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Georges Bank Scallop Stock Assessment - 1997

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ABSTRACT

The 1997 TAC of 4,250 t increased 42% over 1996. Fishing effort rose 17% from 1996 to 1997. The 1992 year class comprised 50% of the catch in 1997.

Although stock biomass is the highest observed in the past 5 years, survey data do not indicate strong recruitment after the 1992 year class.

The 1992 and 1993 year classes will continue to dominate the fishery. Once they are depleted, the incoming 1994 year class does not have the strength to take their place without a reduction in catch-rates and harvesting levels.

There was a high incidence of clappers on the northeast part of the bank, a loss of 5% of biomass for the Canadian side of Georges Bank. It was unlikely that the mortality was due to fishing.

RÉSUMÉ

Le TPA de 1997 de 4,250 a été 42% supérieur à celui de 1996. L'effort de pêche a augmenté de 17% de 1996 à 1997. La classe d'âge de 1992 a constitué 50% des captures en 1997.

Même si la biomasse du stock est la plus élevée qui ait été observée durant les 5 dernières années, les données d'inventaire de recherche n'annoncent pas de fort recrutement après la classe d'âge de 1992.

Les classes d'âge de 1992 et 1993 vont continuer à dominer la pêche. Lorsqu'elles seront épuisées, la nouvelle classe d'âge de 1994 ne sera pas assez forte pour les remplacer sans une baisse dans les taux de capture et les niveaux des prises.

Une présence importante de coquilles vides dans la région nord-est du Banc a été observée, ce qui représente une perte de 5% de biomasse pour la partie canadienne du banc Georges. Il est peu probable que la pêche ait causé cette mortalité.

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 fishing power 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, instituted a program to monitor the presence of small meats in the catch (50-count). 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.

A concensus had been reached on a 1997 TAC of 4,250 tons of meats based on an exploitation rate of about 30% on the directed age group (ages 4-7). This exploitation rate had hovered around 40% from 1983 to 1995. A drop had been advocated in 1995 given the weakness of the 1990 and 1991 year classes which, at ages 4 and 5 were 2 of the main age groups directed for by the fleet. A stronger year class (1992) recruiting to the fishery in 1996 allowed a rise in catch level and exploitation rate. However, caution was advised for 1997 that the fishery not revert to a dependence on a single, incoming year class. 4,259 t were caught in 1997(Table1). Winter catches were up to 23% of the annual catch after 2 years of fishing activity levels closer to traditional values (10%). The harvesting pattern for the first half of the year, 60% of annual catches, has remained fairly constant since 1989 (Fig. 1).

Effort rose 17% from 1996 to 1997 while catches increased 42% (Table 2). The winter fishery generated 15% of the annual effort. The second and third quarter of the year had 30 and 31% of the 1997 effort respectively. The effort expanded in the last quarter, 24%, produced only 14% of the catches. Except for the first quarter, effort is also applied to the south side of Georges Bank (Fig. 2). This suggests a local comeback of scallop beds in this area after a few years of very low effort levels. The concentrations of fishing activities on the northern edge in the second and third quarters (61% of total effort) shows the strong preference for the most prolific beds though.

Catch-rates for 1997 increased 20% (Table 2). This is a modest rise for Georges Bank. The 1997 annual CPUE is the highest encountered since the late 1970's. The monthly profile (Fig. 1) is more revealing. Except for a spur of high (>1 kg/crhm) CPUE during the winter fishery (January to March), the remainder of 1997 shows a smooth declining trend, from 1 to 0.4 kg/crhm thereafter. Catch-rates usually rebound after experiencing a decline due to spawning in the fall. This effect is barely visible in 1997. The geographical distribution of CPUE isopleths for 1997 (Fig. 3) is fairly similar to 1996 (Fig. 4) except that 1997 shows a modest recovery on the south side of the Bank. Areas with CPUE's over 1 kg/crhm are larger in 1997, 1,097 km^2, compared to 855 km^2 the previous year but equal to 1995 (1,100 km^2). Areas with high CPUE's had covered 4,050 km^2 in 1994.

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. (In this situation, the fleet directs for older, still moderately abundant year classes with larger meats rather than fishing low densities of young year classes with small meats.) Then the average meat weight decreased in 1996 with the fishery directing for the 1992 year class earlier (age 4) given the weakness of the 1991 year class. At age 5, the 1991 year class should have been the main year class in the 1996 catch distribution.(Table 3). By then the fishery could not put emphasis on the older and somewhat depleted year classes either. Meat weights are in the high range again in 1997 with summer monthly means over 20 g. There is also a small increase in meats larger than 30 g compared to 1996 (Tables 4 and 5). The 1997 fishery kept directing for the 1992 year class. At age 5, the 1992 year class provided a larger meat weight to the catch. The presence of ≤10 g meats in the catch was severely curtailed once the monitoring program for small meats was in place from the second quarter of 1995 onward. For the year, less than 1% of meats shucked were under 10 g compared to 2% in 1996 (Table 5). The quarterly distribution in table 4 shows the seasonal increase in the fourth quarter when the incoming year class recruits to the fishery (eg. 23 out of 1,000 meats for Q_4 1997; 39 meats for Q_4 1996). These are very small contribution of young scallops compared to the period prior to 1995.

METHODS

Fishery data

Offshore scallop landings are monitored at dockside by an independent agency beginning in 1994. 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). Catch-rate is presented as catch (kg) per hour and per crew-hour-meter. Catch per h 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 quite different management regimes, especially meat count and limit on removals, influence the conduct of the fishery compared to 15 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. In 1991 steps were taken to expand the catch sampling database to all fleets. Data representing harvesting strategies of the different company fleets involved have been included in the catch data matrix for the period 1991-1997. Generally speaking, the data set providing a profile of each fleet shows scallops caught at a larger size than the corresponding data set from the 2 'index' companies. (Robert and Butler, MS 1995). There are, at present, 7 company fleets. 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 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. The strength of recent year classes entering the fishery has been highly variable and reflected in the meat weight distribution in the catch. In 1995, the once plentiful 1988 and older year classes (at age 7+, 29+ g) contributed 20% (by number) of scallops caught. In 1996, depleted old year classes made up only 5% of 29+ g meats. In 1997, the weak 1990 year class and older year classes contributed 7% of meats over 29 g. The youngest recruits, age 4, contributed over 50% of scallops caught in a narrow range of weights (11 - 15 g) in 1996. This was the relatively strong 1992 year class. In 1997 age 4 recruits (1993 year class) account for only 23% of the catch. The fishery continued to focus its effort on the 1992 year class at age 5. It made up 50% by numbers of the 1997 catch.

Catch in numbers-at-age (Table 6) for the cohort analysis are derived from the port sampling data and the sum of U.S. and Canadian catches in NAFO SA 5Zc. Slicing underestimates large year classes and overestimates weak year classes. 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). The values expressing meat weight as a function of shell height use the parameters 9.102^{-6} for the regression coefficient and 3.097 for the exponent of height. These values agree closely with those of Serchuck et al. (1982) for the same stock. Shell heights were clustered into age groups according to a Von Bertalanffy growth equation (Brown et al. 1972, cf. Table 7).

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 mid-quarter values in age - weight analyses and projections.

Research survey data

The annual research survey was carried out on Georges Bank during August 1997. 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. In 1995 the efficiency of the survey design was investigated (Smith and Robert 1998). Results summarised below suggested possible improvements which were implemented with the 1995 survey. Post-1995 survey results are examined to update the study of survey design efficiency.

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 etimate of the mean than another design. The difference between the 2 variances can be characterised 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 difference between variances is expressed here as difference between the SRS variance and the stratified variance. A positive difference indicates that the stratified random design was the more efficient design.

The results reported in Smith and Robert (1998) for the 1989 and 1990 surveys are reproduced below. This stratification design allocated a larger proportion of stations to higher catch-rates strata as determined by the commercial catch-rate data.

		Efficiency (%)		
Year	Age	Allocation	Strata	Total
1989	3	-1.69	5.97	4.28
	4	-70.74	0.00	-70.74
	5	-36.38	1.99	-34.39
1990	3	-35.08	0.32	-34.76
	4	-14.58	5.46	-9.12
	5	-22.80	1.50	-21.30

Efficiency is presented as a percentage of the SRS variance. The total difference of -70.74 for example, means that the variance of the stratified design was 1.7074 larger than the SRS variance. The Strata component was negligible overall and completely dominated by the large negative Allocation component most of the times. Although the Strata component is small, the efficiency of the survey design has been compromised by the station allocation scheme. The allocation pattern was changed in 1995. The number of stations allocated to each stratum became proportional to the size (area) of each stratum. Basically, this was an attempt to minimise the effect of the Allocation component on the efficiency of the survey design. Efficiency analysis of survey results for 1995 to 1997 follow.

Year	Age	Allocation	Efficiency (%) Strata	Total	Maximum
1995	3	-1.30	18.90	17.60	55.10
	4	-1.40	14.40	13.00	34.40
	5	-0.20	0.00	-0.20	2.08
1996	3	-0.20	7.10	6.90	32.60
	4	-1.00	5.20	4.20	28.00
	5	-0.40	0.70	-0.30	36.80
1997	3	0.10	11.40	11.50	57.60
	4	0.00	13.10	13.10	17.60
	5	0.10	4.90	5.00	7.60

According to the recent survey results, it appears that this approach to allocation has paid off by keeping the Allocation component close to zero. This component was not exactly equal to zero because of the requirement to have at least 2 stations per strata where proportional allocation may indicate that one station is required. 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.

The column labelled Maximum in the table above, refers to the expected efficiency if the station allocation had been proportional to the product of the stratum size and the observed stratum standard deviation. In most cases, the increase in efficiency would be substantial if we had known enough about the stratum standard deviations to allocate stations to the strata. Unfortunately, historical patterns of the observed standard deviation in each stratum over the years are not stable enough to predict what the current year's standard deviations might be. This is probably a function of changing the strata boundaries.

An alternative approach would be to consider an adaptive allocation approach where a survey is first conducted to get estimates of means and standard deviations. Then, a second pass is made over the survey area with additional stations allocated per stratum based on some rules such as " add more stations when the stratum mean or standard deviation is greater than some threshold C". 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 the survey.

The average number of scallops at age per standard tow is given in Table 8a. Table 8b 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. The details of the survey results on a per stratum basis are given in Table 9.

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) (Fig. 5). Data points describe a three dimensional surface with latitude, longitude, and density to be plotted. A surface is formed by defining Delaunay triangles where the data points form the vertices of triangles connecting neighbouring 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, here the relative abundance estimate for the area covered by the survey. These estimates are presented in table 10a for ages 3 to 6. 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 10b) from areal 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 8a and 10) to provide density and biomass estimates for the Canadian side of Georges Bank only.

Stock analysis

In the first year of recruitment to the gear (age 3) 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 1997. This pattern, multiplied by the F determined from tuning for the last quarter year (F_{Q4} 1997), 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, and sometimes contradictory, sets of observations. The most important are the commercial CPUE and research survey estimates. F versus effort is sometimes used in the tuning process but of lesser importance.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. F on the oldest animals was found by multiplying the effort pattern by the mean terminal F from the older ages. Because the selectivity is highly domed toward ages 4 and 5, these values are not critical and the normal iterative determination was not undertaken. (At the 1989 CAFSAC retrospective analysis workshop it was shown that iteratively estimating the terminal F from younger ages diverged rather than converged.) 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 multiple correlation coefficient than relating CPUE to a cohort biomass including all ages (Table 11 and Fig. 6). Fishable biomass was also tuned against CPUE. A better fit is usually achieved when tuning fishable biomass for ages 4+.

