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Georges Bank Scallop Stock Assessment - 1999

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Abstract

Georges Bank has been managed as 2 zones, ‘a’ and ‘b’, since 1998. This report deals with zone ‘a’. Zone ‘b’ includes the deeper, less productive waters. Zone ‘b’ is managed with a higher meat count than zone ‘a’ and a rolling TAC. As long as catch rates do not decrease significantly and the meat count is met, a further quota is allowed over the next period.

Catches and TAC’s were 3,700 t (2,500 zone ‘a’; 1,200 zone ‘b’) in 1999. In zone ‘a’ the 1994 and 1995 year classes contributed over 70% to the catch. The total biomass estimate for 1999 is 20% larger than the previous year. The directed biomass estimate (ages 4-7) has also increased, over 25% from 1998. The 1999 fishery had the second highest catch rate index in the series.

The incoming year class for the 2000 fishery is among the strongest encountered over the last 20 years. It is anticipated to have positive impacts and improve the outlook on the stock. Preliminary observations show a weak year class for the 2001 fishery.

Résumé

Depuis 1998, le banc Georges est divisé en zones ‘a’ ‘ et ‘b’ aux fins de la gestion. Le présent rapport porte sur la zone ‘a’. La zone ‘b’, qui comprend les eaux plus profondes et moins productives, est assujettie à un compte de chairs plus élevé que celui de la zone ‘a’ et à un TAC ‘roulant’. Cela signifie que des quotas continuent d’être octroyés période après période, tant et aussi longtemps que les taux de prises ne diminuent pas notablement et que le compte de chairs est respecté.

Les prises et le TAC étaient de 3,700 t (2,500 t dans la zone ‘a’ et 1,200 t dans la zone ‘b’) en 1999. Les classes d’âge de 1994 et 1995 représentaient plus de 70 % des prises. La biomasse totale estimée pour 1999 est supérieure de 20 % à celle de l’année dernière, tandis que l’estimation de la biomasse ciblée (âges 4-7) a aussi augmenté de plus de 25 % par rapport à 1998. L’indice des taux de prises dans la pêche de 1999 venait au deuxième rang des plus élevés de la série.

La nouvelle classe d’âge qui sera recrutée à la pêche en 2000 est parmi les plus fortes des 20 dernières années. On s’attend à ce que cela ait des effets favorables et améliorent les perspectives du stock. Des observations préliminaires dénotent une faible classe d’âge pour la pêche de 2001.

INTRODUCTION

After the jurisdiction for fisheries on Georges Bank had been settled by the World Court (October 1984), the Canadian scallop industry focused on stock rehabilitation through better harvesting of the resource. An Enterprise Allocation (EA) regime was implemented in 1986 partly to reduce fishing effort. There were 77 active license holders in 1984. Today, one third the initial number of license holders are actively involved in the Georges Bank fishery. But the potential fishing effort has not necessarily been reduced by the same ratio. The meat count (size limit) was lowered to 33 meats per 500 g in January 1986 to direct exploitation toward slightly larger scallops. In 1995 the offshore scallop industry, in collaboration with Science Branch, instituted a program to monitor the presence of small (under 10 g) meats in the catch (50-count per 500 g). A tolerance level of 10% by number of meats 10 g or less (or 5% by weight) was established. The low tolerance on 50+ count meats adds more restriction to the regulatory meat count in place.

Satellite-based vessel monitoring of the offshore scallop fleet introduced in early 1998, has allowed micro-management of fishing areas to become a reality. The offshore scallop fishery on the Canadian side of Georges Bank (NAFO subdivision 5Ze) started in the mid-1950's. Most of the scallop grounds are prime habitats for the deep sea scallop and have traditionally been fished to this day. At times, scallop beds form in marginal habitats and although shell growth is similar to the prime areas, meats are small and slow-growing. Scallop abundance in marginal habitats could be high but the size of the meat would make it difficult to fish at legal count (33 meats per 500 g) and these grounds would be more or less ignored. Figure 1 plots the distribution of the catch over the last 5 years. Starting in 1998, the scallop grounds of Georges Bank were divided into the traditional area, zone 'a', mainstay of the fishery and zone 'b', a marginal habitat where no fishing activity had taken place in 1997 and 1996 and relatively low levels of effort prior to that. The traditional area or zone 'a' continues to be managed by EA's and a meat count set at 33 meats per 500 g; this is the area examined in this document. The management of zone 'b' is characterized by rolling TAC's (Robert and Butler MS 1997) and a higher meat count set at 50 meats per 500 g. The fishery in zone 'b' is summarised below but will not be discussed.

Georges Bank TAC's had been in the low range, under 4,000 t of meats, over the last 5 years except for 1997 when a strong year class (1992) recruiting to the fishery, allowed a rise in catch levels and exploitation rates. Weak year classes (1990 and 1991; 1993 and 1994) in succession were the mainstay of the fishery in most recent years and could not sustain the exploitation rates encountered before 1995. (Exploitation rates had hovered around 40% from 1983 to 1994.) The management plan for zone ‘a’ in 1999 had a reduced TAC compared to 1998 because of the absence of good to strong year classes readily available to the fishery. The TAC went from 3,200 t in 1998 to 2,500 in 1999, a reduction of approximately 30%. The outlook for the near future brightens with the arrival of the very strong 1996 year class recruiting to the fishery in year 2000.

The separation of Georges Bank into 2 management zones allowed the exploitation of marginal areas where the 1993 and 1994 year classes had settled in relatively good numbers but where the growth rate was slower. In 1998, the TAC had rolled 4 times for a total catch of 800 t before the meat count became hard to maintain and the fishery closed. In 1999, the TAC rolled 6 times for 1,196 t harvested; all landings met the meat count. Two distinct scallop beds provided moderate to high catch-rates both years. However, during 1999, catch-rates progressively declined by 33%. The mean meat count in the catch decreased from 39 meats per 500 g in 1998 to 34 in 1999. Important shifts were also noticed in the 50+count, from 20% of meats in 1998 to 7% in 1999 and in the under 25-count, from 8% in 1998 to 13% in 1999. As the 1993 year class was removed and replaced by the 1994 year class, it would appear that few incoming small scallops were shucked given the reduction in the 50+ count. The lack of small meats in the catch is not necessarily a reflection of their absence in the area. The 1999 survey results show a localised abundance of the 1995 year class which could prolong the fishery in Georges ‘b’.

The management strategy of the last 2 years allowed a cautious approach to harvesting for zone ‘a’ while overall catches were not departing too much from recent historical levels (Table 1).

METHODS

Fishery data

Offshore scallop landings are monitored at dockside by an independent agency beginning in 1994. Coverage is 100%. The monitoring replaces sale slips issued by fish buyers. Catch information is then transferred to the Statistics Division of Fisheries and Oceans.

Catch and effort data were compiled from commercial logbooks. Logs with complete effort data are called Class 1 and were used to estimate catch-rates. The Class 1 data represent more than 90% of the total logs available (Table 2). Effort is measured in towed hours (h) and towed hours times the width of the 2 drags used times the number of crew (crhm). Monitoring of vessel positions by satellite tracking has been introduced in March, 1998. This monitoring provides improved knowledge of effort distribution both in time and space. While conventional logbooks give an estimated location on a daily basis, satellite polling allows for multiple queries on vessel's location during the course of a day. Satellite-based monitoring systems are set to collect positional data randomly on an hourly basis. Real time information is available once hardware and software components are set up. Objectivity is no doubt, the second qualifier of the monitoring system. Contrary to positions jotted down in logbooks by fishers, estimation or interpretation are not involved with the satellite-based monitoring system. Positional data has a higher daily frequency (set at 24 readings) with the monitoring system compared to logbooks. Accuracy in location of fishing activities is much improved with GPS (Global Positioning System) soon to be DGPS (D for Differential). Locations of vessels found in logbooks are quite often still in LORAN bearings, a less precise system, even though the vast majority of the fleet is equipped with GPS navigational aids. Figure 2 compares effort distribution patterns on Georges Bank on a quarterly basis by fishing days estimated from logbooks and hours fished (time spent at towing speeds) estimated from satellite tracking devices. The main trends are similar but daily readings (Fig. 2A) tend to lump fishing activities that the hourly pollings (Figs 2B, C, D, and E) expose in details. For example, fishing activities in the southernmost part of Georges Bank (Canadian side) during the third and fourth quarters of 1998 are better described with the newer technique.

Catch-rate is presented as catch (kg) per hour and per crew-hour-meter. Catch per hour considers only the period that gear was actively fishing. It does not consider how wide the gear is to estimate how much ground is covered by the tow. Gear width may vary from 8.5 to 15.5 m. Scallop meats caught have to be shucked at sea; the smaller the meats, the more crew needed to shuck. Common fishing practices will first change the number of crew if effort has to be modified. CPUE in kg / h is used in the cohort tuning analysis. High catch-rates encountered recently are not necessarily suitable for comparison with high values of the late 1970's. Technological changes in the localisation of scallop beds and operational procedures at sea coupled with different management regimes, especially meat count and limit on removals, influence the conduct of the fishery compared to 20 years ago.

Catch sampling

Size distributions of meats from the commercial fleet were derived from port samples. Only one or two company fleet(s) have regularly contributed the information during the time period under consideration (1981 – present). In 1991, steps were taken to expand the catch sampling database to all fleets. Data representing harvesting strategies of the different company fleets have been included in the catch data matrix since then. Generally speaking, the meat size composition data for each fleet show scallops caught at a larger size by the additional fleets sampled since 1991 than the corresponding data from the 2 'index' companies. (Robert and Butler, MS 1995). There are, at present, 7 company fleets. Port sampling was extended to cover all trips during 1995 when monitoring for small (under 10 g) meats in the catch was added. The catch sampling program was initially a shared undertaking between DFO and Industry; in 1998 the program became 100% supported by Industry. DFO is responsible for data analysis and oversight of the program for monitoring small meats in the catch.

Canadian port sampling data were applied to the Canadian and U.S. total catch east of the ICJ line prior to 1985. This assumes similar fishing practices for both fleets. Table 3 presents a monthly profile of meat weights in the catch. Table 4 has the normalized frequency of meat weights by quarter. Table 5 lists the frequency distribution of meats on an annual basis. There has been a gradual shift toward larger meats in the catch over the last 10 years, reflecting the implementation of a lower meat count in 1986. More recently, the Industry initiative to discourage the presence of meats under 10 g in the catch has significantly reduced the frequency of this (under 10 g) component in the catch.

Port sampling data were used to construct the numbers-at-age in the catch (Table 6) as in previous assessments. The sum of U.S. and Canadian catches in NAFO SA 5Ze is applied to the catch-at-age data. The total catch (U.S. prior to 1985 and Canadian) from the Canadian zone is decomposed into 2 - g weight frequencies. The weights were converted to shell heights using the allometric relationship derived from 1982 -1985 research and commercial data (Robert and Lundy MS 1987). Shell heights were clustered into age groups according to a Von Bertalanffy growth equation (Brown et al. 1972, cf. Table 7). This approach referred to as slicing, underestimates large year classes and overestimates weak year classes.

Traditionally, catch statistics are compiled on an annual basis and recruitment to a fishery is discussed in terms of year class strength. It is generally accepted that, in any given year the majority of Georges Bank scallops are born in October and the first annual ring is laid down the following spring. This is typically less than 10 mm and becomes difficult to discern as the animal grows. For this reason the ring, which is approximately 25 mm from the umbo is often referred to as the first annulus (Naidu 1970). The convention which we shall adopt is that animals born in the fall of a year will be of that year class and it will be further assumed that they were born on January 1 of that year (cohort ages). The deposition of the ring less than 10 mm will take place during the first year of life. The date of the deposition will be assumed to take place on April 1. A back calculation is then made to estimate the shell height for January 1 (eg. cohort age 3 has a shell height of 61 mm on January 1st, while its biological age is 2.25 years). The annual growth rates for weights, given in Table 7, are converted into rates for heights and this results in a 16% reduction of the ring size being used for the January 1 size. For example, an animal born in the fall of 1988 is of the 1988 year class and will be approximately 25 mm on its second birthday (January 1, 1990) although the ring would not be deposited for a few months. Table 7, as well as all other age data, uses this convention, with correction of ring sizes back to January 1. The actual weights used are start-quarter or mid-quarter values in age - weight analyses and projections.

Research survey data

The annual research survey is carried out on Georges Bank during August each year. A new survey series started in 1994. The design of the survey was based on a stratification by commercial effort (Robert and Jamieson 1986). The logbooks of the commercial fleet in the preceding 9 months were analyzed to determine areas of very high, high, medium, low, and very low catch-rates (>2.0, 1.99-1.0, 0.99-0.5, 0.49-0.2, and <0.2 kg/crhm respectively). This stratification design allocated a larger proportion of stations to higher catch-rates strata as determined by the commercial catch-rate data. In 1995 the efficiency of the survey design was investigated (Smith and Robert 1998). Results suggested possible improvements that were implemented in the 1995 survey.

Efficiency was evaluated by comparing the observed variance from the actual stratified survey design and the expected variance from a simple random sample design (SRS). That is, efficiency measures whether a particular survey design resulted in a more precise estimate of the mean than another design. The difference between the 2 variances can be characterized into 2 components. One of these components, the ‘Strata’ component, reflects the gain in precision due to how well the strata match the distribution patterns of the scallops. The other component, the ‘Allocation’ component, is negative, zero, or positive depending upon whether the stations were allocated to strata arbitrarily, proportional to strata size, or proportional to the product of stratum size and the strata standard deviation. The Strata component was negligible overall and completely dominated by the large negative Allocation component most of the times. Although the Strata component was small, the efficiency of the pre-1995 survey design had been compromised by the station allocation scheme.

The number of stations allocated to each stratum was set to be proportional to the size (area) of each stratum starting in 1995 in an attempt to minimize the effect of the Allocation component on the efficiency of the survey design. Survey data for 1995 to 1997 were analyzed for efficiency (Robert et al 1998 for preliminary results). This approach to allocation paid off by keeping the Allocation component close to zero. There has been some improvement in the Strata component but this will vary from year to year because the strata are redefined each year based on the spatial pattern of the commercial catch-rate.

An adaptive allocation strategy was tested during the 1998 and 1999 stock surveys to improve the efficiency of the results, especially the juvenile (age 2 scallops) index. Under this approach, a survey is first conducted to get estimates of means and standard deviations for each stratum. Then, a second pass is made over the survey area with additional stations allocated per stratum according to the following criteria. Extra sampling is carried out if, for example, 20% of the original stations in a stratum contained more than 100 age 2 scallops. The extra stations in designated strata are allocated proportional to the size of the strata. Thompson and Seber (1996) have provided unbiased estimates for this kind of design. This way, the stratum standard deviations of the current year survey can be used to improve the design and efficiency of that survey.

The stratified average number of scallops at age per tow is given in Table 8. Table 9 has means and standard errors by ages. Parameters were estimated using standard estimators for stratified random surveys (Smith 1996). Confidence intervals were also calculated using bootstrap resampling methods for stratified random survey designs (Smith 1997). These intervals are percentile intervals calculated from 1,000 replications. As for most surveys of marine populations, the general pattern is one of the larger the mean, the larger the standard errors and the wider the confidence intervals. Summary survey results are given in Table 10.

In addition to establishing a stratified mean number per tow, the data are contoured to represent the spatial distribution of the scallop aggregations according to a procedure, ACON, by Black (MS 1993). Data points describe a three dimensional surface with latitude, longitude, and density to be plotted. A surface is formed by defining Delaunay triangles; data points form the vertices of triangles connecting neighboring points. The algorithm used to define the triangles is found in Watson (1982). Collectively, the triangles form a surface. The surface between adjacent contour levels (density of scallops) is illustrated by varying shades of grey. Smoothing of the contours may be performed by interpolating over the surface using inverse weighting of gradients (perpendicular to the planes of the triangles). The interpolation points are found by dividing the sides of the triangle into equal segments. Dividing the sides into 4 segments produces 16 subtriangles. Interpolation is performed on all the new vertices. This method assumes that the data points near the point in question contribute more than distant points (Watson and Philip 1985). The summation of the volumes of all triangles (integration) under the contoured surface approximates the total volume for the area covered by the survey. The degree of interpolation will affect the volume estimates. For the Georges Bank survey data, the estimates stabilize using 16 or more subtriangles when they vary less than 5%.

Biomass indices (Table 11) from aerial expansion of numbers of scallops per standard tow have been computed using weights at age for the middle of the third quarter (August) found in table 7. These estimates correspond to a minimum dredgeable biomass as they are not adjusted for the survey gear efficiency. Data prior to the establishment of the ICJ line, from 1981 to 1985 inclusive, have been recomputed (Tables 10 and 11) to provide density and biomass estimates for the Canadian side of Georges Bank only.

Stock analysis

Two different models have been used here to estimate the population size and fishing mortality rates. A sequential population analysis (SPA) using Non Linear Least Square Regression (NLLS) is run on quarterly age based data tuned against commercial catch-rate indices and survey data. The Collie-Sissenwine production model is run on an annual basis with data partitioned into a recruiting group and a fully recruited group based on shell height from survey data.

Sequential population analysis

In the first year of recruitment the animals experience approximately a 300% increase in weight. To reduce the magnitude of the errors caused by ignoring growth effects, the cohort analysis was carried out on a quarterly basis. This required that catch-at-age, effort distribution, and partial recruitment be determined on a quarterly basis. This was done by adjusting recent year's selectivity pattern to reflect the port sampling data for the last quarter of 1999. This pattern, multiplied by the F determined from tuning for the last quarter year (F_{Q4} 1999), was used as a starting vector for the quarterly cohort analysis.

A natural mortality rate of 0.025 per quarter or 0.1 per year is used in the analytical assessment. No variation is provided for seasonal, age, or time dependent effects. Estimates of natural mortality rate for Georges Bank scallops were reviewed in Robert et al (MS 1994). Basically, it would appear that M levels off at 0.1 for recruited age groups of the deep sea scallop and rises slowly beyond age 10. Considering that very few scallops of the Georges Bank stock reach old age, it is not felt necessary to vary M for recruited ages.

