experiments were very similar. They showed a north-westerly movement in summer, followed by a south or south-easterly movement in autumn or winter (Fig. 34). The distance between the summer and winter centres of density ranged from about 30 miles in the rectangle G12 experiment to about 70 miles in the rectangle G7 experiment. For those experiments with returns extending over a period of several years, this seasonal pattern was repeated annually and, as in experiments elsewhere, there was no tendency for the centre of density to drift progressively away from the position of liberation.

German Bight (reference numbers 21-22 in Tables 1 and 2)

Experiments in the German Bight were carried out in rectangles M6, M7 and N7 in October-December of 1967, 1968 and 1969.

Seasonal movements in the centres of density were very similar to those in the central North Sea experiments. Summer movements were towards the north or north-west and those in autumn and winter were towards the south or south-east. The distances between the summer and winter centres of density were around 70 miles.

Southern Bight (reference numbers 12-13, 15-20 and 46-51 in Tables 1 and 2)

Fish were released in the Southern Bight in rectangles F1, F3, G3, G4, J3, 4 and 5.

In all these experiments, the seasonal movements in the centres of density were similar. Movements were northerly during the summer and southerly during autumn and winter. The distances between the summer and autumn/winter positions of the centre of density ranged from about 120 miles in the rectangle F1 experiment to about 40 miles in the rectangle J5 experiment.

English Channel (reference numbers 55-58 in Tables 1 and 2)

Releases in the English Channel were made in rectangles E51 and F51.

The centres of density of fish liberated in this region averaged up to 70 miles from the position of liberation and showed no consistent seasonal north/south variation as was found in the case of the Southern Bight liberations. In all seasons, however, the centre of density tended towards the north and east of the liberation positions.

To summarise, off the Scottish north and east coasts and off the English east coast, north of Flamborough, seasonal movements in the centres of density of tagged fish were very small and mainly along the coast. However, cod in the central North Sea, and more especially in the Southern Bight, show regular northerly or north-westerly movements in summer and southerly or south-easterly movements in autumn and winter. In all experiments the centres of density are located close to the position of liberation, or move back seasonally near the position of liberation. In no case is there a tendency for the centre of density to move progressively away from the position of liberation during successive years. For each season of recapture, the results for successive years can be combined and these are plotted in Figure 34.

The following points should be noted when interpreting the significance of the parameters V, Vt and ψ. In the simplest possible situation, where fish are dispersing in all directions equally, and clear of all boundaries, V and Vt can be expected to vary at random and to average zero. Therefore only when particular values of V, Vt and ψ are repeated consistently in successive years or experiments, can they be regarded as biologically significant.

In the case of random dispersion from a position close to a coastline the situation is different. Then, random movements parallel to the coast can be expected to cancel one another out, leading to a zero component of movement along the coast. Movements at right angles to the coast can only occur in an offshore direction, however, so that even when dispersion is entirely at random, there will be a consistent offshore component of movement at right angles to the coast. Consequently (in the case of liberations close to a coast), only consistent movements in directions other than at right angles to the coastline can be regarded as significant. To be significant, offshore movements have to be assessed on criteria other than the values of V, $\bar{Vt}$ and ψ alone.

Stock Separation

From the evidence presented, cod do not disperse uniformly throughout the North Sea. Instead, the centres of density show consistent seasonal movements of varying magnitude around their positions of liberation. Further, within any one region, dispersion occurs within limits. As a first approximation, the data suggest that the following regional grouping may be appropriate:

(a) The Norwegian side of the Skagerak

(b) The Danish side of the Skagerak

(c) One or possibly several coastal regions, from Flamborough to the Scottish east and north coasts

(d) The central North Sea

(e) The Southern Bight, from the Straits of Dover to latitude 54°N

(f) The English Channel, south and west of the Straits of Dover.

With the exception of the Skagerak, each of these regions contains one or more of the spawning grounds depicted in Figure 21. The Group then considered if the cod in each of these regions could be treated as a separate 'stock'. Evidence comes from the degree of independence between the results of experiments in different regions. For example, it was noted that fish tagged off the Scottish coast were very rarely recaptured offshore in the central North Sea. Conversely, fish tagged in the central North Sea, although spreading over a considerable region, were almost never recaptured off the Scottish coast or the English coast north of Flamborough. This is significant since the fishing effort off the U.K. east coast is sufficiently high for there to be a very good chance of recapturing tagged fish, if they are present. Regarding the cod off the Norwegian Skagerak coast, the available evidence shows that these make up one or possibly several coastal 'stocks', each apparently independent of the fish in the North Sea or Danish Skagerak. Similarly, cod off the Danish Skagerak coast appear to be independent of those off the Norwegian Skagerak coast. According to Danielssen (1969), of the cod tagged off the Danish Skagerak coast, 81% were returned from the Danish Skagerak, 14% from the North Sea and 5% from the Kattegat. Cod off the Danish Skagerak coast therefore remain mainly in that region, but mix to some extent with cod in the North Sea.

Within the central North Sea and Southern Bight, cod disperse to a greater extent than elsewhere and their interrelationships are much more difficult to determine due to the overlapping of the summer returns from various experiments. Consider, for example, the situation depicted in Figure 35. This shows the approximate limits of the summer recaptures of fish tagged in rectangles F1 and 3 (Southern Bight); H7 and 8 and G12 (central North Sea). In the figure, the limits within which fish have been recaptured during their second and subsequent summers only, have been used, these being assumed to depict maximum dispersal in each case.

The limits of the returns made in winter are similar, except that the northerly limit of the F1 and 3 liberations is about 54°N, i.e. the northerly limit of the Southern Bight returns, moves seasonally north and south between latitudes 54°N and 56°N. Hence, there is a region (marked A in Fig. 35) where Southern Bight and central North Sea cod presumably mix during the summer. The question then arises "What happens to central North Sea cod in region A, during the months when the Southern Bight fish in that region are presumably moving south?" Several libserations have been made in the vicinity of region A in the summer. Bedford (1966) describes a liberation in rectangle F9 in June 1957. During the first and subsequent winters, six returns were obtained from between latitudes 53°30'N and 55°30'N. The winter distribution of returns from another experiment described by Bedford (H7 in June 1957) is similar. Eleven returns were obtained from between latitudes 53°N and 55°N. However, a different result was obtained by Lefranc (1970) who liberated cod in rectangle G7 in June 1966 (Figs. 26 and 29). In this experiment, all the returns in winter came from south of latitude 54°30'N (Fig. 26) but summer returns were found as far north as latitude 56°30'N. These fish therefore appear to have behaved like Southern Bight fish, some of them moving north over region A in summer, but moving south to vacate region A in winter. The fish tagged by Bedford on the other hand showed no tendency to move to the south of region A in winter. Whilst therefore the data suggest that in summer, region A may be a mixing area for Southern Bight and central North Sea fish, the Group felt that further data should be collected to determine this. At present, the only certain conclusion is that central North Sea cod have rarely been recaptured south of latitude 53°30'N and Southern Bight cod have rarely been recaptured north of latitude 56°N.

Discussion

It is possible that, especially during the first few months, movement may be influenced by the presence of the tag, or by the after effects of the tagging process. That tagging causes abnormally high dispersion rates initially cannot be ruled out. If this were so, the rapid decline in a^2 with time shown in Figure 31 is explained. There would then appear to be two possibilities to consider:

(a) That dispersion rates were abnormally high initially, due to the presence of the tag, but that gradually, as the fish became accustomed to the presence of the tag, rates of dispersion declined to normal. This would imply that dispersion rates calculated from short-term experiments would tend to overestimate the true dispersion rates within the population. Values obtained from fish that had been absent for several years ought then to be more reliable.

(b) Alternatively, it might be argued that fish dispersing relatively rapidly due to the presence of the tag might experience a higher mortality rate than those that were less affected. After a time, the surviving fish would inevitably be those that had exhibited relatively little movement. Again this implies that dispersion rates calculated from short-term experiments would tend to overestimate the true rate within the untagged population, and that it would be better to use values of a^2 calculated for fish that had been absent for long periods.

It is notable that observed initial and final 'equilibrium' values of $a^2\bar{t}$ were very different in different parts of the North Sea. Off the

Scottish coast, for example, values of less than 1 mile^2/day were obtained after several years' absence. Similarly, for experiments off the Scottish north coast, in the Moray Firth and off the Scottish east coast. In some other areas, final values of 10-20 miles^2/day were obtained.

These observations are important because if a 'tagging artefact' exists it would hardly be responsible for different dispersal rates in different areas. On the other hand it must be considered that a 'tagging artefact' could have given overestimates of the true dispersal rates within each of the selected regions.

Year Class Strengths

The Group also noted that the relative strengths of different year classes in different regions would be relevant to the question of stock separation. In particular it was noted that although the 1963 year class was very strong in the central and southern North Sea, it was not abundant in the northern North Sea where the main Scottish fishery is centred (Raitt and Symonds 1967, Anon 1969). This supports the evidence that the cod in Scottish waters are largely independent of those in the central and southern North Sea.

The Group concluded that there were grounds for separating the cod into the following 'stocks'. Here the term 'stock', does not carry a rigorous biological meaning. It has been used purely for convenenience and should not necessarily be regarded as having the same meaning as the word 'stock' as used by other authors.

(a) A Norwegian Skagerak 'stock'

(b) One, or possibly several coastal 'stocks' from Flamborough to the Scottish east and north coasts

(c) Separate 'stocks' within the English Channel, Southern Bight, central North Sea and Danish Skagerak regions though lines of demarcation cannot yet be drawn with any real precision. If such lines could be drawn, one might be at the Straits of Dover and one in the region of latitude 54°N. It is stressed however that these are purely tentative at present.

Stock Separation and Yield per Recruit Assessments

For assessment purposes, the implications of the previous section can be assessed at two levels:

(a) by taking account of the effect of fishing in one region on the yields per recruit in other regions,

(b) by taking account of the effect of fishing on the spawning stock in one region on the absolute levels of recruitment to other regions.

Of these, insufficient is known about the circulation and mixing of eggs and larvae from different regions, or about the relationship between spawning stock and recruitment, to enable useful assessments to be made regarding (b). Some observations of a practical nature can be made about (a) however by taking account of the fact that tagged fish appear to remain within a certain distance of their centres of density with a predictable degree of probability.

For purposes of calculation, the values of $a^2\bar{t}$ in Table 4 can be used for predicting the probability of a fish lying within a certain distance of their centre of density after a certain period of time. Theoretical details are given in Appendix II, for the simple situation where fish lie symmetrically within a circle of radius R around their centre of density. It is shown there, that if R is given by:

$$R = 1.73 \sqrt{a^2\bar{t}}$$

R represents the radius of the circle that contains 95% of the fish after time t.

Values of R have been calculated from the data in Table 4 using mean values of $t(\bar{t})$ and are shown in Table 5. Values given under the columns headed A, B and C correspond to successive periods of recapture and, to a first approximation relate to first, second and third years after liberation.

Skagerak

A value of R of 108 miles was obtained for the second year after liberation. This was partly due to the effect of a relatively small proportion of cod moving considerable distances in westerly and south-westerly directions.

Scottish coast

Values of R remained approximately constant at just under 40 miles even in the third year after liberation. In these experiments, such dispersion as did occur was mainly parallel to the coast rather than offshore.

NE English coast

Values of R rose from 47 miles in the first year to 126 miles in the third year. Here also, dispersion tended to be parallel to the coast rather than offshore.

Central North Sea

Values of R increased from 107 miles to 131 miles in the third year. In these experiments dispersion occurred more or less equally in all directions around the centre of density.

Southern Bight

Values of R increased from 114 miles in the first year to 144 miles in the third year.

English Channel

Values of R increased from 126 miles in the first year to 178 miles in the third year. The summer recaptures of cod tagged in rectangle E51 extend both west along the south coast of England and also into the North Sea as far north as latitude 55°N (Fig. 29). Winter recaptures on the other hand are confined within much narrower limits (Fig. 25). However, if the Straits of Dover separate a Southern Bight stock from an English Channel stock, values of R calculated from the returns as a whole will tend to overestimate the values within either of these stocks.

For assessment purposes the main conclusions have been related to the effect of fishing in any one part of the North Sea upon the cod in other parts of the North Sea.

English Channel and Southern Bight

Fishing in the English Channel, and Southern Bight, is unlikely to have any marked effect on the yields per recruit of cod situated north of latitude 56°N.

Central North Sea

Fishing in the central North Sea is unlikely to have much effect on the yield per recruit of cod more than 130 miles from the region being fished or south of latitude 54°N. Fishing off the Scottish coast is unlikely to be affected by fishing in the central North Sea. There could however be an effect on the Flamborough Head fishery off the English coast, depending on the degree of recruitment to this fishery of cod from offshore.

English NE coast

Fishing off the English north-east coast could be expected to influence the UK coastal fishery, possibly as far north as the Scottish east coast, but it is unlikely that fishing in this region would have much effect on the fishery in the central North Sea and Southern Bight.

Scottish coast

Fishing close to the Scottish coast is unlikely to affect fisheries other than those around the Scottish coast.

Danish Skagerak

Fishing in the Danish Skagerak would mainly influence the fish in that region, but could be expected to have a small effect on the central North Sea stock up to 100 miles from the region of fishing.

Northern North Sea

Since there has been very little tagging in offshore waters, north of latitude 57°N, the Group was unable to discuss the cod in that region.

Recommendations

The following recommendations for further work are proposed:

1. To gain further information on the location of cod spawning grounds.
2. To gain further information on the dispersal of eggs and larvae throughout the North Sea.
3. To tag cod in offshore waters between latitudes 53° and 55°N in summer and winter, to investigate further the interrelationships between cod in the Southern Bight and central North Sea.
4. To tag cod in offshore waters north of latitude 57°N.

Hislop, J. R. G. 1970 Preliminary investigations of the pelagic O-group phase of some demersal gadoids. ICES CM 1970/F:12.

Hjort, J. & Petersen, C. G. J. 1905 Short review of the results of the international fisheries investigations. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 3, App.G:1-43.

Jones, R. 1965 FAO/UN, FAO/GFCM seminar on sardine tagging. Split, Yugoslavia, 2-14 November 1964, Report and lectures. FAO Fish. EPTA Rep., (1995).

Lefranc, G. 1970 Biologie de la morue du sud de la Mer du Nord et de la Manche orientale. Revue Trav. Inst. Pêche marit., 34(3):277-296.

Lindquist, A. 1970 Zur Verbreitung der Fischeier und Fischlarven im Skagerak in den Monaten Mai und Juni. Rep. Inst. mar. Res. Lysekil, Ser. Biol., (19), 82 pp.

Løversen, R. 1946 Torskens vekst og vandringer på Sørlandet. FiskDir. Skr. Ser. HavUnders., 8(6): 1-27.

Meek, A. 1924 The development of the cod. Fishery Invest., Lond., Ser. 2, 7(1), 26 pp.

Meyer-Warden, P. F. & Tiews, K. 1965 Der Beifang in den Fängen der deutschen Garnelenfischerei in den Jahren 1954-1960. Ber. Dtsch. Wiss. Komm. Meeresforsch., N.F., 18(1), 13-78.

——— 1965 Grundlagenmaterial zu "Die Zusammensetzung der Fänge der Deutschen Garnelenfischerei in den Jahren 1954-1960". Veröffentlichungen des Institutes für Küsten- und Binnenfischerei (Nr.35), 1-29.

Poulsen, E. M. 1931 Biological investigations upon the cod in Danish waters. Meddr Kommn HavUnders. Ser. Fiskeri., 9(1), 148 pp.

Raitt, D. F. S. 1967 Cod spawning in Scottish waters. Preliminary investigations. ICES CM 1967/F:29 (mimeo).

Raitt, D. F. S. & Symonds, D. J. 1967 The Scottish cod fishery in the North Sea. Mar. Res., 1967, No. 5, 24 pp.

Redeke, H. C. 1909 Berichte über die Holländischen Arbeiten zur Naturgesichte der Gadiden im den Jahren 1902 bis 1906. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 10(B6), 25 pp.

Russell, E. S. 1922 Report on market measurements in relation to the English cod fishery during the years 1912-1914. Fishery Invest., Lond., Ser. 2, 5(1), 55 pp.

Ruud, J. T. 1939 Torsken i Oslofjorden. FiskDir. Skr. Ser. HavUnders., 6(2):1-71.

Schmidt, J. 1909 The distribution of the pelagic fry and the spawning regions of the gadoids in the North Atlantic from Iceland to Spain. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 10(B4), 229 pp.

Thompson, D'Arcy W. 1909 On the statistics of the Aberdeen trawl-fishery 1901-1906, with special reference to cod and haddock. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 10(B2), 38 pp.

West, W. Q.-B. 1970 The spawning biology and fecundity of cod in Scottish waters. Ph.D. Thesis, Aberdeen University.

Westernhagen, H. von 1970 Erbrütung der Eier von Dorsch (Gadus morhua), Flunder (Pleuronectes flesus) und Scholle (Pleuronectes platessa) unter kombinierten Temperatur-und Salzgehaltsbedingungen. Helg. wiss. Meer. 21:21-102.

Wise, J. P. 1961 Synopsis of biological data on cod, Gadus morhua Linnaeus 1758. FAO Fish. Biol. Synopsis (21).

UK, MAFF and DAFS 1966 Fish Stock Record.

APPENDIX I

Formulae used for combining estimates of the movement parameters

$$\bar{V} = \{(\Sigma n V\bar{t} \sin \psi)^2 + (\Sigma n V\bar{t} \cos \psi)^2\}^{\frac{1}{2}} / \bar{\Sigma} n\bar{t}$$

$$\bar{a}^2 = \Sigma n a^2 / \Sigma n$$

$$\tan \bar{\psi} = (\Sigma n V\bar{t} \sin \psi)/(\Sigma n V\bar{t} \cos \psi)$$

$$\bar{\bar{t}} = \Sigma n\bar{t} / \Sigma n$$

$$\overline{V\bar{t}} = \bar{V} \cdot \bar{\bar{t}}$$

$$\overline{a^2 t} = (\Sigma n a^2 \bar{t})/\Sigma n$$

APPENDIX II

Random dispersions within a circle of fixed diameter

From Jones (1965), the proportion of fish lying within a circle of radius R around their centre of density is given by the relationship $P(R,t) = 1 - \exp - R^2/_{a^2t}$.

Consider the situation where 95% of fish lie within a circle of radius R, i.e. $1 - \exp - R^2/_{a^2t} = 0.95$

then $\frac{R^2}{a^2t} = - \log_e (1-0.95) = 3.0$

and, re-arranging terms gives $R^2 = 3a^2t$

and, therefore, $R = 1.73 \sqrt{a^2t}$.. (1)

i.e. $1.73 \sqrt{a^2t}$ gives the radius of the circle that contains 95% of fish after time t.

Table 1

Summary of Tagging Data

Ref. No.	Source	Length group	Liberation area	Liberation period	Recapture period	No. of returns	V	a^2	ψ	$\bar{t}$	$\overline{Vt}$	$a^2\bar{t}$
1	Norway	30-49	Rubjerg	May-Aug.	Sep.-Dec. (3)	9	0.19	56.4	166	102	19	5756
			Robben	1954	Jan.-Apr. (1)	10	0.10	4.5	91	177	19	799
				1958	Sep.-Dec. (3)	5	0.04	0.5	90	445	20	43
				1960	Jan.-Apr. (1)	6	0.01	0.4	77	732	9	33
				1961								
2	"	50-69	"	May-Aug.	May-Aug. (2)	5	0.18	0.4	32	75	14	27
				1954	Sep.-Dec. (3)	35	0.18	7.3	88	99	18	723
				1958	Jan.-Apr. (1)	37	0.07	5.6	116	197	14	1101
				1960	May-Aug. (2)	19	0.05	15.4	241	327	16	5027
				1961	Sep.-Dec. (3)	7	0.04	1.2	102	433	15	518
					Jan.-Apr. (1)	22	0.05	9.0	227	826	44	7404
3	"	>69	"	May-Aug.	Sep.-Dec. (3)	5	0.09	19.8	210	88	8	1743
				1954	Jan.-Apr. (1)	5	0.13	29.8	205	196	26	5838
				1958	Jan.-Apr. (1)	11	0.04	10.3	230	1041	43	10693
				1960								
				1961								
4	"	50-69	Robben	Sep.-Dec.	Jan.-Apr. (1)	13	0.16	6.44	67	107	17	689
				1958	Sep.-Dec. (3)	5	0.01	0.66	104	319	3	211
				1961	May-Aug. (2)	10	0.01	0.39	29	669	9	262
5	"	50-69	"	Jan.-Apr.	May-Aug. (2)	11	0.06	14.62	293	113	7	1652
				1955	Sep.-Dec. (3)	13	0.01	2.13	96	171	2	364
				1956	May-Aug. (2)	7	0.03	6.47	204	483	16	3126
				1965	Sep. onwards	10	0.08	13.64	245	1019	80	13899
6	"	>69	"	Jan.-Apr.	May-Aug. (2)	10	0.08	7.94	48	78	6	619
				1955	Sep.-Dec. (3)	4	0.10	2.10	255	160	16	336
				1956	Sep. onwards	8	0.02	4.17	257	979	21	4082
				1965								
7	France	30-49	G7	June 1966	June-Sep. (2)	24	0.14	121.32	62	36	5	4368
8	"	30-49	"	Sep. 1967	Sep.-Dec. (3)	28	1.18	65	116	20	24	1304
					Jan.-Apr. (1)	5	0.82	44	170	156	128	6774
9	"	50-69	"	June 1966	June-Sep. (2)	43	0.07	172.09	60	32	2	5507
					Jan.-Mar. (1)	4	0.34	22.08	146	223	77	4924
					Apr.-June (2)	3	0.07	37.31	173	331	25	12350
					July-Sep. (2)	3	0.12	13.03	340	392	48	5108
10	"	50-69	"	Sep. 1967	Sep.-Dec. (3)	16	1.03	133	132	27	28	3608
					Jan.-Apr. (1)	6	0.41	15	132	175	72	2663
					May-Aug. (2)	11	0.10	2	80	298	30	508
					May-Aug. (2)	5	0.11	9	35	668	72	5793
11	"	>69	"	June 1966	June-Sep.) (2)	24	0.31	130.10	71	44	14	5724
					July-Sep.)	4	0.07	1.77	85	415	29	735
12	"	30-49	F1	Nov.-Dec.	Nov.-Dec. (3)	29	0.76	75	74	17	13	1298
				1966	Jan.-Apr. (1)	19	0.20	6	91	66	13	435
13	"	50-69	"	Nov.-Dec.	Nov.-Dec. (3)	9	0.73	19	114	13	10	256
				1966	Jan.-Apr. (1)	12	0.32	18	34	98	32	1809
					May-Aug. (2)	8	0.67	60	41	211	141	12541
					Sep.-Dec. (3)	8	0.11	10	43	329	37	3432
14	Netherlands	30-49	J3,4,5	Jan.-Feb.	Jan.-Apr. (1)	124	0.07	22	218	51	3	1122
				1968	May-Aug. (2)	35	0.39	22	346	145	57	3120

