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REPORT OF THE AD HOC WORKING GROUP ON THE FEASIBILITY OF A SOLE EGG SURVEY IN 1984

Lowestoft, 18 - 21 January 1983

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1. INTRODUCTION

1.1 Participants

The ICES Ad Hoc Working Group on the proposed Sole Egg and Larval Survey in the North Sea met at Lowestoft from 18-21 January 1983, with the following participants:

V Christensen	Denmark
R de Clerck	Belgium
R Houghton (Chairman)	United Kingdom
N Lacroix	France
R Millner (Rapporteur)	United Kingdom
J Nichols	United Kingdom
A Rijnsdorp	Netherlands
J Riley	United Kingdom
F van Beek	Netherlands
Y van Keymeulen	Belgium
W Weber	Fed. Rep. of Germany

1.2 Terms of Reference

At the 1982 Statutory Meeting, it was decided (C. Res. 1982/2:21) that:
"a feasibility study for the proposed 1984 sole spawning survey (C. Res. 1981/4:7) should be made under the chairmanship of Mr R G Houghton (United Kingdom) at a meeting of four days, from 18 to 21 January 1983, in Lowestoft".

1.3 Objectives of the Survey

A number of possible objectives for a sole (Solea solea L.) egg and larval survey in the North Sea had been presented and discussed in a Working Paper to the 1982 Flatfish Working Group and at a meeting during the 1982 Statutory Meeting of ICES in Copenhagen: these were as follows:

(a) to describe the distribution of sole spawning grounds and the time of spawning in different parts of the North Sea,

(b) to determine egg and early larval mortality rates,

(c) to estimate total egg production and hence the female spawning stock biomass using suitable estimates of fecundity,

(d) to investigate the factors acting in the planktonic and early demersal stages which could influence the level of recruitment (larval food supply and feeding, predation on eggs and larvae, hydrographic conditions, for example).

Doubts about the practicality of using an extensive sole egg and larval survey for objective (d) were expressed at the Statutory Meeting by several participants. These doubts arose because of the difficulties in sampling the demersal larval stages and of obtaining adequately detailed information on a large scale.

The Working Group confirmed this view and decided to exclude studies of the demersal larval stages from the objectives of the survey. It was felt however that a survey of the planktonic stages (including early larvae) would be of great value in establishing a firm knowledge of their distribution upon which more detailed studies of larval ecology could be based.

Objectives (a) and (c) were both judged to be useful objectives. Knowledge of the time and place of sole spawning in the North Sea is not comprehensive (as will be described in Section 2) and such knowledge will be extremely useful as a basis for further studies on the relationships of the various sub-populations of the North Sea using tagging, for example. Catch-rate trends in the east central, west central and southern North Sea are markedly different and there are indications of a degree of localisation in the stocks. In addition, the recent internationally co-ordinated tagging experiments on pre-recruit sole is likely to provide information on the recruitment from the nurseries into the fisheries. Knowledge of the time and place of sole spawning will assist in their interpretation.

Objective (b) would be difficult to achieve without extensive sampling. A limited sampling scheme, designed to attain objective (a) would provide approximate estimates of egg mortality rates which would probably be sufficient to correct early egg stage production estimates into the numbers of fertilised eggs.

Objective (c) was judged to be the most important and it was decided to plan the surveys to achieve this aim in addition to objective (a). It is well known that VPA estimates of the recent spawning stock biomasses (SSB) are subject to various types of error which, unfortunately, are unquantified. Improved methods of established SSB by VPA, using data on CPUE for example, have been developed (ICES, 1981) and applied to the North Sea sole in recent years. Errors are still likely to exist due to variations in catchability for example, as well as to errors in the assumed value of natural mortality, and to errors in the catch data.

Provided that an egg survey can be designed which can estimate spawning stock with an error no greater than that inherent in the VPA, it would provide a useful, independent measure. We suggest that an error which is better than ± 20% would be useful.

2. REVIEW OF AVAILABLE INFORMATION

2.1 Recent experience of estimating spawning stock from egg surveys

Estimates of egg production have been used to estimate spawning stock biomass (SSB) for a variety of fish stocks from Atlantic mackerel (Berrien, et al., 1981; Lockwood et al., 1981) to Baltic cod (Bagge and Muller, 1977) and North Sea plaice (Bannister et al., 1974).

In the case of the European western mackerel stock it is not possible to compare the estimate with that from the virtual population analysis (VPA) because the latter is derived from the egg survey result. For the Baltic cod, an independent VPA exists and it was possible to show that the egg production estimate was about one tenth of that from the VPA. The problem may have been that the eggs were not staged and, although an allowance was made for egg mortality, this involved a number of simplifying assumptions and could have introduced an error. A further problem was that the surveys covered only part of the spawning and the total egg production was obtained by extrapolation. Bagge and Muller (1977) suggested that the discrepancy might have been due to high mortality immediately after spawning. In North Sea plaice, Bannister et al., (1974) found that the egg production estimate was 50% lower than that from the VPA. This estimate also involved extrapolation to unsampled areas. Recent work by Horwood and Bannister (in preparation) suggests that the discrepancy was principally due to the use of Simpson's (1951) fecundity data in the calculation; recent fecundity estimates for North Sea plaice are twice those obtained by Simpson.

This brief summary indicates that the requirements for a successful survey are as follows:

1. The entire area of egg production should be surveyed.

2. The area should be surveyed frequently enough to establish the shape and amplitude of the production curve of the youngest eggs.

3. Allowances should be made for egg mortality, which should be estimated at the same time.

4. Attention should be paid to the biasses which may be introduced by the lack of fertilisation of eggs.

5. Fecundity should be estimated in the year of the egg production estimate.

6. An accurate estimate of the sex ratio in the spawning stock should be obtained for the year of the estimate.

In the case of North Sea sole, the latter requirement is not so important because the VPA database handles male and female data separately. It is therefore possible to compare the egg production estimate directly with the estimate of female spawning stock from the VPA.

Random errors leading to imprecision can arise at any stage in the estimate, but the main source of error is likely to be in the estimate of the production curve of early stage eggs. The western mackerel egg survey yields an estimate which has a 95% confidence range of +30, -20% due to this cause (Lockwood et al., 1981). The estimate of fecundity is also important since the error in fecundity is multiplicative in the analysis.

The Working Group heard a preliminary report on the 1982 French survey for sole eggs in the Bay of Biscay (Lacroix, pers. comm.). Five cruises had been completed consisting of 85 stations each. The sampling was depth and area stratified and concentrated the sampling in areas where most of the eggs were expected to occur (predicted from previous surveys). The sampling strategy randomised the sampling position within each depth/area stratum. The methods of analysis and results were unfortunately not available to the Working Group. It was pointed out that this strategy could only be employed when there was adequate prior knowledge of the distribution of the eggs. When this was not the case, a regular sampling grid was to be preferred since this would increase the possibility that high concentrations were not missed. A regular grid was also more likely to give a full picture of the egg distribution.

2.2 The Time and Place of Sole spawning in the North Sea and Eastern Channel

The Working Group had available to it the unpublished results of a number of egg surveys covering a large proportion of the likely sole spawning areas in the North Sea and English Channel. In addition, published information exists on sole egg distribution along the English east coast (Riley, 1974) and off the Belgian coast (de Clerck and van de Velde, 1973; for example). The occurrence of ripe and running female soles by months and areas has been described from Dutch market samples by de Veen (1970). Møller-Christensen (1960) described the spawning fisheries for sole along the Danish coast using CPUE and tagging data.

2.2.1 Egg survey results

2.2.1.1 Dutch surveys in 1962:

Four surveys were made by RV WILLEM BEUKELSZ in 1962 in the Southern Bight and in the coastal area of the German Bight during the period 25 April to 26 June (Nijssen-Meyer, 1965; summarised by van Beek as a working paper). The samples were taken in depths greater than 11 m using an early version of the Dutch 'Torpedo' sampler (also known as DG III - Zijlstra (1970)). Sole eggs were staged according to Fabre-Domergue et Bietrix (1905) and expressed as numbers/m^2.

