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Mackerel egg investigations in the North Sea

by

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1. ABSTRACT

This paper deals with the mackerel egg investigations in the North Sea in 1982 and 1983. The egg production is estimated by a computerized method. The confidence limits of the egg samples were estimated at 20-30%. The optimum future distribution of sampling effort in the area is calculated according to Neyman allocation. A comparison of the fecundity of mackerel from different areas measured by different methods is done. The size of the North Sea spawning stock is estimated based on the egg surveys and the fecundity studies.

2. INTRODUCTION

Mackerel egg investigations have been carried out in the North Sea by Norway since 1968. In the early years, the area north of 57^{0}N was covered once during June/July. In 1980-1983 the investigations were extended and the spawning area was surveyed several times during the season to give an estimate of the total egg production. In 1982, also the Netherlands and to some extent Scotland participated in these investigations (Iversen and Eltink, 1983, Walsh, 1983).

3. EGG DISTRIBUTION AND SAMPLING DESIGN

During the first years the area north of 57^{0}N was covered once in June-July. A Juday net, diameter 80 cm and meshsize 500µ, was hauled from a depth of 50 m or 5 m above the bottom to the surface. The gear was abandoned due to difficulties in operating the net in a standard way in all weather conditions, and the hauls were often more oblique than vertical. Iversen (1973) investigated the depth distribution of mackerel eggs under different weather conditions in the North Sea using Clarke-Bumpus samplers and concluded that up to 85% of the eggs are distributed in the upper 5 m of the water column and that nearly all the eggs are in the upper 20 m. Therefore it is essential that the surface layer is sampled representatively.

In 1980 the investigation was carried out with a 20 cm (500µ) Bongo net for the first time. The Bongo net was operated stepwise in the depths 20, 15, 10, 5 m and just below the seasurface. The Bongo net was chosen because it is easy to handle from the side of the vessel. In this way the sampled water was not influenced by the ship's propeller. The sampler was equipped with a sounder to measure the sampling depth and a flowmeter to measure the filtrated water volume. It was then possible to control the depth of the sampler.

The investigations have clearly demonstrated that there is a certain pattern in the horizontal distribution of mackerel egg with the highest egg densities always occuring in the central part of the North Sea in June-July . It is obvious then that a random survey in time and space is not an optimal sampling scheme. A summary of the number of eggs sampled per haul in 1982 and 1983 together with a Neyman allocation (Cochran,1963) using the same data is presented in Fig. 1. A proposed distribution of sampling effort in different areas is shown in Fig.2.

A station with very high egg densities may contribute considerably to the estimate of total egg production (see section 6). Therefore a special sampling strategy should be used to find the size of the area represented by the big egg sample. It is essential then that a preliminary count of the number of eggs in the sampler should be done immediately after the station is taken. If the number of eggs are above a limit then some more stations (three ?) should be taken in a radius of one nautical mile from the station, before the ordinary programme is continued.

3. AGEING OF MACKEREL EGGS

Mackerel eggs from the North Sea have been staged according to data published by Danielssen and Iversen (1977). The applied stage for production estimates, mackerel eggs without visible embryo, includes eggs from time of hatching until formation of the primitive streak. This stage then includes eggs which are older than stage 1A and 1B from the Western area (Lockwood _et_._al_. 1981). Danielssen and Iversen _op.cit._ observed the development once a day, and interpolation had to be done to estimate the actual age of the eggs sampled in the spawning area. The experiments were carried out at constant temperatures 12^0, 14^0, 16^0, 18^0, 20^0 and 22^0C. Lockwood _et_. _al_. _op.cit_. did similar investigations at the same temperatures, but the development was observed more frequently, at least 4 times per 24 hrs, consequently the ageing based on this investigation should be more precise.

In 1983 the ageing of the North Sea mackerel eggs were done in accordance with this data. This is correct if the development under the same temperature regimes in the Western area and in the North Sea are the same. This seem to be a reasonable assumption since it is the same species and the areas are not geographically very far apart. Comparing the data for the two investigations it seems that the egg development rate is similar for the two areas.

5. SPAWNING PERIOD

The timing of the surveys are essential for estimating the total egg production. The surveys have to be done within the spawning period and it is especially important that the period of maximum spawning intensity is sampled representatively. The duration and intensity of the spawning has been investigated at Ekofisk since 1976 and at Cod since 1981 (Bakken _et_. _al_ 1977, Iversen 1981, 1982 and Iversen and Eltink 1983). The samples were supposed to be taken two times per day in the period mid May mid August with a Juday net. Due to technical reasons this has been difficult to achieve every year. In the early 1970s the Ekofisk was centrally situated within the spawning area. During later years the western border of the spawning area has been in the Ekofisk area.

The spawning in the North Sea lasts for about two months. The spawning period at Ekofisk has been within the period mid May to mid August. The longest spawning period of 11 weeks at this location was observed in 1980, week 23-33, with a maximum in week 27,the beginning of July. The shortest period was observed in 1981, week 27-31, with a maximum in week 29. In 1982 the spawning at Ekofisk started the last week of May and ended the second week of July, with a maximum in mid June. The sampling location was situated well within the spawning area. A combination of the results from the surveys and the spawning intensity data give the spawning periods for the years 1980-1983 as shown in Table 1.

6. FECUNDITY

To convert the total egg production estimate to spawning stock size the fecundity and sex ratio of the stock must be known. For the North Sea mackerel the sex ratio is 50/50 (Iversen 1981). The fecundity of a female is defined as the number of eggs spawned within one season. Data on fecundity of mackerel are available from several investigations, Macer (1976), Borges et. al (1980), Lockwood et. al (1981),Martins and Gordo (1983) and Walsh (1983). These investigations are based on the classical method by preparing the ovaries in Gilson's fluid. Morse (1981) and Iversen and Adoff (1983) used a histological method. This method was applied by Iversen and Adoff because it seemed from the investigations done by Borges et. al (1980) that a lot of ova in young stages were ruptured by the Gilson's fluid and these results are excluded in Fig. 3.

The measurements of the fecundity of a 35 cm mackerel ranges from 350 000 to 600 000 eggs, and 700 000 to 1 100 000 eggs for a 43 cm fish (Fig.3). The difference is probably due to the different methods applied in the different investigations, although mackerel from different areas might have different fecundity.

7. TOTAL EGG PRODUCTION

The number of eggs produced per day per square meter is calculated for each station. Based on this a production estimate for the total area per day could be calculated either by hand or by a computer program. The computer routines used is contained in the MAP-LIBRARY from the Institute of Marine Research, Bergen (unpublished manuscript). The routines are written i FORTRAN. The interpolation routine in this package is called ZGRID and is designed and documented by Taylor, Richards and Halstead (1971). To use this routine the stations have to be projected on to a map and a grid placed upon the map (Fig. 4). The routine then interpolates a value to each grid point (Fig. 13-16).

Depending on the values of input parameters to the routine the interpolation method is changed. When the input variable CAY is set to zero, a two dimensional linear interpolation is performed. If CAY has a high value a spline interpolation technique is used. With the input variable NRNG the user decides how many grid units a grid point may be away from any datapoint and still being defined. Parts of the grid may be set to undefined before ZGRID is used. This can be done in two ways, either the coastlines in the map frame or using a polygon given manually. This polygon defines the surveyed area. In this present paper a polygon defines the surveyed area. The interpolated values from ZGRID are entered into the routine INTGRT which integrates the interpolated data taking into consideration the geographical position of each gridpoint. The output is the total number of eggs produced per day in the surveyed area and time period.

It is realised that the computer program may produce different results with the same data set depending on the values of CAY and NRNG. Therefore a survey data set was picked at random and two persons calculated independently a production estimate for the survey by hand. They arrived at practically the same figure. When the same survey was given as input to the computer program together with reasonable values of CAY and NRNG the program also arrived near these figures. These values of CAY and NRNG were then applied for the other surveys.

It is important to note that one station with an extremely high number of eggs may, with the present density of stations, contribute considerably to the total production estimate. This was clearly demonstrated by the program when one station with high egg density was left out of the calculations.

The establishment of a standard computer program has several advantages, the results can be presented immediately and it is easy to explore the effect of different parameters.

A polygon placed just outside the outer stations of a surveyed area assures a minimum estimate of the amount of eggs produced in the total spawning area. In some cases, especially if there are stations with high densities of eggs in the rim of the surveyed area, indicating that the surveyed area was too small, then parts of the grids could be blanked using the coastlines and then let the value of NRNG decide how much of the rest of the grid that should be set to undefined. In this way an estimate of egg production closer to reality is produced.

8. SPAWNING STOCK SIZE ESTIMATES FOR 1982 AND 1983

The egg production and spawning stock size for the North Sea in 1982 is given in Iversen and Eltink (1983) and Anon (1984a). The egg production estimated is done drawing isolines by eye and then integrating the area within each isoline.