Ref. No.	Source	Length Group	Liberation area	Liberation period	Recapture period	No. of returns	V	a^2	ψ	$\bar{t}$	$V\bar{t}$	$a^2\bar{t}$
15	Netherlands	30-49	J3,4,5	Dec. 1969 Jan. 1970	Nov.-Dec. (3)	9	0.85	55	236	19	16	1046
16	"	50-69	"	Jan.-Feb. 1968, 1969	Jan.-Apr. (1)	39	0.29	187	183	41	12	7676
					May-Aug. (2)	16	0.51	25	359	174	89	4409
17	"	>69	"	Jan.-Feb. 1968, 1969	Jan.-Apr. (1)	19	0.32	92	206	37	12	3457
					May-Aug. (2)	5	0.41	18	323	154	62	2855
18	"	50-69	G4	Feb. 1969	Feb.-Apr. (1)	26	0.50	56	7	80	40	4468
					May-Aug. (2)	23	0.61	46	358	175	106	8054
19	Germany	50-69	J5 near Texel Light Vessel	Jan. 1969	Jan.-Apr. (1)	23	0.19	52.26	162	40	8	2090
					May-Aug. (2)	16	0.25	22.68	12	151	37	3425
					Sep.-Dec. (3)	5	0.26	21.31	17	241	62	5136
20	"	>69	"	1969	Jan.-Apr. (1)	33	0.46	198.07	331	30	14	5942
					May-Aug. (2)	19	0.64	85.74	350	153	99	13118
					Sep.-Dec. (3)	5	0.31	8.08	359	240	76	1939
21	"	30-49	M6,M7,N7	Oct.-Dec. 1967 1968 1969	Sep.-Dec.	57	0.20	14.88	206	11	2	164
					Jan.-Apr.	201	0.40	21.23	257	46	18	977
22	"	50-69	"	1967 1968 1969	Sep.-Dec. (3)	12	1.96	45.23	53	10	20	452
					Jan.-Apr. (1)	27	0.19	30.82	272	90	17	2774
					May-Aug. (2)	5	0.37	9.60	301	221	82	2122
23	Scotland	30-49	Moray Firth	Dec.-Feb. 1963 1965	Jan.-Apr. (1)	127	0.43	12.8	288	22	10	287
					May-Aug. (2)	94	0.08	2.8	311	134	10	375
					Sep.-Dec. (3)	14	0.08	4.1	311	243	20	988
					Jan.-Apr. (1)	8	0.05	1.5	312	361	18	542
					May-Aug. (2)	6	0.08	2.9	319	477	36	1385
24	"	30-49	"	1963	Jan.-Apr. (1)	39	0.07	22.1	165	32	2	720
					May-Aug. (2)	38	0.07	2.8	8	116	8	330
					Sep.-Dec. (3)	7	0.01	3.1	94	248	4	765
					Jan.-Apr. (1)	12	0.03	1.4	170	371	11	523
25	"	30-49	"	1963	Jan.-Apr. (1)	191	0.21	7.4	315	40	9	298
					May-Aug. (2)	243	0.05	2.3	322	126	6	288
					Sep.-Dec. (3)	47	0.03	1.0	358	245	8	246
					Jan.-Apr. (1)	19	0.04	1.1	334	376	16	408
					May-Aug. (2)	5	0.02	0.4	3	470	7	186
26	"	50-69	"	1963 1965	Jan.-Apr. (1)	38	0.72	11.8	288	26	19	319
					May-Aug. (2)	21	0.14	5.5	310	128	18	704
					Sep.-Dec. (3)	8	0.05	2.1	339	253	12	530
27	"	50-69	"	1963	Jan.-Apr. (1)	23	0.21	12.4	181	34	7	430
					May-Aug. (2)	20	0.09	3.0	126	107	9	320
					Sep.-Dec. (3)	8	0.05	1.7	150	273	13	456
					Jan.-Apr. (1)	9	0.01	0.9	192	385	4	347
28	"	50-69	"	1963	Jan.-Apr. (1)	31	0.13	9.0	29	26	3	243
					May-Aug. (2)	13	0.12	5.0	48	95	12	479
					Sep.-Dec. (3)	9	0.03	1.1	1	265	7	293
29	"	50-69	"	Sep., Nov. 1963	Sep.-Dec. (3)	83	0.12	17.2	4	34	4	596
					Jan.-Apr. (1)	35	0.09	4.6	346	119	10	548
					May-Aug. (2)	8	0.07	2.3	22	230	16	540

Ref. No.	Source	Length group	Liberation area	Liberation period	Recapture period	No. of returns	V	a^2	Y	$\bar{t}$	$V\bar{t}$	$a^2\bar{t}$
30	Scotland	> 69	Moray Firth	Sep., Nov.	Sep.-Dec. (3)	44	0.04	5.2	90	36	1	189
				1963	Jan.-Apr. (1)	9	0.02	1.4	3	105	3	153
31	"	50-69	East Coast	Sep., Nov.	Sep.-Dec. (3)	53	0.01	3.86	77	18	0.1	69
				1965	Jan.-Apr. (1)	11	0.18	3.42	4	119	22	407
				1966								
32	"	30-49	"	Sep., Nov.	Sep.-Dec. (3)	117	0.03	2.5	204	17	0.6	42
				1965	Jan.-Apr. (1)	16	0.11	5.96	34	135	15	805
				1966	May-Aug. (2)	6	0.02	0.75	64	238	5	178
					Sep.-Dec. (3)	6	0.04	0.70	30	354	13	248
33	"	30-49	North Coast	Feb., Mar.	Jan.-Apr. (1)	10	0.30	18.5	289	87	26	1615
				1963	May-Aug. (2)	17	0.09	8.1	302	163	15	1320
					Sep.-Dec. (3)	12	0.08	3.7	278	289	24	1070
					Jan.-Apr. (1)	9	0.03	0.8	294	448	14	350
					May-Aug. (2)	2	0.13	0.6	278	493	63	298
					Sep.-Dec. (3)	2	0.00	0.1	289	693	1	77
					Jan.-Apr. (1)	4	0.03	0.5	293	786	26	426
34	England (see footnote)	≤ 70	G12 East Bank	June 1962	May-Aug. (2)	84	0.76	85.4	167	32	25	2758
					Sep.-Dec. (3)	22	0.15	32.3	6	98	15	3192
					Jan.-Apr. (1)	7	0.03	46.6	226	253	7	11808
					May-Aug. (2)	29	0.10	17.5	137	361	37	6320
					Sep.-Dec. (3)	9	0.07	5.9	167	473	31	2799
					Jan.-Apr. (1)	9	0.08	3.2	121	623	52	1979
					May-Aug. (2)	9	0.05	10.1	126	737	40	7417
					Sep.-Dec. (3)	4	0.05	8.1	90	818	42	6618
					Jan.-Apr. (1)	11	0.08	2.8	142	979	73	2785
35	"	> 70	"	June 1962	May-Aug. (2)	107	0.79	88.4	154	34	27	3017
					Sep.-Dec. (3)	33	0.13	47.7	181	100	13	4791
					Jan.-Apr. (1)	60	0.36	28.1	157	259	94	7287
					May-Aug. (2)	58	0.05	20.1	167	373	18	7513
					Sep.-Dec. (3)	8	0.15	11.0	136	469	73	5151
					Jan.-Apr. (1)	34	0.10	9.5	139	624	63	5902
					May-Aug. (2)	21	0.03	10.2	48	727	25	7433
					Sep.-Dec. (3)	9	0.03	10.8	195	823	28	8914
					Jan.-Apr. (1)	20	0.07	4.8	144	974	71	4684
					May-Aug. (2)	2	0.09	0.3	110	1050	89	293
36	"	≤ 70	F8,9 Central	June 1957	May-Aug. (2)	41	0.64	119.3	3	36	23	4337
					Sep.-Dec. (3)	21	0.35	90.9	5	119	41	10827
					Jan.-Apr. (1)	6	0.27	77.1	328	265	71	20464
					May-Aug. (2)	14	0.08	4.4	46	364	30	1593
					Sep.-Dec. (3)	3	0.05	5.5	103	480	23	2651
					Jan.-Apr. (1)	1	0.12	0.0	102	600	70	0
					May-Aug. (2)	5	0.04	6.9	44	732	30	5070
37	"	> 70	"	June 1957	May-Aug. (2)	2	0.50	0.0	0	30	15	0
					Sep.-Dec. (3)	2	0.02	125.8	350	90	92	11387
					Jan.-Apr. (1)	1	0.20	0.0	219	270	55	0
					Jan.-Apr. (1)	1	0.17	0.0	42	600	102	0
38	"	>70	H7 Central	June 1957	May-Aug. (2)	5	0.17	5.0	180	36	6	183
					Jan.-Apr. (1)	1	0.12	0.0	90	300	35	0
					Sep.-Dec. (3)	1	0.04	0.0	270	840	35	0
39	"	≤70	"	June 1957	May-Aug. (2)	46	0.47	54.7	295	42	20	2345
					Sep.-Dec. (3)	35	0.06	6.4	315	126	7	811
					Jan.-Apr. (1)	6	0.13	17.8	235	280	35	4997
					May-Aug. (2)	13	0.04	8.8	316	385	16	3378
					Sep.-Dec. (3)	4	0.05	2.2	311	480	23	1063
					Jan.-Apr. (1)	2	0.04	7.5	230	630	25	4749
					May-Aug. (2)	3	0.05	3.8	322	750	38	2839
					Sep.-Dec. (3)	1	0.23	- 0.0	202	870	196	0
					May-Aug. (2)	1	0.07	- 0.0	247	1050	77	0

Ref. No.	Source	Length group	Liberation area	Liberation period	Recapture period	No. of returns	V	a^2	ψ	$\bar{t}$	$V\bar{t}$	$\overline{a^2t}$
40	England	⩽70	H7,H8 Central	March 1961	Jan.-Apr. (1)	30	0.60	35.7	211	44	27	1587
					May-Aug. (2)	49	0.11	21.2	12	133	14	2823
					Sep.-Dec. (3)	2	0.00	3.6	0	255	0	931
					Jan.-Apr. (1)	6	0.03	7.9	30	370	12	2939
					May-Aug. (2)	6	0.05	9.5	0	505	25	4801
					Sep.-Dec. (3)	2	0.05	2.0	0	585	30	1165
					Jan.-Apr. (1)	2	0.05	0.0	90	720	35	0
					May-Aug. (2)	1	0.23	– 0.0	350	810	185	0
41	"	⩽70	"	Feb. 1961	Jan.-Apr. (1)	33	0.54	81.9	19	43	23	3541
					May-Aug. (2)	81	0.48	58.9	4	129	63	7622
					Sep.-Dec. (3)	11	0.37	34.5	6	229	85	7915
					Jan.-Apr. (1)	58	0.07	4.9	50	373	24	1820
					May-Aug. (2)	27	0.12	14.5	338	489	60	7075
					Sep.-Dec. (3)	8	0.07	25.3	22	611	44	15495
					Jan.-Apr. (1)	34	0.04	6.1	62	729	30	4417
					May-Aug. (2)	5	0.08	8.0	30	846	68	6803
					Sep.-Dec. (3)	2	0.18	5.0	354	945	166	4686
					Jan.-Apr. (1)	1	0.00	0.0	0	1050	0	0
42	"	⩽70	H7 Central	Apr. 1956	May-Aug. (2)	62	0.16	18.8	312	79	13	1495
					Sep.-Dec. (3)	18	0.08	14.7	275	190	16	2795
					Jan.-Apr. (1)	3	0.27	82.8	321	330	89	27351
					May-Aug. (2)	10	0.09	9.7	330	447	42	4332
					Sep.-Dec. (3)	7	0.00	0.0	0	544	0	0
					Jan.-Apr. (1)	2	0.26	25.6	355	780	200	19956
43	"	>70	"	Apr. 1956	May-Aug. (2)	14	0.47	75.2	18	66	32	5035
					Sep.-Dec. (3)	6	0.10	4.6	90	180	18	829
					Jan.-Apr. (1)	4	0.13	11.6	68	293	37	3396
					May-Aug. (2)	7	0.21	23.0	324	437	90	10078
					Sep.-Dec. (3)	4	0.10	5.6	305	533	53	2979
					Jan.-Apr. (1)	3	0.07	4.3	131	680	46	2956
					May-Aug. (2)	4	0.13	13.4	19	803	103	10789
					Jan.-Apr. (1)	2	0.02	0.5	49	1005	23	529
44	"	⩽70	F8 Central	Mar. 1963	Jan.-Apr. (1)	1	1.17	– 0.0	90	30	36	0
					May-Aug. (2)	210	0.16	18.2	54	104	17	1897
					Sep.-Dec. (3)	85	0.06	12.4	74	219	13	2728
					Jan.-Apr. (1)	28	0.14	27.7	92	351	49	9755
					May-Aug. (2)	80	0.06	9.9	49	442	27	4381
					Sep.-Dec. (3)	21	0.07	10.3	26	570	37	5898
					Jan.-Apr. (1)	27	0.12	15.8	63	714	86	11284
					May-Aug. (2)	25	0.03	3.6	9	827	25	3001
					Sep.-Dec. (3)	5	0.07	6.8	57	918	65	6207
					Jan.-Apr. (1)	3	0.05	2.3	90	1050	58	2431
45	"	>70	"	Mar. 1963	May-Aug. (2)	9	0.11	14.7	21	93	11	1377
					Sep.-Dec. (3)	2	0.36	23.2	30	195	70	4526
					Jan.-Apr. (1)	1	0.36	– 0.0	60	330	120	0
					May-Aug. (2)	2	0.11	7.1	270	450	51	3208
					Sep.-Dec. (3)	2	0.12	5.4	311	570	68	3108
					Jan.-Apr. (1)	1	0.11	– 0.0	90	660	70	0
					May-Aug. (2)	1	0.20	0.0	40	780	158	0
					Jan.-Apr. (1)	2	0.18	0.9	81	1065	188	992
46	"	⩽70	G3 Southern Bight	Dec. 1965	Jan.-Apr. (1)	26	0.03	45.0	312	60	2	2723
					May-Aug. (2)	25	0.58	32.2	1	196	115	6307
					Sep.-Dec. (3)	18	0.12	14.3	6	308	39	4426
					Jan.-Apr. (1)	5	0.06	22.3	15	432	24	9631
					May-Aug. (2)	4	0.08	5.6	349	585	46	3287
					Sep.-Dec. (3)	7	0.09	13.3	9	677	61	9006
					Jan.-Apr. (1)	3	0.09	9.9	350	770	71	7595
					May-Aug. (2)	2	0.19	0.0	334	885	166	8
					Sep.-Dec. (3)	1	0.12	0.0	17	1020	125	0

Ref. No.	Source	Length group	Liberation area	Liberation period	Recapture period	No. of returns	V	a^2	ψ	$\bar{t}$	$V\bar{t}$	$a^2\bar{t}$
47	England	>70	G3 Southern Bight	Dec. 1965	May-Aug. (2)	4	0.69	6.3	342	173	119	1088
					Sep.-Dec. (3)	1	0.61	- 0.0	334	270	166	0
					Sep.-Dec. (3)	1	0.05	- 0.0	230	1050	48	0
48	"	≤70	F1 Southern Bight	Nov. 1964	Sep.-Dec. (3)	8	0.60	24.9	213	30	18	760
					Jan.-Apr. (1)	34	0.19	40.3	351	120	22	4859
					May-Aug. (2)	36	0.59	40.3	16	224	132	9053
					Sep.-Dec. (3)	16	0.11	16.3	11	341	38	5576
					Jan.-Apr. (1)	15	0.05	9.2	353	468	24	4306
					May-Aug. (2)	18	0.32	9.5	5	590	192	5637
					Sep.-Dec. (3)	9	0.10	24.9	346	690	70	17178
					Jan.-Apr. (1)	8	0.06	14.9	36	833	46	12437
					May-Aug. (2)	1	0.09	0.0	0	960	90	0
					Sep.-Dec. (3)	5	0.01	0.4	308	1062	11	456
49	"	≤70	F3 Southern Bight	Sep. 1965	Sep.-Dec. (3)	9	0.04	1.0	180	80	3	78
					Jan.-Apr. (1)	10	0.36	33.1	18	159	57	5272
					May-Aug. (2)	10	0.39	9.0	8	270	106	2446
					Sep.-Dec. (3)	11	0.04	18.5	22	423	18	7834
					Jan.-Apr. (1)	5	0.10	4.1	24	522	53	2128
					May-Aug. (2)	4	0.11	18.8	345	653	70	12246
					Sep.-Dec. (3)	2	0.00	0.0	0	795	0	0
					Jan.-Apr. (1)	1	0.15	- 0.0	0	990	150	0
50	"	≤70	F3 Southern Bight	Dec. 1964	Jan.-Apr. (1)	51	0.16	36.2	121	78	13	2828
					May-Aug. (2)	120	0.55	31.8	17	204	114	6504
					Sep.-Dec. (3)	33	0.22	40.0	29	312	69	12479
					Jan.-Apr. (1)	27	0.05	7.4	33	440	22	3244
					May-Aug. (2)	33	0.23	8.1	12	552	125	4452
					Sep.-Dec. (3)	21	0.10	13.9	6	677	65	9443
					Jan.-Apr. (1)	9	0.04	5.9	50	790	32	4675
					May-Aug. (2)	7	0.09	11.7	349	917	83	10771
					Sep.-Dec. (3)	7	0.03	6.1	31	1024	30	6205
51	"	≤70	F1 Southern Bight	Dec. 1964	Jan.-Apr. (1)	51	0.21	14.9	219	78	16	1174
					May-Aug. (2)	28	0.19	60.2	6	183	35	11061
					Sep.-Dec. (3)	31	0.02	12.7	276	318	7	4039
					Jan.-Apr. (1)	12	0.06	24.1	12	458	28	11045
					May-Aug. (2)	11	0.21	38.7	3	543	112	21019
					Sep.-Dec. (3)	7	0.03	8.7	269	690	22	6003
					Jan.-Apr. (1)	4	0.04	0.7	221	803	30	573
					May-Aug. (2)	3	0.16	12.0	10	910	142	10928
					Sep.-Dec. (3)	1	0.00	0.0	0	1050	0	0
52	"	≤70	C9 NE Coast	May 1962	May-Aug. (2)	206	0.06	11.1	45	43	3	481
					Sep.-Dec. (3)	24	0.07	9.7	106	134	9	1299
					Jan.-Apr. (1)	13	0.03	11.5	331	309	10	3574
					May-Aug. (2)	6	0.08	19.8	0	395	30	7836
					Sep.-Dec. (3)	2	0.11	0.5	143	540	57	295
					May-Aug. (2)	2	0.05	0.4	151	720	35	293
					Jan.-Apr. (1)	1	0.04	- 0.0	132	1050	46	0
53	"	≤70	C9 NE Coast	May 1963	May-Aug. (2)	407	0.22	11.5	102	49	11	569
					Sep.-Dec. (3)	74	0.28	13.4	138	161	45	2152
					Jan.-Apr. (1)	39	0.07	19.9	111	265	19	5279
					May-Aug. (2)	49	0.01	5.2	40	384	6	2008
					Sep.-Dec. (3)	9	0.06	21.3	130	517	31	10994
					Jan.-Apr. (1)	6	0.05	16.3	116	635	32	10343
					May-Aug. (2)	11	0.03	3.5	83	775	22	2736
					Sep.-Dec. (3)	1	0.00	0.0	0	900	0	0
					May-Aug. (2)	1	0.14	- 0.0	66	1080	146	0

Ref. No.	Source	Length group	Liberation area	Liberation period	Recapture period	No. of returns	V	a^2	ψ	$\bar{t}$	$V\bar{t}$	$a^2\bar{t}$
54	England	⩽70	D7 NE Coast	Nov. 1963	Sep.-Dec. (3)	67	0.53	13.8	107	30	16	422
					Jan.-Apr. (1)	46	0.24	19.6	74	76	18	1502
					May-Aug. (2)	14	0.13	6.5	9	236	30	1538
					Sep.-Dec. (3)	12	0.06	2.8	54	340	21	959
					Jan.-Apr. (1)	1	0.23	0.0	90	450	104	0
					May-Aug. (2)	5	0.15	13.2	1	600	89	7906
					Sep.-Dec. (3)	3	0.02	0.7	49	690	15	505
55	"	⩽70	E51 English Channel	Feb. 1965	Jan.-Apr. (1)	31	0.07	2.2	90	35	2	76
					May-Aug. (2)	18	0.21	108.3	303	115	24	12512
					Sep.-Dec. (3)	18	0.12	45.8	332	237	28	10866
					Jan.-Apr. (1)	13	0.08	17.3	17	367	29	6342
					May-Aug. (2)	7	0.35	28.1	17	497	174	13997
					Sep.-Dec. (3)	8	0.05	6.5	26	611	33	4007
					Jan.-Apr. (1)	5	0.11	18.4	27	714	79	13158
					May-Aug. (2)	4	0.24	34.2	360	863	203	29479
					Sep.-Dec. (3)	2	0.11	12.4	19	1005	110	12473
					Jan.-Apr. (1)	2	0.14	0.2	47	1050	151	261
56	"	⩽70	"	June 1965	May-Aug. (2)	2	0.00	0.0	0	75	0	0
					Sep.-Dec. (3)	8	0.17	7.4	12	139	23	1031
					Jan.-Apr. (1)	2	0.26	16.0	17	240	62	3852
					May-Aug. (2)	3	0.31	22.5	6	390	121	8767
					Sep.-Dec. (3)	1	0.05	0.0	0	570	30	0
					Jan.-Apr. (1)	1	0.05	0.0	0	600	30	0
					May-Aug. (2)	1	0.27	- 0.0	10	780	212	0
					Sep.-Dec. (3)	1	0.04	- 0.0	0	840	30	0
57	"	⩽70	"	Sep. 1964	Sep.-Dec. (3)	29	0.04	3.1	69	66	3	206
					Jan.-Apr. (1)	8	0.03	9.2	53	165	6	1523
					May-Aug. (2)	2	0.24	36.7	244	270	64	9932
					Sep.-Dec. (3)	8	0.13	21.8	248	398	51	8659
					Jan.-Apr. (1)	2	0.04	0.6	90	510	19	321
					May-Aug. (2)	1	0.48	- 0.0	0	690	330	0
					Sep.-Dec. (3)	5	0.06	9.1	0	786	48	7119
					May-Aug. (2)	1	0.22	- 0.0	10	960	212	0
58	"	⩽70	"	Sep. 1965	Sep.-Dec. (3)	24	0.48	28.7	49	40	19	1161
					Jan.-Apr. (1)	5	0.50	25.7	34	174	87	4481
					May-Aug. (2)	1	0.81	0.0	19	270	220	0
					Sep.-Dec. (3)	5	0.07	1.2	33	402	29	499
					Jan.-Apr. (1)	5	0.26	12.4	22	516	135	6419
					May-Aug. (2)	2	0.21	11.3	25	630	131	7146
					Sep.-Dec. (3)	1	0.52	0.0	20	780	405	0
					Jan.-Apr. (1)	1	0.11	- 0.0	23	900	97	0
					May-Aug. (2)	1	0.38	0.0	27	1050	400	0

Footnote. All experiments attributed to England have been those carried out by Bedford and reported by him in his 1966 paper.