Surveys 1 and 4 took place in a small area of the Southern Bight and consisted of 14 and 8 hauls respectively. Surveys 2 and 3 (81 and 89 hauls) indicated high sole egg production over an extensive offshore part of the Southern Bight with additional patches adjacent to the Wadden and Friesian islands. The north-western zero boundary was well defined in the German Bight area. The results of survey 3 (28 May to 7 June) are shown in Figure 1 as an example.

The data from individual hauls in surveys 2 and 3 were used to estimate the production of Stage 1 eggs in the Southern and German Bights (divided at 5°E). The method of calculation is given in Appendix 1. Mean abundances and approximate confidence limits are shown in Table 1.

It is clear from the indices that Stage I egg production was greater in survey 3 (28 May-7 June) than in survey 2 (1-10 May). Production to the east of 5°E was 18% of the total in early May but had risen to 40% in June. This suggests that the production curve in the German Bight was later than in the Southern Bight and that it had a similar or lower amplitude. The full production curve was not defined by these surveys. It is possible that the surveys straddled the peak in the Southern Bight (this seems likely from the English results in 1981).

It was observed in the surveys that the diameter of sole eggs decreased from an average of 1.27 mm in early May, to 1.15 m in early June. This confirms the earlier results by Ehrenbaum (1908) and Tesch (1909) and is an interesting parallel to similar changes observed for soles spawning in captivity (Section 2.3.1).

2.2.1.2 English surveys:

Ten surveys were carried out by RV CORELLA in 1971 in the Southern Bight covering the period 5 January to 9 June. Additional grids of stations were sampled on each survey either in the eastern Channel or in the south-west central North Sea. These surveys were conducted principally for plaice egg distributions. The results have been published by Harding et al., (1978). Other data were available from surveys in the Thames Estuary, the eastern Channel and south-west central North Sea.

The samples were taken using the Lowestoft high speed plankton sampler (Beverton and Tungate, 1967). Sole eggs were staged according to Riley's (1974) criteria and expressed as nos produced/m^2/day after correction for stage duration and temperature at the station using Riley's (1974) regressions.

(i) Southern Bight

Stage Ia egg production indices for the Southern Bight, calculated as in Appendix 1, are shown in Table 2. Also shown are estimates of the total production in the last 5 surveys for the sampled area of the Southern Bight. Spawning began at a low level at the end of January (survey 2) in the area to the north of the Strait of Dover; this patch developed in February and declined in March. The main spawning developed at the end of March (survey 6) and increased to a high level by the end of May (survey 9) and had declined by 7 June (survey 10). The results for Stage I eggs in survey 8 are shown in Figure 2 as an example.

The main production occurred in offshore waters of the Southern Bight centred midway between the Thames Estuary and Zeeland. An area of low production occurred (on each of the last 4 cruises) between the main Southern Bight patch and area of high production located to the north-west of this on the Norfolk Banks.

The total production curve for the Southern Bight is shown in Figure 3 with the estimated confidence limits. Production before mid-March was a small percentage of the total (<5%). The total Stage Ia production between surveys 6 and 10 was 5.25×10^{12} eggs, which at a fecundity of 385 eggs/gm female whole weight (Section 2.3) is equivalent to a female spawning stock biomass of 13600 t. The VPA for 1971 estimated a total female spawning stock of 41000 t. It is possible that the sampled area of the southern Bight contained about a third of the total North Sea spawning stock and so this roughly calculated result is encouraging.

The 1971 sampling grids were based on 8 stations per statistical rectangle over the main area of egg production. The 95% confidence limits on the total production of 5.25×10^{12} were +19.6, -14% (see Appendix 1). These values were used to extrapolate the confidence interval for a greater or a lesser density of stations, as shown in Figure 4.

(ii) South-west central North Sea

The 1971 surveys identified an area of moderate egg production south of Flamborough with the highest concentrations of sole eggs in the shallowest stations in the Wash. The westerly edge of the Norfolk banks spawning was present on each cruise and the zero boundary was well defined in the north (Fig. 2). These distributions were confirmed in surveys carried out in 1976. The level of egg production in this area was lower than that in the Southern Bight as indicated by the Stage Ia indices in Table 3 (compare with Table 2). This estimate does not include the full Norfolk Banks spawning.

(iii) Thames Estuary

Three surveys were carried out by Riley in 1973 along the English east coast in February, April and June. Very few sole eggs were caught in February and June. In April, high sole egg numbers were encountered particularly in the upper Thames estuary and along the north Kent coast. The total sole egg production (no/m^2) was calculated to be 23.3×10^9 for this survey. This was 13.5% of the equivalent production in the Southern Bight on survey 7/71 (1.72×10^{11}).

(iv) Eastern English Channel

According to the 1971 cruises the level of production in the eastern Channel was considerably lower than in the Southern Bight on the same cruises (Tables 2 and 3). However, in 1981, more detailed surveys were carried out in the Channel using RV CORELLA, which concentrated more sampling in the inshore areas. These surveys indicated levels of egg production in early April and early May which were comparable to those obtained in the Southern Bight in 1971. In terms of the Stage Ia index the values were 2.48 and 5.41 for CORELLA 5/81 and 6/81 respectively. Spawning concentrations were found at the extreme eastern end of the Channel, particularly in inshore waters off Beachy Head on the English side and off the R. Somme on the French coast. In 1981 a zero boundary was defined in the Strait of Dover and it is possible that this marks the separation of spawning between the North Sea and eastern Channel stocks. Some migration of tagged eastern Channel sole into the North Sea has been observed (unpublished UK data) but this has not exceeded 5%.

In view of the wind driven residual drift through the Strait it will be necessary to sample in the eastern Channel to ensure that the contours of the North Sea spawning are closed.

2.2.1.3 Belgian surveys:

Belgian surveys took place in 1972, 1973 and 1974 in the area immediately adjacent to the Belgian coast (de Clerck and van de Velde 1973; van de Velde 1973; Smagge and van de Velde 1974; van de Velde and

Smagge 1975). The Dutch type 'Torpedo' was used. The Belgian coast was surveyed several times in 1974 covering the period 21 January to 19 July. Maximum densities of 3.0 sole eggs/m^2 were obtained in the coastal strip between Ostend and Dunkerque. These values are considerably lower than the peak densities observed offshore in the Dutch and English surveys where densities exceeding 20 per m^2 were not uncommon in the main Southern Bight spawning and on the Norfolk Banks.

The production curve was well defined by each survey. That for 1974 showed a peak in egg production in April with relatively low numbers in March and June.

2.2.2 Maturity data

De Veen (1970) reported the results of sampling Dutch commercial catches for maturity stage in the period 1964 to 1969. The results are expressed as percentage occurrence of each stage for each month or half-month of sampling by 4 areas of the North Sea and by female size groups. The results for stage 6 (ripe and running) in large fish are shown in Figure 5.

These results define the time of spawning very well and conform that some spawning occurs in the southern Bight even in January and February. The main spawning period in the extreme south extends from March until May; that in the north, along the Danish coast, from April until July.

2.3 Fecundity estimates

2.3.1 Tank experiments

Experiments on captive fish in tanks could be of value in estimating the number of eggs that are actually spawned and viable. Considerable methodological problems have been encountered, however, which make the routine use of this technique of limited application. Some studies (Fonds, 1979, Danielssen unpublished) have only obtained spawning in the first year of captivity, whilst others have only obtained spawning after several years (Girin, 1978; van Keymeulen, unpublished). Recent work by Houghton et al., (unpublished) in 1982, on a well-established spawning stock, was successful in that it showed that 3 females weighing 2027 gm before spawning produced 954 thousand eggs. This is a relative fecundity of 471 eggs/gm female whole weight. An estimated 51% of the eggs were fertile. An interesting observation was the reduction in egg diameter from 1.4 to 1.2 mm during the spawning period; this has also been observed in the natural spawning in the North Sea (see Section 2.2.1).