Figs. 5-8 give the station grids for the four surveys in 1983. The observed distribution of stage 1A and 1B eggs (Lockwood <u>et</u>. <u>al</u>. 1981 for the different surveys are shown in Figs. 9-12, the isolines are drawn by eye. The spawning started in a rather narrow area Fig.9. During the following surveys the spawning area was much wider. The interpolated values for each grid intersections for the four suveys are shown in Figs. 13-16. The polygones delineating the area for computerized egg production estimates for different coverages are shown in the same figures.

The total egg production and corresponding spawning stock size estimates for 1982 and 1983 are shown in Tables 2 and 3.

The fecundity/weight relationship (Iversen and Adoff, 1983): $f=560 \times W^{1.14}$ (W = weight in gram) is close to linear in the range of actual fish weights. The spawning stock size estimates given in Tables 2 and 3 are based on this relationship.

The last ICES Mackerel Working Group (Anon.1984b) applied spawning stock size estimates of 190 000 and 240 000 tonnes in 1982 and 1983 respectively. These estimates were based on the present computer program for calculating the egg production and the fecundity weight relationship given by Iversen and Adoff (1983).

9. SAMPLING DISTRIBUTION AND CONFIDENCE LIMITS

The accuracy of the mackerel spawning stock estimate is dependent of several factors as standardization of sampling procedures and gear, the egg distribution sampled from in the field, mortality of eggs, the accuracy of the measurement of fecundity and the sex ratio are among the most important.

Here only the confidence limits for the egg production estimate based on the plankton surveys are investigated. Consequently this is a minimum estimate of these limits. To establish confidence limits of the sampled mean of the stations sampled, the statistical distribution of number of eggs per station in time and space should be known. The Poisson distribution is assumed to be a reasonable approximation of the distribution we sample from locally. We sample the same volume from each depth interval in the water column each time. It is assumed that the eggs are randomly distributed horizontally in this small area. We further assumes that the volume we sample each time, v , is much smaller than the total volume in the area, V. Then, n ,the number of eggs in the sample is a Poisson distributed stochastic variable with parameter, λ:

$$E\{n\} = \lambda = N \cdot v \qquad (1)$$

Where N is the total number of eggs in the area. The coefficient of variation K for this distribution is:

$$K = \frac{\sqrt{\lambda}}{\lambda} = \frac{1}{\sqrt{n \cdot v}} \qquad (2)$$

According to (2) the coefficient of variation decreases if the overall density of eggs in the area is high and/or if the sampled volume per station is high. We also see that if v varies from station to station a new element of variance is introduced. Consequently v should be kept constant this is also emphasized by Pennington and Grosslein (1978) in their paper on trawl surveys.

The simple model above is of course not valid over extended areas and time periods. The parameter λ is in itself a function of time and space. Therefore the total distribution sampled is not immediately of a known type. This is a prerequisite to establish the exact confidence limits. Distributions used for trawl and plankton surveys are the negative binominal and delta distribution (e.g. Pennington and Grosslein, 1978), and the log normal distribution (Pope, 1978). Fasham (1978) emphasizes that the structure of the governing equations of the process in time and space should be known. The nature of the underlying distribution can then be deduced from spectral analysis of the data. He also points out that there is almost as many mathematical models as there are data sets to test the models. We think that the method proposed by Ulltang (1978) is the best approach to estimate confidence limits for the mackerel egg surveys in the North Sea. The stations in 1982 and 1983 are almost evenly spread out in time and space in the egg production season and can be anticipated to be randomly sampled in time and space. We pick randomly stations from this distribution, the same number of times as there are stations, and calculate the mean. This was repeated 10 000 times and thereby an emperical sample mean distribution was generated. From the generated distribution the 90 % confidence limits could be obtained. This will be an estimate of the upper and lower confidence limits of our production estimate. We have done this for the 1982 and 1983 surveys based on all stages of eggs. The sample mean distributions are shown in Fig. 17 and 18. The text table below give some important parameters of these empirical distributions. It is seen that the 90% confidence limits were about ±20 % in 1982 and ±30 % in 1983.

Year	Mean sample volume per (m^3)	Mean nr. haul 90%	Lower conf.	Upper 90% conf.	λ min	λ max	N haul
1982	65.4	56.9	46.6(-18.1%)	67.7(+19.0%)	40.5	81.1	584
1983	72.2	107.5	79.2(-26.3%)	140.7(+30.9%)	57.6	173.2	369

10. LITERATURE

ANON. 1984a. Report of the mackerel working group. ICES, C.M.1984/Assess.1 [Mimeo.]

ANON. 1984b. Report of the mackerel working group. ICES, C.M.1984/Assess.8 [Mimeo.]

BAKKEN,E., BJØRKE,H. and ALFONSO,M.H.D. 1977. The spawning period for mackerel in the North Sea. ICES, C.M.1977/H:26 [Mimeo.]

BORGES,M.F.,IVERSEN,S.A. and DAHL,O.1980. On fecundity of North Sea mackerel (*Scomber scombrus*). ICES, C.M. 1980/H:47 [Mimeo].

COCHRAN,W.G. 1963. Sampling techniques. Wiley, N.Y.

DANIELSSEN,D. and IVERSEN,S.A. 1977. The development and mortality of mackerel eggs (*Scomber scombrus* L.) in different temperatures. ICES, C.M.1977/L:19 [Mimeo.]

FASHAM,M.I.R. 1978. The statistical and mathematical analysis of plankton patchiness. Oceanogr.Mar.Biol.Ann.Rev. 16 (43-79).

IVERSEN,S.A. 1973. Utbredelse og mengde av makrellegg (Scomber scombrus L.) og zooplankton i Skagerrak og nordlige del av Nordsjøen i årene 1968-1972. Thesis, Univ. Bergen. 77pp. [Mimeo.]

\- 1977. Spawning, egg production and stock size of mackerel (Scomber scombrus L.) in the North Sea 1968-1975. ICES, C.M. 1977/H:17 [Mimeo.]

\- 1981. Spawning and trends in spawning stock size of North Sea mackerel during the period 1973-1980. ICES, C.M.1981/H:16 [Mimeo].

\- 1982. Spawning and stock size of North Sea mackerel in 1981. ICES, C.M.1982/H:7 [Mimeo.]

IVERSEN,S.A. and ADOFF,G.R. 1983. Fecundity observations on mackerel from the Norwegian coast. ICES, C.M.1983/H:45 [Mimeo.]

IVERSEN,S.A. and ELTINK,A. 1983. Spawning, egg production and stock size of North Sea mackerel in 1982. ICES, C.M.1983/H:46 [Mimeo.]

LOCKWOOD,S.J., NICHOLS,J.H. and DAWSON,W.A. 1981. The estimation of a mackerel (Scomber scombrus L.) spawning stock size by plankton survey. J.Plankton Res. 3(2), 217-233.

MACER,C.T. 1976. Observations on the maturity and fecundity of mackerel (Scomber scombrus L.) ICES, C.M.1976/H:6 [Mimeo.]

MARTINS,M.M. and GORDO,L.S. 1983. On the fecundity of mackerel (Scomber scombrus) from the west continental coat of Portugal. ICES, C.M.1983/H:41 [Mimeo.]

MORSE,W. 1978. Fecundity of Atlantic mackerel (Scomber scombrus L.) in the Northwest Atlantic. ICES, C.M.1978/H:64 [Mimeo.]

PENNINGTON,M.R. and GROSSLEIN,M.D. 1978. Accuracy of abundance indices based on stratified random trawl surveys. ICES, C.M.1978/D:13 [Mimeo.]

TAYLOR,I., RICHARDS,P. and HALSTEAD,R. 1971. Computer routines for surface generation and display. Manuscript report series No. 16. Dept. of Energy, Mines and Resources, Ottawa, Canada.

ULLTANG,Ø. 1978. A note on the confidence limits of the egg production estimates from the mackerel egg surveys in the Western area. Working document presented at the ICES Mackerel Working Group 1978.

WALSH,M. 1983. Investigations on the fecundity of North Sea mackerel. ICES, C.M.1983/H:48 [Mimeo.]

WALSH,M., HOPKINS,P. and RANKINE,P. 1983. Results of the North Sea mackerel egg surveys in 1982. ICES, C.M.1983/H:49 [Mimeo.]

Table 1. The spawning periods of mackerel in the North Sea 1980-1983

Year	Period	Duration (days)
1980	30 May - 10 August	72
1981	25 May - 28 July	65
1982	17 May - 25 July	70
1983	17 May - 25 July	70

Table 2. Production estimates for 1982.

	Stage 1 eggs		Stage 2 eggs
Time	Manual method	EDB	EDB
17/5-82	0	0	0
24/5 - 9/6-82	$2.3 \cdot 10^{12}$	$2.8 \cdot 10^{12}$	$1.3 \cdot 10^{12}$
3/6 - 16/6-82	$2.4 \cdot 10^{12}$	$2.7 \cdot 10^{12}$	$3.1 \cdot 10^{12}$
16/6 - 30/6-82	$2.3 \cdot 10^{12}$	$2.9 \cdot 10^{12}$	$3.0 \cdot 10^{12}$
1/7 - 15/7-82	$1.1 \cdot 10^{12}$	$1.2 \cdot 10^{12}$	$0.8 \cdot 10^{12}$
17/7 - 30/7-82	$0.05 \cdot 10^{12}$	$0.1 \cdot 10^{12}$	$0.2 \cdot 10^{12}$
26/7-82	0	0	0
Total	$105 \cdot 10^{12}$	$126 \cdot 10^{12}$	$109 \cdot 10^{12}$
1000 tons	160	190	165

Table 3. Production estimates for 1983.

