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Mackerel (Scomber scombrus) egg abundance in the southern Gulf of St. Lawrence from 1979 to 1986, and the use of the estimate for stock assessment

by

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Abstract

Mackerel egg surveys carried out in the southern Gulf of St.Lawrence from 1979 to 1986 have been analysed in an attempt to calculate seasonal egg production and its precision, and to assess the possibility of using the data in estimating the size of the stock. For each station, for each cruise, the daily production was estimated from the corrected number of stage 1 eggs, i.e. the observed number of stage 1 eggs in the sample added to the number of dead or deformed eggs, and the duration of the stage, which is a function of the sea surface temperature, at the station. In order to obtain an estimate of the variance of the total egg production, a post-stratification of the survey area was realized using the mean density of stage 1 eggs at each station for the period from 1979 to 1986 as the stratification variable. Three strata corresponding to concentric zones of different egg densities were designed over the area. The square root transformation was used to normalize the data within the stratum. The estimation of the mean and the variance within the stratum and the estimators for the whole population, i.e. total number of eggs produced, the variance, and the confidence interval, were calculated according to the procedure outlined for a stratified sampling method. The total egg production for the season was obtained by locating the median date of a cruise, which corresponds to the time of the daily egg production, in relation with the date of peak spawning. The daily egg production associated to the area under the reproduction curve located at the point of the mid-cruise date, was then extended to the total egg production, i.e. the total area under the curve within 2s of the spawning cycle. The results show an increasing trend in the annual production of makerel eggs beginning in 1983. This increasing trend is also noted in other abundance indices of the stock.

Résumé.

Les croisières d'échantillonnage des oeufs de maquereau réalisées dans le sud-ouest du Golfe Saint-Laurent entre 1979 et 1986 ont été analysées afin de calculer la production saisonnière d'oeufs et la précision du calcul, et pour évaluer la possibilité d'utiliser les données pour l'évaluation du stock. A chaque station, pour chaque croisière, la production journalière a été estimée à partir du nombre corrigé d'oeufs de stade 1, c'est-à-dire le nombre observé d'oeufs de stade 1 auquel est ajouté le nombre d'oeufs morts ou déformés trouvés à la station, et de la durée du stade, qui est fonction de la température en surface, à la station. Afin d'obtenir un estimé de la variance de la valeur de production totale d'oeufs, une post-stratification de la zone d'échantillonnage a été faite en utilisant comme variable stratificatrice la densité moyenne d'oeufs de stade 1 à chaque station pour la période de 1979 à 1986. Trois strates correspondant à des zones concentriques de différentes densités ont été dessinées sur la zone. Une transformation racine-carrée a été utilisée afin de normaliser les données à l'intérieur des strates. L'estimation de la moyenne et de la variance intra-strate, ainsi que le calcul des paramètres pour l'aire totale, c'est-à-dire le nombre d'oeufs total produit, la variance et les intervals de confiance, ont été calculés selon les procédures définies pour l'échantillonnage stratifié. La production totale d'oeufs pour la saison est obtenue en situant la date médiane de la croisière, qui correspond au moment de la production quotidienne estimée, par rapport à la date du maximum de ponte. La production quotidienne d'oeufs, représentant l'aire sous la courbe de reproduction située au point de la date médiane de la croisière, est par la suite élevée à la production totale d'oeufs, c'est-à-dire à la surface totale sous la courbe comprise entre deux fois l'écart-type de la durée du cycle de ponte. Les résultats montrent une tendance à un accroissement de la production annuelle d'oeufs de maquereau qui semble débuter en 1983. Cette tendance est aussi en accord avec les autres indices d'abondance pour ce stock.

Introduction

An attempt to outline a method of calculating total mackerel egg production in the Gulf of St.Lawrence has been made before (Maguire 1981). Unfortunately, the results were inconclusive and the method proved to be of little use for estimating the size of the mackerel stock. The major objection to that approach is that the sampling gear (Miller nets) and the technique used (discrete depth sampling) were not relevant to the assessment work intended. Furthermore, the significance of between year variations in egg abundance estimates could not be evaluated since no confidence limits were provided by the model used for those estimates.

From 1979 to 1986 mackerel egg and larva sampling cruises were conducted over a network of stations and an effort was made to concentrate the cruise dates during mackerel peak spawning time. Standardizing the sampling was a first step to improve the accuracy of egg abundance estimates. However, a procedure providing a measure of the variability of the estimate of egg abundance still had to be developed if those estimates were to be used for the assessment of the stock.

In this work, data from the mackerel egg surveys carried out in the southern Gulf of St.Lawrence from 1979 to 1986 were analysed in an attempt (1) to assess a method of calculating seasonal egg production,and (2) to determine the precision of the estimate and assess the possibility of using the data on mackerel egg production for estimating the size of the stock.

Methods

a) plankton sampling;

A network of 65 stations was designed over the southwestern Gulf of St.Lawrence to cover the zone identified as the area of mackerel spawning and egg distribution (Fig. 1). The stations were evenly spaced twenty miles apart and each represents a sea surface area ranging from 2.1 E+9 m^2 to 13.4 E+9 m^2.

Table 1 presents the cruise dates and the sampling effort (number of stations) sampled at each occasion. A systematic sampling plan was carried out during each cruise so that each station be sampled at least once during a cruise. However, depending on ship time available up to two full coverages of the grid were achieved in some years (Table 1).

Mackerel eggs were sampled using 61cm diameter Bongo nets (MARMAP style) fitted with 333 microns mesh size nets and General Oceanic flowmeters, permitting estimation of the volume of water filtered at each tow. At each station an oblique tow, from the water surface to a maximun of 50 m (according to station depth) was carried out. The samples were immediately preserved in a 10% formaldehyde solution. Sea surface temperatures and for some years XBT temperature profiles were also taken at each station.

b) estimation of stage 0 egg density (daily egg production at a station);

For each station, each year and each cruise the data available for analysis were the number of mackerel eggs separated by developmental stages over a unit (m^2) area of sea surface. The staging of the mackerel eggs was done according to the following criteria:

stage 1: fertilization to closure of blastopore;
stage 2: embryo covers half the egg circumference;
stage 3: end of stage two to the lifting of tail from yolk;
stage 4: from end of the preceding to hatching;
stage 5: deformed eggs.

These stages correspond to four of the six stages recognized by Lockwood and Nichols (1977) in their study of development rates of mackerel egg as a function of temperature. Illustrations drawn from their photographs are presented in Annex 1a.

The problems caused by the presence of large numbers of dead or deformed (stage 5) eggs at some stations have been recognized before (Maguire 1981). In that study, stage 5 eggs which showed the presence of an embryo were considered as being stage 1 eggs and grouped with those eggs in the calculations. Since no recent information allows us to question the validity of that procedure it was also adopted here.

The first step in the procedure to calculate a daily egg production estimate is to determine the incubation time of the eggs at each station. Since there was no direct information on the development rate of mackerel eggs in the Gulf of St. Lawrence, an equation relating the incubation time to the water temperature was derived from Worley (1933) data - see Annex 2 - on developmental time of mackerel eggs from the Wood Hole region. The resulting equation is:

$$\ln(It)=-1.87 \ln(T^{o}) + 9.67$$

where "It" is the incubation time in hours and "T^o" is the water temperature at the station (at the surface or averaged over the first 10 m according to the data available).

Knowing the incubation time, the duration of each of the developmental stages at any station could be obtained. First, the relative duration of each stage is needed. Data from the literature were again used since the information for the stages presented here was not available for the southern Gulf. So, the developmental curves produced by Lockwood and Nichols (1977) -Annex 1b - were used to evaluate the relative duration of our four developmental stages. The results are as follows:

stage 1;	16.4 %	of	total	incubation	time
stage 2;	11.6 %	"	"	"	"
stage 3;	49.7 %	"	"	"	"
stage 4;	22.3 %	"	"	"	"

Those values are very similar to those of Ware and Lambert (1985), if we assume that their stage 1 egg correspond to stages 1 and 2 in this study. It seems then reasonably safe to accept these data as good estimations of the correct values for the Gulf of St. Lawrence.

The data from which the daily egg production (stage 0) had to be estimated are the numbers of stage 1 egg at each station (Anon 1987). When the incubation time is known along with the duration of stage 1 at a station, it is then possible to backcalculate the total number of egg originally spawned at that station.

The value of 0.36 originally used as an instataneous mortality rate for mackerel egg (Maguire 1981) agrees very well with a more recent estimate of 0.38 by Ware and Lambert (1985) The original relation presented was therefore used again in this study, i.e.:

$$E_0 = E_1.\exp\ (0.36.T)$$

where "E_1" is the number of stage 1 eggs at the station, "T" is the duration of stage 1 at the station, in days, and "E_0" the original number of egg spawned (daily production) at the station.

c) estimation of total daily egg production;

A first approach to calculate the daily egg production for the entire spawning area is to multiply the value obtained at a station by the surface surrounding that station (Maguire 1981). The method is believed to be without any important bias since no particular statistical distribution pattern is assumed for the data on egg abundance for a given survey, and also due to the fact that each estimate is somewhat weighted by the relative importance of the sea surface area represented by each station. A problem with this method however is that it is impossible to evaluate the variance or the precision of the annual estimate.

Another problem with this method is the absence of data for a given number of stations in some years, resulting in differences through the years in the total surface compared. Two methods for the estimation of the missing values were used in the analysis. First, when only one or two stations were missing for a given survey the geometric mean of the data from adjacent stations was calculated and used as the production at the missing station. When a part of the area was not sampled during a cruise, the production estimate for that cruise was corrected by a factor calculated as the proportion of the production contributed by the same stations when they were sampled in the first or the second survey of the same year.

If it were possible to obtain an estimate of the variance and confidence intervals for the method of multiplying station egg abundance by station surface, this would provide the best way to estimate the total daily egg production for the whole area. Unfortunately, this is impossible with a single sample for a given station for one cruise. An alternative to this might be to design a stratification scheme for the stations sampled during these surveys. The stratification technique permits the calculation of the variance of the population statistics, as it may also produce a gain in precision of the estimates since the purpose of the stratification is to divide a heterogeneous population into componants which are assumed homogeneous.

The sampling area in the southern Gulf was not initially stratified by any auxiliary variable, so a post-stratification of the region was realized for the purpose of this study. The stratification variable chosen was the mean density of stage 1 egg at the stations for the period of 1979 to 1986. The procedure for stratum delimitation was taken from Frontier (1983). The calculation and the results are illustrated in Annex 3. The estimation of the total daily egg production, the variance, and the confidence intervals were calculated according to the procedure outlined for a stratified sampling plan (Frontier 1983; Cochran 1977), where: (suffix 'h' denotes the stratum and 'i' the unit (station) within the stratum).

1) the number of stage 0 eggs stadardized at each station represents the sampling unit [y_i/n_i]

2) the number of units sampled in a stratum is 'n_h', i.e., $n_h = n_i + n_{i+1} + n_{i+2} + \ldots\ldots$

3) the sampling fraction per stratum 'f_h' is 'n_h/N_h', where 'N_h' is the total number of units or the stratum surface (E+9 m^2)

4) the stratum weight 'W_h' is 'N_h/N', where 'N' is the total area surface (6.945 E+10 m^2).