2.3.2 Histological methods

Three studies, based on counting eggs in the ovary, were avalable for review by the Group:

(a) 1962: Danish study on Danish coast fish by Møller-Christensen (unpublished, Charlottenlund).

(b) 1964: Dutch study on Southern Bight fish by Venema (1964) (Ijmuiden).

(c) 1978-79 French study on Bay of Douarnenez fish by Deniel (1981). (Brest).

A fourth study on Bay of Biscay sole, by le Bec in 1982, was not available for review but is expected to be completed in the near future.

The main difficulty encountered in estimating the fecundity of sole is the wide range of oocyte sizes which are present. It is difficult to know precisely which oocytes will be released during the forthcoming spawning season. In the Dutch study of 1964, however, the diameter of oocytes in the gonads of different development stage was measured. This showed that only oocytes smaller than 0.25 mm were left in the ovaries of spent females. Eggs larger than this were considered to be released during the spawning season (Fig. 6). A similar size limit was used by Deniel in the French study. Unfortunately, the Danish study does not mention this problem and so the results have been excluded from the present summary.

The geometric mean regression coefficients of fecundity (F) on whole weight (W) in grams (including gonads) were as follows:

Dutch: $F = 3.719 + 0.385\,W$ ($r = 0.89$)

French: $F = -81.795 + 0.618\,W$ ($r = 0.93$)

The data points and regression lines are shown in Figure 7. Each regression passes close to the origin and is approximately linear so that it can be tentatively concluded that the relative fecundity will not be dependent upon the weight of the female fish. Relative fecundity is thus estimated at 385 eggs/gm of female in the North Sea in 1964 and 618 eggs/gm in the Bay of Douarnenez in 1967.

Gonad stage 4 and 5 represent ripening ovaries and may be used to test the idea that eggs might recruit from the <0.25 mm group into the potential spawning group during maturation. In fact no significant difference could be established in the fecundity-weight relationship from these two stages in the Dutch study which suggests that all eggs to be spawned may be counted at stage 4.

In order to estimate the error on the estimate of relative fecundity, the 95% confidence limits of the regression slope was obtained for the Dutch study. The influence of the number of observations on the confidence limits is shown in Figure 8 which was derived by assuming that the estimated variance will be the population variance.

2.4 Staging, development rates and identification

2.4.1 Staging

The development of sole eggs was first described by Fabre-Domergue and Bietrix (1905). Stage criteria derived from this paper were used by Nijssen-Meyer (1965) in the analysis of the 1962 Dutch surveys. Riley (1974) defined a different series of development stages which were originally based on those of Apstein (1909). These latter criteria have been used in all the UK cruises.

2.4.2 Development rates

Riley (1974) investigated the relationship between stage duration and temperature over the range 8 to 15°C. Fonds (1979), using different stage criteria, looked at the rate of development for a range of 10 to 19°C. Their results are compared in Figure 9. Stage II of Riley appears to be equivalent to Stage 1 of Fonds (closure of the blastopore). There is a difference of about 80% in the development rate of the early stages determined by the two studies. Stage IV of Riley is equivalent to Stage 3 or 4 of Fonds and again there is a difference, such that, at 12°C, Riley's eggs hatched in 6.2 days and those of Fonds in 5.0 days (24% difference). The precise definition of the stage endpoint is difficult from a practical point of view (Riley defined it as the point at which 50% had reached the end of the stage) and it may be that the discrepancy arises from different methods of establishing the endpoint. There are also difficulties which arise from surface cooling in the experimental containers; Riley countered this by covering the experimental containers and by measuring the temperature at the surface (where the eggs are concentrated) using a thermistor.

Riley's stages are likely to be more useful than those of Fonds because they give a greater degree of discrimination of the egg stages (5 stages as opposed to 3). The discrepancies between the two results needs to be investigated more fully before the survey is analysed.

2.4.3 Identification

The identification of sole eggs in the North Sea is unlikely to cause problems because the species which causes most confusion in the egg stages (Michrochirus variegatus - the Thickback Sole) is rare in the North Sea. The early larvae can be confused with those of the Solenette (Buglossidium luteum) but size differences and the pigmentation pattern provide a reliable means of identification (Nichols, 1976).

3. DESIGN OF THE SURVEY

The survey has been designed to estimate the spawning stock biomass of sole with an error which is better than ± 20%. We have concentrated on the main features of the design which are the time and number of surveys and the geographical positions of the stations. We have also considered the type of plankton sampling gear which should be used and have pointed out the need for a fecundity estimate in the year of the survey. The need for more detailed planning on gear deployment, treatment of the samples and reporting of results is also recognised but it was felt to be inappropriate to comment on this in detail at this stage. This will require the formation of a planning group at a later date.

3.1 Fecundity estimate

Previous experience with plaice (Horwood and Bannister, in prep.) and sole fecundity (de Veen, 1976) has suggested that year to year variations are to be expected. It is therefore desirable that a fecundity estimate should be made in the year of the survey. This can be most effectively achieved by collecting Stage IV gonad samples on fish markets in the period March to June. It appears that the technical problems posed by the range of oocyte sizes can be resolved by relying upon Venema's (1964) estimate and by excluding oocytes less than 0.25 mm. This conclusion should be checked by collecting samples of spent ovaries.

The level of sampling should be sufficient to demonstrate the existence or otherwise of a change in relative fecundity with size (this is not expected from previous results) and sufficient to estimate the mean relative fecundity of the North Sea population with an error of ± 5%. Assuming no variation in fecundity by areas within the North Sea this would probably be achieved with a size-stratified sample of 300 fish.

If relative fecundity is found to vary with size then the mean relative fecundity of the stock will have to be determined by weighting the estimates by the abundance of different size groups in the stock. This can be achieved using the catch-at-age data and estimates of the exploitation pattern from the VPA. This is unlikely to introduce significant circularity in the final comparison of the egg survey and VPA estimates of fecundity.

3.2 Plankton sampling gear and treatment of samples

The plankton sampling equipment which is normally used by the national institutes likely to participate in the survey, are of similar design. They are versions of the Gulf III high speed plankton sampler typically used at 5 knots whilst the ship is underway. Table 4 lists the main dimensions and characteristics of each gear.

As a result of the ICES International Herring Larval Survey there has been a considerable effort devoted to the inter-calibration of these nets (e.g. Schnack, 1974). Much of the discussion has naturally revolved around the efficiency of each for catching larvae, which is a more difficult technique to standardise than is the catching of eggs. Calibrations on several versions of the Gulf III have been carried out in a large flume by the Lowestoft laboratory (see Harding and Arnold 1971 for methods) which have identified efficiency differences between the nets. These are summarised in the final column of Table 3.1. All flowmeter calibrations depend on an accurate knowledge of the volume accepted in free flow (by the sampler without the net), as a ratio of the theoretical volume in free flow (area of nosecone x distance). The flume calibrations allow the flowmeter factors to be accurately calculated and hence provide a means of accurately measuring the volume filtered.

Standardisation of gear, beyond the use of a similar type of net, therefore appears to be unnecessary for those nets which have been calibrated in the flume. Ship to ship calibration is also unnecessary if the flowmeter calibrations are acceptable.

Standardisation of the method of deployment of the gear is required, probably including ship's speed, speed of shooting and hauling, depth profile of the tow (double oblique to within 1 or 2 m of the sea-bed) and the rules to be adopted for dealing with shallow stations. These details should be more fully discussed by the planning group at a later date, who should also decide upon the hydrographical observations which are required (particularly sea temperature).

The method of sample preservation is known to have a large effect on larval shrinkage (Wood, 1982) and may also have an effect on the appearance of the egg stages. It will therefore be necessary to standardise the method of sample preservation, to provide guidelines on sample sorting and to describe the agreed characteristics for identifying the egg stages. These important details should be discussed and agreed by the planning group at a later stage; the output of the group should be a manual for the implementation of the survey.

