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HORSE MACKEREL EGG PRODUCTION AND SPAWNING STOCK SIZE IN THE NORTH SEA IN 1991

by

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Abstract

During the period 18 February to 11 July 1991 the spawning area of North Sea horse mackerel (*Trachurus trachurus* L.) was investigated by research vessels from the Netherlands and Germany. Based on the plankton samples and temperature observations obtained during this period the egg production and spawning stock size were estimated. The total horse mackerel egg production in 1991 of 195 x 10^{12} stage I eggs represents a spawning stock biomass of 247 thousand tonnes. In 1988, 1989 and 1990 egg surveys estimated the spawning stock biomass at 120, 217 and 255 thousand tonnes respectively.
The daily egg mortality was estimated at 32 % in 1991 compared to 30 % in 1988, 37 % in 1989 and 38 % in 1990.

Introduction

The annual egg production of horse mackerel in the central and southern North Sea was estimated by a series of egg surveys in 1988 (Iversen et al., 1989), in 1989 and 1990 (Eltink, 1990; Eltink, 1991) and in 1991. In 1988 and 1990 Norway and Denmark covered the main spawning area of mackerel in the central and northern North Sea, while the Netherlands covered the main spawning area of sole and horse mackerel in the southeastern part of the central North Sea and the southern North Sea. In 1989 and 1991 no complete egg survey was carried out for mackerel, but for horse mackerel and sole a complete coverage in time and area was achieved. Horse mackerel and sole spawn in the North Sea in the same area, but the peak of spawning of sole is about three weeks earlier (van Beek, 1989).

In this paper the annual egg production and the spawning biomass of horse mackerel is estimated from the 1991 North Sea egg surveys, which have been carried out by the Netherlands and Germany.

Material and Methods

The egg surveys in the central and southern North Sea were carried out during the period 18 February - 11 July 1991. The area was covered by six surveys encompassing the spawning period for both sole and horse mackerel. The timing, mid-dates and the number of hauls of the surveys are shown in the Table 1. The mid-dates were obtained from the dates of egg sampling, but weighted by the number of samples per day.

The station grid was planned in accordance with the strategy of having more intensive sampling in the high production areas. In order to achieve this, the samples were taken if possible in the middle of the 1/2, 1/4 or 1/8 ICES rectangles. Based on this strategy 1, 2, 3 or 4 samples could be taken in a half ICES rectangle. Figure 1 shows as an example the station grid of the fifth coverage with the 1/2, 1/4 and 1/8 ICES rectangles and Figures 2 - 4 show that most intensive sampling took place along the French, Belgian, Dutch, German and Danish coast and that the sampling intensity decreased further off shore.

A Dutch Gulf III high speed plankton sampler with a mesh size of 500 µm was towed at a speed of 5 knots in oblique hauls to about 5 m above the bottom. The sampler fished 3 minutes per 10 meter depth, but in shallow waters, where the haul duration was less than 10 minutes, more than one oblique haul was carried out. The plankton samples were preserved in 4% formaldehyde. The horse mackerel eggs were sorted into different developmental stages according to the description by Pipe and Walker (1987).

Using calibrated flowmeter readings to access the volume filtered per haul, the number of eggs in each stage was raised to numbers per m^3 and then converted to numbers per m^2 by multiplying with the bottom depth at each station. The number of eggs per m^2 were then raised to numbers produced per m^2 per day using the development equations for horse mackerel given by Pipe and Walker (1987):

Stage I	ln Time = -1.608 ln Temperature + 7.713
Stage II	ln Time = -1.548 ln Temperature + 7.927
Stage III	ln Time = -1.819 ln Temperature + 9.123
Stage IV	ln Time = -1.929 ln Temperature + 9.555

Where time is the age of the eggs at the end of each stage in hours and temperature is the temperature (^{0}C) at 5 m depth at the station where the eggs were sampled. The numbers produced per m^2 per day were then raised by the area of the 1/2, 1/4 or 1/8 ICES rectangles they represented and summed to give numbers in each stage produced over the total survey area for each of the six sampling periods.

To demonstrate any changes in spawning by time and by area, the total area was also divided in three sub-areas: the area south of 52^0 30' N, the central area and the area east of 6^0 00' E (Figure 1).

If more than one observation per 1/2, 1/4 or 1/8 ICES rectangle was available, the arithmetic mean of the observed values was used.

For each sub-area the stage I to IV egg production estimates of each survey period were plotted against the mid cruise date to give production curves (only for stage I eggs shown in Figure 5). These production curves of the three sub-areas were then combined for plotting the egg production curves for stage I, II, III and IV horse mackerel eggs for the total spawning area (Figure 6). The egg productions were calculated by integrating the area under the curves.

An extrapolation took place for the unsampled sub-area south of 52^0 30' N during the sixth coverage, which was not done for the surveys from 1988 - 1990. As in earlier years no extrapolation took place of unsampled rectangles around the sampled rectangles.

To estimate the spawning stock biomass of North Sea horse mackerel, the fecundity-weight relationship of 1655 eggs per gramme pre-spawning female was used, which has been estimated for the western horse mackerel by Eltink and Vingerhoed (1989). The total number of stage I eggs were then converted into a pre-spawning stock biomass, which was then increased by 5% to obtain the spawning stock biomass (Eltink and Vingerhoed, 1989).

For the estimation of the daily mortalities during each coverage and for all coverages combined the following procedure was followed:

Of each coverage the average duration of each egg stage was obtained by taking the mean of the egg stage durations of each 1/2, 1/4 or 1/8 ICES rectangle weighted by the number of eggs of that egg stage. The ln on the egg productions of each egg stage was plotted against the age of the eggs in days. The Z was obtained from the slope of a linear regression, which resulted in the daily egg mortality of each single coverage. For the total egg survey the average duration of each egg stage was obtained by taking the mean of the egg stage durations of each coverage weighted by the daily egg productions of each coverage.

Results

The distributions of horse mackerel eggs observed during the coverages 4 to 6 are shown in Figures 2 - 4.

Table 2 shows by sub-area the daily horse mackerel egg productions in millions by egg stage for each coverage, while Table 3 is showing these data for the total area together with the daily egg mortality of each coverage.

No horse mackerel eggs were found during coverage 1 - 3 (the first coverages were aimed to cover the egg production of sole). During the fourth coverage (mid-date 16 May) the onset of spawning was indicated in the southern and central sub-area (Table 2 and Figure 2). During the fifth coverage high egg productions were observed (Tables 2 and 3; Figures 3). During the sixth coverage (mid-date 10 July) still high egg productions occurred in the central and eastern sub-area (Tables 2 and 3 and Figure 4), but unfortunately the southern sub-area was not covered. This last coverage did not indicate the end of spawning as it did in earlier years.