5) the sample mean (within stratum) is:

$$\bar{y}_h = \sum_{i=1}^{h} y_i/n_i$$

6) the sample variance (within stratum) is:

$$s^2_{\bar{y}h} = \sum_{i=1}^{h} (y_i - \bar{y}_h)^2/n_h-1$$

7) the population mean and variance are then calculated by the weighted summation of the means and variances of each stratum:

$$\bar{Y} = \sum_{h=1}^{k} W_h \; y_h$$

$$V_{\bar{Y}} = \sum_{h=1}^{k} W_h^2 \; s^2_{\bar{y}h}/n_h$$

8) the number for the entire population is obtained by the relation:

$$\hat{Y} = N.\bar{Y}$$

9) the variance of the estimated population total is calculated by the relation:

$$V_{\hat{Y}} = N^2.V_{\bar{Y}}$$

10) finally the confidence intervals for the population total are then evaluated as follows:

$$\hat{Y} \pm t_{(\alpha/2)}\sqrt{V_{\bar{Y}}}$$

where the t-value is read from tables of Student's 't' , with the effective number of degrees of freedom chosen as the smallest of the (n_h-1) values (Cochran 1977).

However the best results from a stratified sampling design are obtained when the within stratum populations are really homogeneous, i.e. when the observed data vary little from one unit to another (Cochran 1977). In order to improve the homogeneity of the data within the strata we used the square root transformation. The arithmetic mean within a stratum and its variance were then backcalculated by the relations derived from equations given in Hoyle (1968):

$$\bar{c} = \bar{y}^2 + s/n$$

$$v_{\bar{c}} = (4\bar{y}^2 s/n(n-1))+((2s^2/(n-1)(n+1))[n-2/n^2]$$

where; 'y' and 's' are respectively the mean and the residual sum of squares of the square root transformed data, and 'n' the number of stations sampled in the stratum (Hopkins, pers. comm.). The estimation of the total production and the variance are then calculated following the techniques outlined above.

d) estimation of seasonal (total) egg production

From the total daily egg production over the entire area we can calculate the total production for the entire spawning period. To do this we need to know the shape of the spawning cycle for the southern Gulf mackerel population, the duration of spawning and the moment of maximum spawning for every year. Mean spawning duration was estimated by Maguire (1981) to be 28 days with a standard deviation of 7 days. The shape of the seasonal spawning cycle is believed to be normal (Maguire 1981; Ware and Lambert 1985). What we needed to determine was the date of the maximum spawning activity for a given year. Since it was not possible to obtain this value for each year an alternative was to determine a long term mean date of the maximum spawning for the years available (1979 to 1986).

The mean abundance of stage 1 eggs per sampling day in the area of maximum egg densities (strata 5 and 6, Annex 4a and 4b) was calculated for the period from 1979 to 1986. A square root transformation was then used to normalize the data. The trans-

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formed data were then plotted as a function of the sampling dates in the area. In order to complete the data matrix (since none of the cruises from 1979 to 1986 covers the entire range of the spawning season) extreme values (zeros) obtained from Maguire (1981) were added to the graphic to mark the beginning and the end of the spawning cycle. The date of maximum spawning was then estimated by fitting a curve to the distribution (Annex 5).

Finally, once the date of maximum spawning is determined, the estimation of the total egg production for a given season is obtained by locating the median date of the cruise, which is associated to the daily production estimation for that cruise, in relation to the date of maximum spawning.

The area under the curve located at the point of the mid-cruise date was calculated using the density function of a Gaussian distribution curve as presented by Maguire (1981):

$$Y_t = (1/s\sqrt{2\pi}).\exp^{-0.5[(D-D')^2/s^2]}$$

where: D = the date corresponding to the daily production.
D'= the date of maximum spawning.
s = the standard deviation of the spawning cycle (=7 days).
Y_t= area under the curve corresponding to the date of the daily egg production.

the value was then extended to the total egg production for that year, i.e. the total area under the curve within 2s of the spawning cycle, or Y_{max}=0.95, with the relation:

$$(Y_{max}/Y_t).\text{Daily production.}$$

Results and discussion

a) distribution of stage 1 eggs and total egg abundance per station

Figures 2 to 8 show the distribution of stage 1 eggs, total egg densities, and the sea surface temperatures for each year and cruise from 1979 to 1986. Although differences in overall abundance between the years are present, the spatial distribution of mackerel eggs appears consistent over the period. The pattern consists of a persistant area of high egg density in Baie des Chaleurs and central southwestern Gulf, surrounded by zones of lower densities at the boundaries of the spawning area. This particular distribution of the eggs is almost identical to the pattern found in the earlier report of Maguire (1981) for the years 1970 to 1979. So, the zones of different densities discriminated by the stratification of the area (Annex 4a and 4b) are certainly a good representation of the reality.

In addition, it appears that the relationship between egg distribution and sea surface temperatures is rather loose (Fig. 2 to 8), justifying in a sense the decision to use the mean densities of stage 1 eggs as the best criterion for the stratification of the zone instead of temperature.

b)total daily egg production

Table 2 summarizes the estimates of total daily egg production calculated from the "station surface" X "station egg density" method. With the exeption of 1982/A and 1986/A, these estimates present relatively little fluctuations through the years However, it is difficult to compare the data from different years since we did not know the relative precision of these estimates. The objective of the stratification was to overcome this problem.

The sampling area was first divided in 6 discrete strata based on the class intervals identified from the frequency distribution of the mean stage 1 egg densities at the stations (Annex 3). The total daily egg production for each year based on the 6-stratum post-stratification design are shown in table 3a. The values are very similar to those estimated from the "station surface" X "station egg abundance" method. Egg production estimates appear reasonably accurate through the years with coefficient of variation ranging from a minimum of 8.9 % in 1985 (first cruise) to a maximum of 24.2 % for 1983.

Moreover, starting in 1984, the relative precision of the estimates increases due probably to a more uniform distribution of the eggs over the entire area (Fig. 2 to 8), which itself appears to be related to the relative increase in mackerel egg abundance observed since 1983.

However, a closer look at the stratification results for each year reveals that for some years in some strata the variances of the means are still very high (Table 4). This suggests that the precision of the estimates could still be improved.

Unfortunately, by subdividing the area in 6 strata, the number of stations included in each stratum becomes relatively low which rendered inappropriate a transformation of the raw data to reduce the variance within strata. To overcome this, the number of strata was reduced from 6 to 3 by grouping stratum 1 with stratum 2, stratum 3 with 4, and stratum 5 with 6. This was also advantageous as it produced a more recognizable geographical pattern of concentric zones of different egg densities (Annex 4b).

Grouping the strata had at first little effect on the values of the estimates of the variances as shown in table 3b. However, by increasing the numbers of stations within each stratum it was possible to apply the square-root transformation to the data in an attempt to reduce the variance within the stratum thereby increasing the precision of the total daily egg production estimates for each year and cruise.

Table 5 shows that the square root transformation method was very efficient for normalizing the data within individual strata, resulting in a significant reduction of the variance of the mean densities within the stratum (Table 6). Because of the gain in precision achieved by using this transformation, values of table 6 were the ones retained for the estimation of the daily egg production of each cruise.

Table 7 presents the total daily egg production values estimated with the mean densities within stratum calculated from square root transformed data. As it can be seen, the gain in precision is impressive with coefficients of variation ranging from 2.3 % to 5.1 %. This is not unreasonable considering that, at least at the spatial scale of the sampling, the range of the egg density estimates is relatively narrow and that the distribution in the area tends to be more uniform as the total abundance increases (Fig. 2 to 8). So, the square root transformation was very efficient at reducing the dispersion of the data within strata.

c)total (seasonal) egg production;

The "mean date of maximum spawning" in the southern Gulf was estimated by fitting a curve to the square root mean stage 1 egg densities per sampling days for the centre area of the spawning zone, i.e. strata 5 and 6 (Annex 4b). This sector was identified as the major spawning area because of the constant high densities of stage 1 eggs through the years (Fig. 2 to 8) and also because for at least the first cruises of each year, the proportion of stage 1 eggs was highest in this area (Annex 6).

The mean Julian date was 174.9 (June 23th). The method of integrating the total egg production from the median date of each cruise, located in relation to the date of maximum spawning, was taken from Maguire (1981) and probably represents the best solution in the cases presented here where we have only one single point (or two for some years) on the spawning cycle.

Following this, the "mean date of maximum spawning" and the daily production calculated from the transformed data of the three stratum design were used for the estimation of the total mackerel egg production for each cruise and year from 1979 to 1986 (Table 8). The observed increasing trend in the annual production of mackerel eggs beginning in 1983 was also noted in the other indices of mackerel population size (Gascon et Mercille 1986).

The method used to approximate the date of peak spawning certainly has weaknesses. However, we believe that it is the best estimate one can get in the absence of annual data on the duration and the date of peak spawning. One way to estimate the reliability of the approach is to consider the two estimates calculated from each cruise on a given year as two independent points on the reproduction cycle, from which we should expect to obtain the same total production estimate. The results of two years out of four appear to confirm this expectation: in 1984 and 1986 the differences in the estimates are of 20.5 % and 9.4 % respectively, what we consider good in the circumstances. The other two years, 1982 and 1985, can both be considered as abnormal years, since in 1982 spawning appear to have begun earlier in the season. In 1985, the large daily estimate for the second cruise which was later in the season (Table 7), suggests a serious skewness in the spawning curve for that year. When we consider the sensitivity of the method of taking the long term mean of peak spawning date as the date of reference for the maximum spawning in a given year, we may expect large deviations from the "real" value if the true annual spawning peak diverge significantly from the long term mean (Fig. 9).

Conclusion

It is possible to obtain a precise estimate of the total daily production of mackerel eggs in the southern Gulf of St.Lawrence mainly because of the possibility of discriminating with a relativelly good accuracy the zones of different egg densities in the spawning area. Futhermore, by adjusting the sampling effort to the relative contribution of individual strata to the global variance the estimate could be improved in the future.

However even an exact count of every egg present in the area at a given time will be worthless if we cannot fit the value into the accurate production curve for that particular area. The method presented in this report appears the best compromise in the absence of reliable data on the production cycle or the sea temperature cycle from which we can infer the reproduction cycle for a given year. But, it was also demonstrated that the technique is very sensitive to errors in the estimation of the true annual date of peak spawning.

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Table 1 Cruise dates and the number of stations sampled for each year from 1979 to 1986.

CRUISE	YEAR	DATE	STATION SAMPLED
P-221	1979/A	12-06//19-06	60
P-239	1980/A	23-06//02-07	61
P-273	1982/A	07-06//16-06	64
P-275	1982/B	24-06//05-07	63
P-292	1983/A	21-06//02-07	79
N-30	1984/A	19-06//29-06	80
N-30	1984/B	29-06//04-07	49
P-324	1985/A	20-06//01-07	85
P-324	1985/B	01-07//08-07	58
P-337	1986/A	16-06//27-06	58
P-338	1986/B	30-06//08-07	65

Table 2 Daily egg production from egg density X station area method, cruise median date, mean sea surface temperature and number of stations sampled for each year.

YEAR/CRUISE	JULIAN DATE (mid-point)	$T^{o}s$ (mean)	N	DAILY EGG * PRODUCTION
1979/A	166	11.6	61	1.8903 E+13
1980/A	178	10.2	58	1.1087 E+13
1982/A	162	9.4	64	4.3900 E+13
1982/B	179	11.4	63	1.1507 E+13
1983/A	177	13.6	65	0.9394 E+13
1984/A	175	10.4	65	2.8300 E+13
1984/B	182	13.6	49	0.8780 E+13
1985/A	176	11.3	65	2.8380 E+13
1985/B	185	13.6	55	2.4500 E+13
1986/A	173	11.5	58	5.5292 E+13
1986/B	185	13.3	65	1.7216 E+13

* all production estimates are calculated for the whole area: i.e. 6.945 E+10 m^2 (65 stations)

Table 3a Daily egg production estimated with post-statification of the area sampled (6-stratum design), variance of the estimate and confidence interval (95%).

