Not to be cited without the
permission of the author(s)[1]

Canadian Atlantic Fisheries
Scientific Advisory Committee

CAFSAC Research Document 91/69

Ne pas citer sans
autorisation des auteur(s)[1]

Comité scientifique consultatif des
pêches canadiennes dans l'Atlantique

CSCPCA Document de recherche91/ 69

Georges Bank Scallop Stock Assessment - 1990

By

G. Robert, G. A. P. Black, and M.A.E. Butler
Biological Sciences Branch
Halifax Fisheries Research Laboratory
Department of Fisheries and Oceans
Scotia-Fundy Region
P. O. Box 550
Halifax, N. S.
B3J 2S7

[1]This series documents the scientific basis for fisheries management advice in Atlantic Canada. As such, it addresses the issues of the day in the time frames required and the Research Documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research Documents are produced in the official language in which they are provided to the Secretariat by the author(s).

[1]Cette série documente les bases scientifiques des conseils de gestion des pêches sur la côte atlantique du Canada. Comme telle elle couvre les problèmes actuels selon les échéanciers voulus et les Documents de recherche qu'elle contient ne doivent pas être considérés comme des énoncés finals sur les sujets traités mais plutôt comme des rapports d'étape sur les études en cours.

Les Documents de recherche sont publiés dans la langue officielle utilisée par les auteur(s) dans le manuscrit envoyé au secrétariat.

ABSTRACT

Catches have stabilised in the range of 4,300 - 6,800 t since the implementation of Entreprises Allocations in 1986 while catch-rates have varied between 0.4 - 0.7 kg / crhm. Research survey indices also suggest a dampening of the large variation previously experienced in the stock recruitment. The 1990 catches exceeded the 5,200 t TAC by 5 %. CPUE was 15 % better than in 1989. An unusual 30 % of annual catches were reported for the first quarter of the year; historically, the figure is 10 %.

The fishery is strongly targetting ages 4 and 5 scallops. Average fishing mortality rates ranged from 0.31 to 0.39 during the period 1988 - 90 but F on age 4 has increased by 32 %. Trends in cohort analysis indicate that stock biomass is relatively stable, 12 - 14,000 t , while recruitment is declining to some extent. Different fishing scenarios are presented for 1991; risks involved are discussed in terms of biomass loss.

RESUME

Les captures se sont stabilisées entre 4,300 et 6,800 t depuis la mise en place d'allocations par entreprise en 1986 alors que les taux de capture ont varié entre 0.4 et 0.7 kg / crhm. Les indices d'inventaires de recherche suggèrent aussi une moins grande variation dans le recrutement du stock Les captures de 1990 ont dépassé le TPA de 5,200 t de 5 %. Les taux de capture étaients 15 % supérieurs à ceux de 1989. Durant le premier quart de l'année on a débarqué 30 % des prises annuelles, ce qui est inhabituel; historiquement, le pourcentage est 10 %.

La pêche concentre beaucoup d'effort sur les pétoncles de 4 et 5 ans. Le taux moyen de mortalité dû à la pêche a varié de 0.31 à 0.39 durant les années 1988 - 90 mais F sur l'âge 4 a augmenté de 32 %. Certaines tendances dans l'analyse de cohortes indiquent que la biomasse du stock est relativement stable, 12 - 14,000 t, alors que le recrutement est en baisse jusqu'à un certain point. Différentes stratégies de pêche sont présentées pour 1991; les risques impliqués sont discutés en termes de pertes de biomasse.

INTRODUCTION

Prior to the establishment of the 200 - mile fishing zone in 1977 Canadian and American vessels fished Georges Bank (NAFO SA 5Ze) for scallops. The Canadian deep-sea fleet had to restrict its fishing activities to a national zone in 1985 after the World Court decision (October 1984) on the jurisdiction for fisheries of Canada and the United States on Georges Bank. The Canadian zone, NAFO subdivision 5Zc, is the portion of Georges Bank east of the International Court of Justice (ICJ) line. During the late 1970's, the fishery peaked at 11,000 t (SA 5Zc Table 1) produced by the strong 1972 year class; but such performance deteriorated rapidly. The lack of consensus in the management of the scallop resource in the disputed area coupled with increased effort, contributed as much to the decline in landings as the vanishing 1972 year class. The year of the dispute settlement, 1984, the Canadian fleet caught only 1,945 t of meats, its lowest catch in 25 years. The Canadian scallop industry then focussed on stock rehabilitation through a better utilisation of the resource. An experimental Entreprise Allocation (EA) regime was implemented for 3 years to reduce fishing effort. From 77 active license holders in 1984, the number of vessels dropped (25 %) to 57 in 1989. The meat count (size limit) was also lowered to 33 meats per 500 g in January 1986 to direct exploitation on slightly older scallops. Starting in 1989, EA has become a permanent feature of the Georges Bank scallop management plan.

During the post-1985 period catches have stabilised in the range of 4,300 - 6,800 t while catch-rates have varied between 0.4 - 0.7 kg/crhm. This is less variation than the one that was experienced during the decade 1975 - 85 (Table 2). Figure 1 shows the monthly catches and CPUE's for the last three years. Research survey indices also suggest a dampening of the large variation previously experienced in the stock recruitment. The 1990 catches exceeded the TAC by 5 %. The fleet directed exploitation to scallop beds shallower than 100 m (Figure 2) and ignored the deeper areas of marginal importance. CPUE was slightly better than in 1989 (15 %). But the improvement in catch-rates may have been artificial because of the fishing strategy used. An unusual 30 % of annual catches were reported for the first quarter of the year; historically, the figure is 10 % (Figure 3). Also, the fishery was targetting dense aggregations of small meated scallops (young age 4) and not always meeting the 33 meats per 500 g regulation.

METHODS

Fishery data

Catch and effort data are compiled from logbooks. Logs with complete effort data are called Class 1 and are used to determine catch-rates. The Class 1 data represent more than 90% of the total (Table 2). Effort is measured in towed hours times the width of the 2 drags used times the number of crew (crhm). 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. Data on size distribution of meats from the commercial fleet are derived from port samples. Characteristics of monthly meat weight frequencies for selected years are given in Table 3. Canadian port sampling data were applied to the Canadian and U.S. total catch east of the ICJ line. This assumes similar fishing practices for both fleets. The meat weight frequency distribution in 2 - g intervals is given in Table 4 for the last 4 years on a quarterly basis. Fishing practices may be seen to change and focus on small animals during the first quarter of 1990. Table 5 lists the frequency distribution but on an annual basis.

Catch in numbers-at-age (Table 11) 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 weight frequencies. The weights were converted to shell heights using the allometric relationship derived from 1982 -1985 research and commercial data (Robert and Lundy 1987). The values expressing meat weight as a function of shell height use the parameters 9.102E-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. Von Bertalanffy growth coefficients relating shell height and age were taken from Brown et al. (1972). The conversion height - age was done by straight linear interpolation between intervals. It had been proposed to use Mixture analysis to enhance the partitioning of weight classes into age groups. To meet tighter deadlines, the use of Mixture analysis has been postponed until next year.

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 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 6, 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 1978 is of the 1978 year class and will be approximately 25 mm on its second birthday (January 1, 1980) although the ring would not be deposited for a few months. Table 6, as well as all other age data, uses this convention, with correction of ring sizes back to January 1. For use in age - weight analyses and projections, the actual weights used are mid-quarter values.

Research survey data

A research survey was carried out on Georges Bank during August 1990. 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 high and low catch-rates. The areas of high catch-rates were sampled more heavily as they represent the area most important to the fleet (and presumably the areas of greatest abundance). The average number of scallops at age per tow is given in Table 7. 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 and integrated to estimate total numbers (Table 8). These estimates correspond to a minimum dredgeable biomass as they are not adjusted for the survey gear efficiency. 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 (abundance of scallops) is illustrated by varying shades of grey. Smoothing of the contours may be performed by interpolating 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 abundance estimate for the survey area. 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%. To assure the abundance estimates from similar areas are compared, only those points east of the ICJ line are used. A method to more accurately define a common overlapping area for comparison is still under development. A more complete description of the contouring method and volume estimation may be found in Black (MS 1988).

Estimates of spatial covariance (variograms) were performed to look into the correlation between samples, on an age basis (Figure 6). In geostatistics, variograms are commonly used to determine quantitatively the minimum distance at which point samples are not auto-correlated.

Stock analysis

Because cohort analysis deals with the removals from a cohort, it is not appropriate to use data collected on an annual basis for a dynamic species like scallops. In the first year of recruitment the animals experience approximately a 300% increase in weight. In order 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 the most recent two year's selectivity pattern to reflect the port sampling data for the last quarter of 1990. This pattern, multiplied by the F determined from tuning for the last quarter year (F_{Q4} 1990), was used as a starting vector for the quarterly cohort analysis. Natural mortality was set at .025 per quarter (M = 0.1 on an annual basis, Dickie 1955; Merrill and Posgay 1964) and no attempt was made to include a seasonal, age or time dependent effects.

The SPA is tuned against a number of independent, and sometimes contradictory, sets of observations. The most important are the commercial CPUE and the research survey estimates. F versus effort is also used to aid in the tuning process. 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' the exact numbers or 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, 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.) For the purposes of tuning, the terminal F (quarterly rate) ranged from 0.11 to 0.30 (Table 10). A range of this magnitude was required to be in a position to examine the best fit for F versus effort (F_{Q4} = 0.11); the strongest relationship (R^2 = 0.618) for research survey vs cohort biomass corresponded to an F_{Q4} = 0.27. The residuals of the last two year's data and the correlation coefficient were used as tuning criteria. 81 % of the variability could be explained by CPUE vs cohort biomass while research surveys and effort correlation coefficients were only moderate. The positive residual values in table 10 denote that the residuals are below the regression line and the negative ones, above. It should be noted that 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. The annual CPUE values are compared to first quarter biomasses.