Figure 5 shows the stage I egg production curves of the southern, central and eastern sub-areas. It demonstrates that the highest egg productions occurred in the southern and eastern part of the spawning area, while the central sub-area showed the lowest egg production.

Figure 6 shows the egg production curves for egg stages I - IV of the total area covered based on data from Table 3. The annual egg productions of each egg stage were calculated by integrating the area under these curves and are presented in Table 4 together with the annual egg productions of the 1988, 1989 and 1990 egg surveys.

Figure 7 shows the production curve for stage I horse mackerel eggs in 1990 and for comparison also the curves of 1988, 1989 and 1990.

The spawning stock biomass of horse mackerel in the North Sea in 1991 was estimated at 247,000 tonnes, when applying the fecundity-weight relationship mentioned above to the total stage I egg production of $195 * 10^{12}$ eggs, assuming a sex ratio of 1:1 and increasing the pre-spawning stock biomass with 5 % to obtain the spawning stock biomass (Table 5). The annual estimates of total stage I egg production, of pre-spawning and spawning stock biomass of North Sea horse mackerel during the period 1988 - 1991 are shown in Table 5.

Figure 8 shows the ln on the egg productions of each egg stage being plotted against the age of the eggs in days. The Z was obtained from the slope of a linear regression, which resulted in the daily egg mortalities of the egg surveys in 1988, 1989, 1990 and 1991 as presented in Table 4.

Figure 9 shows the mean sea water temperatures of each coverage in 1988 - 1991. Figure 10 shows also the mean sea water temperatures, but now weighted by the number of stage I eggs and therefore represents the temperature where actual spawning takes place.

Discussion

In 1988 for the first time several egg surveys in the North Sea were carried out that covered the spawning of the horse mackerel both in time and area. This survey resulted in a total egg production of 87 x 10^{12} eggs and a spawning stock size of 110,000 tonnes (Iversen et al., 1989). The daily egg production of each coverage in 1988 was estimated by a method described by Iversen and Westgaard (1984). The disadvantage of this method is that it calculates the egg productions in squares. When the highest egg production occurs close inshore as is the case for horse mackerel, then the egg production areas between the shore and the squares will not be included in the egg production estimate. Therefore, the annual egg productions of egg stages I - IV were recalculated for 1988, but now using the same method as applied to the 1989, 1990 and 1991 data to make these 1988 estimates comparable (Table 4). A revised annual egg production of 94 x 10^{12} stage I eggs and a revised spawning stock size of 120,000 tonnes in 1988 were estimated (Table 4 and 5). This revision increased the annual egg production of stage I eggs and also the spawning stock biomass by about 10 %.

The coverage of the spawning area and season in 1991 has not been as good as in the three earlier years. Spawning started later and ended also later than expected due to the cold spring. The onset of spawning did not occur during the third coverage as expected, but only during the fourth coverage. During the last and sixth coverage still a very high level of spawning was observed and therefore a last coverage was missing to indicate the end of spawning. Furthermore the eastern sub-area was not covered during the fourth period and the southern sub-area was not covered during the sixth period. For the unsampled eastern sub-area during the fourth coverage no eggs were assumed to be produced, because the onset of spawning was just indicated in the southern and central sub-area and in addition the eastern sub-area is expected to have relative low spawning at the beginning of the spawning season (see Figure 2 and Table 2). The error from this assumption on the final egg production and the spawning stock biomass is expected to be negligible. However, a large extrapolation took place for the unsampled southern sub-area during the sixth coverage, when spawning was expected to be nearly finished. The egg production of this unsampled southern sub-area was assumed to be equal to the extrapolated value obtained from the egg production of the fifth coverage and the point where spawning was expected to be finished (see Figure 5). If the actual egg production of this unsampled sub-area is assumed to have been within the range of 50 % above and 50 % below the extrapolated estimate, it would only affect the final total egg production and also the final biomass to be within the range of 13 % above and 11% below the egg production or biomass estimated. The assumption of the end of the spawning season was rather arbitrary, because there was no seventh coverage in the beginning of August to indicate this end of spawning. The duration of the spawning season in 1991 was assumed to have been 85 days. The assumed durations of the spawning season in 1988, 1989 and 1990 were respectively 91, 95 and 81 days.

As in earlier years no extrapolation took place of unsampled rectangles around the sampled rectangles. Therefore, the egg production and spawning stock biomass are likely to be underestimated since plankton sampling was not always continued until zero values were met at the edge of the station grid (Figures 3 and 4). This was especially the case in the southern area during the fifth coverage (Figure 3). The total horse mackerel egg production in 1991 of 195 x 10^{12} stage I eggs represents a spawning stock biomass of 247 thousand tonnes. In 1988, 1989 and 1990 egg surveys estimated the spawning stock biomass at 120, 217 and 255 thousand tonnes respectively.

Eltink and Vingerhoed (1989) estimated the fecundity-weight relationship of western horse mackerel at 1655 eggs per gramme pre-spawning female. This seems to be the most appropriate relationship to use although it is based on fish of the western horse mackerel population. This estimate is close to the recalculated fecundity of 1492 eggs per gramme female as estimated by Macer (1974) for the North Sea horse mackerel.

Also the threshold of 101 µm above which oocytes should be counted was relatively close to Macer's estimate of 118 µm. The fecundity estimate used was of potential fecundity rather than realized fecundity. Potential fecundity is the maximum number of oocytes which might be spawned in the current season, with no allowance for resorption (atresia) or de novo formation of developing oocytes. For potential fecundity it is assumed that the number of eggs destined to be spawned in a season is fixed as identifiable developing oocytes prior to spawning (Anon., 1991a). However, horse mackerel might be an indeterminant spawner and fecundity might therefore be higher (Eltink and Vingerhoed, 1989).

The daily egg mortality rates were low in 1988 and 1991 (32 % and 30 %) compared to those in 1989 and 1990 (37 % and 38 %). The lower daily egg mortalities in 1988 and 1991 are probably related to the lower sea water temperatures in those years (Table 4 and Figure 9).

