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Georges Bank Scallop Stock Assessment - 1995

By

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ABSTRACT

A TAC of 2,000 t had been advocated for 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. The 1995 catch level corresponded to 40% of the 1994 catch. Effort also decreased by 40% from 1994 to 1995 while catch-rates dropped 33%. The presence of small meats (≤10 g) in the catch was curtailed during 1995 once a monitoring programme was in place.

The 1995 stock biomass is 67% of recent high values reached in 1992, the directed biomass (ages 4-7), 58%. Low biomass is mainly caused by the poor representation of the 1990 and 1991 year classes at ages 4 and 5. The latest recruitment estimate (age 3) appear to be improving although it is still below the long term average.

The Georges Bank scallop stock needs rebuilding after the passage of 2 weak year classes. The stock had previously encountered low biomass of 10,000 t or less in the early 1980's. The 1995 drop in biomass, 10,500 t, does not appear as prolonged. However, it would be prudent to give stock rebuilding due consideration. Given the stock composition the 1996 fishery depends on, and the recent stock history, a conservative exploitation strategy should be adopted for 1996.

RÉSUMÉ

On avait recommandé pour 1995 l'adoption d'un TAC de 2,000 t, compte tenu de la faiblesse des classes d'âge de 1990 et 1991 qui, aux âges 4 et 5, constituaient deux des principaux groupes d'âge sur lesquels la pêche était dirigée. Les prises de 1995 représentaient 40 % de celles de 1994. L'effort a aussi diminué de 40 % entre 1994 et 1995 tandis que les taux de capture ont baissé de 33 %. La présence de petits pétoncles (≤10 g) dans les prises a été réduite en 1995 après que le programme de vérification fut mis en place.

En 1995, la biomasse du stock se situe à 67 % de la valeur maximale établie récemment en 1992, la biomasse ciblée (âges 4-7), 58 %. Une représentation inadéquate des classes d'âge 1990 et 1991, à 4 et 5 ans est principalement responsable pour la biomasse peu élevée. Selon l'estimation la plus récente, le recrutement semble s'être amélioré, quoiqu'il demeure bien inférieur à la moyenne à long terme.

Le stock de pétoncle du banc Georges a besoin de se rétablir après le passage des faibles classes d'âge de 1990 et 1991. Le stock avait fait face à des biomasses basses, à 10 000 t ou moins, au début des années 1980. La chute de biomasse en 1995, à 10 500 t, ne semble pas aussi prolongée. Cependant, il serait prudent de considérer sérieusement le rétablissement du stock. Compte tenu de la composition du stock dont dépend la pêche de 1996, et de l'histoire récente du stock, il conviendrait d'adopter une stratégie d'exploitation prudente pour 1996.

INTRODUCTION

After the jurisdiction for fisheries on Georges Bank (Fig. 1) 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, about half the initial number of license holders are actively involved in the Georges Bank fishery. The meat count (size limit) was lowered to 33 meats per 500 g in January 1986 to direct exploitation toward slightly larger scallops.

A TAC level of only 2,000 t had been advocated for 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. Catches were 1,984 t of scallop meats. The 1995 catch level corresponded to only 40% of the 1994 catch (Table 1). The decline in catches follows the reduced abundance of 2 strong year classes, 1988 and 1989, after 2 to 3 years of exploitation and weaker recruitment afterwards. Prior to 1995, catches had been in the narrow range of 5-6,000 tons for the last 5 years. Catches were less than the TAC in 1995 due to administrative penalties. Catches from the first quarter of the year had reached up to 30% of the total for the year over the last 6 years. For the first time since 1988, winter 1995 catches at 13% are more in line with traditional levels of 10% for the first quarter.

Annual catch-rates since 1990 are in the medium to high range, peaking in 1993 (Table 2). Catch-rates dropped 33% from 1994 to 1995. They varied little from month to month in 1995 (Fig. 2); fall spawning brought a further (small) drop (October) but they appear to recover. Catch-rates usually experience a small decline due to spawning (see Fig. 2 for 1992 and 1993). The available incoming biomass dampens monthly variations and allows catch-rates to rebound in good years. Contrary to that, a declining biomass in 1994 could not sustain CPUE in the high range. From June to September, rates had experienced a 45% drop and did not recover from these low values. A detailed geographical distribution of CPUE isopleths for 1994 (Fig. 3) and 1995 (Fig. 4) shows a fragmented distribution of areas with high CPUE's. Areas with CPUE's over 1 kg/crhm covered 4,050 km^2 in 1994 or 85% of the total area; in 1995 such areas had been reduced to 1,100 km^2. The southern half of the Bank had CPUE under 0.5 kg/crhm with only a very small area higher than that.

Fishery performance in terms of CPUE could have been better over the short term with more fishing activity taking place on the dense aggregations of small scallops on the northern Edge, following historical patterns. Given the scarcity of meats ages 4 and 5, there was a possibility in 1995 to start the exploitation of the 1992 year class at age 3, blending these small meats with big ones to satisfy the regulation meat count of 33 meats per 500 g. This overexploitation of small scallops would have led to a significant quantity of meat yield being lost to the stock. The Industry, in collaboration with Science, instituted a programme 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 based on the size composition of the catch made up of good year classes that have reached most of their yield potential. The low tolerance on 50+ count meats adds more restriction to the regulatory meat count in place.

The average monthly meat weight in the catch has been increasing since 1993 reflecting the weakness of the 1990 year class recruiting to the fishery. Data for 1994 and 1995 are also presented in table 3. This is a very different catch composition from 1981 when the fishery was competitive and temporarily deregulated. The quarterly distribution of meat weights in table 4 shows the progressive shift toward large scallops (30+ g) in the catch over the last 4 years. 1995 had an impressive component of large meats especially during the second and third quarters. The presence of ≤10 g meats in the catch was severely curtailed during 1995 once the monitoring programme for small meats was in place from the second quarter onward.

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 1991-1995. Generally speaking, the 1991-1995 data set representing all companies profiles scallops caught at a larger size than the corresponding data set from the 2 'index' companies. (For a comparison, see table 5 this document and the same table in Robert and Butler, MS 1995). 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 1995 catch (Table 5) reflects the stock composition to the extent that age 7 scallops (29+ g) represent 20% of animals caught, this is the once plentiful 1988 year class. So far in the recent history of the Georges Bank fishery, 10% had been the highest representation granted age 7 scallops, in 1994. Younger recruits, age 4, contributed 45% of the catch in 1994-95 corresponding to the low abundance of the 1990 and 1991 year classes. In comparison, the 1988 and 1989 year classes had contributed 60% in 1992-93. The 1995 catch also lacks ≤10 g scallops, only 7% by numbers for the year. Table 4 offers a detailed picture broken down by quarters. During the first quarter, 13% were scallops ≤10 g. Starting with the second quarter the monitoring programme for small meats was fully implemented and the presence of 10 g meats dropped from 13 to 6% for the rest of the year.

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. 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 1995. 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. A very high stratum was added in 1991 to reduce the variability of the high stratum. The range of catch-rate values encountered has increased markedly. Since 1992 40% of the total catch-rate points used were over 1 kg/crhm, the minimum benchmark of the high stratum. The maximum value in the data set peaked at 10 kg/crhm in 1993 to steadily decrease to 7.3 in 1994 and 3.7 in 1995. Then, only 14% of the catch-rate points correspond to the high stratum. The average number of scallops at age per tow is given in Table 8. 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 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 8 and 10) to provide density and biomass estimates for the Canadian side of Georges Bank only.

Stock 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 1995. This pattern, multiplied by the F determined from tuning for the last quarter year (F_{Q4} 1995), 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.) A dome-shaped selectivity vector seemed peculiar to some participants of the Gulf of Maine assessment review meeting. This point was deliberated at the meeting. Results are summarised in an appendix to this document. Other technical aspects such as using disaggregated ages versus aggregates and a non-zero intercept in tuning plots are also addressed in the Appendix. In addition to tuning for cohort biomass over the complete range of ages 3 to 11, 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 was also achieved when tuning fishable biomass for ages 4+.

Best performers for tuning gave high multiple correlation coefficients and residual values for 1994 and 1995 closest to the regression line (Table 11). Tuning iterations estimated a quarterly rate for terminal F in a narrow range (0.06-0.09). 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. This also holds true for regression of fishable biomass for ages 4 to 6. 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+ on CPUE: the maximum multiple correlation coefficient, 0.810, for the regression of cohort biomass ages 4+ on CPUE corresponded to an F_{Q4} of 0.09. That terminal F provides for both the 1994 and 1995 residual points to be very close to the regression line.

Cohort ages 3 - 7 on research biomass ages 3 - 7: A maximum multiple correlation coefficient of 0.684 occurs at F_{Q4} equal to 0.09. A similar F_{Q4} of 0.08 provides a very small residual for 1995 with a lower coefficient at 0.665. A small negative 1994 residual also corresponds to this terminal F. Ages 3 to 7 have been well represented in the survey data for the last 9 years. 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 represented in the research data.

Fishable biomass ages 4+ on CPUE: The relationship is much weaker with a maximum correlation of 0.468 at a terminal F equal to 0.07. The 1995 residual point is almost on the regression line at F_{Q4} equal to 0.06 but the 1994 point is off the line under the range of F selected (Fig. 6).

Cohort biomass all ages on CPUE: Similarly to the regression cohort biomass for ages 4+ on CPUE, the best fit is at a terminal F equal to 0.09. However, the variability explained by the relationship is only 69% compared to 81% under the first scenario; the residuals are also bigger. This may relate to the fact that age 3 scallops have gradually contributed little to fishery performance after the implementation of the meat count at 33 per 500 g in 1986.

Strong correlations of cohort biomass on CPUE and cohort biomass on research survey biomass estimates for specific age groups occurred at an F_{Q4} of 0.09. 69 to 81% of the variability could be explained when the cohort biomass was tuned against CPUE and 68% for the cohort biomass against survey estimates. The last 2 years residual points were in close proximity to the regression line (Fig. 6) in the first case.In the second case, a slightly lower F at 0.08 gets the last 2 years residual points closest to the line. The regression of fishable biomass for ages greater than 4 on CPUE gave a best fit for the last year residual at a terminal F of 0.06; at this F the relationship (with 46% of variability explained) is not that different from the maximum possible (47%).

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. This was not necessarily helpful in all situations. A presentation of NLLS on offshore scallop data may be found in Robert et al (MS 1994). This analysis was performed to confirm results reached earlier and carry out retrospective analysis of the recent years' estimation of F and biomass.