Table 2

Regrouping of data in Table 1, including means calculated using the formulae in Appendix I .

Ref. No.	Length Group	Area	Liberation period	Recapture period	No. of returns	V	a^2	ψ	$\bar{t}$	$V\bar{t}$	$a^2\bar{t}$
1	30-49	013, 14 M13,N13	May-Aug. 1954-1961	1st autumn	9	0.19	56	166	102	19	5756
				2nd "	5	0.04	0.5	90	445	20	43
				Mean	14	0.07	36	140	224	16	3716
				1st winter	10	0.10	4	91	177	19	799
				2nd "	6	0.01	0.4	77	732	9	33
				Mean	16	0.04	3	88	385	15	512
2-3	50-69	013, 14 M13,M14	May-Aug. 1954-1961	1st summer	5	0.18	0.4	32	75	14	27
	50-69			2nd "	19	0.05	15	241	327	16	5027
				Mean	24	0.04	12	249	274	11	3985
	50-69			1st autumn	35	0.18	7	88	99	18	723
	> 69			1st "	5	0.09	20	210	88	8	1743
	50-69			2nd "	7	0.04	1	102	433	15	518
				Mean	47	0.10	7	93	148	15	801
	50-69			1st winter	37	0.07	6	116	197	14	1101
	> 69			1st "	5	0.13	30	205	196	26	5838
	50-69			2nd "	22	0.05	9	227	826	44	7404
	> 69			2nd "	11	0.04	10	230	1041	43	10693
				Mean	75	0.04	9	207	505	20	4673
4-6	50-69	013,14 M13,M14	Sep.-Apr. 1953-1965	1st winter	13	0.16	6	67	107	17	689
	50-69			1st summer	11	0.06	15	293	113	7	1652
	> 69			1st "	10	0.08	8	48	78	6	619
	50-69			2nd "	10	0.01	0.4	29	669	9	262
	> 69			2nd "	7	0.03	6	204	483	16	3126
				Mean summer	38	0.005	8	329	318	2	1286
	50-69			1st autumn	5	0.01	0.7	104	319	3	211
	50-69			1st "	13	0.01	2	96	171	2	364
	> 69			1st "	4	0.10	2	255	160	16	336
				Mean autumn	22	0.01	2	223	203	2	324
34,35	≤ 70	G12	June 1962	1st summer	84	0.76	85	167	32	25	2758
	> 70				107	0.79	88	154	34	27	3017
	≤ 70			2nd "	29	0.10	17	137	361	37	6320
	> 70				58	0.05	20	164	373	18	7513
	≤ 70			3rd "	9	0.05	10	126	737	40	7417
	> 70				21	0.03	10	48	727	25	7433
	> 70			4th "	2	0.09	0.3	110	1050	89	293
				Mean	310	0.12	60	150	201	24	4506
	≤ 70			1st autumn	22	0.15	32	6	98	15	3192
	> 70				33	0.13	48	181	100	13	4791
	≤ 70			2nd "	9	0.07	6	167	473	31	2799
	> 70				8	0.15	11	136	469	73	5151
	≤ 70			3rd "	4	0.05	8	90	818	42	6618
	> 70				9	0.03	11	195	823	28	8914
				Mean	85	0.05	30	150	284	14	4723

Ref. No.	Length group	Area	Liberation period	Recapture period	No. of returns	V	a^2	ψ	$\bar{t}$	$V\bar{t}$	$a^2\bar{t}$
34,35	≤70	G12	June 1962	1st winter	7	0.03	47	226	253	7	11808
	>70				60	0.36	28	157	259	94	7287
	≤70			2nd "	9	0.08	3	121	623	52	1979
	>70				34	0.10	10	139	624	63	5902
	≤70			3rd "	11	0.08	3	142	979	73	2785
	>70				20	0.07	5	144	974	71	4684
				Mean	141	0.14	18	149	528	74	6118
38	≤70	H7	June 1957	1st summer	46	0.47	55	295	42	20	2345
	>70			1st "	5	0.17	5	180	36	6	183
39	≤70			2nd "	13	0.04	9	316	385	16	3378
	≤70			3rd "	3	0.05	4	322	750	38	2839
				Mean	67	0.13	40	300	140	18	2406
	≤70			1st autumn	35	0.06	6	315	126	7	811
	≤70			2nd "	4	0.05	2	311	480	23	1063
				Mean	39	0.05	6	314	162	8	837
	≤70			1st winter	6	0.13	18	235	280	35	4997
	≤70			2nd "	2	0.04	8	230	630	25	4749
				Mean	8	0.09	16	234	368	33	4935
40-43	≤70	H7	Feb. &	1st winter	30	0.60	36	211	44	27	1587
	≤70		Mar. 1961		33	0.54	82	19	43	23	3541
	≤70		Apr. 1956	2nd "	6	0.03	8	30	370	12	2939
	≤70				58	0.07	5	50	373	24	1820
	≤70				3	0.27	83	321	330	89	27351
	>70				4	0.13	12	68	293	37	3396
	≤70			3rd "	2	0.05	0	90	720	35	0
	≤70				34	0.04	6	62	729	30	4417
	≤70				2	0.26	26	355	780	200	19956
	>70				3	0.07	4	131	680	46	2956
	>70			4th "	2	0.02	0.5	49	1005	23	529
				Mean	177	0.05	26	44	342	17	3296
	≤70			1st summer	49	0.11	21	12	133	14	2823
	≤70				81	0.48	59	4	129	63	7622
	≤70				62	0.16	19	312	79	13	1495
	>70				14	0.47	75	18	66	32	5035
	≤70			2nd "	6	0.05	10	0	505	25	4801
	≤70				27	0.12	14	338	489	60	7075
	≤70				10	0.09	10	330	447	42	4332
	>70				7	0.21	23	324	437	90	10078
	≤70			3rd "	5	0.08	8	30	846	68	6803
	>70				4	0.13	13	19	803	103	10789
				Mean	265	0.18	33	355	204	37	5018
	≤70			1st autumn	2	0	4	0	255	0	931
	≤70				11	0.37	34	6	229	85	7915
	≤70				18	0.08	15	275	190	16	2795
	>70				6	0.10	5	90	180	18	829
	≤70			2nd "	2	0.05	2	0	585	30	1165
	≤70				8	0.07	25	22	611	44	15495
	≤70				7	0	0	0	544	0	0
	>70				4	0.10	6	305	533	53	2979
	≤70			3rd "	2	0.18	5	354	945	166	4686
				Mean	60	0.08	15	355	357	29	4863

Ref. No.	Length group	Area	Liberation period	Recapture period	No. of returns	V	a^2	ψ	$\bar{t}$	$\overline{Vt}$	$a^2\bar{t}$
36	⩽ 70	F8,9	June 1957	1st summer	41	0.64	119	3	36	23	4337
37	> 70			1st "	2	0.50	0	0	30	15	0
	⩽ 70			2nd "	14	0.08	4	46	364	30	1593
	⩽ 70			3rd "	5	0.04	7	44	732	30	5070
				Mean	62	0.14	80	18	166	23	3637
	⩽ 70			1st autumn	21	0.35	91	5	119	41	10827
	> 70			1st "	2	0.02	126	350	90	92	11387
	⩽ 70			2nd "	3	0.05	6	103	480	23	2651
				Mean	26	0.25	84	6	158	40	9927
44	⩽ 70	F8	Mar. 1963	1st winter	6	0.27	77	328	265	71	20464
45	⩽ 70			2nd "	28	0.14	28	92	351	49	9755
	⩽ 70			3rd "	27	0.12	16	63	714	86	11284
	> 70			4th "	2	0.12	0.9	81	1065	188	992
	⩽ 70			4th "	3	0.05	2	90	1050	58	2431
				Mean	66	0.11	26	69	545	60	10756
	⩽ 70			1st summer	210	0.16	18	54	104	17	1897
	> 70			1st "	9	0.11	15	21	93	11	1377
	⩽ 70			2nd "	80	0.06	10	49	442	27	4381
	> 70			2nd "	2	0.11	7	270	450	51	3208
	⩽ 70			3rd "	25	0.03	4	9	827	25	3001
				Mean	326	0.08	15	47	244	20	2585
	⩽ 70			1st autumn	85	0.06	12	74	219	13	2728
	> 70			1st "	2	0.36	23	30	195	70	4526
	⩽ 70			2nd "	21	0.07	10	26	570	37	5898
	> 70			2nd "	2	0.12	5	311	570	68	3108
	⩽ 70			3rd "	5	0.07	7	57	918	65	6207
				Mean	115	0.06	11	51	319	19	3496
52	⩽ 70	C9	May 1962	1st summer	206	0.06	11	45	43	3	481
53			" 1963	1st "	407	0.22	11	102	49	11	569
				2nd "	6	0.08	20	0	395	30	7836
				2nd "	49	0.01	5	40	384	6	2008
				3rd "	2	0.05	0.4	151	720	35	293
				3rd "	11	0.03	4	83	775	22	2736
				Mean	681	0.09	11	91	88	8	744
	⩽70			1st autumn	24	0.07	10	106	134	9	1299
				1st "	74	0.28	13	138	161	45	2152
				2nd "	2	0.11	0.5	143	540	57	295
				2nd "	9	0.06	21	130	517	31	10994
				Mean	109	0.19	13	136	191	36	2660
				1st winter	13	0.03	12	331	309	10	3574
				1st "	39	0.07	20	111	265	19	5279
				2nd "	6	0.05	16	116	635	32	10343
				Mean	58	0.05	18	106	313	16	5421

Ref. No.	Length group	Area	Liberation period	Recapture period	No. of returns	V	a^2	Ψ	$\bar{t}$	$V\bar{t}$	$a^2\bar{t}$
54	< 70	D7	Nov. 1963	1st autumn	67	0.53	14	107	30	16	422
				2nd "	12	0.06	3	54	340	21	959
				3rd "	3	0.02	0.7	49	690	15	505
				Mean	82	0.16	12	96	100	16	504
				1st winter	46	0.24	20	74	76	18	1502
				1st summer	14	0.13	6	9	236	30	1538
				2nd "	5	0.15	13	1	600	89	7906
				Summer mean	19	0.14	8	5	332	46	3214
13	50-69	F1	Nov. 1964	1st winter }	12	0.32	18	34	98	32	1809
48	and		Dec. 1964		34	0.19	40	351	120	22	4859
51	<70		Nov.-Dec. 1966		51	0.21	15	219	78	16	1174
				2nd " }	15	0.05	9	353	468	24	4306
					12	0.06	24	12	458	28	11045
				3rd " }	8	0.06	15	36	833	46	12437
					4	0.07	0.7	221	803	30	573
				Mean	136	0.04	21	349	233	9	4013
				1st summer }	8	0.67	60	41	211	141	12541
					36	0.59	40	16	224	132	9053
					28	0.19	60	6	183	35	11061
				2nd " }	18	0.32	9	5	590	192	5637
					11	0.21	39	3	543	112	21019
				3rd "	3	0.16	12	10	910	142	10928
				Mean	104	0.34	41	13	329	112	10590
				1st autumn }	9	0.73	19	114	13	10	256
					8	0.60	25	213	30	18	760
					31	0.02	13	276	318	7	4039
				2nd " }	8	0.11	10	43	329	37	3432
					16	0.11	16	11	341	38	5576
					7	0.03	9	269	690	22	6003
				3rd "	9	0.10	25	346	690	70	17178
				Mean	88	0.04	16	351	333	13	5078
12	30-49	F1	Nov.-Dec. 1966	1st autumn	1298	29	0.76	75	74	17	13
				1st winter	435	19	0.20	6	91	66	13
7	30-49	G7	June 1966	1st summer	24	0.14	121	62	36	5	4368
9,11	≥50			1st winter	4	0.34	22	146	223	77	4924
				1st summer }	43	0.07	172	60	32	2	5507
					24	0.31	130	71	44	14	5724
				2nd " }	3	0.07	37	173	331	25	12350
					3	0.12	13	340	392	48	5108
					4	0.07	2	85	415	29	735
				Mean summer	77	0.08	139	64	81	6	5578
8	30-49	"	Sep. 1967	1st autumn	28	1.18	65	116	20	24	1304
				1st winter	5	0.82	44	170	156	128	6774
10	50-69	"	"	1st autumn	16	1.03	133	132	27	28	3608
				1st winter	6	0.41	15	132	175	72	2663
				1st summer	11	0.10	2	80	298	30	508
				2nd "	5	0.11	9	35	668	72	5793
				Mean summer	16	0.10	4	56	414	41	2160

Ref. No.	Length group	Area	Liberation period	Recapture period	No. of returns	V	a^2	ψ	$\bar{t}$	$V\bar{t}$	$a^2\bar{t}$
22	50-69	N6,7,	Oct.-Dec. 1969	1st autumn	12	1.96	45	53	10	20	452
		N7		1st winter	27	0.19	31	272	90	17	2774
				1st summer	5	0.37	10	301	221	82	2122
16	50-69	F3	Autumn & winter	1st winter	39	0.29	187	183	41	12	7676
17	and	G3	1964-1970		19	0.32	92	206	37	12	3457
18	≤ 70	G4			26	0.50	56	7	80	40	4468
19		J3,4,5			23	0.19	52	162	40	8	2090
20					33	0.46	198	331	30	14	5942
46					26	0.03	45	312	60	2	2723
47					10	0.36	33	18	159	57	5272
49					51	0.16	36	121	78	13	2828
50				2nd "	5	0.06	22	15	432	24	9631
					5	0.10	4	24	522	53	2128
					27	0.05	7	33	440	22	3244
				3rd "	3	0.09	10	350	770	71	7595
					9	0.04	6	50	790	32	4675
				Mean winter	276	0.06	80	30	143	9	4364
				1st summer	16	0.51	25	359	174	89	4409
					5	0.41	18	323	154	62	2855
					23	0.61	46	358	175	106	8054
					16	0.25	23	12	151	37	3425
					19	0.64	86	350	153	99	13118
					25	0.58	32	1	196	115	6307
					4	0.69	6	342	173	119	1088
					10	0.39	9	8	270	106	2446
					120	0.55	32	17	204	114	6504
				2nd "	4	0.08	6	349	585	46	3287
					4	0.11	19	345	653	70	12246
					33	0.23	8	12	552	125	4452
				3rd "	2	0.19	0	334	885	166	8
					7	0.09	12	349	917	83	10771
				Mean	288	0.38	30	8	267	101	6339
				1st autumn	5	0.26	21	17	241	62	5136
					5	0.31	8	359	240	76	1939
					18	0.12	14	6	308	39	4426
					9	0.04	1.0	180	80	3	78
					33	0.22	40	29	312	69	12479
				2nd "	7	0.09	13	9	677	61	9006
					11	0.04	18	22	423	18	7834
					21	0.10	14	6	677	65	9443
				3rd "	2	0	0	0	795	0	0
					7	0.03	6	31	1024	30	6205
				Mean	118	0.11	20	17	435	48	7784

Ref. No.	Length group	Area	Liberation period	Recapture period	No. of returns	V	a^2	$\bar{V}$	$\bar{t}$	$V\bar{t}$	$a^2\bar{t}$
14	30-49	J3,4,5	Jan & Feb '68,'69	1st autumn	9	0.85	55	236	19	16	1046
15			Dec. '69,Jan. '70	1st winter	124	0.07	22	218	51	3	1122
				1st summer	35	0.39	22	346	145	57	3120
55	⩽ 70	E51	June 1965	1st autumn	8	0.17	7.4	12	139	23	1031
56				1st winter	2	0.26	16.0	17	240	62	3852
57				1st summer	3	0.31	22.5	6	390	121	8767
			Sep. 1964	1st winter	31	0.07	2.2	90	35	2	76
					8	0.03	9	53	165	6	1523
					5	0.50	26	34	174	87	4481
			Feb. 1965	2nd "	13	0.08	17	17	367	29	6342
					2	0.04	0.6	90	510	19	321
					5	0.26	12	22	516	135	6419
58	⩽ 70	F51	Sep. 1965	3rd "	5	0.11	18	27	714	79	13158
				Winter mean	69	0.13	9	28	221	29	3158
				1st summer	18	0.21	108	303	115	24	12512
					2	0.24	37	244	270	64	9932
				2nd "	7	0.35	28	17	497	174	13997
					2	0.21	11	25	630	131	7146
				3rd "	4	0.24	34	360	863	203	29479
				Mean	33	0.22	72	360	327	72	14402
				1st autumn	18	0.12	46	332	237	28	10866
					29	0.04	3	69	66	3	206
					24	0.48	29	49	40	19	1161
				2nd "	8	0.05	6	26	611	33	4007
					8	0.13	22	248	398	51	8659
					5	0.07	1	33	402	29	499
				3rd "	2	0.11	12	19	1005	110	12473
					5	0.06	9	0	786	48	7119
				Mean	99	0.06	19	3	234	14	3978

Table 3

Showing values of a^2 by successive periods of recapture (numbers of fish in brackets after each value)

Area \ Period[a]	1	2	3	1	2	3	1	2	3	Ref. Nos. (from Table 1)
Skagerak		10(26)	13(66)	8(65)	13(26)	6(84)	———	———	———→	1-6
Scottish Coast	11(459)	2(446)	6(402)	3(128)	2(27)	0.6(8)	0.5(4)			23-33
English Coast[b]		12(613)	13(165)	19(98)	7(69)	10(23)	14(7)	6(18)		52-54
Central	60(63)	65(493)	36(152)	21(150)	17(376)	11(125)	12(114)	10(124)	9(39)	34-45
Southern Bight	61(392)	42(291)	21(226)	22(347)	25(107)	13(71)	7(33)	10(34)	13(20)	12-22 46-51
English Channel		37(20)	24(69)	16(28)	26(13)	11(23)	12(13)	20(8)	10(7)	55-58

[a] 1 January-April

2 May-August

3 September-December

[b] English coast north from Flamborough Head

Table 4

Showing values of $a^2\bar{t}$ by successive periods of recapture (numbers of fish in brackets after each value)

Period[a] / Area	1	2	3	1	2	3	1	2	3	Ref. Nos. (from Table 1)
Skagerak		942(26)	1392(66)	1337(65)	4515(26)	5475(84)	-----------	-----------	-----------→	1-6
Scottish Coast	364(459)	375(446)	299(402)	489(128)	564(27)	205(8)	426(4)			23-33
English Coast[b]	-	539(613)	1325(165)	3280(98)	2419(69)	4828(23)	8865(7)	3801(18)		52-54
Central	2611(63)	3593(493)	4343(152)	5943(150)	3786(376)	3639(125)	5782(114)	5171(124)	6203(39)	34-45
Southern Bight	2906(392)	6651(291)	3199(226)	2246(347)	7967(107)	7129(71)	3955(33)	7607(34)	9901(20)	12-22 46-51
English Channel	-	11261(20)	3444(69)	4455(28)	11088(13)	4514(23)	7579(13)	16526(8)	8649(7)	55-58

[a] 1 January-April

2 May-August

3 September-December

[b] English coast north from Flamborough Head

Table 5

	Mean Values of a^2t			Values of R*		
Area	A	B	C	A	B	C
Skagerak	1265	3795	-	61	108	-
Scottish Coast	348	487	426	33	38	37
NE English Coast	706	3155	5220	47	98	126
Central North Sea	3667	4255	5568	107	114	131
Southern Bight	4166	4072	6749	114	112	144
English Channel	5201	5824	10403	126	133	178

A - means of the first 3 periods of recapture (1, 2, 3) in Table 4.

B - corresponding means for second 3 periods of recapture.

C - corresponding means for third 3 periods of recapture.