Best performers for tuning gave high multiple correlation coefficients and residual values for 1996 and 1997 closest to the regression line (Table 11). Tuning iterations estimated a quarterly rate for terminal F in the range (0.07-0.10). A few more F values and estimated variables are presented in table 11 to give a better perspective. The positive residual values in table 11 denote that the residual points are below the regression line and the negative ones, above. It should be noted that the annual CPUE values are compared to the second quarter biomasses. Q2 corresponds to the quarter where the largest catches are encountered, from 40 to 50% of the total annual catch. The research survey biomass estimates are derived from the average weights at the third quarter. These are compared to third quarter biomasses from the cohort analysis.

Regression of cohort biomass ages 4- 8 on CPUE: CPUE is expressed as kg/h, CPUEH and kg/crhm, CPUEC. CPUEH: the maximum multiple correlation coefficient, 0.824, for the regression of cohort biomass ages 4 - 8 on CPUE corresponded to an F_{Q4} of 0.07. That terminal F provides for the 1997 residual point to almost be on the regression line (Fig. 6). An F_{Q4} of 0.08 puts the 1996 residual closer to the regression line with a small drop in the correlation coefficient. CPUEC: The maximum multiple correlation coefficient at an F_{Q4} of 0.08 is lower, 0.759 versus 0.824; the 1997 residual point is on the regression line. Once again, the 1996 residual point gets closer to the regression line at the next F_{Q4} with a slight drop in correlation coefficient.

Cohort ages 3 - 7 on research biomass ages 3 - 7: A maximum multiple correlation coefficient of 0.714 occurs at F_{Q4} equal to 0.10 with a 1996 residual point closer to the line. The 1997 residual point is closest to the line at F_{Q4} equal to 0.09 with a difference of only 1% for the correlation coefficient (Fig. 6). Ages 3 to 7 have been consistently represented in the survey data for the last decade. The selected ages offer a better match to corresponding ages in the stock biomass compared to matching the stock biomass for all ages to the ages observed in the research data.

Fishing effort on F: The relationship is not as cohesive as the previous 3 based on CPUE and/or research data. The maximum correlation occurs at a very low terminal F. Residual points for the last few years cross the regression line at higher values for terminal F. At F_{Q4} equal to 0.09, the correlation coefficient indicates that over 70% of the variability is still explained and the 1997 point has stabilised at 0.01, the 1996 point at -0.02. Both decrease at higher terminal F's.

Although 76% or more of the variability could be explained when the cohort biomass was tuned against 2 measures of CPUE, and the 1997 residual point was located on the regression line for a terminal F equal to 0.07-0.08, the reliability of CPUE as index of stock abundance has weakened considerably. Recently, the introduction of Differential Global Positioning System (DGPS) has allowed very precise navigation to locate scallop beds and return to specific sites. Such technological developments are being added to captain's traditional knowledge (of scallop beds) and the latest bed mapping results from research surveys. Also, in 1997, gear experiments were carried out at times throughout the fleet. The extent of changes in rake behaviour due to modifications of its components has not been fully established. Tuning against research survey data justified 70% of the variability, a percentage lower than CPUE tuners. The regression of fishing effort versus F still explains 74% of the variability (not its maximum) at that F_{Q4} level and the last 2 years' residual points vary very little. Fishing effort has never been a consistently reliable tuning indicator using offshore scallop data.

A sequential population analysis using Non Linear Least Square Regression (NLLS) (ADAPT, Gavaris 1988) was also carried out. Data used are identical to data used in the linear regressions. Residuals were log transformed. The independent estimates selected to carry out NLLS were annual and quarterly values of CPUE and research surveys indices. At times NLLS would not find a solution to minimise residual(s), especially when estimating multiples parameters (F for different ages for example). A Partitioned Search was then used. NLLS would be computed for value(s) incremented over small intervals within a preset narrow range of values for the parameters to be estimated. A presentation of NLLS on offshore scallop data may be found in Robert et al (MS 1994). Retrospective analysis of the recent years' estimation of F and biomass was also carried out.

The ADAPT model estimated F at age 5 for the last quarter of 1997 calibrating with CPUE data, with research survey results for ages 3 - 7 and, with CPUE and survey results simultaneously. Ages included in the tuning are from 4 to 8. These combinations gave the lowest coefficients of variation for their categories. The statistical diagnostics are as follows:

CPUE (kg/hour) for tuning
mean square of the residual = 0.0297
$F_5 = 0.069$ s.e. = 0.011 CV = 0.158

Research survey (ages 3 - 7) for tuning
mean square of the residual = 0.1053
$F_5 = 0.097$ s.e. = 0.027 CV = 0.275

CPUE (kg/hour) and survey results (ages 3 - 7) for tuning
mean square of the residual = 0.0677
$F_5 = 0.083$ s.e. = 0.014 CV = 0.164

Residuals derived from the tuning exercise using CPUE and survey results in combination are plotted in figure 7. Over the period 1981 to 1997, there is no discernible pattern in the residuals distribution.

A Thompson-Bell type yield per recruit analysis with quarterly time steps is 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 strategie was highly similar to 1996. Upon examination of the yield per recruit it was not necessary to update the model parameters.

The regulations in effect on the offshore fleet are that the catch should average no more than 33 meats 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. The only other way in which this programme differs from the normal stock projection is that the variables are updated quarterly. The annual growth is divided into quarterly components of 10, 35, 35, and 20% and annual effort is partitioned into quarters by the rates of 25, 38, 25, and 12%, which reflects the 1997 and the 1998 winter fishery. Although the first half of the year has traditionally experienced 50% or more of the annual effort, the effort in the first quarter used to be in the order of 10%. In recent years the effort figure for the first quarter has quite often been twice to three times the historical value. With the implementation of EA's in 1986, the annual distribution of effort has shifted markedly not only toward the beginning of the year but also in-between quarters. Companies are aligning fishing plans more closely to particular market demands. Lately, the important changes in recruiting year classes modified the partitioning of fishing activities within the year. 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.

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.

RESULTS

Research surveys

Sampling locations of the 1997 research survey are plotted in figure 5, contour plot for age 7 and in figure 8. Table 8a presents survey results as mean number of scallops at age per standard tow. Table 8b has estimates for the mean and associated parameters. Density estimates for older recruits (ages 6+) are quite stable over the last four years (Table 8a). This age group corresponds to the 1991 and older year classes. The 1990 and 1991 year classes had been reported as weak in previous survey results. There are a few small size patches of age 6 scallops, maximum 15 scallops per tow (Fig. 5). Age 7 concentrations are fewer; at a maximum of 5 scallops per tow, they are located on the south side of the Bank. The abundance index of the main age usually directed for, age 5, is good at 23 scallops per tow on average. On a stratum basis, it varies from 16 (very low) to 39 (very high) (Table 9). The contour plot suggests a fairly large distribution (isopleth 25+ per tow) on the northen Edge and Peak but also a few beds on the south side of Georges Bank. The 1992 year class is good to moderate; it was fished intensively at age 4. The abundance index for age 4 recruits is underestimated given that the 1993 year class settled heavily on the Peak, in places not covered by the 1997 survey. These locations are a marginal habitat and not fished on a regular basis (see last year's Research Document for more details). The index is highly variable on a stratum basis, up to 82 scallops per tow in the very high stratum. A good size bed of age 4 scallops on the northern Edge near the ICJ line is mainly responsible for the large number associated with the very high stratum.

Density estimates of prerecruits are low overall. The mean density of the 1994 year class at age 3, 42 scallops per standard tow, is made up of very low values (7 - 18) from the first 3 strata and values as high as 152 from the very high stratum. High concentrations of the 1994 year class have been located on the northern Edge near the ICJ line. A bed of fair proportions on the South side near latitude 41.5° will also contribute to the restocking of this area of Georges Bank which had experienced a significant decline in recruitment over the last 5 years. Beds of major importance of the 1995 year class (age 2) have only been found in the northen Edge area of the Bank. Such patchiness led to a low overall mean density of 18 scallops per tow. Even if the gear is lined, age 2 scallops are not reliably caught by the survey gear. Therefore, these results only show trends and rough estimates of density. Relatively speaking, the low overall estimates for prerecruits could be troublesome.

Indices of minimum dredgeable biomass derived from volume estimates (ages 3 to 6) and aerial expansion (ages 3 to 7) show a drop of 50% approximately from 1996 to 1997. The younger ages (3 - 4) are responsible for the biomass decline (Tables 10).

The presence of clappers (scallop with upper and lower shells still attached together at the hinge but no animal tissues inside the shells) is usually a non-issue for the Georges Bank scallop stock. A ratio Clapper/Live (C/L) scallops of 0.1 or less reflects mortalities naturally grouped under the coefficient 'M'. At times, the last incident had taken place in 1986, a localised massive die-off occurs. Despite numerous testings, a physiological cause has not been identified. Suffice to say here that the 1986 and the incident reported here happened to scallop beds in marginally growing areas when densities were higher than normal for these locations. An environmental signal coupled with overcrowding may have triggered a poor state of health leading to clappers. The 1997 stock survey allowed the mapping of an area almost 900 km^2 on the Peak where C/L ratios were up to 0.7+ (Fig. 8). A bar graph comparing modes of shell height for both live scallops and clappers (see fig.8) shows that die-off was not size specific but match the local scallop height distribution. This area had been settled quite heavily by the 1993 year class (Robert and Butler, MS 1997). The mean density per standard tow is 100 live scallops and 43 clappers in the height range 75 - 120 mm. A mode of live scallops is around 105 mm while the mode for clappers is at 95 mm. It has been estimated that the loss of biomass per tow for scallops greater than 100 mm was 19% of the total (live plus clappers). The difference in shell height between live and dead animals, observations of epifauna settled inside the clapper's shells and the disintegration of the hinge and resilium would date this event to the winter of 1996 - 1997 (Nov. 1996 - Mar. 1997). This corresponds to the time when fishermen started to report the presence of clappers in this area. Fishing activities are sometimes perceived to be the cause for the presence of clappers. Fishing locations occupied during the January to March, 1997 period were plotted against the clapper area identified by the stock survey in figure 9. Most of the winter fishing did not take place in the clapper area; less than 10% of the locations fished were in the clapper area. Moreover, they covered a very small portion of the 900 km^2 affected by the die-off.

Cohort analysis

The virtual population results are given in terms of numbers-at-age, biomass-at-age, and F-at-age (Tables 12 to 14); they have been combined into annual values from quarterly analysis for the terminal F_{Q4} level of 0.08. The Georges Bank stock saw the passage of 2 good year classes with over 500 million scallops at age 3 each class during the early 1990's (Table 12 and Fig. 10). They were followed by the 2 poorest year classes to be observed over the last 17 years (since 1981). Recruitment then improved with age 3's in 1995 slightly above the median value for the population. Subsequently, the model estimates numbers at age 3 below the median; these values are not supported by a lot of data and probably underestimated. Numbers at age 3 in the research surveys coincide well with the strength of these same year classes in the population estimates (Fig. 10 bottom graph). Total numbers for the population estimate went up in 1996 after the 1994 and

1995 which estimates had been among the lowest recorded since 1981 (Table 12). 1997 numbers are down again due to low levels of ages 6 and 7. At present, abundance is concentrated (62%) in young recruits (ages 4 and 5) and age 8+ (17%). Total biomass estimates (Table 13, Fig. 11) have been increasing after a low in 1995. The biomass estimate for 1997 is the highest encountered over the last 5 years. Annual fishing mortality rates are presented in table 14. Mean F on all ages has varied little since 1988 and is much lower than before the implementation of EA's (pre-1986) (Fig. 11 bottom). Both overall F and F on the directed age group (4 - 7) experienced an important reduction from 1994 to 1995 and remained at these lower levels until now. 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 much thereafter. Fishing mortality at age 3 has been reduced to almost nil with the monitoring of small meats in the catch.