Horse mackerel egg surveys have now been carried out from 1988 - 1991. A preliminary relation between spawning time/area and temperature can be described from this time series, because the hydrographical conditions have been very different during these years (Figure 9 and 10). Cold and mild water temperatures occurred in winter/spring and slow, average and strong water temperature increases occurred in spring/summer. The following can be observed from these limited available data:

* The onset of spawning appears to be about the end of April or the beginning of May (in 1988 and 1990), but if sea water temperatures remain low the onset of spawning might be retarded by about 3 weeks (in 1991). High egg productions seem to occur when water temperatures are above 12°C, while the onset of spawning starts already when water temperatures are far below 12°C (Figure 10).
* The egg distribution around peak spawning time reflects roughly the distribution of the spawning population. If the sea water temperatures stay relatively low until the second week of June (below 12°C) then the main egg production takes place in the southern sub-area where the temperatures are relatively higher (in 1988 and 1991). The higher the sea water temperatures the higher the egg productions in the central and eastern sub-areas (in 1989 and especially in 1990) (Eltink, 1990 and Eltink, 1991). Fish migrations from the English Channel into the southern North Sea, which take place prior to spawning, seem to be related to temperature. Fish seem to migrate further north and east in case of high water temperatures, but seem to remain south in case of low water temperatures.
* The peak of spawning seems to coincide roughly with the first three weeks in June, but might also be retarded by about 3 weeks due to very low sea water temperatures.
* The end of spawning already can be reached already in the third week of July if water temperatures have been high over a long time period (in 1990). Probably the spawning season ends generally at the end of July, but can also be retarded till the second week of August (in 1991). The duration of the spawning season seems to be approximately between 80 and 95 days. High temperatures at the beginning of the spawning season probably synchronize spawning and therefore shorten the spawning season.

The increase in biomass from 1988 to 1989 and 1990 could not be explained by an incoming strong recruiting year class (Anon., 1991b). The eggs of horse mackerel have been distributed much more northward in 1989 and 1990 possibly due to higher water temperatures. The egg surveys during these years seem to have covered most of the egg production. However, in 1988 when low water temperatures occurred, spawning seemed to have taken place predominantly in the southern sub-area. The relative low biomass estimate from the 1988 egg survey, being about twice as low as the estimates of the three following years, might have been caused by relatively more spawning in the English Channel in 1988, which area was not covered by the egg surveys. Again in 1991 low temperatures seem to have caused predominant spawning in the southern sub-area. Therefore, the 1991 survey might also have been underestimated severely.

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Table 1. The timing of the North Sea egg surveys by the Netherlands and Germany in 1991.

Ship name	Coverage 1	2	3	4	5	6
Isis (Netherlands)	18/2-21/2	18/3-22/3	15/4-26/4	13/5-22/5	11/6-20/6	8/7-11/7
Tridens (Netherl.)	-	18/3-22/3	15/4-19/4	15/5-17/5	-	-
Solea (Germany)	-	-	-	-	28/5-13/6	-
Number of hauls	39	89	133	67	124	47
Mid-dates	20/2	20/3	20/4	16/5	12/6	10/7
Days after 1/1/91	51	79	110	136	163	191

Table 2. Daily horse mackerel egg productions (millions) by coverage and by egg stage for the three sub-areas of the North Sea egg surveys in 1991.

Sub-area	Coverage	I / day	II / day	III / day	IV / day
South of 52° 30'N	1	0	0	0	0
South of 52° 30'N	2	0	0	0	0
South of 52° 30'N	3	0	0	0	0
South of 52° 30'N	4	1 458	309	0	0
South of 52° 30'N	5	2 864 764	342 117	202 912	86 865
South of 52° 30'N	6	not covered	not covered	not covered	not covered
Centre	1	0	0	0	0
Centre	2	0	0	0	0
Centre	3	0	0	0	0
Centre	4	4 697	685	36	0
Centre	5	514 026	116 724	61 329	24 761
Centre	6	405 581	69 610	81 494	15 496
East of 6° 00'E	1	0	0	0	0
East of 6° 00'E	2	0	0	0	0
East of 6° 00'E	3	0	0	0	0
East of 6° 00'E	4	not covered	not covered	not covered	not covered
East of 6° 00'E	5	394 987	63 947	44 612	7 722
East of 6° 00'E	6	1 323 752	274 130	123 513	27 108

Table 3. Horse mackerel egg productions (* 10^6) per day for egg stages I - IV and daily egg mortalities for each of the coverages of the North Sea egg surveys in 1991.

Coverage	Mid-date	I / day	II / day	III / day	IV / day	Daily egg mortality
1	20/2/91	0	0	0	0	- %
2	20/3/91	0	0	0	0	- %
3	20/4/91	0	0	0	0	- %
4	16/5/91	6 156*	994*	36*	0*	51 %
5	12/6/91	3 773 777	522 787	308 852	119 348	28 %
6	10/7/91	3 186 845#	517 799#	308 244#	86 798#	42 %

* Area east of 6° E not covered by egg survey and assumed to have no egg production.

\# Area south of 52° 30′ N not covered. Given estimates include extrapolated values for the southern area.

Table 4. Annual horse mackerel egg productions (* 10^{12}) for the egg stages I - IV and the daily egg mortalities of the North Sea egg surveys from 1988 - 1991.

Year	Annual Stage I	Annual Stage II	Annual Stage III	Annual Stage IV	Daily egg mortality
1988	94.4 #	25.1	10.9	4.3	30 %
1989	170.9	35.2	15.4	4.4	37 %
1990	201.2	45.7	14.1	5.2	38 %
1991	194.8	29.2	17.3	5.8	32 %

\# = revised from Iversen et al., (1989).

Table 5. Annual estimates of total stage I egg production, of pre-spawning and spawning stock biomass of North Sea horse mackerel derived from the North Sea egg surveys from 1988 - 1991.

Year	Annual stage I egg production (* 10^{12})	Horse mackerel pre-spawning stock biomass (* 10^3 t) ©	Horse mackerel spawning stock biomass (* 10^3 t) $
1988	94 #	114	120 #
1989	171	207	217
1990	201	243	255
1990	195	235	247

© Using the weight fecundity relationship of 1655 eggs per g pre-spawning female (Eltink and Vingerhoed, 1989) and a sex ratio of 1:1 (Anon., 1990).

$ Spawning stock biomass adjusted using the relative weight of pre-spawning and spawning fish on the spawning grounds (increase of 5%) (Eltink and Vingerhoed, 1989).

\# Revised from Iversen et al., (1989).