* $R = 1.73 \sqrt{a^2t}$

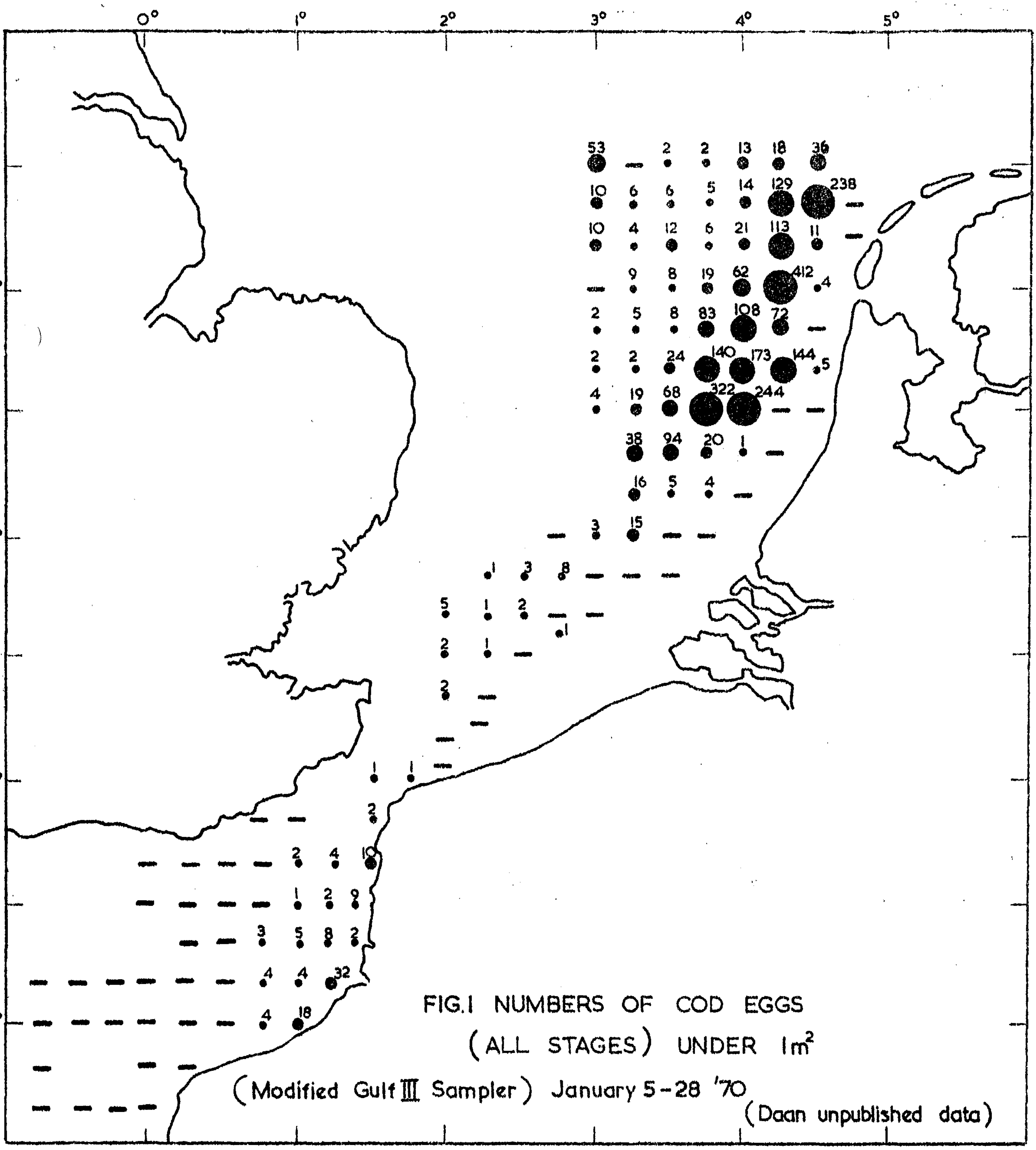


FIG. 1 NUMBERS OF COD EGGS (ALL STAGES) UNDER $1 m^2$

(Modified Gulf III Sampler) January 5-28 '70

(Daan unpublished data)

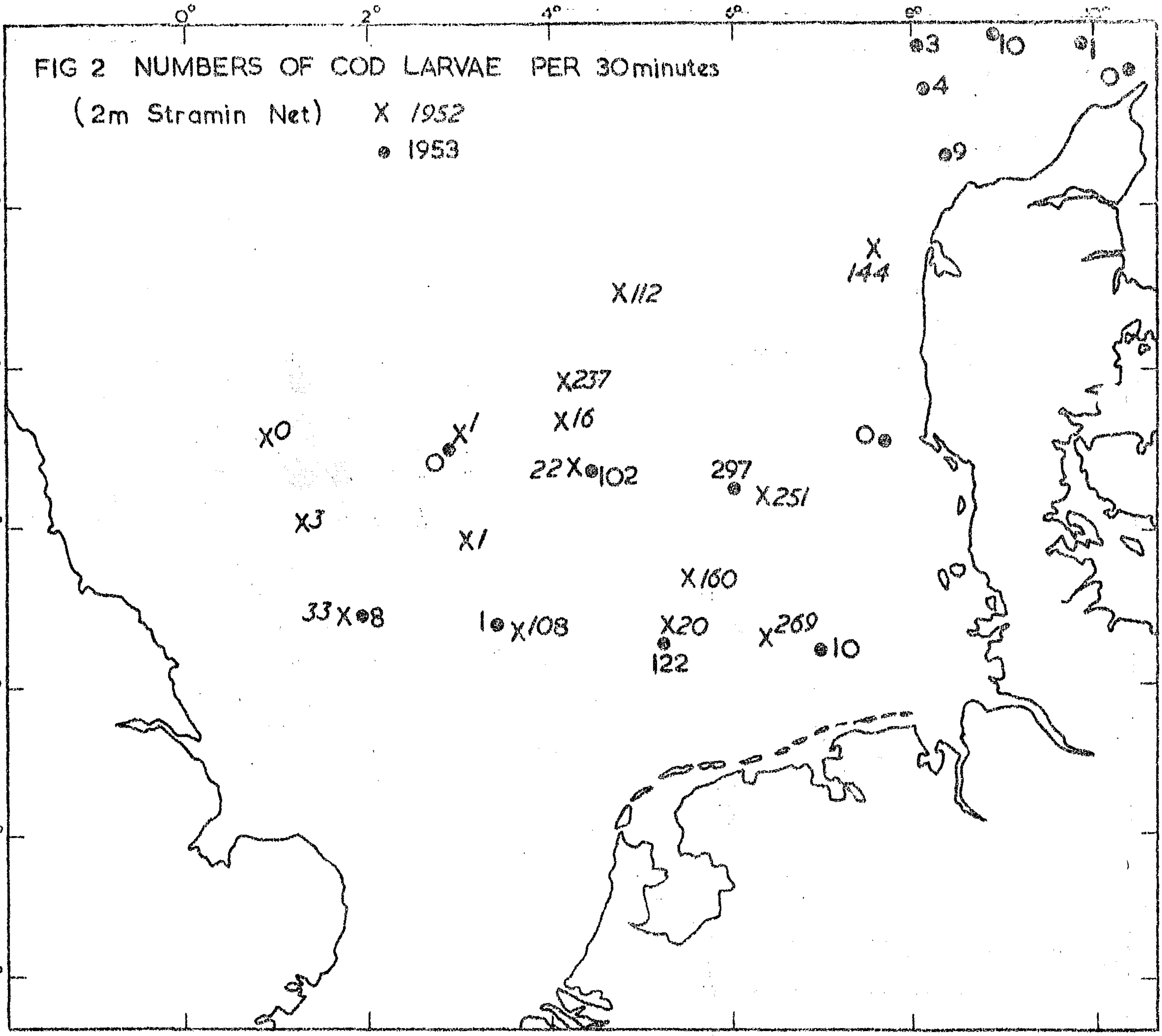


FIG 2 NUMBERS OF COD LARVAE PER 30 minutes (2m Stramin Net)

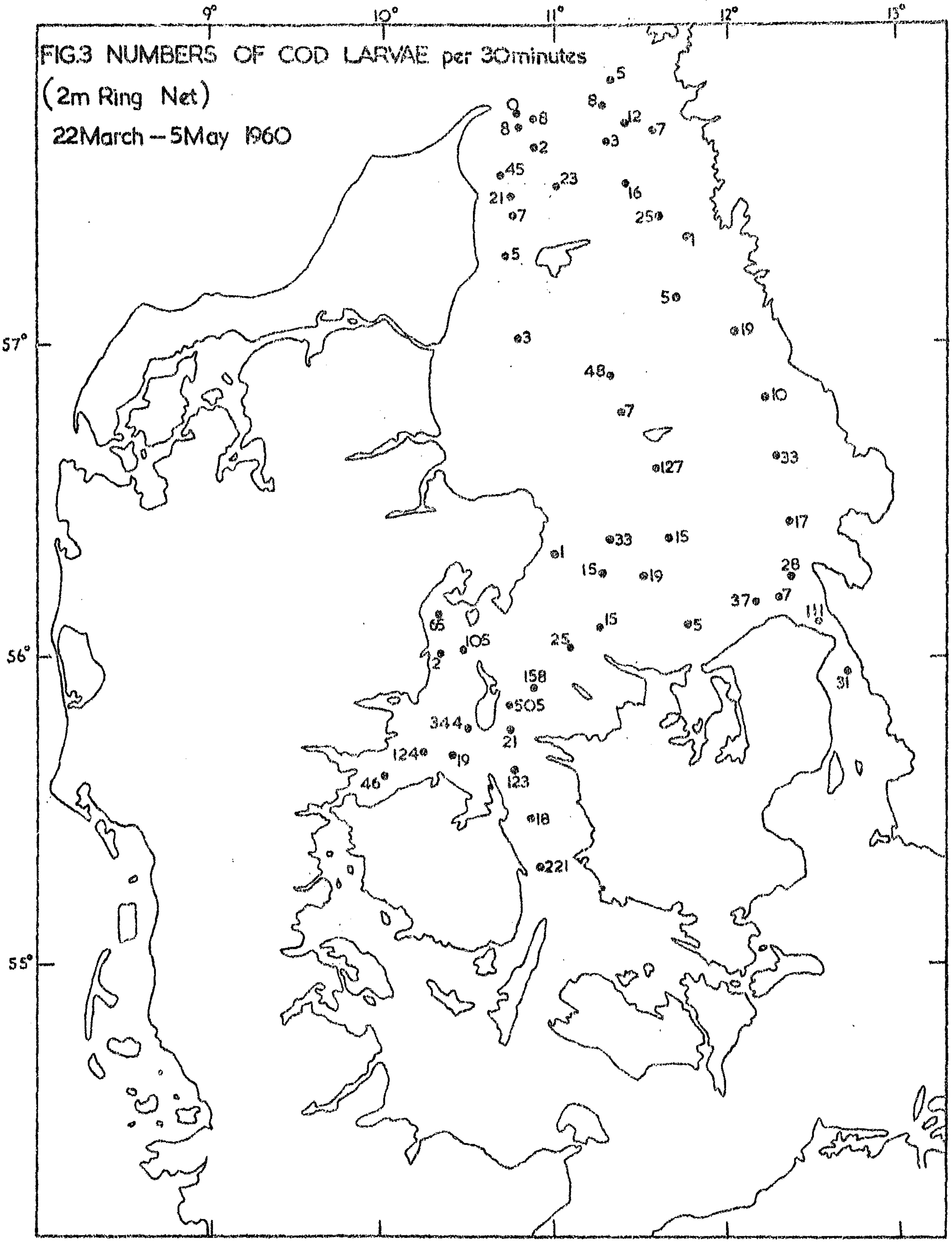


FIG.3 NUMBERS OF COD LARVAE per 30minutes (2m Ring Net) 22March – 5May 1960

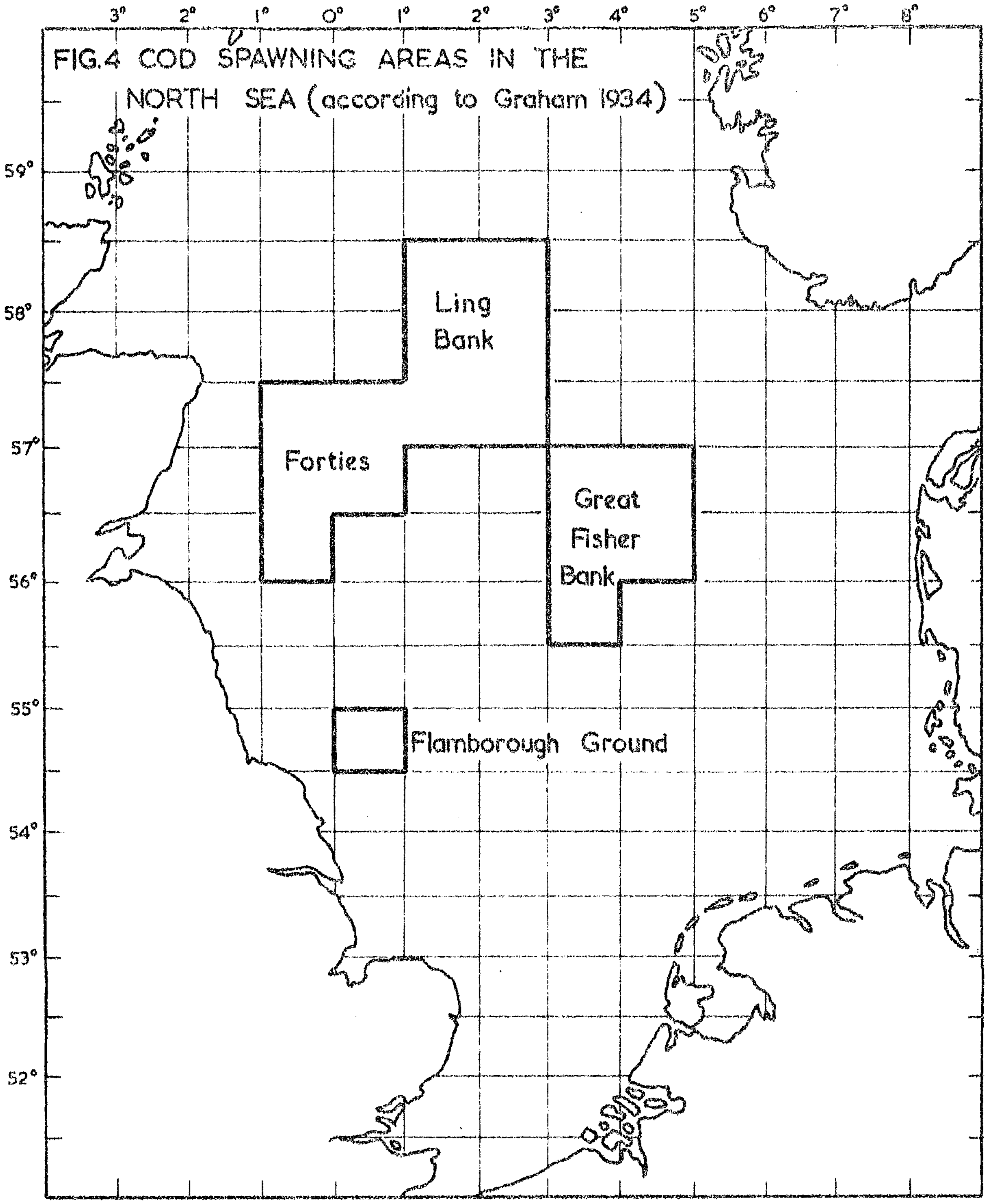


FIG.4 COD SPAWNING AREAS IN THE NORTH SEA (according to Graham 1934)
3°
2°
1°
0°
1°
2°
3°
4°
5°
6°
7°
8°
59°
58°
57°
56°
55°
54°
53°
52°
Ling Bank
Forties
Great Fisher Bank
Flamborough Ground