Retrospective analysis

A retrospective analysis of the biomass and average fishing mortality rate for the main age group 4 to 8 was carried out on the last 5 year's data. Table 15 and figure 12 detail the biomass and fishing mortality rate estimates adding one set of data per year for the last 5 years. Looking down each column in table 15 shows the generally small fluctuations but no apparent trends of persistent under or over estimation of the 2 variables. Figure 12 shows graphically the lack of trend 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.

Stock projections

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 1992 stock assessment led to estimates of 1.10 for F_{max} and 0.70 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 $F_{0.1}$. It was updated with the 1996 assessment. F_{max} was estimated at 0.89 and $F_{0.1}$ at 0. 54. The same selectivity was used in the cohort analysis, yield per recruit, and the catch projections. The projections are carried out at $F_{0.1}$, F_{max} and other selected F values using the numbers-at-age of the last quarter from the 1997 cohort analysis aged forward to the first quarter of 1998. The projections for a one year period assume a recruitment level of 400 million scallops to reflect a long standing average value. The partial recruitment vector used : 0.02, 0.51, 1.00, 0.32, 0.22, 0.30 for ages 3-8 is the average for 1995 - 1997. Age 5 selectivity acts as the inflexion point for the selectivity curve; the slope changes on each side of age 5.

Catch projections were carried out for 1998 with a terminal F_{Q4} at 0.08. The quarterly catch pattern for 1998 was set with a level of activity to reflect the effort patterns of 1997 during the first half of the year. Biomass projections are lower than last year. Detailed scenarios for $F_{0.1}$ and F_{max} are found in table 16 with additional scenarios in table 17. Figure 13 plots changes in biomass (%) and exploitation rates for fishing scenarios ranging from 3,000 to 5,300 tons. Fishing at $F_{0.1}$, (3,650 t) in 1998 corresponds to an exploitation rate of 20% and produces a directed biomass (ages 4-7) slightly over 9,000 tons. A scenario keeping the effort at the 1997 level (3,850 t) provides a similar directed biomass estimate. A fishing scenario with a 1998 catch equal to the TAC for 1997 (4,250 t) gives a directed biomass estimate of 8,600 t at the end of 1998; this TAC level has an exploitation rate of 24%. The last 2 options, $F_{replacement\ yield}$ and F_{max} correspond to F values over

0.80 or an exploitation rate greater than 25%. Under such scenarios the directed biomass drops to less than 8,000 tons. Under present stock conditions, the directed biomass has been estimated at 50 to 47% of the total biomass.The total biomass ranges from 18,250 to 16,450 t.

CONCLUSIONS

The 1997 TAC was up 40% from the previous year. The annual estimate for catch-rate was the highest encountered since the late 1970's. This high level of performance was not sustained throughout the year; year end catch-rates were only 40% of January cath-rate. The 1992 year class, at age 5, made up 50% by numbers of the 1997 catch. The strong dependence on the 1992 year class resulted from the very low densities of the 1990 and 1991 year classes. The dependence on a single year class leads to significant year to year variability in catches and more risk to stock replacement.

The stock biomass is the highest observed over the last 5 years but is concentrated in the 1993 and 1992 year classes at ages 4 and 5, the age group most heavily exploited. Once ages 4 and 5 scallops are depleted, the incoming 1994 year class does not have the strength to take their place without a reduction in catch-rates and harvesting levels.

Research survey estimates for young recruits, age 4, suggest a considerable degree of patchiness in its distribution. It is possibly underestimated as the 1997 survey did not cover a marginal habitat on the Peak of the Bank where the 1993 year class settled heavily. Estimates for prerecruits are low overall with an extremely patchy distribution. Establishing the status of year classes as early as possible is essential to forecasting but a challenge to interpreting the information properly, especially for prerecruits.

Scallop beds on the Peak of Georges Bank experienced heavy die-offs during the winter of 1996 - 97. Most of the die-offs were from the 1993 year class according to the modal distribution. A tow on the Peak lost 19% of its biomass (estimate for scallops over 100 mm shell height). The marginal status of this area meant that the loss of biomass projected for the stock was about 5%.

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Table 1.- Estimated (pre-1985) catches (t of meats) from Georges Bank, NAFO subarea 5Zc. Since October 1984 the ICJ line 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

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

Table 2.- Catch and effort data. Canadian catches (tons of meats) in NAFO subarea 5Zc. Canadian total effort is derived from effort from Class 1 data.

Year	Catch	Effort		CPUE	
	tons	hours 10^3	crhm* 10^3	kg/h*	kg/crhm
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
1990	5218	72	10570	72.09	0.494
1991	5805	66	9687	88.40	0.599
1992	6151	73	10957	84.10	0.561
1993	6183	64	9874	96.76	0.627
1994	5003	64	9566	78.12	0.523
1995	1984	39	5687	50.94	0.349
1996	2996	31	4855	95.37	0.617
1997	4259	36	5742	119.63	0.744

* crew-hour-meter; hour

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

	% catch examined / catch landed	meat weight (g) mean	min	max	s.e.	n meats
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
1996	0.041					
January		14.90	7.92	39.00	0.08	339
February		16.56	5.63	57.47	0.04	3962
March		16.30	5.74	58.81	0.03	8384
April		16.11	6.29	59.75	0.02	10976
May		17.65	5.52	65.27	0.02	9147
June		17.59	4.46	68.36	0.02	7579
July		16.90	6.54	68.40	0.02	8359
August		16.49	6.82	55.45	0.03	5818
September		16.79	6.46	66.24	0.02	7362
October		16.81	6.30	53.13	0.03	6010
November		16.49	7.18	55.76	0.03	4307
December		16.11	8.82	61.54	0.06	630
1997	0.027					
January		16.21	8.24	50.24	0.03	1878
February		16.74	8.57	52.80	0.02	5765
March		17.07	7.70	56.21	0.02	9244
April		18.14	6.87	70.90	0.02	8129
May		19.69	8.56	57.38	0.02	9560
June		21.57	7.52	65.43	0.03	5169
July		21.66	7.76	64.69	0.04	5139
August		22.00	7.69	57.32	0.07	1843
September		18.72	7.18	75.66	0.03	5126
October		18.27	4.46	65.35	0.03	5562
November		18.93	7.74	57.46	0.04	3230
December		17.79	7.46	47.29	0.09	574

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

Grams	1994	Q1	Q2	Q3	Q4	1995	Q1	Q2	Q3	Q4
1		0	0	0	0		0	0	0	0
3		0	0	0	0		0	0	0	0
5		1	5	4	5		4	1	0	0
7		9	29	32	30		37	10	5	8
9		52	71	69	79		92	50	46	56
11		123	104	98	102		107	116	117	159
13		156	131	102	98		111	126	158	185
15		143	124	101	94		104	96	122	143
17		124	112	95	85		77	74	88	101
19		97	90	89	100		69	62	67	72
21		74	79	85	87		64	55	62	53
23		57	61	70	73		62	52	46	44
25		43	49	57	62		58	48	39	37
27		35	34	45	50		47	43	33	30
29		25	29	40	37		43	38	32	28
31		21	22	30	26		38	37	30	23
33		15	16	21	23		30	33	28	16
35		9	13	18	15		20	28	23	13
37		7	10	13	11		14	26	20	11
39		4	8	9	7		9	24	18	6
41		3	5	7	5		7	18	14	5
43		1	4	7	3		4	18	13	3
45		1	2	3	3		4	13	10	4
47		1	2	2	1		1	9	8	2
49		1	1	2	1		1	7	6	1

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

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	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
1	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
5	3	1	2	1	0	0	3	1	0	0
7	28	14	24	12	7	6	23	11	2	1
9	98	83	96	64	47	36	65	55	19	7
11	163	179	164	141	135	113	109	126	93	39
13	179	219	177	174	196	190	126	148	214	116
15	152	182	146	162	184	196	119	116	242	190
17	104	117	113	126	135	150	107	85	171	196
19	75	72	80	93	89	102	94	67	93	140
21	54	43	62	65	56	68	81	58	47	98
23	36	30	43	44	41	45	64	49	30	65
25	27	18	30	30	28	32	51	44	21	44
27	22	14	19	21	22	22	40	37	16	31
29	16	7	13	18	17	13	32	34	12	22
31	11	6	9	11	12	10	24	32	10	15
33	9	4	6	9	8	6	18	27	8	11
35	6	4	5	6	6	4	13	22	6	7
37	5	2	3	6	4	2	10	19	5	6
39	4	2	2	4	4	2	7	16	4	4
41	3	1	2	4	2	1	5	13	3	3
43	2	1	1	2	2	1	4	12	2	2
45	1	1	1	3	1	0	2	9	1	1
47	1	0	0	1	1	0	1	6	1	1
49	1	0	0	1	1	0	1	5	1	1
51	1	0	0	1	0	0	1	3	0	1
53	0	0	0	1	0	0	0	2	0	0
55	0	0	0	1	1	0	0	1	0	0
57	0	0	0	0	0	0	0	1	0	0
59	0	0	0	0	0	0	0	1	0	0
61	0	0	0	0	0	0	0	0	0	0
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.

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	293	45	34	66	65	2	21	21	16
4	501	176	100	72	147	188	198	129	166
5	62	83	53	30	35	107	171	85	99
6	15	15	14	19	10	8	19	21	16
7	8	76	4	8	9	2	4	6	8
8+	153	12	10	7	9	4	7	6	3
Total	894	338	215	202	275	311	420	268	308

Ages	1990	1991	1992	1993	1994	1995	1996	1997
3	11	13	15	5	8	5	3	2
4	180	158	181	179	74	36	107	65
5	117	130	125	153	140	22	47	132
6	14	20	26	19	23	18	7	5
7	8	6	8	8	10	5	9	4
8+	5	18	12	10	18	10	5	17
Total	335	345	367	374	273	96	178	225

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.- Total weighted average (by stratum) number of scallops at age per tow.

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

* new survey series

Table 8b.- Estimates of the mean number of scallops at age for recent surveys and associated standard errors (mean) and confidence intervals.

Year	Age	Mean	SE	95% Confidence intervals 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

Table 9.- Stratified average number of scallops at age per tow and total number of scallops per 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	1994	49	6	21	23	7	3	1	114	53
	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
Low	1994	111	5	5	11	7	2	1	143	111
	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
Medium	1994	25	6	10	14	6	2	1	65	15
	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
High	1994	82	19	24	13	5	2	1	148	33
	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
Very high	1994	132	43	35	16	5	1	0	234	40
	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

Table 10a.- Indices of abundance of scallop age-classes by volume estimates: numbers-at-age (10^6), minimum dredgeable biomass at survey time (t of meats).

