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Georges Bank Scallop Stock Assessment - 1993

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ABSTRACT

Georges Bank 1993 catches were similar to 1992 catches (6,183 vs 6,151 t); the TAC was kept at the same level (6,200 t). The set TAC was not the highest available option. Industry considered it more appropriate given the potential weakness of the 1990 and 1991 year classes and such effects on future catches. The relatively abundant 1988 and 1989 year classes are the main components of the catch and are reflected in the above average catch-rates encountered throughout 1993. Research survey results indicate that the 1989 year class might not be as strong as first indicated. It would also appear that the 1991 year class (age 2 prerecruits) occurs at very low densities in the southern portion of the Bank.

According to VPA, fishing mortality rates on the targetted age group (ages 4 - 6) are quite high, averaging 0.77 over the last 5 years. Given the likelihood of decreasing recruitment, F could increase to maintain catches at the 1992 - 93 levels, one of the possible options. The stock biomass which had been rising gradually since 1989, will decline due to low recruitment and fishing pressure.

RESUME

Les prises du banc Georges en 1993 furent similaires a celles de 1992 (6,183 vs 6,151 t); le TPA demeura le même (6,200 t). Des options disponibles, le TPA établi n'était pas le plus élevé. L'Industrie jugea cette option plus appropriée étant donné la possibilité de classes d'age faibles en 1990 et en 1991 et les effets sur les prises futures. Les classes d'ages de 1988 et 1989, relativement abundantes, sont les principales composantes des captures et se réfletent dans les taux de capture au-dessus de la normale tout au cours de 1993. L'inventaire du stock indique que la classe d'age de 1989 n'est peut-être pas aussi robuste qu'observée précédemment. Il semblerait de plus que la classe d'age de 1991 (prérecrues d'age 2) est de tres faible densité dans la région sud du Banc.

D'apres l'APV, les taux de mortalité dû a la pêche sur le groupe d'age ciblé (ages 4 - 6) sont quelque peu élevés, en moyenne 0.77 durant les 5 dernieres années. F pourrait augmenter pour garder les prises au niveau de 1992 - 1993, une des options disponibles, vu la possibilité de recrutement moins fort. La biomasse du stock qui avait agrandi graduellement depuis 1989 va diminuer a cause du bas recrutement et de l'intensité de la pêche.

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 (Fig. 1). 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 focused on stock rehabilitation through a better utilisation 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. In 1993, only 42 vessels, about half the initial number of license holders, were actively involved in the Georges Bank fishery. The meat count (size limit) was also lowered to 33 meats per 500 g in January 1986 to direct exploitation toward slightly larger scallops.

Over the last 3 years, TAC's and catches have been maintained around 6,000 t; 1993 recorded the second highest catches since 1986 (Table 1). Although TAC options presented to industry went up to 7,150 t for 1993 (Robert et al. MS 1993), the offshore scallop fleet sector recommended a 6,200 t TAC, the same level as in 1992. A cautious approach was based on indications from survey results of potentially poor recruitment from the 1990 and 1991 year classes. The 1993 TAC was set at 6,200 t.

A fairly large portion of catches, 25 %, came from the first quarter of 1993. This is the second time in recent years that winter catches are more than double the traditional levels for the first quarter. Concurrently, catch-rates are excellent; on an annual basis, values for the 1990's are in the medium to high range (Table 2). The 1993 rates, 15 % higher than 1992, recovered from the slight dip from 1991 to 1992. Monthly variations have been relatively moderate. From record values during the summer of 1992, CPUE's experienced a seasonal drop in the fall related to spawning (Fig. 2). The biomass present allowed for a strong rebound which maintained rates above 0.6 kg/crhm throughout the winter of 1993. Catch-rates declined smoothly for the remainder of 1993. A closer look at the geographical distribution of the 1993 CPUE's (Fig. 3) shows the area with rates over 1 kg/crhm extending farther to the east and south than in 1992 (Robert et al. MS 1993); it is also more fragmented. The monthly profile of scallop meat weight is very uniform in 1993 (Table 3). The drop in meat weight, when a new year class recruits to the fishery is not noticeable in the fall of 1993. The reduced presence of small meats is shown by the remarkably low frequencies in the 7 and 9-g interval in the quarterly distribution of meat weights from the catch (Table 4). The abundant 1989 year class is located in the 15-g+ interval.