MEAN CATCH PER 10HRS FISHING OF LARGE COD BY MOTOR TRAWLERS IN ENGLAND

1960—64 ● = > 10 cwt ● = 5 — 10 cwt ● = 3 — 5 cwt ● = 1 — 3 cwt ● = <1 cwt

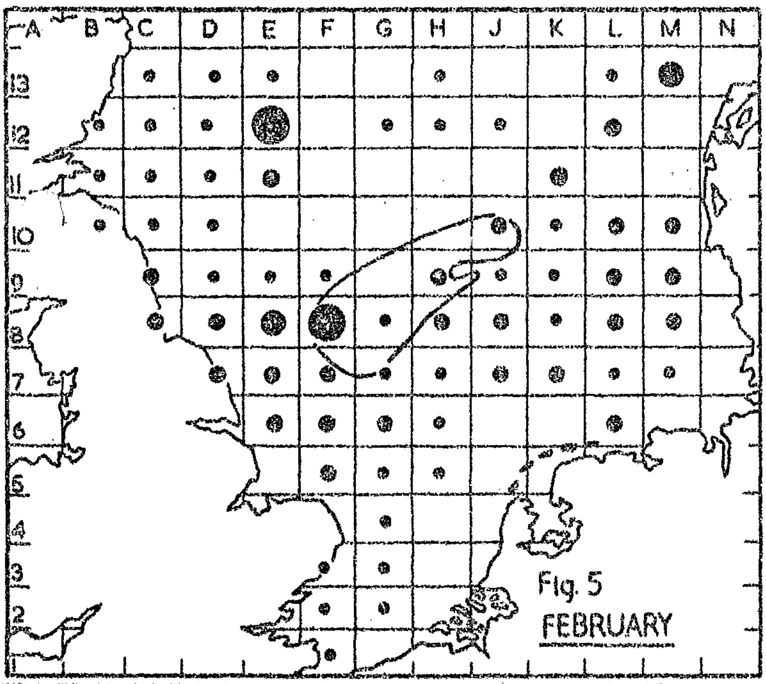


Fig. 5 FEBRUARY

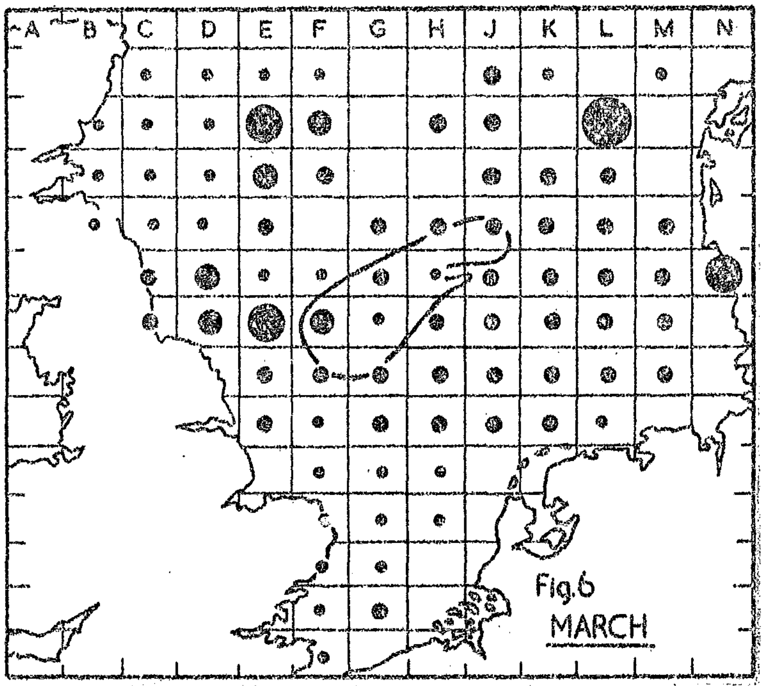


Fig.6 MARCH

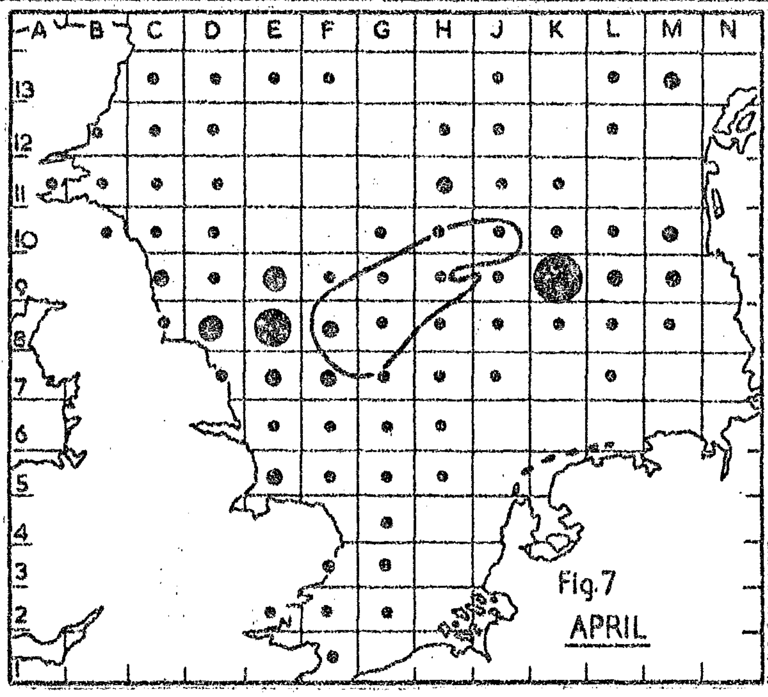


Fig.7 APRIL

MEAN CATCH PER 10HRS FISHING OF LARGE COD BY MOTOR SEINERS IN ENGLAND

1960–64 ● = >10 cwt ● = 5–10 cwt ● = 3–5 cwt ● = 1–3 cwt ● = <1 cwt

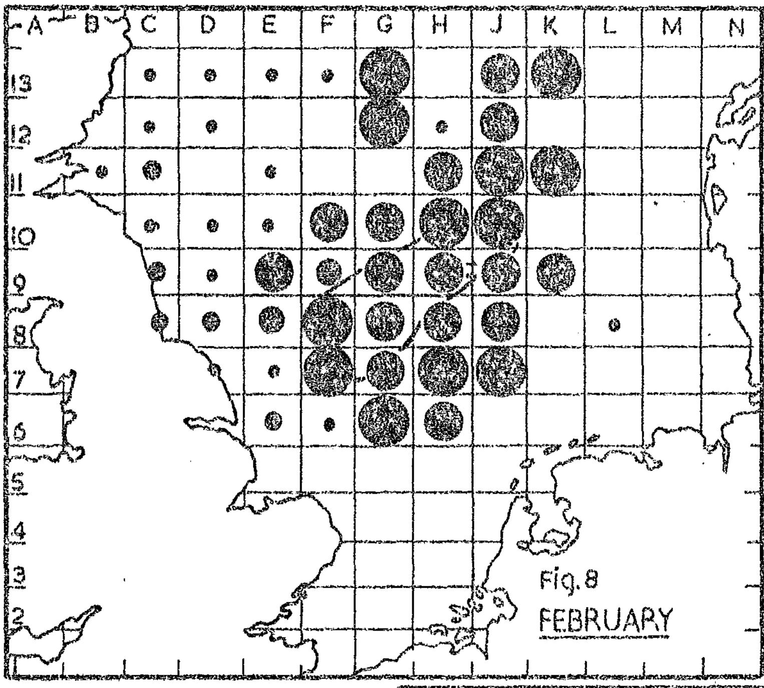


Fig. 8 FEBRUARY

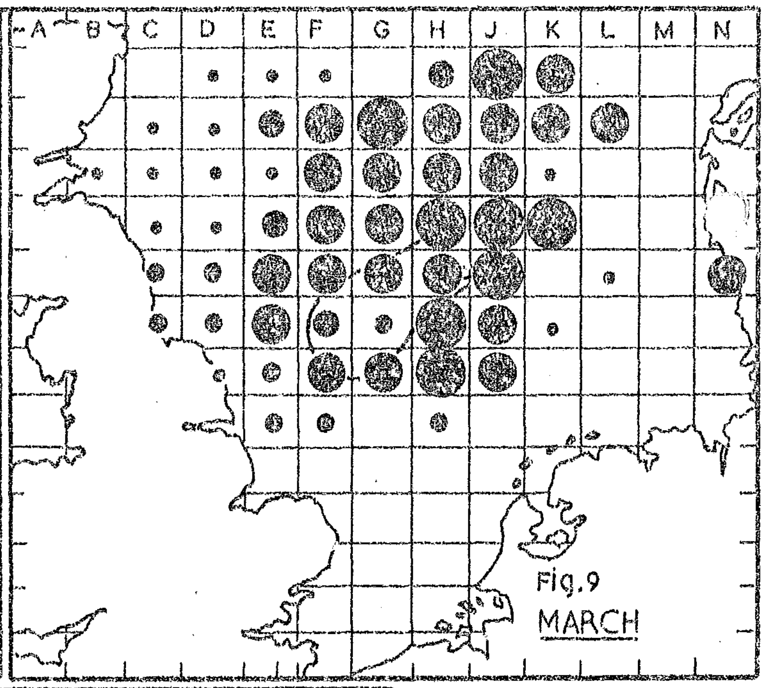


Fig. 9 MARCH

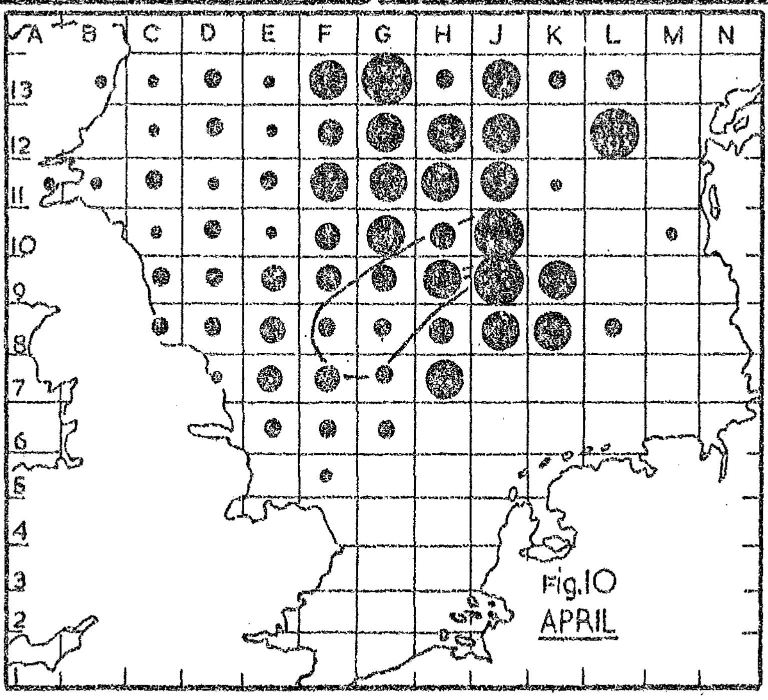
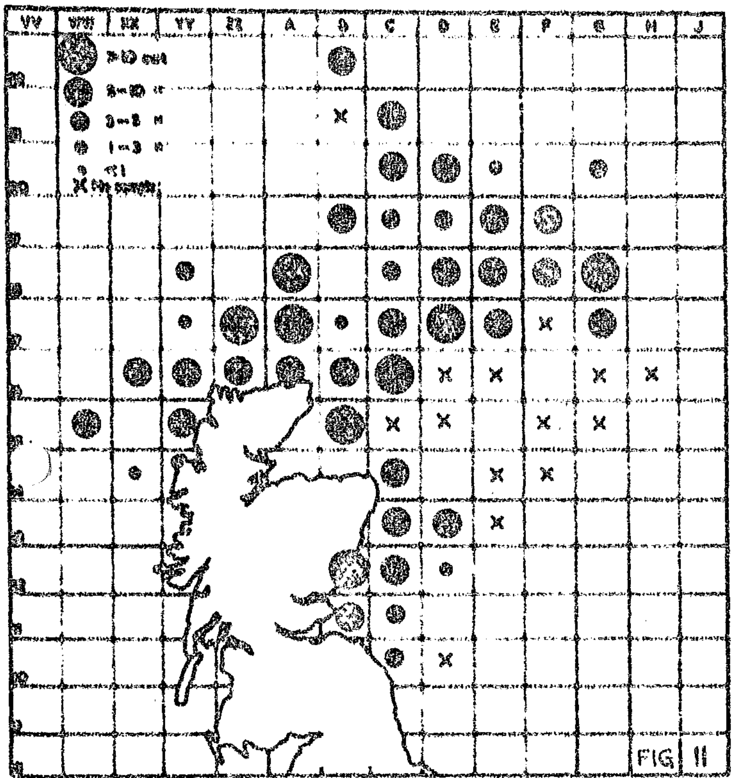
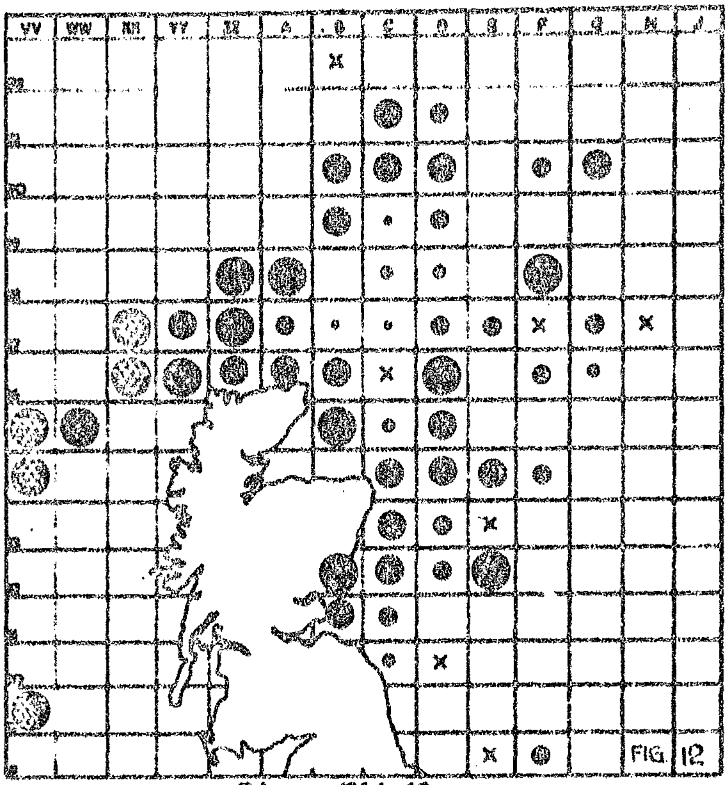


Fig. 10 APRIL

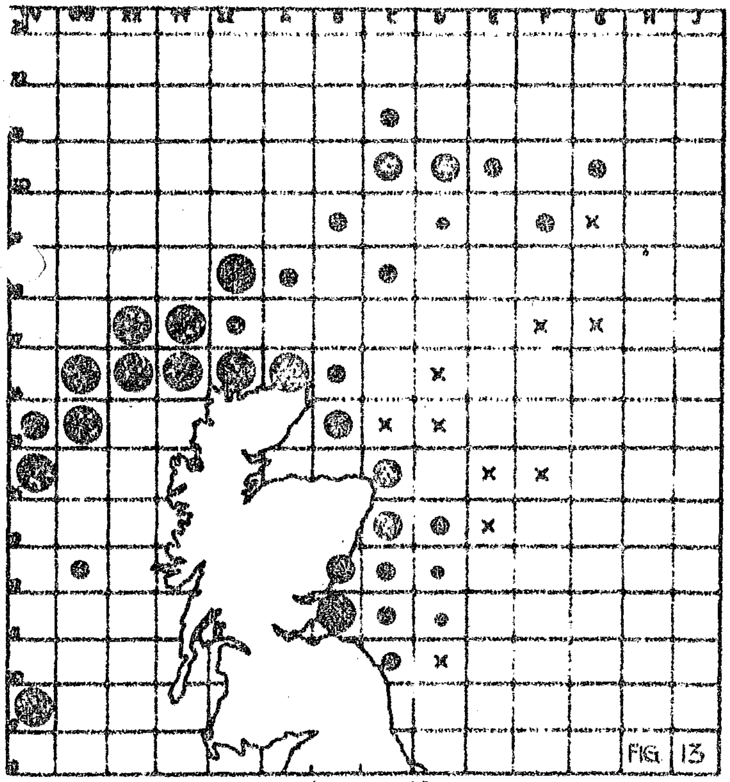
MEAN CATCH PER 10 HRS FISHING OF COD LANDED OVER 50 cm BY MOTOR TRAWLERS IN SCOTLAND



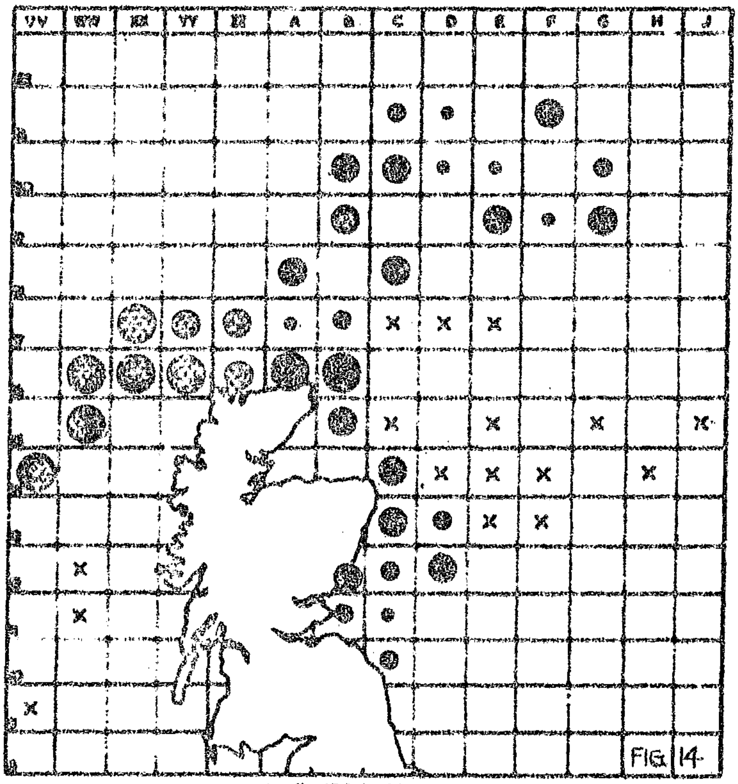
January 1964–68



February 1964–68



March 1964–68



April 1964–68

FROM WEST 1970

MEAN CATCH PER 10 HRS. FISHING OF COD OVER 50cm LANDED BY SEINERS IN SCOTLAND

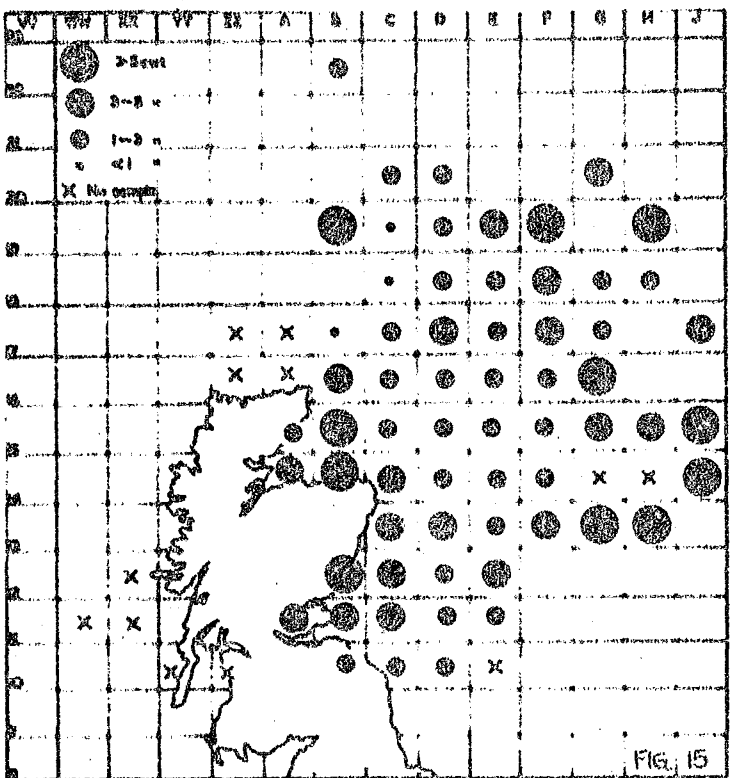


FIG. 15
January 1965—68

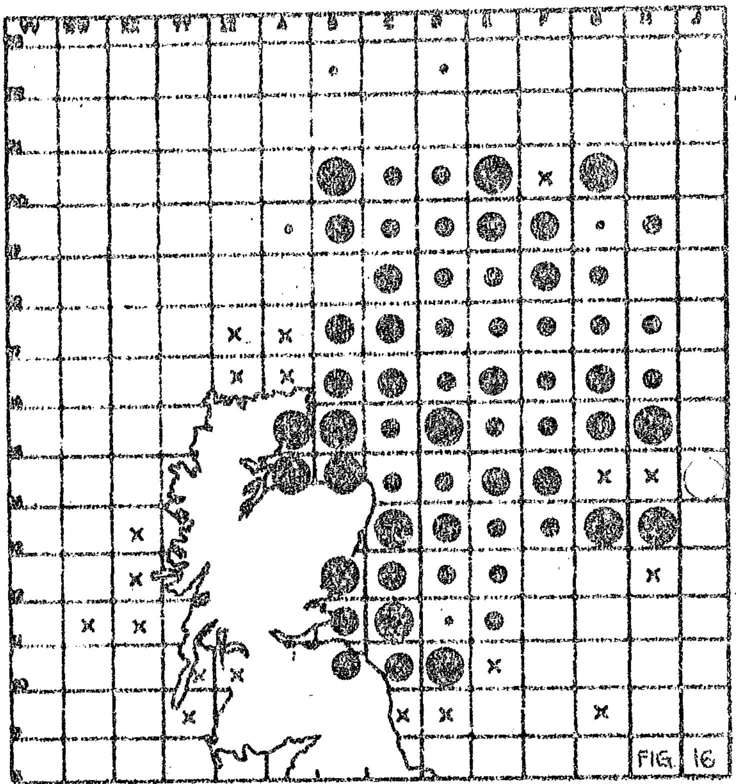


FIG. 16
February 1964—68

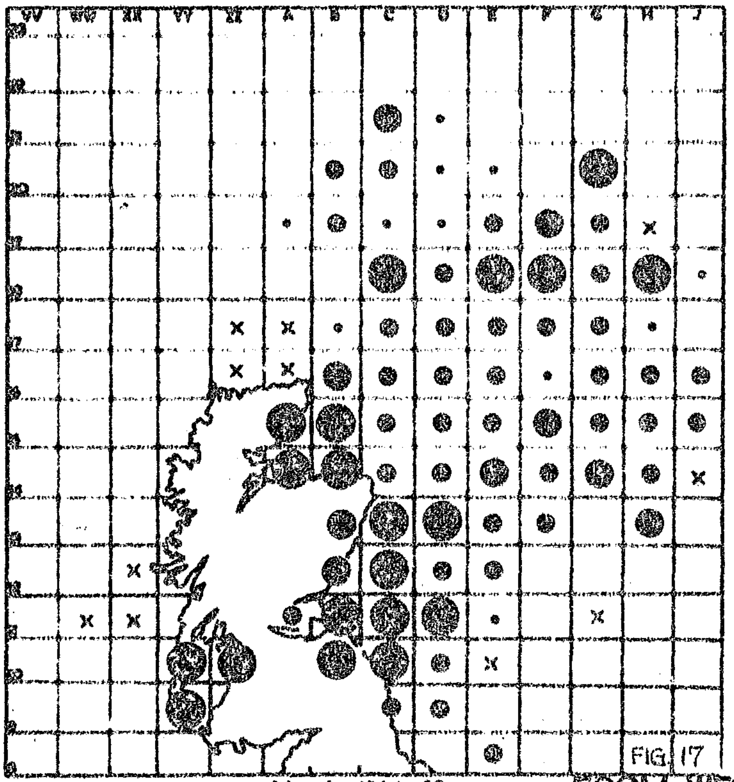


FIG. 17
March 1964—68

FROM WEST 1970

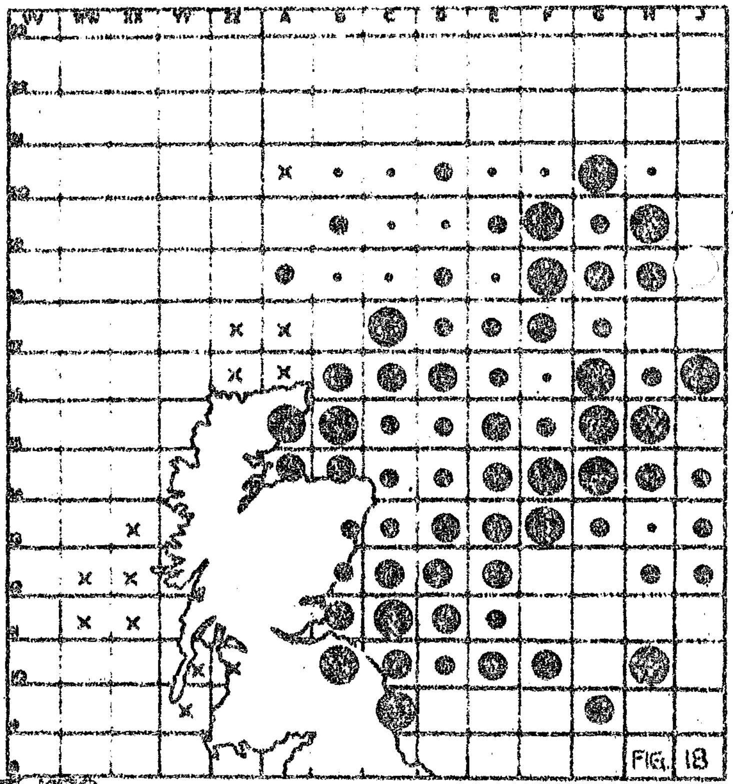
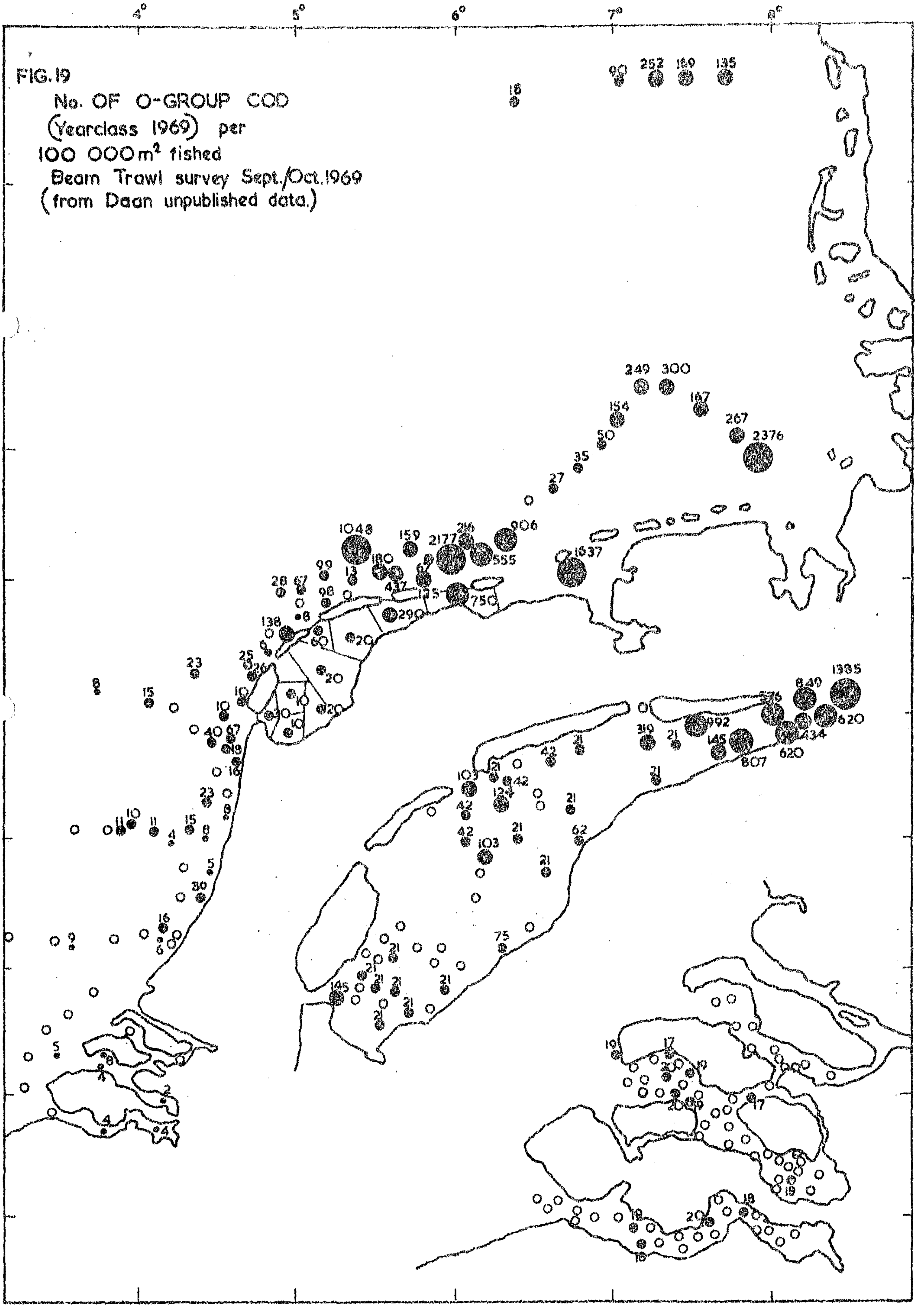