The CPUE vs cohort biomass estimates had a maximum R^2 at F_{Q4} = 0.24. It is also at this F value that the 1990 residual crosses the regression line. The research survey biomass vs the cohort biomass has the strongest R^2 at F_{Q4} equal to 0.27. Although the 1990 residual never crosses the regression line for the range of F's used, the 1989 residual crosses with F_{Q4} equal to 0.24. The tuning of effort vs F had a weaker correlation (0.534) and is not considered further. Plots of the regressions used in the tuning process are presented in Figure 4 (F vs effort plot only). The CPUE vs cohort biomass shows a linear pattern of points with the last year being just below the regression line and the two before that being above the regression. (Figure 4). The unusual years 1977 - 1978 fit the regression line slightly better than in previous years' assessments. The research survey biomass vs cohort biomass (Figure 4) shows a strong linear distribution. The approximate agreement between tuning of CPUE and research biomass against the cohort analysis results gives us a measure of confidence that the correct terminal F_{Q4} is in the vicinity of 0.24 - 0.27. Although F_{Q4} equal to 0.27 was providing the best correlation for research survey tuning, the correlation was not as high as with CPUE tuning. The higher correlation (0.810) in the CPUE tuning with the 1990 residual almost on the regression line with F_{Q4} equal to 0.24 and the 1989 residual in research survey tuning being closest to the line at that same F_{Q4} indicates that the terminal F_{Q4} should be set at 0.24.

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 classes 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 had required a re-calculation of the yield per recruit in the 1988 stock evaluation (Mohn et al 1989) and a newly defined partial recruitment pattern. As for 1989, the yield per recruit was re-examined for 1990 but there was no need for a re-evaluation as the fishing strategy remained practically the same.

The regulations in effect on the offshore fleet are that the catch should average no more than 33 meats per 500 grams which corresponds to an average weight of 15 grams 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. 1984a) 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 32, 28, 21 and 19%, which reflects the 1990 fishery. The effort figure for the first quarter is 2 - 3 times the historical value; conversely, the second quarter usually had 50 % of the annual effort compared to 28 % in 1990. This is a marked shift in the annual distribution of effort. Early 1991 results tend to indicate that this new fishing strategy is being continued. Selectivity for the projections follows the pattern of the fishery as revealed from the cohort analysis instead of that of the gear (Caddy 1972). Starting numbers-at-age for the projections were derived by projecting ahead the fourth quarter 1990 cohort estimates to January 1991.

Stock projections and fishing scenarios were carried out for $F_{0.1}$, F_{max} but also for $F_{replacement\ yield}$ where the biomass at the end of the year is assumed to equal the biomass at the beginning of the year, $F_{same\ effort}$, and $F_{same\ catch}$ where 1991 effort or catch levels would correspond to their respective 1990 values.

Biological risk analysis

A biological risk analysis was carried out assuming that fishing at F_{max} does not incur any risk in the present scenario of projections for this particular scallop fishery. Biological risk is defined here as the potential loss of biomass when fishing at an F higher than F_{max}, all other variables remaining the same. Risk and implications on biomass changes, depending on F scenarios are calculated for the next year only. Scenarios with F values less than F_{max} such as $F_{0.1}$, actually provide for a bonus since biomass will increase under this set of rules. This risk factor is easily converted in percentages. The risk analysis is biological only and does not consider market whims for meat sizes or currency fluctuations, etc. F_{max} is established as the no-risk scenario because previous work (R.K. Mohn pers. comm.) had shown that, from a long term yield point of view, little yield was gained with an $F_{0.1}$ regime compared to an F_{max} regime. Also the fleet has operated under F_{max} or greater for the last two years with no apparent negative consequences.

RESULTS

Research surveys

Sampling locations of the 1990 research survey are plotted in Figure 5. Station locations are indicated in the plot for age 6. No stations were allocated to the area deeper than 100 m as the catch data (Figure 2) showed no commercial activity below this isobath. Research survey results for 1990 indicate an important reduction of age 4 scallops compared to previous years. The low abundance of scallops age 5 and over remains the same although with a small improvement. There is also a diminution in the relative abundance of pre-recruits (Table 7) from the last two surveys. Pre-recruit levels ranks 6th in decreasing order for the 1980's. Stratified average number of scallops per tow (Table 9) indicates that the decline in age 4 was pronounced in all strata except the high stratum. The same trends are observed in table 8 where indices of abundance have been contoured. The sum of contour indices - at - age was compared to the estimated total number of scallops per tow times the area expansion of each survey stratum for all strata. Ages 3 to 6 comprise the majority of age groups represented There was a 9 % difference between the contour estimate and the area expansion one, the contour estimate being the lower of the two. Biomass figures given in table 8 are for ages 3 to 6 inclusive; they represent a minimum dredgeable biomass as they do not take into account dredge efficiency. Figure 5 maps the distribution of ages 3 - 6. High density patches of age 6 are more frequent than in the 1989 survey (Robert and Black 1990) but aggregations of young recruits are of lower magnitude.

Estimates of spatial covariance are displayed for ages 4 and 5 in Figure 6. Covariance is represented on the y - axis; distance in km on the x - axis. For age 4, the covariance sill is around 1,200 at a distance of about 5 - 10 km; for age 5, the sill is 200 approximately at a distance of 5 km. Results from samples 5 km or more apart would not be auto - correlated for the main commercial ages.

Cohort analysis

The cohort analysis results are given in terms of numbers-at-age, biomass-at-age, and F-at-age (Tables 12 to 14) which have been combined into annual values from quarterly analysis for the terminal F_{Q4} level of 0.24. At this F level, the residual values of the cohort biomass on CPUE and research survey biomass cross the regression line (Figure 4). The 1982 year-class is the largest seen in the last 10 years. Recruitment has been declining over the last three years although biomass has held steady, 12 - 14,000 t range, for the last five years. There is usually very little survivorship above age 6 seen in table 12. The F-at-age estimates show the shift in targeted ages from 1985 to 1986 with the drop in meat counts to 33 meats per 500 g forcing the targeted age to be of an older, bigger scallop while there is almost no fishing directed on age 3. Age 5 is very strongly targeted; F-at-age 5 equals 1.35 for 1990, slightly lower than 1.59 in 1989. Age 4 was fished harder in 1990 though. The average F values show some degree of recent stabilization compared to the earlier years.

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. 1987). The assessments from the last two years have an F_{max} which was estimated to be at an F of 0.966 and $F_{0.1}$ at 0.592. This year's re-analysis gives similar values of 1.07 and 0.68 respectively. The same selectivity is used in the cohort analysis, yield per recruit, and the stock projections (Table 15) which are carried out at F_{max} and $F_{0.1}$ using the cohort analysis numbers-at-age of the last quarter aged forward to the first quarter of the new year. This partial recruitment is less domed than the one used before; the annual values for the partial recruitment for ages 3 to 11 were 0.02, 0.28, 1.00, 0.47, 0.28, 0.19, 0.23, 0.23, and 0.13. The new values are 0.04, 0.37, 1.00, 0.37, 0.13, 0.10, 0.20, 0.30, and 0.20. The projections are given for a one year period and assume a recruitment level of 375 million animals to reflect the decreasing trend observed in research survey results. The $F_{0.1}$ and F_{max} catch levels for a terminal F_{Q4} of 0.24 are 2,500 and 3,700 t respectively. The mean weights of the catch are projected to be well above the legal limit of 33 meats per 500 grams (Table 15). The projected biomass increases by 8 % under F_{max} and 15% per annum under $F_{0.1}$ and the assumed recruitment pattern.

Other fishing scenarios for 1991 are summarised in table 16. As F increases and catches rise, biomass decreases steadily. While fishing at $F_{0.1}$ would require a fishing mortality rate less than half the 1990 value, the F value to maintain catches at the 5,200 level would have to be about 20 % larger. Maintaining the biomass constant (replacement yield option) would only require a slight drop in fishing effort compared to 1990.

Risk analysis

As fishing mortality rates rise beyond F_{max}, catches also increase implying a biomass loss (relative to F_{max} biomass levels) or an ascending biological risk (Figure 7). Under the range of values used for F, there is a direct correlation between potential catches and risks involved. The biomass gain under $F_{0.1}$ scenario is represented graphically as a negative risk or bonus. Fishing to maintain the biomass constant with a 4,500 t catch stipulates a 7 % risk. Keeping effort constant between 1990 and 1991 rises the risk factor to 8 % but, keeping the 1991 catch to the 1990 value increases the risk by 13 %.

CONCLUSIONS

Catches have been rising steadily over the last three years. Catch-rates have followed a similar pattern with a considerable dampening of month - to - month fluctuations (Figure 1). However, the fishery is strongly targetting ages 4 and 5 scallops. Average fishing mortality rates ranged from 0.31 to 0.39 during the period 1988 - 1990 but F on age 4 has increased by 32 % and F on age 5 is very high, 1.35 in 1990. Trends in cohort analysis indicate that stock biomass is relatively stable, 12 - 14,000 t range while recruitment is declining to some extent. A drop in recruitment is also observed in research survey results; the abundance of older (age > 5) age groups is holding up though.

Tuning with CPUE minimised the 1989 and 1990 residuals at F_{Q4} equal to 0.24. This F value also gave the strongest correlation coefficient (0.818). Tuning with research survey results minimised the 1989 residual at the same F value although the 1990 residual never crosses the regression line. The concurrence betweent the tuning variables led to the use of F_{Q4} equal to 0.24.