YEAR/Cr	DAILY EGG PRODUCTION	VARIANCE	lower limit	upper limit	C.V. (%)
1979/A	2.095 E+13	1.024 E+25	1.455 E+13	2.734 E+13	15.0%
1980/A	1.091 E+13	0.466 E+25	0.660 E+13	1.523 E+13	19.9%
1982/A	4.336 E+13	6.300 E+25	2.750 E+13	5.922 E+13	18.3%
1982/B	1.150 E+13	0.521 E+25	0.693 E+13	1.606 E+13	19.8%
1983/A	0.888 E+13	0.461 E+25	0.458 E+13	1.316 E+13	24.2%
1984/A	2.038 E+13	0.667 E+25	1.522 E+13	2.554 E+13	12.7%
1984/B	0.969 E+13	0.233 E+25	0.664 E+13	1.274 E+13	15.7%
1985/A	2.853 E+13	0.654 E+25	2.342 E+13	3.364 E+13	8.9%
1985/B	2.264 E+13	0.689 E+25	1.739 E+13	2.789 E+13	11.6%
1986/A	5.106 E+13	2.394 E+25	4.129 E+13	6.084 E+13	9.6%
1986/B	1.715 E+13	0.397 E+25	1.317 E+13	2.114 E+13	11.6%

Table 3b Daily egg production estimated with post-stratification of the area sampled (3 - stratum design), variance of the estimate and confidence interval (95%).

YEAR/Cr	DAILY EGG PRODUCTION	VARIANCE	lower limit	upper limit	C.V. (%)
1979/A	2.130 E+13	1.283 E+25	1.414 E+13	2.846 E+13	16.8%
1980/A	1.041 E+13	0.390 E+25	0.646 E+13	1.435 E+13	18.9%
1982/A	4.163 E+13	7.567 E+25	2.425 E+13	5.901 E+13	20.9%
1982/B	1.129 E+13	0.511 E+25	0.677 E+13	1.581 E+13	20.0%
1983/A	1.054 E+13	0.401 E+25	0.654 E+13	1.454 E+13	19.0%
1984/A	2.022 E+13	0.699 E+25	1.493 E+13	2.550 E+13	13.1%
1984/B	0.963 E+13	0.257 E+25	0.643 E+13	1.284 E+13	16.6%
1985/A	2.813 E+13	0.702 E+25	2.284 E+13	3.342 E+13	9.4%
1985/B	2.275 E+13	0.529 E+25	1.702 E+13	2.847 E+13	10.1%
1986/A	5.053 E+13	2.523 E+25	4.049 E+13	6.057 E+13	9.9%
1986/B	1.683 E+13	0.429 E+25	1.269 E+13	2.097 E+13	12.3%

Table 4 Strata surfaces (m^2), number of stations sampled in each stratum, mean stage 0 egg density/m^2 and variance from 1979 to 1986 (6-stratum design).

YEAR/Cr	DATA	STRATA I	II	III	IV	V	VI
1979/A	SURF(E+9)	14.4	13.2	12.6	11.4	7.3	10.6
	N	10	13	13	10	7	8
	MEAN/m^2	54.19	182.24	178.31	484.79	888.01	305.82
	VAR(E+3)	13.11	45.56	19.39	155.95	703.99	78.91
1980/A	SURF(E+9)	14.4	13.2	12.6	11.4	7.3	10.6
	N	11	11	13	9	7	7
	MEAN/m^2	1.21	13.11	70.74	307.51	338.27	352.39
	VAR(E+3)	0.005	0.16	7.93	57.16	72.57	195.90
1982/A	SURF(E+9)	14.4	13.2	12.6	11.4	7.3	10.6
	N	12	14	13	10	7	8
	MEAN/m^2	14.86	70.99	308.77	383.72	639.09	2811.54
	VAR(E+3)	1.85	19.51	284.50	165.87	567.94	3511.30
1982/B	SURF(E+9)	14.4	13.2	12.6	11.4	7.3	10.6
	N	12	14	13	9	7	8
	MEAN/m^2	2.78	68.73	132.98	189.96	195.07	508.37
	VAR(E+3)	0.06	6.69	102.56	77.33	32.06	168.81
1983/A	SURF(E+9)	14.4	13.2	12.6	11.4	7.3	10.6
	N	13	14	12	10	7	8
	MEAN/m^2	25.15	61.73	93.54	125.4	202.67	339.72
	VAR(E+3)	0.77	2.63	30.21	33.93	58.56	234.50
1984/A	SURF(E+9)	14.4	13.2	12.6	11.4	7.3	10.6
	N	13	14	13	10	7	8
	MEAN/m^2	39.51	68.91	221.42	346.88	680.10	670.75
	VAR(E+3)	3.75	3.07	66.67	88.99	429.95	96.98
1984/B	SURF(E+9)	14.4	13.2	12.6	11.4	7.3	10.6
	N	7	11	11	9	4	7
	MEAN/m^2	35.90	65.96	48.67	120.46	572.20	216.67
	VAR(E+3)	2.57	12.07	2.06	10.19	112.73	7.17

Table 4 (continued)

YEAR/Cr	DATA	STRATA I	II	III	IV	V	VI
1985/A	SURF(E+9)	14.4	13.2	12.6	11.4	7.3	10.6
	N	13	14	13	10	7	8
	MEAN/m^2	56.74	103.64	291.22	584.96	715.56	1033.48
	VAR(E+3)	7.91	10.49	69.52	66.32	211.31	192.22
1985/B	SURF(E+9)	14.4	13.2	12.6	11.4	7.3	10.6
	N	13	10	12	8	4	8
	MEAN/m^2	60.79	139.09	230.65	414.31	494.20	828.57
	VAR(E+3)	4.81	11.00	95.56	99.27	120.34	216.39
1986/A	SURF(E+9)	14.4	13.2	12.6	11.4	7.3	10.6
	N	9	11	13	10	7	8
	MEAN/m^2	7.64	328.50	749.12	1103.45	1041.74	1580.85
	VAR(E+3)	0.28	40.41	200.91	711.24	258.10	846.03
1986/B	SURF(E+9)	14.4	13.2	12.6	11.4	7.3	10.6
	N	13	12	13	10	7	8
	MEAN/m^2	97.91	233.75	133.88	191.35	318.13	613.74
	VAR(E+3)	15.35	80.63	20.33	29.53	64.37	102.96

Table 5 Shapiro-Wilks statistic and normality test for data on stage 0 egg density/m^2 (raw and square-root transformed data). H_0, null hypothesis, accepted for P<W greater or equal 0.010.

STRATA	YEAR/Cr	N	RAW DATA		SQUARE-ROOT TRANSFORMATION	
			W:normal	P<W	W:normal	P<W
I	1979/A	23	0.7126	0.001	0.9098	0.039*
	1980/A	22	0.7139	0.001	0.8840	0.013*
	1982/A	26	0.4750	0.001	0.7276	0.001
	1982/B	26	0.6200	0.001	0.7676	0.001
	1983/A	27	0.8560	0.001	0.9530	0.275*
	1984/A	27	0.8240	0.001	0.9234	0.052*
	1984/B	18	0.6320	0.001	0.8659	0.014*
	1985/A	27	0.8020	0.001	0.9165	0.035*
	1985/B	23	0.8600	0.003	0.9541	0.357*
	1986/A	20	0.7936	0.001	0.8683	0.010*
	1986/B	25	0.6770	0.001	0.9282	0.082*
II	1979/A	23	0.8110	0.001	0.9508	0.306*
	1980/A	22	0.7960	0.001	0.9229	0.085*
	1982/A	23	0.7580	0.001	0.8899	0.014*
	1982/B	22	0.5690	0.001	0.7890	0.001
	1983/A	22	0.5371	0.001	0.7606	0.001
	1984/A	23	0.8570	0.003	0.9546	0.365*
	1984/B	20	0.8439	0.004	0.9403	0.255*
	1985/A	23	0.8950	0.018*	0.9288	0.103*
	1985/B	20	0.7320	0.001	0.9216	0.112*
	1986/A	23	0.8730	0.006	0.9658	0.586*
	1986/B	23	0.8010	0.001	0.9109	0.041*
III	1979/A	15	0.7789	0.002	0.9250	0.227*
	1980/A	14	0.8320	0.012*	0.9151	0.184*
	1982/A	15	0.8560	0.021*	0.9750	0.891*
	1982/B	15	0.8220	0.007	0.9477	0.471*
	1983/A	15	0.6560	0.001	0.8772	0.043*
	1984/A	15	0.9120	0.147*	0.9656	0.752*
	1984/B	11	0.7247	0.001	0.8011	0.011*
	1985/A	15	0.8770	0.043*	0.8885	0.064*
	1985/B	12	0.9470	0.552*	0.9808	0.962*
	1986/A	15	0.9235	0.217*	0.9500	0.505*
	1986/B	15	0.9216	0.203*	0.9362	0.330*

Table 6 Stratum surfaces (m^2), number of stations sampled in each stratum, and mean stage 0 egg density and variance back-calculated from square root transformed data, from 1979 to 1986.

YEAR/Cr	DATA	STRATA I	STRATA II	STRATA III
1979/A	SURF(E+9)	29.61	21.91	17.93
	N	25	21	15
	MEAN/m^2	141.35	311.59	577.49
	VAR(E+3)	1.05	3.95	20.28
1980/A	SURF(E+9)	29.61	21.91	17.93
	N	24	20	14
	MEAN/m^2	7.66	183.04	345.33
	VAR(E+3)	0.004	1.79	7.24
1982/A	SURF(E+9)	29.61	21.91	17.93
	N	28	21	15
	MEAN/m^2	50.78	361.97	1797.71
	VAR(E+3)	0.16	8.67	197.60
1982/B	SURF(E+9)	29.61	21.91	17.93
	N	28	20	15
	MEAN/m^2	36.05	171.23	362.18
	VAR(E+3)	0.077	2.12	7.17
1983/A	SURF(E+9)	29.61	21.91	17.93
	N	29	20	15
	MEAN/m^2	46.02	111.65	275.78
	VAR(E+3)	0.069	0.701	5.40
1984/A	SURF(E+9)	29.61	21.91	17.93
	N	29	21	15
	MEAN/m^2	57.78	292.86	675.10
	VAR(E+3)	0.13	3.86	14.15
1984/B	SURF(E+9)	29.61	21.91	17.93
	N	20	18	11
	MEAN/m^2	49.38	89.36	345.96
	VAR(E+3)	0.17	0.335	4.57

Table 6 (continued)

YEAR/Cr	DATA	STRATA I	II	III
1985/A	SURF(E+9)	29.61	21.91	17.93
	N	29	21	15
	MEAN/m^2	83.79	447.33	885.13
	VAR(E+3)	0.296	4.34	14.25
1985/B	SURF(E+9)	29.61	21.91	17.93
	N	25	20	12
	MEAN/m^2	97.47	323.69	717.11
	VAR(E+3)	0.338	4.13	16.06
1986/A	SURF(E+9)	29.61	21.91	17.93
	N	22	21	15
	MEAN/m^2	201.95	952.94	1329.29
	VAR(E+3)	2.436	18.20	40.02
1986/B	SURF(E+9)	29.61	21.91	17.93
	N	27	21	15
	MEAN/m^2	152.63	171.95	475.78
	VAR(E+3)	0.952	0.943	7.71

Table 7 Daily egg production estimated from post-stratification of the area (3-stratum design), and mean stage 0 egg density and variance calculated from square root transformed data, and confidence interval (95%).