FIG. 18
April 1964—68



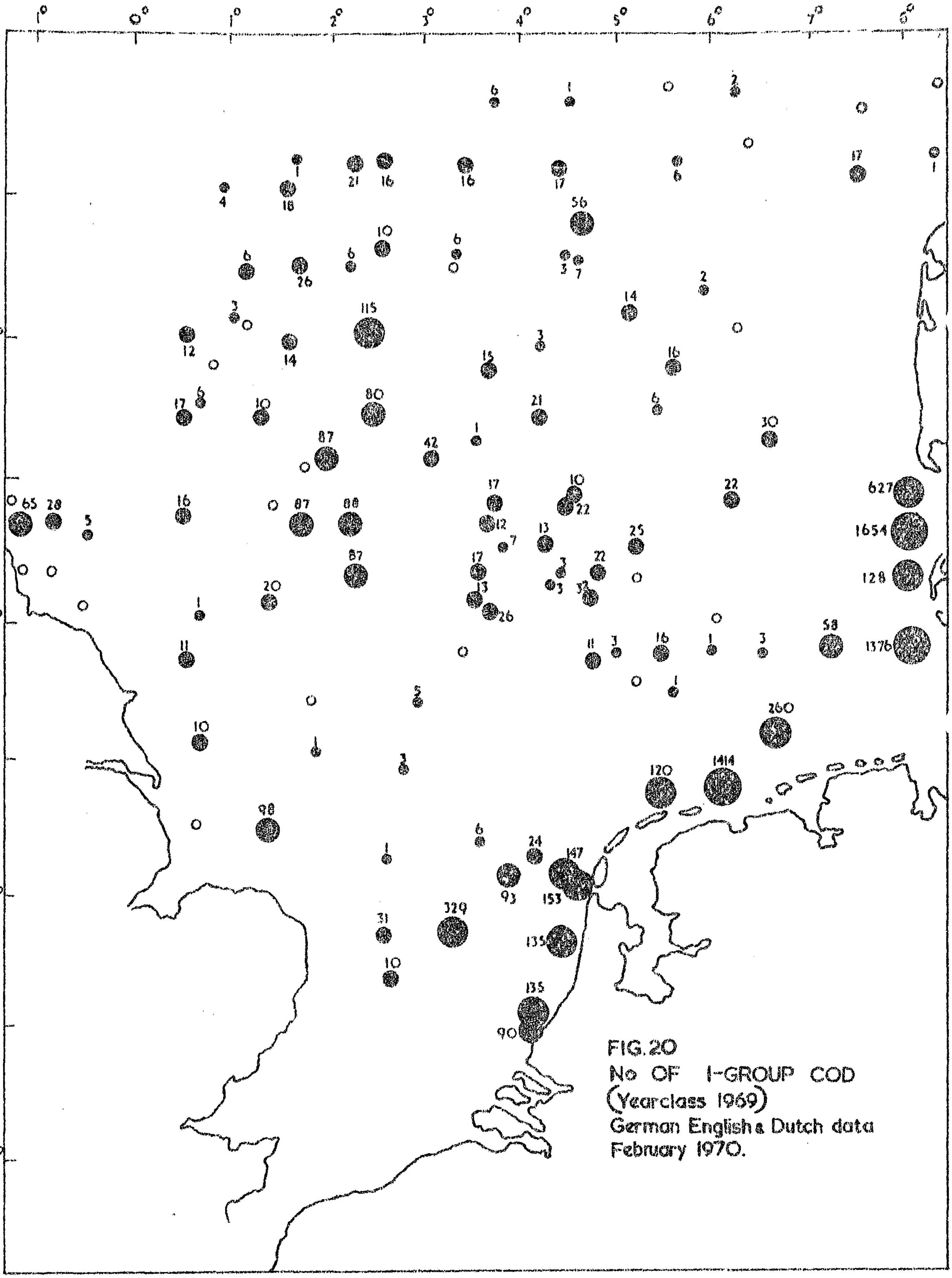


FIG. 20
No OF I-GROUP COD
(Yearclass 1969)
German English & Dutch data
February 1970.

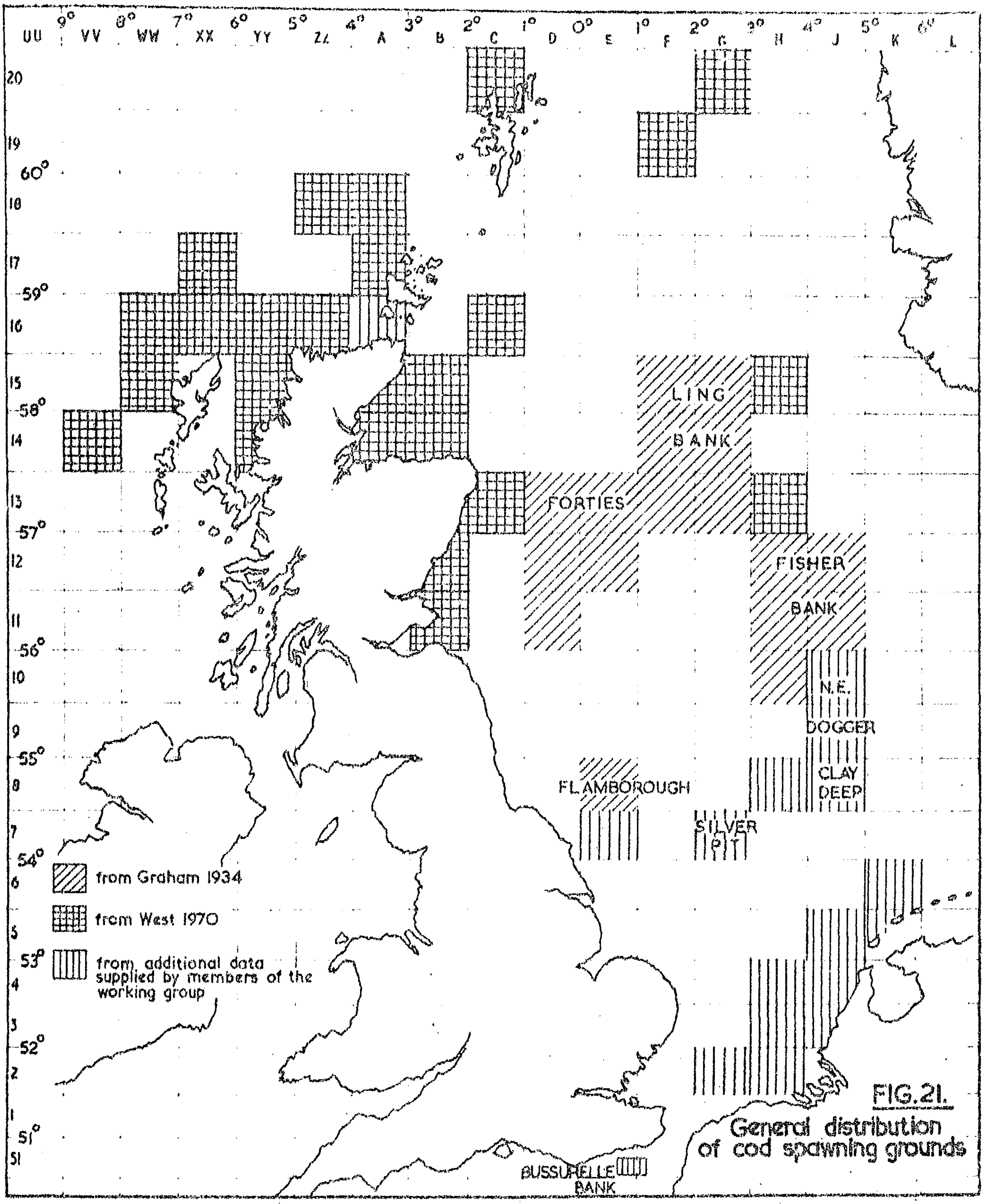
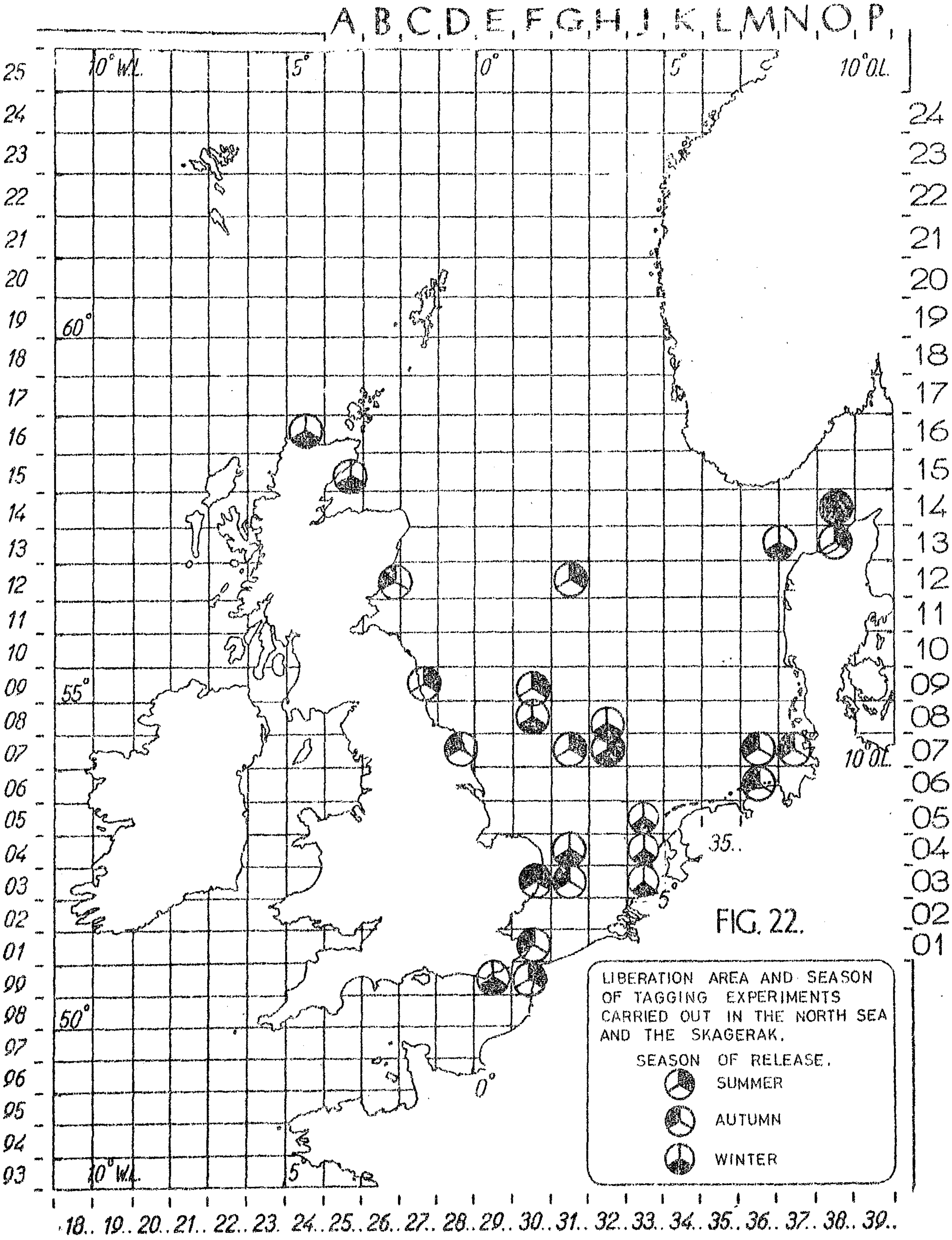


FIG.21.

General distribution of cod spawning grounds


A B C D E F G H J K L M N O P
10° W.L.
5°
0°
5°
10° O.L.
60°
55°
50°
35..
FIG. 22.
LIBERATION AREA AND SEASON OF TAGGING EXPERIMENTS CARRIED OUT IN THE NORTH SEA AND THE SKAGERAK.
SEASON OF RELEASE.
SUMMER
AUTUMN
WINTER
18.. 19.. 20.. 21.. 22.. 23. 24.. 25.. 26.. 27.. 28.. 29.. 30.. 31.. 32.. 33.. 34.. 35.. 36.. 37.. 38.. 39..

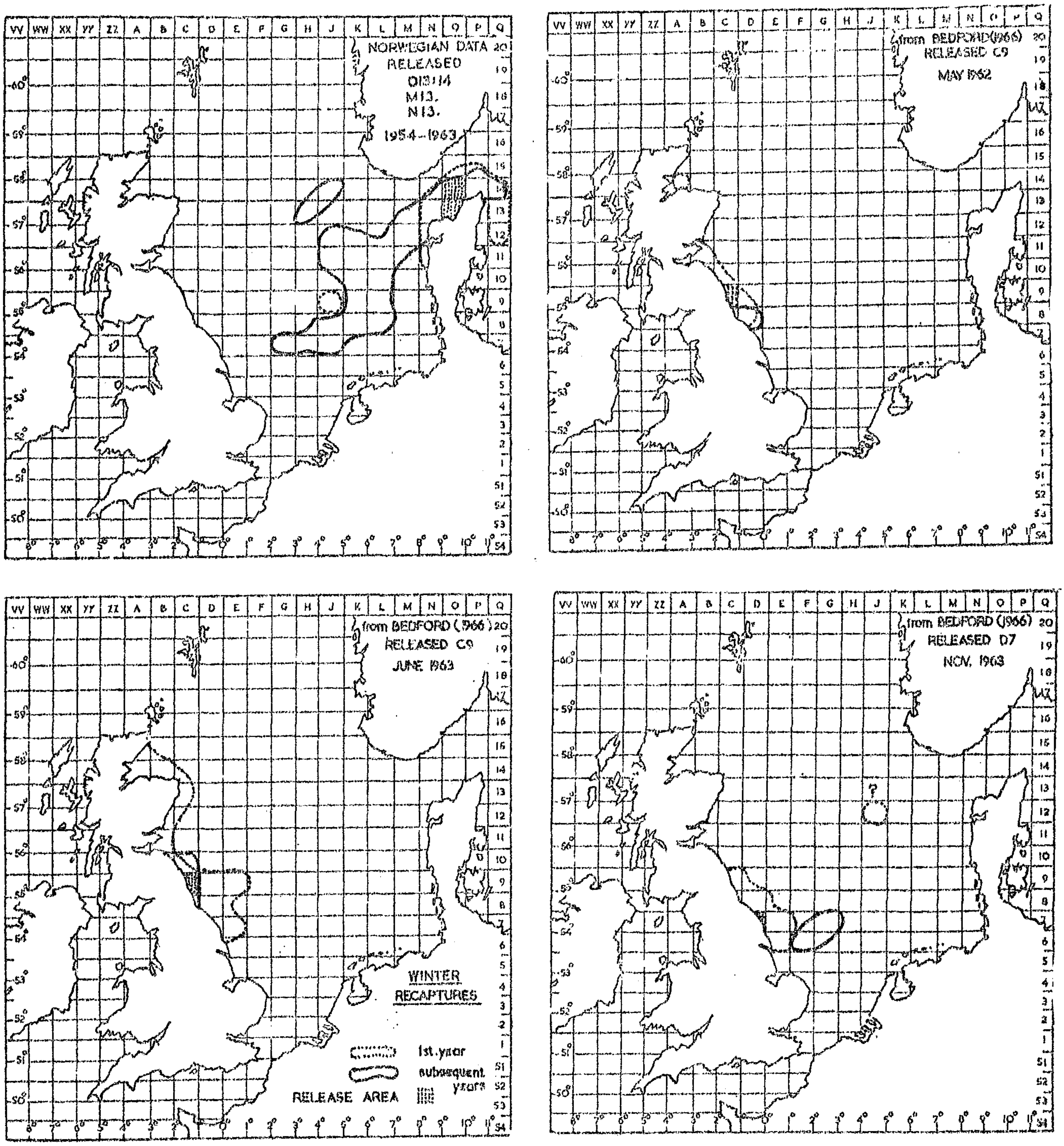
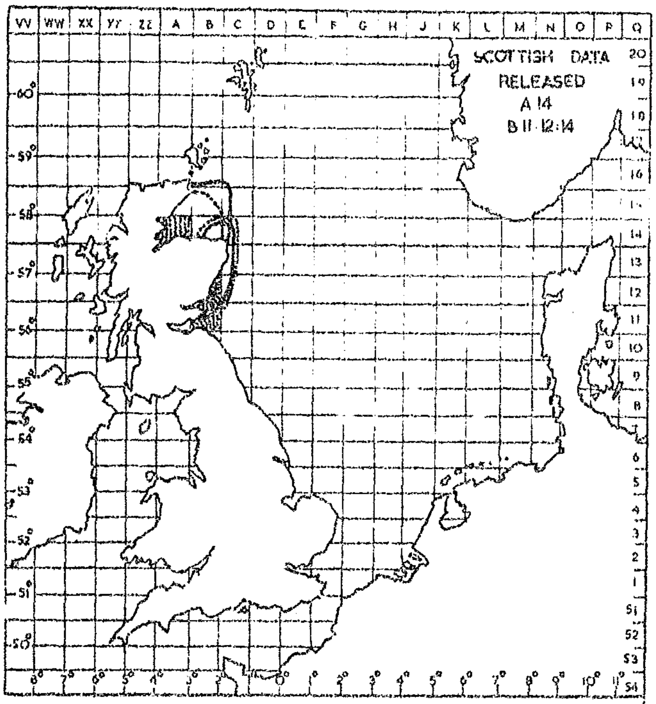

NORWEGIAN DATA
RELEASED
Q13/14
M13.
N13.
1954-1963
from BEDFORD (1966)
RELEASED C9
MAY 1962
from BEDFORD (1966)
RELEASED C9
JUNE 1963
WINTER
RECAPTURES
1st. year
subsequent years
RELEASE AREA
from BEDFORD (1966)
RELEASED D7
NOV. 1963

FIG. 23.