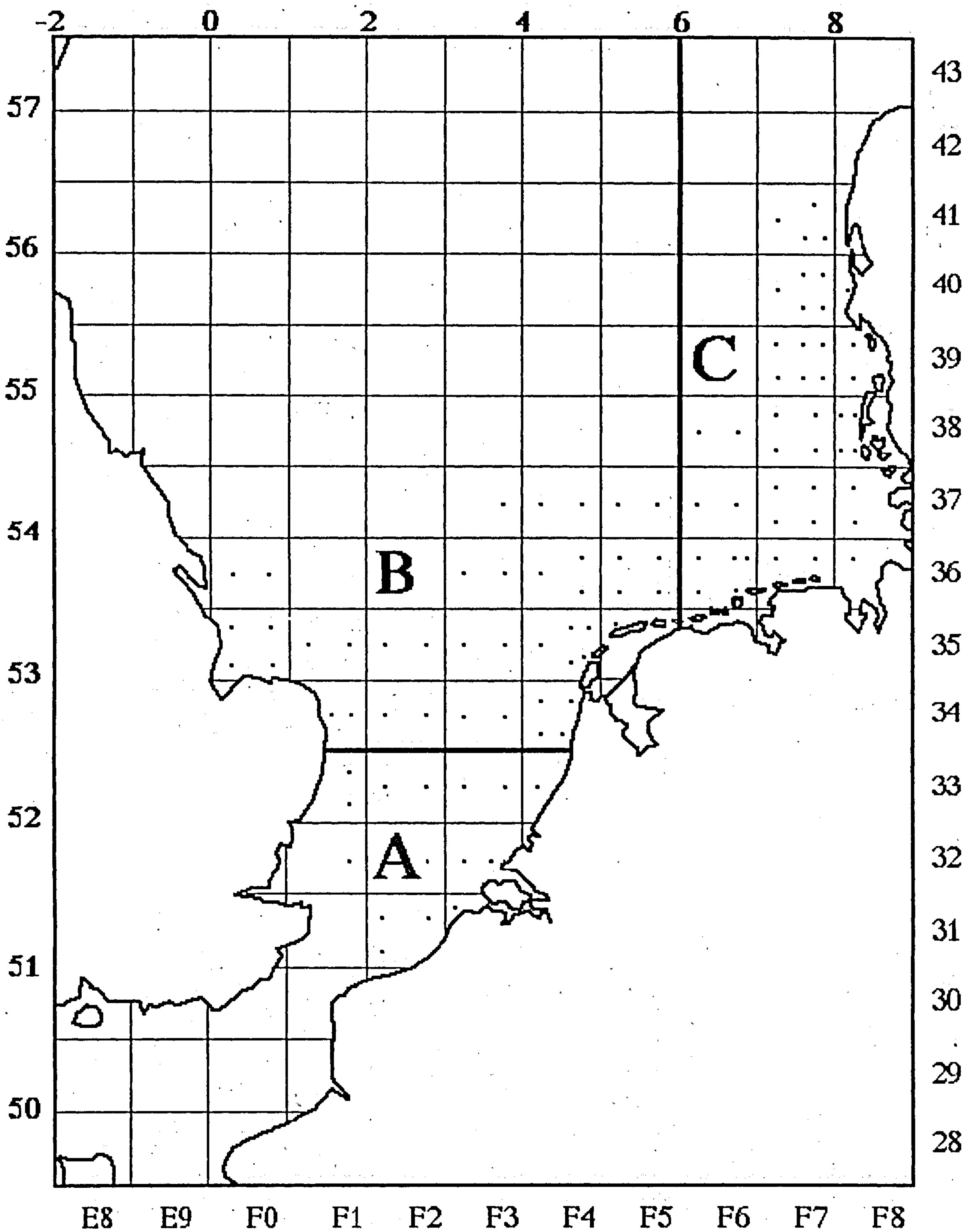

Figure 1. The area covered by the North Sea egg surveys is divided in three sub-areas (stationgrid of the fifth coverage as example):