	Stage 1 eggs		Stage 2 eggs
Time	Manual method	EDB	EDB
17/5-83	0	0	0
25/5 - 4/6-83	$0.9 . 10^{12}$	$1.1 . 10^{12}$	$0.14 . 10^{12}$
4/6 - 23/6-83	$4.6 . 10^{12}$	$4.9 . 10^{12}$	$0.92 . 10^{12}$
24/6 - 1/7-83	$3.1 . 10^{12}$ *	$3.8 . 10^{12}$ *	$3.3 . 10^{12}$ *
2/7 - 9/7-83	$1.1 . 10^{12}$	$1.1 . 10^{12}$	$1.6 . 10^{12}$
25/7-83	0	0	0
Total	$142.4 . 10^{12}$	$160.5 . 10^{12}$	$88.5 . 10^{12}$
1000 tons	215	240	135

* This survey covered parts of the spawning area. Therefore the estimate based on this survey was increased by 40% to give a total egg production estimate.

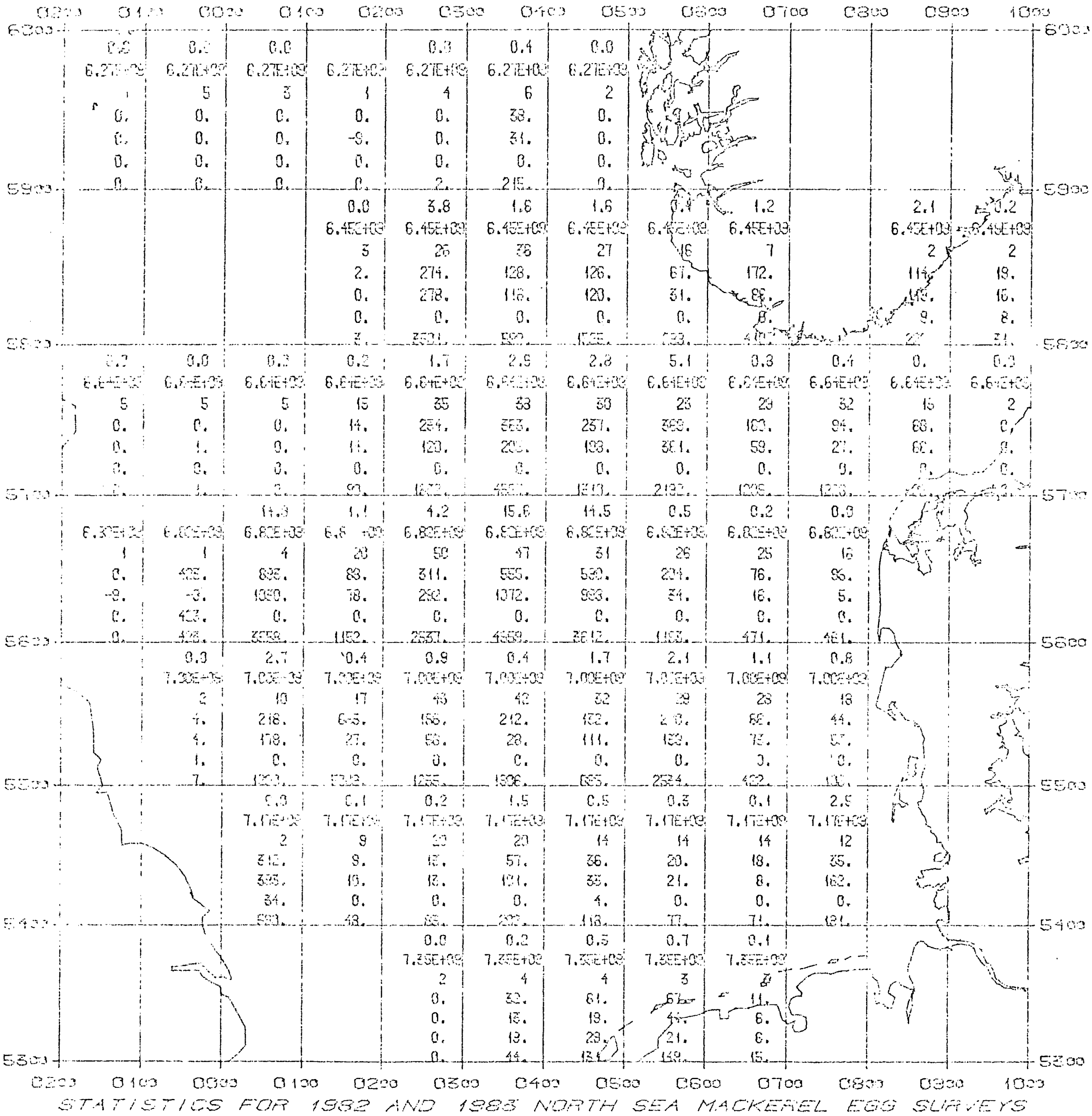

Fig. 1. Statistics for the 1982 and 1983 egg surveys in 1 x 1 degree rectangles. From top to bottom the figures are: Optimum percent of total effort (Neyman); area of rectangle in m^2; number of stations; mean number per haul (all stages); standard deviation; minimum value; maximum value.

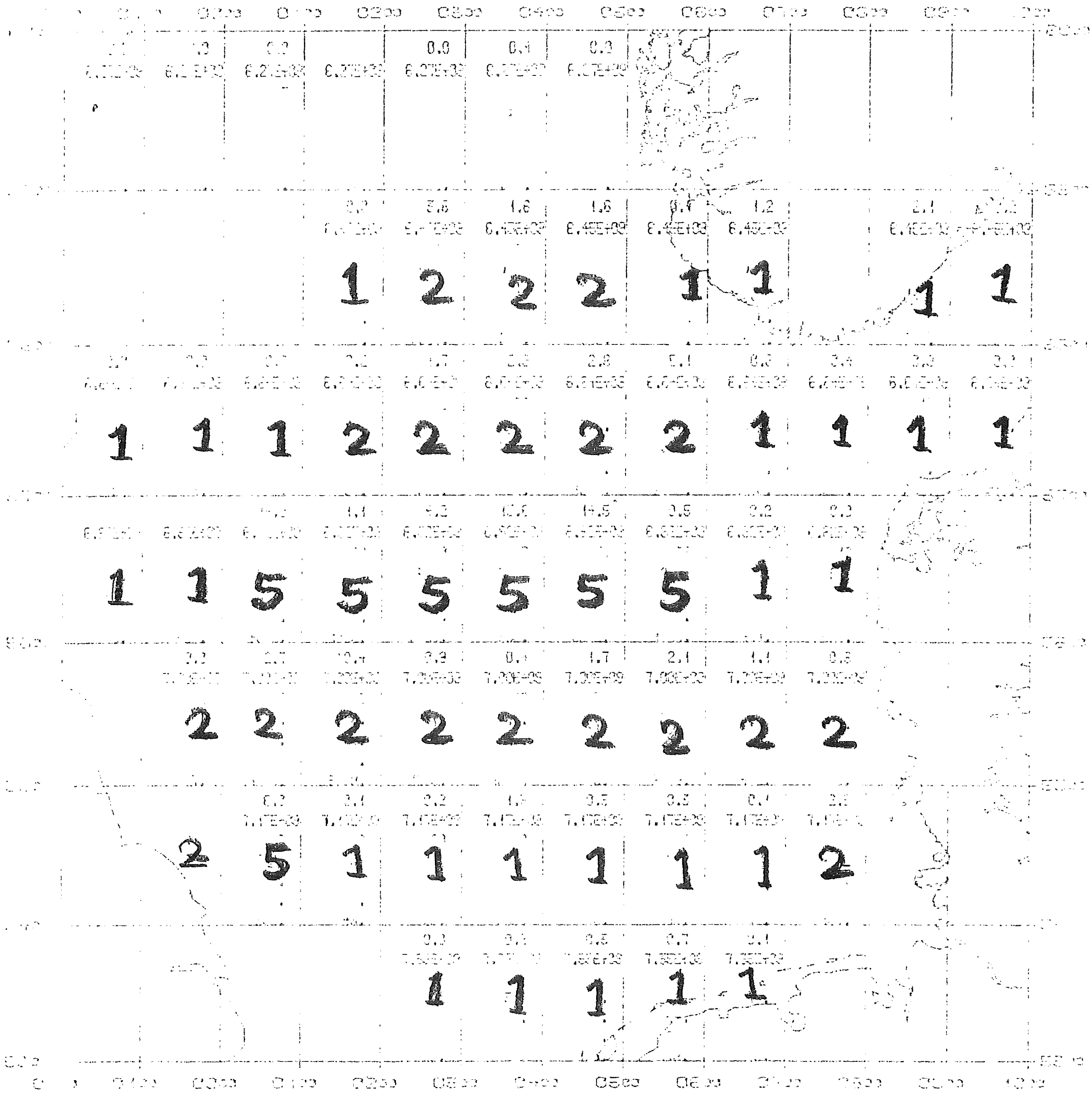

Fig. 2. Proposed sampling effort for the mackerel egg survey in the North Sea in 1984.