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 re-examined but there was no need for a re-evaluation as the fishing strategy, hence partial recruitment remained practically the same. Improvements in the fishery in 1991 - 1992 required a re-evaluation as older age groups (>age 7) became more represented in the catch (Table 4). The yield per recruit was examined for change in partial recruitment. A difference of 10% did not warrant any changes being made to the model.

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 program 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 10, 45, 30, and 15%, which reflects the 1995 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 had been twice to three times the historical value. 1995 is the first year to return to historical levels. 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 1995 research survey are plotted in Figure 5. Station locations are indicated in the plot for age 6. Table 8 presents survey results in terms of the abundance of scallops on an age basis per standard tow. The number of old scallops, ages 6+ (1989 and older year classes), remains relatively stable. For only the second time in the last 15 years, age 8 scallops are recorded in the survey; they were present in all strata except the very high stratum (Table 9). The 1995 stock survey results indicate that the abundance of age 5 scallops, the 1990 year class which is a weak class, has dropped more than 50% from 1994 to 1995 presumably from fishing activities. The abundance of age 4 scallops is also low. This is the 1991 year class, another poor year class. However, that year class has remained almost unchanged. Slow growers in this group could have benefitted from the programme discouraging the shucking of 50-count meats. Maximum isopleth contoured is only 25 animals per tow (Fig. 5).

Abundance of prerecruits offers some improvement. The abundance of the 1992 year class (age 3), has been confirmed as a relatively strong year class on the northern Edge of the Bank. But it occurs at very low densities on the southern side (Fig. 6). The mean number per tow jumps 60% if only the area of the northern Edge is considered. Another good year class (1993, age 2) has been observed during the last survey. 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 abundance. Nevertheless, the presence of the 1993 year class has been established over a greater area of the Bank compared to the 1992 year class with a somewhat well defined aggregation in the southern part of the Bank (Fig 7). In this case, considering only the northern Edge brings the number of age 2 scallops to 266 from 159 per standard tow (Table 8).

The relative indices of biomass for the main age groups (Tables 10) are showing a reversal of the delining trend experienced since 1993. While recruited ages may experience a small biomass increase, a major increase takes place for the age 3 prerecruits.

Cohort analysis

The SPA 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 0.09. Numbers-at-age for the early 1990's have seen the passage of 2 good year classes in the stock with over 500 million scallops at age 3 each (Table 12 and Fig. 8) to be followed by the two poorest year classes since 1981. Numbers at age 3 in the research surveys coincide well with the strength of these same year classes in the population estimates. Overall numbers in the 1995 population estimate for 1994 and 1995 are among the lowest recorded since 1981 (Table 12). In 1995, the number at age 5 is unusually low; age 6 are quite abundant for old age groups. Similarly, biomass estimates (Table 13, Fig. 9) have been decreasing substantially from the recent peak in 1992. Annual fishing mortality rates are presented in table 14. Overall F on ages 3-11 had varied little since 1988 and was much lower than before the implementation of EA's (pre-1986) (Fig. 9 bottom). Both overall F and F on the target age group 4 -7 have experienced an important reduction from 1994 to 1995. 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 to 0.02 from 1994 to 1995. Average F on the directed ages 4 to 7 has been quite stable since 1989 and decreased noticeably from 1994 to 1995.

The ADAPT model estimated F at age 4 for the last quarter of 1995 calibrating with research survey data as in the first tuning procedure. Ages included in the tuning are from 3 to 8. All other variables are identical to the first tuning. The statistical diagnostics are as follows:

relative change in phi parameter = < 0.001
mean square of the residual = 0.1318
$F_4 = 0.087$ s.e. = 0.0266 CV = 0.305

F_4 estimate fits well with the value established with the first tuning procedure. The coefficient of variation is equal to 31%. A retrospective analysis of the biomass for ages 3 to 8 and average fishing mortality rate was carried out on the last 5 year's data. Table 15 details the biomass and fishing mortality rate estimates adding one set of data per year for the last 5 years. Looking down each column shows the generally small fluctuations but no apparent trends of persistent under or over estimation of the 2 variables. No constraint was put on the terminal population to initiate the stock projection given the lack of pattern shown in the retrospective analysis.

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 reevaluated 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 not necessary to change the F reference points following the 1995 assessment. 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 1995 cohort analysis aged forward to the first quarter of 1996. The projections for a one year period assume a recruitment level of 400 million scallops to reflect the improvement in recruitment with the 1993 year class. It is conservative, being below the long term median of about 420 million (figure 7). The partial recruitment vector used : 0.05, 0.62, 1.00, 0.39, 0.24, 0.18, 0.19, 0.21, and 0.21; last year was: 0.04, 0.53, 1.00, 0.35, 0.20, 0.13, 0.11, 0.18, 0.10. The selectivity is greater on age 8+ than last year. Age 5 selectivity still acts as the inflexion point for the selectivity curve; the slope changes on each side of age 5.

Given the low profile of CPUE's throughout 1995 with light fishing activities in the last quarter and the abundance patterns for the main age group found in survey results, catch projections were carried out for 1996 with a terminal F_{Q4} at 0.09. The quarterly catch pattern for 1996 was set with a decreased level of activity during the winter fishery to reflect the return to historical levels of effort during the first quarter. Biomass projections for selected fishing scenarios are improving from last year. Detailed scenarios for $F_{0.1}$ and F_{max} are found in table 16 with additional scenarios in table 17. A fishing scenario keeping the same TAC for 1996 (2,000 t) as in 1995 gives a directed biomass estimate (ages 4-7) of 9,100 t at the end of 1996. A scenario keeping the effort at the 1995 level (2,300 t) provides a slightly lower directed biomass estimate. Fishing at $F_{0.1}$, (2,900 t) in 1996 produces a directed biomass at the end of 1996, 10% smaller than the first scenario (Table 17). The last 2 options in table 17 put F values at high levels and do not offer the stock biomass to rise much from the low 1995 tonnage. The biomass figure for ages 4 to 7 is more important since these particular ages are directed for by the fishery. The directed biomass is a sizable component, 56 to 59%, of the total biomass. The first 3 options with low catch scenarios and exploitation rates under 30% remove from 13 to 20% of the biomass.

CONCLUSIONS

In the early 1980's, Georges Bank scallop stock experienced a gradual and important reduction in biomass due to very high fishing mortality rates directing for young scallops in a highly competitive fishery (Fig. 9). Very low recruitment made for a slow recovery. With the implementation of EA's in 1986, F decreased markedly. Age 3 scallops were no longer directed for by the fleet to any great extent. Since 1989, F on the directed age group, ages 4 to 7, had been quite stable until 1994; it dropped by almost 50% in 1995. With good to excellent recruitment pulses provided by the 1986, 1988, and 1989 year classes, biomass (ages 3+) had steadily increased to peak in 1992. It then started to decline with incoming weaker recruitment. 1995 biomass levels are 67% of the 1992 values.

The 1996 fishery will depend mainly on the 1989 and 1992 year classes. The 1989 year class at age 7 (in 1996) is represented by large 30+ g scallops (under 20-count). In its 4th year of exploitation, the strength of this once abundant year class is declining. The 1992 year class at age 4 (9-16 g meats; 40-count on average) is a good year class but on the northern Edge of the Bank only. These young recruits in their first year of exploitation could contribute more yield to the fishery if fished at least a year later (age 5). Blending the small size 1992 year class with the bigger meats 1989 year class will take place on a large scale since the more abundant young recruits are below the size to meet the 33-count by themselves. Yet, numbers of the 1989 year class are dwindling. It is expected that meeting the 33-count will not necessarily be an easy task, especially in the first quarter before spring growth resumes.

The stock needs rebuilding after the passage of the weak 1990 and 1991 year classes into the fishery. Stock biomass is estimated at about 12,000 tons at the beginning of 1996. Although it is rising from 10,000 tons at the beginning of 1995, a biomass, 20% higher for example, could better stand negative effects on recruitment or growth over the next few years. From an historical perspective, the Georges Bank scallop stock had previously encountered a period of low stock biomass of 10,000 t or less in the early 1980's. The most recent occurrence (1995) of a drop in biomass does not appear as prolonged.

There is also a certain degree of uncertainty associated with estimating the strength of the 1992 year class. This year class has not been fished yet, therefore its presence has not been detected in the catch data. Survey results have shown so far that the 1992 year class was of moderate strength on the northern Edge of the Bank.

Given the stock composition the 1996 fishery depends on, and the recent stock history, a conservative exploitation strategy should be adopted for 1996.

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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

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

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

* 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
1994	0.017					
January		18.49	6.70	57.41	0.04	3279
February		17.57	5.22	56.59	0.03	4850
March		17.55	5.09	63.00	0.03	7410
April		19.46	5.25	62.26	0.05	3118
May		17.70	3.59	64.86	0.04	5693
June		17.84	4.27	50.47	0.06	2859
July		20.83	4.42	68.87	0.05	4441
August		18.28	3.97	57.03	0.05	3899
September		18.47	5.01	53.40	0.05	2760
October		18.50	4.07	56.18	0.04	5001
November		20.38	4.63	73.09	0.07	2595
December		18.22	4.77	55.43	0.10	1126
1995	0.057					
January		17.90	5.87	56.44	0.13	568
February		19.67	5.31	55.26	0.13	771
March		19.10	4.62	51.96	0.05	4520
April		20.45	4.85	62.67	0.06	3998
May		21.80	3.78	75.02	0.04	8839
June		23.10	5.59	77.86	0.05	7078
July		21.66	3.81	70.47	0.04	7920
August		21.43	6.57	72.68	0.06	4470
September		18.01	5.53	65.20	0.05	3895
October		18.02	2.59	61.42	0.03	8403
November		16.83	5.14	52.49	0.04	4504
December		18.02	7.58	50.35	0.11	563

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	1992	Q1	Q2	Q3	Q4	1993	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		8	5	7	8		3	4	6	13
9		46	39	50	59		26	29	37	61
11		124	121	136	165		104	110	108	137
13		185	185	195	221		215	206	166	170
15		193	180	180	188		231	217	167	159
17		154	130	135	124		174	146	150	130
19		102	88	87	83		100	89	119	104
21		64	52	61	48		54	62	80	76
23		44	45	39	32		30	42	56	52
25		27	34	29	20		21	32	39	36
27		17	29	22	16		13	22	26	23
29		13	23	18	9		8	13	16	14
31		8	19	12	7		9	11	11	9
33		6	12	9	5		4	6	7	6
35		4	9	4	5		3	4	5	3
37		3	6	4	3		1	3	3	3
39		1	6	4	2		1	2	2	1
41		1	4	1	1		1	1	1	1
43		1	4	1	1		1	1	0	0
45		1	2	1	1		1	0	0	0
47		0	2	1	1		0	0	0	0
49		0	1	0	0		0	0	0	0