Sampling dates	Age (years)				
	3	4	5	6	Biomass
1981	279.47	53.60	9.34	3.48	2965
1982	121.76	56.95	15.47	3.43	2056
1983	99.32	50.76	14.31	5.28	1841
1984	85.74	30.32	8.08	2.21	1245
1985	557.64	45.29	5.88	1.26	4628
1986	309.16	225.53	26.46	3.81	5942
1987	214.58	145.50	41.78	11.27	4704
1988	238.53	105.06	23.45	5.05	3744
1989	266.38	161.01	31.79	5.24	4899
1990	188.70	72.16	31.18	8.72	3207
1991	158.67	89.56	29.10	7.79	3174
1992	347.56	188.88	40.19	11.89	6209
1993	94.79	72.29	37.79	12.77	2814
1994*	32.87	34.86	23.69	10.80	1512
1995	250.86	63.09	21.21	13.03	3415
1996	112.87	158.56	40.71	9.71	4122
1997	67.70	45.74	32.36	9.73	2059

* new survey series

Table 10b.- Minimum dredgeable biomass at age (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.

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	0.1	2,126.01
1983	557.60	657.42	277.26	71.87	84.97	1,649.12
1984	629.55	511.33	166.36	71.87	0.1	1,379.12
1985	3,705.36	657.42	110.90	35.94	0.1	4,509.64
1986	2,446.25	5,295.89	665.36	71.75	0.1	8,479.26
1987	1,762.72	2,301.00	942.78	359.29	169.94	5,535.73
1988	1,978.62	1,899.22	554.43	143.77	84.97	4,661.01
1989	2,356.33	2,593.11	720.93	143.77	84.97	5,899.11
1990	1,600.84	1,424.38	831.86	287.55	84.97	4,229.60
1991	1,852.68	1,789.70	720.93	215.52	84.97	4,578.83
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	94.80	3,811.43
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

* new survey series

Table 11. - Tuning criteria for the regressions of cohort biomass ages 4-8 on CPUE in kg/hour (CPUEH), cohort biomass ages 4-8 on CPUE in kg/crhm (CPUEC), cohort biomass ages 3-7 on research survey biomass estimates ages 3-7, of fishing effort on F, for selected F_{Q4}.

	Coh Biom ages 4-8 vs CPUEH			Coh Biom ages 4-8 vs CPUEC		
F_{Q4}	R^2	1996*	1997*	R^2	1996*	1997*
0.06	0.800	-1565	-1051	0.697	-2105	-2078
0.07	0.824	-845	-92	0.746	-1280	-915
0.08	0.809	-305	627	0.759	-662	-43
0.09	0.762	114	1186	0.741	-181	635
0.10	0.697	450	1633	0.700	204	1178
0.11	0.624	725	1999	0.647	519	1621

	Coh Biom ages 3-7 vs Res Biom ages 3-7			Fishing effort vs F		
F_{Q4}	R^2	1996*	1997*	R^2	1996*	1997*
0.06	0.438	-3215	-3479	0.824	-0.02	0.04
0.07	0.562	-1988	-2083	0.802	-0.02	0.03
0.08	0.651	-1068	-1037	0.776	-0.02	0.02
0.09	0.700	-352	-223	0.744	-0.02	0.01
0.10	0.714	221	428	0.708	-0.03	0.01
0.11	0.705	689	961	0.668	-0.03	0.00

* Residual value with respect to regression line

Table 12.- Population numbers (at beginning of the first quarter) (10^6) east of the ICJ line from cohort analysis using a terminal F_{Q4} of 0.08.

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	647	240	212	461	616	453	351	433	501
4	673	301	173	160	354	494	408	296	371
5	102	137	105	63	76	180	268	180	145
6	35	33	45	46	29	35	62	82	82
7	27	17	16	28	24	16	24	38	54
8+	131	103	90	57	36	33	37	40	55
Total	1615	831	641	815	1135	1211	1150	1069	1208

Ages	1990	1991	1992	1993	1994	1995	1996	1997
3	440	532	610	172	145	512	364	165
4	438	387	468	537	150	123	458	327
5	178	227	199	251	315	66	78	313
6	38	52	83	64	84	154	39	26
7	59	21	28	51	39	54	122	28
8+	86	112	89	73	84	69	93	176
Total	1239	1331	1477	1148	817	978	1154	1035

Table 13.- Biomass Q1 (t of meats) east of the ICJ line from cohort analysis using a terminal F_{Q4} of 0.08.

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	2118	787	696	1511	2018	1484	1148	1419	1640
4	6510	2911	1677	1545	3423	4780	3943	2863	3590
5	1752	2351	1807	1076	1305	3089	4607	3088	2483
6	851	808	1094	1102	689	855	1495	1983	1976
7	801	518	492	838	710	473	719	1145	1622
8+	4856	3921	3567	2251	1320	1239	1416	1507	1993
Biom 3+	16888	11296	9333	8323	9465	11920	13328	12005	13304
Biom 4+	14770	10509	8637	6812	7447	10436	12180	10584	11664

Ages	1990	1991	1992	1993	1994	1995	1996	1997
3	1441	1743	1998	563	476	1677	1192	542
4	4234	3742	4530	5190	1454	1194	4434	3158
5	3059	3891	3426	4317	5416	1129	1332	5381
6	911	1252	2009	1536	2028	3711	932	640
7	1769	638	849	1521	1173	1612	3647	846
8+	3160	4158	3435	2829	3167	2533	3416	6391
Biom 3+	14574	15424	16247	15956	13714	11855	14953	16958
Biom 4+	13133	13681	14249	15393	13238	10178	13761	16416

Table 14.- Annual fishing mortality east of the ICJ line from cohort analysis using a terminal F_{Q4} of 0.08.

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	0.66	0.23	0.18	0.17	0.12	0.01	0.07	0.05	0.03
4	1.49	0.95	0.92	0.64	0.58	0.51	0.72	0.62	0.63
5	1.02	1.01	0.74	0.69	0.66	0.97	1.08	0.69	1.24
6	0.61	0.61	0.38	0.55	0.49	0.29	0.38	0.32	0.22
7	0.36	0.54	0.27	0.36	0.52	0.17	0.17	0.16	0.16
8+	0.21	0.26	0.19	0.21	0.26	0.09	0.23	0.23	0.10
F ages 3+	0.73	0.60	0.45	0.44	0.44	0.34	0.44	0.34	0.40
F ages 4-7	0.87	0.78	0.58	0.56	0.56	0.48	0.59	0.45	0.56

Ages	1990	1991	1992	1993	1994	1995	1996	1997
3	0.03	0.03	0.03	0.03	0.06	0.01	0.01	0.02
4	0.56	0.56	0.52	0.43	0.73	0.36	0.28	0.24
5	1.13	0.90	1.04	1.00	0.62	0.43	0.97	0.57
6	0.47	0.50	0.39	0.38	0.34	0.13	0.21	0.23
7	0.15	0.34	0.34	0.17	0.30	0.11	0.08	0.15
8+	0.08	0.15	0.17	0.13	0.27	0.27	0.10	0.11
F ages 3+	0.40	0.42	0.42	0.36	0.39	0.22	0.28	0.22
F ages 4-7	0.58	0.58	0.57	0.50	0.50	0.26	0.39	0.30

Table 15.- Retrospective analysis of biomass (10^2 tons) for the first quarter of the year, ages 4 to 8 and annual fishing mortality rates for ages 4 to 8. The analysis was carried out for the last 5 years as per row label.

Biomass

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
1993	6.4	4.6	4.0	5.5	8.3	9.3	7.7	8.9	10.0	9.7	10.7	11.6				
1994	6.4	4.6	4.0	5.5	8.1	9.2	7.6	8.9	10.1	10.3	10.7	11.4	8.5			
1995	6.4	4.6	4.0	5.5	8.1	9.0	7.3	8.6	9.7	9.8	10.5	11.3	8.7	5.7		
1996	6.4	4.6	4.0	5.5	8.1	9.0	7.3	8.5	9.6	9.8	10.6	11.8	9.4	6.7	8.5	
1997	6.4	4.6	4.0	5.5	8.1	9.0	7.3	8.3	9.5	9.5	10.3	11.7	9.6	6.6	9.2	9.9

Fishing mortality rate

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
1993	0.86	0.68	0.71	0.76	0.63	0.81	0.57	0.54	0.56	0.59	0.56	0.48				
1994	0.86	0.68	0.71	0.76	0.63	0.83	0.57	0.53	0.53	0.53	0.54	0.52	0.63			
1995	0.86	0.68	0.71	0.76	0.63	0.85	0.60	0.55	0.56	0.57	0.55	0.53	0.60	0.32		
1996	0.86	0.68	0.71	0.76	0.63	0.85	0.60	0.57	0.57	0.59	0.56	0.50	0.54	0.27	0.37	
1997	0.86	0.68	0.71	0.76	0.63	0.85	0.60	0.58	0.60	0.62	0.60	0.51	0.54	0.29	0.41	0.38

Table 16 .-Stock projections at $F_{0.1}$ (0.54) and at F_{max} (0.89) using starting numbers from cohort analysis with a terminal F_{Q4} of 0.08.

F = 0.54	1998_{Q1}	1998_{Q2}	1998_{Q3}	1998_{Q4}
Mean Wgt. Catch	20.53	21.30	23.21	29.15
Catch (Mill.)	43.10	61.22	36.28	21.26
Catch (t)	885	1,304	842	620
Cum. Catch (t)	885	2,189	3,031	3,651
Biomass	16,910	17,207	17,425	18,265

F = 0.89	1998_{Q1}	1998_{Q2}	1998_{Q3}	1998_{Q4}
Mean Wgt. Catch	20.59	21.44	23.36	28.41
Catch (Mill.)	68.78	90.91	50.43	26.97
Catch (t)	1,416	1,949	1,178	766
Cum. Catch (t)	1,416	3,365	4,543	5,309
Biomass	16,350	15,908	15,714	16,459

Table 17.- Fishing scenarios established for 1998 given different options of fishing mortality rate. Biomass figures are for the end of 1998. Under the biomass for ages 4 to 7, the percentage that the target biomass represents from the total biomass is in parenthesis. Catch figures are rounded off to the nearest 50 t.