YEAR/Cr	DAILY EGG PRODUCTION	VARIANCE	lower limit	upper limit	C.V. (%)
1979/A	2.134E+13	5.611E+23	1.973E+13	2.295E+13	3.5%
1980/A	1.042E+13	2.089E+23	0.944E+13	1.140E+13	4.4%
1982/A	4.163E+13	44.320E+23	3.712E+13	4.617E+13	5.1%
1982/B	1.130E+13	2.070E+23	1.032E+13	1.220E+13	4.0%
1983/A	0.874E+13	1.345E+23	0.795E+13	0.953E+13	4.2%
1984/A	2.021E+13	3.945E+23	1.886E+13	2.156E+13	3.1%
1984/B	0.961E+13	1.498E+23	0.878E+13	1.044E+13	4.0%
1985/A	2.812E+13	4.129E+23	2.674E+13	2.950E+13	2.3%
1985/B	2.281E+13	5.510E+23	2.122E+13	2.440E+13	3.2%
1986/A	5.064E+13	13.680E+23	4.813E+13	5.315E+13	2.3%
1986/B	1.680E+13	1.904E+23	1.586E+13	1.770E+13	2.6%

Table 8 Total mackerel egg production in the southwestern Gulf of St. Lawrence from 1979 to 1986.

YEAR/CRUISE	JULIAN DATE (mid-point)	$T^{o}s$ (mean)	TOTAL EGG PRODUCTION
1979/ A	166	11.6	7.981 E+14
1980/ A	178	10.2	1.915 E+14
1982/ A	162	9.4	38.027 E+14
1982/ B	179	11.4	2.236 E+14
1983/ A	177	13.6	1.523 E+14
1984/ A	175	10.4	3.368 E+14
1984/ B	182	13.6	2.677 E+14
1985/ A	176	11.3	4.745 E+14
1985/ B	185	13.6	10.781 E+14
1986/ A	173	11.5	8.763 E+14
1986/ B	185	13.3	7.940 E+14

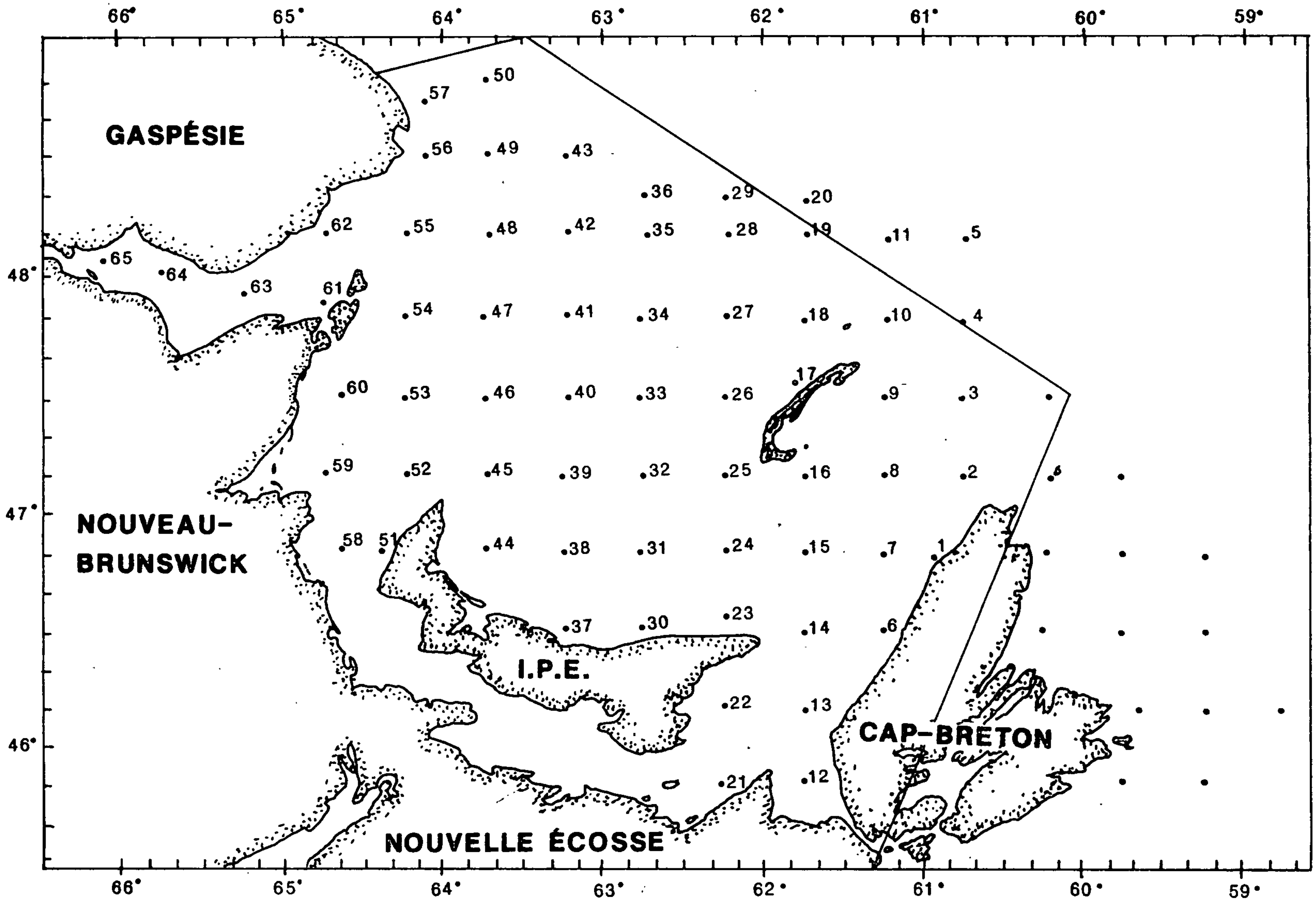


Figure 1 The survey area and the location of the 65 permanent stations on the grid in southwestern Gulf of St.Lawrence.

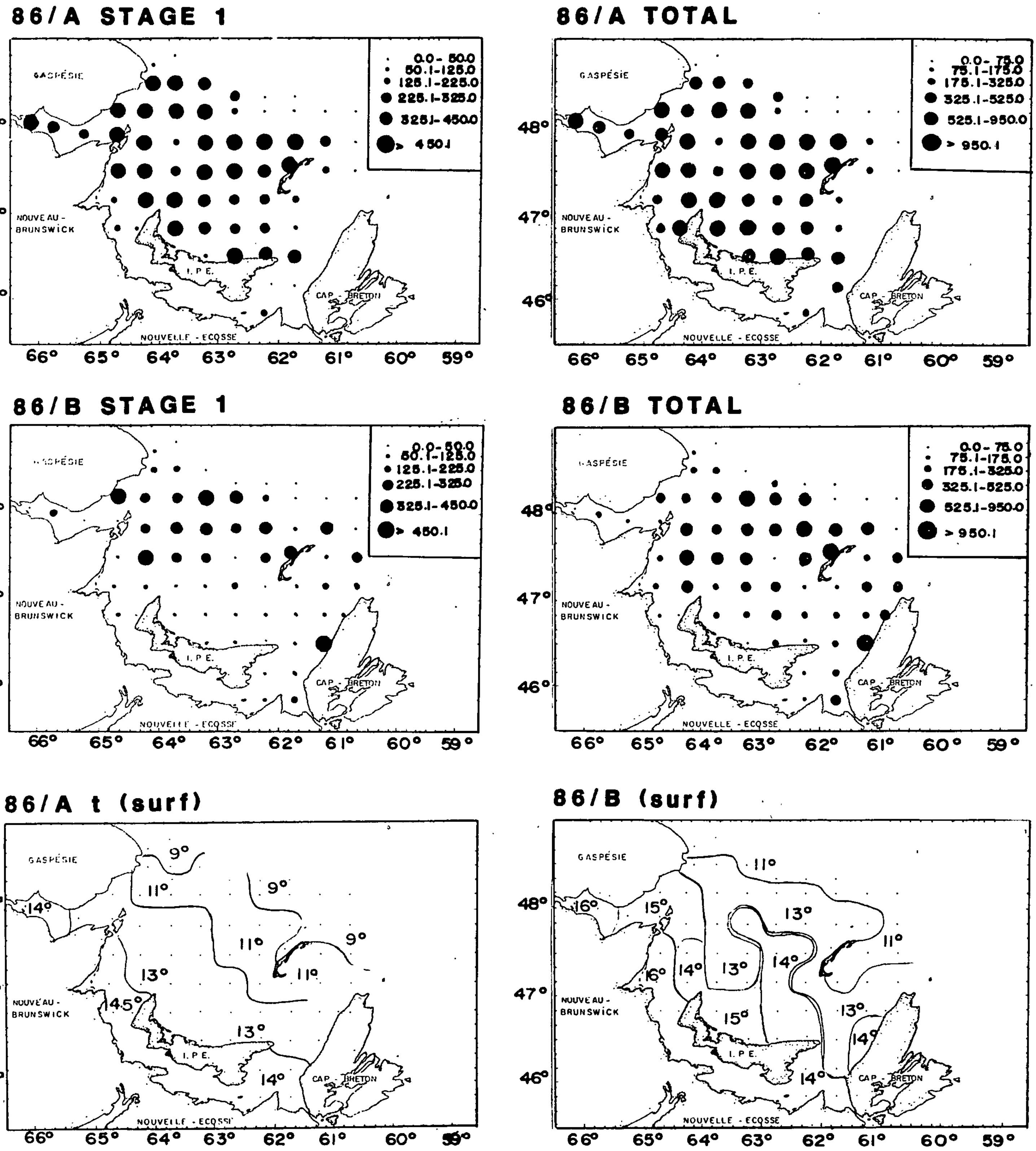


Figure 2 Distribution of stage 1 eggs (nb/m^2), total eggs abundance (nb/m^2), and sea surface temperatures for the year 1986.

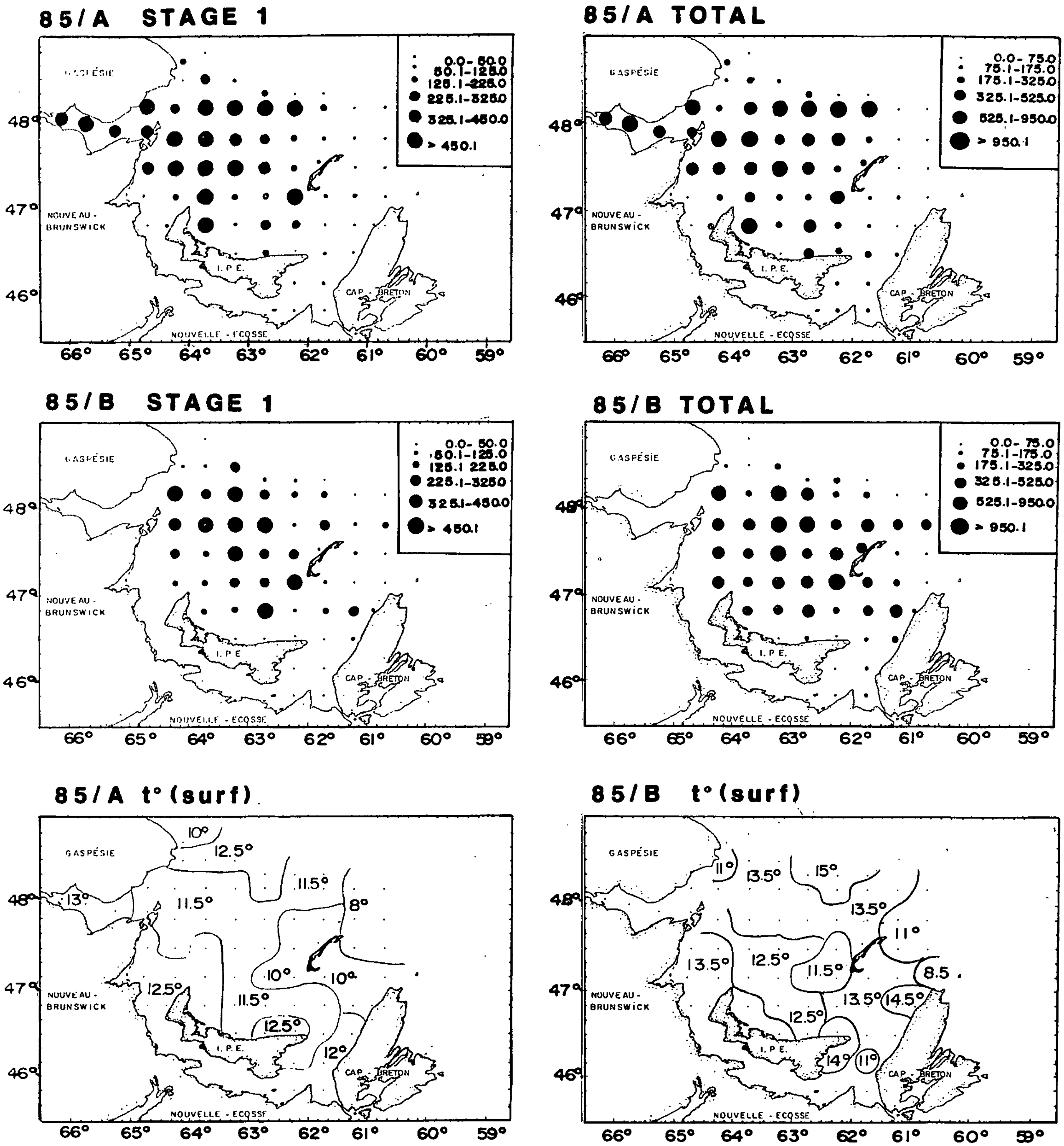


Figure 3 Distribution of stage 1 eggs (nb/m^2), total eggs abundance (nb/m^2), and sea surface temperatures for the year 1985.