A. The southern area south of 52° 30' N
B. The central area
C. The eastern area east of 6° E

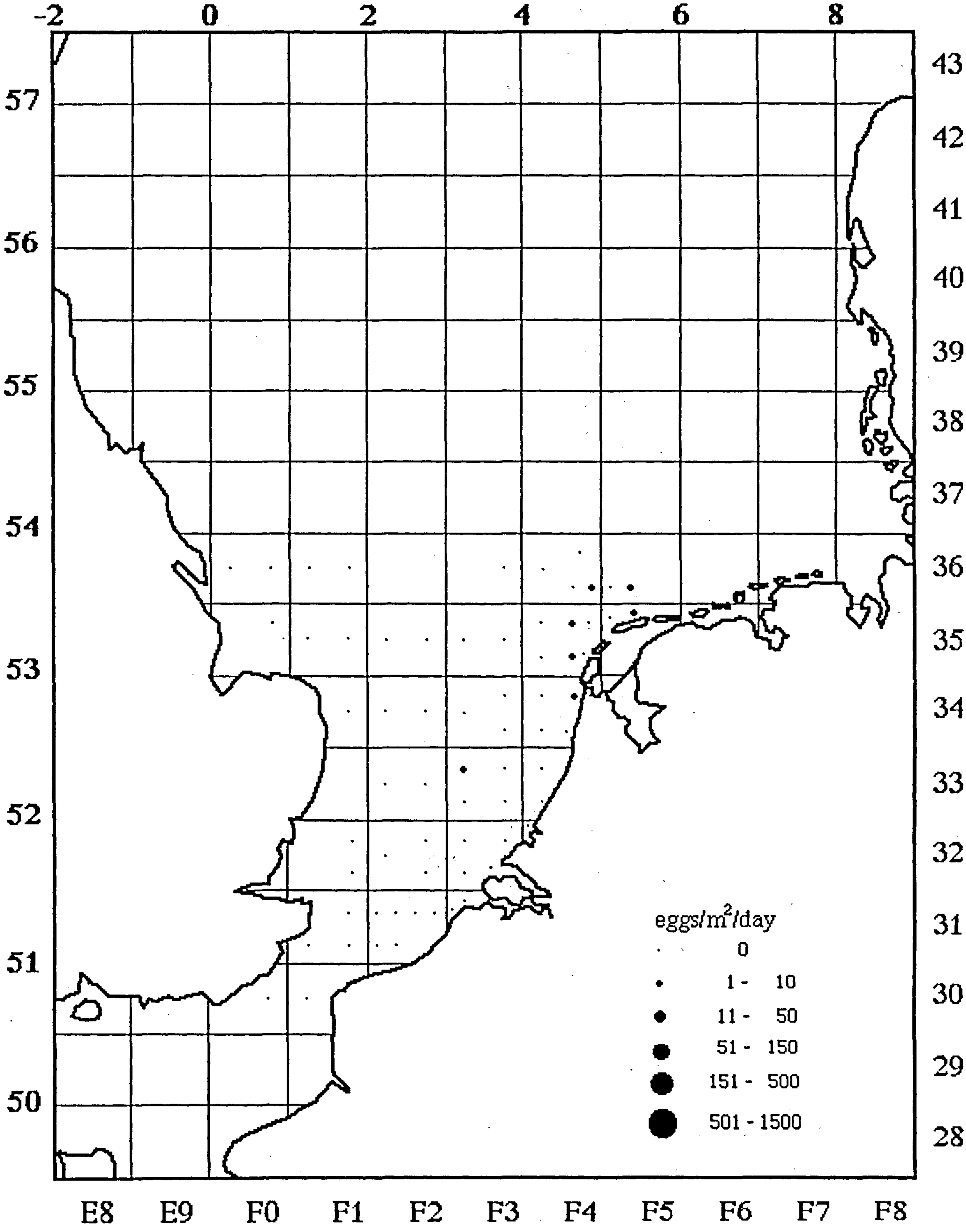

Figure 2. The distribution of stage I horse mackerel eggs as numbers per m^2 per day for survey period 4: 13 May 1991- 22 May 1991

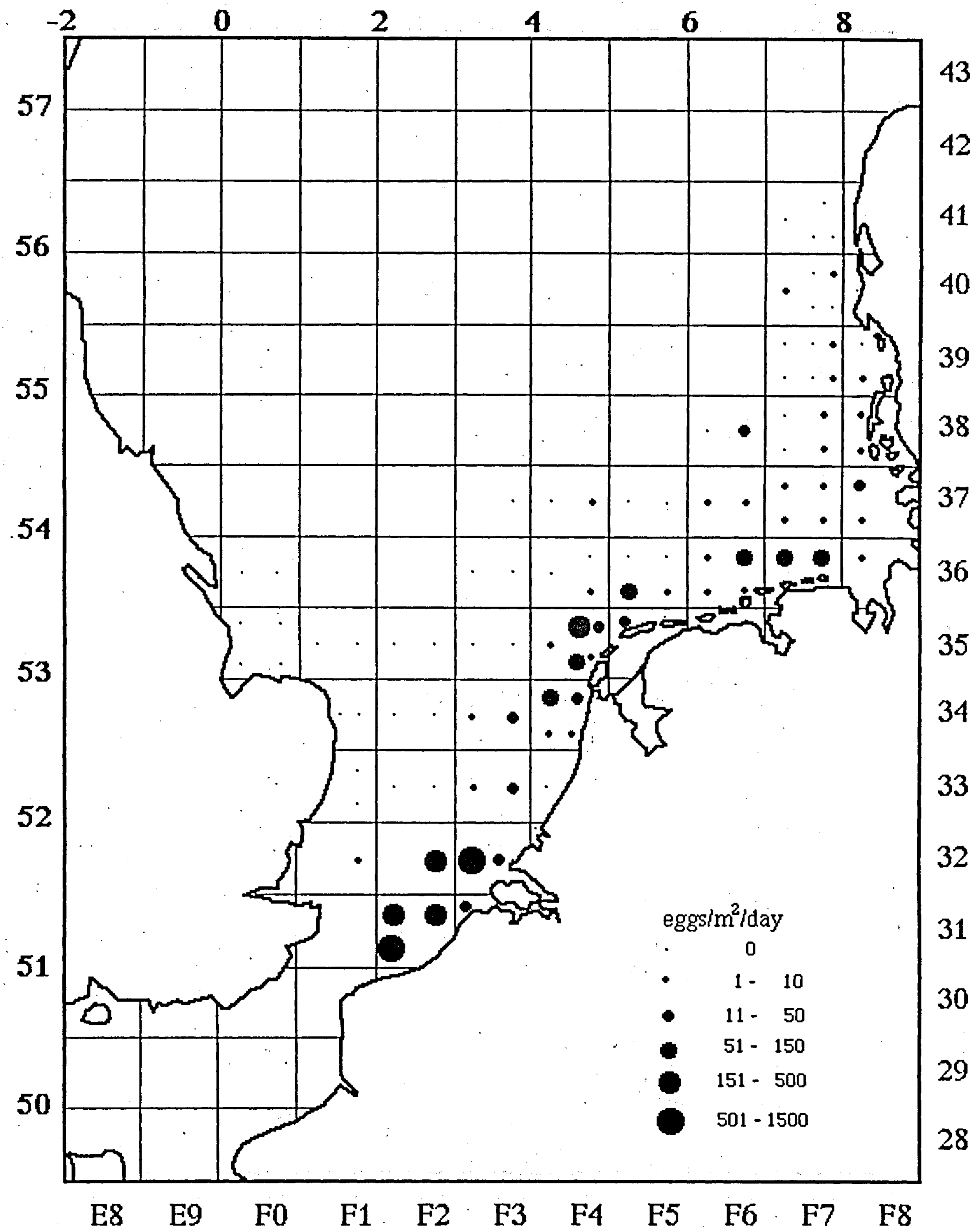

Figure 3. The distribution of stage I horse mackerel eggs as numbers per m^2 per day for survey **period** 5: 28 May 1991- 20 June 1991