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

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	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
1	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
5	0	2	3	1	2	1	0	0	3	1
7	6	17	28	14	24	12	7	6	23	11
9	41	79	98	83	96	64	47	36	65	55
11	125	150	163	179	164	141	135	113	109	126
13	209	175	179	219	177	174	196	190	126	148
15	225	168	152	182	146	162	184	196	119	116
17	160	129	104	117	113	126	135	150	107	85
19	96	89	75	72	80	93	89	102	94	67
21	55	59	54	43	62	65	56	68	81	58
23	28	44	36	30	43	44	41	45	64	49
25	17	29	27	18	30	30	28	32	51	44
27	11	18	22	14	19	21	22	22	40	37
29	8	12	16	7	13	18	17	13	32	34
31	3	9	11	6	9	11	12	10	24	32
33	3	6	9	4	6	9	8	6	18	27
35	3	4	6	4	5	6	6	4	13	22
37	2	3	5	2	3	6	4	2	10	19
39	1	2	4	2	2	4	4	2	7	16
41	2	1	3	1	2	4	2	1	5	13
43	1	1	2	1	1	2	2	1	4	12
45	0	0	1	1	1	3	1	0	2	9
47	0	0	1	0	0	1	1	0	1	6
49	0	1	1	0	0	1	1	0	1	5
51	1	0	1	0	0	1	0	0	1	3
53	0	0	0	0	0	1	0	0	0	2
55	0	0	0	0	0	1	1	0	0	1
57	0	0	0	0	0	0	0	0	0	1
59	0	0	0	0	0	0	0	0	0	1
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
67	0	0	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0	0
77	0	0	0	0	0	0	0	0	0	0
79	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	289	45	33	65	65	2	21	21	16
4	492	170	90	68	144	185	186	119	159
5	75	93	65	33	37	108	188	96	103
6	16	13	14	20	11	10	16	22	19
7	8	6	3	8	10	3	3	5	9
8+	13	10	9	6	7	3	6	5	3
Total	894	338	215	202	275	311	420	268	308

Ages	1990	1991	1992	1993	1994	1995
3	11	13	15	5	8	5
4	173	150	175	176	64	33
5	124	140	131	158	158	23
6	13	20	27	19	20	20
7	8	6	8	8	8	5
8+	6	16	11	8	15	10
Total	335	345	367	374	273	96

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 8.- 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

* new survey series

Table 9.- Stratified average number of scallops at age per tow and stratified 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	1992	21.6	105.1	85.9	27.7	6.1	2.3	1.4	250.3	142.8
	1993	4.4	197.2	90.2	17.9	8.2	2.3	0.8	321.0	173.8
	1994*	48.7	6.0	20.7	23.3	7.0	3.0	1.3	110.0	52.9
	1995	93.1	14.9	13.7	10.6	5.0	2.4	1.2	140.8	36.6
Low	1992	31.7	86.3	71.9	28.2	9.8	1.4	0.0	230.2	73.6
	1993	2.9	25.8	29.6	14.1	6.3	2.4	1.3	82.4	22.2
	1994*	111.3	4.7	5.4	10.8	6.7	2.4	0.9	142.4	111.0
	1995	155.0	48.3	16.5	8.6	7.0	3.1	1.6	240.0	111.3
Medium	1992	56.2	166.7	91.8	44.3	10.7	1.6	0.7	372.1	67.0
	1993	7.3	59.3	38.2	21.2	11.3	3.9	1.7	142.9	40.3
	1994*	24.6	6.3	10.3	13.8	6.2	2.4	1.6	65.1	15.1
	1995	286.6	178.6	39.8	9.3	5.2	2.0	0.9	522.3	196.4
High	1992	85.1	170.9	104.1	18.9	5.9	1.6	0.8	387.4	47.4
	1993	11.2	22.5	36.3	20.5	7.1	2.5	0.9	101.0	14.2
	1994*	82.4	19.2	23.5	12.9	5.0	1.7	0.9	145.6	32.8
	1995	403.8	384.2	80.1	7.2	4.7	2.3	0.8	883.1	255.2
Very High	1992	110.9	262.7	127.3	15.1	4.3	0.9	0.3	521.4	74.0
	1993	10.7	29.1	48.3	27.9	6.1	1.3	0.4	123.6	8.1
	1994*	131.6	43.1	34.5	15.8	4.9	1.4	0.7	232.0	40.4
	1995	66.6	408.3	80.0	5.3	2.7	0.7	0.3	563.7	165.3

* new survey series

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

* 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	Total biomass
1981	3,435.56	876.56	277.26	143.74	4,733.12
1982	881.37	840.04	332.71	71.87	2,126.00
1983	557.60	657.42	277.26	71.87	1,564.15
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	5,365.79
1988	1,978.62	1,899.22	554.43	143.77	4,576.04
1989	2,356.33	2,593.11	720.93	143.77	5,814.14
1990	1,600.84	1,424.38	831.86	287.55	4,144.63
1991	1,852.68	1,789.70	720.93	215.52	4,578.83
1992	3,507.50	3,944.53	1,275.39	431.22	9,158.65
1993	755.46	1,680.08	1,330.84	503.09	4,269.47
1994*	431.69	876.56	776.33	359.35	2,443.93
1995	1,744.76	986.13	554.52	431.22	3,716.63

* new survey series

Table 11. - Tuning criteria for the regressions of cohort biomass ages 4+ on CPUE in kg/hour, cohort biomass ages 3-7 on research survey biomass estimates ages 3-7, of fishable biomass ages 4+ on CPUE (Q2) in kg/hour, and cohort biomass (all ages) on CPUE for selected F_{Q4}.

	Coh Biom ages 4+ vs CPUE			Coh Biom ages 3-7 vs Res Biom ages 3-7		
F_{Q4}	R^2	1994*	1995*	R^2	1994*	1995*
0.05	0.535	-3013	-5362	0.399	-2665	-4043
0.06	0.650	-1795	-3398	0.525	-1571	-2207
0.07	0.737	-925	-1996	0.615	-789	-896
0.08	0.789	-273	-944	0.665	-202	88
0.09	0.810	234	-126	0.684	254	853
0.10	0.809	640	529	0.682	619	1464

	Fish Biom ages 4+ vs CPUE			Coh Biom vs CPUE		
F_{Q4}	R^2	1994*	1995*	R^2	1994*	1995*
0.05	0.413	-3092	-696	0.494	-2048	-5998
0.06	0.455	-2321	-42	0.600	-766	-3663
0.07	0.468	-1769	424	0.666	150	-1996
0.08	0.463	-1356	774	0.691	837	-745
0.09	0.447	-1034	1046	0.685	1371	228
0.10	0.428	-776	1263	0.660	1799	1006

* 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 0.09.

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	652	232	209	447	623	449	354	443	502
4	672	309	167	158	342	501	404	300	381
5	112	145	118	66	78	172	278	187	157
6	33	30	43	46	28	35	54	75	79
7	25	15	15	26	22	15	22	34	47
8	43	15	7	10	15	11	11	17	26
9	16	34	11	5	8	10	8	8	14
10	6	11	28	8	3	6	9	5	6
11	3	3	7	22	6	2	5	6	3
Total	1563	794	605	787	1125	1201	1144	1075	1214

Ages	1990	1991	1992	1993	1994	1995
3	438	510	583	151	145	330
4	439	385	449	512	132	124
5	193	234	206	239	297	59
6	45	58	80	63	68	120
7	54	28	35	47	39	42
8	34	41	20	24	36	27
9	22	26	32	16	19	27
10	13	18	18	26	13	14
11	5	11	14	12	22	10
Total	1244	1313	1436	1091	771	754

Table 13.- Biomass Q2 (t of meats) east of the ICJ line from cohort analysis using a terminal F_{Q4} of 0.09.

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	2891	1038	900	1997	2787	2010	1585	1981	2245
4	6637	3224	1534	1697	3745	5494	4277	3229	3970
5	1854	2345	1852	1125	1401	3056	4094	3202	2340
6	768	707	1048	1068	689	853	1198	1775	1827
7	723	422	450	737	660	433	635	989	1337
8	1447	518	255	345	525	361	343	579	862
9	574	1259	397	168	282	378	277	278	533
10	200	425	1089	291	113	224	326	171	227
11	126	109	299	892	224	64	202	253	92
Biom 3+	15220	10048	7824	8321	10426	12874	12936	12458	13432
Biom 4+	12330	9010	6924	6324	7639	10864	11351	10477	11187

Ages	1990	1991	1992	1993	1994	1995
3	1957	2281	2606	677	650	1475
4	4141	4030	4700	5301	1324	1331
5	2527	3470	2866	3154	4357	983
6	1046	1337	1823	1437	1548	2909
7	1576	818	990	1365	1103	1253
8	1140	1362	678	791	1152	925
9	802	931	1163	582	676	975
10	499	709	672	989	506	542
11	202	451	577	478	856	413
Biom 3+	13891	15390	16074	14774	12173	10808
Biom 4+	11934	13110	13468	14097	11522	9333

Table 14.- Annual fishing mortality east of the ICJ line from cohort analysis using a terminal F_{Q4} of 0.09.

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	0.65	0.23	0.18	0.17	0.12	0.01	0.07	0.05	0.03
4	1.44	0.86	0.83	0.60	0.59	0.49	0.67	0.55	0.58
5	1.21	1.11	0.85	0.75	0.70	1.07	1.21	0.77	1.14
6	0.72	0.60	0.42	0.62	0.56	0.37	0.36	0.36	0.28
7	0.39	0.57	0.27	0.40	0.63	0.22	0.15	0.17	0.21
8	0.14	0.26	0.35	0.21	0.31	0.18	0.21	0.07	0.06
9	0.30	0.11	0.23	0.40	0.18	0.08	0.43	0.17	0.03
10	0.62	0.29	0.12	0.22	0.49	0.03	0.19	0.54	0.07
11	0.71	0.65	0.43	0.08	0.21	0.08	0.08	0.20	0.27
F ages 3+	0.69	0.52	0.41	0.38	0.42	0.28	0.37	0.32	0.30
F ages 4-7	0.94	0.79	0.59	0.60	0.62	0.54	0.60	0.46	0.55

Ages	1990	1991	1992	1993	1994	1995
3	0.03	0.03	0.03	0.04	0.06	0.02
4	0.53	0.53	0.53	0.45	0.70	0.33
5	1.10	0.97	1.08	1.16	0.80	0.53
6	0.37	0.43	0.43	0.38	0.38	0.19
7	0.17	0.23	0.27	0.18	0.25	0.14
8	0.17	0.16	0.14	0.12	0.19	0.11
9	0.07	0.30	0.12	0.08	0.22	0.14
10	0.03	0.15	0.28	0.07	0.17	0.21
11	0.09	0.07	0.10	0.14	0.15	0.18
F ages 3+	0.29	0.32	0.33	0.29	0.32	0.21
F ages 4-7	0.54	0.54	0.58	0.54	0.53	0.30

Table 15.- Retrospective analysis of biomass (10^2 tons) for the first quarter of the year, ages 3 to 8 and annual fishing mortality rates for ages 3 to 8. The analysis was carried out for the last 5 years as per row label.