Different fishing scenarios are presented for 1991 ranging from $F_{0.1}$ with 2,500 t to $F_{1990\ catch}$ with 5,200 t. Basically, the harder one fishes, the higher the catch but higher catches translate into lower biomass at the end of the year. Lower biomass is related to a risk potential compared to the reference level of F_{max} involving no risk. Keeping the catch for 1991 at 5,200 t, the 1990 landing, means a 13 % risk (Table 16).

There are special problems in applying traditional assessment techniques to scallop stocks. Other possible methods that are statistically more rigorous such as the ADAPT method based on scallop meat weight frequencies to bypass the conversion problems of meat weight frequency distribution into age frequency distribution are being looked into. Under this approach the meat weight frequencies from the commercial catch are compared to the meat weight frequencies derived from the research survey indices.

REFERENCES

Black, G.A.P. 1988. manuscript - ACON - A shaded contour program for plotting irregularly spaced data. (Version 3.03) 50p.

Brown, B.E., M. Parrack, and D.D. Flesher. 1972. Review of the current status of the scallop fishery in ICNAF Division 5Z. Int. Comm. Northw. Atl. Fish. Res. Doc. 72/113: 13 p.

Caddy, J.F. 1972. Size selectivity of the Georges Bank offshore dredge and mortality estimate for scallops from the northern edge of Georges in the period June 1970 to 1971. Int. Comm. Northw. Atl. Fish. Res. Doc. 72/5: 10p.

Dickie, L.M. 1955. Fluctuations in abundance of the giant scallop, *Placopecten magellanicus* (Gmelin), in the Digby area of the Bay of Fundy. J. Fish. Res. Bd Can. 12(6): 797 - 857.

Gulland, J.A. 1961. Fishing and the stock of fish at Iceland. Fish Invest. Lond. Ser. 2. 34(4): 52 p.

Merrill, A.S. and J.A. Posgay. 1964. Estimating the natural mortality rate of the sea scallop (*Placopecten magellanicus*). Int. Comm. Northwest Atl. Fish. Res. Bull. 1: 88 - 106.

Mohn, R.K., G. Robert, and D.L. Roddick. 1984a. Georges Bank scallop stock assessment - 1983. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 84/12: 28 p.

Mohn, R.K., G. Robert, and D.L. Roddick. 1984b. Status and harvesting strategies for Georges Bank scallop stock (NAFO SA 5Ze). ICES, CM84/K:15, 31 p.

Mohn, R.K., G. Robert, and D.L. Roddick. 1987. Georges Bank scallop stock assessment - 1986. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 87/9: 23 p.

Mohn, R.K., G. Robert, and G.A.P. Black. 1989. Georges Bank scallop stock assessment - 1988. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 89/21: 26 p.

Naidu, K.S. 1970. Reproduction and breeding cycle of the giant scallop *Placopecten magellanicus* (Gmelin) in Port au Port Bay, Newfoundland. Can. J. Zool. 48: 1003-1012.

Robert, G. and G.S. Jamieson. 1986. Commercial fishery data isopleths and their use in offshore sea scallop (*Placopecten magellanicus*) stock evaluations. Can. Spec. Publ. Fish. Aquat. Sci. 92: 76-82.

Robert, G. and M.J. Lundy. 1987. Shell height-meat weight allometry for Georges Bank scallop (*Placopecten magellanicus*) stocks. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 87/40: 39p.

Robert, G. and G.A.P. Black. 1990. Georges Bank scallop stock assessment - 1989. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 90/19: 30 p.

Serchuck, F.M., P.W. Wood, Jr., and R.S. Rak. 1982. Review and assessment of the Georges Bank, mid-Atlantic and Gulf of Maine Atlantic sea scallop (*Placopecten magellanicus*) resources. Woods Hole Lab. Ref. Doc. 82-06: 132 p.

Watson, D.F. 1982. ACORD - Automatic contouring of raw data. Comp. & Geosci. 8: 97-101.

Watson, D.F. and G.M. Philip. 1985. A refinement of inverse distance weighted interpolation. Geo-Processing 2: 315-327.

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.

Year	U.S.A.	Canada	Total
1957	3562	732	4294
1958	3024	1167	4191
1959	2601	2235	4836
1960	2008	2568	4576
1961	4472	4382	8854
1962	3200	5315	8515
1963	1953	5270	7223
1964	462	5034	5496
1965	24	3059	3083
1966	25	2537	2562
1967	34	3212	3246
1968	41	3904	3945
1969	97	3368	3465
1970	51	2868	2919
1971	3	2345	2348
1972	26	2746	2772
1973	5	1975	1980
1974	0	4541	4541
1975	0	6524	6524
1976	0	7809	7809
1977	77	11126	11203
1978	212	10970	11182
1979	314	7642	7956
1980	761	4751	5512
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	5220	5220

Year	Recommended TAC	Set TAC	Catch
1986	—	4300	4900
1987	6500	6850	6793
1988	4800	5400	4336
1989	4700	4700	4676
1990	4800	5200	5220

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

Year	Catch	Effort			CPUE
		days	hours 10^3	crhm* 10^3	kg/crhm
1972	2746	5404	75	9220	0.298
1973	1975	3716	54	6333	0.312
1974	4541	6071	90	10810	0.420
1975	6524	7234	105	13389	0.487
1976	7809	6129	90	12222	0.639
1977	11126	7386	82	11051	1.007
1978	10970	7692	100	13686	0.802
1979	7642	7327	105	14372	0.532
1980	4751	6232	86	11785	0.403
1981	7612	8020	100	14484	0.526
1982	3918	5564	73	9977	0.393
1983	2418	4825	67	8690	0.278
1984	1945	5716	70	8598	0.226
1985	3812	7376	105	12644	0.301
1986	4900	3915	52	6957	0.704
1987	6793	5736	78	10808	0.629
1988	4336	5853	85	11283	0.385
1989	4676	5154	78	10774	0.434
1990	5220**	4726	72	10575	0.494

* crew-hour-meter
** provisional

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

	% catch examined / catch landed	meat weight (g) mean	min	max	s.e.	n meats
1981	0.01306					
January		0.00	0.00	0.00	0.00	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
1989	0.00724					
January		15.46	5.19	45.89	0.05	1722
February		15.54	5.57	53.99	0.05	2090
March		15.23	6.05	60.15	0.05	2687
April		14.89	5.93	52.64	0.03	3640
May		15.39	5.41	67.19	0.03	4849
June		16.17	6.34	53.16	0.04	2027
July		0.00	0.00	0.00	0.00	0
August		0.00	0.00	0.00	0.00	0
September		0.00	0.00	0.00	0.00	0
October		12.60	5.16	43.86	0.03	2849
November		12.85	4.12	68.34	0.05	1818
December		12.69	5.92	31.46	0.06	713
1990	0.00704					
January		14.00	4.78	38.82	0.04	1539
February		13.11	5.58	36.03	0.04	2078
March		13.66	4.76	55.69	0.04	2699
April		16.52	5.26	75.19	0.05	2543
May		17.46	3.88	57.91	0.05	1995
June		16.22	6.75	46.51	0.06	1166
July		16.75	6.33	55.80	0.06	1789
August		16.56	6.31	60.82	0.06	1596
September		15.54	6.01	47.98	0.06	1384
October		16.70	5.42	62.22	0.04	3725
November		16.65	5.57	50.63	0.06	1907
December		16.79	6.53	57.40	0.08	835

Table 4.- Frequencies of numbers at weight in 2-g intervals (normalized to 1000) by quarter for recent years.

Grams	1987	Q1	Q2	Q3	Q4	1988	Q1	Q2	Q3	Q4
1		0	0	0	0		0	0	0	0
3		0	0	0	0		0	0	0	0
5		1	0	2	3		5	1	4	3
7		13	3	13	30		34	17	32	33
9		64	32	55	130		121	70	98	120
11		143	122	140	177		193	137	164	181
13		150	187	201	163		152	176	179	187
15		144	213	201	134		90	170	149	150
17		138	143	148	100		81	118	98	102
19		95	86	89	86		53	82	76	70
21		76	63	51	55		60	59	52	49
23		63	53	34	37		43	41	37	28
25		42	34	20	27		31	36	27	19
27		28	19	14	16		32	27	23	15
29		16	11	9	11		22	19	16	11
31		11	12	6	9		18	14	12	8
33		6	7	5	7		20	11	8	6
35		3	6	3	5		7	8	6	4
37		3	3	3	3		8	4	4	4
39		1	1	2	2		7	4	4	3
41		1	1	1	1		9	2	2	3
43		0	1	0	1		3	1	2	1
45		0	0	0	1		2	1	2	1
47		0	0	0	0		3	2	1	0
49		0	0	0	1		1	0	1	0

Grams	1989	Q1	Q2	Q3	Q4	1990	Q1	Q2	Q3	Q4
1		0	0	0	0		0	0	0	0
3		0	0	0	0		0	0	0	0
5		1	0	0	3		4	0	0	1
7		15	7	0	28		50	10	15	18
9		90	52	0	133		161	57	76	83
11		191	157	0	208		221	134	151	146
13		218	230	0	201		195	178	178	158
15		159	211	0	154		133	155	152	146
17		96	141	0	94		86	128	123	117
19		67	78	0	67		56	95	86	86
21		46	42	0	42		37	79	63	71
23		36	28	0	26		22	52	49	49
25		23	15	0	17		13	39	36	36
27		17	13	0	11		8	25	21	24
29		9	6	0	4		4	14	16	19
31		8	6	0	5		3	11	11	13
33		5	4	0	1		2	6	8	9
35		5	4	0	1		2	6	5	6
37		3	1	0	1		1	4	2	5
39		4	2	0	1		1	1	2	5
41		2	1	0	0		0	3	2	2
43		2	0	0	0		0	1	1	2
45		1	0	0	0		0	1	1	1
47		0	0	0	0		0	0	0	1
49		0	0	0	0		0	0	0	1

Table 5.- Frequencies of numbers at weight in 2-g intervals (normalized to 1000) by year.