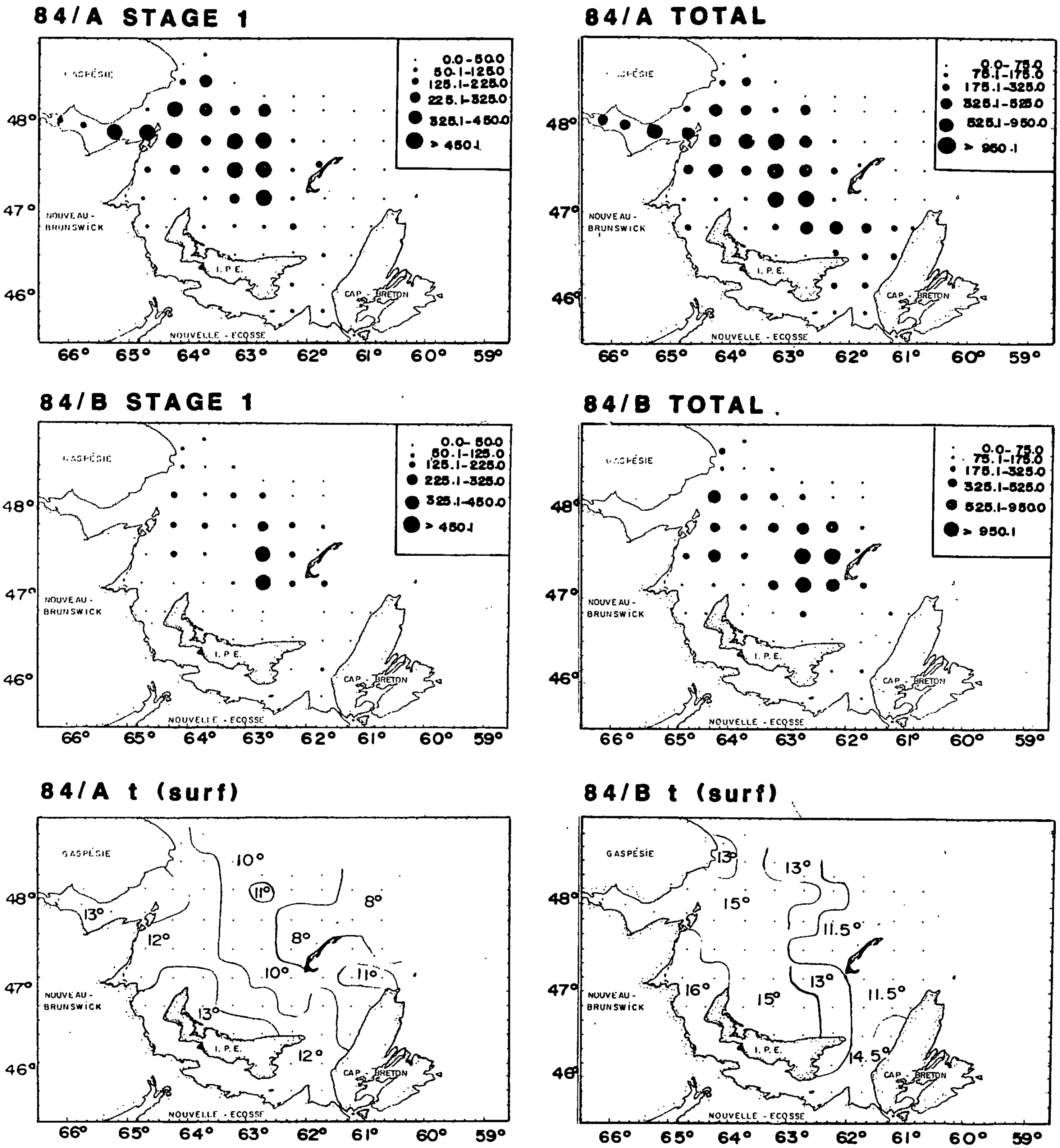


Figure 4 Distribution of stage 1 eggs (nb/m^2), total eggs abundance (nb/m^2), and sea surface temperatures for the year 1984.

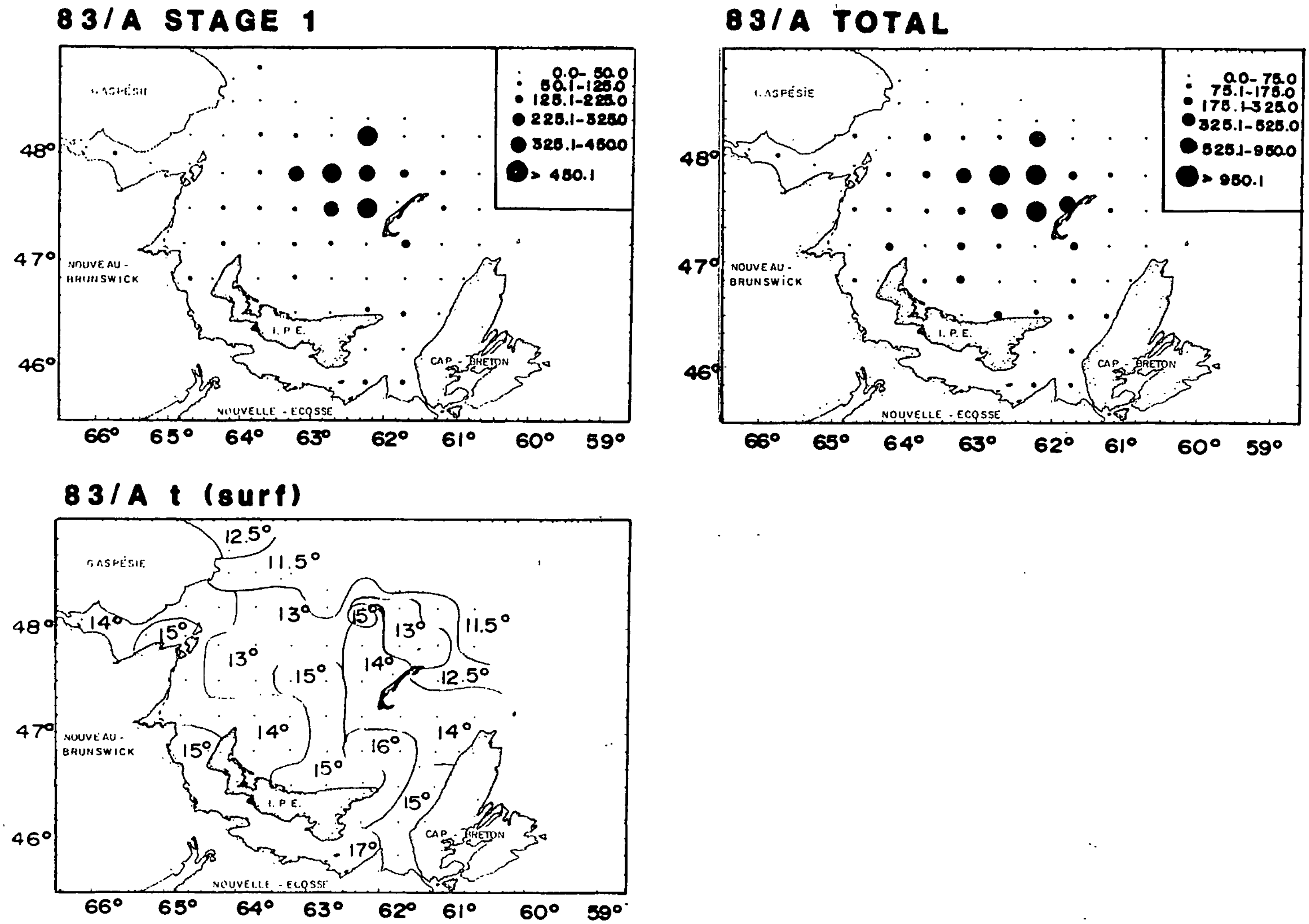


Figure 5 Distribution of stage 1 eggs (nb/m^2), total eggs abundance (nb/m^2), and sea surface temperatures for the year 1983.