No.	Options	Fvalues	Biomass (t)	Biomass 4 - 7	Exploitation rate	Catch (t)
1	$F_{0.1}$	0.54	18,265	9,133 (50%)	20%	3,650
2	$F_{1997effort}$	0.58	18,066	9,033 (50%)	21%	3,850
3	$F_{1997\,TAC}$	0.66	17,600	8,624 (49%)	24%	4,250
4	$F_{replacement\ yield}$	0.81	16,837	7,913 (47%)	29%	4,950
5	F_{max}	0.89	16,459	7,736 (47%)	32%	5,300

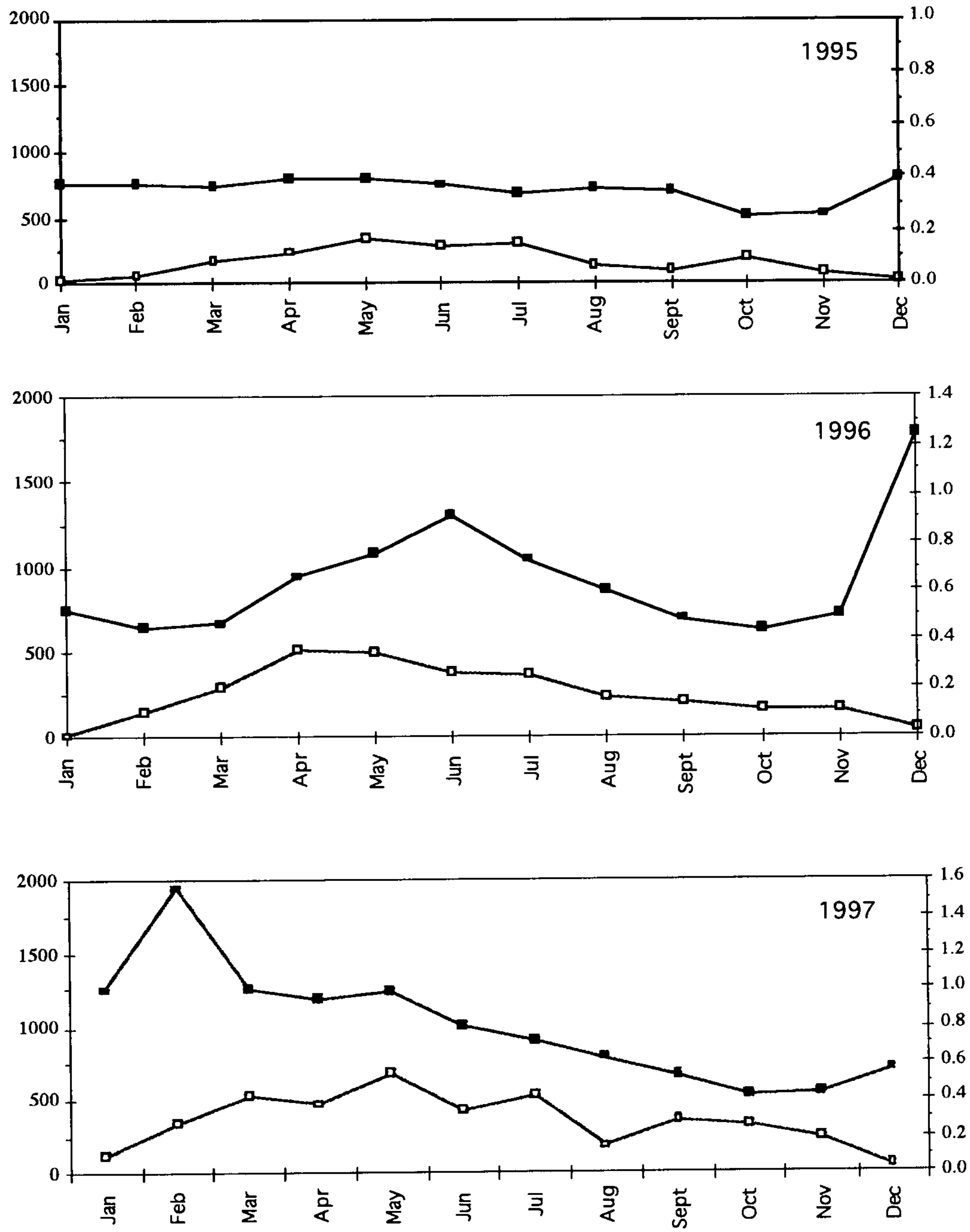

Figure 1.- Monthly catches in tons of meats (hollow square, scale on the left) and CPUE in kg/crhm (full square, scale on the right) for Georges Bank during 1995 - 1997.

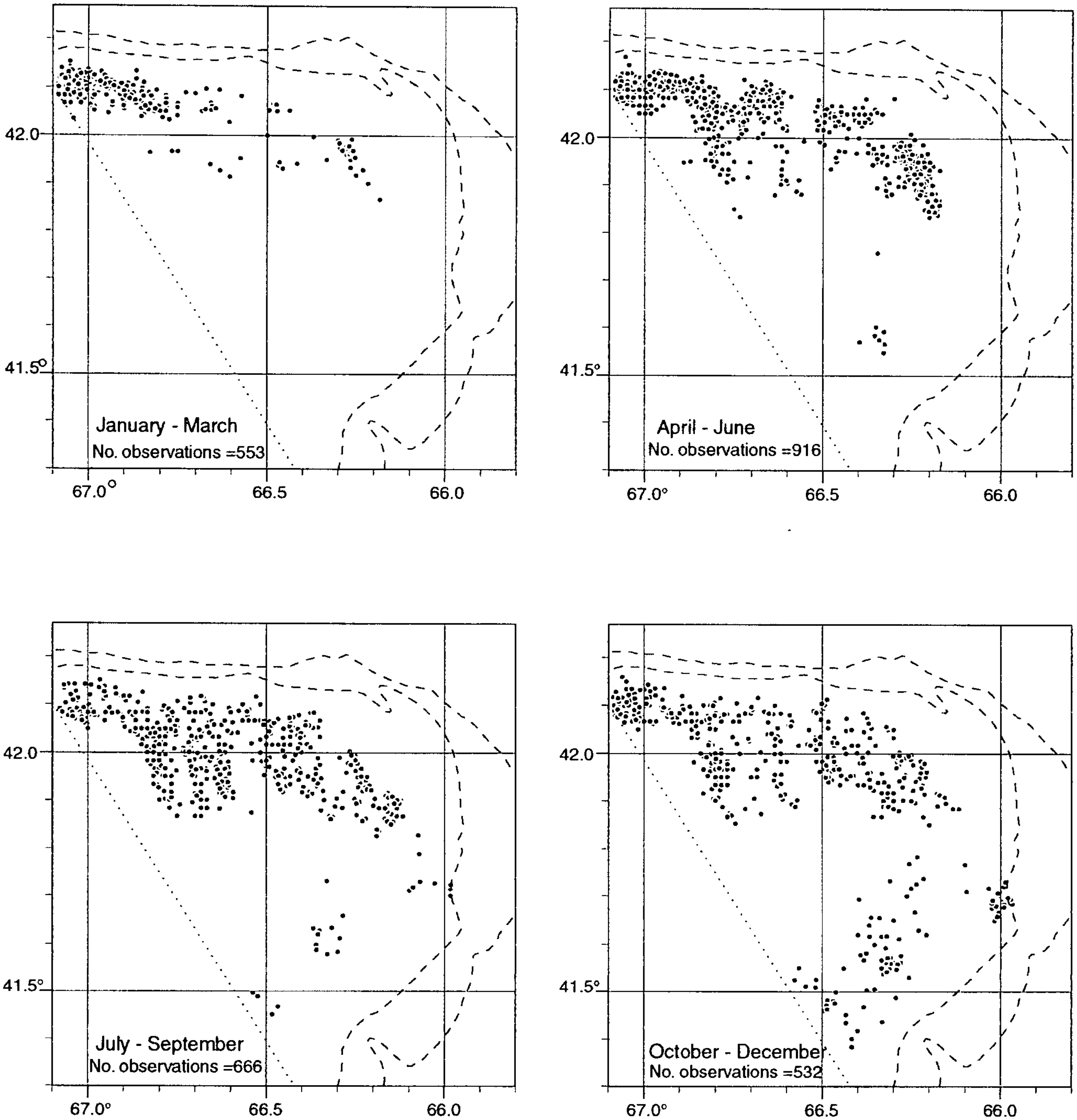

Figure 2.- Fishing locations on Georges Bank in 1997 by quarter of the year. Dots represent fishing locations visited at least once. Total number of days fished per quarter is indicated on each map.

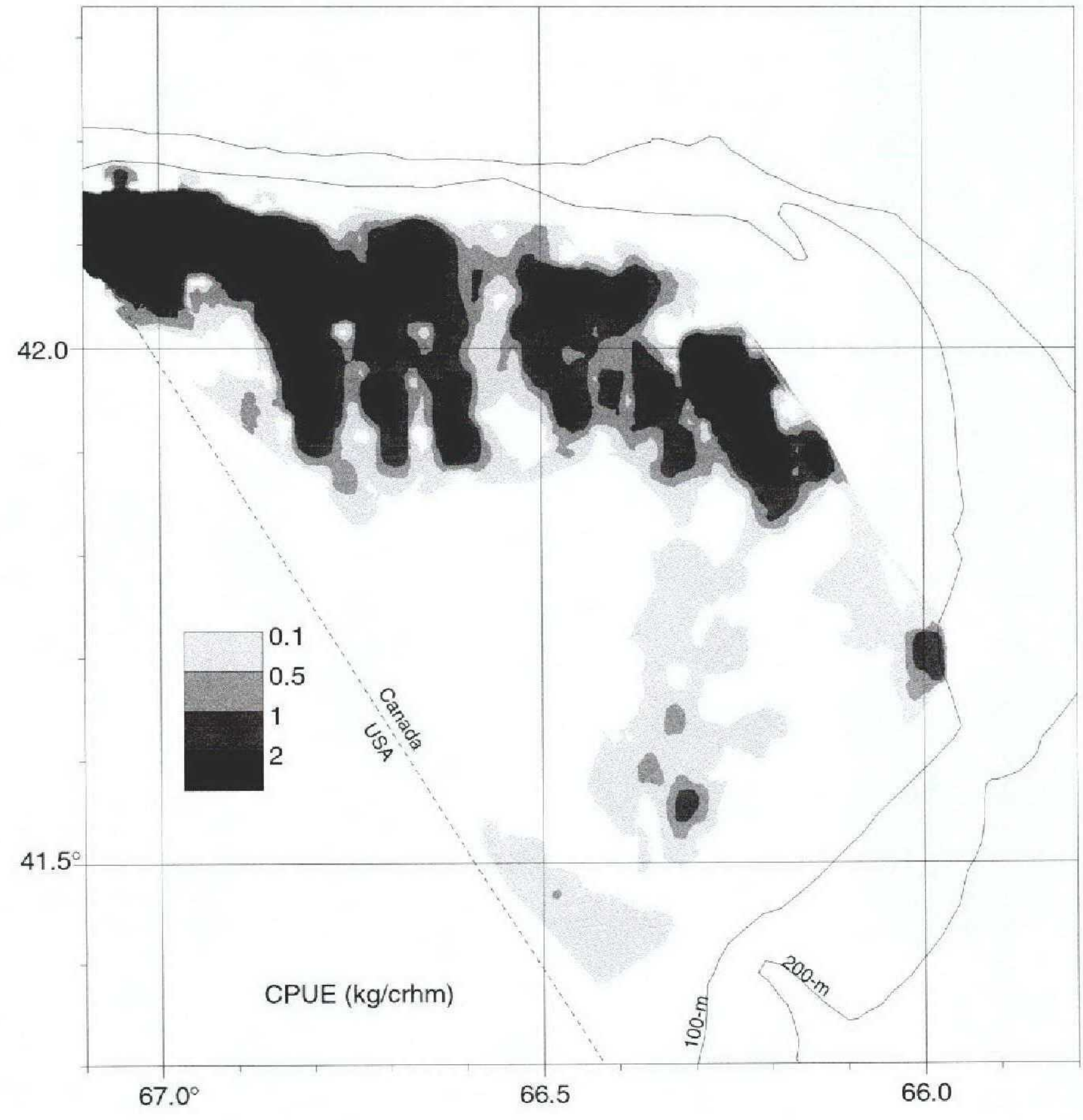

Figure 3.- Catch-rates encountered on Georges Bank in 1997. The scale of grey shades represent ascending catch-rates up to 2+ kg/crhm.