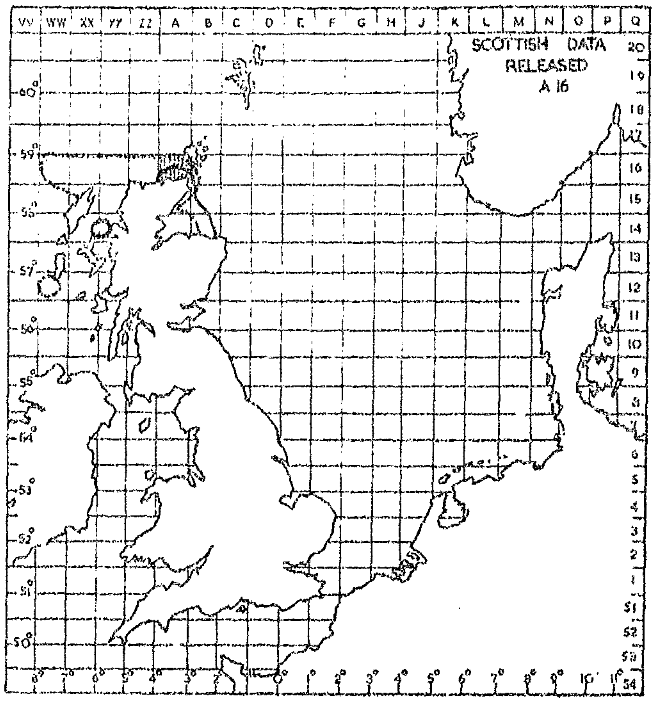


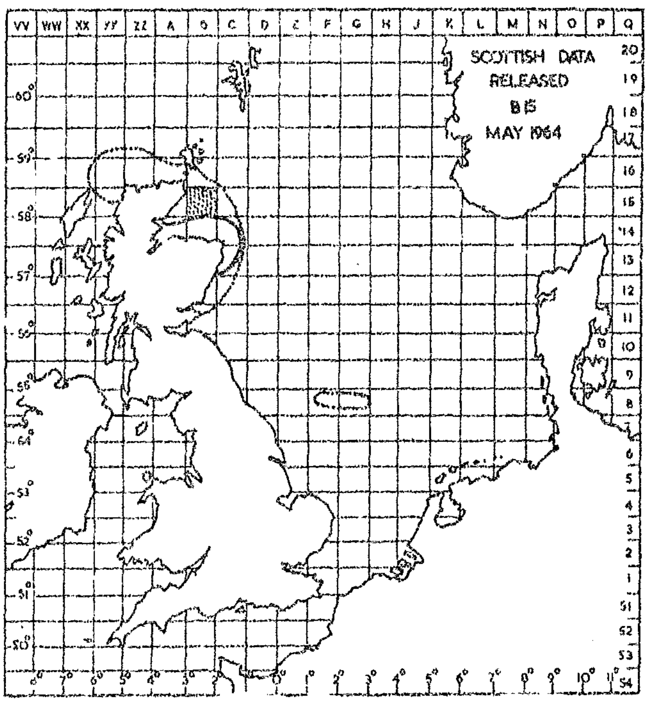
FIG. 24

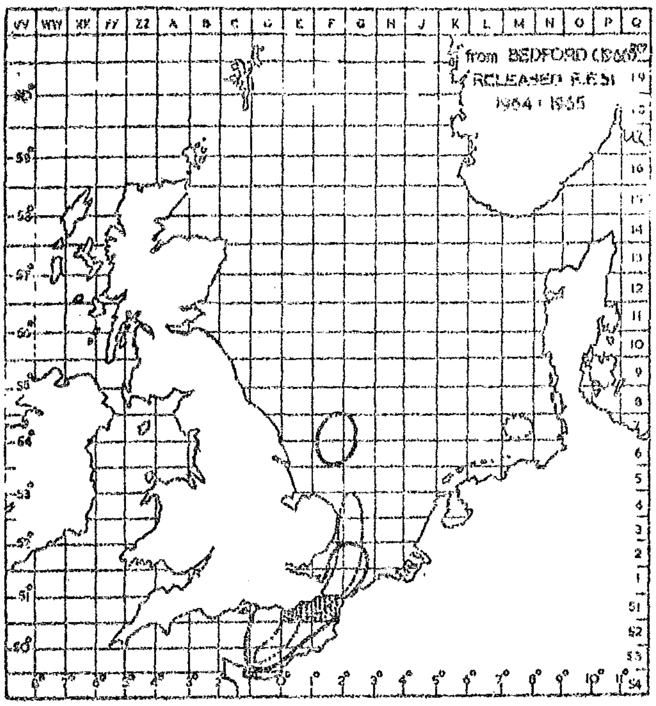
WINTER RECAPTURES

1st year

subsequent years

RELEASE AREA





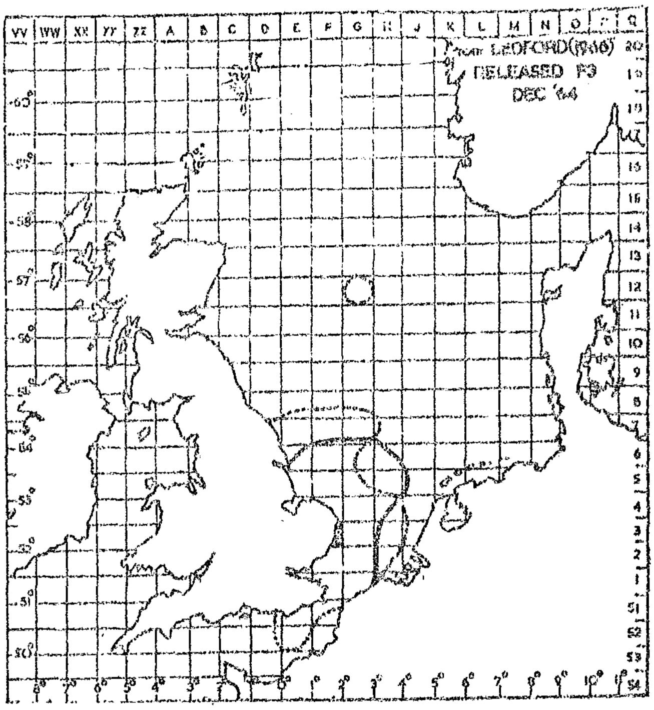


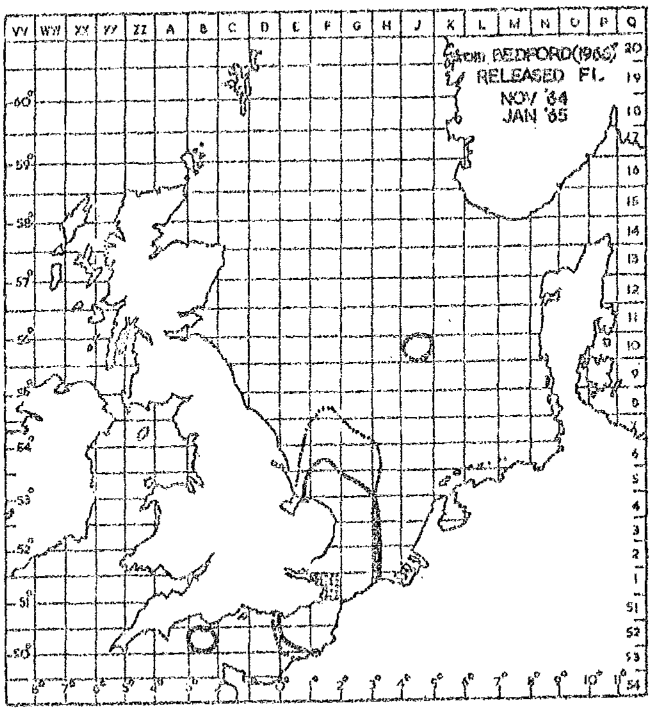
FIG. 25.

WINTER RECAPTURES

1st. year

subsequent years

RELEASE AREA



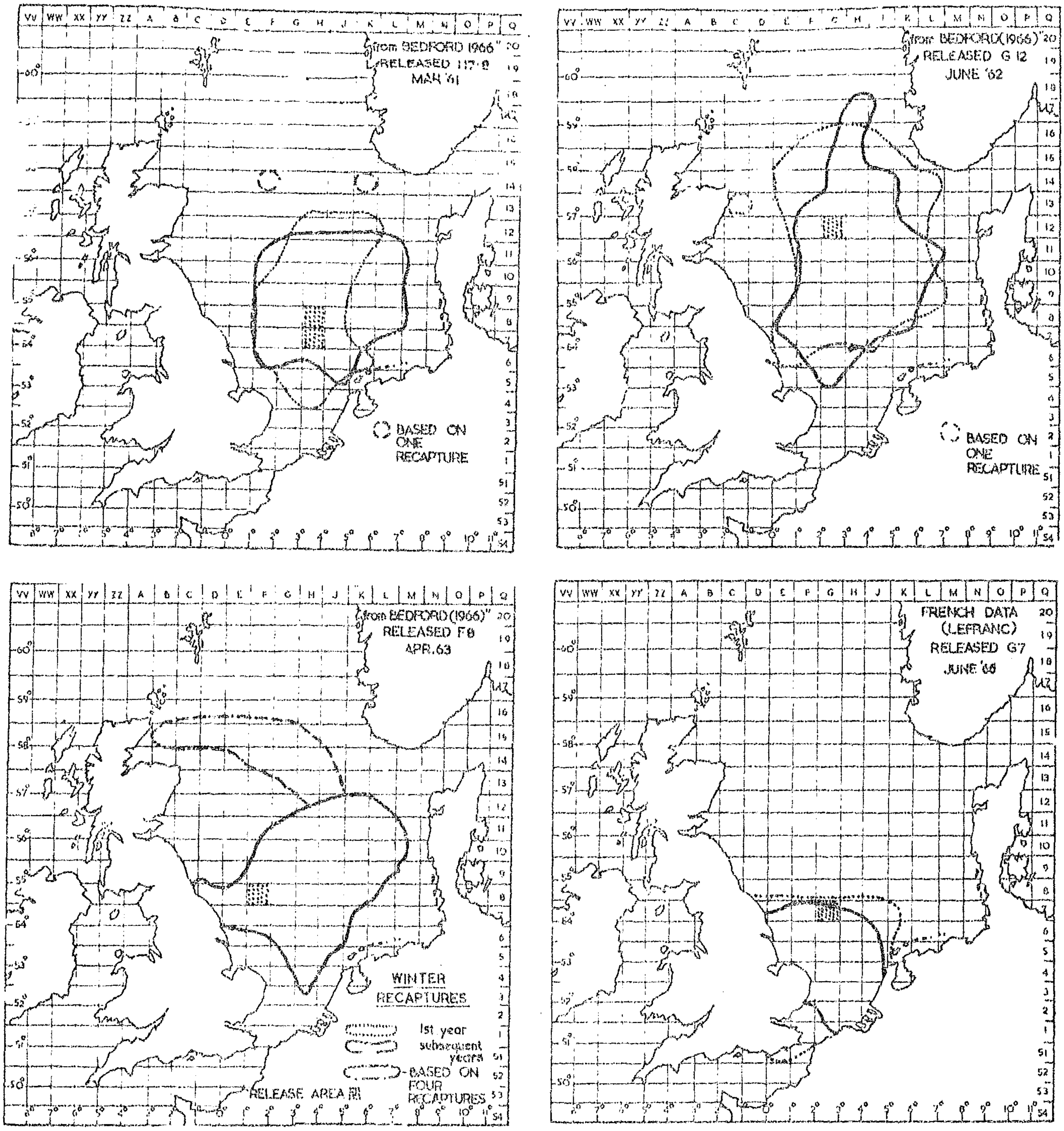

from BEDFORD 1966"
RELEASED 117·8
MAR '61
BASED ON
ONE
RECAPTURE
from BEDFORD (1966)"
RELEASED G 12
JUNE '62
BASED ON
ONE
RECAPTURE
from BEDFORD (1966)"
RELEASED F8
APR. 63
WINTER
RECAPTURES
1st year
subsequent
years
BASED ON
FOUR
RECAPTURES
RELEASE AREA
FRENCH DATA
(LEFRANC)
RELEASED G7
JUNE '66

FIG. 26.

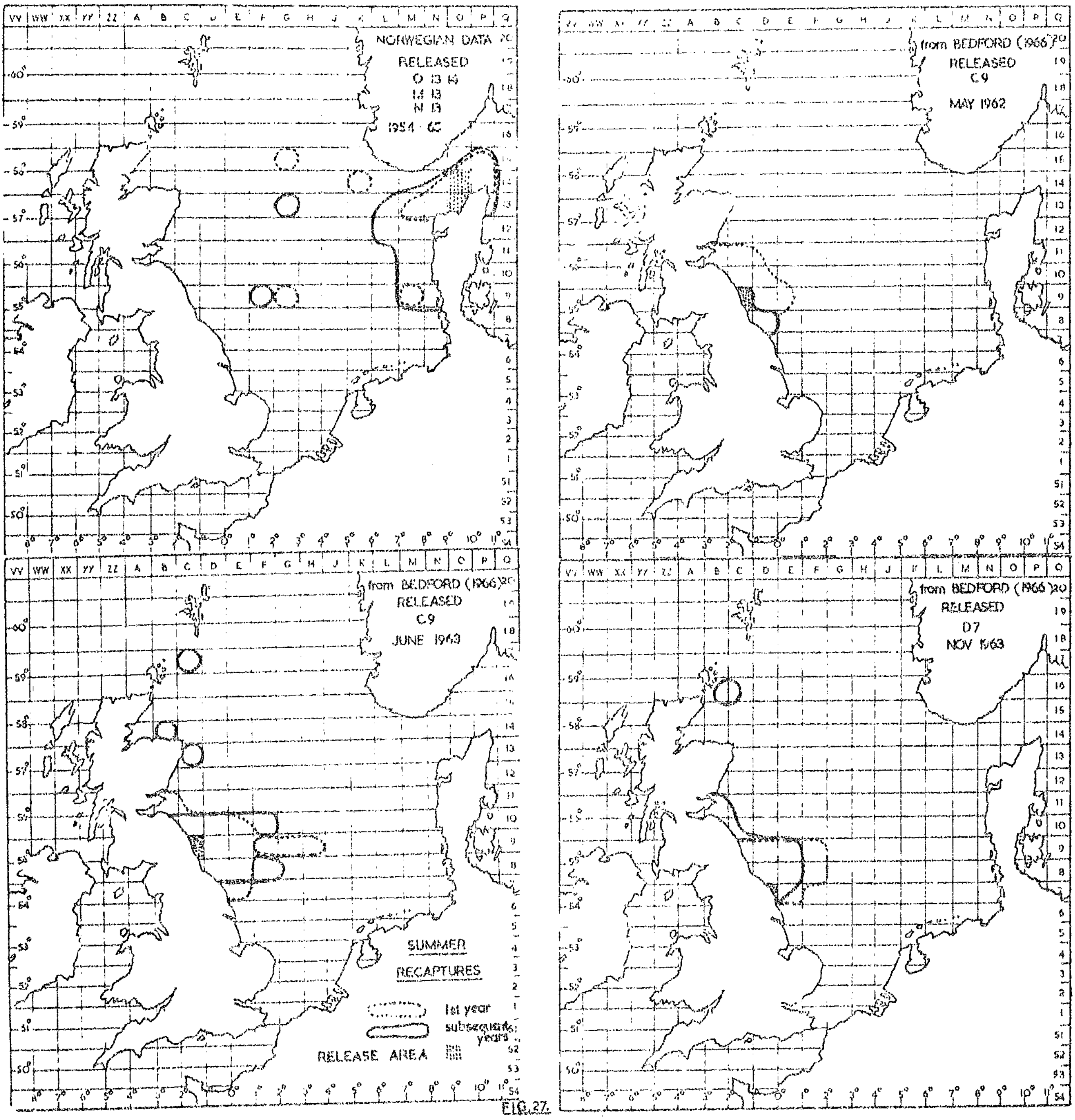
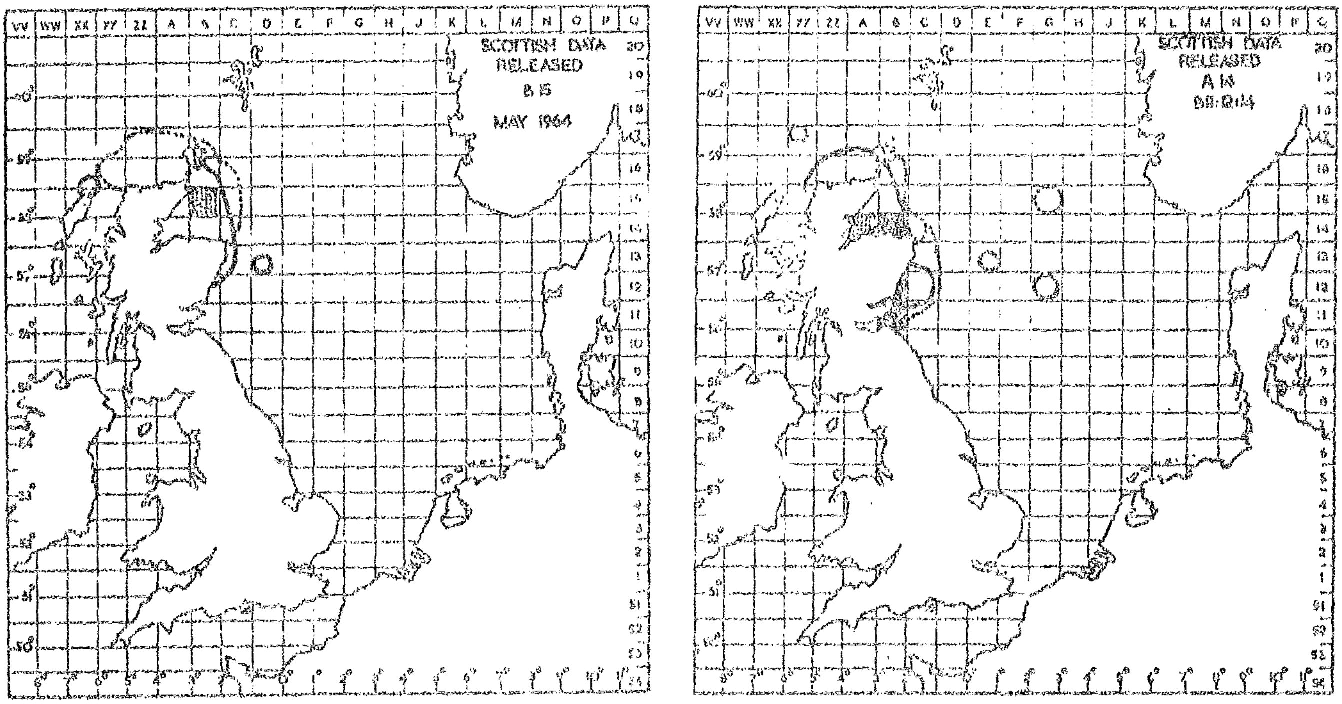

NORWEGIAN DATA
RELEASED
O 13 14
14 13
N 13
1954 - 65
from BEDFORD (1966)
RELEASED
C9
MAY 1962
from BEDFORD (1966)
RELEASED
C9
JUNE 1963
SUMMER
RECAPTURES
1st year
subsequent years
RELEASE AREA
from BEDFORD (1966)
RELEASED
D7
NOV 1963

FIG. 27.



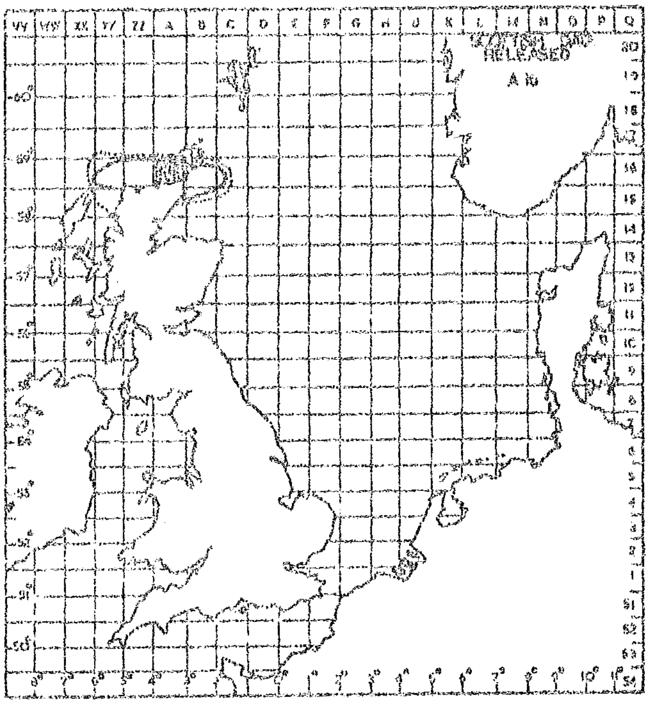


FIG. 28.

SUMMER RECAPTURES

1st. year

subsequent years

RELEASE AREA

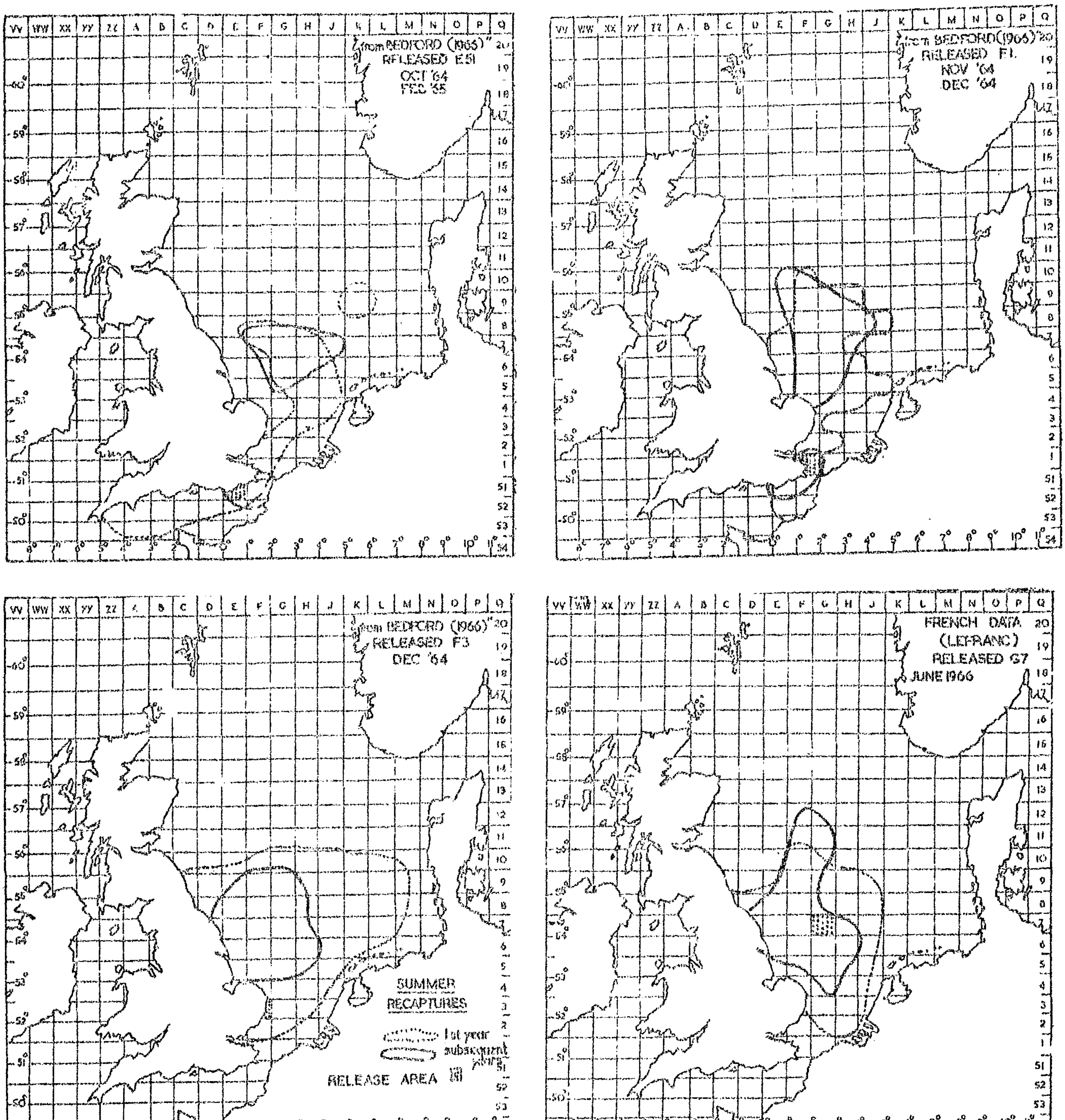

from BEDFORD (1965)
RELEASED E51
OCT '64
FEB '65
from BEDFORD (1966)
RELEASED F1
NOV '64
DEC '64
from BEDFORD (1966)
RELEASED F3
DEC '64
SUMMER
RECAPTURES
1st year
subsequent years
RELEASE AREA
FRENCH DATA
(LEFRANC)
RELEASED G7
JUNE 1966

FIG. 29.