The SPA is tuned against a number of independent sets of observations. The most important are the commercial CPUE and research survey estimates. Tuning selectivity is more difficult in scallop data than for most fisheries. This is because the SPA is done on a quarterly basis and the F's on the most recent year affect only the last quarter. Thus one cannot 'dial up' in an iterative fashion the exact numbers of F's one might want for the most recent year as can be done with annually collated data. Because the selectivity is highly domed toward ages 4 and 5, these values are not critical and the normal iterative determination was not undertaken. Peculiarities of some technical aspects such as the dome-shaped selectivity vector, using disaggregated ages versus aggregates, and a non-zero intercept in tuning plots were examined at the RAP session, spring 1996 (Robert and Butler MS 1996). In addition to tuning for cohort biomass over the complete range of ages 3 to 8, iterations were carried out on cohort biomass for certain age groups. Nowadays, indices of abundance in the research surveys best represent ages 3 to 7; indices for ages 3 - 7 were used to calibrate a cohort biomass for these ages. Over the last few years the contribution of age 3 scallops toward achieving good catch-rates has been small. It was found that relating CPUE to a cohort biomass ages 4+ had higher statistical validity than relating CPUE to a cohort biomass including all ages (Robert et al 1998).

A sequential population analysis (SPA) using Non Linear Least Square Regression (NLLS) (ADAPT, Gavaris 1988) was carried out. The ADAPT used in this report was a compiled verson written in ACON (Black MS 1993) and uses the the Marquardt algorithm for the NLLS minimization. The model used is as follows:

Parameter(s):

Number (i = age 4) for the last quarter of 1999 ($N_{i,1999Q4}$)

Structure imposed:

Error in catch assumed to be negligible

Partial selection fixed for ages 1 and 2

F on oldest age in the last quarter assumed equal to the weighted average for ages fully recruited to the fishery during that quarter

No intercept was fitted

Log transformed residuals

Input:

Catch at age for ages 3+ from 1981 to 1999 on a quarterly basis

Survey results for ages 3 to 7 (i) inclusive, from the middle of the third quarter of the year from 1981 to 1999 (t) ($J_{i,t}$)

Commercial annual catch-rate assigned to the middle of the second quarter (quarter with the highest amount of catch over a year period) from 1981 to 1999 ($C_{i,t}$).

Objective function:

Minimize the residuals for $\Sigma\Sigma$ ($\ln J_{i,t} - \ln N_{i,t})^2$

Summary:

Number of observations: 19 years of catch data or 76 quarters
19 years of survey data from mid-Q_3
19 years of catch-rates data in Q_2

age	1	2	3	4	5	6	7	8
selectivity	0.00	0.00	0.08	1.00	0.873	0.299	0.137	0.089

The model estimated for F at age 4 in the last quarter of 1999 calibrated by CPUE data and survey results for ages 3 to 7. Ages included in the tuning are from 4 to 8. The statistical diagnostics are as follows:

CPUE (kg/hour) and survey results (ages 3 - 7) for tuning
mean square of the residual = 0.0778
Estimated parameter = 5.73592 CV = 16.39

Base q’s = 0.009 and 0.513

The coefficient of variability on the 1999 population estimate for age 4 is 16%.

Confidence intervals for biomass estimates and fishing mortality rates were obtained using the non-parametric bias corrected percentile bootstrap method for 1,000 replicates.

A Thompson-Bell type yield per recruit analysis with quarterly time steps was used to take into account the dynamic growth of the younger age groups of scallops. However, this method does not include the effects of blending. A change in fishing strategy to adapt to the 33 meat count regulation required a re-calculation of the yield per recruit in the 1988 stock evaluation (Mohn et al MS 1989) and redefinition of the partial recruitment pattern. Subsequently, the yield per recruit was examined for change in partial recruitment. A difference of 10% (or less) between old and new yield per recruit determination does not warrant any changes being made to the model. The implementation of the monitoring of meats under 10 g in the catch resulted in the near-absence of age 3 scallops in the catch starting during the 1995 fishery. The impact of the monitoring program was stronger on the 1996 fishery. It affected the partial recruitment vector to an extent larger than 10% and the yield per recruit was re-evaluated. The 1997 fishing strategy was highly similar to 1996. The model parameters were updated again in 1999 although the difference triggering the change was not large at 15%.

Production model

The catch-at-age estimates required for the ADAPT/SPA analysis in this assessment have been obtained using a constant age/shell height relationship. The use of a constant relationship has been criticized in the past because it does not allow for possible changes in growth rate. As an alternative, we applied the Collie and Sissenwine's (1983) version of the DeLury model to the Georges Bank scallop data. The notation of the model used here is from Conser (1995). This model does not require estimates of the age composition of the scallops instead the population is characterized as consisting of the number of animals fully recruited to the fishery in year y, N_y and those animals which will recruit to the fishery in year y, R_y. In our application of the model, we use size classes to differentiate between the fully recruited and recruits.

The dynamics of the change in population numbers from one year to the next are described as follows,

$$N_{y+1} = \left(N_y + R_y - C_y\right) \times \exp\left(-M\right) \times \exp\left(\varepsilon_y\right) \qquad (1)$$

where C_y represents the number of scallops in the catch in year y, **M** is the rate of natural mortality and ε_y is a random error term with mean zero and variance σ^2_ε.

This error term is referred to as process error. We cannot observe the actual number of scallops in the population but we do monitor numbers of scallops by size class (shell height) in the survey. Therefore we assume the numbers in the survey are related to numbers in the population via catchability coefficients as,

$$n_y = q_n N_y$$
$$r_y = q_r R_y$$

Substituting back into equation 1 gives,

$$n_{y+1} = \left(n_y + \frac{q_n}{q_r} r_y - q_n C_y \right) \times \exp(-M) \times \exp(\varepsilon_y)$$

Finally, we assume that there is measurement error associated with our survey estimates.

$$n'_y = n_y \times \exp(\eta_y),\ y = 1,\ldots,Y$$
$$r'_y = r_y \times \exp(\delta_y),\ y = 1,\ldots,Y-1$$

Note that given the large number of parameters to estimate it is usually difficult to estimate $\boldsymbol{q_r}$. In this analysis we assumed that $\boldsymbol{q_r} = \boldsymbol{q_n}$ which seems reasonable given that the survey dredge is lined to estimate pre-recruits (scallops whose shell height is under 75 mm, diameter of the dredge's rings). Parameter estimates are obtained for the $\boldsymbol{n_y}$, $\boldsymbol{r_y}$ and $\boldsymbol{q}_{\text{n}}$ by minimizing the following nonlinear least squares objective function.

$$S(\theta) = \lambda_\varepsilon \sum_{y=2}^{Y} \varepsilon_y^2 + \sum_{y=1}^{Y} \eta_y^2 + \lambda_\delta \sum_{y=1}^{Y-1} \delta_y^2$$

The λ terms are weights that allow one to fit the model minimizing the process error relative to the measurement error or vice-versa.

In our application of the Collie-Sissenwine model we defined the fully recruited and recruits in the following manner:

1. Fully recruited:
- 1981–1985: survey densities (number per square km) for shell heights 75 mm and greater.
- 1986–1999: survey densities (number per square km) for shell heights 90 mm and greater.
2. Recruits:

- 1981–1985: survey densities (number per square km) for shell heights 50 to 75 mm.
- 1986–1999: survey densities (number per square km) for shell heights 75 to 90 mm.

For the initial fit of the model we set λ_ε to 2.0 and λ_δ to 1.0 to emphasize the fit to the model in equation 1. Commercial catch was calculated for the survey year which ran from August to July.

Stock projections

The regulations in effect on the offshore fleet are that scallop meats in the catch should average no more than 33 per 500 g which corresponds to an average weight of 15 g per meat. Placing a limitation on the average instead of stipulating a minimum means that the fishermen may take small animals and then balance them with larger ones. Such a practice, called blending, renders the use of most yield models and stock projections inappropriate. If there are not enough larger animals to blend in, then the mortality on the small ones will have to be reduced. Thus, the partial recruitment is a function of abundance-at-age. In order to take this practice into account, a stock projection program was written (Mohn et al. MS 1984) in which the mortality on the animals beneath the stipulated average meat weight is adjusted until the mean weight of the catch is within 1% of the required average. Selectivity for the stock projections follows the pattern of the fishery as revealed from the cohort analysis rather than that of the gear (Caddy 1972). Starting numbers-at-age for the projections are derived by projecting ahead the fourth quarter cohort estimates of the present year to January of the next year. Recruitment is estimated according to the relative densities of prerecruits observed in the stock survey for age 3. The geometric mean of the time series is used for ages 1 and 2.

Catch projections and fishing scenarios under the current meat count were carried out for different rates of F including $F_{0.1}$ and F_{max}, to present TAC options and their respective implications on the stock biomass. The adjusted (age 3 only) population estimate for the beginning of 2000 was used to establish the prognosis. Forecast results carry an inherent degree of uncertainty. This uncertainty is compared to the risk of achieving reference targets like replacement yield. Moreover, overall uncertainty would be greater because the risk calculations do not consider variations in weights at age, variations in natural mortality rates, or systematic error in data and model mismatch.

RESULTS

Description of the fishery

Catches have been on a declining trend since they peaked at the 6,000 t level in 1992-93. Zone 'a' catches have declined 33% from 1998 to 1999. Considering zone 'a' alone, 1999 Georges Bank catches rank 3rd lowest since 1981; only 1995 and 1984 are lower (Table 2). While monthly catches were somewhat evenly distributed during 1998 (Fig. 3), there was a large rise in the April-June, 1999 landings ; 64% of the annual catch was landed before July. Both 1998 and 1999 had more than 20% of landings from the winter fishery. This value is considerably higher than the historical 10% for the first quarter of the year.

After the 1997 fishery experienced the highest catch-rates since the late 1970's, the 1998 fishery suffered a 35% drop (Table 2 zone 'a'). However, the 1999 CPUE's caught up 33% of the previous year losses to make them 2nd highest (kg/h) or 3rd highest (kg/crhm) in the series. During 1999, monthly catch-rates were low to moderate (under 0.5 kg/crhm) until June while the bulk of the quota was fished (Fig. 3). After June, rates kept rising until the end of the year. The spatial distribution of CPUE isopleths (zone 'a') was fairly similar in 1997 and 1998 (Figs 4 a and b) except that the 1998 fishery covered more grounds in the south part of Georges Bank. The distribution pattern changed in 1999 (Fig 4c) with minimum activity in the northwest corner, near the ICJ line and in the extreme south part of the Bank. Areas maintaining high CPUE's (>1 kg/crhm) have been over 1,000 km^2 since 1997, 1,014 km^2 in 1999 (Table 2). Only 700 km^2 had supported high rates in 1995. Areas up to 2,000 km^2 had delivered high rates in the past. Zone 'a' effort dropped about 40% from 1998 to 1999 (Table 2). The quarterly distribution of effort from the satellite-based monitoring data for 1999 (Fig. 5) shows fishing intensity over all parts of the Bank from January to June. During the remainder of the year, little activity took place in the northwest corner and in the south part. Zone 'a' October to December activities were concentrated over 2 specific areas that had not been exploited at that scale before that.

Composition of the catch

The average monthly meat weight in the catch had been increasing from 1993 to 1995 reflecting the weakness of the 1990 and 1991 year classes recruiting to the fishery. Then it decreased in 1996 with the fishery directing for the 1992 year class earlier (age 4) given the weakness of the 1991 year class. Monthly mean meat weights were in the high range again in 1997 and 1998 with summer monthly means over 20 g (Table 3). Monthly means had a small drop in the fall of 1998 and then increased to higher values still until June, 1999. Monthly means then decreased to a low of 17 g in September. The presence of meats under 10 g in the catch was severely curtailed once the monitoring program for small meats was in place from the second quarter of 1995 onward. There were under 1% of small meats in the 1999 catch, the lowest levels observed ever (Table 4). Usually, smaller meats appear in the catch in greater numbers in the fourth quarter when the incoming recruits enter the fishery as is the case for 1996 and 1997. The fishery ignored incoming small recruits in 1999. Meats of that size were either not available and/or not needed, larger sizes being plentiful. Table 5 and figure 6a presents the meat weight distribution on an annual basis. Figure 6b details the changes in meat weight during 1999.

The strength of recent year classes entering the fishery has been highly variable and was reflected in the meat weight distribution in the catch. In 1995, the once plentiful 1988 year class (at age 7, 29+ g) contributed 20% of scallops caught but in 1996, depleted old year classes made up only 5% of 29+ g meats (Table 5). In 1997, the weak 1990 year class and older year classes contributed 6% of meats over 29 g. The percentage of older scallops rises to 13% in 1998. Ages 7+ scallops are represented by the poor 1991 and 1990 year classes in addition to the 1989 year class. This percentage is similar in 1999 at 15%. The supply of very large meats was nearly exhausted by mid-year (Fig. 6b). The 1993 year class at age 6 in 1999 contributed 9% of meats (24-29 g) in the catch. The 1994 and 1995 year classes at ages 5 and 4 respectively, made up 34 and 41% of the number of meats in the catch. Age 5 scallops, the usual mainstay of the fishery did not play the first role in 1999; age 4 young recruits did. A good supply of young scallops at a large size may have contributed to the high catch-rates encountered despite the average strength of the 1994 (age 5) and 1995 (age 4) year classes.

Research surveys

Sampling details related to the number of locations surveyed on a stratum basis and size of area covered by each stratum are found in table 8a. The sampling locations of the 1999 research survey are plotted in figure 7 on the panel for the contour plot for age 7. Figure 8 shows a collection of annual profiles of shell height in 5-mm intervals for survey results since 1981. Modes of strong year classes can be followed through until dispersed by fishing activities. The 1996 year class in particular, first observed in 1998 with modes of small scallops less than 60 mm shell height appears to be the strongest observed over the last 19 years. Survey estimates for 1999 have 2 modes around 60 and 90-100 mm respectively. The first mode matches the smallest mode of the 1996 year class noticed for the first time in 1998. The fastest growing component of the 1996 year class would have formed the second mode.

Tables 8b, 9, and 10 have survey results in terms of number at age for ages 2 to 8 per stratum for recent years, relevant statistical parameters, and a summarised history in the average number at age per year for 1981 to 1999. Figure 7 illustrates the distribution of isopleths of number per tow for ages 2 to 7 for the latest survey. While the abundance of age 5+ scallops remains quite stable over the recent past (Table 10), there has been a large input of prerecruits in 1999 corresponding to ages 3 and 4 based on shell height. The abundance at age 4 (1995 year class) in 1999 may not be related to the estimates for that year class from the 1998 survey. The abundance at age 3 in 1999 (1996 year class) first observed in 1998 at age 2 appears to be underestimated. The abundance of the youngest age group observed (1997 year class) is lower than the 1996 year class. The 1997 year class is overestimated in table 10. Assigning age group with the knife-edge boundaries used in the slicing approach has the slower growing scallops of the 1996 year class (age 3) included in the age 2 group. They would belong to the scallop bed at the extreme south part of Georges Bank on the Canadian side (Fig. 7). Excluding the slow growth component, the 1997 year class could be labeled as below average or weak. On the other hand, the faster growing scallops of the 1996 year class at age 3 are ‘wearing’ a size 4 shell.

The distribution of commercial catch-rates leading to the 1999 survey stratification is mapped in figure 9. We will follow the estimated abundance of age 4 scallops in the strata with CPUE’s >1kg/crhm (high or stratum 4 and very high or stratum 5). This discourse could also be applied to the other strata to a lesser extent. The area outlined by the 2 darkest shades of gray (CPUE’s >1kg/crhm) on the map is mainly located in the top left corner of figure 9. This area, on the northern edge of the Bank, is highly productive with nutrient-loaded shelf-edge waters pushed up the Bank and incorporated in the gyre circulation. Although the placement of strata from commercial CPUE’s changes somewhat from year to year, the area in the top left corner of the map always generates high to very high strata. According to table 8b, the average number/tow for age 4 in 1999 is 118 and 532 for the high and very high stratum respectively. These figures do not reconcile with average number/tow at age 3 in 1998. Estimates of number/tow in terms of shell height groupings on a stratum basis are plotted in figure 10 for 1999 and figure 11 for 1998. In 1999, stratum 4 and 5 have an important mode at 85-90 mm shell height (‘size 4’ approximately; Fig. 10). In 1998, the only mode present to justify the 1999 observation is at 50-55 mm shell height (age-‘size 2’ approximately; fig. 11). Figure 12 shows the location and estimated numbers at age for ages 2 to 4 from the 1998 research survey (left side of the pie chart) and from the 1999 research survey (right side of the pie chart). Colors (gray shades) in the chart refer to the different ages (yellow (light gray) for age 2; red (medium gray) for age 3; blue (dark gray) for age 4); pie size refers to numbers per tow for the 3 ages. The area of high catch-rates on the northern edge of the Bank is outlined. In this area in particular, the 1998 survey shows high numbers of age 2’s (light color, left side) and very few age 3’s (medium color, left side). One would expect that, very few age 3’s in 1998 are followed by very few age 4’s in 1999. However, the 1999 survey observations (right side of the chart) indicated higher quantities of age 4’s (dark color) than expected from the 1998 survey results. As the modal distribution of shell height had shown in figures 10 and 11 the abundance of age 2’s and the near absence of age 3’s in 1998 was followed by a significant presence of ages 3 and 4 in 1999. If one considers the size 3 scallop only from the 1999 survey, the 1996 year class was underestimated especially in the fast growing areas of the northern edge.

Given the very high degree of patchiness and variability in distribution of the youngest age surveyed, an adaptive allocation sampling strategy was implemented in 1998 and 1999. In 1998, extra sampling had been carried out in all strata with the rule that extra tows were assigned to a stratum if 20% of the first phase stations in a stratum had more than 100 age 2 scallops. The abundant 1996 year class was well represented in every stratum. Table 12a reports the abundance estimates and statistical characteristics for juveniles according to the regular survey design (left side of table), the estimates for the adaptive allocation strategy (RB), and for the total sample size without correction for bias (right side of table). The adaptive allocation strategy has brought the variance down by 30%, from 52832 to 37321. In an attempt to make the sampling rule more selective in 1999, extra tows were carried out if 30% of stations in a stratum had more than 100 scallops at age. It was felt worthwhile to pursue this approach with age 3's. Applying the 30% rule to age 2 in 1999 would have meant little re-sampling. In this case the rule was 12.5% of stations in a stratum with more than 100 scallops. The adaptive allocation strategy brought the variance down by 8% for age 2, from 3550 to 3278 and by 19% for age 3, from 955 to 772.