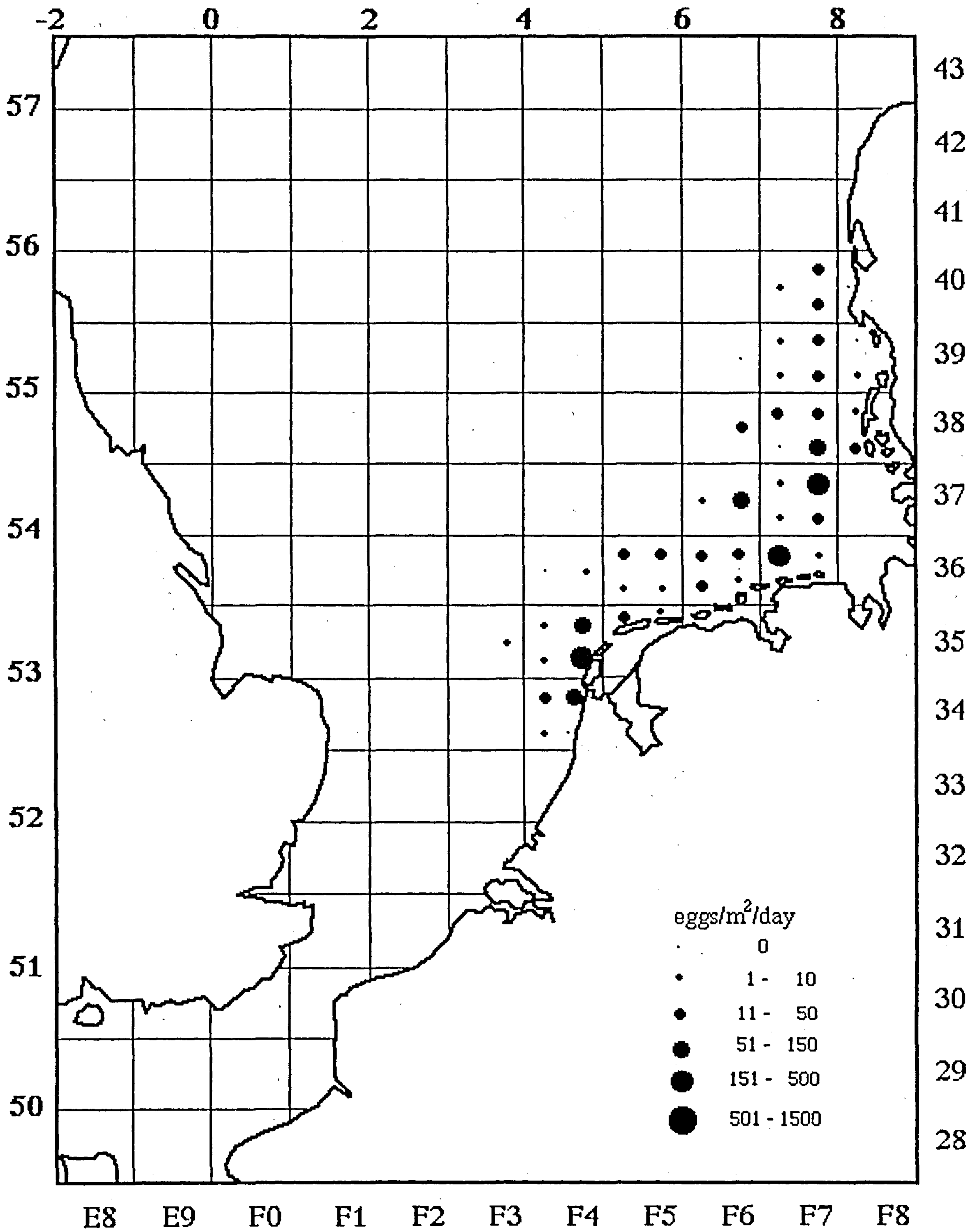

Figure 4. The distribution of stage I horse mackerel eggs as numbers per m^2 per day for survey **period 6**: 8 July 1991- 11 July 1991

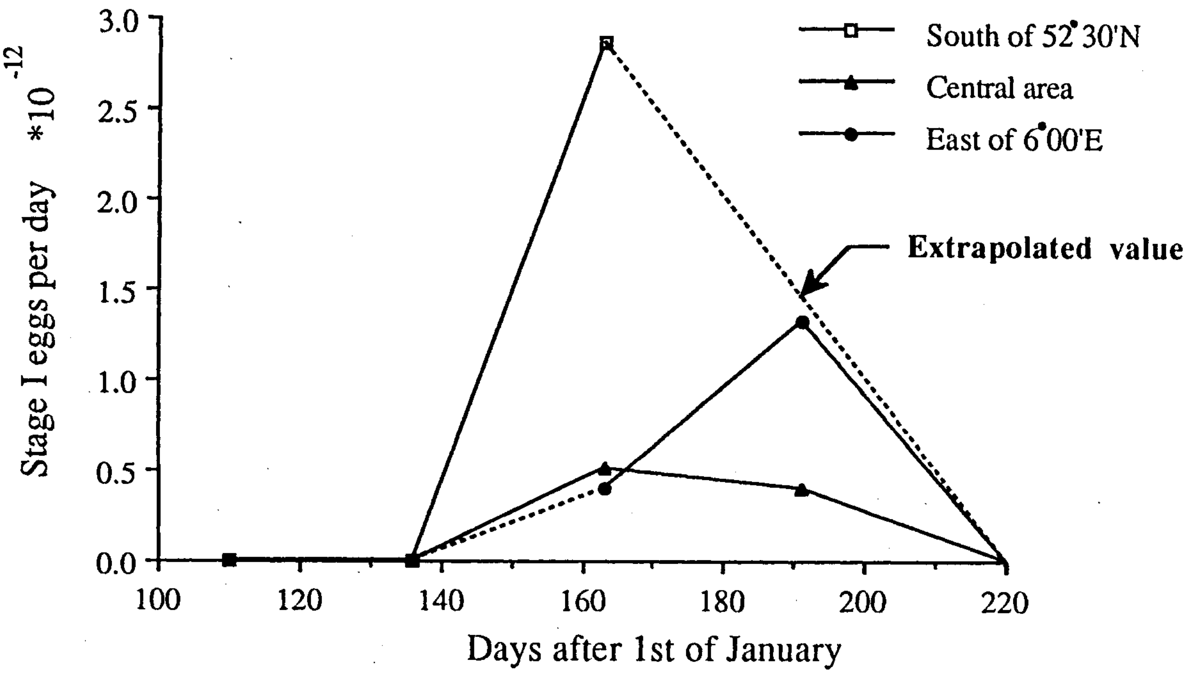

Figure 5. Production curves for stage I horse mackerel eggs for the southern, central and eastern sub-areas in the North Sea in 1991.