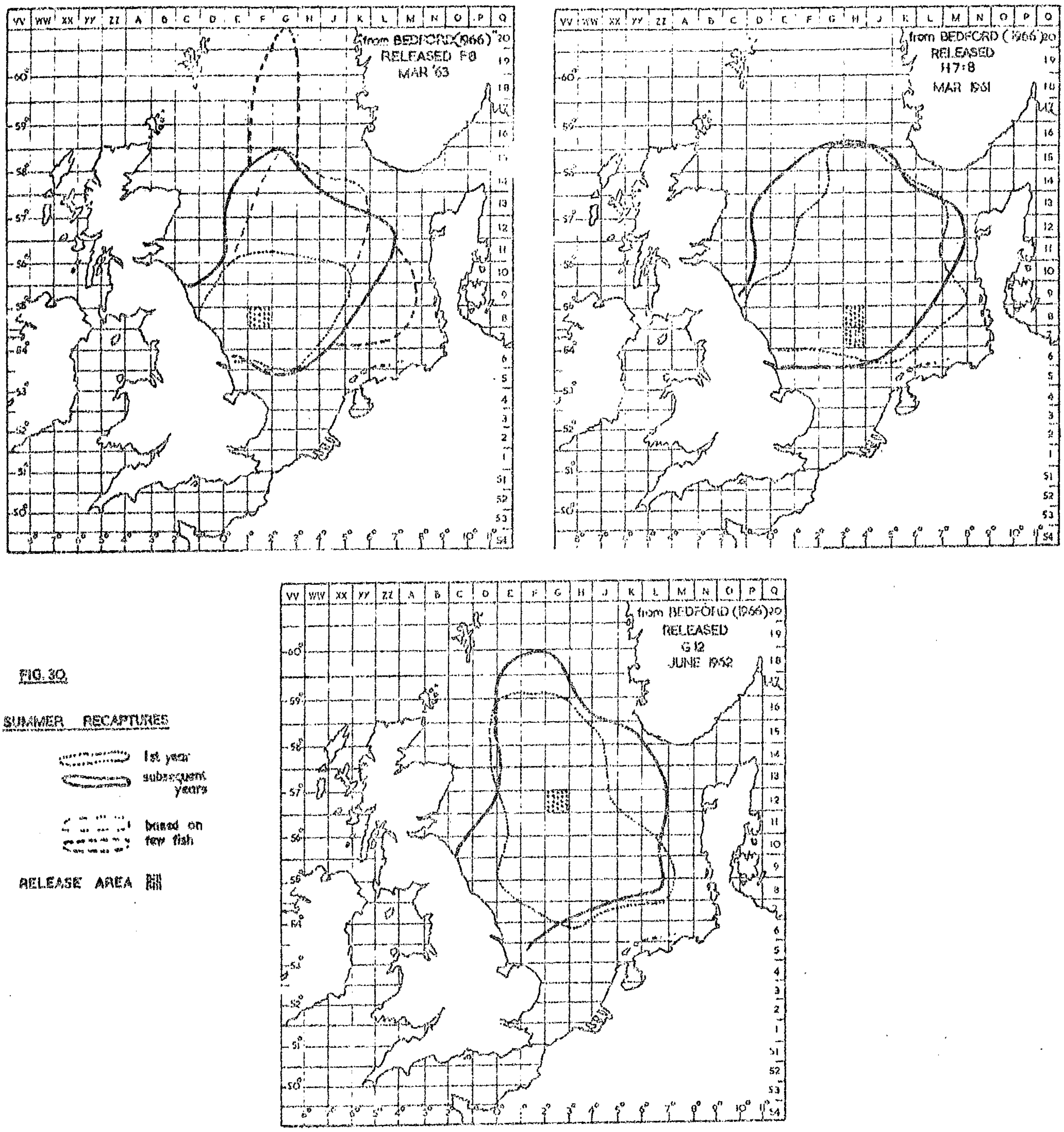


FIG. 30.

SUMMER RECAPTURES

1st year

subsequent years

based on few fish

RELEASE AREA

FIG. 31. SHOWING VALUES OF a^2 DURING SUCCESSIVE PERIODS OF RECAPTURE

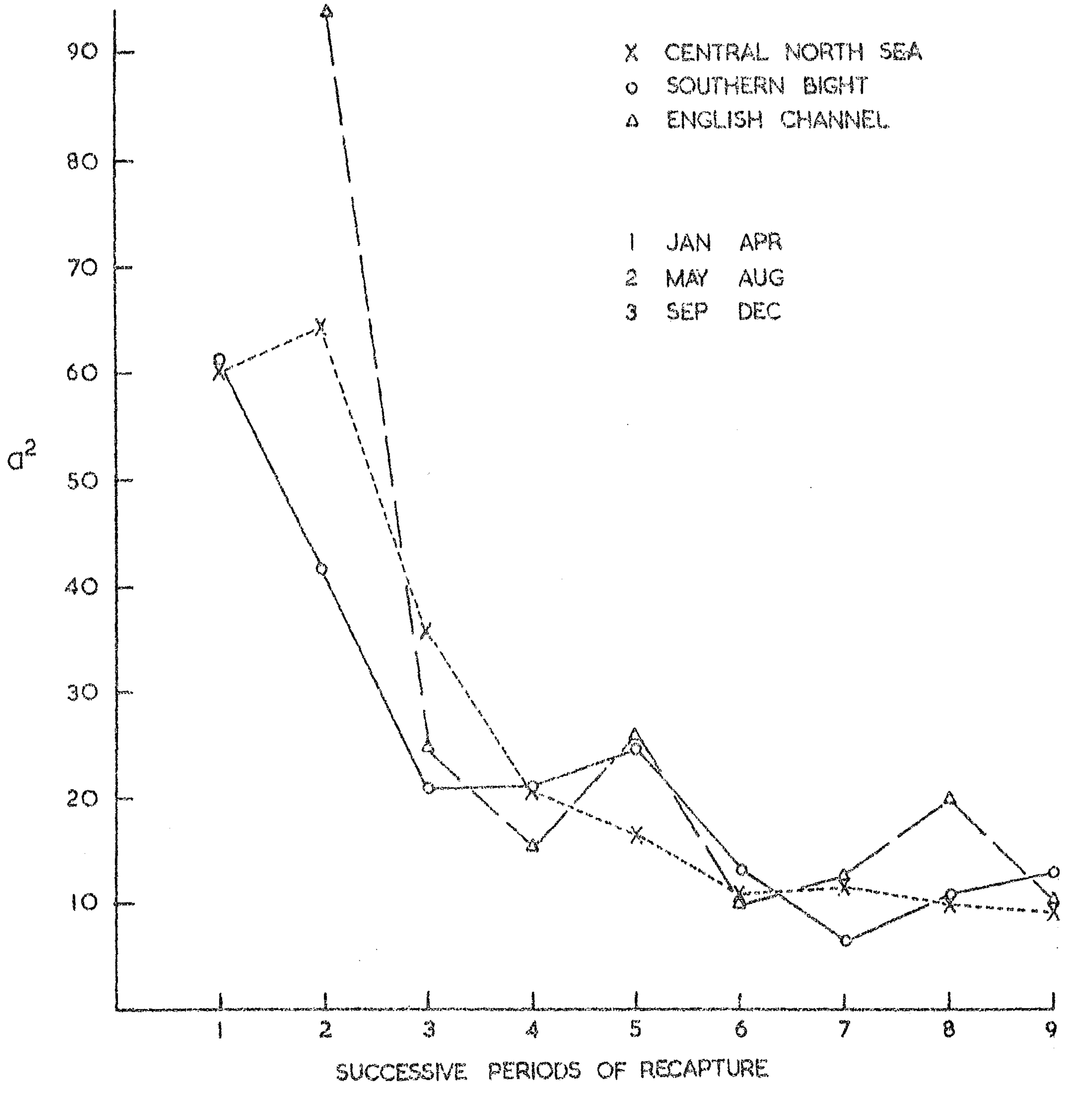


FIG.32. SHOWING VALUES OF σ^2 DURING SUCCESSIVE PERIODS OF RECAPTURE

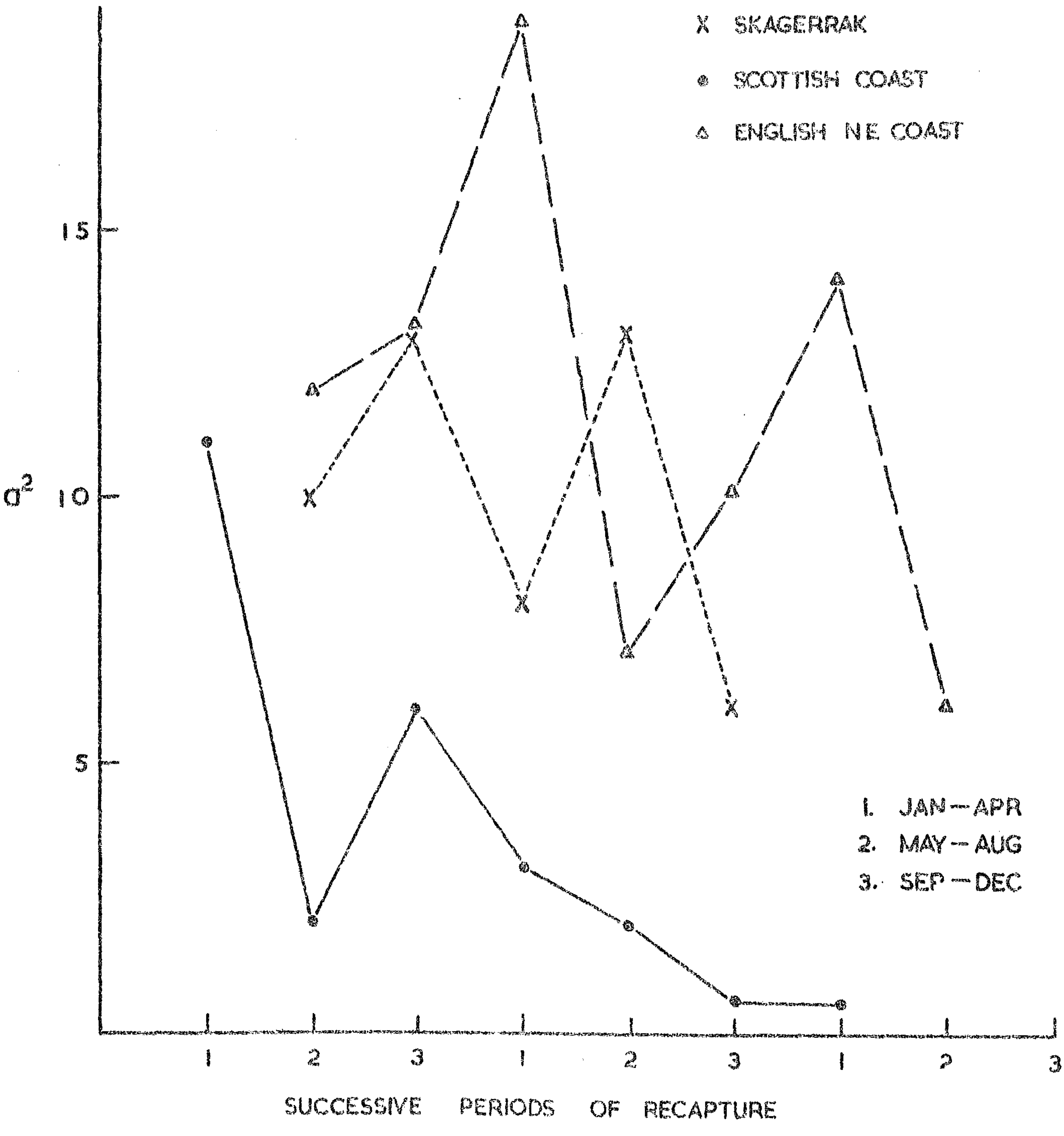
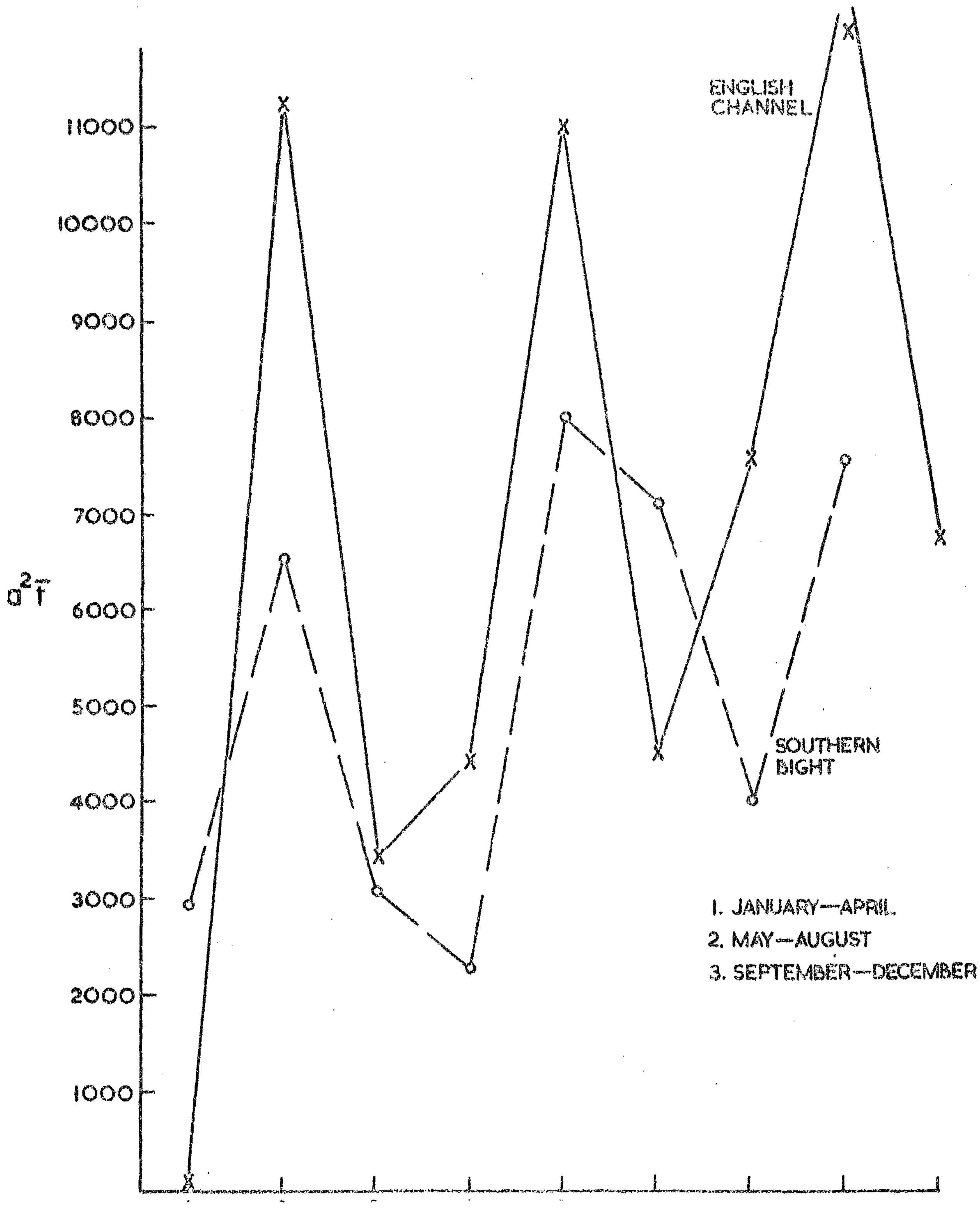


FIG. 33. SHOWING SEASONAL VARIATION IN THE VALUES OF $a^2\bar{t}$



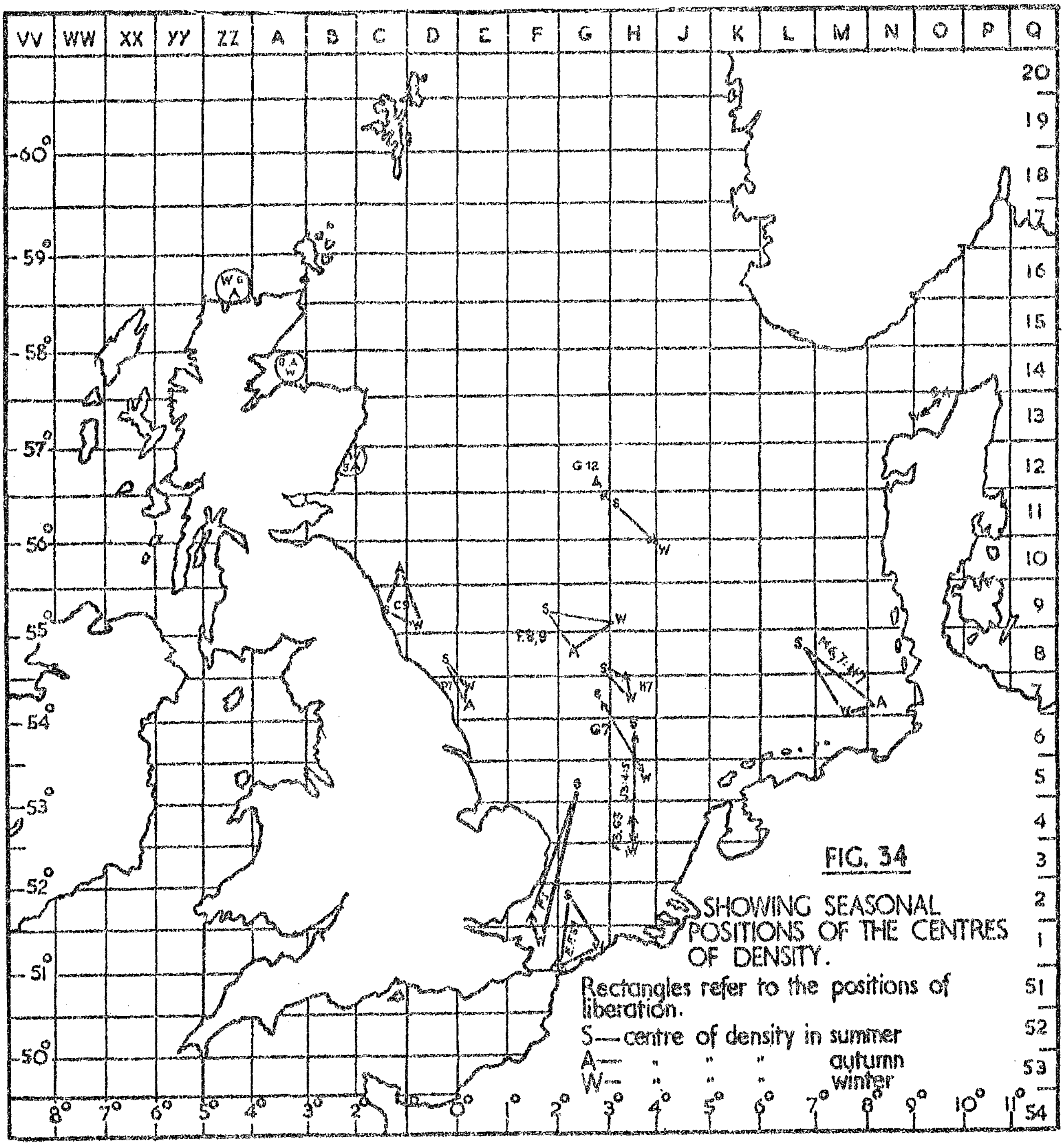


FIG. 34

SHOWING SEASONAL POSITIONS OF THE CENTRES OF DENSITY.

Rectangles refer to the positions of liberation.

S—centre of density in summer
A— " " " autumn
W— " " " winter

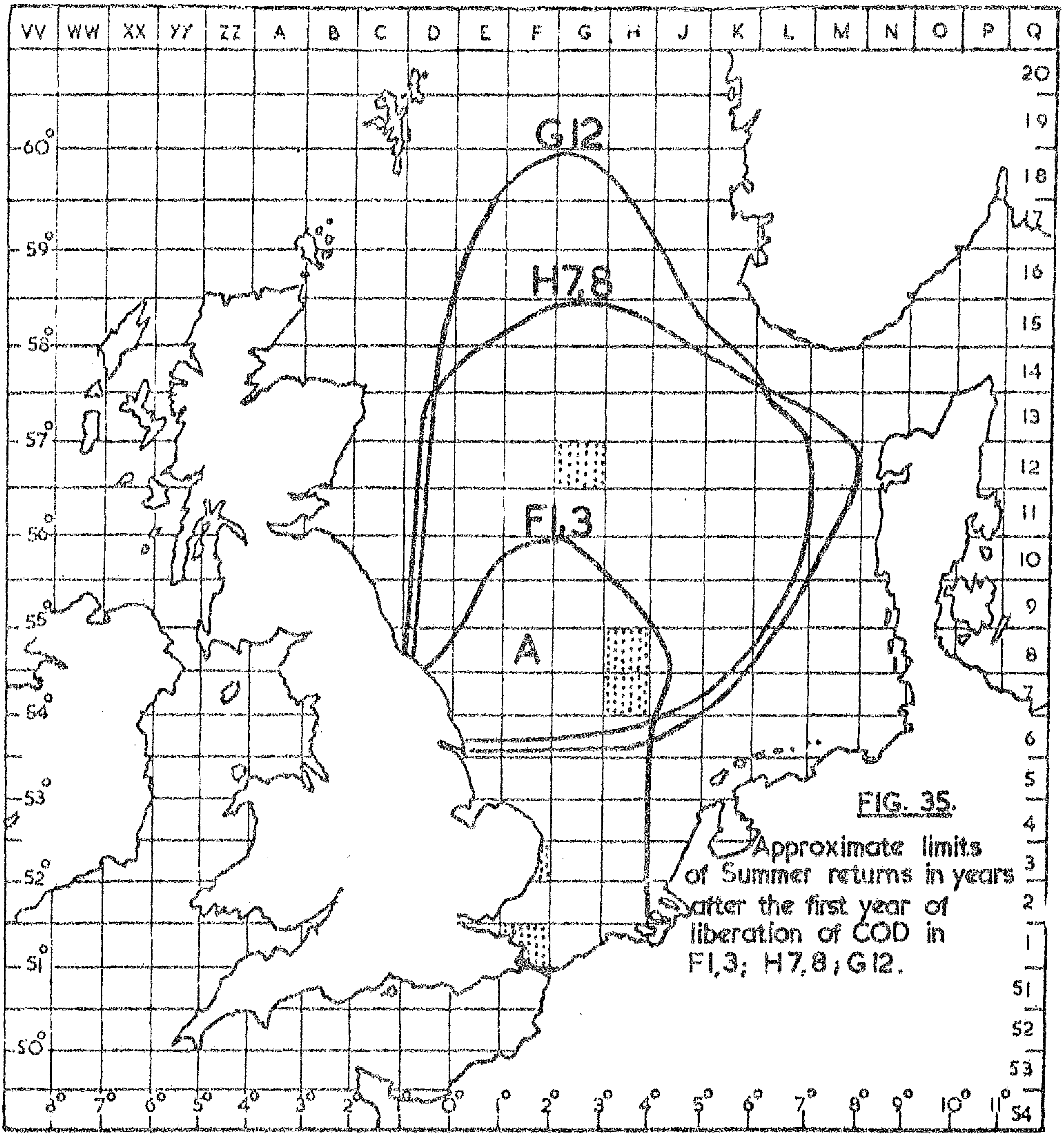


FIG. 35.

Approximate limits of Summer returns in years after the first year of liberation of COD in F1,3; H7,8; G12.