3.3 Timing of the Surveys

The information reviewed in Section 2.2 defined the timing of sole egg production in the Channel and Southern Bight. The main spawning starts in early March, reaches a peak in mid-May and declines fairly rapidly in early June. In the most northerly spawning areas of the south-west central North Sea and German Bight the onset of spawning probably occurs in April, the peak in early June and the end in early July, a delay of about four weeks over the Southern Bight.

The minimum requirement for estimating egg production, when the timing and shape of the production curve is known, is three surveys. In view of the relatively slow build-up of production in April and May it was judged that four surveys would be required; the first to take place before mid-April, the second to take place between mid-April and mid-May to define the rising part of the curve, the third to be timed to coincide with the expected peak in the Southern Bight in late May and the fourth during June to define the end of the production. Considering the delay in spawning which occurs in the German Bight in particular, this strategy will result in having the minimum of three surveys to define the production in northern areas.

As will be explained in the following section it will not be necessary to sample the whole area on each survey. Sampling will be concentrated in the south in the early part of the seaon and in the north at the end.

The dates which have been selected for each survey are shown in the table below. Each period lasts 14 days and it is intended that the complete grid for that period should be completed within the indicated dates. This is to ensure that each survey is as synoptic as possible.

Survey	Period	Week number
1	26 March-8 April	13,14
2	23 April-6 May	17,18
3	14 May-27 May	20,21
4	18 June-1 July	25,26

3.4 The Survey Grid

Planning charts were prepared for each of the three planning periods (March to mid-April, mid-April to mid-May and mid-May to June). These defined the position of the zero boundaries and the areas of highest egg production, as far as they were known from the available data. It was decided to deal with areas deeper than 10 m separately from areas less than 10 m, since the latter would probably require the use of small vessels.

3.4.1 Stations deeper than 10 m

The analysis of the English Southern Bight egg data indicated that an error of less than +20 and -15% on the total egg production would be obtained at a sampling density of 8 stations per statistical rectangle in the areas of the highest egg production (see Figure 4). In areas of low egg production a sampling density of 4 per rectangle was judged to be appropriate. Sampling grids were prepared for each planning period using these principles:

(i) Survey 1

The first survey grid (Figure 10) to be carried out between 26 March and 8 April, was designed to cover the early spawning in the eastern Channel and Southern Bight. The southern boundary was taken as a line through a zone of low egg production between Beachy Head on the English coast and Veulette on the French coast. No spawning has been observed north of 53°30'N in this period and this formed the northern boundary.

(ii) Surveys 2 and 3

The second and third surveys are to be carried out using the same grid between 23 April and 6 May and 14 to 27 May (Figure 11). The southern limit of the grid is the same as in the first survey but the northern limit has been extended to cover the spawning in the south-west central North Sea, in the German Bight and off the Danish coast.

(iii) Survey 4

For the final survey between 18 June and 1 July, the northern boundary of the previous survey is retained but the southern limit is redrawn at 51°N as spawning activity south of this latitude is at a much reduced level (Figure 12).

3.4.2 Stations shallower than 10 m

The available information indicates that significant sole spawning occurs in the Wash, Thames, eastern Channel, Belgian coast, the Waddensea and amongst the Friesian Islands in depths of less than 10 m. These six areas will require a sampling effort equivalent to the high density areas offshore. The shallow sampling areas are indicated on Figures 9, 10 and 11. Precise sampling positions cannot be determined without accurate local knowledge, but the Group has recommended a minimum number of stations which should be sampled to cover each area at the required sampling density (see below).

3.4.3 Total numbers of stations and sampling time

Table 5 is a summary of the sampling effort required within 'synoptic' areas. The boundaries of these have been defined to coincide (as far as possible) with areas of low egg production and to break up each grid into convenient units for planning and implementation. The synoptic grids should be sampled by one ship in as short a period as possible.

The steaming distances have been measured in lines of latitude and converted to days on the basis of an average speed of 7 knots. Previous experience has shown that this can be achieved, for this type of grid in these depths, for gears operated at 5 knots and with an inter-station speed of 10 knots. These estimates of sampling time do not include any allowance for bad weather, or steaming to and from the home port.

Also included in Table 5 is an approximate estimate of the time in man-days which will be required to sort the samples for all fish eggs and larvae and to identify and stage the sole egs. These estimates are based on previous experience at Lowestoft which has shown that 3 samples can be sorted per man-day.

The Group also considered the effect of reducing the sampling density to 4 stations per rectangle. This would only reduce ship's-time by about 10% since the steaming distance would have to be the same in order to cover the whole area. The largest saving would be in the sorting time which would be reduced by about 50%. The Group considered that the plans should be based on the 8 stations sampling density; if sorting time is a severe problem then this would not preclude a decision to sort alternate samples to provide a first estimate of the production. The errors on the estimate will not be precisely known until the data are collected and it is possible that a satisfactory margin of error could be achieved with a smaller number of samples.

4. IMPLEMENTATION OF THE SURVEYS

The 'synoptic' grids indicated in section 3.6 form a basis for planning the implementation of the survey as a whole. They provide a convenient breakdown of the area into smaller grids which can be sampled by individual research ships (Table 6).

It had been suggested that an overlap between each grid should be allowed for in the design, so that, as far as possible, each ship's sampling should close off the high density contours in each area. However, this would increase the number of samples to be taken by about 25% and would cause additional difficulties in working up the results (how to resolve conflicting results in the overlap area, for example). So long as the plankton sampling gears are calibrated and are used in a standard way, the need for an overlap area is doubtful and so this proposal has been abandoned.

The shallow stations perhaps pose less of a problem than those offshore since they can probably be sampled using small commercial vessels, for example. Some allowance should be made for them by the nation in whose coastal belt they occur.

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APPENDIX 1

Calculation of egg production indices and confidence limits

Several methods exist for converting values of eggs caught per m^2 by station into an estimate of total egg production. Essential features are the conversion of eggs caught into eggs produced per day (using the stage duration estimated from sea temperature); correction for mortality and the integration of station values into an estimate of the total production for the survey. The latter can be achieved in various ways including estimation of areas within contours or the summation of small area estimates of production. One may also choose to use eggs/m^3 and small area volumes, or egg/m^2 and areas before integration. Estimates of egg production per unit area may be derived from eggs/m^3 in at least two ways (station depth or small area average depth). The total egg production for the season is usually obtained by integrating the area beneath a graph of total eggs produced per day.

In this report an approximate method of obtaining egg production indices was employed; this had the advantage that it provided confidence limits on the estimate. The method was developed by J G Pope for the western mackerel surveys (Lockwood et al., 1981a).

The mean number of eggs/m^2 (or eggs/m^2/day in the case of the English 1971 surveys) was calculated by taking the logarithm of the non-zero values:

$$x = \ln\ (\mu \neq 0)$$

where μ is the observed number of eggs/m^2 at each station. The mean of the transformed data ($\bar{x}$) was re-transformed to the arithmetic mean ($\bar{\mu}$) using:

$$\bar{\mu} = \exp\ \left[\bar{x} + \frac{S^2}{2}\ \frac{(n-1)}{n}\ \right]$$

where S^2 is the varianced of the log-transformed data and n is the number of observations.

The 95% confidence limits on this estimate was calculated from:

$$\bar{\mu}.\ \exp\ [\pm\ 2\ \text{s.e.}]$$

where s.e. is the standard error of $\bar{x}$ (i.e. $S/\sqrt{n}$).

Normally the mean density per unit area ($\bar{\mu}$) would be raised to the area within the non-zero contour of the distribution. In our case, there was insufficient time to do this, and so approximate indices of the total production were obtained by calculating:

$$\text{Index} = \bar{\mu}\ .\ \frac{n}{t}$$

where n is the number of non-zero stations and t is the total number of stations in the grid. The confidence limits of the index were assumed to be the same as those of μ, expressed in percent.