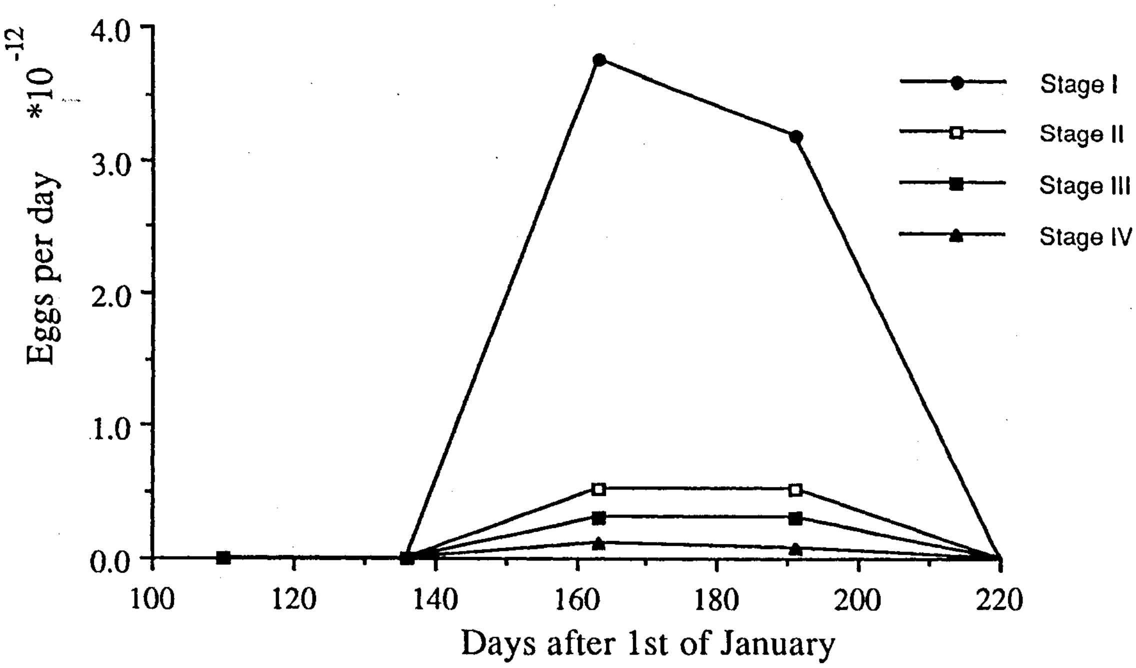

Figure 6. Production curves for stage I, II, III and IV horse mackerel eggs for the total area covered by egg surveys in the North Sea in 1991 (including extrapolated value for uncovered area during last survey). The total egg productions are for stage I eggs $194.8 \cdot 10^{12}$, for stage II eggs $29.2 \cdot 10^{12}$, for stage III eggs $17.3 \cdot 10^{12}$ and for stage IV eggs $5.8 \cdot 10^{12}$.

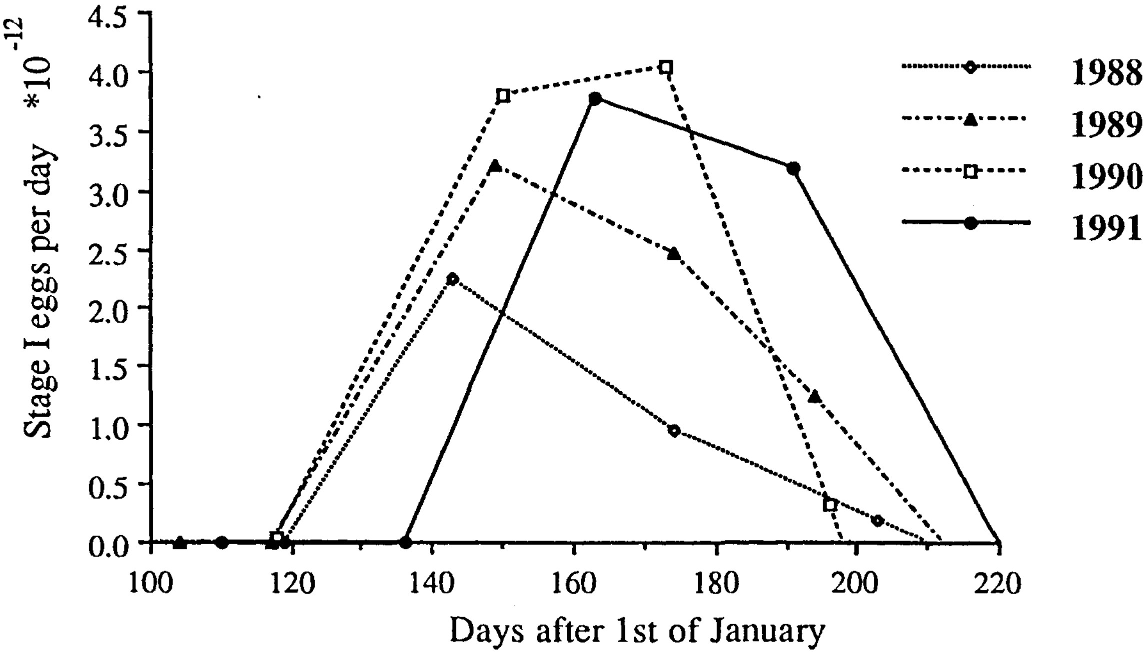

Figure 7. Production curves for stage I horse mackerel eggs for the the total area covered by egg surveys in the North Sea in 1988, 1989, 1990 and 1991. The egg productions are respectively $94 \cdot 10^{12}$, $171 \cdot 10^{12}$, $201 \cdot 10^{12}$ and $195 \cdot 10^{12}$ stage I eggs.