In all cases the adaptive designs provided smaller variances for the mean at the second stage of sampling (Table 12a). However, a smaller variance would be expected given the increased number of samples at the second stage. For this sampling approach to have any advantages, the reduction in variance at the second stage would have to be greater than the reduction expected simply because of the increased sampling intensity. While there may be a number of arbitrary ways of adding extra tows to strata, allocation proportional to the size of the strata is the best way with respect to reducing the variance when strata variability is not known. In order to be advantageous, the adaptive allocation would have to provide smaller variances than would have been obtained, had a proportional allocation been used for the total of the first and second stage sample sizes.

In 1998, all strata received additional sampling and the actual final adaptive sampling allocation was equivalent to the proportional allocation. However, the variance for the adaptive sampling was still smaller than expected probably due to the variances in some of the strata (e.g., 1 and 3 in Table 12a) being much smaller than expected given the increase in sample size alone (Table 12b). Not all of the strata received extra sampling in 1999 and the adaptive allocation provided smaller variances than expected for a strict proportional allocation (Table 12b).

The relationship between the commercial catch and the population estimates for older scallops (age 9+) is poorly understood. The population estimates based on survey data would be too high, the numbers in the catch not high enough, hence a low selectivity vector of < 10%. There were a few contradictory observations. First, the sampling intensity of the fleet is considerably greater than the limited time spent surveying by the research vessel. One would expect a better representation of older scallops in the catch. Or, more importantly, there might be an element of patchiness misrepresenting older animals in survey data. Figure 13 shows the location of survey tows in August 1999 where 5 or more age 9+ scallops were caught. Figure 14 points out the locations where the fleet found pockets of old scallops and fished these sites. The overall correspondence of the 2 maps is poor. There was no fishing activity where the survey found most of its old scallops aggregated around 41º 30’ latitude, 66º 30’ longitude (compare figures 13 and 14). The survey had only one tow with 7 age 9+ scallops in it near where the fleet activities were most concentrated in the area of 42º 00’ latitude, 66º 36’ to 66º 42’ longitude. Other tows in the immediate vicinity did not have old scallops. Short of increasing sampling intensity and related costs a great deal, it would not appear easy for survey work to get a better match between survey and commercial data.

The index of minimum dredgeable biomass derived from aerial expansion had dropped 20% from 1997 to 1998 and slightly more than 50% from 1996 (Table 11). It was near the low end of biomass indices in the series from 1981 to the present. The absence of a strong year class and the weak representation of the 1993 year class at age 5 contributed to the low 1998 biomass estimate. The input of the strong 1996 year class represented partly in the ‘age-size’ 3 and 4 category produced a much larger biomass index for 1999. It is the 2nd highest of the series at 8,500 t for the group considered and almost twice the mean for the period 1981-1999.

Stock status indices

A stock biomass index relevant to the next year’s fishery, has been developed from research survey data for shell height groupings. The index profile covers the period 1981 to 1999 (Fig. 15). Fully recruited indices (shell height greater than 100 mm) have generally been much higher after the implementation of catch limits and lower meat count in 1986. There is more volatility in the index of the height class of young recruits (shell height between 90 and 100 mm). During 1981 to 1999, only 3 years stand out with more than 400 kg/km^2, 1986, 1992, and 1999. The index is high for 1999 suggesting a very large influx of young recruits to the 2000 fishery. From 1998 to 1999, the index for fully recruited scallops improved 16%, the index for young recruits, 400%.

While conducting research surveys, samples are collected throughout the area to establish allometric relationships between shell height and meat weight. The health status of the stock may be monitored following the meat weight of a scallop of fixed shell height at survey time. Data have been compiled from 1990 to 1999. According to figure 16, the meat of a 100-mm scallop would have been 17% heavier in 1999 than in 1998. Heavy meats had not been seen on Georges Bank since at least 1990 according to this data. A 14-g meat in a 100-mm shell is more typical of the period 1993-1998 and closer to the biomass estimates used in the cohort analysis. The 1999 surge in meat weight could partly explain the acceleration of catch-rates in the fishery starting in May (Fig. 3) without a major drop in meat count. It may also be involved in the rapid growth observed in the 1996 year class, especially on the northern edge of the Bank.

Sequential population analysis

The SPA analysis provided results in terms of numbers-at-age, biomass-at-age, and F-at-age estimates; they have been combined into annual values from quarterly analysis. Residuals derived from the tuning exercise using CPUE and survey results in combination are plotted in figure 17. Over the period 1981 to 1999, there is no discernible pattern in the distribution of residuals.

Retrospective analysis of the estimation of fishing mortality rates and biomass was also carried out. The analysis proceeds by peeling off 4 quarters at a time. Table 13 presents the results for the last 5 years. Figure 18 shows the lack of trend in under or over estimation in the data. No constraint was put on the terminal population to initiate the stock projection given the lack of pattern shown in the retrospective analysis.

Tables 14 to 16 give the Georges Bank scallop stock characteristics. The Georges Bank stock saw the passage of 2 good year classes with over 500 million scallops at age 3 (1988 and 1989 year classes) during the early 1990's (Table 14). (Age 3 scallops is the first age observed reliably in survey data; ages 1 and 2 are derived by inference in the SPA and not shown). These year classes were followed by the 2 poorest year classes to be observed since 1981. Recruitment then improved with age 3's in 1995 near the median value for the population. Subsequently, recruitment declines again with the 1993 and 1994 year classes. According to the model, the 1995 year class would be average. However, other data, especially research survey data, show otherwise. The model overestimates the strength of the 1995 year class when it attempts to justify the numbers at age (size) 4 in 1999. Size 4 scallops in 1999 as detailed in the survey results were age 4 scallops plus the faster growing members of the 1996 year class. The catch data also included both year classes of scallops as the same age group. The model could not estimate numbers at age 3 properly since they were not represented in the catch as size 3. The 1996 year class representation in table 13 is underestimated. Numbers at age 3 in the research surveys coincide well with the strength of these same year classes in the population estimates (Fig. 19). The 1995 and 1996 year classes, as discussed above, need to be adjusted; an adjustment based on the survey information is shown as the dotted line in figure 19, top. The 1996 year class, at age 3, is conservatively estimated at the median level for the population (432 mill.) by dropping the selectivity for age 3 from 0.08 (see earlier in this document) to 0.033. Total numbers (ages 3+) for the population estimate are on the rise after 1994 which estimate had been among the lowest recorded since 1981 (Table 14). When numbers for age 3 are (conservatively) adjusted in 1999, total numbers will rank in the 1 billion-plus scallops. At least half of the present population is made up of the 1996 year class; the age 3's in a size 3 and the fraction of age 3's in a size 4 representing themselves as age 4 scallops in 1999. The remainder of the 1995 year class and the 1994 year class (age 5) rank distantly behind.

Total biomass estimates (Table 15) have been increasing after bottoming out first in 1995 then in 1998. The biomass estimate for 1999 is 20% larger than the previous year. This is a conservative estimate as the figure is not adjusted for a considerably higher biomass for age 3. However, the directed biomass (ages 4 - 7) which had experienced a small peak in 1996 then dropped, is rising again (Fig. 20). The directed biomass is has increased over 25% from previous years. It will remain at higher levels for quite a while given the incoming strong 1996 year class.

Annual fishing mortality rates are presented in table 16. Mean F on all ages had varied little from 1988 to 1994 when it was lower than before the implementation of EA's (pre-1986). After dropping for 1995 mean F rose again in 1996 before declining until 1999. F on the directed age group (4 - 7) experienced an important reduction from 1994 to 1995, rose to the pre-1995 levels in 1996 before declining at lower levels similar to mean F (Fig. 20 bottom). The 1999 F on all ages and on directed ages are the lowest of the series. The fishing mortality at age 3 (F3) had peaked in 1981 when the meat count regulation had been relaxed and the strong 1978 year class was recruiting to the fishery. It has become minimal with the meat count reduction to 33 per 500 g in 1986. It dropped from 0.06 in 1994 to 0.01 in 1995 and did not vary thereafter. Fishing mortality at age 3 has been reduced to almost nil with the monitoring of small meats in the catch. Figure 21 has the corresponding profiles for exploitation rates. The exploitation rate on the directed age group declined since 1996 to reach the lowest point in 1999 at 15%.

The spawning stock biomass is calculated using an empirical maturity ogive. There is no apparent linear stock-recruitment relationship for the time period 1981-1996. It would appear that, spawning stock biomasses ranging from 10 to 15,000 t during the early 1990's have produced weak year classes regardless of size (Fig. 22). Spawning stock biomass levels had been lower during the 1980's. Low or high levels do not relate to high recruitment. Moderate levels around 10,000 t seem to produce higher recruitment. A non-linear curve fitting routine could be considered to establish the presence of a relationship.

Production model

The initial application of the Collie-Sissenwine model to the data resulted in a poor fit to the survey estimates of fully recruited scallops in 1992 and in the most recent years (1996–1999; Fig. 23). The main difficulty that the model had was with 1999 where the observed numbers of fully recruited animals was so much larger than expected. That is, the expected numbers fully recruited in 1999 based on the estimates of fully recruited and recruits in 1998 minus the numbers caught and numbers from natural mortality from September 1998 to August 1999. The estimate of fishing mortality for 1998–1999 was estimated to be 0.04 (Table 17, column labeled 75–89 mm).

The possibility that the higher growth rates observed in 1999 resulted in scallops smaller than 75 mm growing enough to be fully recruited during the year was investigated by re-fitting the model using an increasingly larger size range of shell heights to define recruits in 1998. The resulting estimates of fishing mortality for each fit are presented in table 17. The fit using recruits defined as scallops between shell height 55 and 89 mm provided the best fit with respect to the observed number of fully recruited scallops in the survey. Residual patterns for recruits and fully recruited for this fit are plotted in figure 24 and the fitted numbers in figure 25. The estimate of fishing mortality for 1998–1999 for this case was 0.13 (Fig. 26).

Biomass figures (derived from N times the mean weight in the catch) for fully recruited scallops as of the 1999 survey was estimated to be 14,322 t (Fig. 26). This point in time is the 'start' of a new (survey) year. To approximate a biomass figure for the start of calendar year 2000, one has to bridge the gap from survey to calendar year. The fourth quarter 1999 fishery landed 414.5 t with a total catch of 22 million scallops. The predicted biomass as of January 1st 2000 was 11,897 t plus an additional amount from the recruiting class of scallops not yet quantified by this modeling exercise.

Stock projections and outlook

The quarterly based yield per recruit analysis uses mid-quarter meat weights and the quarterly expanded selectivity derived from the cohort analysis (See Mohn et al. MS 1987). The 1996 stock assessment led to estimates of 0.89 for F_{max} and 0.54 for $F_{0.1}$. The yield per recruit model is re-evaluated with each new year of data. A change of 10% or less in the values for F_{max} and $F_{0.1}$ is the criteria used to justify modification of the estimates for F_{max} and $F_{0.1}$. Based on the 1999 assessment, F_{max} was estimated at 1.02 and $F_{0.1}$ at 0. 61. The same selectivity was used in the cohort analysis, yield per recruit, and the catch projections. The projections are carried out at selected F values including $F_{0.1}$ and F_{max} using the adjusted population estimates from the VPA for the beginning of 2000. The VPA estimates are used since the 2 models (Collie-Sissenwine and Adapt) through different approaches, expressed similar trends in population estimates and fishing mortality rates at the terminal point of the exercise (Fig.27). The projections for 2000 assume a recruitment level at age 3 of 400 million scallops to reflect the near average strength of the 1997 year class as observed in the research survey results. Given the lack of apparent relationship between stock spawning biomass and incoming recruitment, the geometric mean of the population estimates was used for ages 1 and 2. Numbers at age 3 to 8 in million of scallops, at the beginning of year 2000 are: 400, 389, 302, 135, 67, and 44. The partial recruitment vector used is: 0.009, 0.43, 1.00, 0.51, 0.33, 0.23 for ages 3-8.

The passage of the strong 1996 year class into the exploitable biomass puts the Georges Bank stock in very good standing for 2000. It contributes to potential catch scenarios 3 times the 1999 catch. Catch projections at $F_{0.1}$ would be around 6,050 t (table 18, Fig. 28) for 2000. The population biomass is projected to stay relatively the same, at 19,800 t at the end of 2000 under that scenario. The 1995 and 1996 year classes, at ages 5 and 4 respectively, would represent 28% of the population estimate and 44% of the total biomass. The biomass for ages 4 to 7 is expected to increase slightly (6%) in 2000. Catch projections at F_{max} would be around 8,600 t for 2000. A higher catch makes for a smaller total biomass at the end of 2000. This biomass would be 16% smaller than the same biomass at the beginning of 2000. The directed biomass would lose 11% during the year. The effects of other catch scenarios may be considered on figure 28.

The projection results carry a certain degree of uncertainty due to the estimates of year class strengths. There is no doubt that the 1996 year class will have a significant impact on the Georges Bank scallop stock over the next 4 years. The extent of the impact will get better defined as the year class ages. To date, its abundance estimates rely mainly on survey observations. However, the statistical robustness of the estimate is enhanced by the 2-phase survey design. Besides its sheer size, the 1996 year class influences stock biomass in a particular way as rapid growth was observed during 1999, especially in scallop beds located on the northern edge of the Bank. It is possible to estimate the uncertainties from the model about stock size and use these in a risk analysis. The risk plot incorporates the difference between the model and the data in variables that can be estimated (natural mortality, growth, shell height/meat weight relationship). In the model used here, there is a 30% probability that a catch scenario of 5,400 t fishes at an F greater than $F_{0.1}$ (Fig. 29). A catch scenario of 6,050 t has a 50% risk of exceeding the target level while 6,800 t increase the risk to 80%.

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Table 1.- Estimated (pre-1985) catches (t of meats) from Georges Bank, NAFO subarea 5Ze, east of the ICJ line which separates fishing areas for both countries. TAC's are for the Canadian side only.

Year	U.S.A.	Canada	Total
1981	2000	7612	9612
1982	1054	3918	4972
1983	714	2418	3132
1984	889	1945	2834
1985	0	3812	3812
1986	0	4900	4900
1987	0	6793	6793
1988	0	4336	4336
1989	0	4676	4676
1990	0	5218	5218
1991	0	5805	5805
1992	0	6151	6151
1993	0	6183	6183
1994	0	5003	5003
1995	0	1984	1984
1996	0	2996	2996
1997	0	4259	4259
1998	0	3991	3991
1999	0	3699	3699

Year	Recommended TAC	Set TAC	Catch
1986	---	4300	4900
1987	6500	6850	6793
1988	4800	5400	4336
1989	4700	4700	4676
1990	4800	5200	5218
1991	5200	5800	5805
1992	5800	6200	6151
1993	6200	6200	6183
1994	5000	5000	5003
1995	2000	2000	1984
1996	3000	3000	2996
1997	4250	4250	4259
1998	4250	4000	3991
1999	3700	3700	3699

Table 2.- Catch and effort data. Canadian catches (tonnes of meats) in NAFO subarea 5Ze. Canadian total effort is derived from effort from Class 1 data. The fished area shown generated high catch-rates (greater than 1 kg/crhm).

Year	Catch	Effort		CPUE		Area
	tonnes	hours 10^3	crhm* 10^3	kg/h*	kg/crhm	km^2
1981	7612	100	14484	76.12	0.526	
1982	3918	73	9977	53.67	0.393	
1983	2418	67	8690	36.09	0.278	
1984	1945	70	8598	27.79	0.226	
1985	3812	105	12644	36.31	0.301	
1986	4900	52	6957	94.23	0.704	
1987	6793	78	10808	87.09	0.629	
1988	4336	85	11283	51.01	0.385	
1989	4676	78	10774	59.96	0.434	1992
1990	5218	72	10570	72.09	0.494	2097
1991	5805	66	9687	88.40	0.599	1930
1992	6151	73	10957	84.10	0.561	2044
1993	6183	64	9874	96.76	0.627	1049
1994	5003	64	9566	78.12	0.523	2157
1995	1984	39	5687	50.94	0.349	700
1996	2996	31	4855	95.37	0.617	855
1997	4259	36	5742	119.63	0.744	1097
1998**	3991	49	7707	81.42	0.518	1259
zone a	3191	43	6640	74.96	0.481	
zone b	800	6	1066	124.07	0.750	
1999**	3699	33	5284	111.42	0.700	1014
zone a	2503	25	3900	100.41	0.642	
zone b	1196	9	1486	132.38	0.805	

* crew-hour-meter; hour
**Fishery data for 2 zones in 1998 and 1999

Table 3.- Port sampling data. Monthly profile of the catch from NAFO Subarea 5Ze from the frequency distribution of scallop meat weights for selected years from port sampling data.

	% catch examined / catch landed	meat weight (g)				n meats
		mean	min	max	s.e.	
1981	0.013					
January		---	---	---	---	0
February		8.96	3.26	53.21	0.06	1386
March		11.00	2.58	65.10	0.05	3673
April		10.19	4.70	54.38	0.08	402
May		11.56	3.37	76.60	0.02	19036
June		12.15	2.26	79.87	0.02	24514
July		11.44	2.55	73.25	0.02	16301
August		10.50	2.37	74.49	0.02	15204
September		9.90	2.23	59.09	0.03	4321
October		7.28	2.37	56.52	0.03	3165
November		8.13	2.10	54.47	0.03	4146
December		8.56	2.30	53.68	0.04	3004
1998	0.041zone a					
January		17.72	8.30	55.35	0.04	3707
February		18.51	6.08	56.32	0.03	6286
March		18.51	6.59	58.74	0.04	4665
April		19.16	5.56	55.75	0.03	8681
May		21.53	5.90	75.08	0.04	6805
June		21.83	7.44	69.05	0.05	3699
July		21.92	7.29	70.00	0.04	5972
August		19.74	7.66	64.26	0.05	3570
September		19.21	6.07	57.58	0.05	3933
October		20.58	6.15	63.05	0.03	6844
November		20.13	5.97	69.46	0.03	8751
December		19.21	8.36	57.03	0.04	3665
1999	0.033zone a					
January		22.32	8.20	61.88	0.07	2030
February		21.54	6.62	69.24	0.04	5387
March		24.15	6.33	65.09	0.06	3966
April		22.70	7.18	76.05	0.06	4419
May		21.49	7.44	82.97	0.05	6353
June		19.67	6.93	68.71	0.05	4621
July		20.82	9.32	86.12	0.07	2669
August		21.76	8.56	83.74	0.08	1854
September		17.21	8.71	67.98	0.04	2337
October		18.01	8.84	73.01	0.04	2792
November		18.44	9.32	57.45	0.04	1907
December		21.41	12.43	61.57	0.06	705

Table 4.- Port sampling data. Frequencies of numbers of meats at weight in 2-g intervals (normalized to 1000) by quarters for recent years from port sampling data.