In the case of the 1971 English survey, the cruise confidence limits were combined to estimate the confidence limits on the total production for the year. This was achieved using another formula from Pope (Lockwood et al., 1981b).

$$C.L. = \sqrt{\frac{\Sigma(\bar{\mu}\ c)^2}{(\Sigma\bar{\mu})^2}}$$

where c is the confidence limit in % for a particular cruise and Σ denotes summation over cruises. The formula should be used twice, once for the positive limits and once for the negative limits.

It should be pointed out that these confidence limits are likely to be over-estimates of the true confidence limits. The reason for this is that the estimated variance includes the variation in density which is due to the (structured) spatial distribution. This problem is more fully discussed by English (1964).

Table 1 Indices of sole egg production (no/m^2/Stage 1) from the 1962 Dutch surveys

	Survey 2		Survey 3	
Date	1-10 May		28 May-7 June	
Area	W of 5°E	E of 5°E	W of 5°E	E of 5° E
Total Stations	42	39	43	41
Total non-zero values	35	21	38	35
x	1.405	0.394	2.133	1.682
S^2	0.865	0.724	0.882	1.049
μ	6.205	2.093	12.960	8.948
Index	5.171	1.127	11.453	7.638
% of survey	82	18	60	40
	100%		100%	
Upper 95% C.L. on $\bar{\mu}$	+37%	+45%	+36%	+41%
Lower 95% C.L. on $\bar{\mu}$	-27%	-31%	-26%	-29%

Table 2 English surveys 1971; Stage Ia sole eggs in the Southern Bight

Survey	1	2	3	4	5	6	7	8	9	10
Date (midcruise)	9 Jan	25 Jan	9 Feb	2 Mar	12 Mar	27 Mar	17 Apr	2 May	20 May	7 June
Total stations	63	54	46	72	78	81	85	80	81	72
No. of non-zero stations	63	4	1	9	4	25	54	57	59	36
$\bar{x}$	0	-2.298	0.971	-0.317	-0.267	-0.621	0.299	0.689	1.073	0.772
s^2	-	0.002	-	1.946	1.819	1.626	1.306	1.202	1.180	0.891
$\bar{\mu}$ ($m^{-2}.d^{-1}$)	-	0.101	(2.639)	1.729	1.514	1.172	2.560	3.596	5.220	3.338
Index		0.012	0.106	0.255	0.085	0.380	1.626	2.722	3.990	1.970
Upper 95% C.L. (%)	-	+1	-	+266	+517	+92	+43	+37	+36	+35
Lower 95% C.L. (%)	-	-1	-	-73	-84	-48	-30	-27	-27	-26
Area surveyed ($Km^2.10^{-3}$)	-	-	-	-	-	33.3	38.3	34.8	33.3	29.9
Total prodn. ($10^{-10}.m^{-2}.d^{-1}$)	-	-	-	-	-	1.204	6.230	8.910	12.650	4.9889

Table 3 English surveys 1971; Stage Ia eggs in the SW Central North Sea and Eastern English Channel

Survey	1	2	3	4	5	6	7	8	9	10
Survey (mid-date)	9 Jan	25 Jan	9 Feb	2 Mar	12 Mar	27 Mar	17 Apr	2 May	20 May	7 June
South-west Central North Sea										
Total stations	0	0	0	0	0	42	0	46	0	47
No. of non-zero stations	-	-	-	-	-	1	-	19	-	13
Index	-	-	-	-	-	0.003		0.643		0.305
Eastern Channel										
Total stations	24	11	24	25	24	0	24	0	24	0
No. of non-zero stations	0	0	4	2	2	-	6	-	4	-
Index	0	0	0.612	0.033	0.009	-	0.252	-	0.484	-

Table 4 Comparison of the Gulf III-type plankton samplers in use

Nation	Name of sampler	Version (S=small L=large E=Enclosed U=Unencased)	Body diameter (cm)	Body length (cm)	Net length (cm)	Nosecone type (H=hemi-spherical C=conical)	Nosecone aperture diameter (cm)	Normal operating speed (knots)	Free-flow efficiency (%)	References
England	"Tin tow-net"	S,E	50.6	218	180	H	20.3	5	53	1,3
England	MG82	S,E	53.0	275	245	C	20.3	5	Not calibrated	
England	MG82	L,E	76.0	275	245	C	40.6	5	>100	2
Netherlands	"Torpedo"/ DGIII	E	53.0	200	130	C	19.4	5	90	2,4
Belgium	GULF III/RV.2	E	53.0	200	130	C	19.4	5	90	
Germany	"Nackthai"	U						?	Not calibrated	
Denmark	Scottish GULF III	E	53.8	200	150	C	18.9	5	86	3
France	GULF III	E	50.3	232	175	C	19.0	5	Not calibrated?	

References
1. Harding & Arnold (1970)
2. Nichols et al., (unpublished)
3. Nichols (1982)
4. Zijlstra (1970)

Table 5 Summary of the sampling effort required to complete the whole survey

'Synoptic' area	Stations > 10m				
	Survey	No. stations	Steaming distance (n.m)	No. days survey	No. man/days sorting
Danish coast	1	0	0	0	0
	2/3	53	660	4	18
	4	53	660	4	18
German Bight	1	13	220	1.5	4
	2/3	47	530	3	16
	4	47	530	3	16
NE England	1	15	260	1.5	5
	2/3	45	590	3.5	15
	4	45	590	3.5	15
S Bight	1	43	460	2.5	14
	2/3	47	460	2.5	16
	4	30	460	2.5	10
E Channel	1	26	280	1.5	9
	2/3	26	290	1.5	9
	4	4	60	.5	1
Total all areas	1	97	1220	7	32
	2/3	218	2530	15	73
	4	179	2300	13.5	60
Total all areas >10m		712	8580	50.5	238

Area	Stations < 10 m			
	Survey	No. stations	No. days survey	No. man/days sorting
Humber/Wash	1	4	2	1
	2/3	6	2	2
	4	6	2	2
Thames	1	6	2	2
	2/3	6	2	2
	4	6	2	2
E Channel	1	7	2	2
	2/3	7	2	2
	4	0	0	0
Belgian coast	1	8	4	3
	2/3	8	4	3
	4	8	4	3
E Waddensea	1	0	0	0
	2/3	8	5	3
	4	8	5	3
W Waddensea	1	0	0	0
	2/3	10	5	3
	4	10	5	3
Total all areas	1	25		8
	2/3	45		15
	4	38		13
Total all areas <10m		153		51

Table 6 Table for planning the implementation of the survey. Stations >10m in depth only.

Period	Survey	'Synoptic' grid (>10m) C	SB	SWC	GBW	GBE
26 Mar-8 Apr	1	26-280	43-460	15-260	13-220	
		1.5	2.5	1.5	1.5	
23 Apr-6 May	2	26-290	47-460	45-590	47-530	53-660
		1.5	2.5	3.5	3.0	4.0
14 May-27 May	3	26-290	47-460	45-590	47-530	53-660
		1.5	2.5	3.5	3.0	4.0
18 Jun-1 Jul	4	4-60	30-460	45-590	47-530	53-660
		0.5	2.5	3.5	3.0	4.0

NB: (1) C = Channel, SB = Southern Bight, SWC = South-west Central North Sea, GBW = Western German Bight, GBE = Eastern German Bight

(2) The figures against each grid are: above left = no. of stations, above right = distance in nautical miles, below = time at 7 knots in days

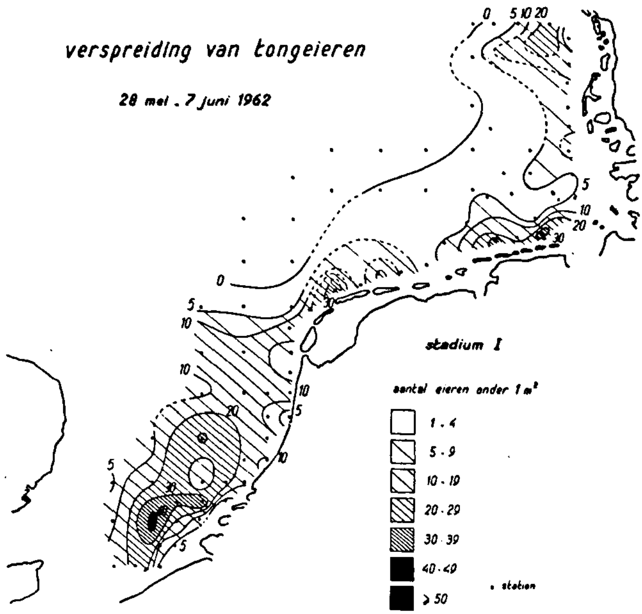

Figure 1. Distribution of Stage 1 sole eggs from the 3rd Dutch survey in 1962 (nos/m^2).