Biomass

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
1991	12.1	7.2	5.4	5.6	8.0	10.7	12.2	11.3	12.6	12.8	10.8				
1992	12.1	7.2	5.4	5.5	7.7	10.2	11.5	10.5	12.3	13.2	13.3	14.6			
1993	12.1	7.2	5.4	5.4	7.5	9.7	10.6	9.3	10.7	11.6	11.6	12.2	12.1		
1994	12.1	7.2	5.4	5.4	7.4	9.6	10.5	9.2	10.6	11.6	12.0	12.1	11.3	8.2	
1995	12.1	7.2	5.4	5.4	7.4	9.5	10.3	8.9	10.4	11.6	12.3	13.5	13.4	11.0	8.6

Fishing mortality rate

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
1991	0.90	0.76	0.61	0.63	0.65	0.47	0.50	0.33	0.39	0.42	0.51				
1992	0.90	0.76	0.61	0.64	0.69	0.55	0.59	0.40	0.39	0.39	0.39	0.39			
1993	0.90	0.76	0.61	0.64	0.70	0.60	0.67	0.48	0.48	0.47	0.48	0.48	0.44		
1994	0.90	0.76	0.61	0.64	0.70	0.60	0.69	0.49	0.47	0.46	0.45	0.48	0.49	0.62	
1995	0.90	0.76	0.61	0.64	0.70	0.60	0.70	0.51	0.47	0.45	0.44	0.41	0.39	0.39	0.22

Table 16 .-Stock projections at $F_{0.1}$ (0.70) and at F_{max} (1.10) using starting numbers from cohort analysis with a terminal F_{Q4} of 0.09.

F = 0.70	1996_{Q1}	1996_{Q2}	1996_{Q3}	1996_{Q4}
Mean Wgt. Catch	18.88	17.07	19.38	24.68
Catch (Mill.)	12.47	76.70	42.06	21.67
Catch (t)	236	1,309	815	535
Cum. Catch (t)	236	1,545	2,360	2,895
Biomass	12,957	13,197	13,412	14,375

F = 1.10	1996_{Q1}	1996_{Q2}	1996_{Q3}	1996_{Q4}
Mean Wgt. Catch	18.89	17.09	19.42	24.07
Catch (Mill.)	19.39	112.94	57.46	28.15
Catch (t)	366	1,930	1,116	678
Cum. Catch (t)	366	2,296	3,412	4,090
Biomass	12,819	12,351	12,188	13,331

Table 17.- Fishing scenarios established for 1996 given different options of fishing mortality rate. Biomass figures are for the end of 1996. Under the biomass for ages 4 to 7, the percentage that the directed biomass represents from the total biomass is in parenthesis. Exploitation rates refer to the directed biomass only. Catch figures are rounded off to the nearest 50 t.

No.	Options	Fvalues	Biomass (t)	Biomass 4 - 7	Exploitation rate	Catch (t)
1	$F_{1995\ TAC}$	0.45	15,361	9,063 (59%)	20%	2,000
2	$F_{1995\ effort}$	0.53	15,032	8,869 (59%)	23%	2,300
3	$F_{0.1}$	0.70	14,375	8,194 (57%)	28%	2,900
4	F_{max}	1.10	13,031	7,297 (56%)	42%	4,100
5	$F_{replacement\ yield}$	1.38	12,228	6,848 (56%)	49%	4,800

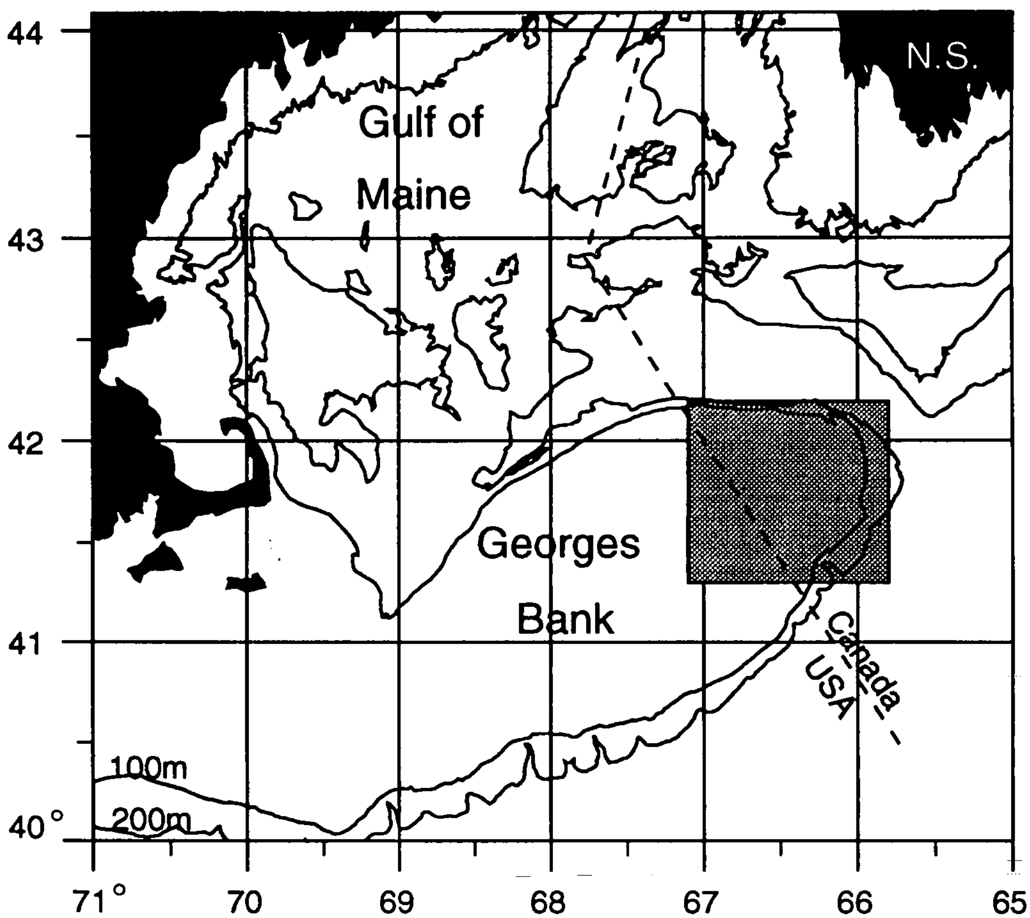


Figure 1.- Georges Bank and surrounding areas. The dashed line represents the international boundary between Canada and USA waters as determined by the International Court of Justice. Inset: see figures 3 to 5.

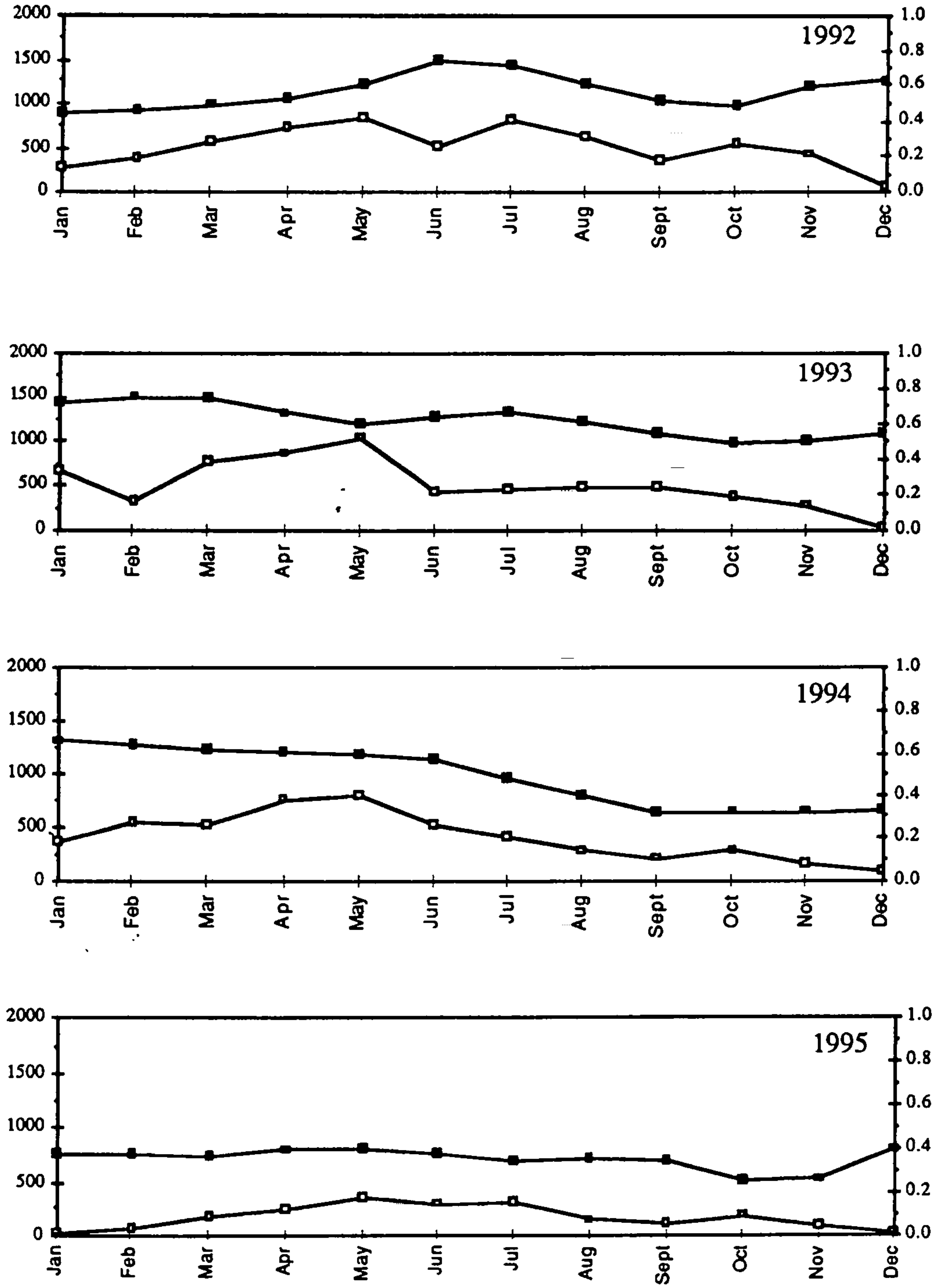


Figure 2.- Monthly CPUE in kg/crhm (filled square, scale on the right) and catch in tons of meats (open square, scale on the left) from Georges Bank over the last 4 years.