METHODS

Fishery data

Catch and effort data are compiled from logbooks. Logs with complete effort data are called Class 1 and are used to estimate catch-rates. The Class 1 data represent more than 90% of the total (Table 2). Effort is measured in fishing days (fd), 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 fishing day, per hour, and per crew-hour-meter. Catch per fd is a somewhat crude estimate. 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. CPUE in kg / h is used in the cohort tuning analysis. 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. 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.

Size distributions of meats from the commercial fleet are derived from port samples. Only one or two company fleet(s) have regularly contributed the information. An experimental program is under way to determine if there would be a difference in catch meat weight profile with sampling extended to all companies given their different fishing strategies. 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. Table 5 lists the frequency distribution on an annual basis. There has been a gradual shift toward larger meats in the catch over the last 10 years, reflecting the implementation of a lower meat count in 1986. More recently, it would appear that the 1993 catch was focussed on fewer size groups with very few meats under 10 g and considerably fewer meats over 30 g.

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 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 6).

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 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. 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 1993. 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. The areas of very high and high catch-rates were sampled more heavily as they represent the area most important to the fleet (and

presumably the areas of greatest abundance). It was felt necessary in 1991 to add a very high stratum to reduce the variability of the high stratum. The range of catch-rate values encountered has increased markedly. Both in 1992 and 1993, 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 was 10 kg/crhm. This reflects the steady rise in average catch-rates. 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 (Fig. 4). 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 8a 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%. A more complete description of the contouring method and volume estimation may be found in Black (MS 1993).

The area surveyed varies to some extent from year to year, given the spatial distribution of scallop beds exploited. Figure 5 plots survey locations on an annual basis from 1981 to 1993. Each map also shows an area (dashed line polygon) represented by locations surveyed every year; this area of common coverage is defined as a minimum polygon. Over the 13-year period, the minimum polygon area (Fig. 6) covered 50 % of the total area surveyed at one point or another. Relative abundance estimates (volume estimates) may also be computed for the minimum polygon (Table 8b) as for each annual survey area (Table 8a).

Biomass indices (Table 8c) 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 6. 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 7 and 8) to provide density and biomass estimates for the Canadian side of Georges Bank only.

There is a correlation of 93 % between survey biomass indices for recruited ages 4 to 6 determined by volume estimates of area surveyed and the biomass computed by aerial expansion of stratified means (Fig. 7).

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 1993. This pattern, multiplied by the F determined from tuning for the last quarter year (F_{Q4} 1993), was used as a

starting vector for the quarterly cohort analysis.

Since analytical assessments have been carried out for Georges Bank scallops (Mohn et al. MS 1984), natural mortality had been set at .025 per quarter (M = 0.1 on an annual basis) and no attempt was made to include a seasonal, age or time dependent effects. It was felt appropriate to investigate other possible estimates for natural mortality. The rationale behind its present value lies in fieldwork investigations undertaken by Dickie (1955) in the Bay of Fundy, Merrill and Posgay (1964) for Georges Bank and more recently, MacDonald and Thompson (1986) in Newfoundland. The last authors established that M was levelling off at 0.1 for adult age groups to rise slowly at age 11 and older. Several indirect methods of estimating M are reviewed in Rivard (1988), Sinclair et al. (1990), and Vetter (1988). A number of methods revolve around the analysis of catch data while others try to correlate M with other life history parameters. Catch curve analyses can seriously bias the estimation of M when some assumptions (recruitment, random sample, catchability, M independent of age) are not met. Analyses of commercial and research survey catch data from Georges Bank were not successful. Too many assumptions could not be adhered to: recruitment is far from uniform; constant catchability does not apply to the catch; M according to field investigations varies with age, to mention a few. Research survey data show fluctuations in recruitment of more than 10 fold. The targeting of specific size groups in the scallop fishery most seriously violate the assumption of catchability. Using molluscan data Hoenig (1983) has correlated mortality rate with maximum observed age for unexploited or lightly exploited stocks. Following his method and estimating 25 to 30 years for maximum age would put M at 0.18 to 0.15 respectively. The figure for maximum age is derived from the catch-at-age data where under 1 % of meats sampled would reach that age. Pauly (1980) predicts M from growth parameters and mean water temperature for finfish. For temperatures around 10 - 12 C and Browns (1972) growth equation for Georges Bank scallops would give values for M of 0.7 and 1.5. Pauly's empirical equation may apply to finfish but not necessarily to shellfish. Orensanz et al. (1991) cautions that these equations can only provide very rough estimates. By using indirect derivatives, a Z value is arrived at, but Z has still to be partitioned between F and M. Furthermore, Vetter (1988) warns about the complex effects of different estimations of M and their assumptions on fishery models. The effects were generally a function of both the values of F and M. We concluded that a M value of 0.1, as established by field investigations of several researchers, was more appropriate than theoritical estimations relying on assumptions that could not be met.