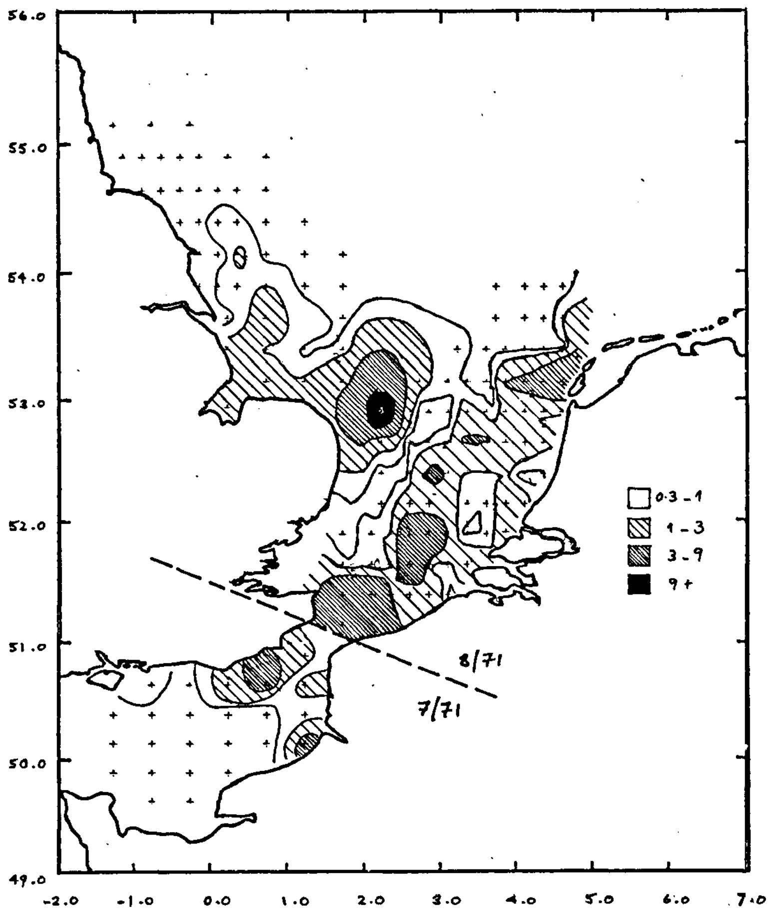

Figure 2. Distribution of Stage 1 sole eggs from the 8th English survey in 1971 (nos/m^2/day).

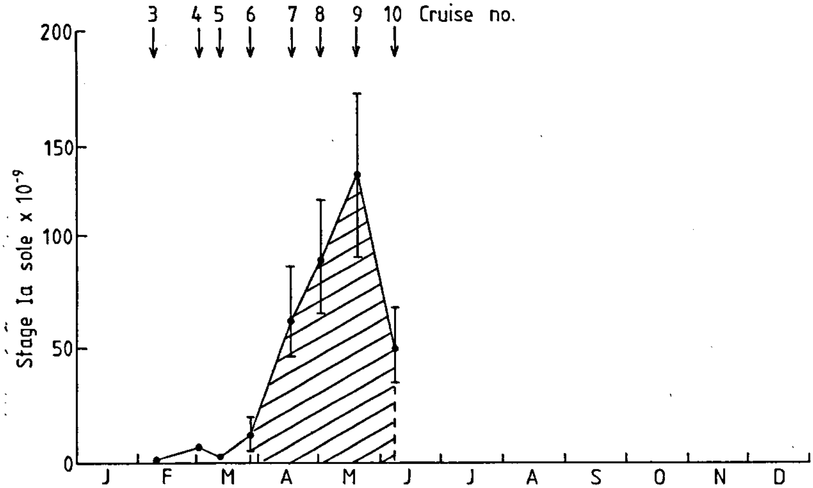

Figure 3. Production curve of Stage 1 sole eggs from the English surveys in 1971.

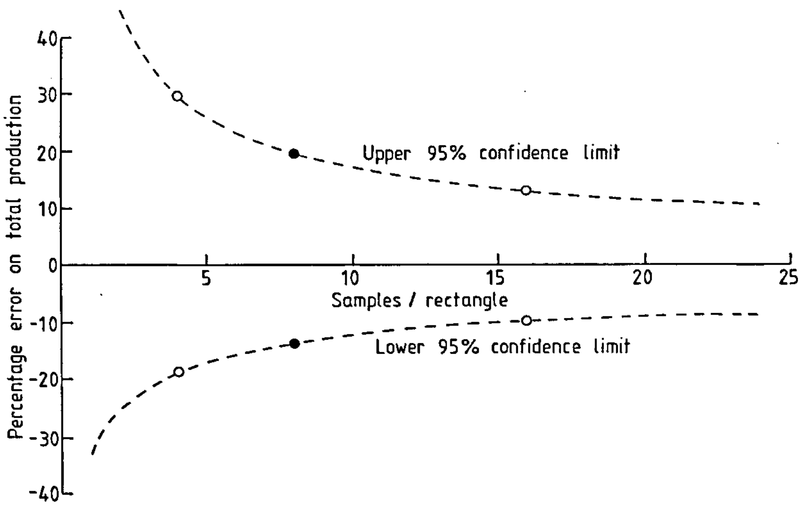

Figure 4. Confidence limits on the estimate of total production of Stage 1 eggs from the 6th to 10th English surveys in 1971 (Southern Bight only).

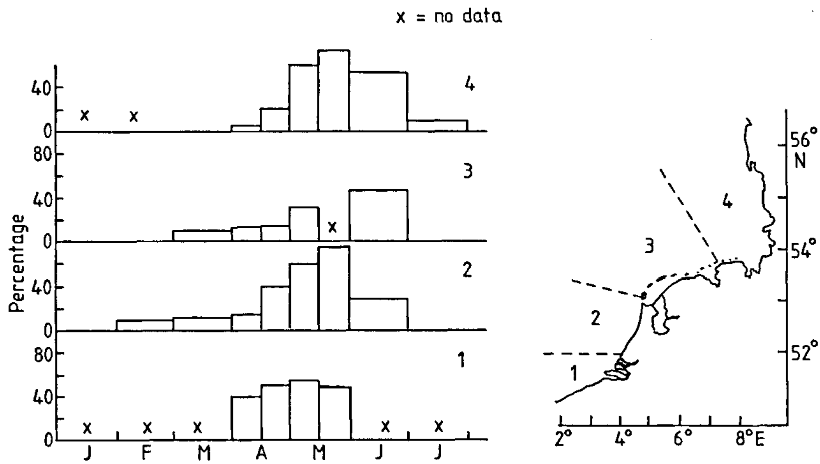

Figure 5. Percentages of ripe and running female soles (>38 cm) for four areas of the North Sea in 1964 to 1969 (de Veen, 1970).