	Year									
Grams	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1	0	0	0	0	0	0	0	0	0	0
3	16	2	12	7	1	0	0	0	0	0
5	84	26	66	96	20	0	2	3	1	2
7	204	99	110	205	112	6	17	28	14	24
9	253	146	118	169	211	41	79	98	83	96
11	177	159	125	108	197	125	150	163	179	164
13	96	132	111	69	136	209	175	179	219	177
15	52	103	90	55	87	225	168	152	182	146
17	31	73	70	46	57	160	129	104	117	113
19	20	55	53	41	42	96	89	75	72	80
21	15	45	44	37	30	55	59	54	43	62
23	11	33	36	30	21	28	44	36	30	43
25	8	27	27	25	17	17	29	27	18	30
27	6	21	23	20	13	11	18	22	14	19
29	5	17	18	18	11	8	12	16	7	13
31	4	13	15	15	9	3	9	11	6	9
33	3	11	13	12	7	3	6	9	4	6
35	3	8	10	11	6	3	4	6	4	5
37	2	6	8	8	5	2	3	5	2	3
39	2	5	8	6	4	1	2	4	2	2
41	1	4	6	5	3	2	1	3	1	2
43	1	3	6	4	3	1	1	2	1	1
45	1	2	5	3	2	0	0	1	1	1
47	1	2	4	2	2	0	0	1	0	0
49	1	1	4	2	1	0	1	1	0	0
51	1	1	2	2	1	1	0	1	0	0
53	1	1	3	1	1	0	0	0	0	0
55	1	1	3	1	1	0	0	0	0	0
57	0	0	1	1	0	0	0	0	0	0
59	0	1	2	0	0	0	0	0	0	0
61	0	0	2	0	0	0	0	0	0	0
63	0	0	1	0	0	0	0	0	0	0
65	0	0	2	0	0	0	0	0	0	0
67	0	0	1	0	0	0	0	0	0	0
69	0	0	1	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0	0	0
73	0	0	0	1	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0	0
77	0	0	1	0	0	0	0	0	0	0
79	0	0	0	0	0	0	0	0	0	0

Table 6.- 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 7.- Total weighted average (by stratum) number of scallops at age per tow.

Sampling dates	Age (years)								
	2	3	4	5	6	7	8	9	10^+
1981	166	179	24	5	2	1	0	0	0
1982	22	41	20	5	1	0	0	0	0
1983	41	26	15	4	2	1	0	0	0
1984	175	25	9	2	1	0	0	0	0
1985	82	165	15	2	0	0	0	0	0
1986	198	136	145	12	1	0	0	0	0
1987	94	98	63	17	5	2	0	0	0
1988	98	110	52	10	2	1	0	0	0
1989	117	131	71	13	2	1	0	0	0
1990	105	89	39	15	4	1	0	0	0

Table 8.- 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

Table 9.- Stratified average number of scallops at age per tow and stratified total number of scallops per tow, N.

Stratum	Sampling dates	Age (years)									N	s.d.
		2	3	4	5	6	7	8	9	10+		
Very low	1985	32	79	6	1	0	0	0	0	0	170	375
	1986	42	154	50	5	1	0	0	0	0	292	582
	1987	43	171	76	10	1	0	0	0	0	301	595
	1988	39	104	67	9	1	0	0	0	0	236	417
	1989	50	55	95	16	2	0	0	0	0	225	356
	1990	40	41	33	19	5	1	0	0	0	148	185
Low	1985	74	64	11	2	0	0	0	0	0	188	324
	1986	165	143	49	14	2	0	0	0	0	376	769
	1987	61	56	71	17	2	1	0	0	0	208	277
	1988	50	116	57	12	2	0	0	0	0	250	328
	1989	44	68	73	13	2	1	0	0	0	203	231
	1990	70	39	27	10	5	1	0	0	0	161	194
Medium	1985	173	511	22	2	0	0	0	0	0	710	1164
	1986	70	35	63	14	2	0	0	0	0	185	139
	1987	90	29	33	17	3	1	0	0	0	173	171
	1988	17	45	37	9	3	1	0	0	0	112	103
	1989	155	143	88	22	3	0	0	0	0	412	463
	1990	105	142	21	13	3	1	0	0	0	290	518
High	1985	110	255	22	2	0	0	0	0	0	392	481
	1986	309	144	232	14	1	0	0	0	0	702	854
	1987	108	109	65	18	6	2	0	0	0	315	347
	1988	141	113	48	10	2	1	0	0	0	317	272
	1989	138	161	57	9	2	1	0	0	0	369	474
	1990	131	99	47	15	3	1	0	0	0	298	307

Table 10. - Tuning criteria for the regressions of cohort biomass on CPUE and on research survey biomass estimates and of fishing mortality on effort.

	CPUE			Research Survey Biomass			Effort		
F_{Q4}	R^2	1989*	1990*	R^2	1989*	1990*	R^2	1989*	1990*
0.11	0.569	-7820	-8980	0.355	-3394	-11275	0.534	+0.06	+0.07
0.12	0.621	-6861	-7565	0.377	-2866	-9836	0.534	+0.06	+0.06
0.13	0.666	-6049	-6367	0.399	-2420	-8618	0.534	+0.05	+0.05
0.14	0.702	-5354	-5341	0.422	-2038	-7575	0.532	+0.05	+0.04
0.15	0.731	-4751	-4451	0.445	-1707	-6671	0.530	+0.04	+0.03
0.16	0.754	-4224	-3673	0.467	-1417	-5879	0.527	+0.04	+0.02
0.17	0.772	-3759	-2987	0.489	-1161	-5181	0.523	+0.04	+0.01
0.18	0.785	-3345	-2376	0.511	-934	-4561	0.518	+0.03	0.00
0.19	0.795	-2975	-1830	0.531	-730	-4006	0.513	+0.03	-0.01
0.20	0.802	-2642	-1339	0.550	-547	-3506	0.508	+0.03	-0.02
0.21	0.806	-2341	-894	0.567	-382	-3055	0.502	+0.03	-0.03
0.22	0.809	-2067	-490	0.582	-231	-2644	0.495	+0.02	-0.04
0.23	0.810	-1817	-121	0.594	-94	-2269	0.488	+0.02	-0.05
0.24	0.810	-1588	217	0.605	32	-1925	0.480	+0.02	-0.06
0.25	0.809	-1377	528	0.612	148	-1609	0.472	+0.02	-0.07
0.26	0.807	-1183	815	0.616	255	-1317	0.464	+0.02	-0.08
0.27	0.805	-1003	1081	0.618	354	-1047	0.455	+0.01	-0.09
0.28	0.802	-835	1328	0.617	446	-796	0.446	+0.01	-0.10
0.29	0.799	-680	1557	0.613	531	-563	0.437	+0.01	-0.10
0.30	0.796	-534	1772	0.607	611	-345	0.427	+0.01	-0.11

* Position of residual value with respect to regression line

Table 11.- Catch-at-age in numbers (10^6) east of the ICJ line.

Ages	1972	1973	1974	1975	1976	1977	1978	1979	1980
3	239	148	192	381	166	174	115	65	127
4	97	84	199	273	366	568	320	201	177
5	32	17	45	50	93	144	198	114	69
6	3	4	6	8	16	13	70	44	20
7	2	1	3	2	7	4	25	23	12
8	1	0	1	1	3	2	13	8	6
9	0	0	0	0	3	1	10	5	3
10	0	0	0	0	1	1	8	5	2
11	0	0	0	0	1	0	8	3	2
Total	374	253	446	717	656	908	767	469	420

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	5	3	2	2	4	2	2	1	2
9	4	3	2	1	1	1	3	1	0
10	2	3	3	1	1	0	1	2	0
11	2	1	2	2	1	0	0	1	1
Total	894	338	215	202	275	311	420	268	308

Ages	1990
3	13
4	172
5	121
6	13
7	8
8	5
9	1
10	0
11	0
Total	335

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 0.24.

Ages	1972	1973	1974	1975	1976	1977	1978	1979	1980
3	492	527	730	1191	1248	772	489	411	878
4	177	215	334	473	709	968	528	331	309
5	113	68	116	113	170	294	333	173	109
6	10	72	46	63	55	66	130	114	49
7	11	6	62	36	49	35	47	51	61
8	2	9	5	53	30	38	27	18	24
9	1	1	8	4	47	25	33	12	9
10	0	1	1	7	3	39	21	20	6
11	0	0	0	0	6	2	35	12	14
Total	807	899	1301	1940	2317	2238	1644	1143	1459

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	652	227	202	452	693	478	326	414	374
4	672	309	161	151	346	564	430	275	355
5	112	145	118	61	72	175	335	211	134
6	33	30	43	46	24	30	57	126	100
7	25	15	15	26	22	11	17	37	94
8	43	15	7	10	15	11	7	13	28
9	16	34	11	5	8	10	8	5	10
10	6	11	28	8	3	6	9	5	3
11	3	3	7	22	6	2	5	6	3
Total	1563	788	592	780	1188	1286	1194	1091	1100

Ages	1990
3	295
4	323
5	170
6	25
7	73
8	77
9	24
10	9
11	2
Total	997

Table 13.- Biomass (t of meats) east of the ICJ line from cohort analysis using a terminal F_{Q4} of 0.24.