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 useful 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 toward ages 4 and 5 (Fig. 8), 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.) In addition to tuning for cohort biomass (ages 3 - 11), iterations were carried out on cohort numbers ages 4 to 6 and biomass for those 3 ages. Since 1986, ages 4 to 6 represent 50 % or more of the animals in the stock compared to the other ages. Fishable biomass was also tuned against CPUE.

For the purposes of tuning, the terminal F (quarterly rate) ranged from 0.05 to 0.15 (Table 10). If fishable biomass were excluded from the tuning process, the minimum terminal F value used could have been increased from 0.05 to 0.08. Tuning of cohort biomass on research survey biomass within the minimum polygon was also excluded. It gave a poorer fit than survey biomass estimates over the survey area. Depending on the year, a scallop bed or portion thereof may contribute to the stock biomass under exploitation but not be included in the minimum polygon. Regression of cohort biomass on CPUE: the maximum correlation coefficient, 0.772, for the regression of cohort biomass on CPUE corresponded to an F_{Q4} of 0.07; the residual (1993)

crosses the regression line closer to 0.08. Cohort ages 4 - 6 on CPUE: cohort numbers and biomass for ages 4 to 6 regressions have higher correlation coefficient, 88 and 89 % for very similar terminal F's. Residual points come very close to the line at F_{Q4} = 0.10. Cohort biomass on research survey biomass: the maximum correlation coefficient is only of the order of 0.62. While the 1992 residual crosses the line at 0.10, the 1993 residual is at 0.15. F versus effort: contrary to the tuning variables presented so far, there is a poor fit for a maximum correlation coefficient under the selected F_{Q4}'s but the 1993 residual is right on the regression line at the same F_{Q4} than for cohort ages 4 to 6 vs CPUE tuning (Table 10). The correlation coefficient is then of lower value, around 47 %. Fishable biomass on CPUE: the correlation coefficient is somewhat intermediate when residual points come near the line at a low F_{Q4} (0.05) compared to the other tuning variables. The residual points of the last two year's data and the correlation coefficient were used as tuning criteria. The highest variability, close to 90 %, could be explained by CPUE versus specific ages in the cohort. High values were also maintained when the residual points for the last two years were very small. The positive residual values in table 10 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. This also holds true for regression of ages 4 to 6 and for fishable biomass 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.

Strong correlations between CPUE and different cohort variables occurred at an F_{Q4} in the vicinity of 0.10. When all ages were considered in the cohort analysis, 76 % of the variability could be explained when the last two residual points were very small at a terminal F equal to 0.08 (Table 10 and Fig. 9). More of the variability could be explained when focussing on the ages targeted by the fishery, namely ages 4 to 6. In terms of biomass, almost 90 % of the variability related to CPUE as the tuning factor and the 1993 residual comes very close to the regression line at an F_{Q4} equal to 0.10 (Fig. 9 middle). This value for a terminal F is supported when the cohort biomass is regressed against the research surveys and with F versus effort. At an F_{Q4} of 0.10 in the cohort versus research biomass, the1992 residual crosses the line but not the 1993 residual. Plotting residuals between cohort biomass and research survey biomass for 1993, shows the underrepresentation of ages 4 and under in the survey; confirming suspicions that the survey gear was, at times, not fishing properly. Tuning with the 1993 residual as prime factor would also mean that the 1991 point would go below the line (positive residual). It has been established previously (Robert et al. MS 1993) that the 1991 survey had in all probabilities underestimated the stock biomass at the time. Generally speaking, it might be more difficult to get a tight relationship in cohort biomass versus research survey tuning since only ages 3 - 6 are considered from survey results; they are the main age groups in the stock though. Also the selectivity of the research survey gear is not taken into account. The data also applies to the third quarter of the year. Although less than 50 % of the variability between F and effort could be explained by the regression, it too was placing the most recent residual point on the line with an F_{Q4} of 0.10 (Fig. 9). Given the low value for terminal F (0.05) generated by the regression fishable biomass on CPUE compared to the other tuning variables used, it is not considered further in the analysis.

A sequential population analysis using Non Linear Least Square Regression (NLLS) (ADAPT, Gavaris 1988) was also attempted. 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 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 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. 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 25, 40, 20, and 15 %, which reflects the fishery in the last four years. Although the first half of the year has traditionally experienced 50 % or more of the annual effort, the effort in the first quarter used to be in the order of 10 %. In recent years the effort figure for the first quarter has been twice to three times the historical value. With the implementation of EA's in 1986, the annual distribution of effort has shifted markedly not only toward the beginning of the year but also in-between quarters. Companies are aligning fishing plans more closely to particular market demands. 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.