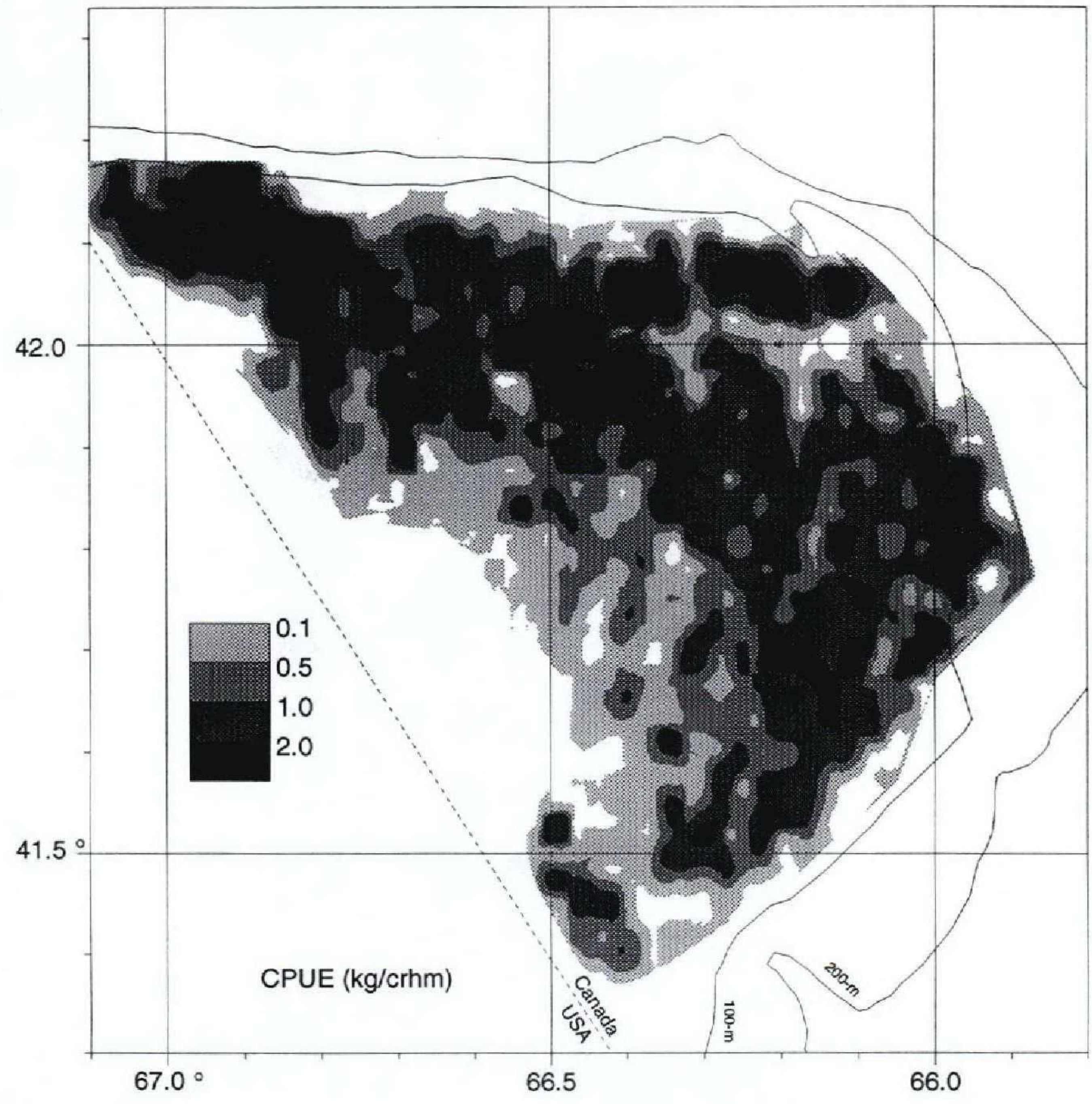


Figure 3.- Catch-rates encountered on Georges Bank in 1994. The scale of grey shades represents an ascending catch-rate up to 2+ kg / crhm.

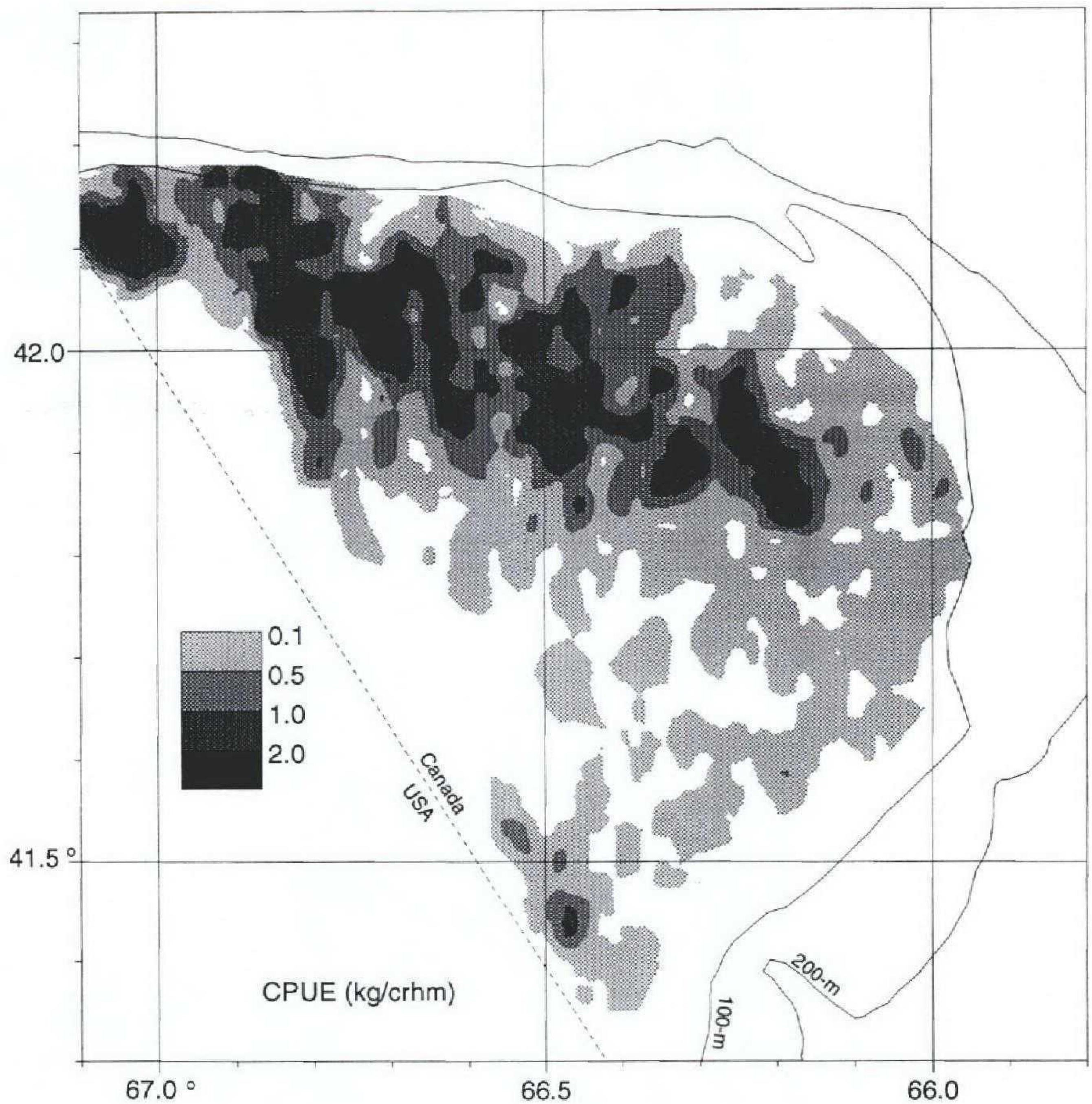


Figure 4.- Catch-rates encountered on Georges Bank in 1995. The scale of grey shades represents an ascending catch-rate up to 2+ kg / crhm.