Ages	1972	1973	1974	1975	1976	1977	1978	1979	1980
3	1610	1725	2389	3901	4087	2528	1602	1347	2876
4	1709	2079	3230	4577	6853	9359	5105	3200	2985
5	1945	1176	1990	1947	2917	5050	5722	2979	1872
6	252	1735	1115	1511	1325	1584	3142	2745	1179
7	341	185	1842	1069	1472	1040	1401	1526	1820
8	53	305	167	1821	1037	1314	944	626	841
9	33	33	290	147	1763	927	1238	469	340
10	16	22	24	266	130	1576	849	810	248
11	14	10	17	15	245	70	1446	486	575
Total	5974	7270	11063	15256	19829	23446	21448	14188	12737

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	2135	742	660	1479	2270	1565	1069	1357	1223
4	6503	2987	1559	1463	3343	5458	4161	2656	3431
5	1921	2486	2032	1051	1237	3013	5749	3621	2303
6	797	729	1039	1106	574	716	1371	3052	2417
7	753	435	448	765	664	318	509	1094	2803
8	1486	527	256	355	531	369	240	435	973
9	611	1278	401	179	286	386	305	169	392
10	220	434	1105	305	116	229	344	190	120
11	140	112	305	920	230	67	209	268	104
Total	14566	9731	7806	7622	9252	12121	13957	12843	13766

Ages	1990
3	965
4	3121
5	2916
6	598
7	2187
8	2637
9	910
10	363
11	99
Total	13795

Table 14.- Annualised fishing mortality east of the ICJ line from cohort analysis using a terminal F_{Q4} of 0.24.

Ages	1972	1973	1974	1975	1976	1977	1978	1979	1980
3	0.73	0.36	0.33	0.42	0.15	0.28	0.29	0.19	0.17
4	0.85	0.52	0.98	0.92	0.78	0.97	1.01	1.01	0.92
5	0.35	0.29	0.52	0.63	0.85	0.72	0.98	1.17	1.10
6	0.43	0.05	0.16	0.14	0.36	0.24	0.84	0.52	0.56
7	0.15	0.14	0.05	0.07	0.15	0.14	0.84	0.63	0.24
8	0.46	0.04	0.12	0.02	0.10	0.05	0.69	0.60	0.31
9	0.36	0.30	0.05	0.08	0.07	0.05	0.39	0.60	0.39
10	0.45	0.22	0.41	0.03	0.57	0.03	0.50	0.28	0.51
11	0.28	0.34	0.28	0.28	0.21	0.21	0.30	0.37	0.15
Mean	0.45	0.25	0.32	0.29	0.36	0.30	0.65	0.60	0.48

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	0.65	0.24	0.19	0.17	0.11	0.01	0.07	0.06	0.05
4	1.44	0.86	0.87	0.64	0.58	0.42	0.61	0.62	0.64
5	1.21	1.11	0.85	0.85	0.79	1.03	0.87	0.65	1.59
6	0.72	0.60	0.42	0.62	0.70	0.46	0.34	0.20	0.21
7	0.39	0.57	0.27	0.40	0.63	0.32	0.20	0.16	0.10
8	0.14	0.26	0.35	0.21	0.31	0.18	0.34	0.09	0.06
9	0.30	0.11	0.23	0.40	0.18	0.08	0.43	0.31	0.04
10	0.62	0.29	0.12	0.22	0.49	0.03	0.19	0.54	0.14
11	0.71	0.65	0.43	0.08	0.21	0.08	0.08	0.20	0.27
Mean	0.69	0.52	0.41	0.40	0.44	0.29	0.35	0.31	0.34

Ages	1990
3	0.05
4	0.82
5	1.35
6	0.84
7	0.12
8	0.07
9	0.06
10	0.05
11	0.16
Mean	0.39

Table 15.-.Stock projections at current F_{max} (0.966) and at $F_{0.1}$ (0.594) using starting numbers from cohort analysis with a terminal F_{Q4} of 0.24.

F = 0.966	1991_{Q1}	1991_{Q2}	1991_{Q3}	1991_{Q4}
Rate on smalls	1.00	1.00	1.00	1.00
Mean Wgt. Catch	18.41	18.31	19.08	23.00
Catch (Mill.)	49.35	87.01	38.40	19.16
Catch (t)	908	1,593	733	441
Cum. Catch (t)	908	2,501	3,234	3,675
Biomass	12,700	12,482	12,660	13,705

F = 0.594	1991_{Q1}	1991_{Q2}	1991_{Q3}	1991_{Q4}
Rate on smalls	1.00	1.00	1.00	1.00
Mean Wgt. Catch	18.39	18.30	19.17	23.54
Catch (Mill.)	31.26	59.07	27.51	14.08
Catch (t)	575	1,081	527	331
Cum. Catch (t)	575	1,656	2,183	2,515
Biomass	13,055	13,435	13,890	15,028

Table 16.- Fishing scenarios established for 1991 given five different options of fishing mortality rate. Biomass figures are for the end of 1991. Catch figures are rounded off to the nearest 50 t.

No.	Options	Fvalues	Biomass (t)	Catch (t)	% Risk
1	$F_{0.1}$	0.59	15,028	2,500	bonus 10%
2	F_{max}	0.97	13,705	3,700	0 %
3	$F_{replacement}$ yield	1.29	12,750	4,500	7 %
4	F_{1990} effort	1.35	12,590	4,650	8 %
5	F_{1990} TAC	1.61	11,946	5,200	13 %

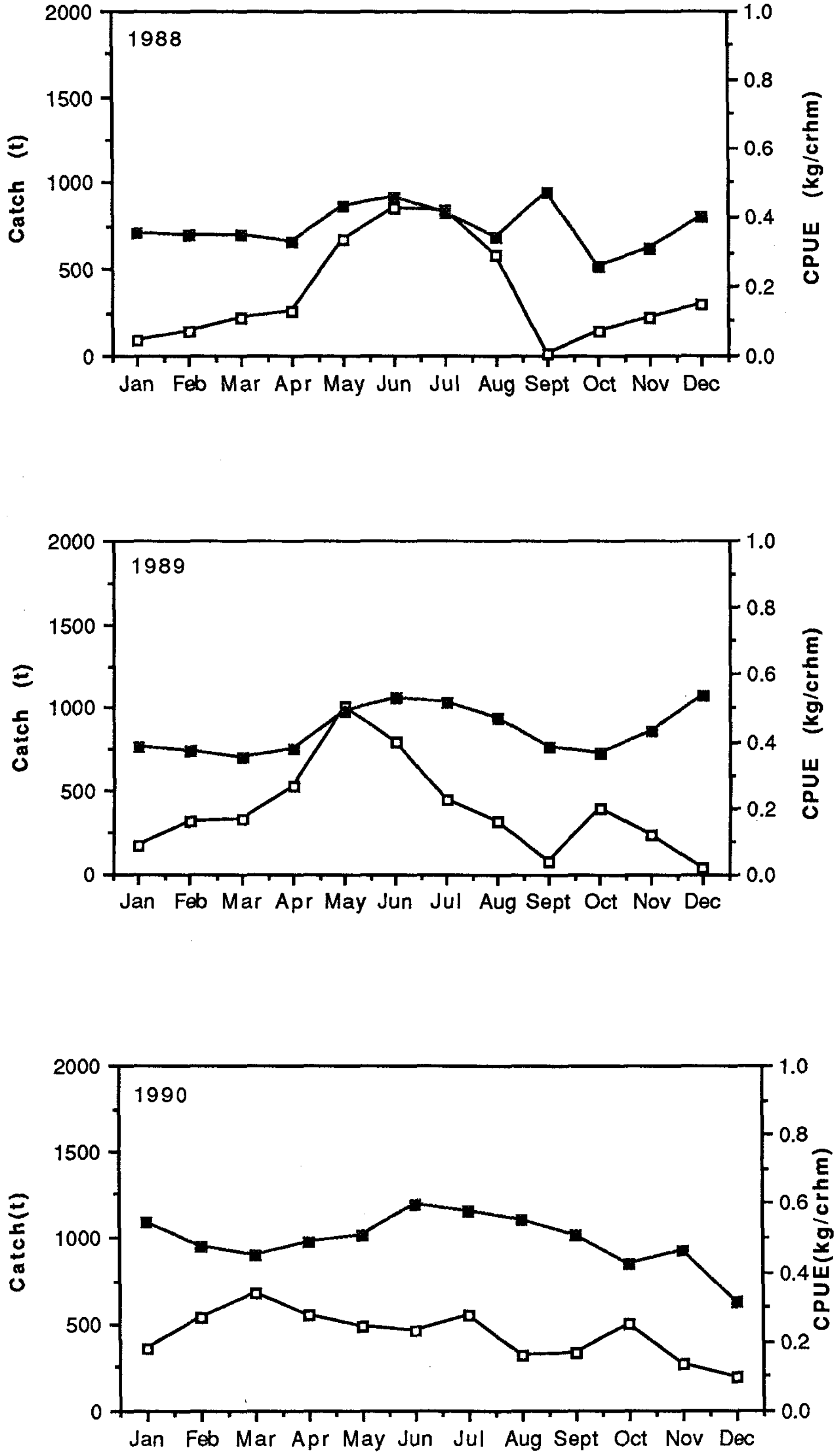

Figure 1.- Monthly CPUE (filled square) and catch in tons of meats (open square) for the deep-sea fleet fishing Georges Bank.