Grams	1996	Q1	Q2	Q3	Q4	1997	Q1	Q2	Q3	Q4
1		0	0	0	0		0	0	0	0
3		0	0	0	0		0	0	0	0
5		0	0	0	0		0	0	0	0
7		3	0	1	3		0	0	1	2
9		29	7	19	36		5	2	10	21
11		143	54	92	134		44	21	41	71
13		270	183	215	224		168	81	99	127
15		228	273	232	197		274	162	143	164
17		120	217	165	123		236	203	145	169
19		54	115	94	83		124	165	125	130
21		26	50	54	54		60	123	109	92
23		17	26	39	39		31	79	81	67
25		15	17	25	27		17	50	66	51
27		16	12	19	19		13	36	45	34
29		14	9	12	14		8	23	36	23
31		15	7	9	9		5	15	26	17
33		11	7	7	9		3	12	20	11
35		10	5	5	8		2	7	16	6
37		10	4	3	5		2	6	10	5
39		7	4	3	4		2	4	7	3
41		5	3	2	3		2	3	5	3
43		3	2	2	2		1	2	4	2
45		2	2	1	1		0	1	3	1
47		1	1	0	1		0	1	2	1
49		0	1	1	1		0	1	2	0
Grams	1998a	Q1	Q2	Q3	Q4	1999a	Q1	Q2	Q3	Q4
1		0	0	0	0		0	0	0	0
3		0	0	0	0		0	0	0	0
5		0	0	0	0		0	0	0	0
7		1	3	2	3		1	0	0	0
9		11	26	25	21		12	10	1	1
11		78	77	82	74		52	63	33	27
13		172	121	136	129		88	144	109	99
15		184	126	141	140		93	178	202	176
17		137	120	106	126		109	136	208	206
19		101	93	79	101		110	84	158	192
21		84	78	63	83		110	55	88	137
23		67	70	61	69		84	43	41	69
25		53	59	60	55		69	39	21	37
27		37	51	53	48		51	36	18	19
29		25	42	48	37		40	33	13	11
31		17	36	39	30		32	31	16	6
33		10	26	29	22		28	26	14	4
35		9	20	22	17		25	21	14	3
37		4	15	14	14		22	20	14	1
39		4	11	12	9		17	17	9	3
41		2	7	9	5		13	13	6	1
43		2	6	4	6		11	11	6	2
45		1	4	5	3		8	10	7	1
47		1	3	3	2		7	8	5	1
49		0	2	2	2		4	5	4	0

Table 5.- Port sampling data. Frequencies of numbers of meats at weight in 2-g intervals (normalized to 1000) by year from port sampling data.

	Year									
Grams	1990	1991	1992	1993	1994	1995	1996	1997	1998a	1999a
1	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
5	2	1	0	0	3	1	0	0	0	0
7	24	12	7	6	23	11	2	1	2	0
9	96	64	47	36	65	55	19	7	21	8
11	164	141	135	113	109	126	93	39	78	50
13	177	174	196	190	126	148	214	116	138	115
15	146	162	184	196	119	116	242	190	146	157
17	113	126	135	150	107	85	171	196	122	151
19	80	93	89	102	94	67	93	140	94	120
21	62	65	56	68	81	58	47	98	78	88
23	43	44	41	45	64	49	30	65	67	58
25	30	30	28	32	51	44	21	44	57	44
27	19	21	22	22	40	37	16	31	48	35
29	13	18	17	13	32	34	12	22	38	28
31	9	11	12	10	24	32	10	15	31	25
33	6	9	8	6	18	27	8	11	22	21
35	5	6	6	4	13	22	6	7	17	19
37	3	6	4	2	10	19	5	6	12	17
39	2	4	4	2	7	16	4	4	9	14
41	2	4	2	1	5	13	3	3	6	10
43	1	2	2	1	4	12	2	2	5	9
45	1	3	1	0	2	9	1	1	3	8
47	0	1	1	0	1	6	1	1	3	6
49	0	1	1	0	1	5	1	1	2	4
51	0	1	0	0	1	3	0	1	1	3
53	0	1	0	0	0	2	0	0	1	3
55	0	1	1	0	0	1	0	0	1	2
57	0	0	0	0	0	1	0	0	0	1
59	0	0	0	0	0	1	0	0	0	1
61	0	0	0	0	0	0	0	0	0	1
63	0	0	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0	0	0

Table 6.- Catch-at-age in numbers (10^6) east of the ICJ line. GB ‘a’, ages 3 to 8.

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	284	51	41	60	47	2	28	24	14
4	491	167	100	82	160	140	195	145	181
5	84	80	44	29	46	149	145	66	96
6	18	25	13	14	9	17	38	13	8
7	8	10	9	9	7	2	11	13	4
8	9	6	8	8	6	1	3	6	5
Total	894	338	215	202	275	311	420	268	308

Ages	1990	1991	1992	1993	1994	1995	1996	1997	1998a
3	10	13	13	8	10	4	2	2	4
4	168	150	181	163	90	39	99	52	52
5	136	133	121	166	118	24	61	145	57
6	14	32	29	19	29	13	7	13	33
7	4	9	17	10	12	9	5	7	7
8	4	6	5	7	14	8	4	7	7
Total	337	343	367	373	273	97	178	225	160

Ages	1999a
3	<1
4	57
5	31
6	10
7	15
8	7
Total	121

Table 7.- Shell height (mm), meat weight (g) and meat count per 500 grams at age, biological and cohort. Height and weight as of first day of quarter.

Biological age	Cohort age	Shell height	Meat weight	Count /500g
2.25	3.00	61.23	3.11	161
2.50	3.25	63.22	3.44	145
2.75	3.50	74.57	5.73	87
3.00	3.75	83.13	8.03	62
3.25	4.00	87.30	9.34	54
3.50	4.25	89.23	10.00	50
3.75	4.50	96.26	12.64	40
4.00	4.75	102.35	15.29	33
4.25	5.00	105.51	16.80	30
4.50	5.25	107.02	17.55	28
4.75	5.50	111.60	19.99	25
5.00	5.75	115.81	22.42	22
5.25	6.00	118.08	23.81	21
5.50	6.25	119.18	24.50	20
5.75	6.50	122.23	26.49	19
6.00	6.75	125.13	28.49	18
6.25	7.00	126.72	29.63	17
6.50	7.25	127.50	30.20	17
6.75	7.50	129.55	31.73	16
7.00	7.75	131.54	33.26	15
7.25	8.00	132.65	34.13	15
7.50	8.25	133.19	34.57	14
7.75	8.50	134.58	35.69	14
8.00	8.75	135.94	36.82	14
8.25	9.00	136.70	37.47	13
8.50	9.25	137.08	37.79	13
8.75	9.50	138.03	38.60	13
9.00	9.75	138.96	39.41	13
9.25	10.00	139.48	39.88	13
9.50	10.25	139.74	40.11	12
9.75	10.50	140.39	40.68	12
10.00	10.75	141.02	41.26	12
10.25	11.00	141.38	41.58	12
10.50	11.25	141.56	41.75	12
10.75	11.50	142.00	42.15	12
11.00	11.75	142.44	42.55	12

Table 8a.- Research stock survey sampling allocations.

Survey year: 1998

Stratum	Ratio of area surveyed	Number of stations
1 very low	0.43478	65
2 low	0.16082	24
3 medium	0.13488	20
4 high	0.13908	21
5very high	0.13043	20

Survey year: 1999

Stratum	Ratio of area surveyed	Number of stations
1 very low	0.43716	65
2 low	0.23481	35
3 medium	0.13022	20
4 high	0.09260	14
5very high	0.10521	16

Table 8b.- Stratified average number of scallops at age per standard tow and mean number of scallops of all ages per standard tow, N. A new survey series starts in 1994.

Stratum	Sampling dates	Age (years)							N	s.e.
		2	3	4	5	6	7	8		
Very low	1995	93	15	14	11	5	2	1	141	37
	1996	30.6	21.9	28.2	12.8	5.2	3.3	2.7	104.6	23.9
	1997	19.9	17.8	20.0	16.0	5.8	2.7	3.0	85.1	18.0
	1998	936.5	12.0	13.1	4.0	4.5	2.1	3.5	991.1	549.4
	1999	141.3	78.5	38.5	5.8	4.9	2.6	1.3	276.7	133.4
Low	1995	155	48	17	9	7	3	1	240	111
	1996	28.9	81.9	153.6	41.6	6.4	2.5	2.4	317.4	112.9
	1997	1.9	7.2	20.6	26.4	9.2	2.6	2.0	69.9	14.8
	1998	430.3	14.7	46.0	11.5	9.6	3.3	2.2	517.5	202.0
	1999	142.3	259.7	113.1	6.8	6.4	3.8	1.6	535.9	171.9
Medium	1995	287	179	40	9	5	2	1	522	196
	1996	291.3	141.2	189.1	31.7	4.5	1.7	0.9	660.4	343.0
	1997	37.9	12.8	31.1	21.3	5.9	1.7	0.8	111.4	33.5
	1998	685.9	18.4	11.4	12.5	13.3	4.9	1.6	748.1	377.5
	1999	335.8	171.5	41.1	22.2	12.0	4.4	1.4	590.2	297.3
High	1995	404	384	80	7	5	2	1	883	255
	1996	154.9	88.8	159.9	18.9	4.2	1.9	1.3	429.9	284.2
	1997	58.5	88.8	41.8	24.0	5.1	1.5	0.9	220.6	79.0
	1998	343.0	64.3	34.8	17.4	10.2	3.4	1.4	474.5	106.1
	1999	66.2	142.7	118.4	19.0	8.1	2.9	0.9	358.7	123.9
Very high	1995	66	408	80	5	3	1	0	564	165
	1996	351.4	143.1	209.4	30.8	2.1	0.8	0.5	737.9	326.8
	1997	35.9	151.9	82.1	39.0	4.8	0.8	0.7	315.2	63.3
	1998	220.6	49.9	96.7	31.8	10.9	3.0	1.8	414.7	114.3
	1999	33.1	259.2	531.7	37.5	7.6	2.4	0.4	872.3	175.2

Table 9.- Estimates of the mean number of scallops at age for recent surveys and associated standard errors (mean) and confidence intervals.

				95% Confidence intervals	
Year	Age	Mean	SE	Lower	Upper
1995	2	160.0	43.1	85.6	248.2
	3	97.1	18.7	63.6	137.1
	4	26.9	3.9	20.2	35.6
	5	9.3	1.1	7.2	11.7
	6	5.6	0.5	4.7	6.6
	7	2.5	0.3	2.0	3.0
	8	1.2	0.2	0.9	1.5
1996	2	93.3	33.1	38.9	153.7
	3	60.6	10.8	42.3	81.8
	4	93.2	19.3	60.2	134.6
	5	22.0	4.8	14.5	32.0
	6	4.9	0.5	4.1	5.9
	7	2.7	0.2	2.3	3.1
	8	2.1	0.3	1.6	2.6
1997	2	17.9	4.9	9.8	28.6
	3	41.4	9.9	23.9	63.8
	4	32.3	4.2	24.6	41.3
	5	22.7	2.4	18.2	27.9
	6	6.3	0.5	5.3	7.3
	7	2.1	0.2	1.8	2.5
	8	1.9	0.2	1.5	2.4
1998	2	618.2	229.9	278.1	1140.1
	3	25.5	4.0	18.7	34.3
	4	32.2	4.7	23.4	42.0
	5	11.8	1.1	9.7	14.1
	6	8.2	0.8	6.7	9.9
	7	2.9	0.3	2.4	3.6
	8	0.8	0.1	0.6	1.0
1999	2	148.5	59.6	50.5	283.3
	3	158.1	30.9	102.9	223.5
	4	115.6	19.6	80.6	156.3
	5	12.7	1.7	9.8	16.1
	6	6.7	0.6	5.6	8.0
	7	3.1	0.3	2.6	3.6
	8	1.3	0.1	1.0	1.5

Table 10.- Mean number of scallops at age per standard tow from survey data since 1981.

Sampling dates	Age (years)						
	2	3	4	5	6	7	8
1981	177	191	24	5	2	1	0
1982	26	49	23	6	1	0	0
1983	44	31	18	5	1	1	0
1984	271	35	14	3	1	0	0
1985	104	206	18	2	0	0	0
1986	198	136	145	12	1	0	0
1987	94	98	63	17	5	2	0
1988	98	110	52	10	2	1	0
1989	117	131	71	13	2	1	0
1990	105	89	39	15	4	1	0
1991	359	103	49	13	3	1	0
1992	83	195	108	23	6	2	0
1993	10	42	46	24	7	2	0
1994*	90	24	24	14	5	2	1
1995	159	97	27	10	6	2	1
1996	95	60	93	22	5	3	2
1997	18	42	32	23	6	2	1
1998	618	26	32	12	8	3	1
1999	149	158	116	13	7	3	1

* new survey series

Table 11.- Minimum dredgeable biomass for selected ages (t of meats) using aerial expansion as per number of scallops per standard tow. Weights at age for the middle of the third quarter (August) are used. The total biomass is the sum for ages 3 to 7.

Sampling dates	Age (years)					
	3	4	5	6	7	Total biomass
1981	3,435.56	876.56	277.26	143.74	84.97	4,818.09
1982	881.37	840.04	332.71	71.87	-	2,126.00
1983	557.60	657.42	277.26	71.87	84.97	1,649.12
1984	629.55	511.33	166.36	71.87	-	1,379.11
1985	3,705.36	657.42	110.90	35.94	-	4,509.63
1986	2,446.25	5,295.89	665.36	71.75	-	8,479.25
1987	1,762.72	2,301.00	942.78	359.29	169.94	5,535.69
1988	1,978.62	1,899.22	554.43	143.77	84.97	4,661.04
1989	2,356.33	2,593.11	720.93	143.77	84.97	5,899.07
1990	1,600.84	1,424.38	831.86	287.55	84.97	4,229.50
1991	1,852.68	1,789.70	720.93	215.52	84.97	4,663.78
1992	3,507.50	3,944.53	1,275.39	431.22	169.94	9,328.59
1993	755.46	1,680.08	1,330.84	503.09	169.94	4,439.41
1994*	431.69	876.56	776.33	359.35	169.94	2,613.87
1995	1,744.76	986.13	554.52	431.22	169.94	3,886.57
1996	1,079.23	3,396.68	1,219.94	359.35	254.91	6,310.11
1997	755.46	1,168.75	1,275.39	431.22	169.94	3,800.76
1998	467.67	1,168.75	665.42	574.96	254.91	3,131.71
1999	2,841.98	4,236.72	720.87	503.09	254.91	8,557.57
long term mean	1,725.82	1,910.75	706.28	274.24	152.95	4,737.84

* new survey series

Table 12a.- Abundance estimates for juvenile scallops (age 2) from adaptive allocation from the 1998 and 1999 stock surveys and for age 3 from the 1999 survey. The sample size, mean and variance of the mean for each stratum of the initial survey sampling are denoted by Sta_1, n_1 and var(n_1) respectively. The Rao-Blackwell estimates for the adaptive allocation sampling are labeled with 'RB'. The last 2 columns give the mean and variance of the mean for total sample size without correction.

Age 2 in 1998

Stratum	Sta_1	n_1	var(n_1)	Sta_1+Sta_2	μ_{RB}	var(μ_{RB})	n_{1+2}	var(n_{1+2})
1	65	885.8	259235.6	78	759.6	180637.8	759.6	180637.8
2	24	400.8	37362.5	29	344.2	25993.2	344.2	25993.2
3	20	685.6	138672.6	24	577.4	98027.3	577.4	98027.3
4	21	343.0	8748.8	25	456.4	29666.5	456.4	29666.5
5	20	218.4	9931.1	24	218.3	8495.0	205.9	7274.2
Stratified		618.3	52832.2		555.5	37321.1	553.8	37300.3

Age 2 in 1999

Stratum	Sta_1	n_1	var(n_1)	Sta_1+Sta_2	μ_{RB}	var(μ_{RB})	n_{1+2}	var(n_{1+2})
1	65	141.4	12813.8	65	141.4	12813.8	141.4	12813.8
2	35	142.3	6595.6	35	142.3	6595.6	142.3	6595.6
3	20	335.8	42802.3	26	308.2	26933.4	307.4	26720.5
4	14	66.1	1196.9	19	57.8	867.4	53.3	673.0
5	16	33.1	145.1	21	38.1	134.0	34.5	92.7
Stratified		148.5	3550.2		144.7	3278.1	143.8	3272.4

Age 3 in 1999

Stratum	Sta_1	n_1	var(n_1)	Sta_1+Sta_2	μ_{RB}	var(μ_{RB})	n_{1+2}	var(n_{1+2})
1	65	78.4	590.3	65	78.4	590.3	78.4	590.3
2	35	259.6	10642.3	46	228.8	7555.4	213.2	6323.9
3	20	171.5	10527.5	20	171.5	10527.5	171.5	10527.5
4	14	142.7	3730.9	14	142.7	3730.9	142.7	3730.9
5	16	259.2	4071.9	21	224.2	2942.7	224.2	2942.7
Stratified		158.1	955.1		147.1	772.4	143.5	704.5

Table 12b.- Comparisons of variance of the mean from the adaptive sampling experiment. Proportional variance refers to the expected variance from allocating the first and second stage samples in a proportional allocation scheme.