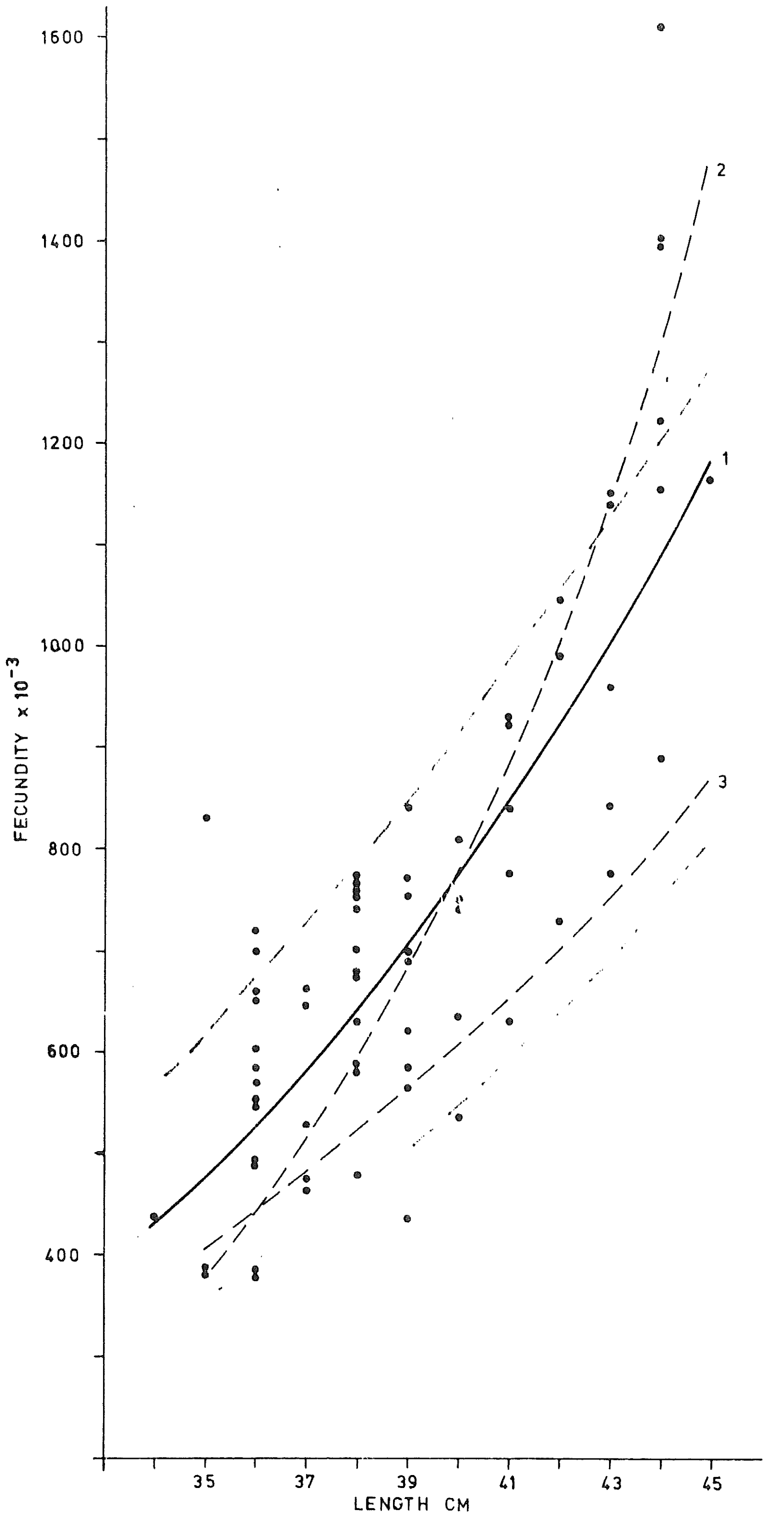

Fig. 3. The fecundity total length relation with the fitted curve (1) for North Sea mackerel (Iversen and Adoff, 1983). The other curves:

2) Northwest Atlantic mackerel (Morse, 1978),

3) Mackerel from west of Ireland (Lockwood & al., 1981),

4) Mackerel from west of Portugal (Martins and Gordo, 1983),

5) Mackerel from the Shetland area (Walsh, 1983).

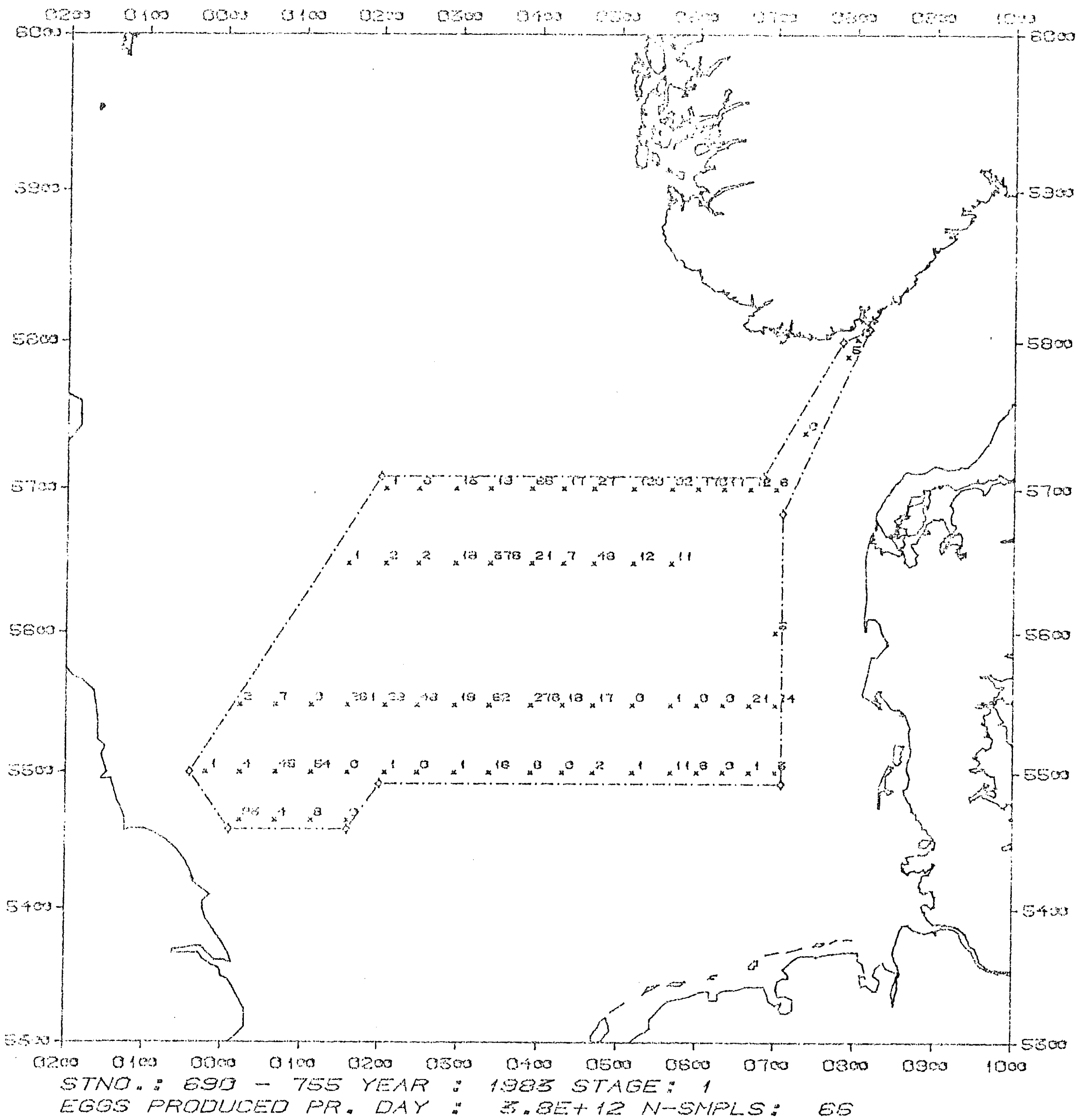

Fig. 4. The stations of the third egg survey in 1983 showing the number of eggs produced per day per square meter at each station. The polygon used to set parts of the grid undefined for this coverage is also shown.