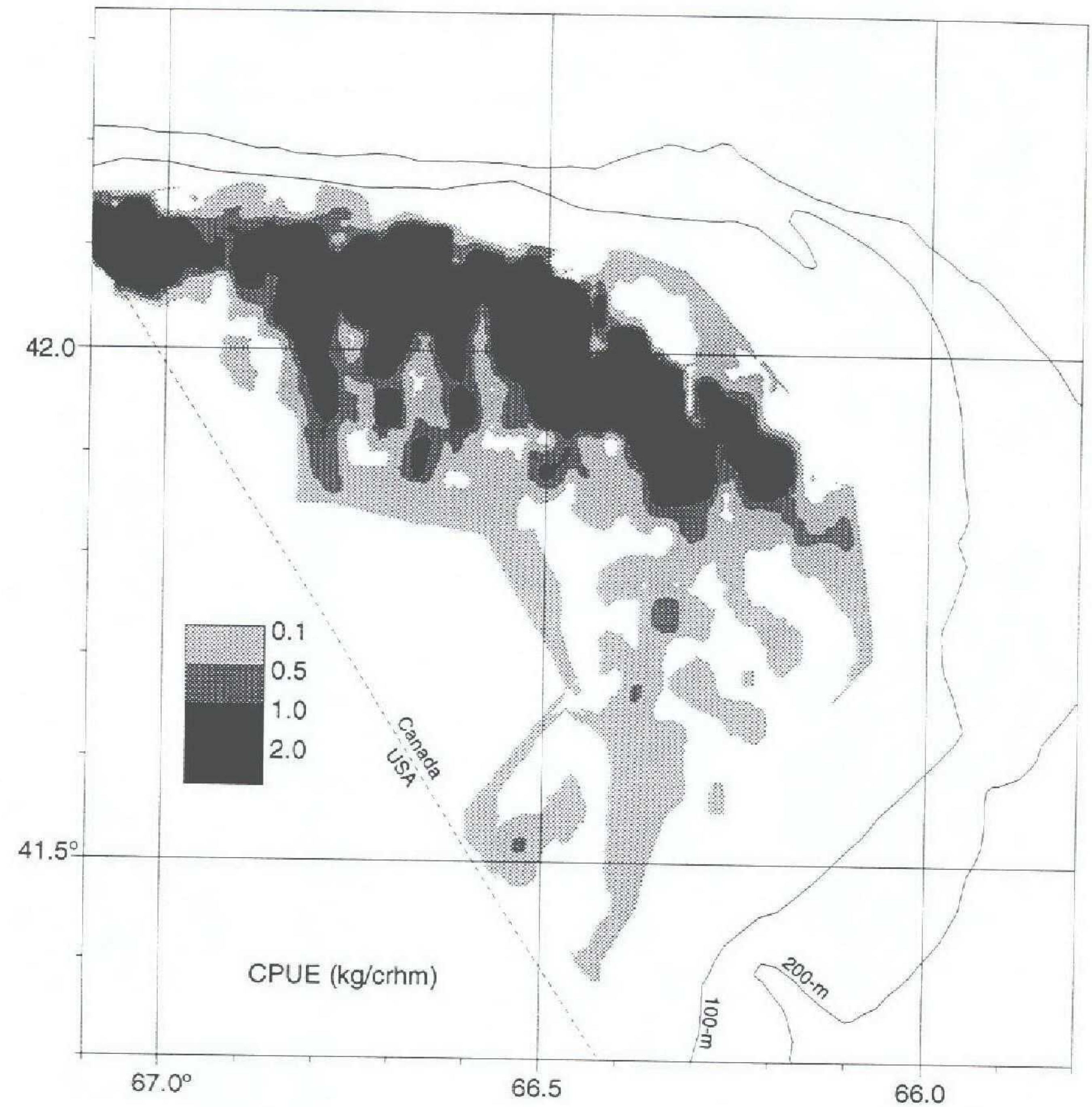

Figure 4.- Catch-rates encountered on Georges Bank in 1996. The scale of grey shades represents an ascending catch-rate up to 2+ kg/crhm.

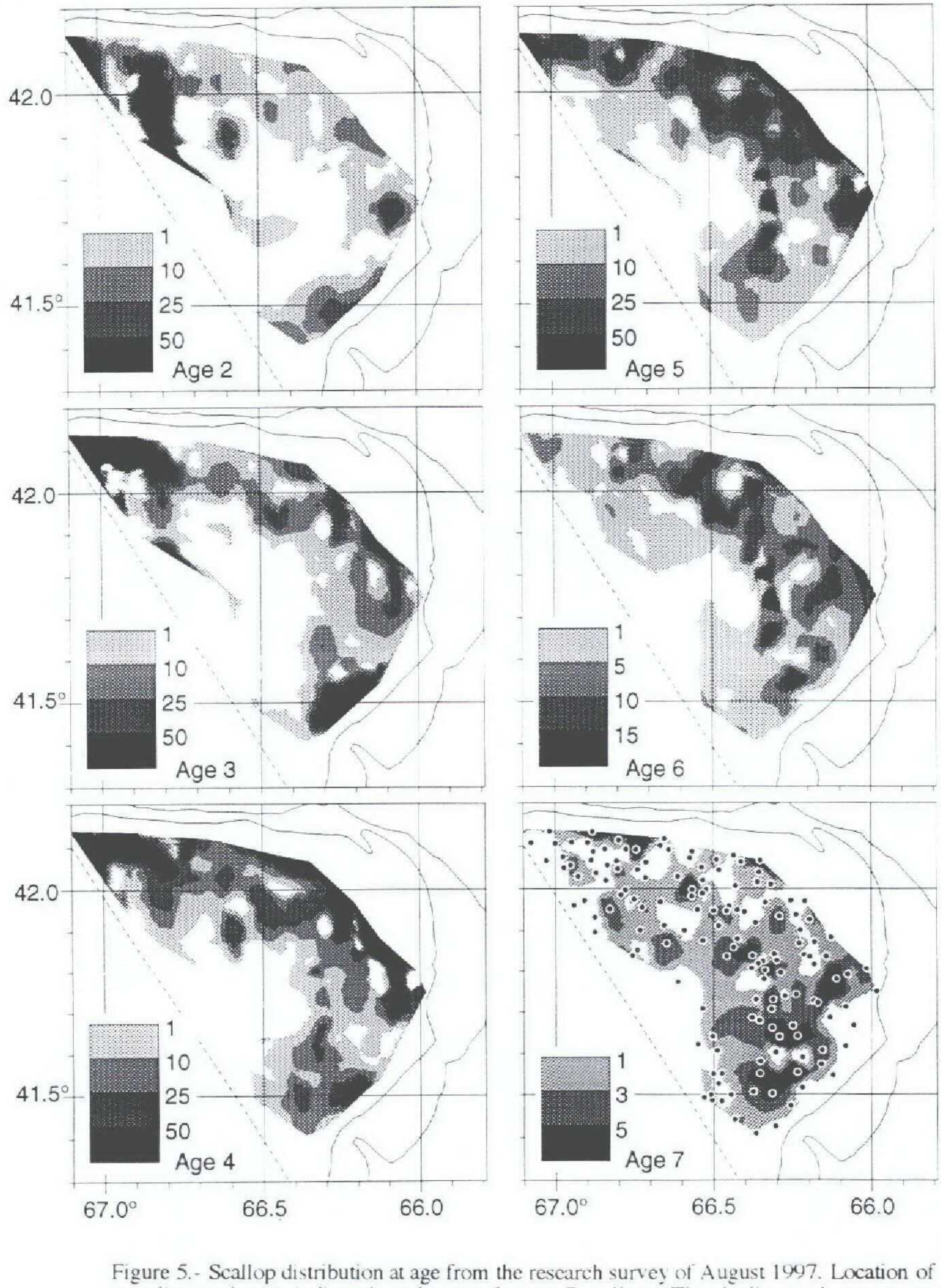

Figure 5.- Scallop distribution at age from the research survey of August 1997. Location of sampling stations is indicated on the map for age 7 scallops. The shading scale represents number of scallops per standard tow.

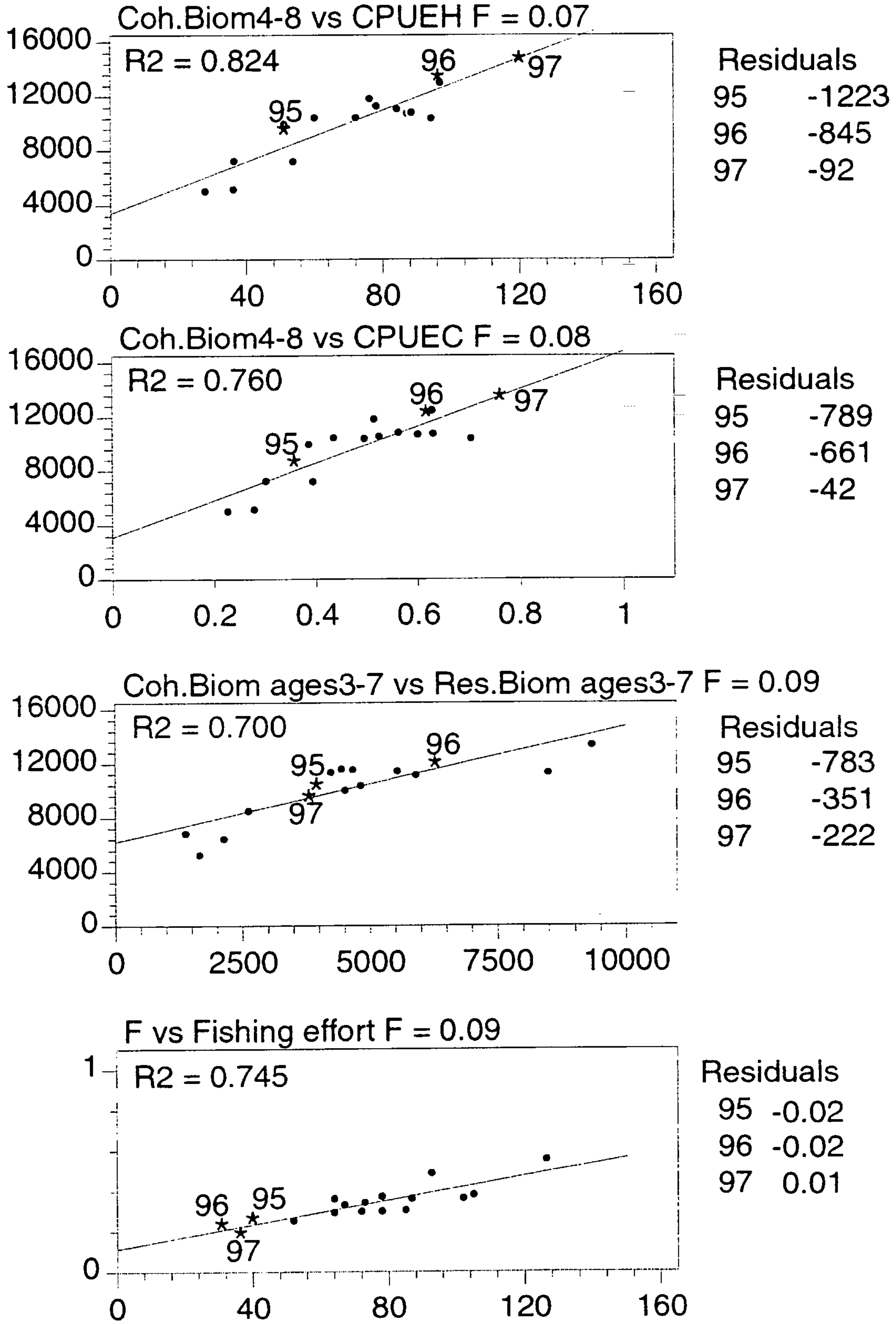

Figure 6.- Cohort biomass for ages 4-8 (tons of meats) versus CPUE (kg/h), cohort biomass for ages 4-8 versus CPUE (kg/crhm), cohort biomass for ages 3-7 versus research survey biomass for ages 3-7 and F versus fishing effort using a terminal FQ4 as shown. Asterisks mark the position of the last 3 years points from the regression line. Residual values are to the right of each graph.