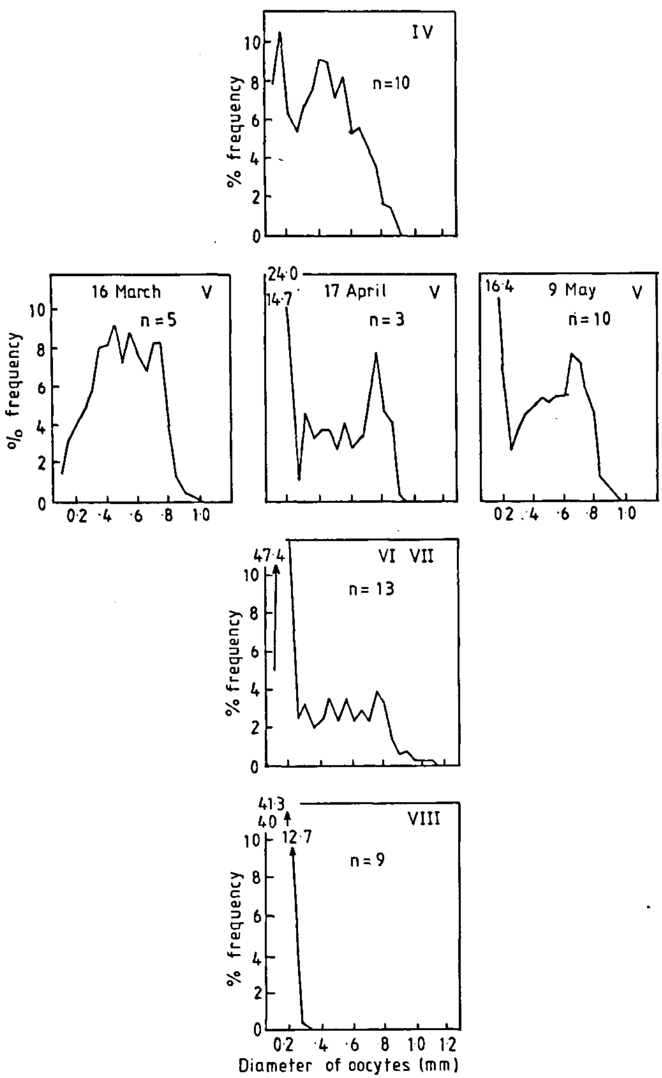

Figure 6. Size distribution of oocytes from various stages of sole ovary (Venema, 1964).

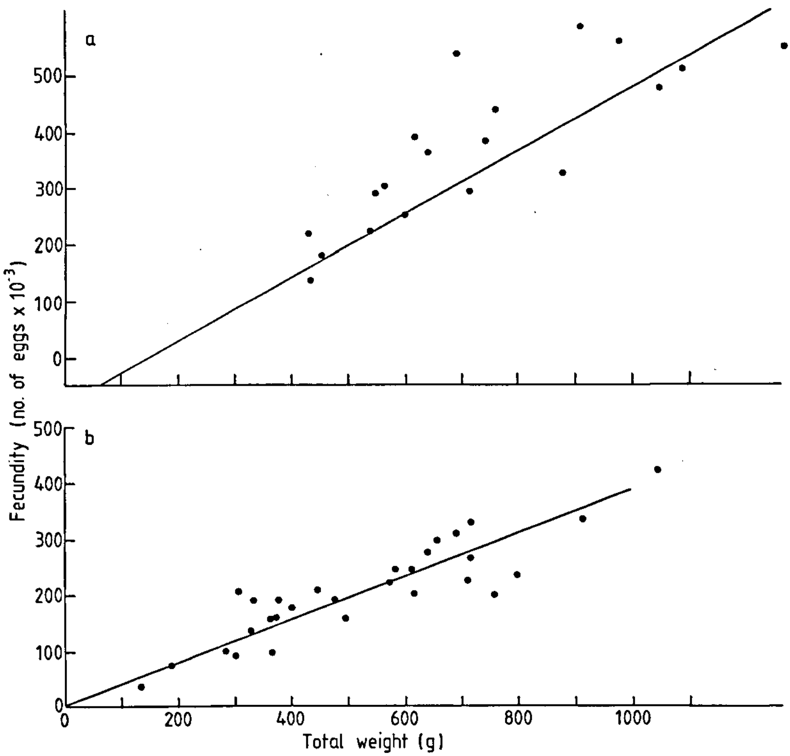

Figure 7. Fecundity/weight relationships for Dutch (above) and French (below) data.

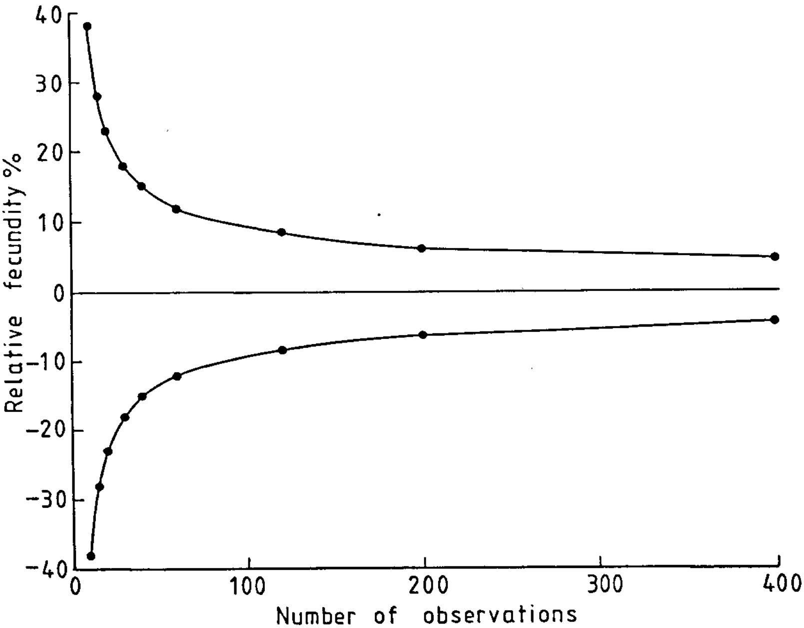

Figure 8. Confidence limits on estimates of relative fecundity based on Dutch data (Venema, 1964).

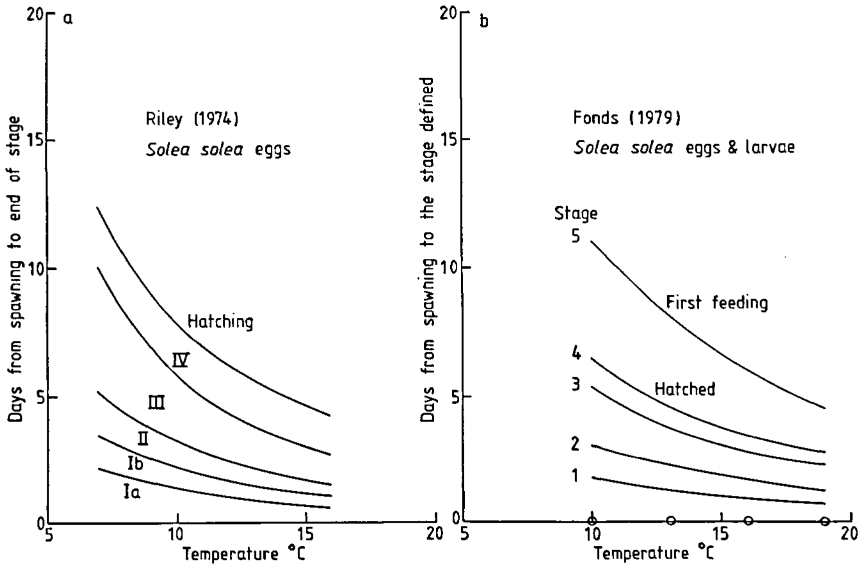

Figure 9. Stage duration against temperature for sole eggs and larvae from Riley (1974) and Fonds (1979).