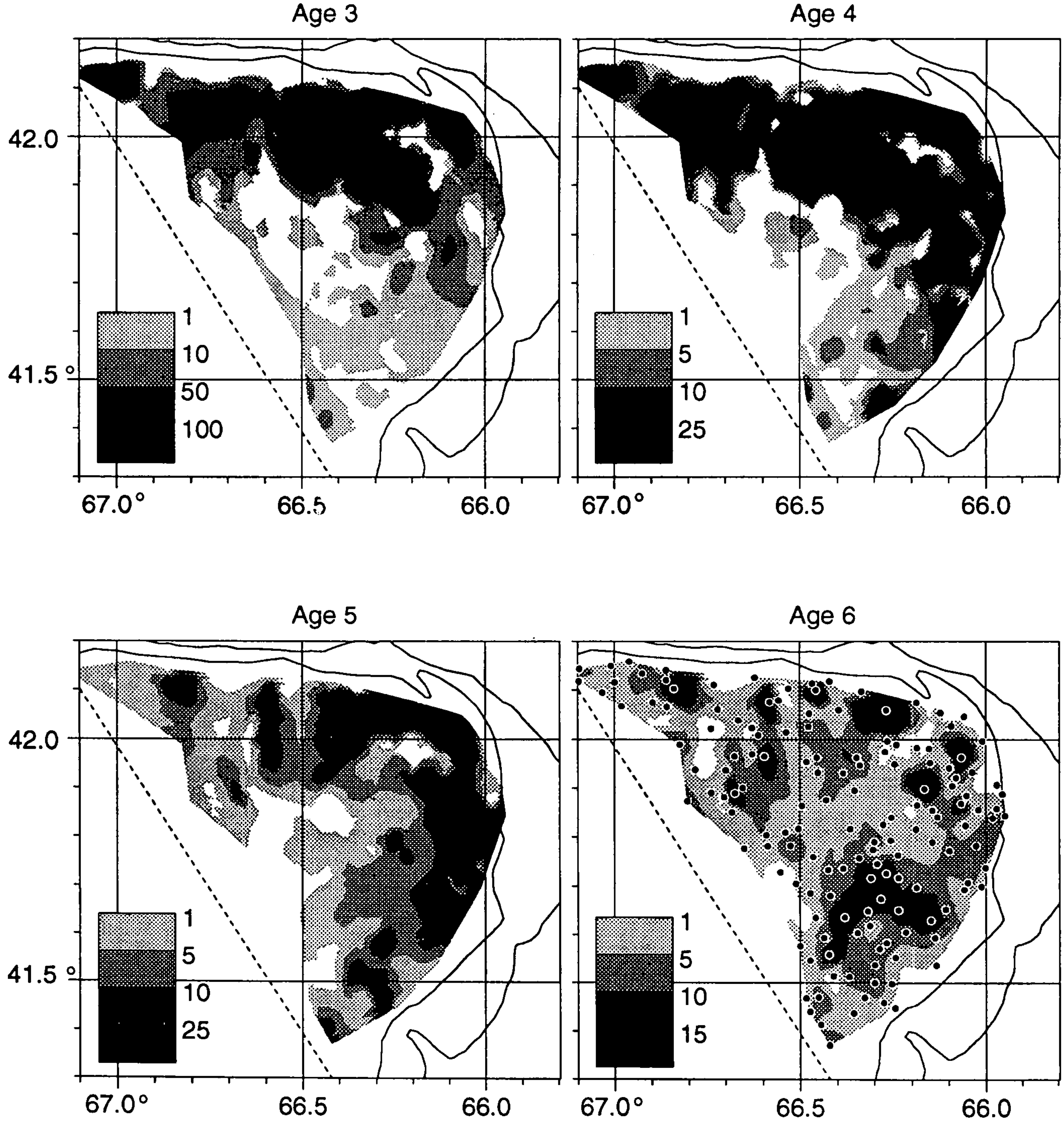


Figure 5.- Scallop distribution according to age from the research survey of August 1995. Location of sampling stations is indicated on the graph for age 6 scallops. The shading scale represents number of scallops per standard tow.

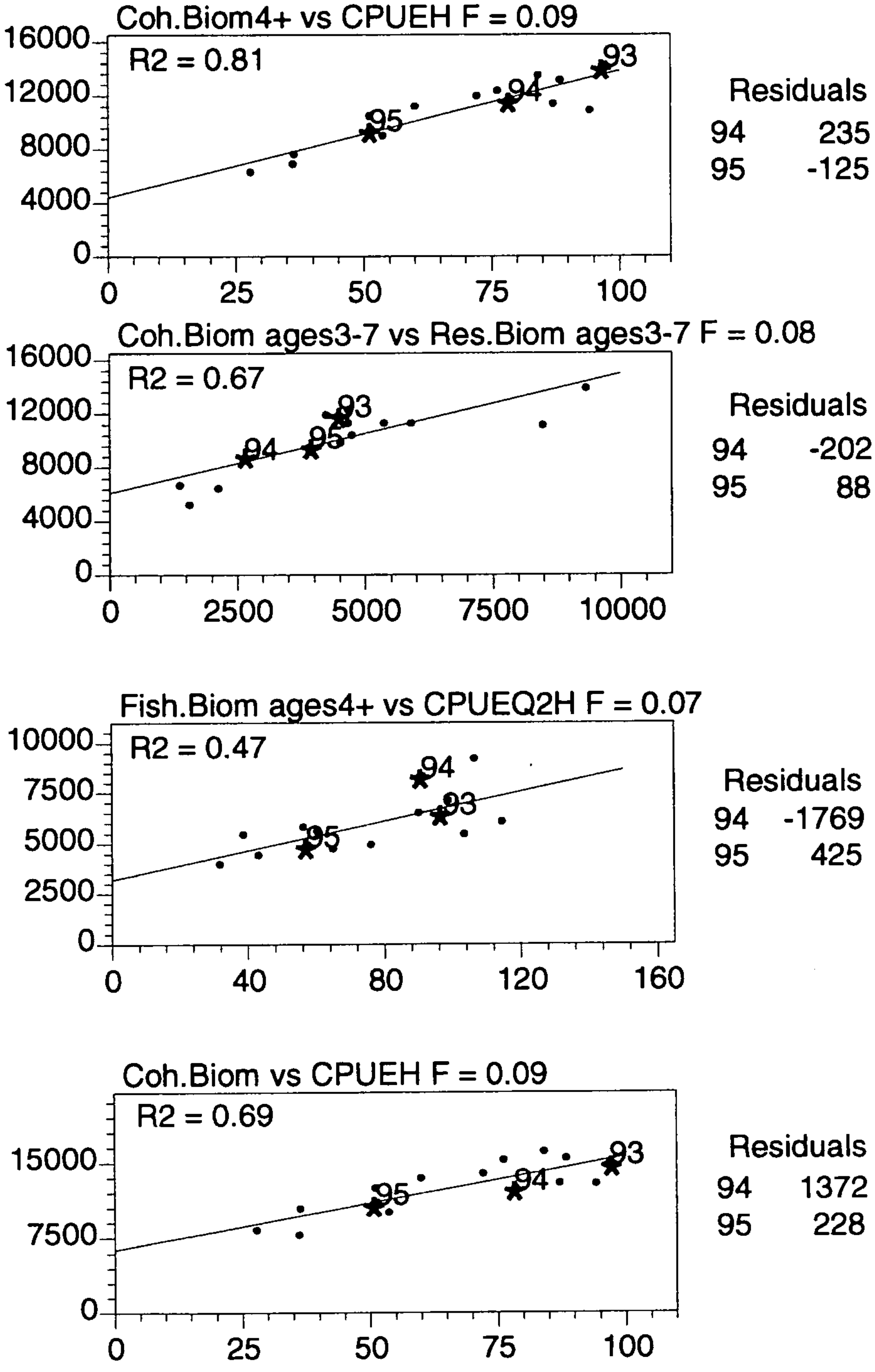


Figure 6.- Cohort biomass for ages 4+ (tons of meats) versus CPUE (kg/h), cohort biomass for ages 3-7 versus research survey biomass for ages 3-7 (tons of meats), fishable biomass for ages 4+ versus CPUE from the second quarter, and cohort biomass all ages versus CPUE using a terminal F_{Q4} as shown. Asterisks mark the position of the last 3 years' points from the line. Residual values for the last 2 years are to the right of each graph.

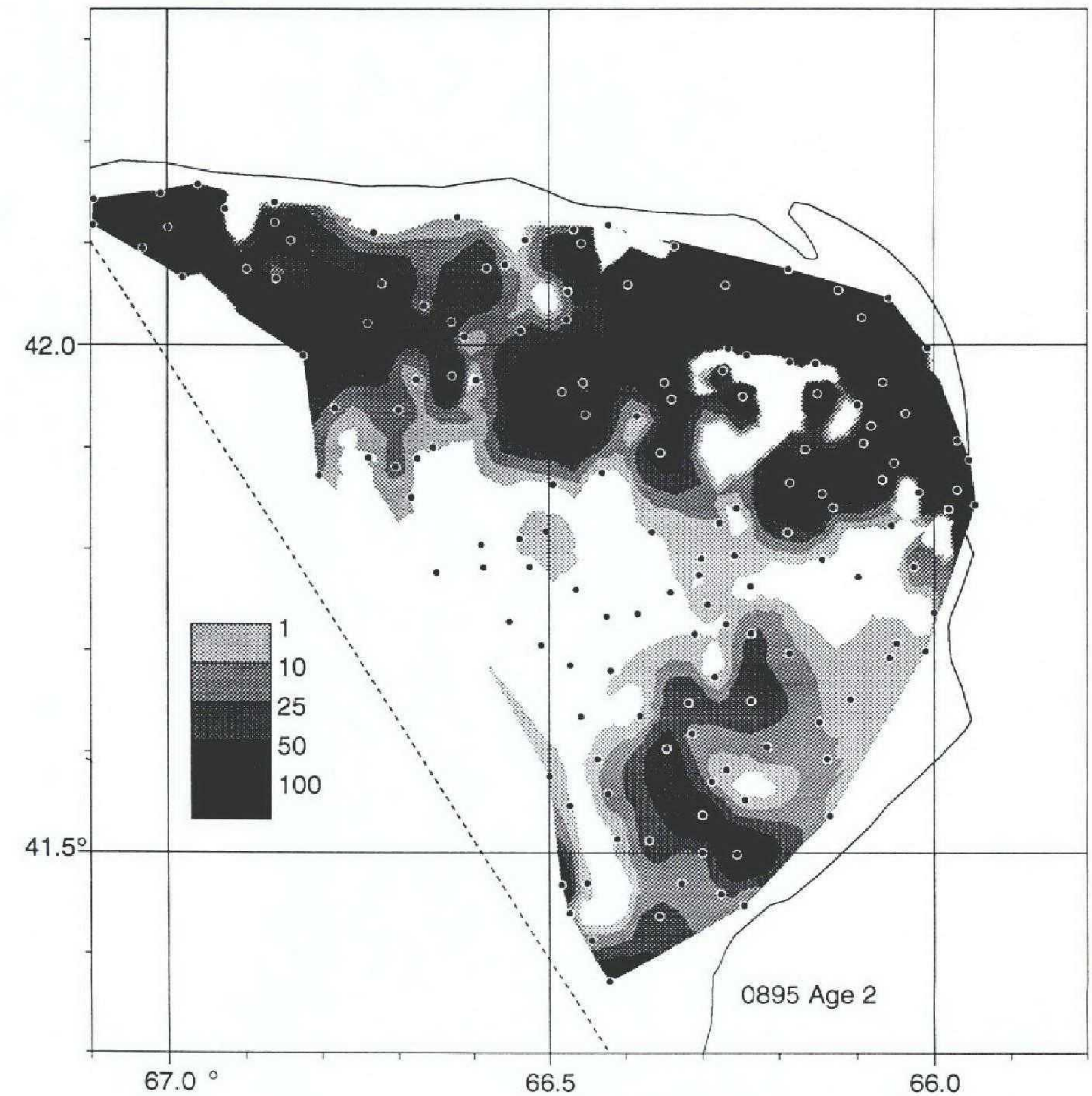
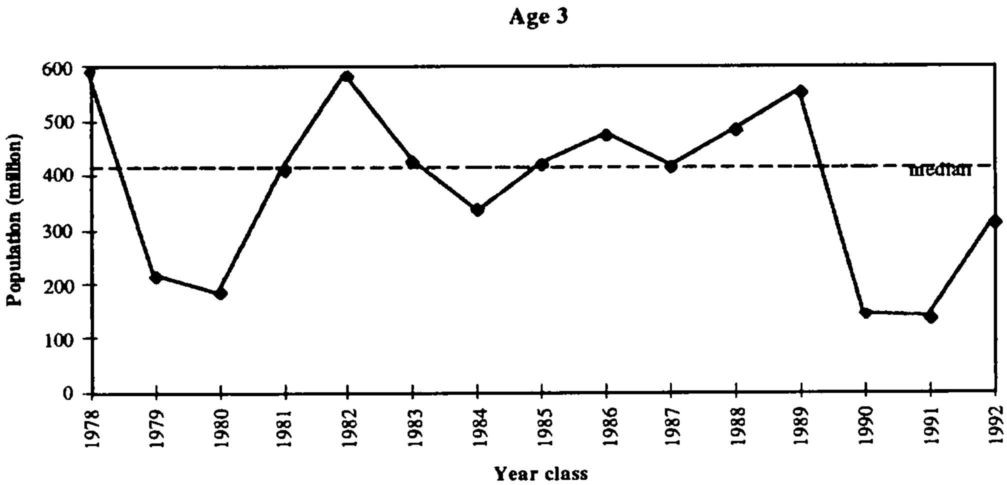