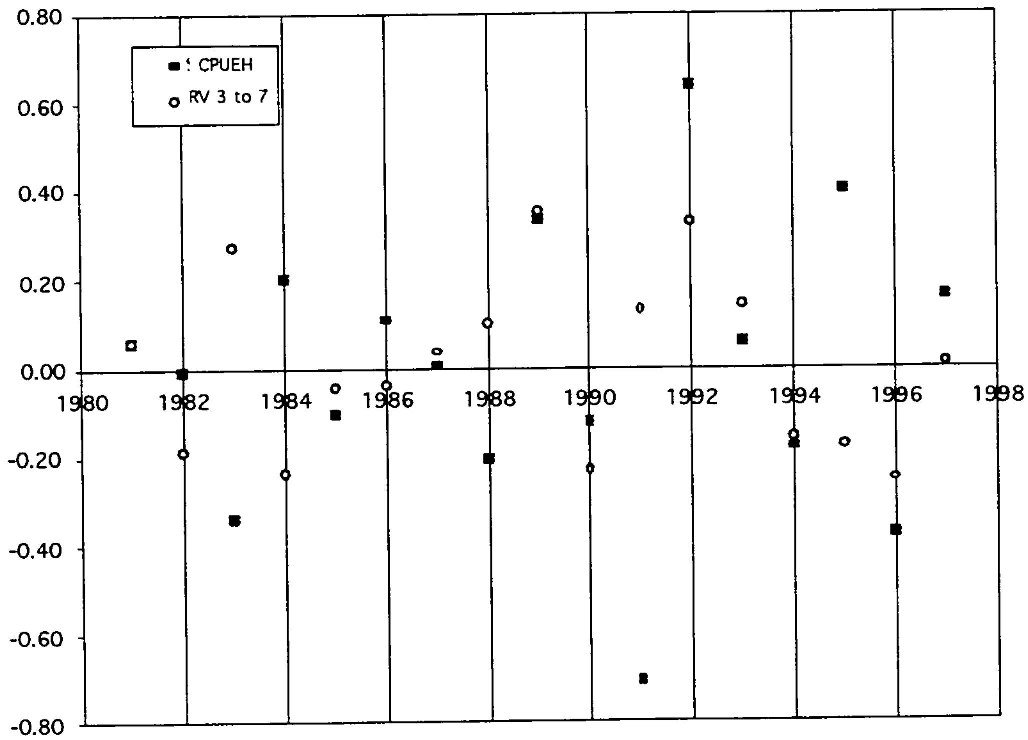

Figure 7.- Residual patterns when tuning against CPUE (hours) and research survey results for ages 3 to 7.

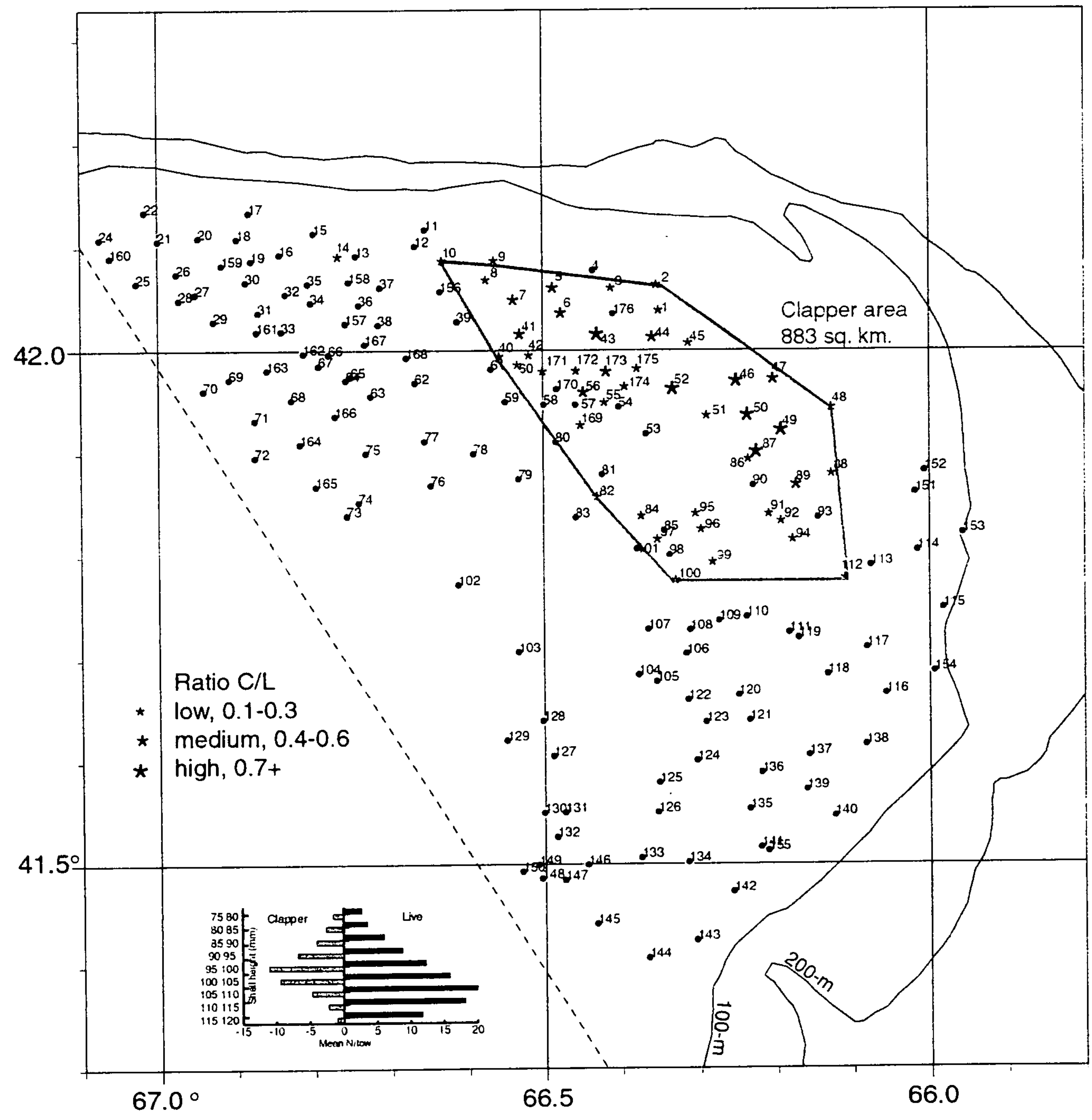

Figure 8.-
Incidence of clappers during the August 1997 Georges Bank stock survey. The ratio of clapper versus live scallops per tow (75-120 mm shell height) is scaled with a star symbol (see legend on map) at stations where the ratio was greater than 0.1. Otherwise, sampling locations are shown with a dot. A bar graph compares shell height distribution of live scallops and clappers.

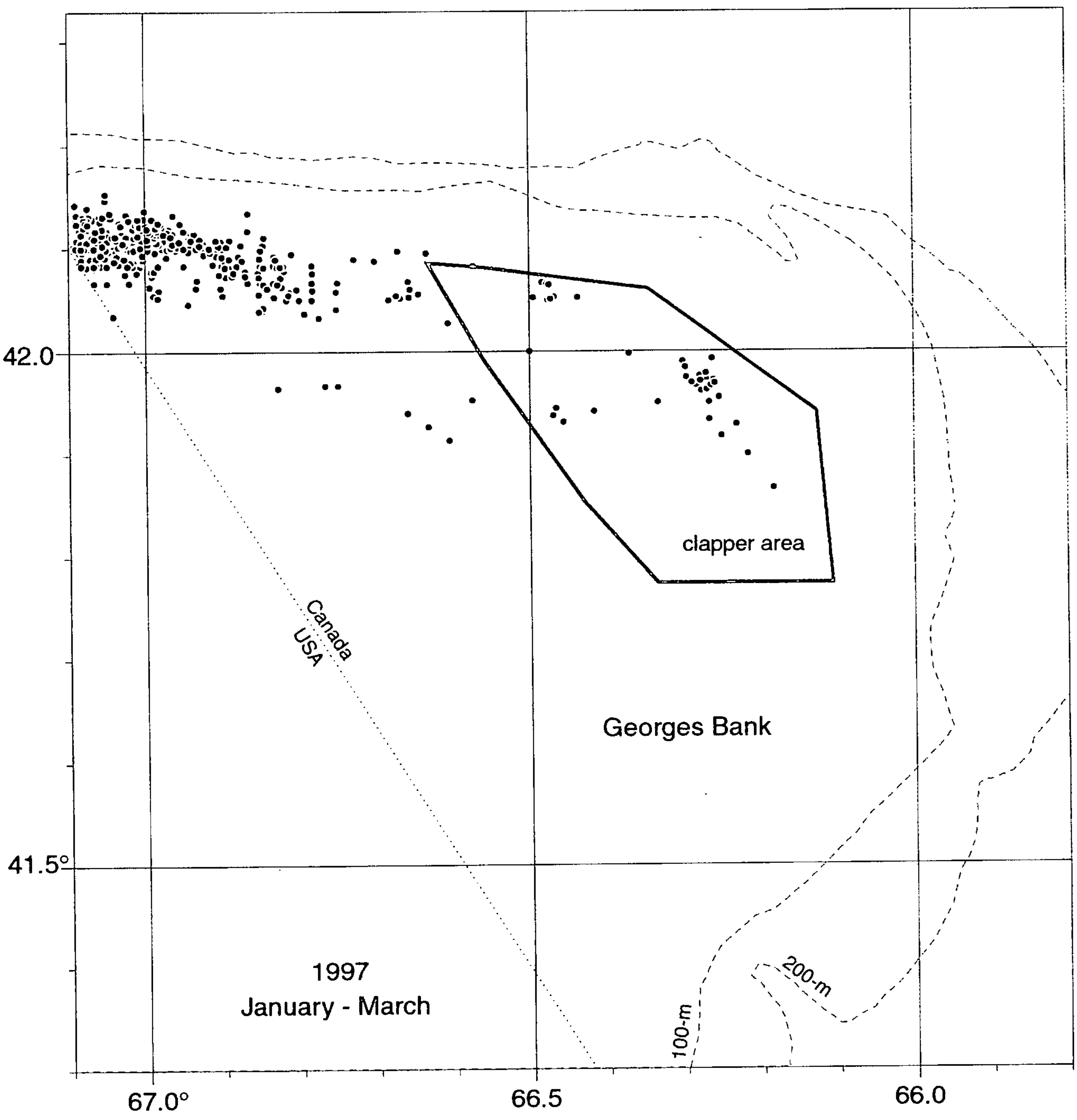

Figure 9.-
Locations fished according to logbooks during the period January-March 1997 are shown as dots. The clapper area is outlined from data collected during the August 1997 scallop stock survey.