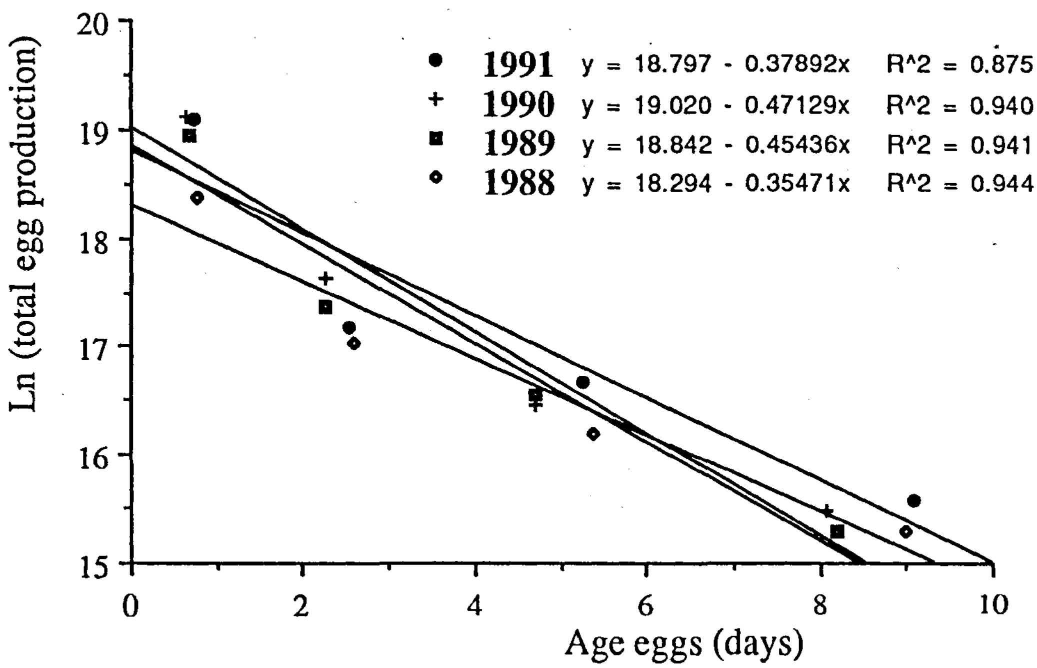

Figure 8. The ln on the total egg production of egg stage I, II, III and IV plotted against the age of the eggs in days.
The daily egg mortalities are 30%, 37%, 38% and 32% respectively for the whole survey periods in 1988, 1989, 1990 and 1991.

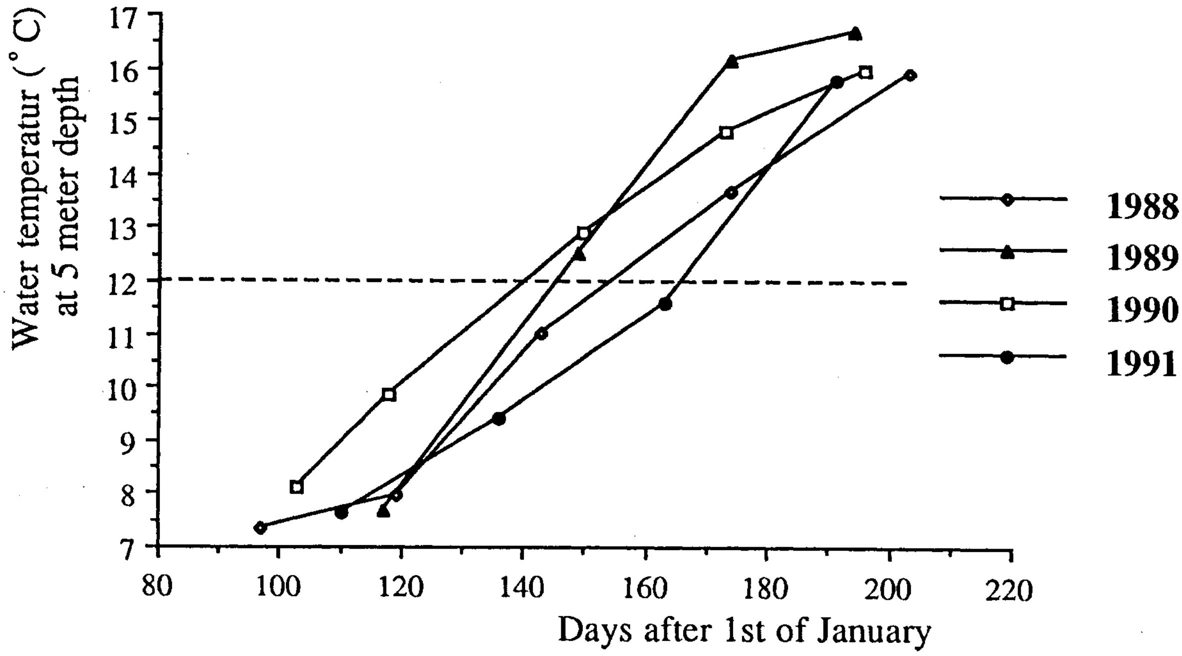

Figure 9. The mean sea water temperatures at 5 meter depth during the North Sea egg surveys in 1988 -1991.

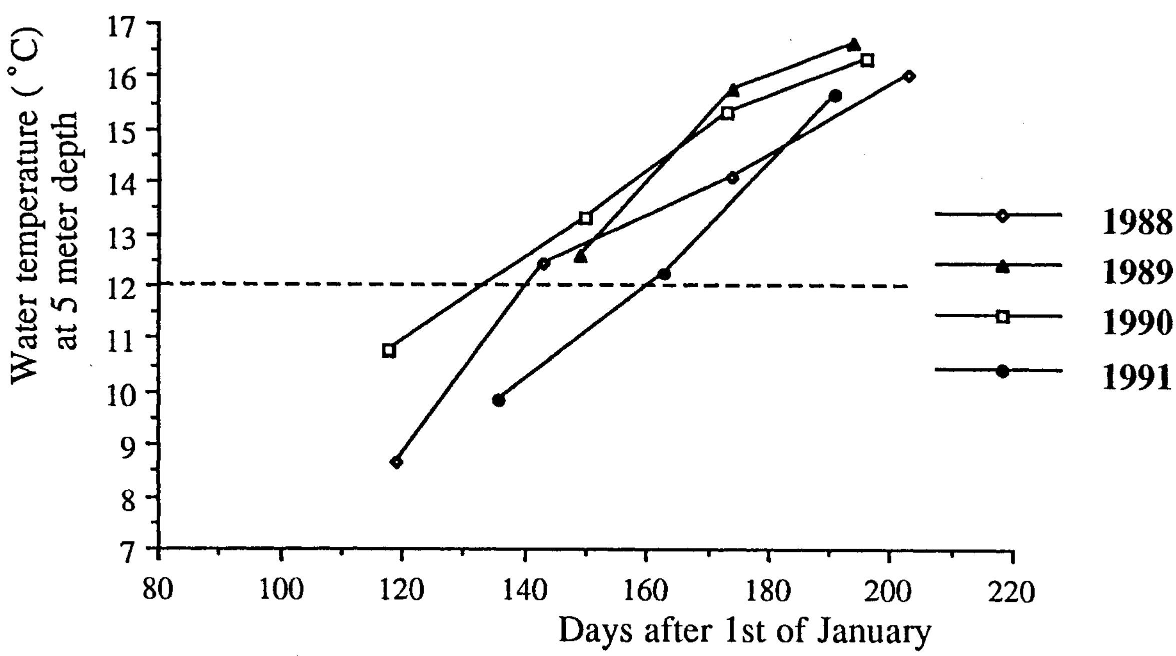

Figure 10. The mean sea water temperatures at 5 meter depth during the North Sea egg surveys in 1988 - 1991, but now weighted by the number of stage I horse mackerel eggs.