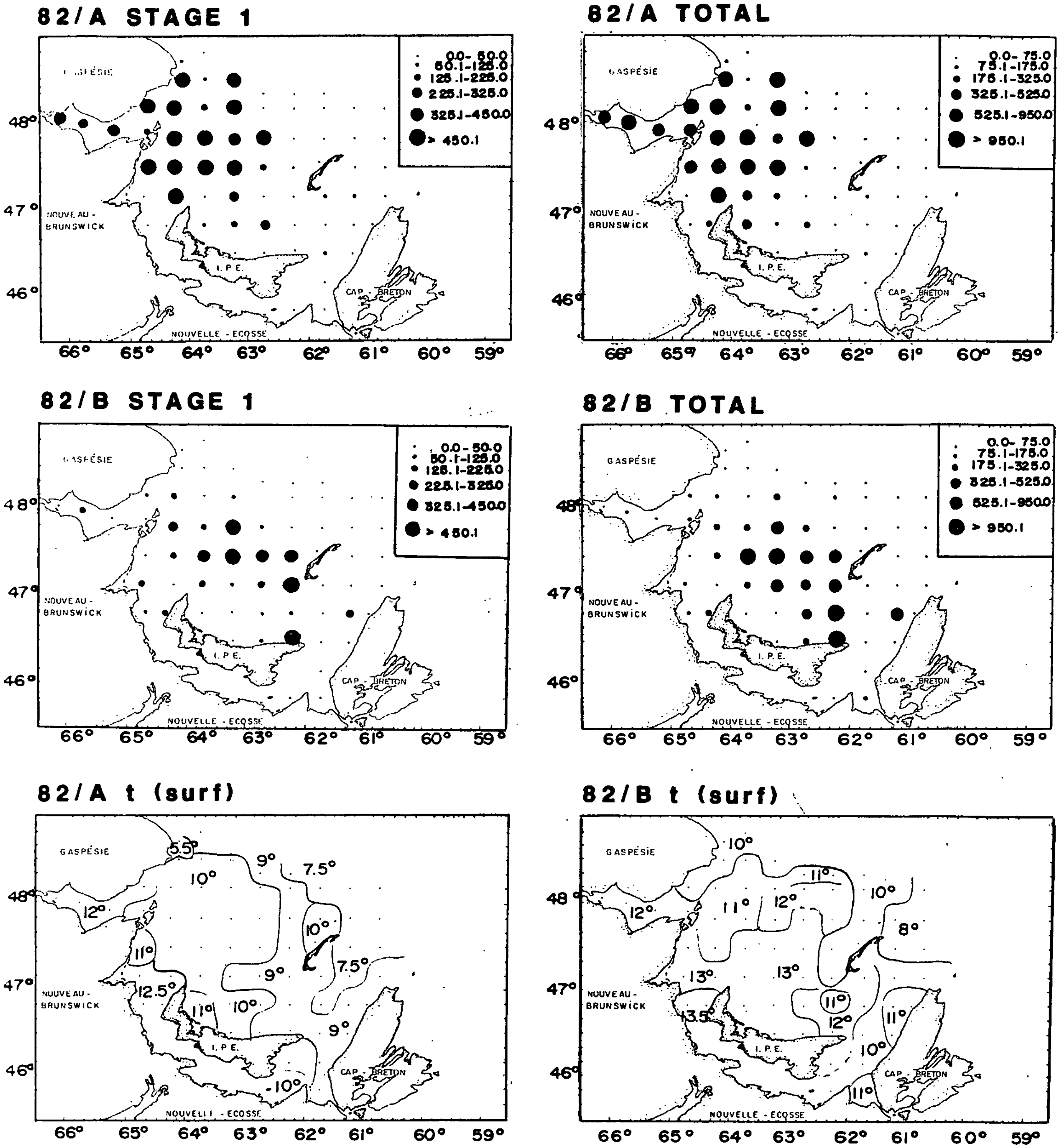
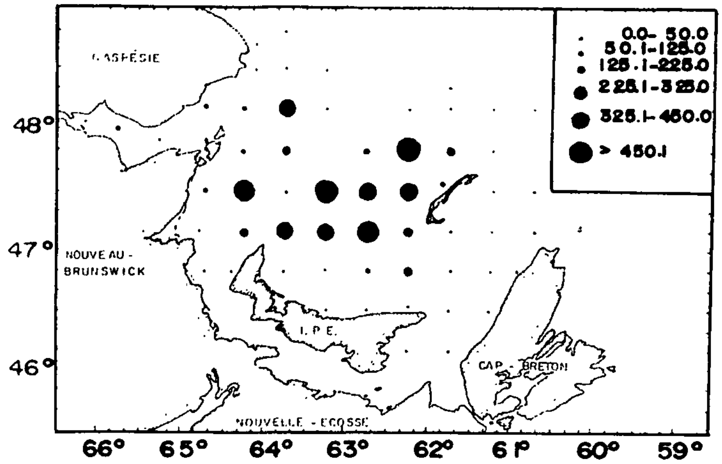
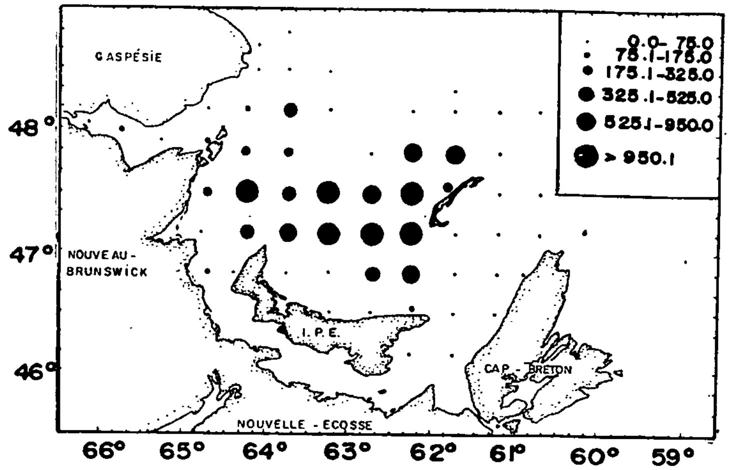


Figure 6 Distribution of stage 1 eggs (nb/m^2), total eggs abundance (nb/m^2), and sea surface temperatures for the year 1982.

80/A STAGE 1



80/A TOTAL



80/A t (surf)

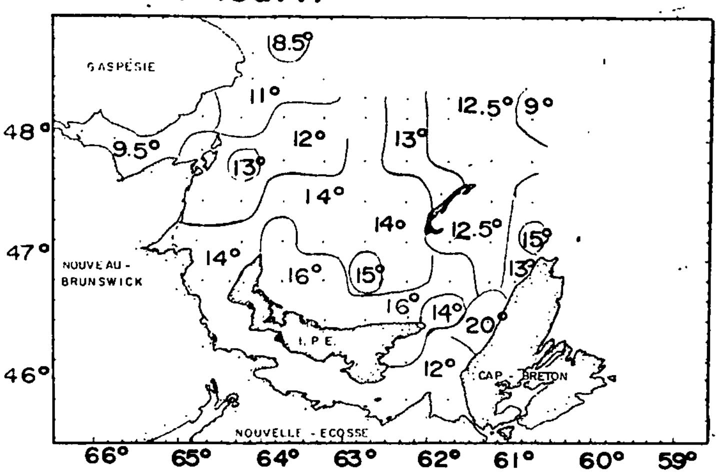


Figure 7 Distribution of stage 1 eggs (nb/m^2), total eggs abundance (nb/m^2), and sea surface temperatures for the year 1980.

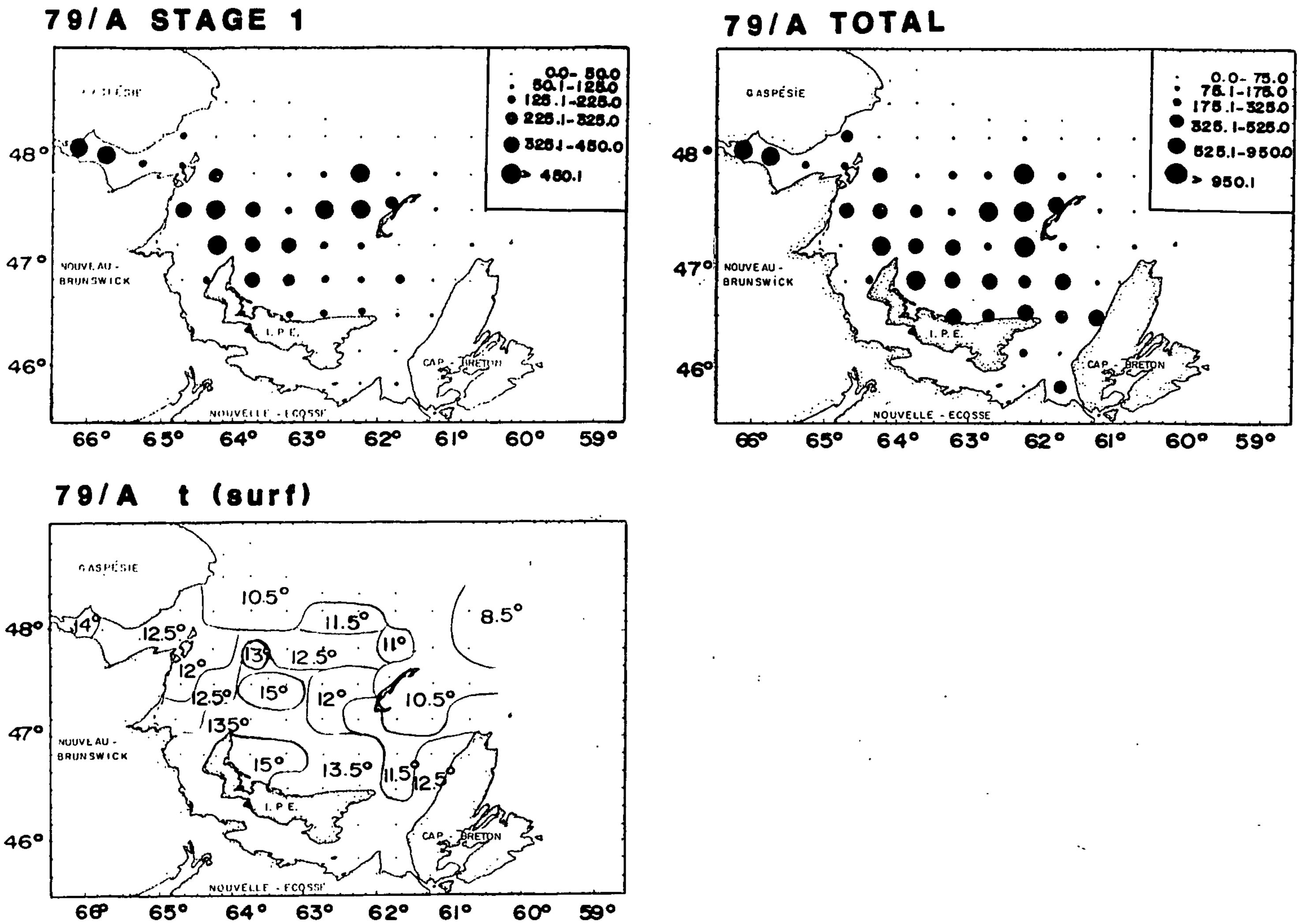


Figure 8 Distribution of stage 1 eggs (nb/m^2), total eggs abundance (nb/m^2), and sea surface temperatures for the year 1979.