Figure 10.- Time series of estimated population numbers at age 3 in millions (top graph) and normalised abundance index from reserch surveys for age 3 (bottom graph). The dashed line draws the geometric mean for recruitment. Year classes are labeled on the X-axis.

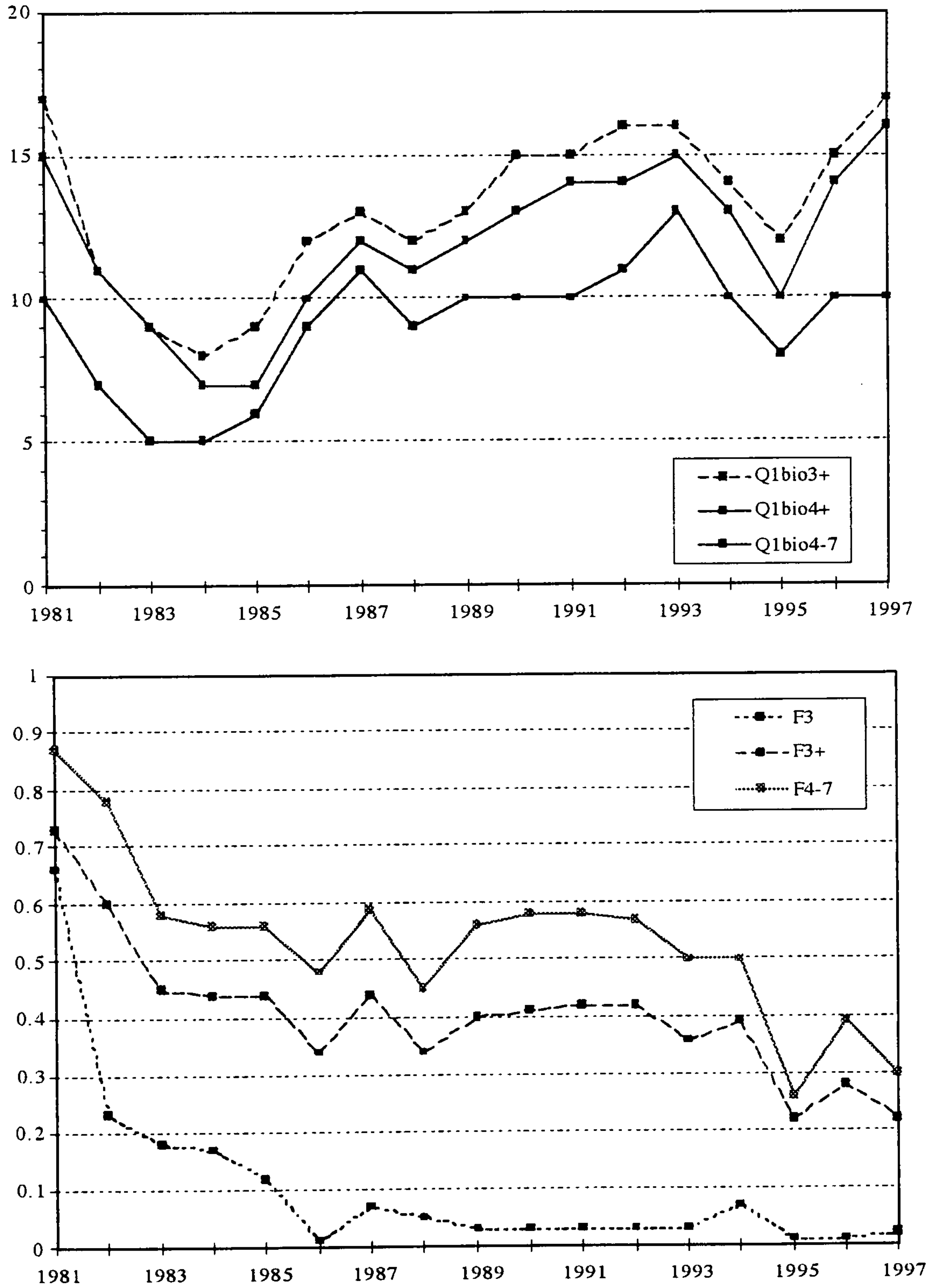

Figure 11.- Trends in population biomass (thousands of tons, meat weight) and annualised fishing mortality rates for the period 1981 to 1997. Fishing mortality rates are the mean for the ages indicated in the F label.

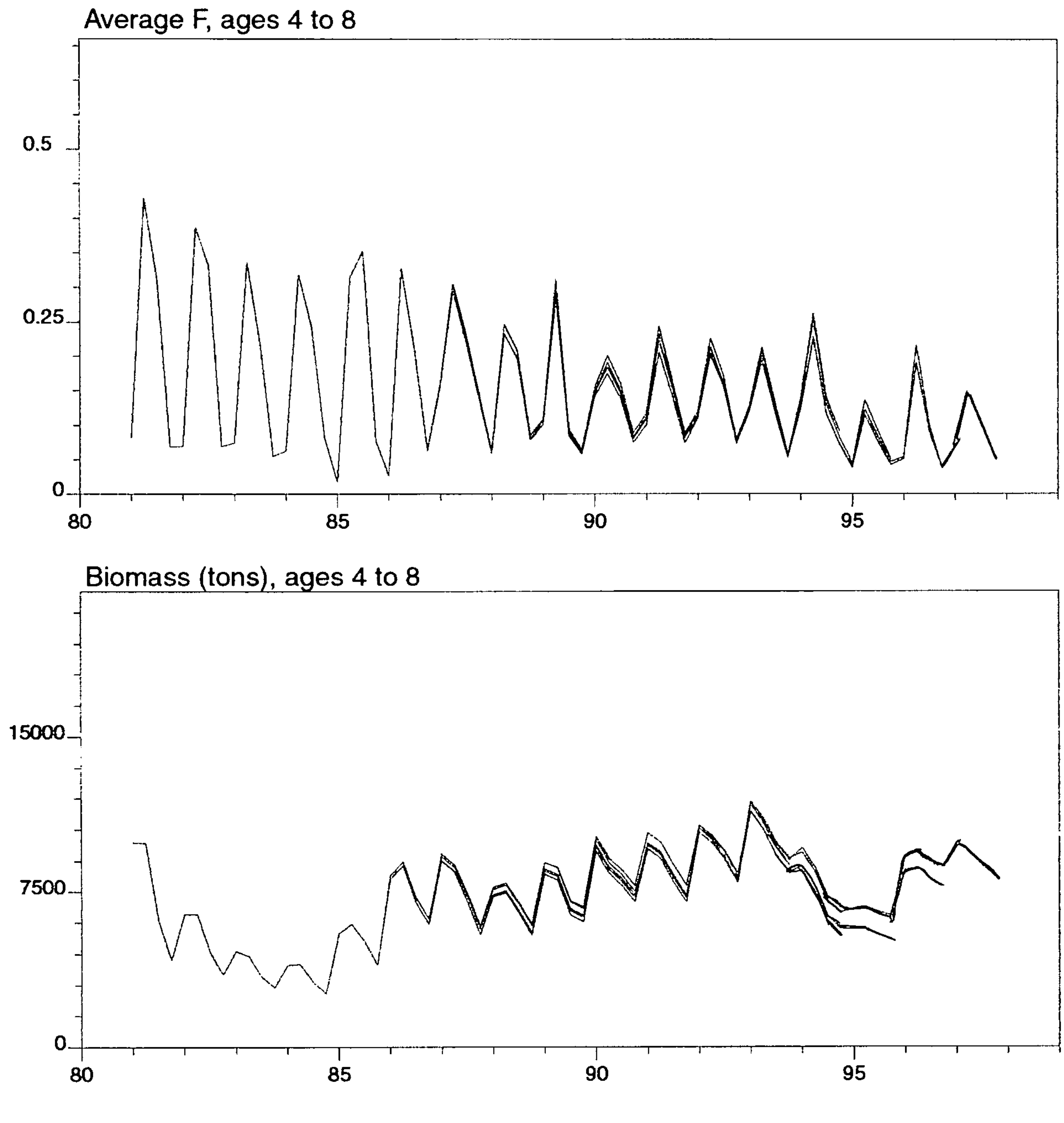

Figure 12 .- Retrospective analysis patterns for fishing mortality rates and biomass estimates, ages 4 to 8, peeling by sequences of 4 quarters over the last 5 years.

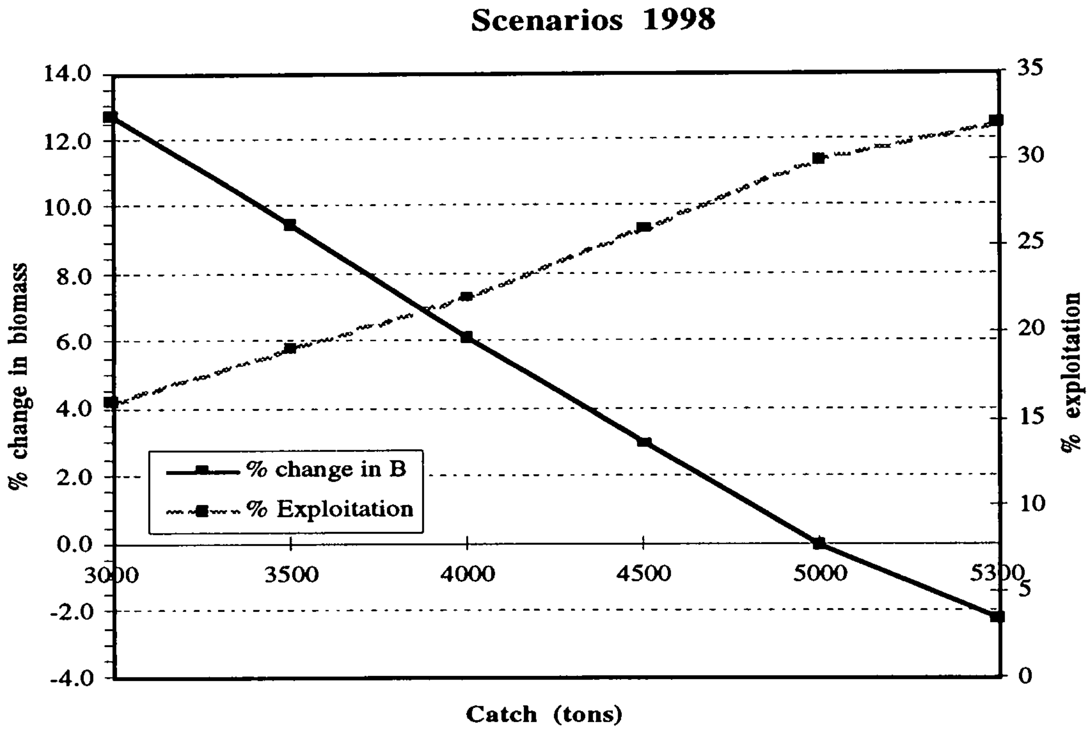

Figure 13.- Changes in stock biomass at the end of 1998 compared to the end of 1997 and exploitation rates corresponding to different catch scenarios ranging from 3,000 to 5,300 tons of meats.