	Variance of the mean		
Estimate	Stage 1	Proportional	Adaptive
Age 2 in 1998	52832.2	44020.0	37321.1
Age 2 in 1999	3550.2	3316.5	3278.1
Age 3 in 1999	955.1	860.6	772.4

Table 13.- Retrospective analysis of biomass (10^3 tonnes) for the first quarter of the year and annual fishing mortality rate for age 4. Results are shown for the last 5 years as per row label.

Biomass

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
1995	1.45	3.23	4.68	3.72	2.90	3.71	4.24	3.83	4.36	4.47	1.29	1.21				
1996	1.45	3.24	4.72	3.76	2.89	3.66	4.19	3.81	4.57	4.99	1.39	1.15	3.11			
1997	1.45	3.24	4.74	3.77	2.89	3.69	4.12	3.78	4.56	5.35	1.42	1.09	3.51	2.35		
1998	1.45	3.24	4.76	3.80	2.89	3.69	4.07	3.81	4.68	5.62	1.52	1.12	3.52	1.98	1.54	
1999	1.47	3.24	4.73	3.76	2.89	3.69	4.13	4.14	4.52	5.21	1.41	1.10	3.55	2.44	2.75	3.85

Fishing mortality rate

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
1995	0.70	0.63	0.53	0.78	0.61	0.61	0.56	0.55	0.55	0.52	0.88	0.36				
1996	0.71	0.62	0.52	0.77	0.61	0.62	0.57	0.55	0.52	0.45	0.78	0.38	0.43			
1997	0.71	0.62	0.52	0.77	0.61	0.61	0.58	0.56	0.52	0.42	0.75	0.41	0.37	0.33		
1998	0.71	0.62	0.51	0.76	0.61	0.61	0.59	0.55	0.50	0.39	0.68	0.39	0.37	0.41	0.46	
1999	0.69	0.62	0.52	0.77	0.61	0.61	0.58	0.49	0.52	0.43	0.76	0.40	0.36	0.32	0.23	0.13

Table 14.- Population numbers (at beginning of the first quarter) (10^6) east of the ICJ line from cohort analysis.

Population Numbers Q1

Age	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
3	647	239	203	440	610	432	354	445	489	484
4	671	301	172	151	335	489	389	299	381	427
5	98	135	105	61	68	162	264	163	147	187
6	34	30	44	46	27	29	46	78	66	40
7	28	16	13	26	24	15	18	24	50	45
8	45	18	8	8	16	13	11	13	16	39
Total	1523	738	545	733	1081	1140	1081	1020	1150	1222

Age	1991	1992	1993	1994	1995	1996	1997	1998	1999
3	530	609	166	134	409	279	312	433	182
4	427	467	536	145	113	365	250	280	389
5	217	235	250	314	61	68	229	164	200
6	60	74	96	83	153	35	18	83	88
7	23	36	43	69	53	121	25	12	56
8	33	15	25	31	53	43	101	19	9
Total	1291	1437	1116	777	842	911	935	990	925

Table 15.- Biomass Q1 (t of meats) east of the ICJ line from cohort analysis. The total biomass and the sum of biomass ages 4 to 7 are also given.

Age	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	1790	748	637	1379	1913	1355	1108	1393	1532
4	5999	2758	1575	1388	3066	4483	3564	2738	3496
5	1605	2241	1747	1017	1136	2693	4375	2701	2440
6	801	698	1031	1077	644	675	1086	1841	1569
7	821	479	380	781	700	432	527	703	1486
8	1541	611	278	278	553	433	376	431	555
B3+	12557	7536	5647	5920	8011	10072	11036	9807	11079
B4-7	9926	6177	4732	4263	5545	8284	9552	7982	8991

Age	1990	1991	1992	1993	1994	1995	1996	1997	1998
3	1517	1662	1908	522	420	1282	875	978	1357
4	3912	3911	4278	4910	1333	1038	3349	2289	2567
5	3111	3596	3908	4147	5219	1017	1135	3803	2719
6	944	1424	1753	2272	1951	3611	817	429	1970
7	1332	687	1061	1260	2025	1552	3573	727	342
8	1310	1133	527	856	1065	1800	1447	3434	636
B3+	12126	12414	13436	13967	12014	10301	11195	11660	9590
B4-7	9299	9618	11001	12589	10528	7219	8873	7248	7597

Age	1999
3	572
4	3569
5	3321
6	2080
7	1655
8	300
B3+	11496
B4-7	10624

Table 16.- Annual fishing mortality east of the ICJ line from cohort analysis. The average F for ages 3 to 8 and ages 4 to 7 are also given.

Age	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	0.66	0.23	0.19	0.17	0.12	0.01	0.07	0.05	0.04
4	1.50	0.95	0.93	0.69	0.62	0.52	0.77	0.61	0.61
5	1.10	1.03	0.74	0.71	0.77	1.16	1.12	0.80	1.20
6	0.64	0.73	0.40	0.55	0.52	0.37	0.56	0.34	0.28
7	0.34	0.59	0.36	0.39	0.52	0.18	0.24	0.28	0.17
8	0.14	0.25	0.37	0.31	0.31	0.16	0.25	0.11	0.11
Ave									
3+	0.73	0.63	0.50	0.47	0.48	0.40	0.50	0.36	0.40
4-7	0.90	0.82	0.61	0.59	0.61	0.56	0.67	0.51	0.57

Age	1990	1991	1992	1993	1994	1995	1996	1997	1998
3	0.03	0.03	0.03	0.03	0.07	0.01	0.01	0.01	0.01
4	0.58	0.49	0.53	0.43	0.76	0.40	0.37	0.32	0.24
5	1.03	0.97	0.80	1.01	0.62	0.47	1.23	0.91	0.52
6	0.44	0.42	0.45	0.24	0.35	0.13	0.24	0.35	0.30
7	0.20	0.31	0.26	0.21	0.16	0.11	0.08	0.18	0.17
8	0.15	0.21	0.21	0.12	0.25	0.06	0.06	0.10	0.12
Ave									
3+	0.41	0.41	0.38	0.34	0.37	0.20	0.33	0.31	0.23
4-7	0.56	0.55	0.51	0.47	0.47	0.28	0.48	0.44	0.31

Age	1999
3	0.00
4	0.13
5	0.26
6	0.15
7	0.13
8	0.09
Ave	
3+	0.13
4-7	0.17

Table 17. Fishing mortality rate estimates in 1998–1999 (survey year 1998) for increasing number of size classes assumed to recruit to the population in 1998–1999.

	Shell Height (mm)					
Year	75–89	70–89	65–89	60–89	55–89	50–89
1981–82	0.81	0.81	0.81	0.82	0.83	0.83
1982–83	0.54	0.54	0.54	0.54	0.55	0.55
1983–84	0.49	0.49	0.49	0.50	0.51	0.51
1984–85	0.32	0.32	0.32	0.33	0.34	0.34
1985–86	0.43	0.43	0.43	0.44	0.44	0.44
1986–87	0.62	0.62	0.62	0.62	0.63	0.63
1987–88	0.57	0.57	0.58	0.58	0.58	0.58
1988–89	0.50	0.50	0.50	0.50	0.51	0.51
1989–90	0.53	0.53	0.53	0.54	0.54	0.54
1990–91	0.41	0.41	0.41	0.41	0.41	0.41
1991–92	0.49	0.49	0.50	0.50	0.51	0.52
1992–93	0.67	0.67	0.67	0.67	0.68	0.68
1993–94	0.67	0.67	0.68	0.68	0.69	0.70
1994–95	0.33	0.33	0.33	0.33	0.34	0.34
1995–96	0.20	0.20	0.21	0.22	0.23	0.24
1996–97	0.39	0.40	0.40	0.43	0.46	0.48
1997–98	0.23	0.24	0.25	0.30	0.38	0.41
1998–99	0.04	0.04	0.05	0.07	0.13	0.20

Table 18.- Fishing scenarios established for 2000 given different options of fishing mortality rate. Corresponding exploitation rate (E) are also listed. Total biomass figures are for the end of 2000; the change from the start of the year is in parentheses. The target biomass is presented for ages 4 to 7. Catch figures are rounded off to the nearest 50 t.

No.	Options	F rate	E rate age3+	E rate ages 4-7	Biomass (t) all ages	Biomass (t) ages 4 to 7	Catch (t)
1	$F_{1999effort}$	0.27	22%	13%	22,598 (13%)	17,174 (21%)	3,200
2	$F_{replyld}$	0.59	43%	25%	19,923 (0%)	15,141 (7%)	5,900
3	$F_{0.1}$	0.61	44%	26%	19,774 (-1%)	15,028 (6%)	6,050
4	F_{interm}	0.80	53%	33%	18,458 (-8%)	13,659 (-4%)	7,350
5	F_{max}	1.02	61%	40%	17,123 (-16%)	12,671 (-11%)	8,600

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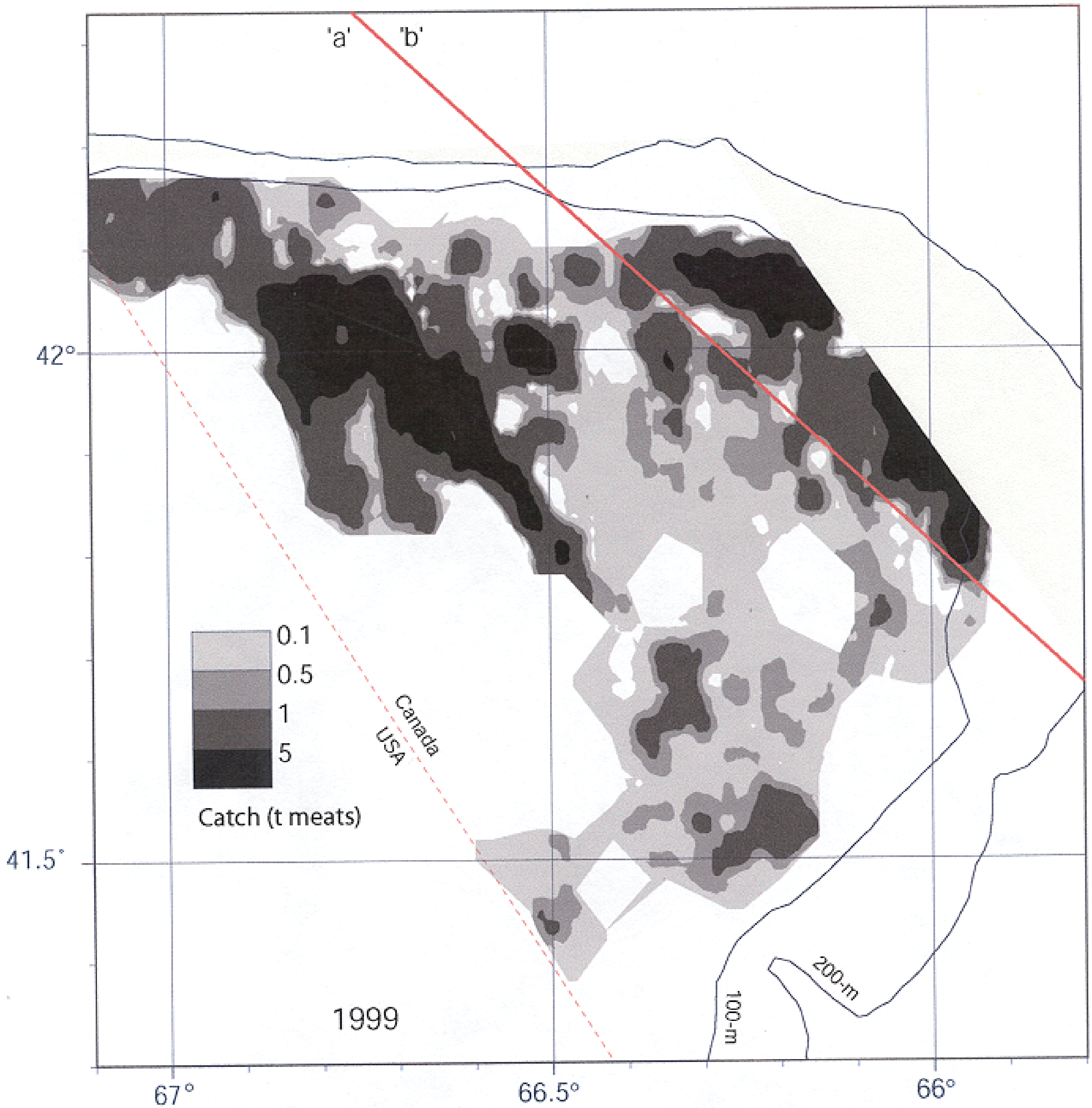


Figure 1.- Catch distribution (tonnes of scallop meats) on Georges Bank over the last 5 years. A) for the calendar year 1999. Zones a and b are outlined for the 1999 fishery. The legend for the isopleths shading is in the lower left corner of the map.

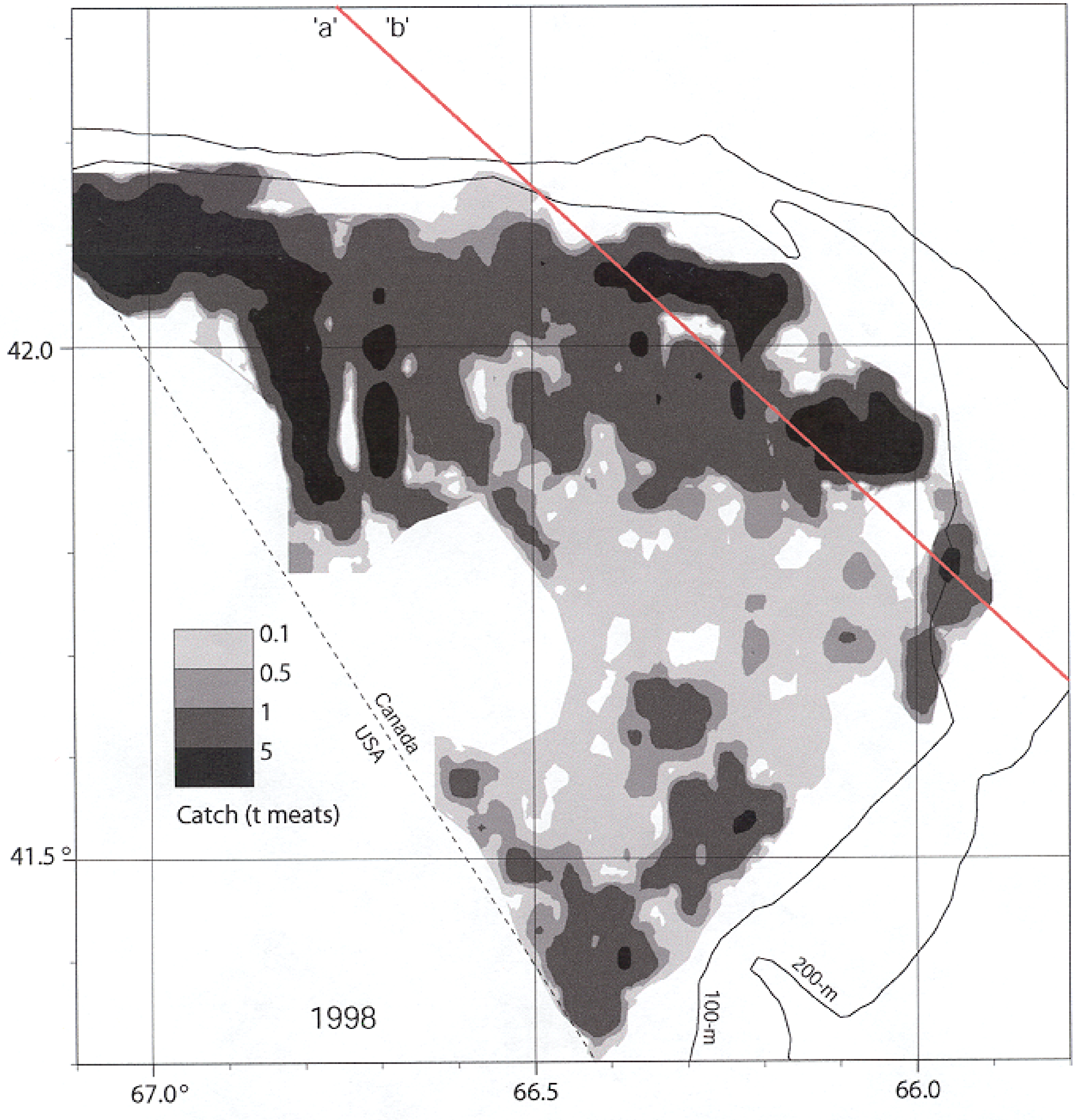


Figure 1.- continued. B)Catch distribution for 1998. Zones a and b are outlined for the 1998 fishery.