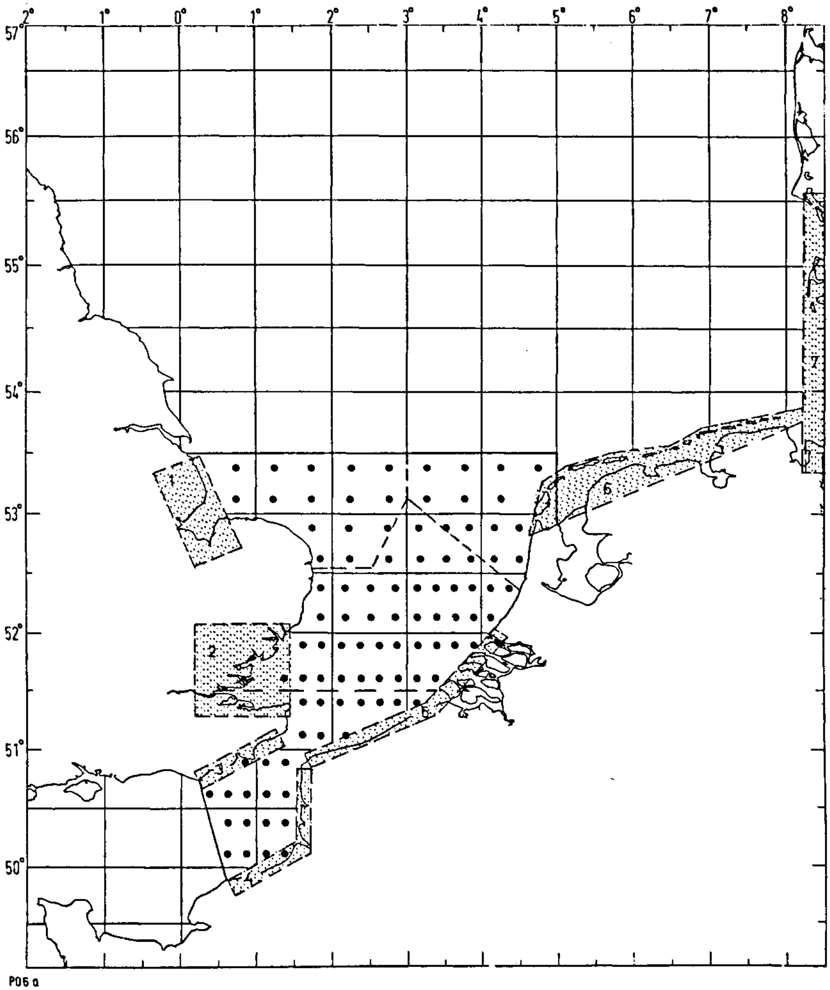

Figure 10. Proposed survey grid for Survey 1 (26 March - 8 April).

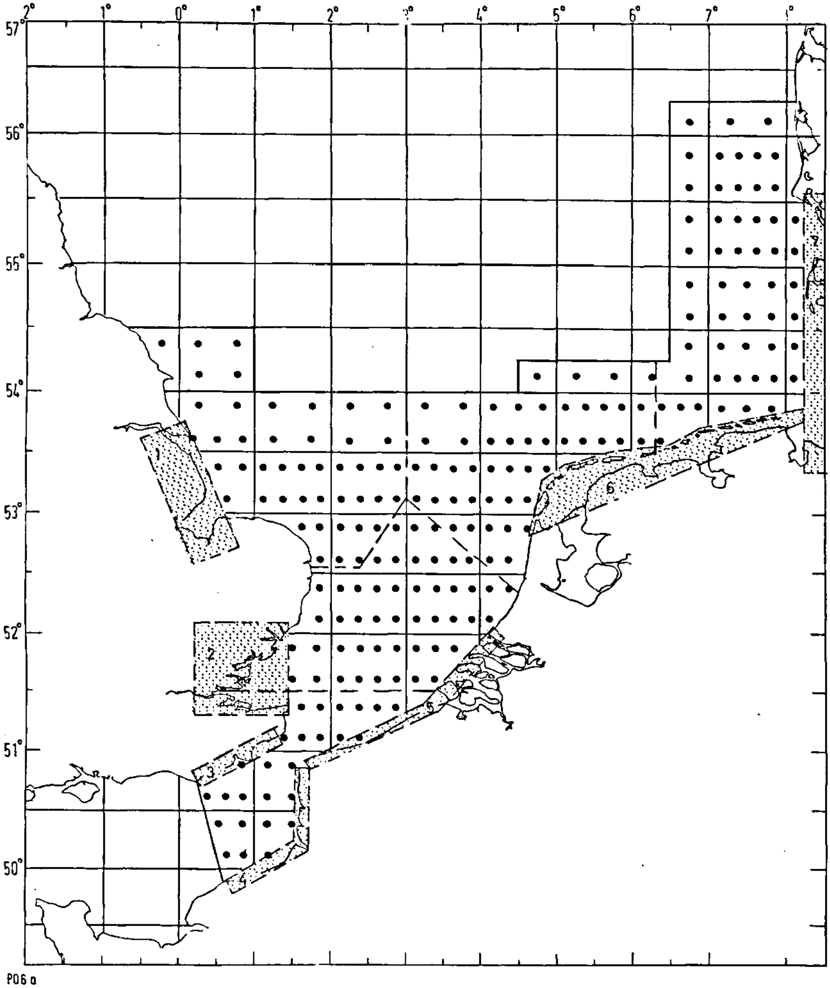

Figure 11. Proposed survey grid for Surveys 2 and 3 (23 April-6 May, 14 May-27 May).

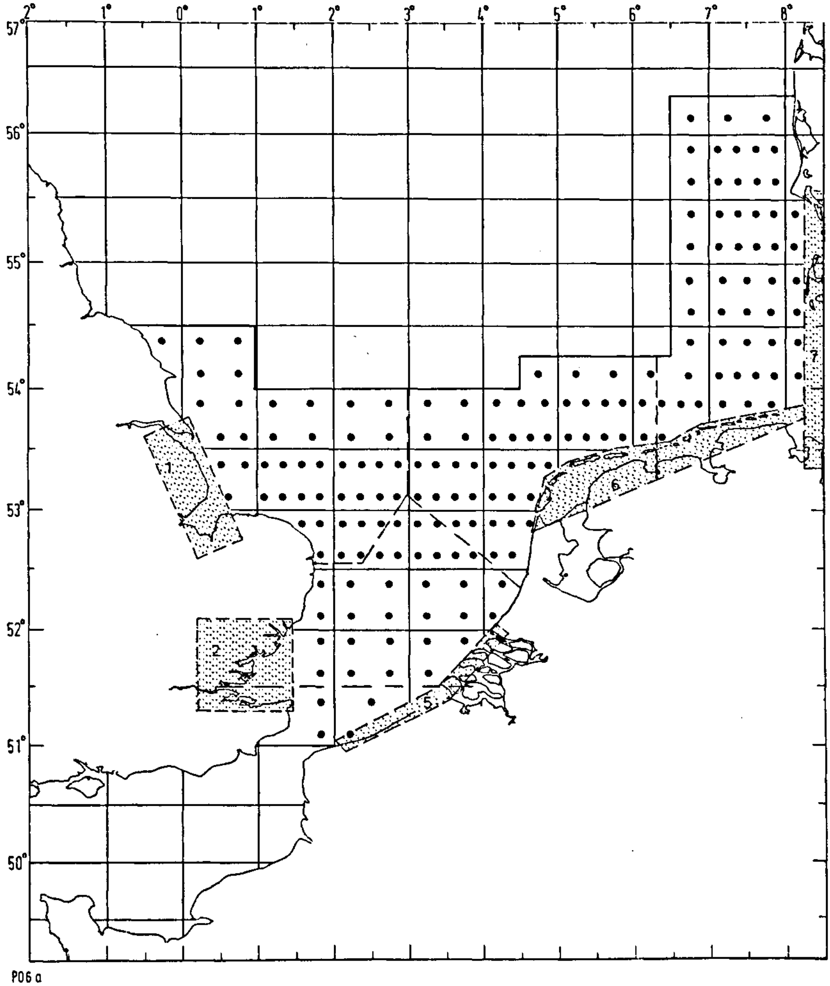

Figure 12. Proposed survey grid for Survey 4 (18 June - 1 July).