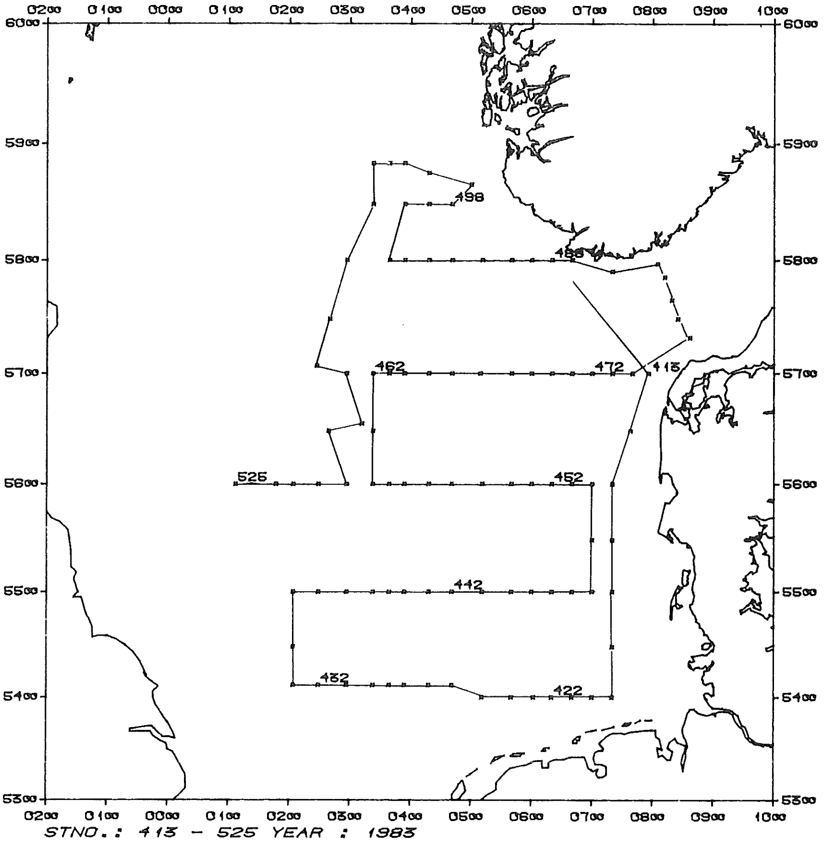

Fig. 5. Station grid first survey, 25 May - 4 June 1983.

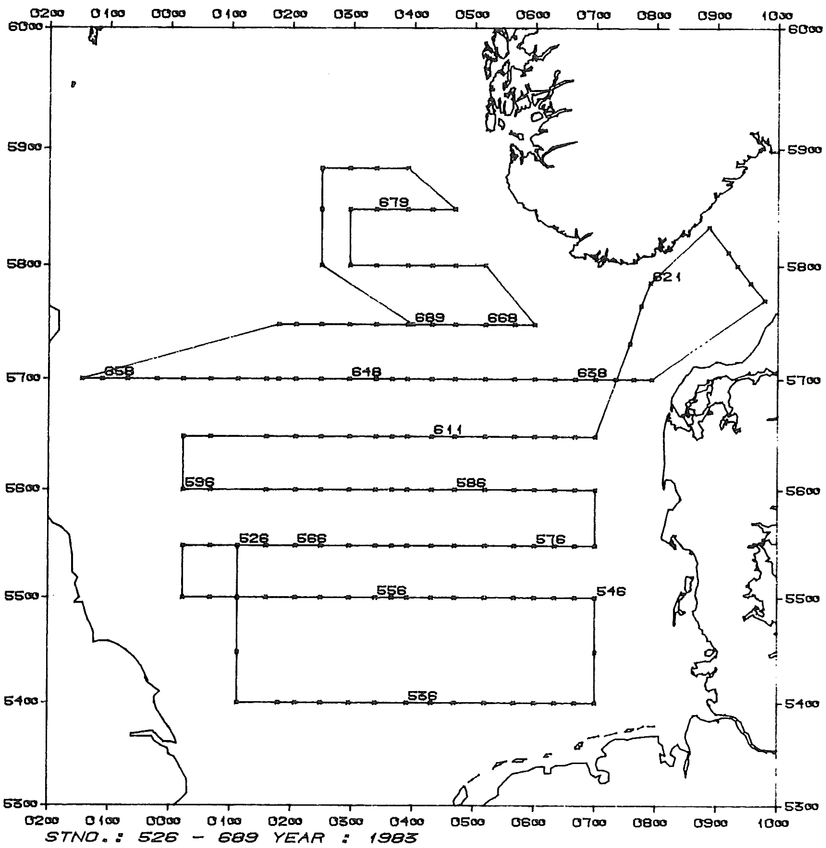

Fig. 6. Station grid second survey, 4 - 23 June 1983.

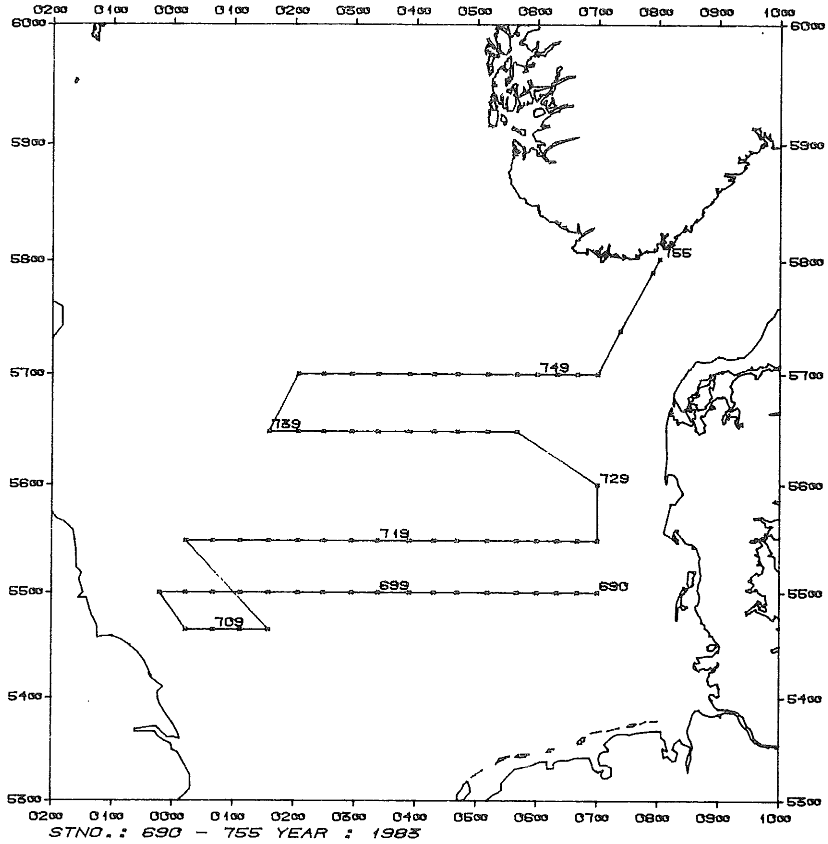

Fig. 7. Station grid third survey, 24 June - 1 July 1983.

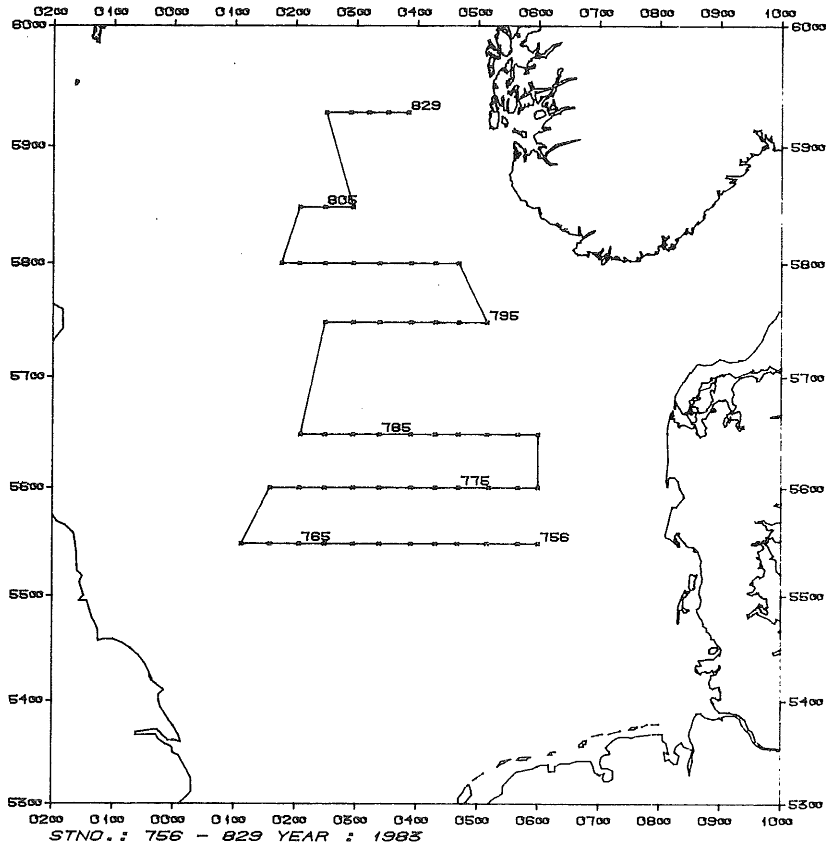

Fig. 8. Station grid fourth survey, 2 - 9 July 1983.