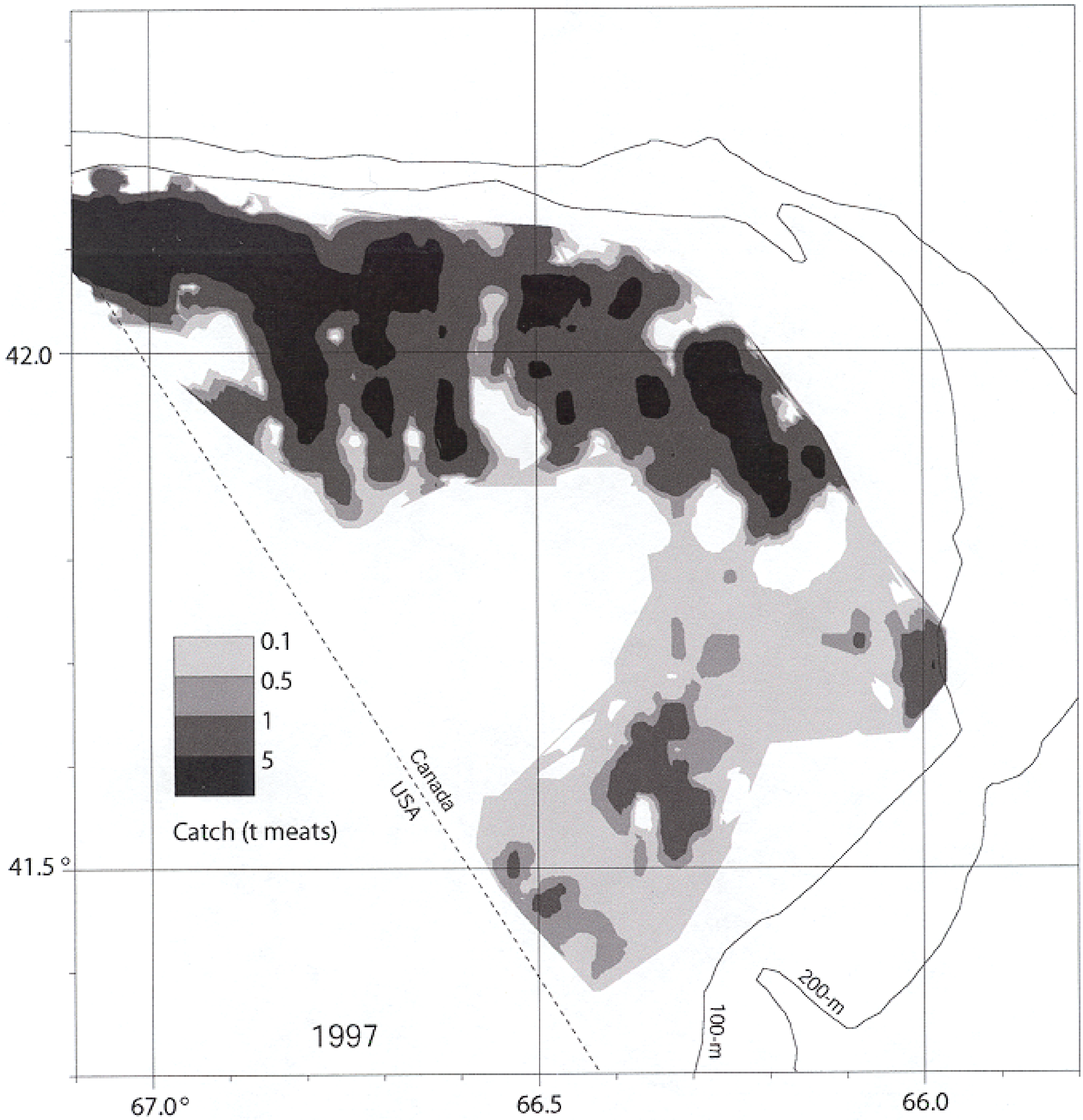


Figure 1 continued.- C) Catch distribution for 1997.

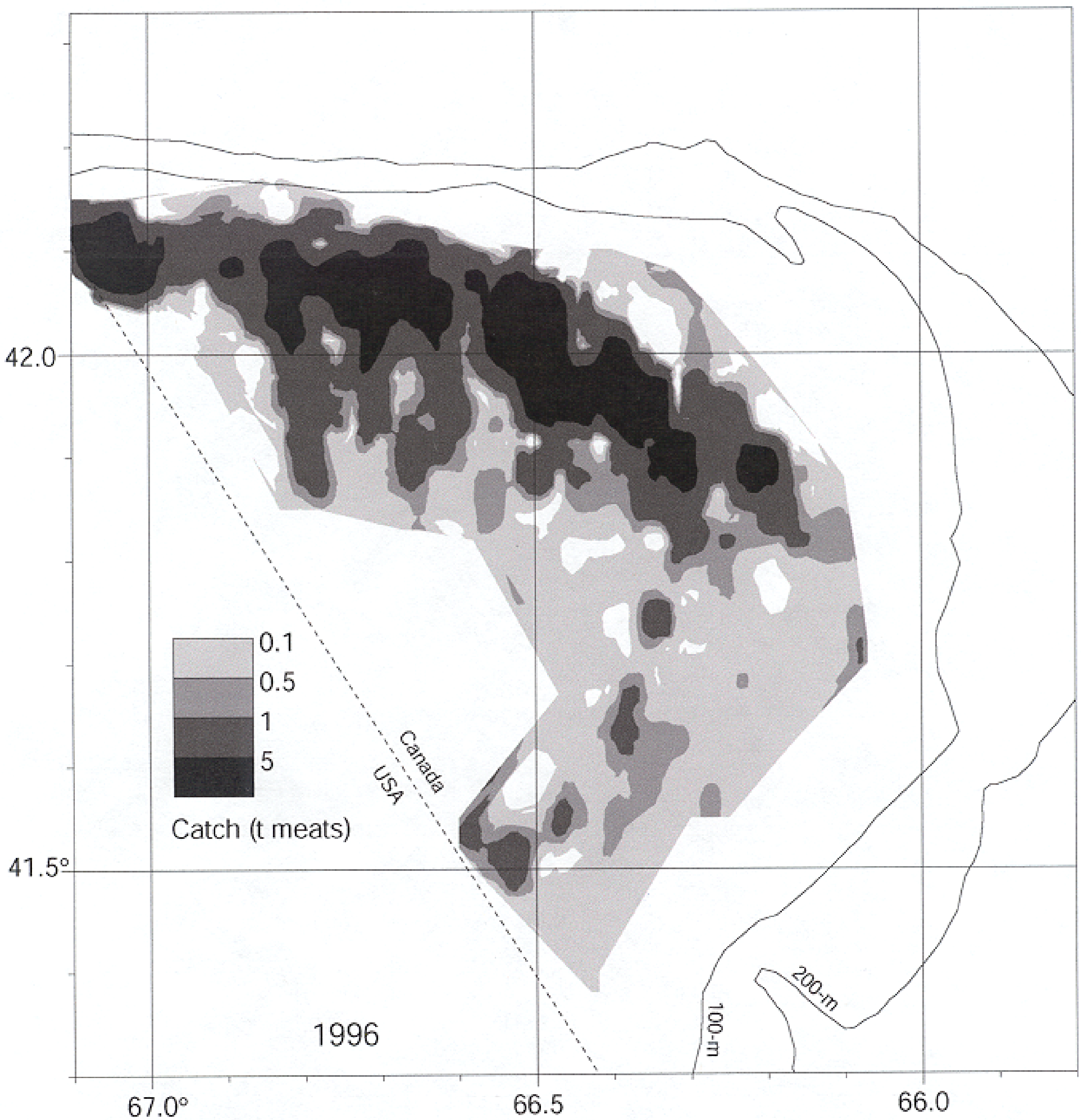


Figure 1 continued.- D) Catch distribution for 1996.

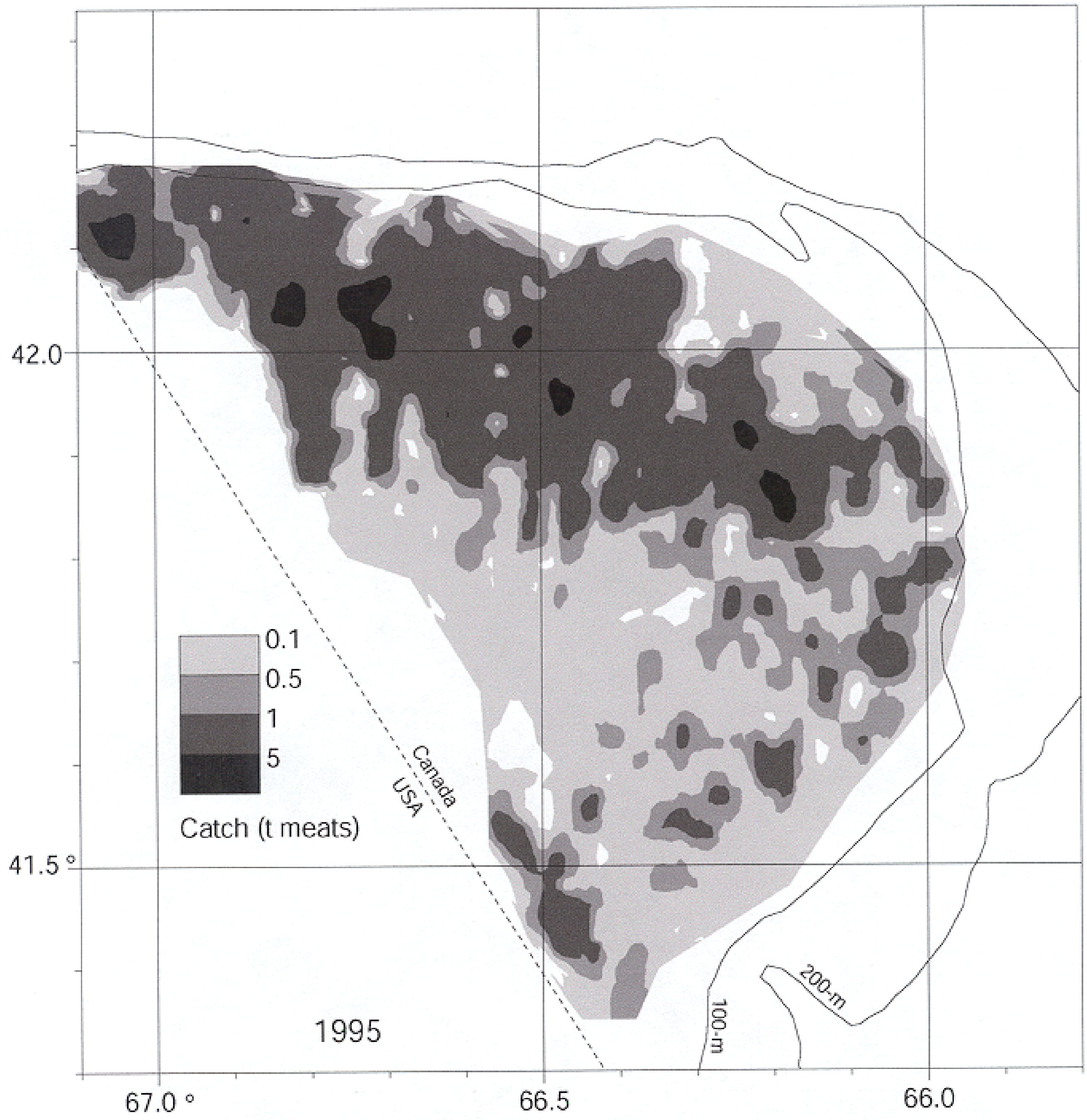


Figure 1 continued.- E) Catch distribution for 1995.

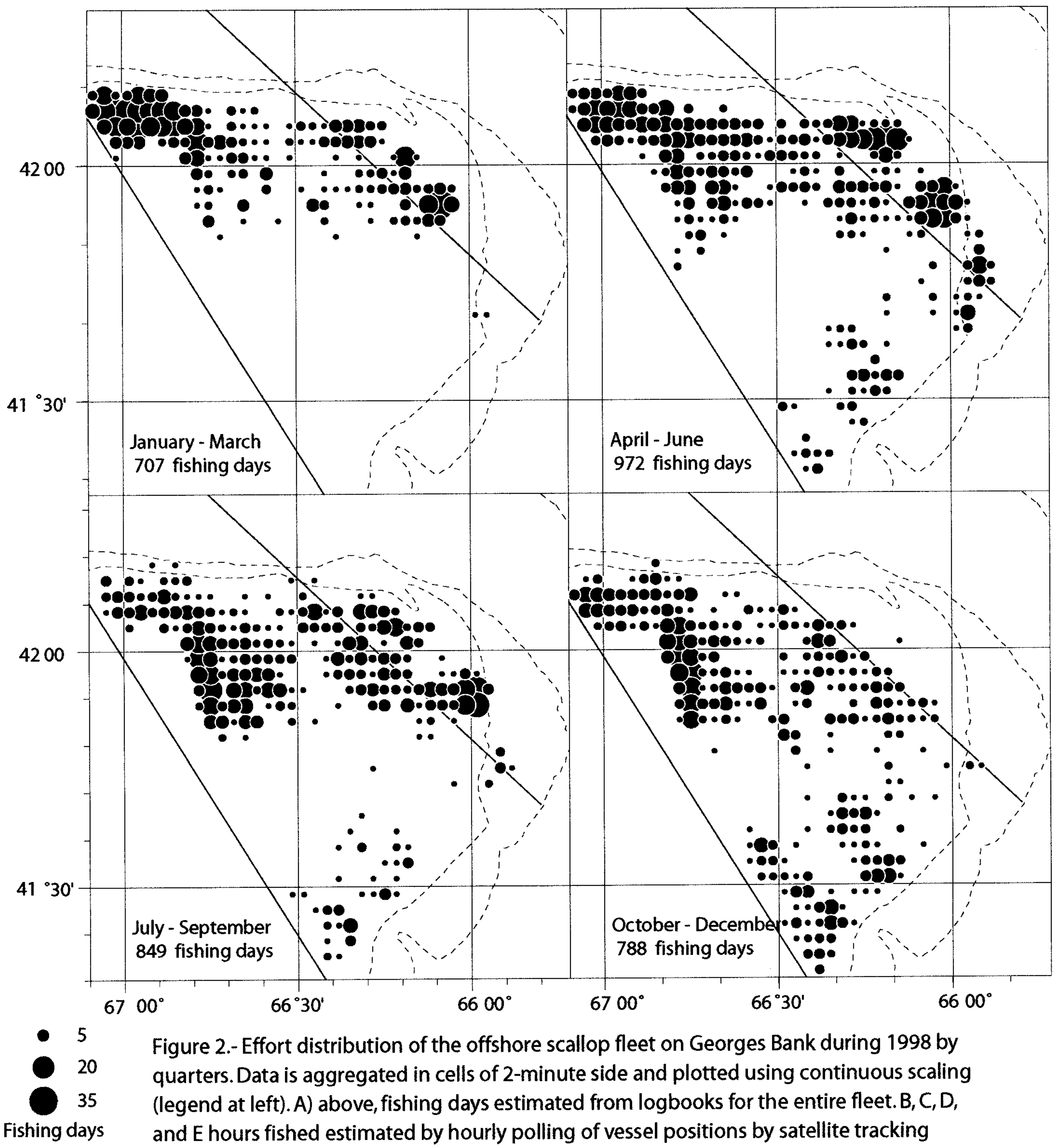
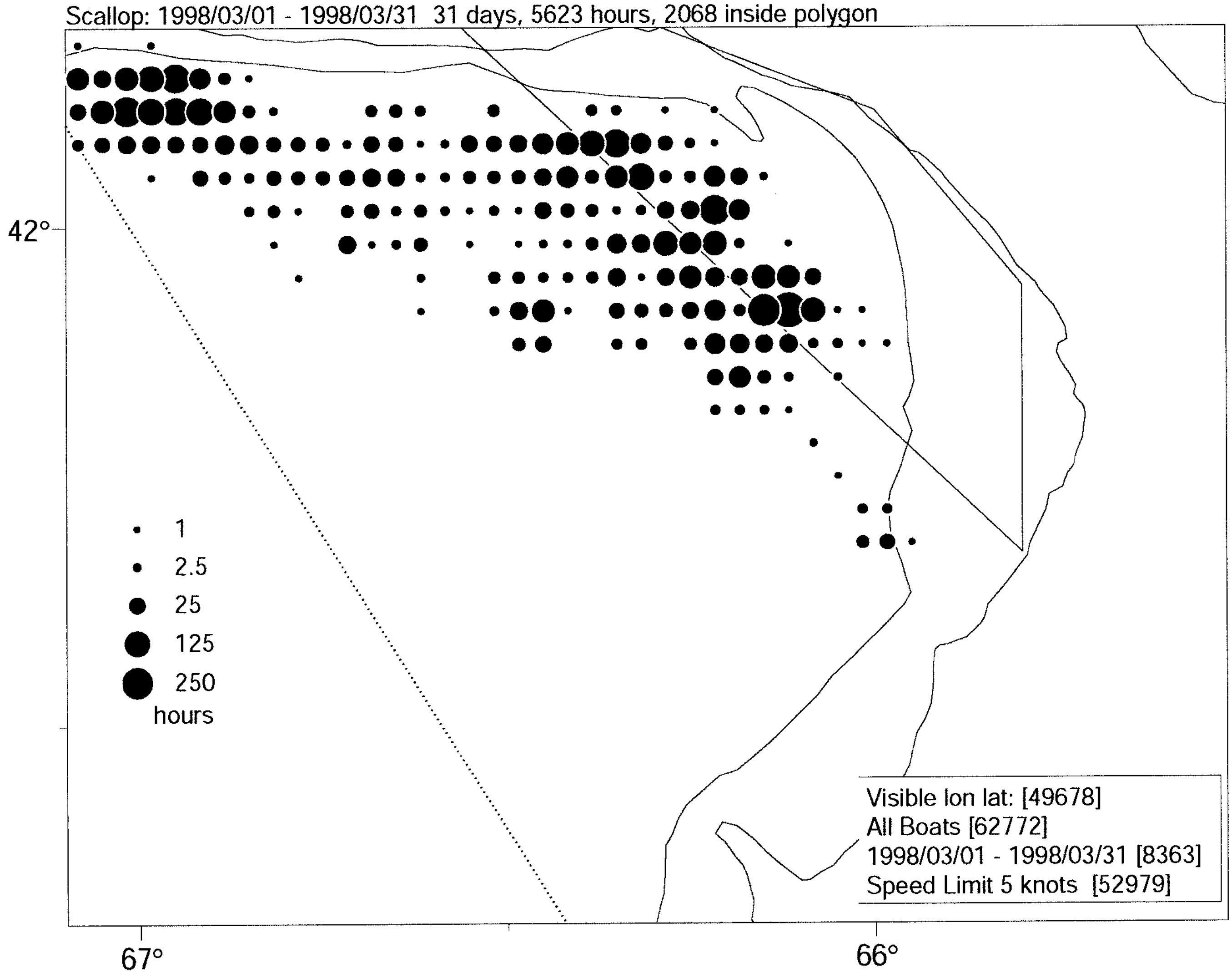


Figure 2.- Effort distribution of the offshore scallop fleet on Georges Bank during 1998 by quarters. Data is aggregated in cells of 2-minute side and plotted using continuous scaling (legend at left). A) above, fishing days estimated from logbooks for the entire fleet. B, C, D, and E hours fished estimated by hourly polling of vessel positions by satellite tracking devices for 70% of the fleet.