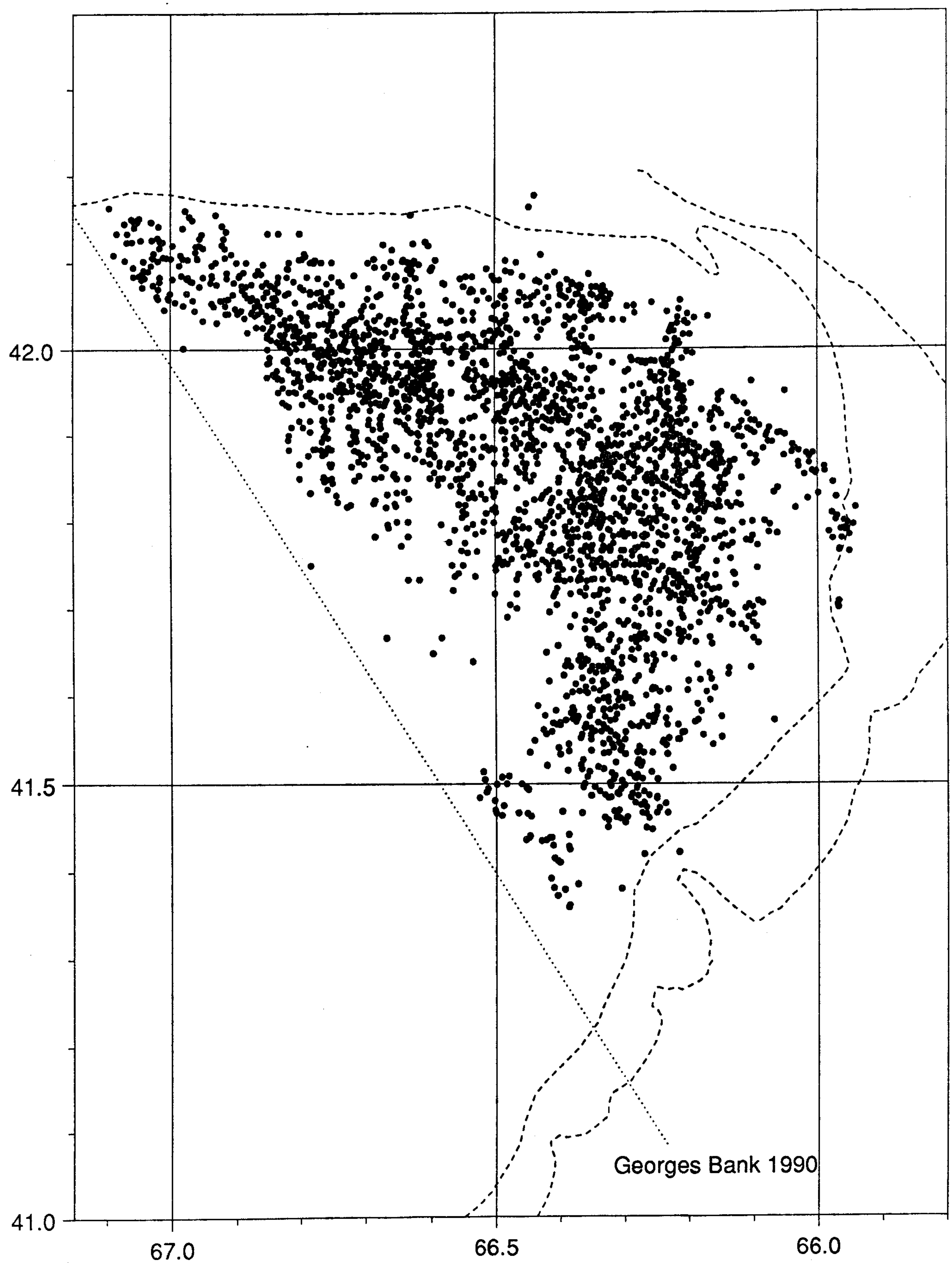

Figure 2.- Fishing locations exploited by the deep-sea fleet on Georges Bank in 1990.

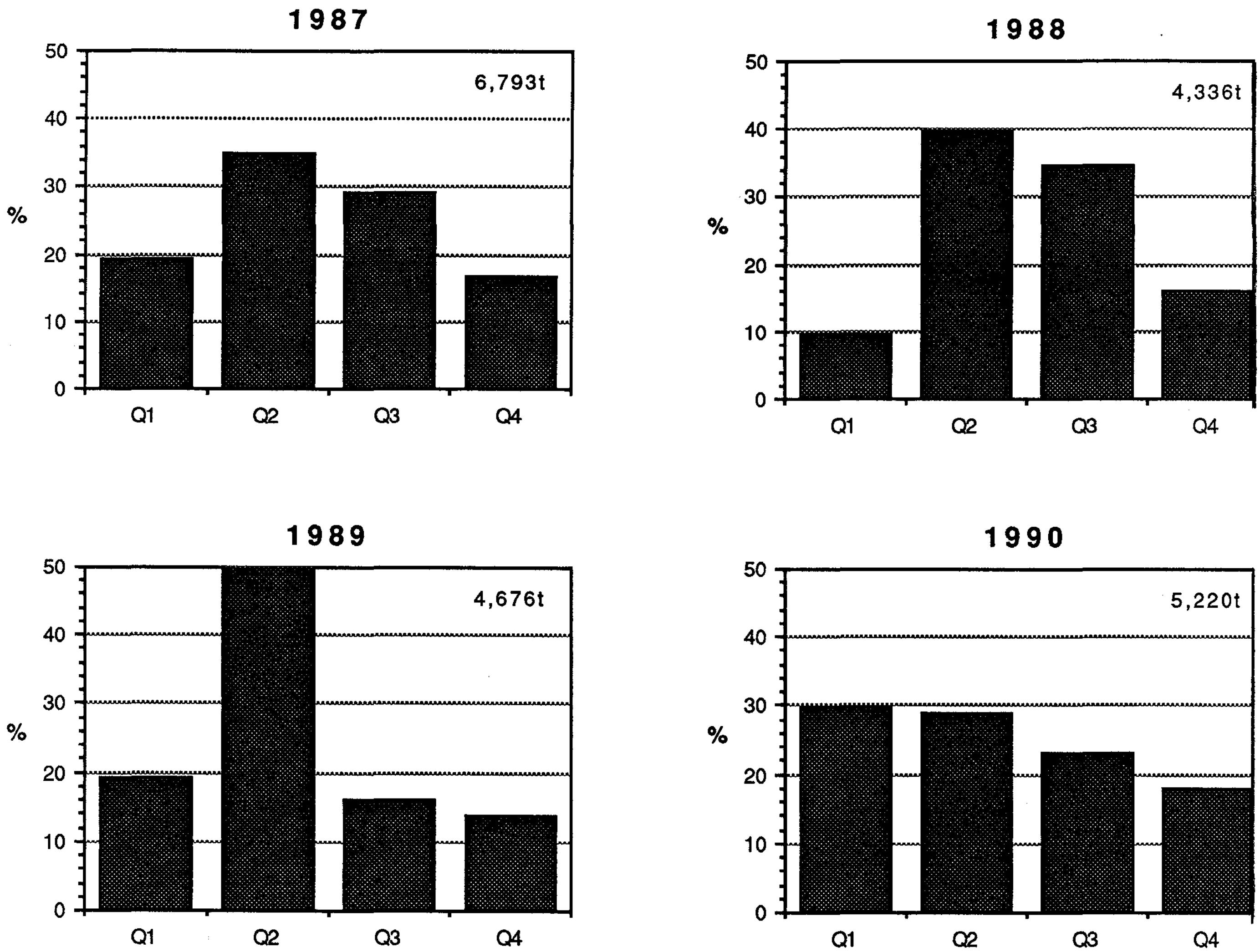

Figure 3.- Variability in the quarterly distribution of annual catches for the last four years.