Figure 7.- Distribution of the 1993 year class at age 2 in the 1995 stock survey. Dots represent sampling locations. The 100-m isobath (smooth line) and the ICJ line (dashed) are indicated.



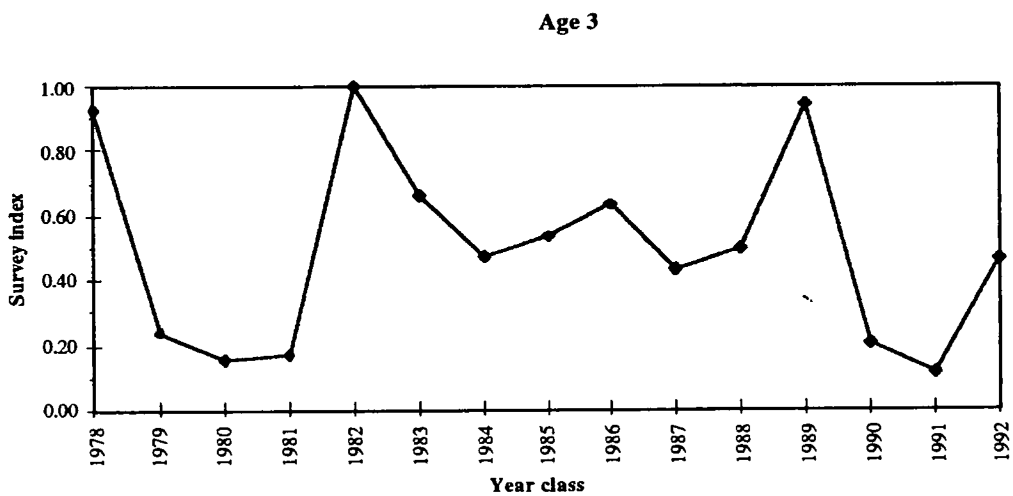


Figure 8.- Time series of estimates population numbers at age 3 in million (top graph) and normalised abundance index from research surveys for age 3 (bottom graph). The dashed line shows the geometric mean for recruitment. Year classes are labeled on the X-axis.

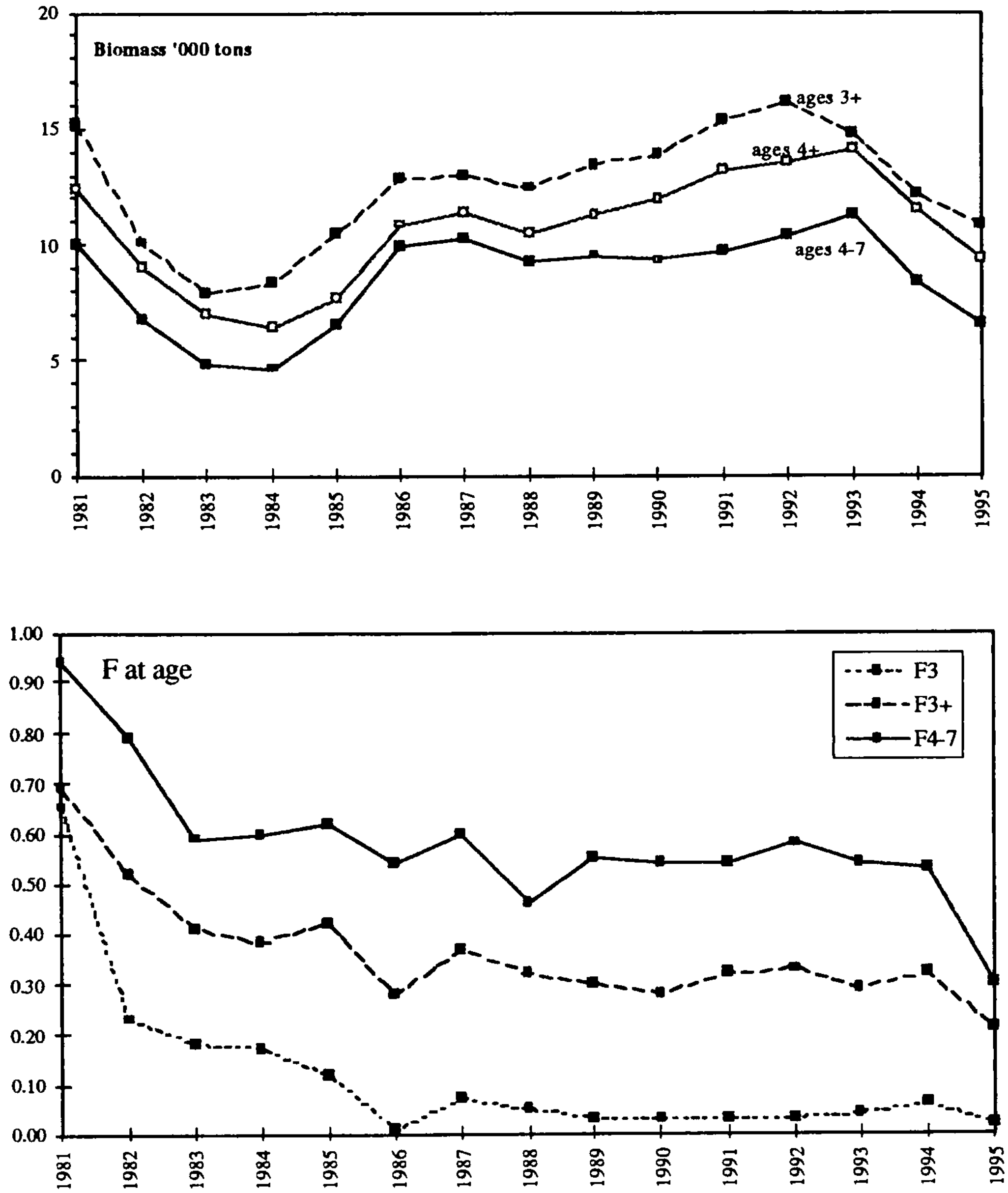


Figure 9.- Trends in population biomass and fishing mortality rates. Fishing mortality rates are the mean for the ages indicated in the F label.

Appendix

Three points are further discussed in this appendix, tuning with disaggregated ages and a dome-shaped selectivity vector, disaggregated ages with an asymptotic selectivity vector, and the non-zero intercept in regression plots of tuning indices. The analysis was carried out by R.K. Mohn.

The catch-at-age matrix for ages 3 to 10 (Table 6) and survey results for ages 3 to 6 (Table 10b) were used for data input in the supplementary runs. Three tuning indices were defined: biomass for ages 3 to 4 (B34), biomass for ages 5 to 6 (B56), and biomass for ages 3 to 6 (B36). Biomass for these age groups came from survey numbers times biomass at age during the third quarter as indicated in table 7. Natural mortality rate (M) equals 0.1. The dome-shaped selectivity vector was taken from the document.

Tuning with disaggregated ages: Two runs of age disaggregated VPAs were carried out using the ACON software package. The purpose was to study the domed pattern of the selectivity vector and the runs are not intended as alternate estimates of resource status. A summary output follows. In the first run a domed selectivity vector was assumed. In the second run, an asymptotic selectivity vector which reached full recruitment at age 5 was used. In either case, F at ages 3-8 in the terminal year were estimated in the NLLS with qs for ages 3-6 estimated algebraically. F's at the oldest age were determined using the approach of Laurec-Shepard.