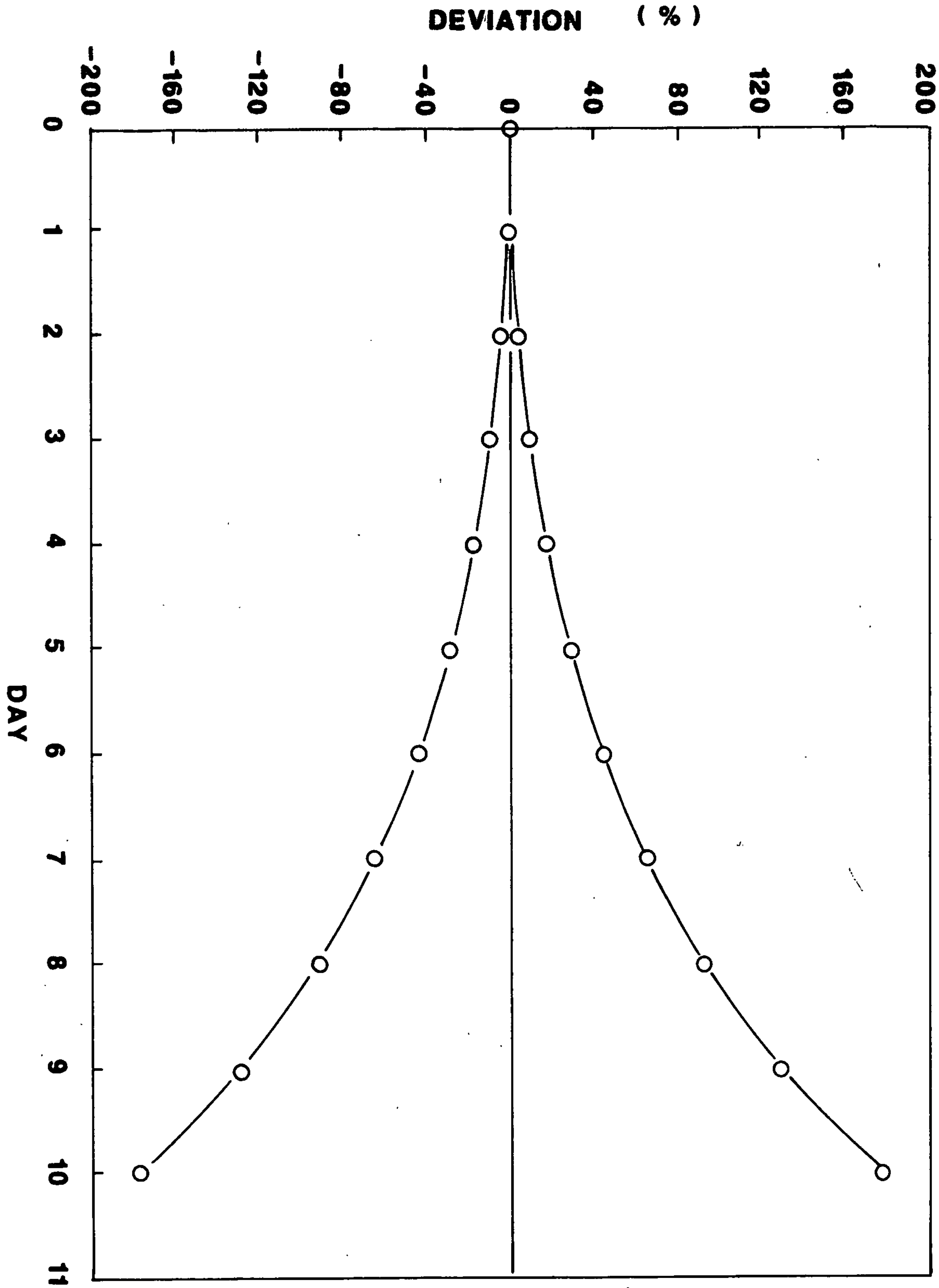
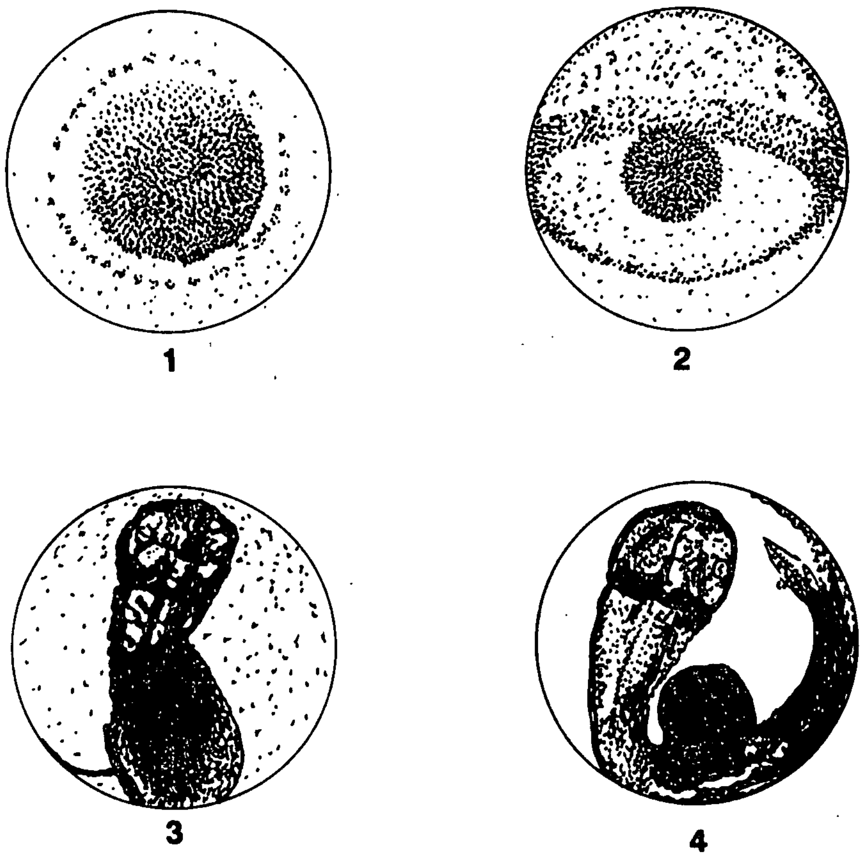
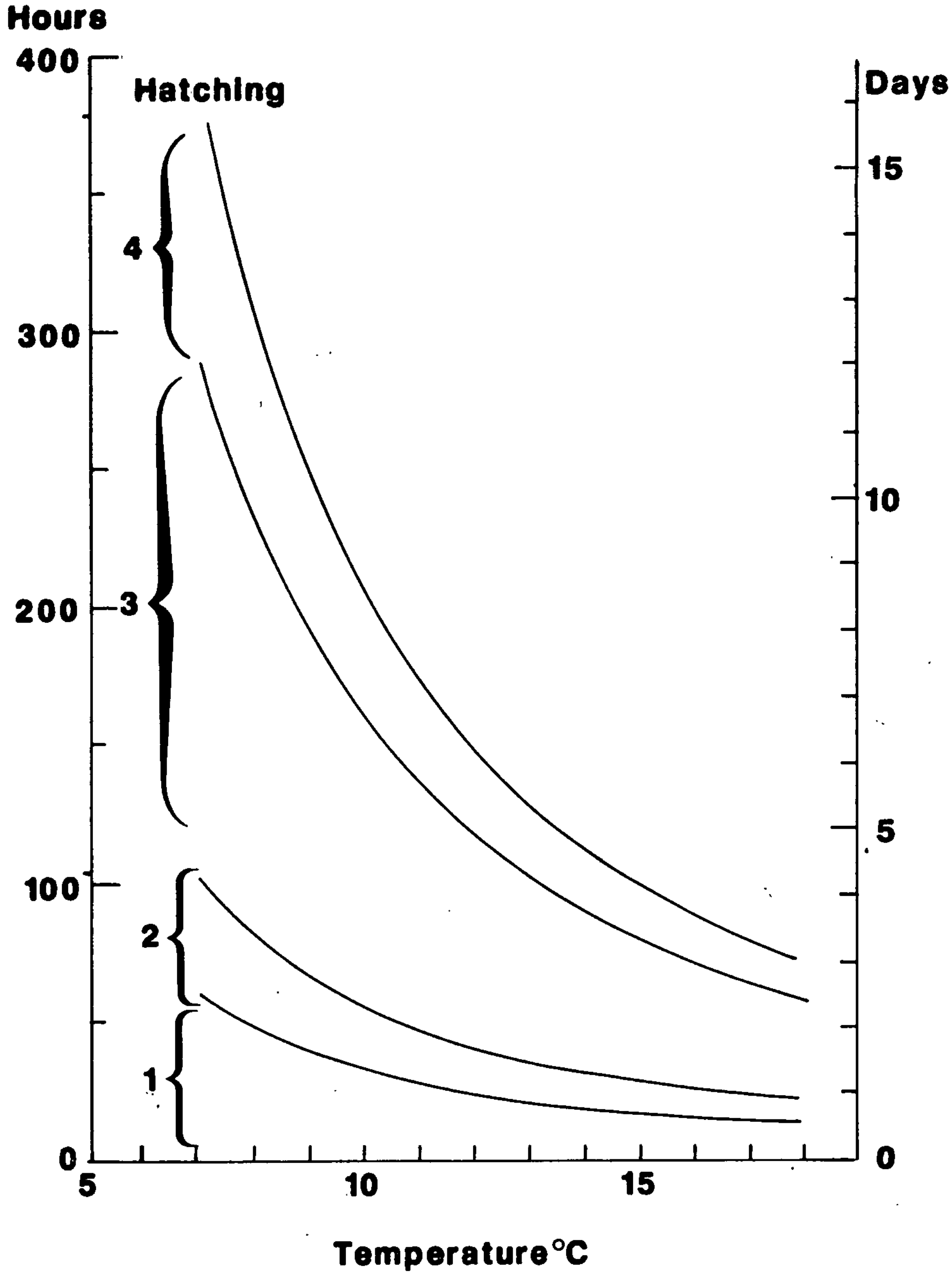


Figure 9 Expected deviation (%) from the real seasonal value of total egg production estimated for each day of difference between the true date of maximum spawning for a given year and the long-term mean.



Annex 1a Developmental stages of mackerel eggs, and identification of the four developmental stages recognized in this study. (draw from photographs presented by Lockwood and Nichols, 1977).



Annex 1b Incubation times and stage duration of mackerel eggs as a function of water temperature (from Lockwood and Nichols, 1977).

Annex 2 Relationship between the incubation time of mackerel eggs vs sea temperature (from Worley 1933)

T^{o}(<=15^{o}C)	Time (h)	Ln T^{o}C [X]	Ln Time [Y]
10	208.3	4.60	2.71
11	185.2	4.71	2.64
12	156.2	4.88	2.56
13	131.6	5.05	2.48
14	111.1	5.22	2.39
15	100.0	5.34	2.30