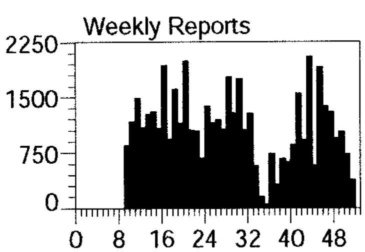
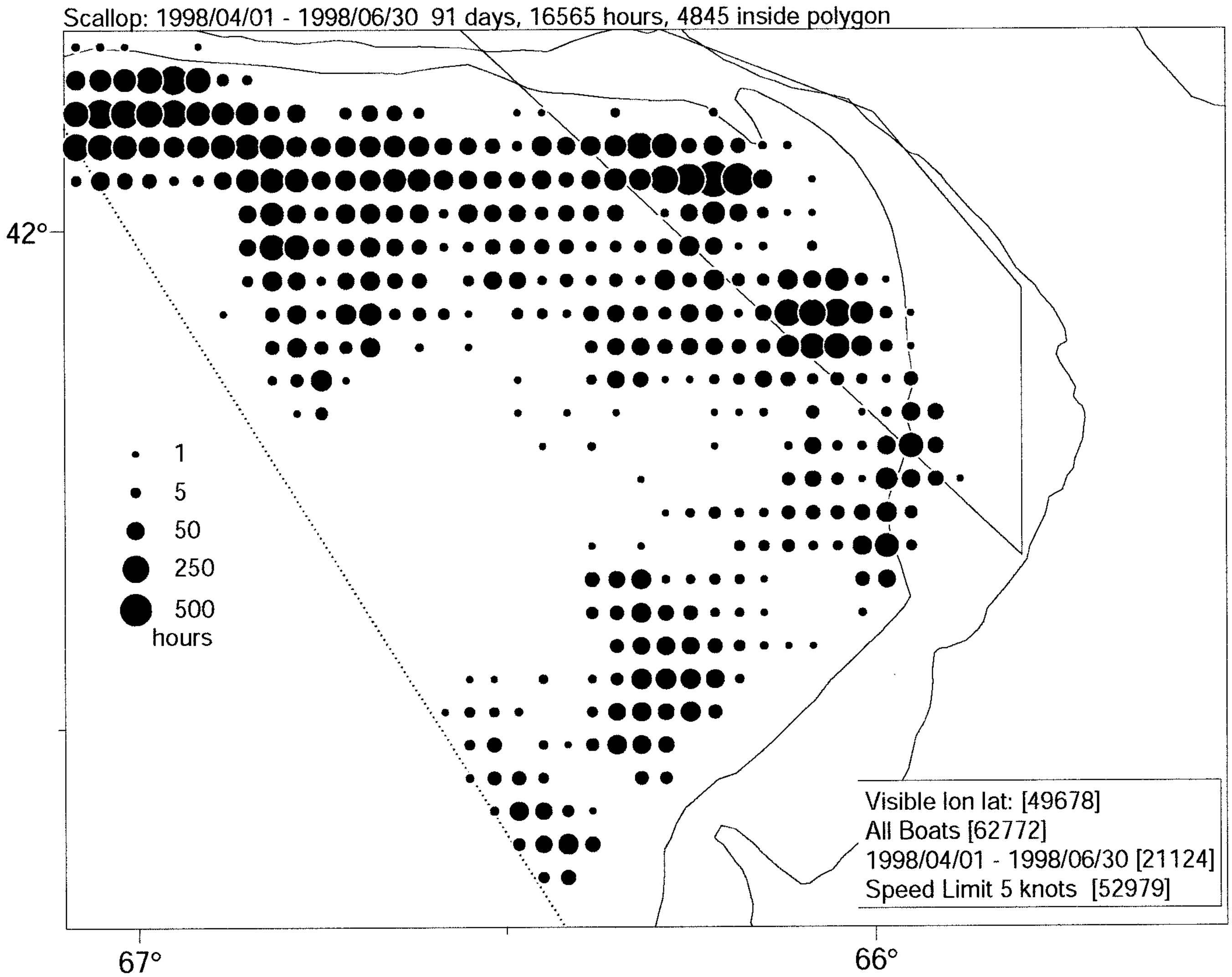


Figure 2 continued.- B) Effort distribution for 1998 Q1 (March only).



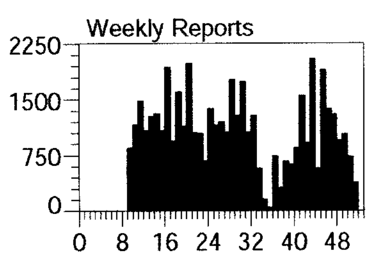
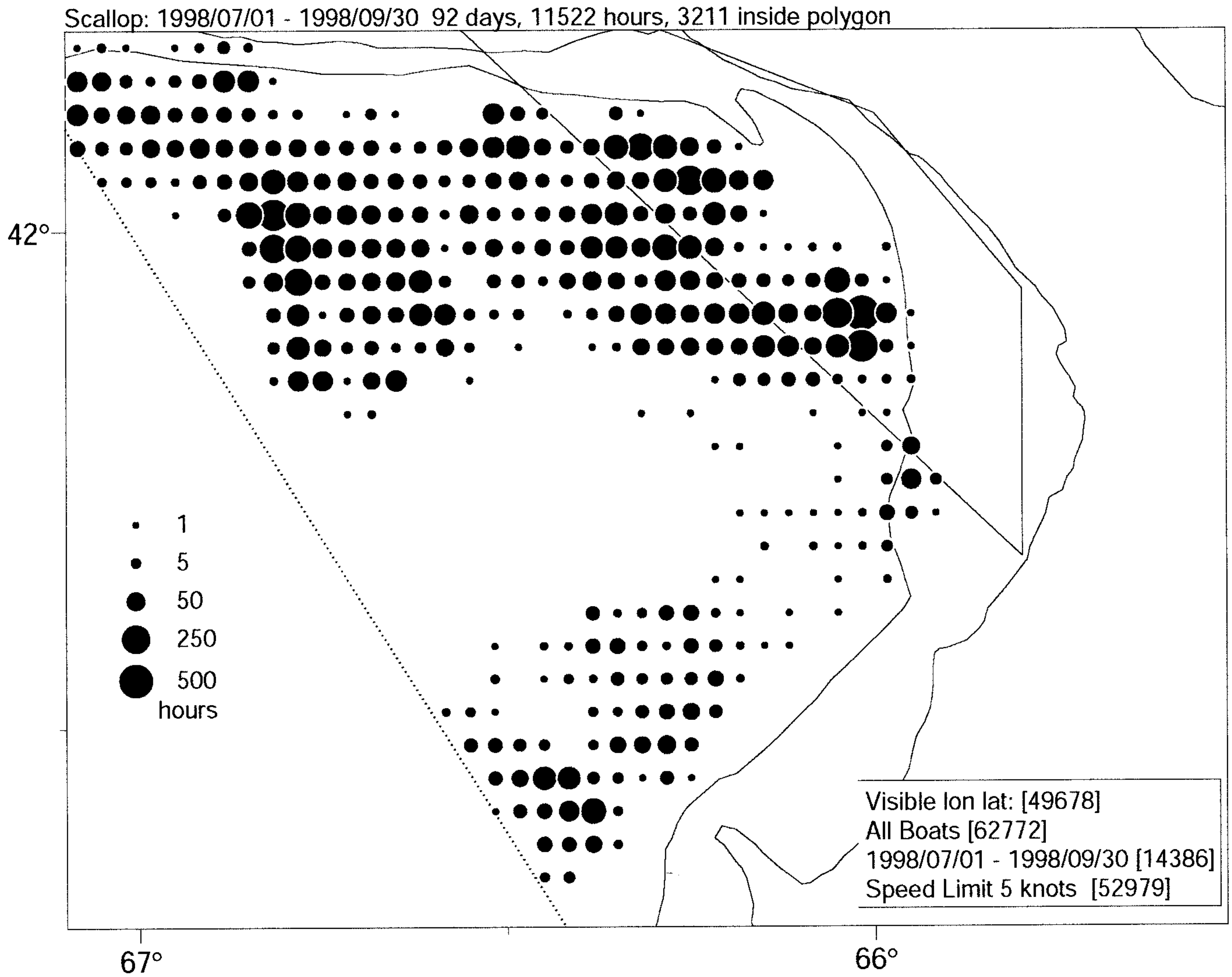


Figure 2 continued.- C) Effort distribution for 1998 Q2.



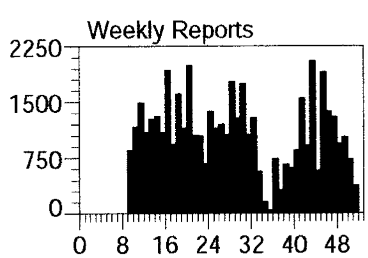
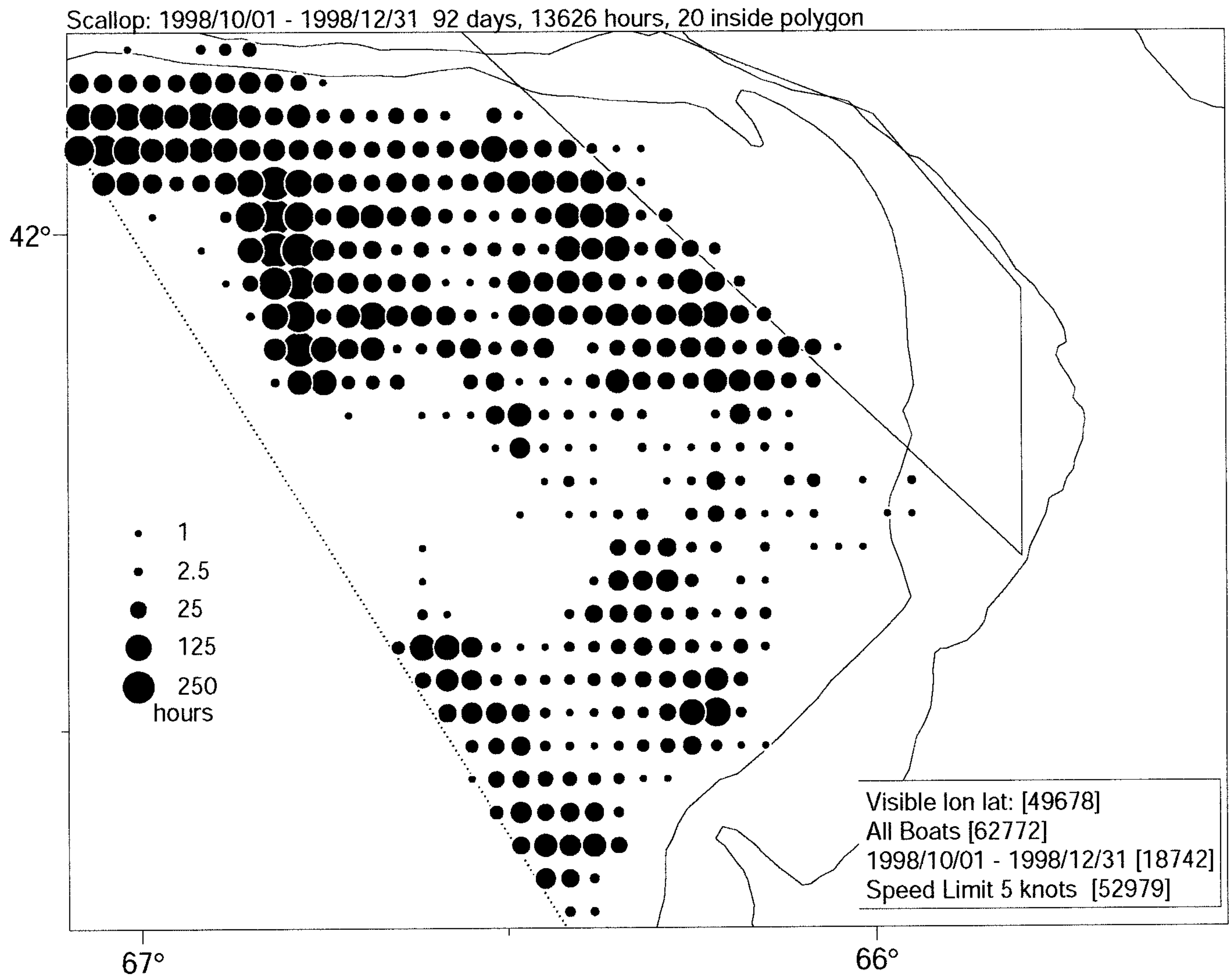


Figure 2 continued.- D) Effort distribution for 1998 Q3.



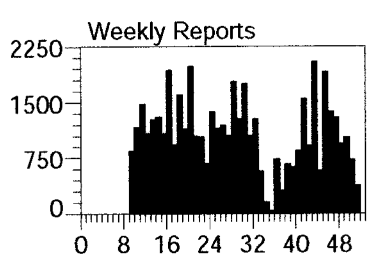


Figure 2 continued.- E) Effort distribution for 1998 Q4.

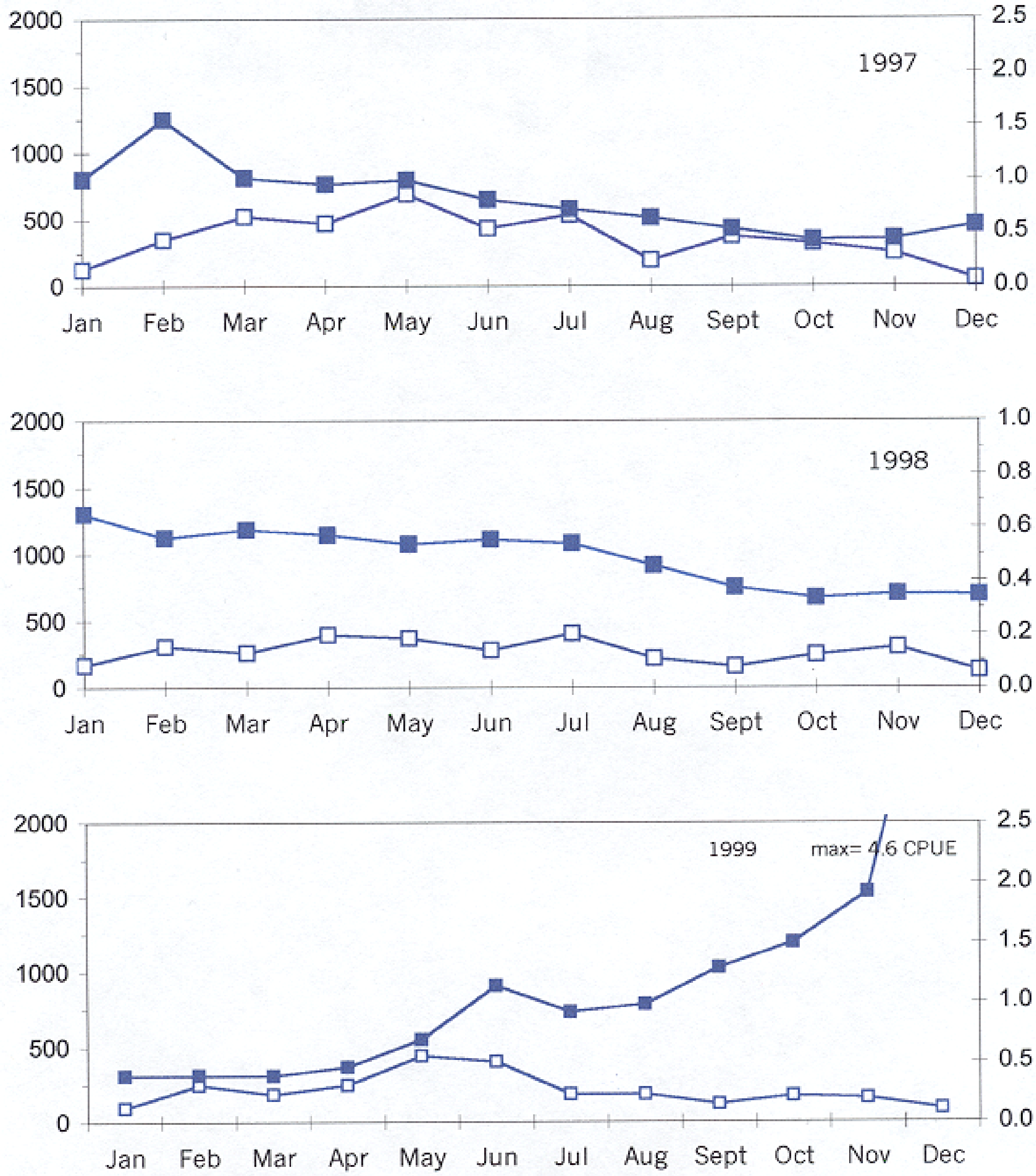


Figure 3.- Monthly catches in tons of meats (hollow square, scale on the left) and CPUE in kg/crhm (full square, scale on the right) for Georges Bank during 1997 to 1999 zone a.