Summary output for domed shape vector:

```
NLLS("QModel",par,resid,parout,seout,nobias,prflag,0)
1, lambda = 0.010000, rss = 20.60, sumresid = 0.00, param = 0.2 0.2 0.2 0.2 0.2 0.2
2, lambda = 0.100000, rss = 18.68, sumresid = -0.00, param = 0.15 0.21 0.21 0.21 0.18 0.17
      ......
20, lambda = 0.000010, rss = 9.69, sumresid = 0.00, param = 0.014 0.33 0.29 0.25 0.066 0.045
21, lambda = 0.000010, rss = 9.68, sumresid = 0.00, param = 0.014 0.33 0.28 0.25 0.065 0.044
```

Residuals table

Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994.	1995
age 3	0.6	0.1	-0.2	-1.0	0.4	0.3	0.2	0.0	0.0	-0.3	-0.2	0.4	-0.1	-0.3	0.1
age 4	-0.7	-0.4	0.2	-0.0	-0.9	0.7	0.4	0.3	0.3	-0.4	-0.2	0.5	-0.3	0.1	0.5
age 5	0.1	-0.1	-0.5	-0.1	-0.3	0.1	-0.0	-0.1	0.4	0.1	-0.3	0.3	0.3	-0.1	0.2
age 6	0.4	0.4	-0.4	-0.8	-0.2	0.8	0.5	-0.9	-0.5	0.5	-0.3	0.1	0.2	-0.1	0.3

mean square residual = 0.19358

	Est. Param	SE	CV	Bias	
1	0.01444	0.006055	0.419312	-2.88706	f3
2	0.32866	0.102496	0.311859	-0.00333	f4
3	0.28483	0.086491	0.303657	0.06752	f5
4	0.25085	0.081840	0.326251	0.37845	f6
5	0.06523	0.023319	0.357458	-1.07359	f7
6	0.04420	0.016398	0.370994	-1.66828	f8
7	4.44614	0.501642	0.112827	1.18922	q3
8	6.52775	0.739417	0.113273	1.03622	q4
9	5.90529	0.689659	0.116787	1.39466	q5
10	4.29204	0.559765	0.130419	1.62137	q6

Annual fishing mortality rates:

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	0.63	0.24	0.21	0.18	0.12	0.01	0.07	0.05	0.03
4	1.49	0.86	0.93	0.77	0.63	0.51	0.76	0.58	0.51
5	1.48	1.28	0.85	0.97	1.19	1.33	1.35	1.06	1.38
6	0.77	1.04	0.57	0.60	0.93	1.16	0.61	0.46	0.54
7	0.65	0.66	0.63	0.66	0.61	0.63	1.31	0.34	0.31
8	0.36	0.48	0.42	1.03	0.72	0.21	1.03	2.26	0.20
9	0.44	0.34	0.60	0.34	2.26	0.34	0.48	2.26	-0.10
10	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60

Ages	1990	1991	1992	1993	1994	1995
3	0.02	0.02	0.03	0.03	0.06	0.01
4	0.48	0.43	0.45	0.48	0.49	0.33
5	0.85	0.79	0.72	0.85	0.95	0.28
6	0.54	0.28	0.30	0.18	0.21	0.25
7	0.40	0.45	0.15	0.12	0.10	0.07
8	0.25	0.52	0.38	0.07	0.11	0.04
9	0.13	0.48	0.48	0.19	0.11	0.07
10	0.60	0.60	0.60	0.60	0.60	0.07

Summary output for asymptotic vector:

NLLS("QModel",par,resid,parout,seout,nobias,prflag,0);
1, lambda = 0.010000, rss = 20.42, sumresid = -0.00, param = 0.2 0.2 0.2 0.2 0.2 0.2
2, lambda = 0.100000, rss = 18.26, sumresid = -0.00, param = 0.15 0.21 0.21 0.21 0.18 0.16
......
9, lambda = 0.001000, rss = 10.31, sumresid = 0.00, param = 0.014 0.3 0.28 0.27 0.076 0.052
10, lambda = 0.010000, rss = 10.31, sumresid = 0.00, param = 0.014 0.3 0.28 0.27 0.076 0.052

Residuals table

Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994.	1995
age 3	0.6	0.1	-0.2	-1.0	0.4	0.3	0.2	0.1	0.1	-0.3	-0.2	0.4	-0.1	-0.4	0.1
age 4	-0.7	-0.4	0.1	-0.1	-0.8	0.8	0.4	0.4	0.4	-0.3	-0.2	0.5	-0.3	0.0	0.3
age 5	0.0	-0.2	-0.5	-0.2	-0.5	0.4	0.2	-0.0	0.5	0.3	-0.1	0.2	0.2	-0.2	0.0
age 6	0.3	0.1	-0.6	-0.8	-0.5	0.5	1.0	-0.6	-0.3	0.7	-0.1	0.5	-0.0	-0.3	0.0

mean square residual = 0.206266

	Est. Param	SE	CV	Bias	
1	0.01404	0.005983	0.426126	-1.26163	f3
2	0.30306	0.098828	0.326097	-0.02383	f4
3	0.27909	0.088107	0.315696	-0.03870	f5
4	0.26860	0.091240	0.339691	0.01118	f6
5	0.07640	0.029175	0.381872	-1.23784	f7
6	0.05190	0.020790	0.400568	-1.89302	f8
7	4.60430	0.538187	0.116888	1.30448	q3
8	6.91472	0.807992	0.116851	0.96913	q4
9	6.93076	0.807176	0.116463	1.05274	q5
10	5.78646	0.686752	0.118683	0.99737	q6

Annual fishing mortality rates:

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	0.63	0.24	0.21	0.18	0.12	0.01	0.07	0.05	0.04
4	1.49	0.86	0.93	0.77	0.63	0.51	0.76	0.58	0.58
5	1.48	1.28	0.85	0.97	1.19	1.33	1.35	1.06	1.38
6	0.77	1.04	0.57	0.60	0.93	1.16	0.61	0.46	0.54
7	0.65	0.66	0.63	0.66	0.61	0.63	1.31	0.34	0.31
8	0.36	0.48	0.42	1.03	0.72	0.21	1.03	2.26	0.20
9	0.44	0.34	0.60	0.34	2.26	0.34	0.48	2.26	-0.10
10	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60

Ages	1990	1991	1992	1993	1994	1995
3	0.02	0.02	0.03	0.03	0.06	0.01
4	0.56	0.45	0.47	0.49	0.48	0.30
5	1.14	1.10	0.78	0.92	0.99	0.28
6	0.54	0.47	0.55	0.21	0.24	0.27
7	0.40	0.45	0.31	0.28	0.12	0.08
8	0.25	0.52	0.38	0.16	0.31	0.05
9	0.13	0.48	0.48	0.19	0.31	0.22
10	0.60	0.60	0.60	0.60	0.60	0.22

Runs with disaggregated ages generate similar results to runs with aggregated data used in the document. Runs with a domed shape selectivity vector have a better fit than runs with an asymptotic vector.

Non-zero intercept: Annual fishing mortality rates to maximise the correlation coefficient and go through the intercept were established by trial and error. A table of resulting coefficients follows for a range of F's, given the tuning indices for biomass of different age groups. Figure A1 shows the regressions tuning with B56 at the F which maximises R^2 and the F which intercepts the origin respectively. R^2 varies little whether the coefficient is at its maximum or whether the regression goes through the origin. The 1995 residual point gets on the regression line at an F equal to 0.33.

Correlation coefficients table:

F	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
B34	0.20	0.37	**0.39**	0.38	0.37	0.36	0.35	0.35	0.34	0.34
B56	0.53	0.64	0.71	**0.73**	0.73	0.71	0.69	0.67	0.65	0.63
B36	0.20	0.40	0.51	**0.51**	0.49	0.46	0.43	0.41	0.39	0.38

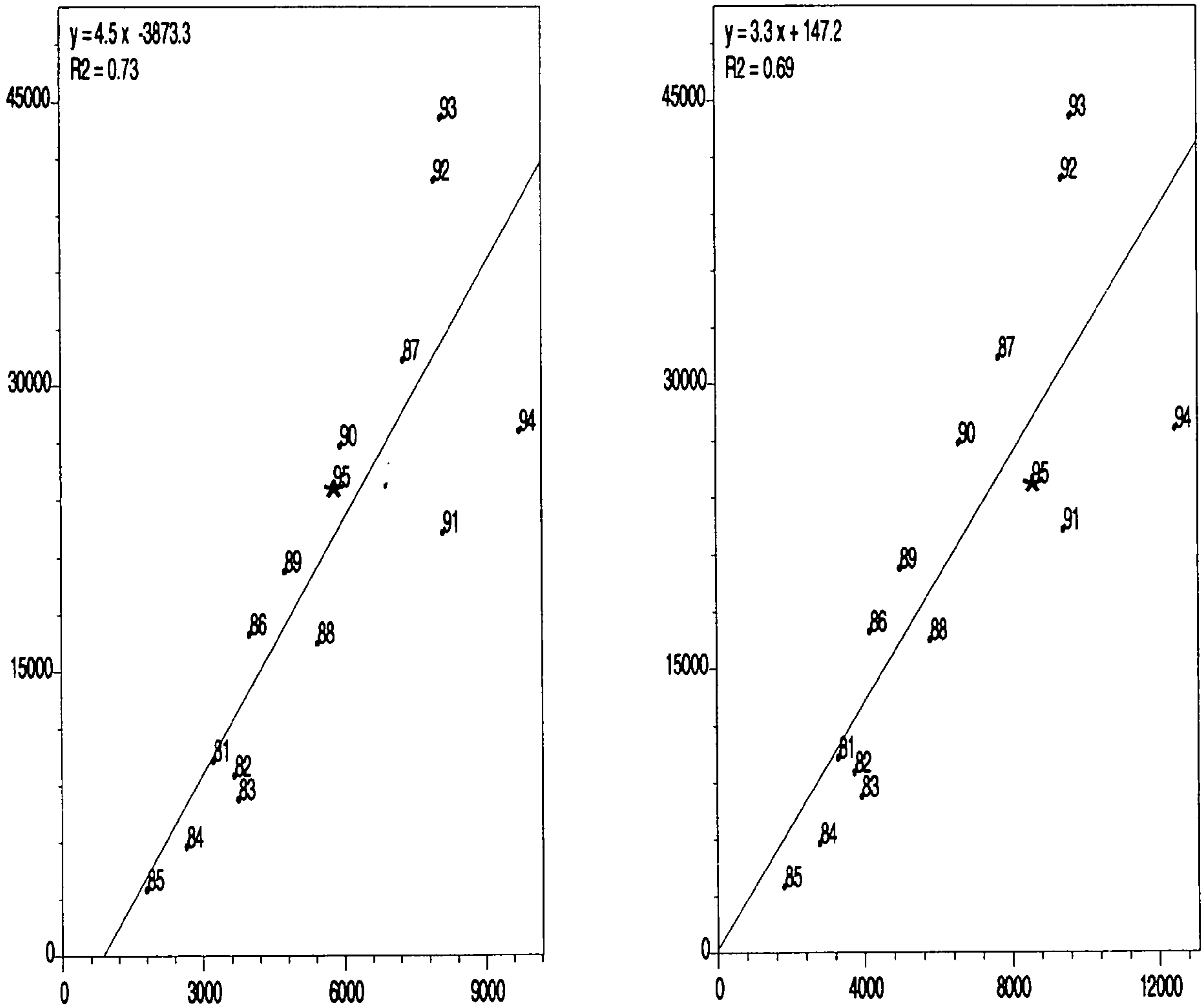


Figure A1.- Regressions of cohort biomass ages 5 and 6 on research biomass with a terminal F of 0.40 to maximise the correlation coefficient (left graph) and a terminal F of 0.26 to go through the origin (right graph).