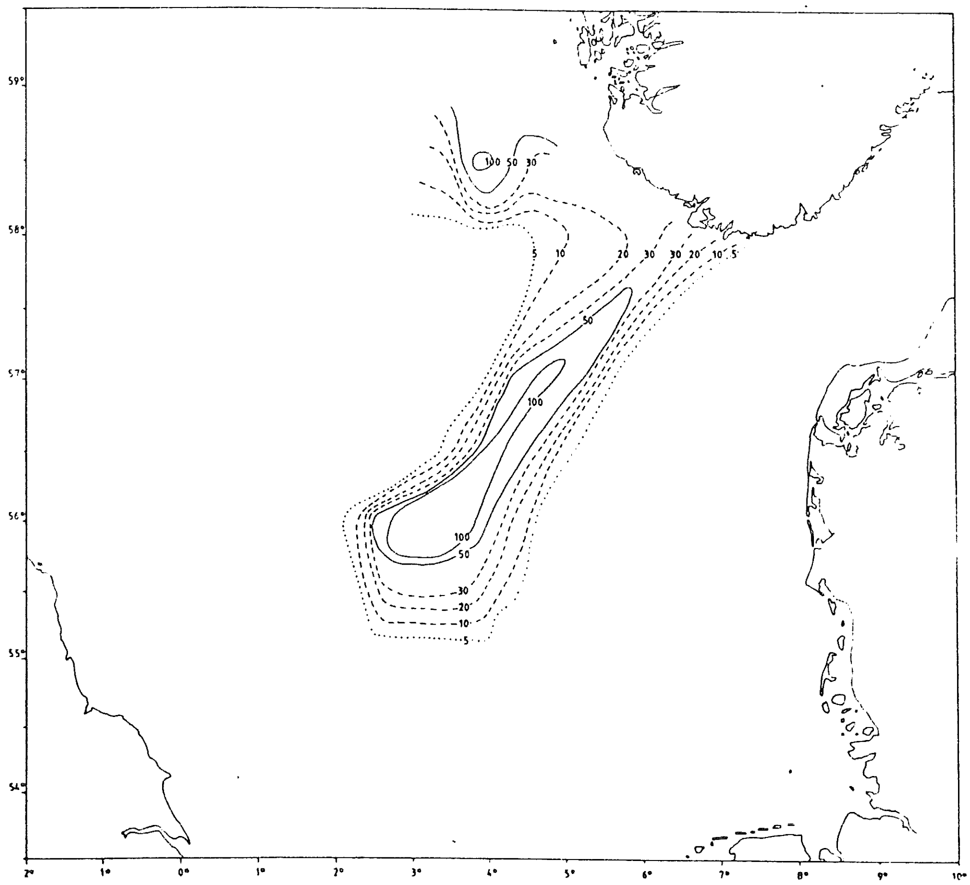

Fig. 9. The distribution of mackerel eggs, stage 1A and 1B, per square metre during the first survey.

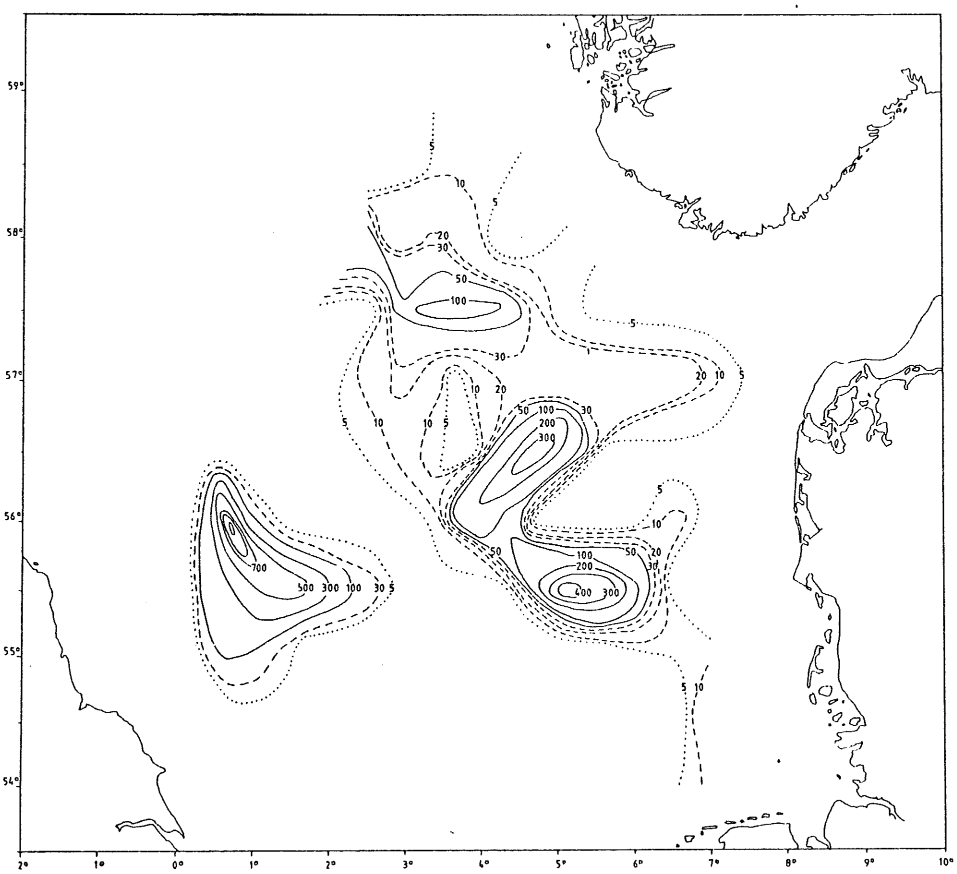

Fig. 10. The distribution of mackerel eggs, stage 1A and 1B, per square metre during the second survey.

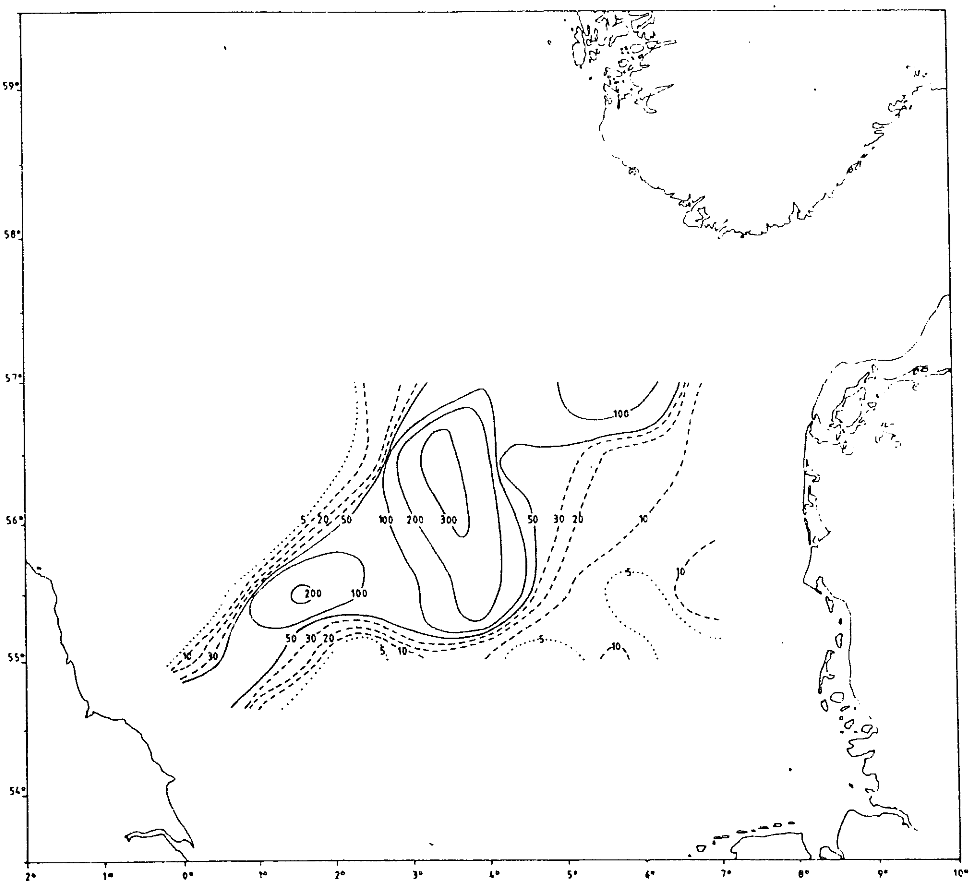

Fig. 11. The distribution of mackerel eggs, stage 1A and 1B, per square metre during the third survey.