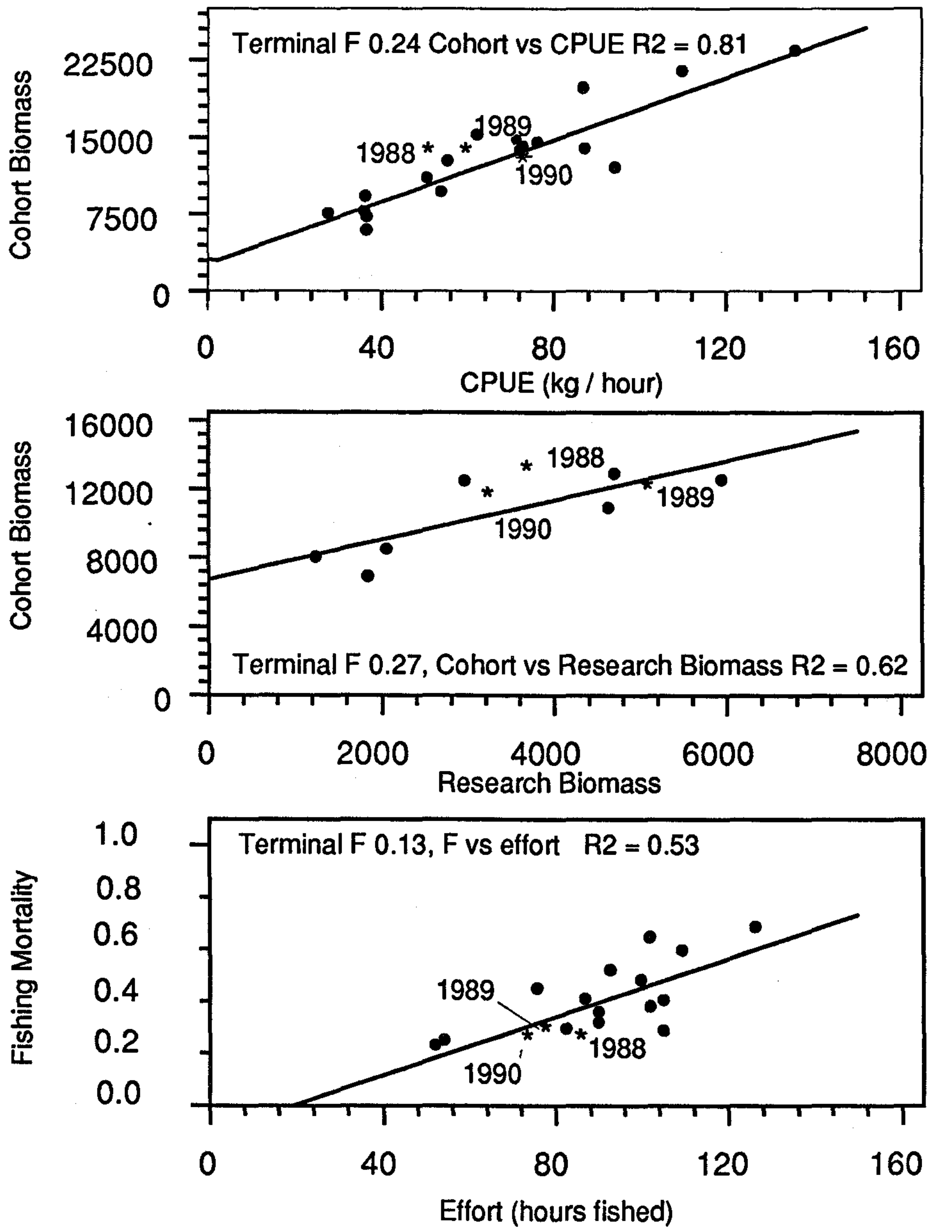

Figure 4 .- Cohort biomass (t of meats) vs CPUE (kg/h), cohort biomass vs research survey biomass (t of meats), and fishing mortality vs effort (hours fished) using terminal F_{Q4} as shown above.

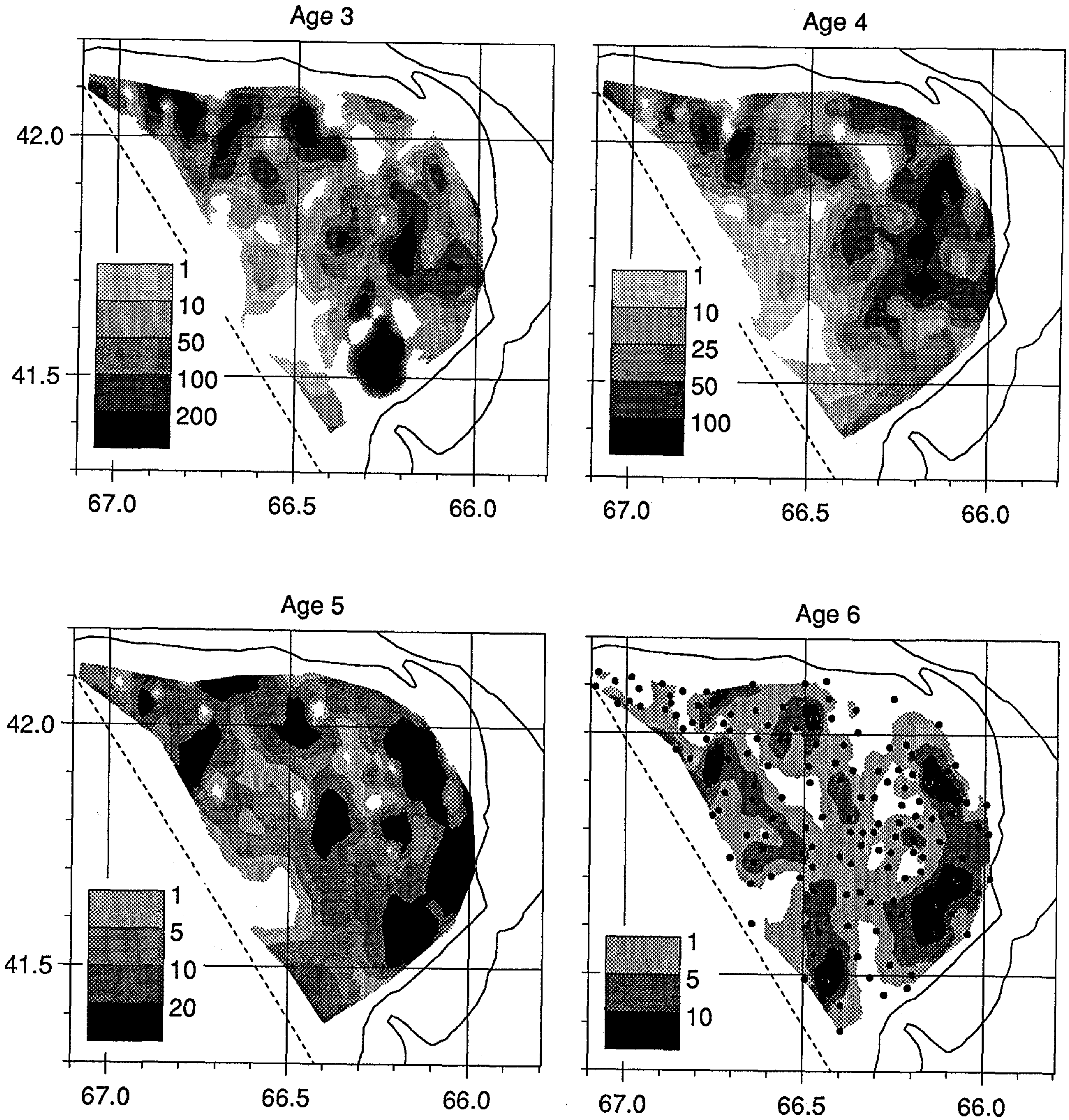

Figure 5.- Scallop distribution according to age from the research survey of August 1990. Location of sampling stations is indicated on the graph for age 6 scallops.The shading scale (lower left corner of graph) represents number of animals per standard tow.

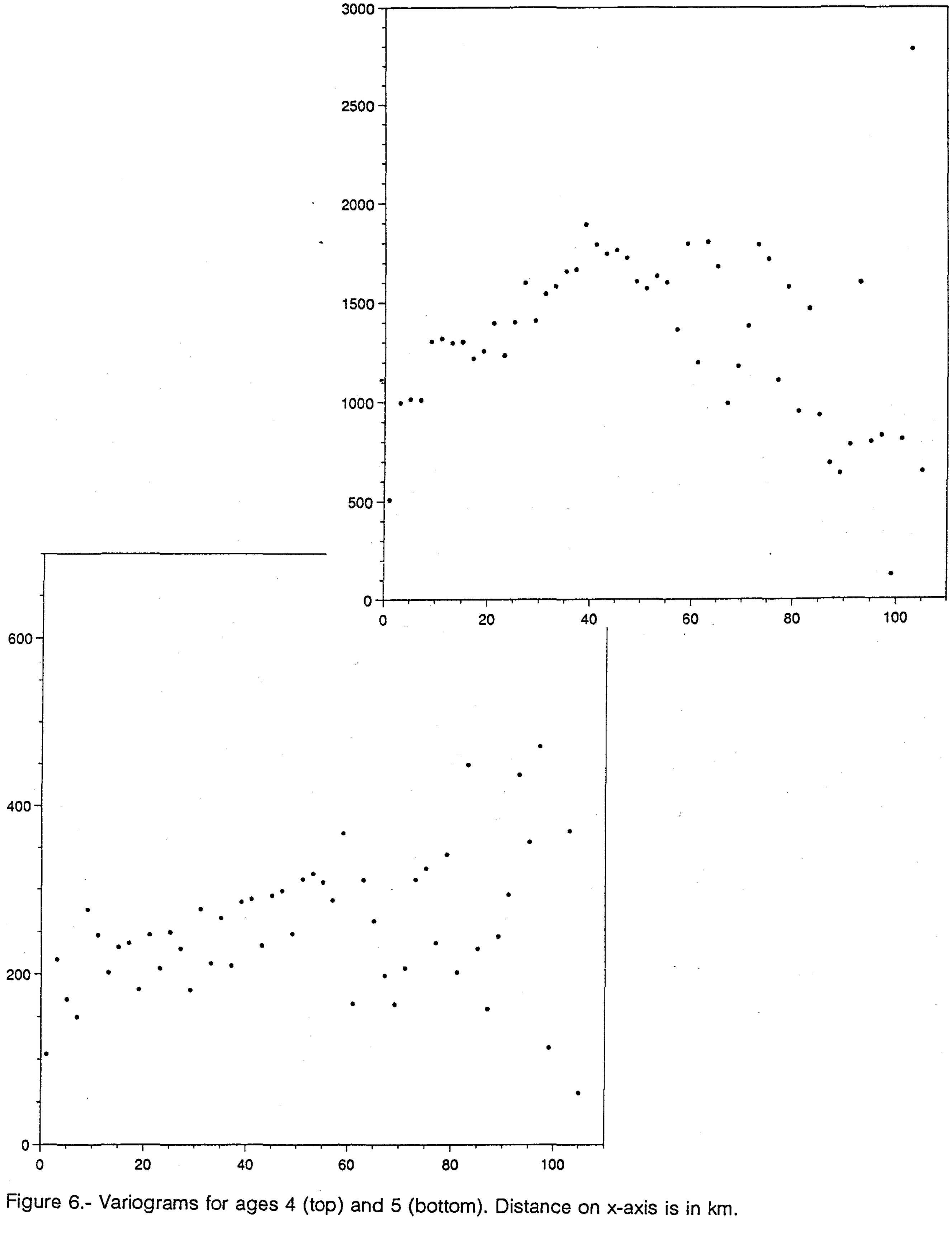

Figure 6.- Variograms for ages 4 (top) and 5 (bottom). Distance on x-axis is in km.