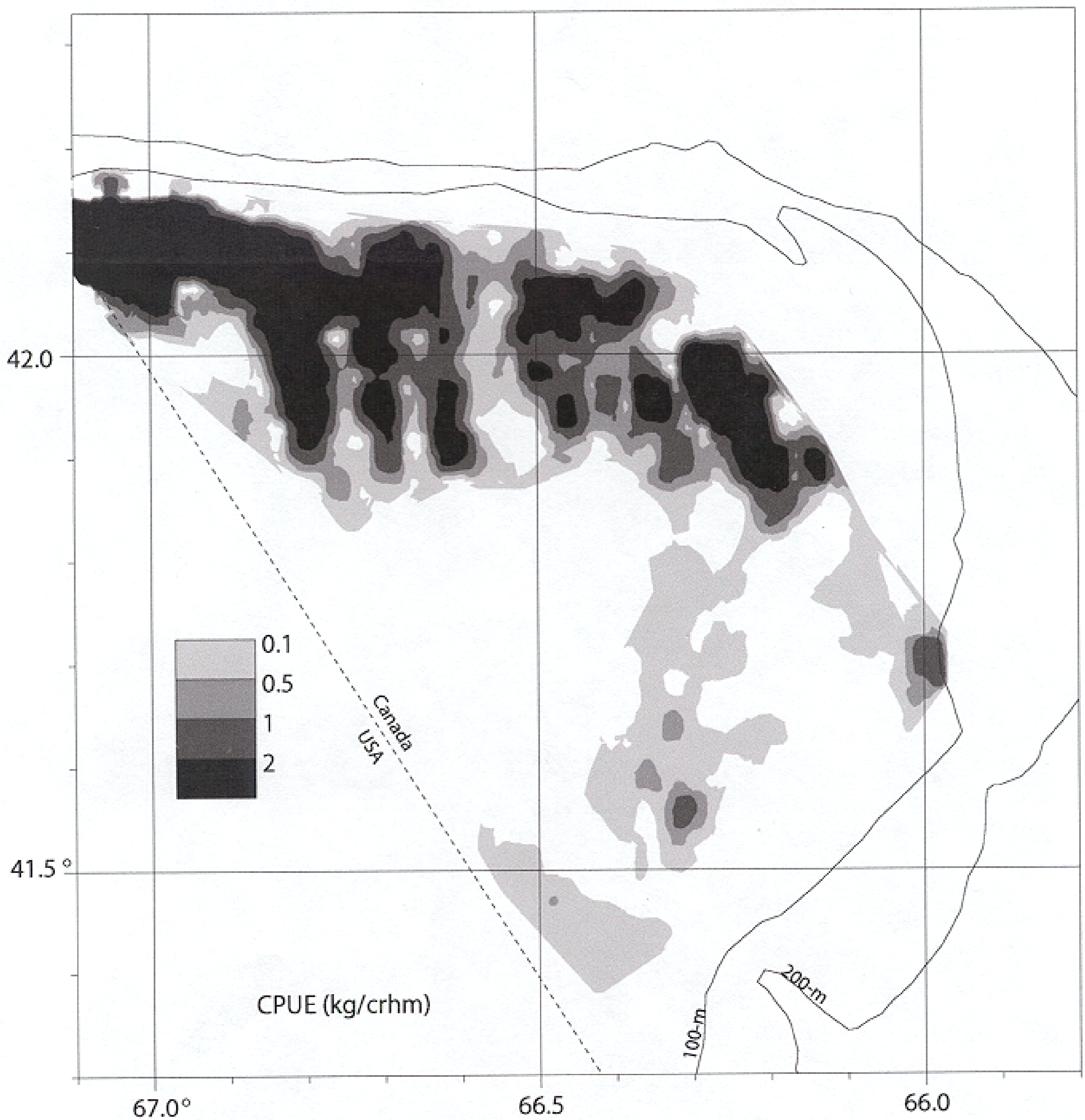


Figure 4a.- Catch-rates encountered on Georges Bank in 1997. The scale of isopleth shading represents ascending catch-rates up to 2+ kg/crhm.

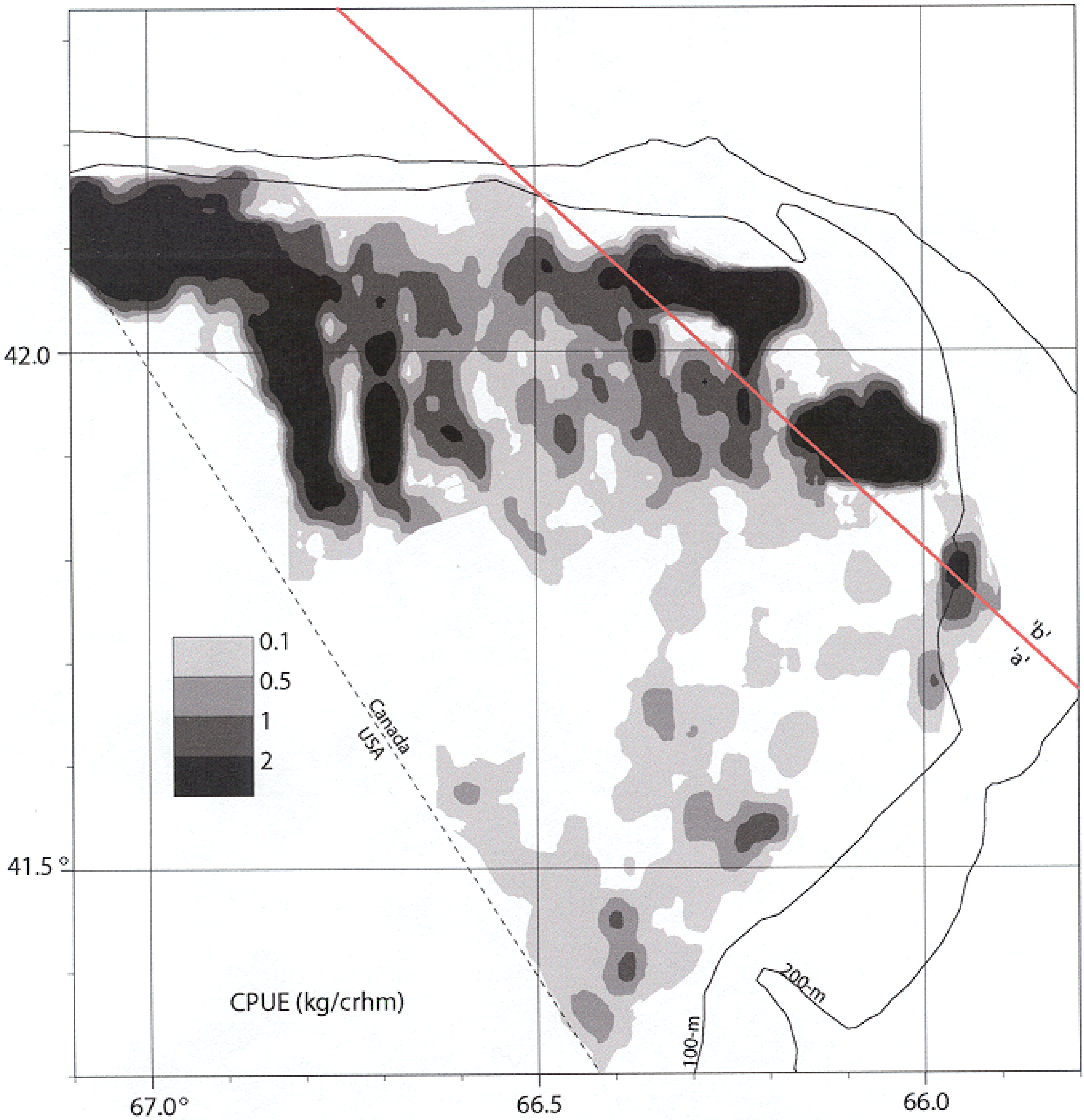


Figure 4b.- Catch-rates encountered on Georges Bank in 1998. The scale of isopleth shading represents ascending catch-rates up to 2+ kg/crhm.

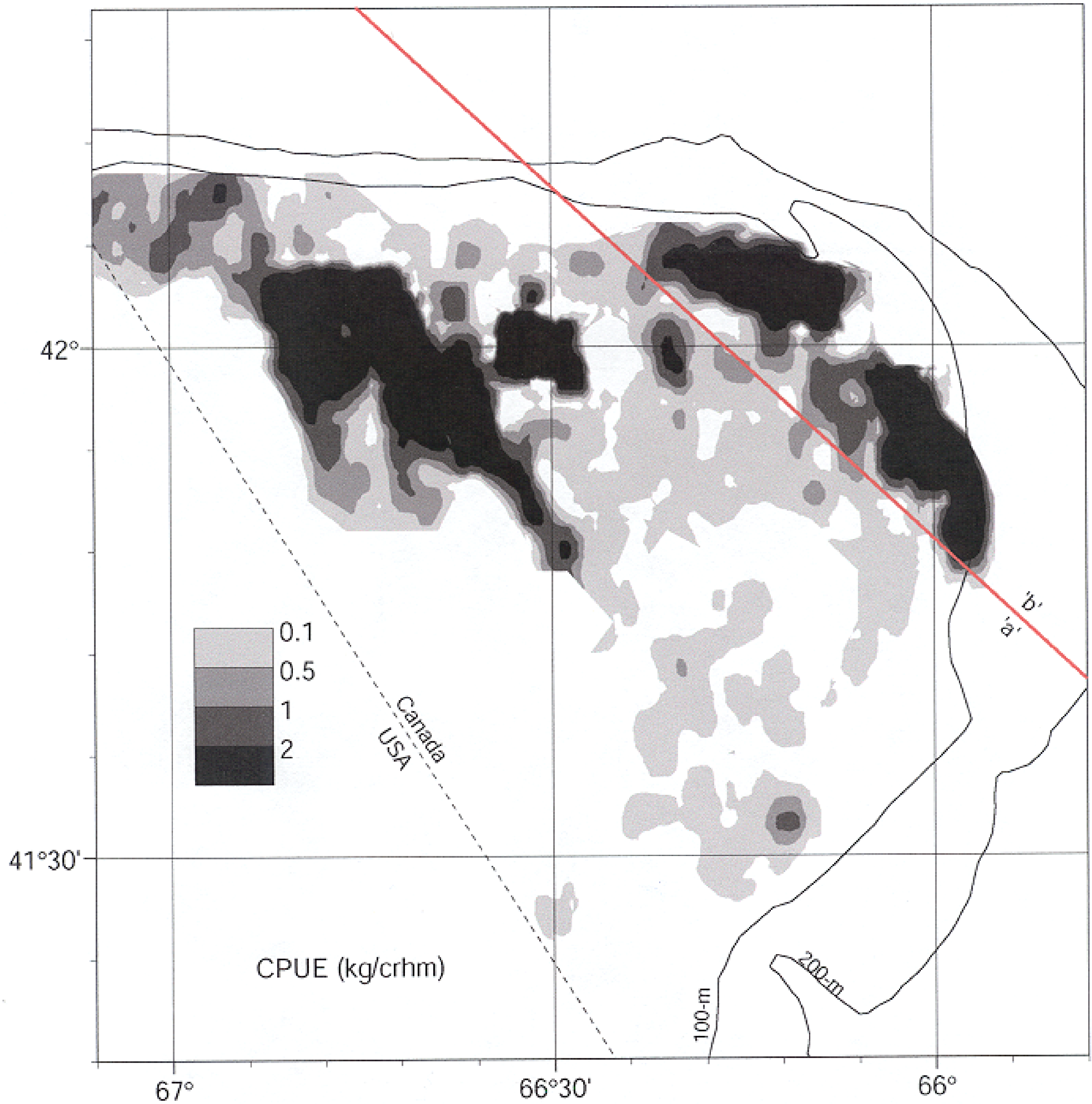


Figure 4c.- Catch-rates encountered on Georges Bank in 1999. The scale of isopleth shading represents ascending catch-rates up to 2+ kg/crhm.

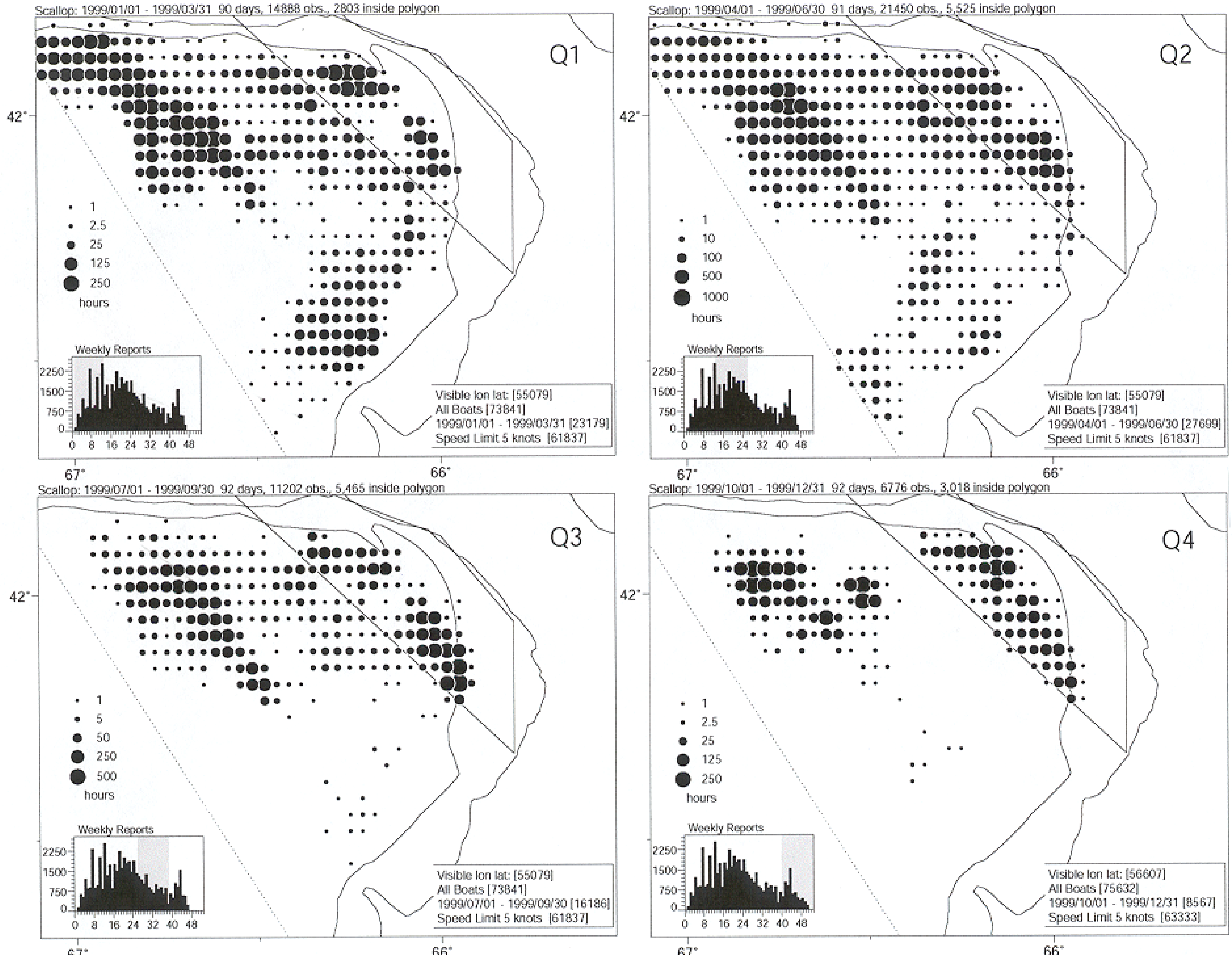


Figure 5.- Effort (hours fished) distribution on Georges Bank 'a' and 'b' (inside polygon) from satellite tracking data during 1999 on a quarterly basis. Data has been aggregated by 2-minute square.

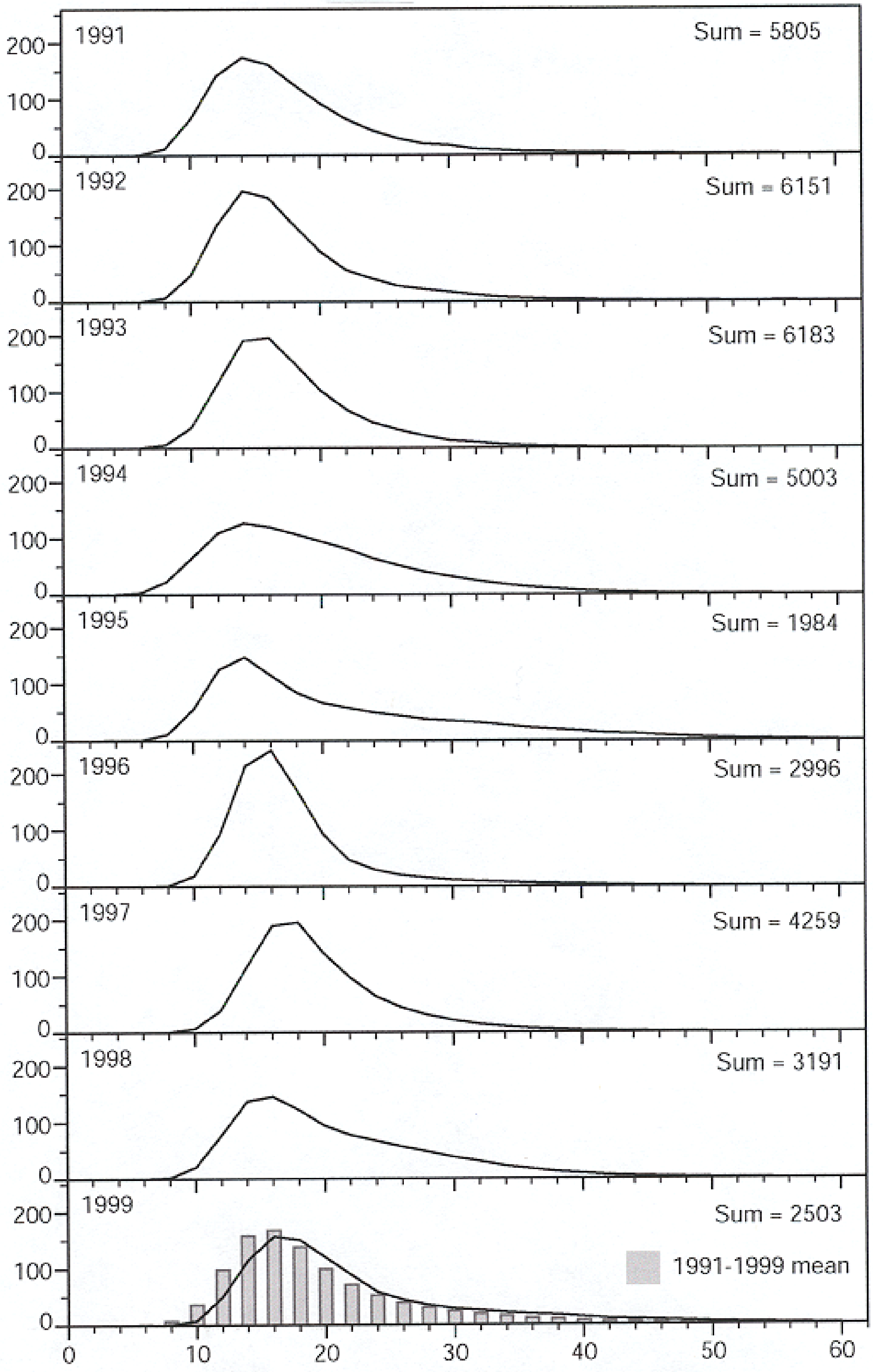


Figure 6a.- Georges Bank 'a' catch-at-weight in 2-g intervals. The sum is the annual catch in tonnes of meats,1991-1999. The histogram represents the mean catch-at-weight distribution for the period considered.