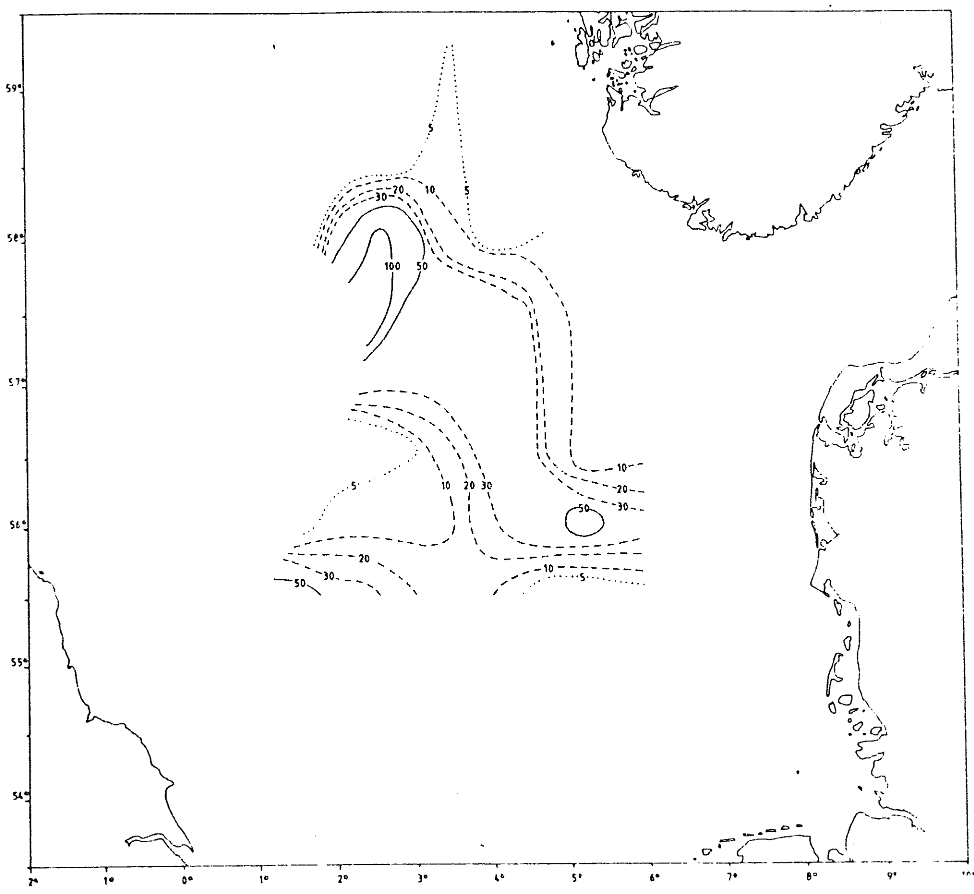

Fig. 12. The distribution of mackerel eggs, stage 1A and 1B, per square metre during the fourth survey.

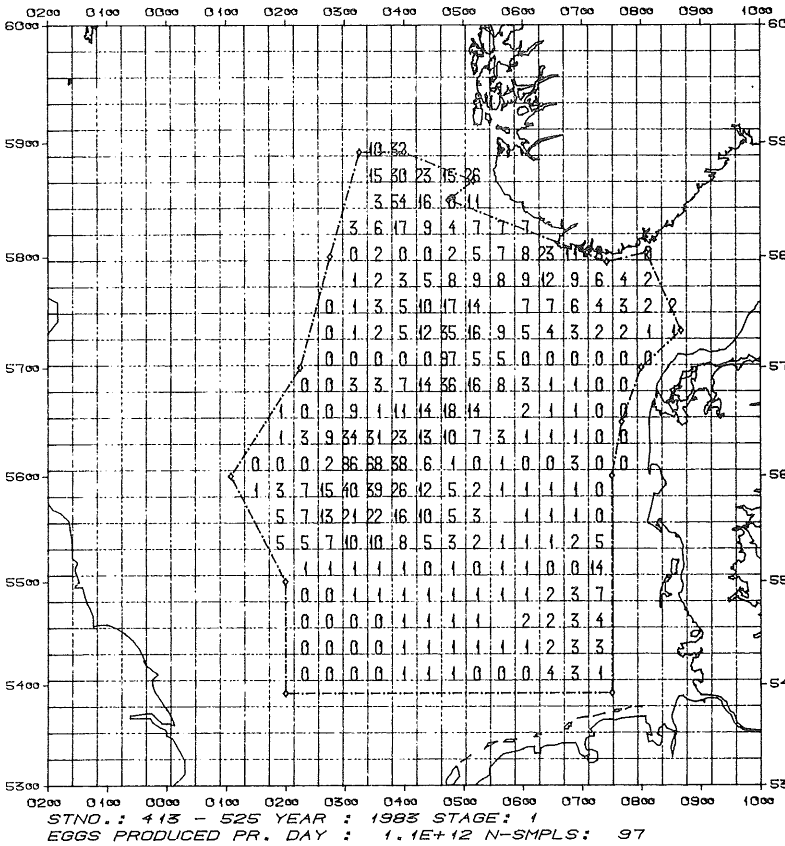

Fig. 13. Interpolated values of each grid intersection for the first survey in 1983.

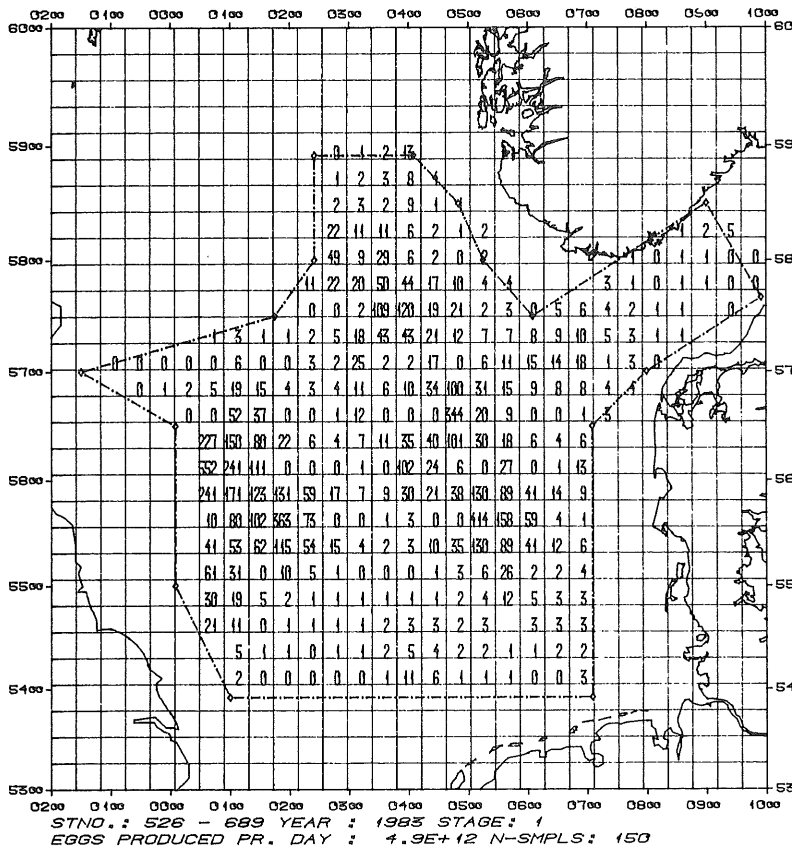

Fig. 14. Interpolated values of each grid intersection for the second survey in 1983.

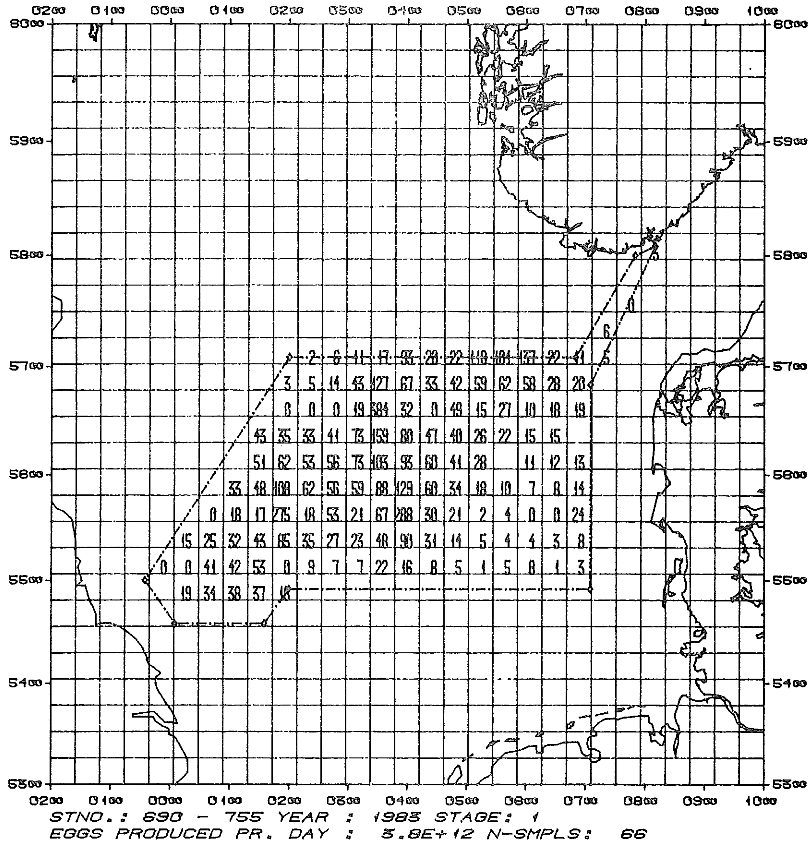

Fig. 15. Interpolated values for each grid intersection for the third survey in 1983.