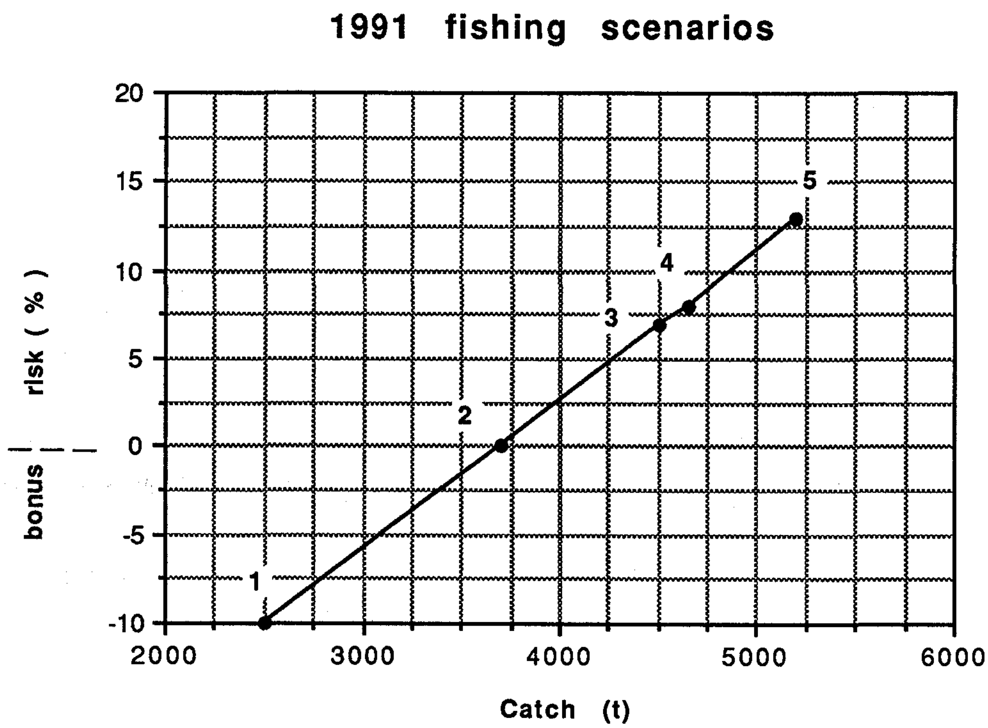

Figure 7.- Fishing scenarios for 1991 relating catch levels with risk involved in terms of biomass loss. Options are numbered as per table 16.

APPENDIX

Trials were also carried out using the ADAPT method to calibrate the sequential population analysis. Relative abundance indices for ages 4 - 6 from research surveys covering the period 1981 - 1990 were chosen as independent estimates with different scenarios of catch-at-age to be estimated. Results with non-logged and logged residuals are presented although transforming the data did not bring outstanding advantages. Natural mortality equals 0.1 as previously stated in the text; the error in catch-at-age is assumed negligible. Scenarios examining 1) ages 3 - 6 in the catch, 2) ages 3 - 9, and ages 3 - 11 are presented below.

---

1) Ages 3 - 6

Non-logged residuals

Mean square of the residuals = 3191.69

Estimated parameter		s.e.	c.v.
Age 4	0.190	0.077	0.405
Age 5	0.275	0.196	0.713
Age 6	0.077	0.154	1.983
q1	0.676	0.071	0.105
q2	0.466	0.092	0.198
q3	0.340	0.335	0.984
q4	0.062	0.144	2.317

Correlation matrix

	Age 4	Age 5	Age 6	q1	q2	q3	q4
Age4	1	-.22	.04	.37	.27	.09	-.24
Age 5		1	-.6	.10	-.02	.03	.22
Age 6			1	.23	.17	.11	-.77
q1				1	.38	.26	-.55
q2					1	.18	-.42
q3						1	-.61
q4							1

Logged residuals

Mean square of the residuals = 10.80

Estimated parameter		s.e.	c.v.
Age 4	0.482	0.470	0.975
Age 5	0.506	0.536	1.060
Age 6	0.321	0.322	1.005
q1	0.526	0.098	0.185
q2	0.386	0.074	0.190
q3	0.359	0.075	0.209
q4	0.393	0.145	0.369

Correlation matrix

	Age 4	Age 5	Age 6	q1	q2	q3	q4
Age 4	1	-.39	-.43	.13	.16	-.27	-.30
Age 5		1	-.54	-.01	-.12	.05	-.29
Age 6			1	-.20	-.19	-.07	.18
q1				1	-.03	-.12	-.17
q2					1	-.07	-.05
q3						1	.23
q4							1

---

2) Ages 3 - 9

Non-logged residuals

Mean square of the residuals = 3752.01

Estimated parameter		s.e.	c.v.
Age 4	0.127	0.037	0.293
Age 5	0.306	0.502	1.641
Age 6	0.353	0.562	1.592
q1	0.668	0.051	0.076
q2	0.446	0.073	0.163
q3	0.355	0.185	0.521
q4	0.377	0.271	0.717

Correlation matrix

	Age 4	Age 5	Age 6	q1	q2	q3	q4
Age4	1	.04	-.10	.29	.18	-.10	-.24
Age 5		1	-.91	.17	.09	-.03	-.24
Age 6			1	-.05	-.06	-.05	-.03
q1				1	.08	-.12	-.34
q2					1	-.10	-.24
q3						1	-.39
q4							1

Logged residuals

Mean square of the residuals = 0.82

Estimated parameter		s.e.	c.v.
Age 4	0.864	1.839	2.129
Age 5	0.943	2.079	2.205
Age 6	0.383	0.668	1.746
q1	0.322	0.092	0.287
q2	0.310	0.091	0.295
q3	0.300	0.091	0.302
q4	0.282	0.097	0.342

Correlation matrix

	Age 4	Age 5	Age 6	q1	q2	q3	q4
Age 4	1	-.72	-.31	.10	.19	-.19	-.08
Age 5		1	-.40	-.01	-.15	.19	.02
Age 6			1	-.24	-.18	-.16	-.09
q1				1	-.02	-.07	-.11
q2					1	-.08	-.09
q3						1	-.05
q4							1

3) Ages 3 - 11 Non-logged residuals

Mean square of the residuals = 2229.21

Estimated parameter		s.e.	c.v.
Age 4	0.159	0.053	0.330
Age 5	0.121	0.077	0.636
Age 6	0.152	0.113	0.743
q1	0.591	0.047	0.080
q2	0.391	0.058	0.148
q3	0.224	0.137	0.611
q4	0.088	0.237	2.702

Correlation matrix

Age 4	Age 5	Age 6	q1	q2	q3	q4	
1	.15	-.33	.36	.24	.06	.02	Age4
	1	-.50	.37	.25	.14	.02	Age 5
		1	.16	.04	.06	.04	Age 6
			1	.29	.15	.04	q1
				1	.08	.02	q2
					1	.01	q3
						1	q4

Logged residuals

Mean square of the residuals = 0.17

Estimated parameter		s.e.	c.v.
Age 4	0.470	0.159	0.339
Age 5	0.097	0.046	0.476
Age 6	0.023	0.009	0.383
q1	0.564	0.083	0.147
q2	0.358	0.051	0.144
q3	0.209	0.034	0.164
q4	0.109	0.022	0.204

Correlation matrix

Age 4	Age 5	Age 6	q1	q2	q3	q4	
1	-.06	.21	.36	.28	.32	.50	Age 4
	1	.12	.17	.18	.34	.12	Age 5
		1	.18	.17	.30	.35	Age 6
			1	.15	.20	.23	q1
				1	.18	.19	q2
					1	.26	q3
						1	q4

Results are quite disparate for both the estimated parameters and their standard error and there are no consistencies between scenarios. Most scenarios produce large coefficients of variability. It does not appear that the variability get reduced by using the logs of residuals. Coefficients in the 50 - 100 % range are quite common. Scenario no. 2 produces a coefficient of the order of 200 %. Correlation can also be strong (circled values in table) especially between ages 5 and 6.

The exercise would require a great deal of 'tuning' from the operator to render the estimates similar to what is known about the population using other calibrating methods. Part of the difficulties experienced may come from the fact that selectivity of the gear has little effect compared to the selectivity of the fishery. The catch is not necessarily made up of what the gear caught but what size and quantity of scallops fishermen decided to shuck from what the gear brought on board the vessel. Research survey indices would correspond more easily to the catch if only the gear factor had to be taken into account. But in the case of the scallop catch-at-age matrix gear and, to a larger extent, the fishing strategy influences selectivity values. To be used in this context the ADAPT method needs another serie of 'q's.

Similarly, the blending practice, so peculiar to that fishery, has to be considered by any calibrating method employed. The scallop fishery targets a sedentary species and varies fishing locations according to the size required to meet demands of two types. The market place dictates the size of scallop meats but the meat count regulation, preventive measure against growth overfishing, also plays an important role in the size distribution of the catch. The meat count regulation is an average count; therefore, very small meats may be shucked provided that they will be counterbalanced by large meats; the process is called blending (see Mohn et al. 1984b for details). Blending has to be reflected in the F-at-age estimates. For example, a scenario with high F's at age 4 and low to very low F's at age over 5 is invalid. Great numbers of small age 4 meats have to be balanced against some large older scallop meats. In other words, the partial recruitment is a function of abundance at age.