$$Y = aX + b$$

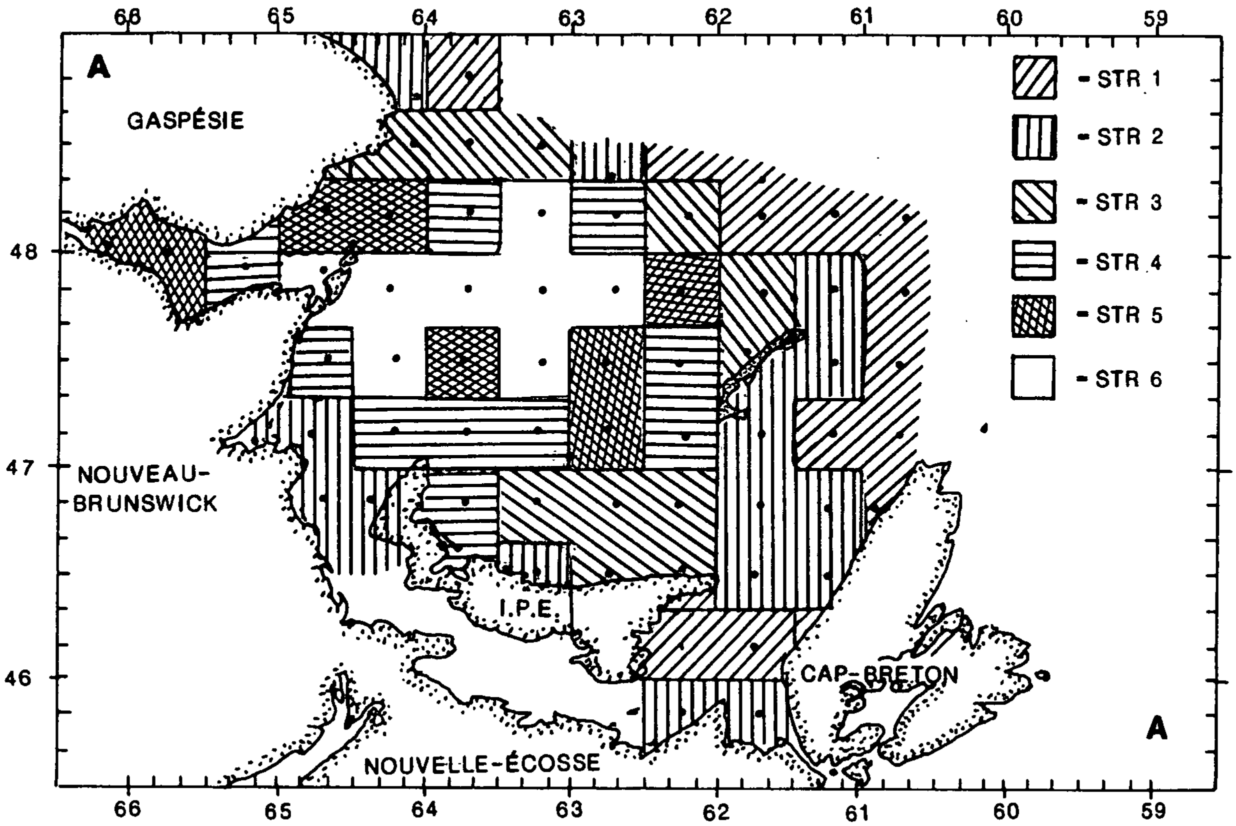
a= -1.87
b= 9.67
r= 0.998
N= 6

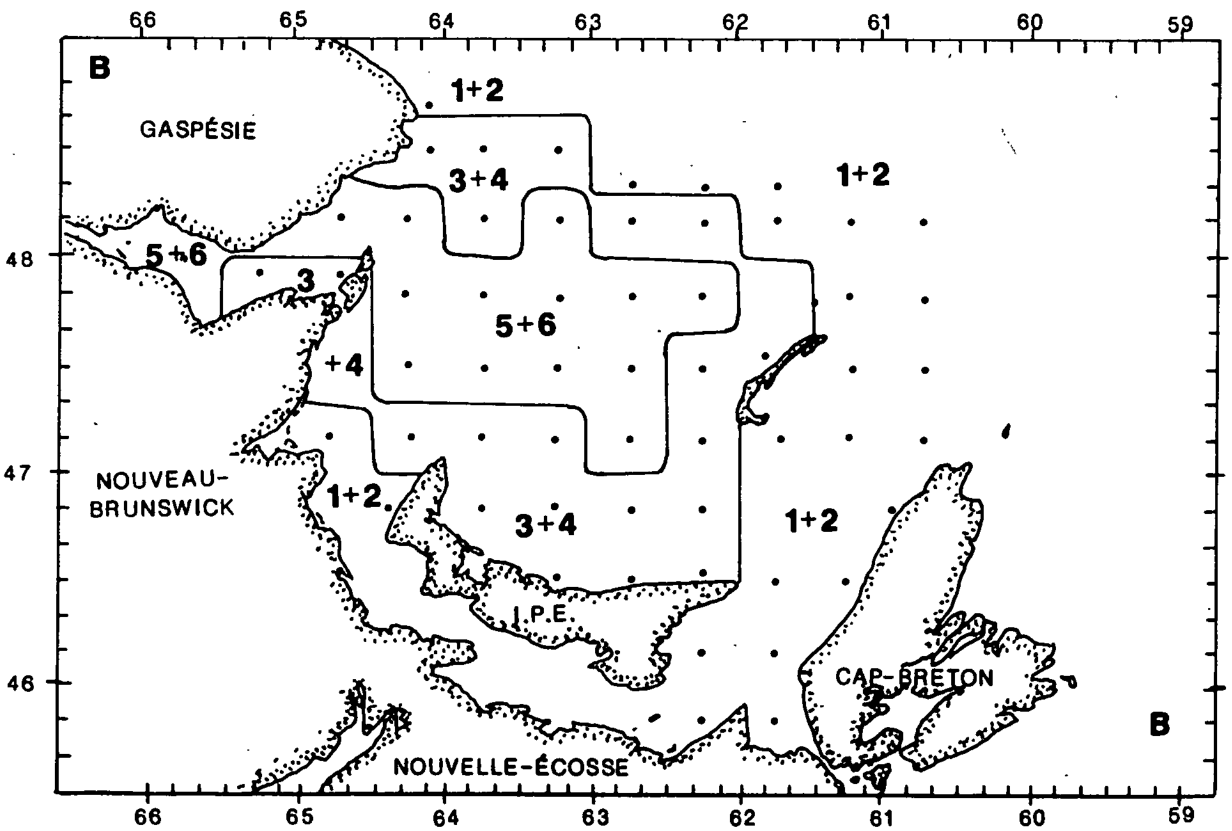
$$\mathrm{Ln[time\ incubation]} = -1.87\mathrm{Ln[temperature]} + 9.67$$

Annex 3 Frequency distribution of mean densities of stage 1 eggs (nb/m^2) and calculation of stratum intervals

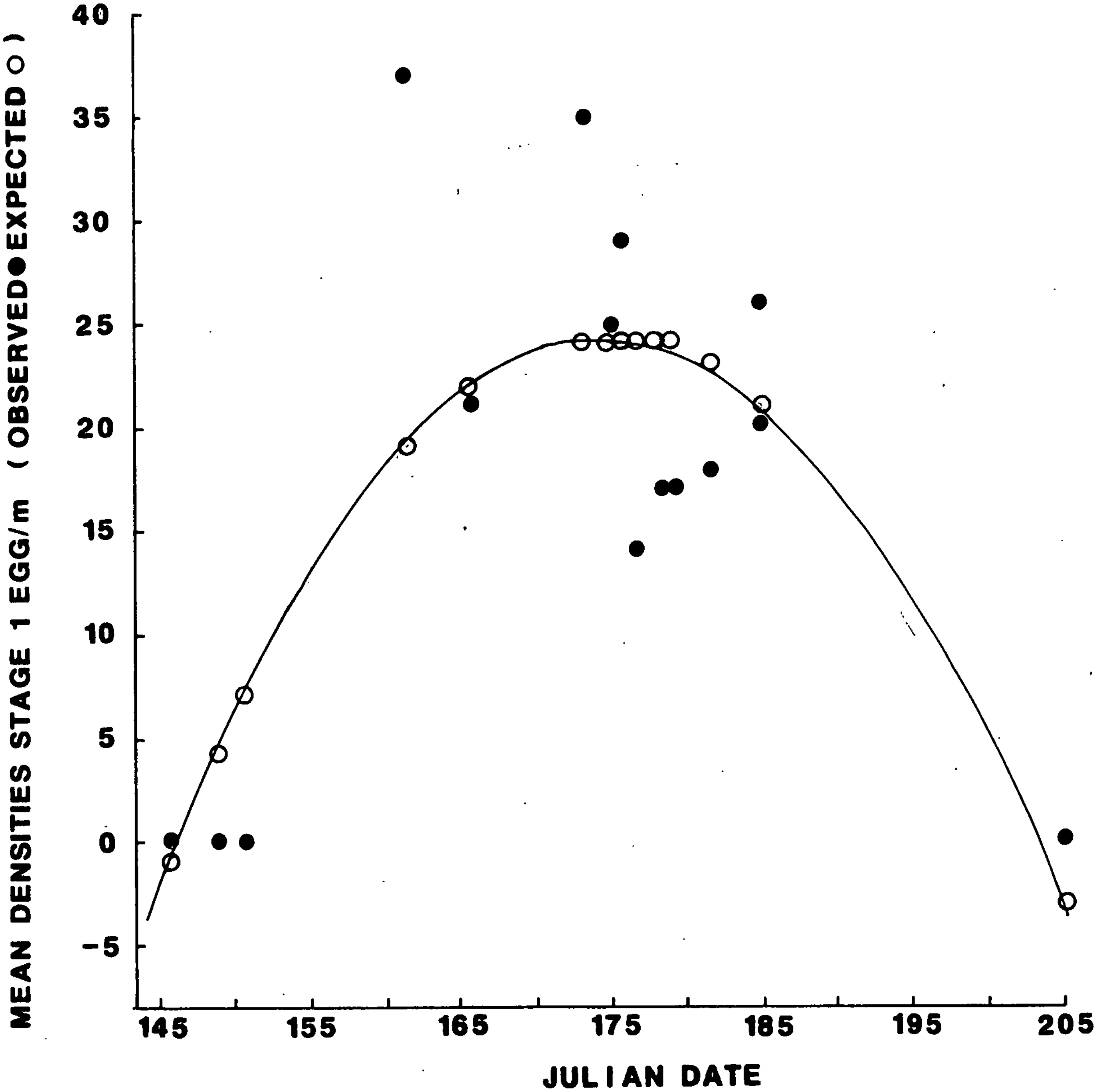
class interval	fx	$\sqrt{fx}$	cum $\sqrt{fx}$	limit	stratum interval
0.0- 24.9	6	2.45	2.45	[0]	(0.0-
25.0- 49.9	8	2.83	5.28	[5.73]	50.0)
50.0- 74.9	10	3.16	8.44		1
75.0- 99.9	3	1.73	10.17		
100.0-124.9	2	1.41	11.58	[11.46]	(50.1-
125.0-149.9	7	2.64	14.22		125.0)
150.0-174.9	1	1.00	15.22		2
175.0-199.9	1	1.00	16.22		
200.0-224.9	2	1.41	17.63	[17.19]	(125.1-
225.0-249.9	5	2.24	19.87		225.0)
250.0-274.9	2	1.41	21.28		3
275.0-299.9	0	0.00	21.28		
300.0-324.9	3	1.73	23.01	[22.92]	(225.1-
325.0-349.9	2	1.41	24.42		325.0)
350.0-374.9	2	1.41	25.83		4
375.0-399.9	3	1.73	27.56		
400.0-424.9	1	1.00	28.56		
425.0-449.9	0	0.00	28.56	[28.65]	(325.1-
450.0-474.9	1	1.00	29.56		450.0)
475.0-499.9	2	1.41	30.97		5
500.0-524.9	0	0.00	30.97		
525.0-549.9	1	1.00	31.97		
550.0-574.9	1	1.00	32.97		
575.0-599.9	0	0.00	32.97		
600.0-624.9	0	0.00	32.97		
625.0-649.9	0	0.00	32.97		
650.0-674.9	0	0.00	32.97		
675.0-699.9	0	0.00	32.97		(>450.1)
700.0-724.9	0	0.00	32.97		6
> > 725.0	2	1.41	34.38	[34.38]	

Annex 4 Stratification of the survey area. a) result for a 6-stratum design. b) result for 3-stratum design by grouping strata 1 with 2, 3 with 4, and 5 with 6.





Annex 5 Observed mean densities of stage 1 eggs per sampling day in the central southwestern Gulf, predicted values and the adjusted reproduction curve permitting the estimation of a peak spawning date for the area.



Annex 6 Mean proportion (%) of stage 1 egg in each stratum, cruise median date, and mean sea surface temperature for each year and cruise.

YEAR/Cr	JULIAN DATE (mid-point)	T°s (mean)	STRATA I	II	III	IV	V	VI
			(mean proportion/s)					
1979/A	166	11.6	49.2 (40.1)	40.0 (27.6)	49.5 (25.7)	51.7 (21.1)	66.5 (18.8)	51.1 (24.1)
1980/A	178	10.2	55.5 (42.5)	49.0 (23.8)	56.7 (31.1)	55.5 (29.9)	70.3 (32.7)	63.3 (17.6)
1982/A	162	9.4	82.0 (34.2)	76.3 (35.2)	72.0 (29.1)	63.4 (36.2)	68.9 (29.6)	66.0 (26.4)
1982/B	179	11.4	44.8 (37.0)	43.4 (30.2)	32.8 (26.2)	53.1 (22.6)	56.5 (26.4)	72.7 (21.8)
1983/A	177	13.6	70.4 (30.0)	44.3 (20.0)	49.6 (30.7)	39.1 (6.9)	50.0 (18.9)	49.1 (9.0)
1984/A	175	10.4	72.5 (35.4)	53.2 (30.0)	61.3 (31.5)	52.8 (17.4)	63.0 (15.6)	53.6 (25.3)
1984/B	182	13.6	49.4 (43.0)	42.8 (23.8)	45.8 (26.2)	29.8 (22.5)	38.9 (8.9)	36.2 (11.7)
1985/A	176	11.3	63.8 (35.3)	52.3 (23.9)	52.6 (24.3)	61.7 (14.9)	75.7 (21.3)	65.9 (16.1)
1985/B	185	13.6	48.2 (32.1)	39.6 (17.6)	53.7 (31.9)	52.3 (22.1)	44.8 (11.5)	69.4 (15.2)
1986/A	173	11.5	33.3 (45.5)	59.9 (25.0)	60.5 (24.3)	60.4 (21.8)	71.2 (10.7)	82.2 (15.8)
1986/B	185	13.3	60.4 (36.5)	44.2 (21.5)	42.5 (31.5)	36.6 (20.7)	56.4 (20.0)	56.8 (17.8)