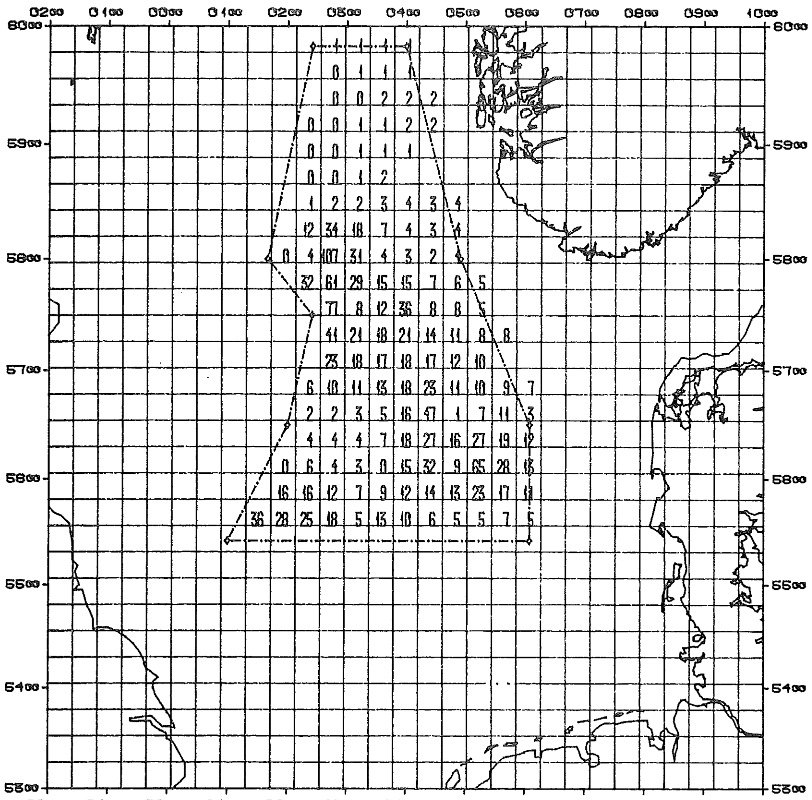

Fig. 16. Interpolated values for each grid intersection for the fourth survey in 1983.

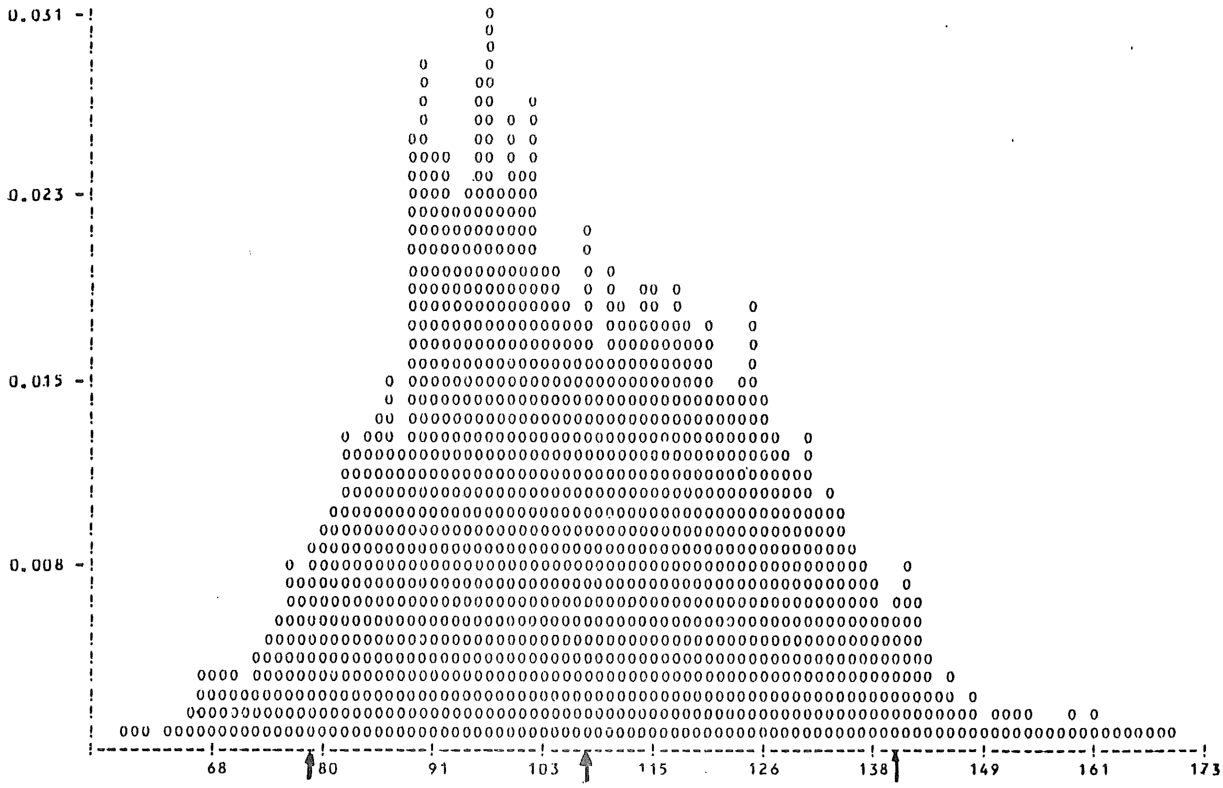

Fig. 17. Simulated sample mean distribution of the mackerel egg surveys in the North Sea in 1982. Mean, upper and lower 90 percent confidence limits of the distribution are indicated by arrows.

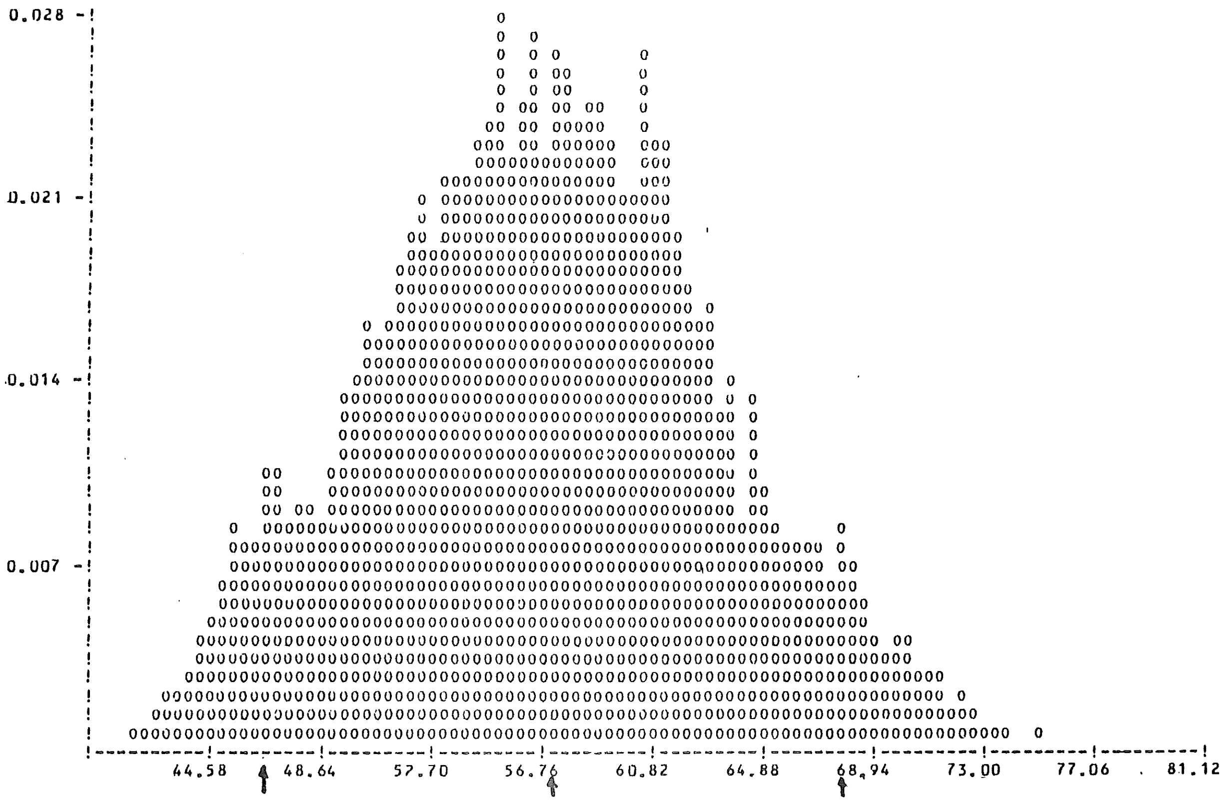

Fig. 18. Simulated sample mean distribution of the mackerel egg surveys in the North Sea in 1983. Mean, upper and lower 90 percent confidence limits of the distribution is indicated by arrows.