Stock 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 1993 research survey are plotted in Figure 4. Station locations are indicated in the plot for age 6. As in 1992 all reported catch activity took place above 100 m; therefore, no stations were allocated to the area deeper than 100 m. In years of good abundance, the fleet does not venture in these marginally exploitable areas. The 1993 survey shows that the abundance of recruited ages (4+) is good to excellent (Table 7). Recent rebuilding of the stock has allowed the observation of age 8 scallops in 3 of the 5 strata (Table 9); numbers at age 7 are also on the rise. The 1988 year class (age 5) of moderate to high abundance in previous surveys suffered an important decrease; nevertheless the number of age 5 left is comparatively high. Previous surveys were indicating that the 1989 year class (age 4) was strong. The 1993 survey contradicts that somewhat. It is possible that aggregations (total or partial) of age 4 scallops might not have been sampled. The abundance-at-age for prerecruits is abnormally low. Because of difficulties with the survey gear at times, it is questionable whether prerecruit abundance is representative. However, it is indicative of a declining trend in recruitment following the 1988 and 1989 year classes. The presence of age 2 scallops was not observed throughout the southern portion of the Bank, representing 37 % of the sampling locations. Biomass indices derived from volume estimation or aerial expansion (Tables 8a-c) also reflects the decrease in biomass of commercial ages related to exploitation and declining recruitment.

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 0.10. From a population numbers point of view (Table 12), the last 3 years see the passage of the 1988 and 1989 year classes into the population, the 1989 year class being larger than 1988. Relatively speaking, both would be comparable to the 1978 and 1982 year classes. The biomass profile has been increasing over the last 6 years (Table 13) although within a small range. Table 14 presents a series of annualised fishing mortality. The series is decomposed into segments in Fig. 10. 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. Nowadays, F3 has come down to very low levels with the targetting of older ages. The mean F on all ages (F3-11) has varied little since 1986. The average value for 1987 to 1993 equals 0.36. The drop in F for 1993 might not be as important, 1993 being the last data point in the cohort generating exercise. The same is true for F 4-6. Ages 4 to 6 are the main age groups in the catch matrix. F4-6 is much higher generally speaking; after a dip in 1988, it has averaged 0.77 over the last 5 years.

Selected results of sequential population analysis using NLLS are given in the appendix. Quite often, NLLS cannot find a minimum residual given the independent estimates and parameters to be estimated. The estimation of multiple parameters may generate invalid values, see the very high coefficients of variation in the first example. According to the correlation matrix, there are very strong relationships between the parameters. It would appear that NLLS may work better when estimating a single parameter, F at age 5 in selected examples. In this case a partitioned search did not improve the estimated value of F at age 5 by much, from 0.098 to 0.096, with annual CPUE as independent estimate. Yet, with CPUE and research survey indices as independent estimates, NLLS could not estimate a single parameter. Results from the NLLS iterations would indicate that NLLS has difficulties fitting the present set of data.

Population variables were also iterated with annualised values of M equal to 0.15 and 0.18. The same tuning criteria were used to establish a terminal F for the last quarter. Biomass at the end of 1993 are given as a comparative point. The biomass corresponding to F_{Q4}= 0.10 is included for reference.

M_Q, (annual)	F_{Q4}	Biomass (t) at the end of 1993
0.025, (0.10)	0.10	15,009
0.038, (0.15)	0.09	16,732
0.045, (0.18)	0.09	16,793

For a same value of F, a larger M rate has the net effect of generating a higher stock biomass figure. The differences in biomass referring to a higher M, derived from life history parameters, are 11 and 12 % larger compared to the biomass with M equal to 0.10.

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 1988 and 1989 assessments had an F_{max} which was estimated to be at an F of 0.97 and $F_{0.1}$ at 0.59. The 1992 estimate was 1.097 for F_{max} and 0.700 for $F_{0.1}$. The difference between the newly calculated values and the ones used previously justified a recalculation of the yield per recruit

model. The exercise was repeated in 1993. Estimated values were highly similar to 1992; no changes were brought to F_{max} and $F_{0.1}$. The same selectivity is used in the cohort analysis, yield per recruit, and the stock projections (Table 15). The projections are carried out at $F_{0.1}$ and F_{max} using the numbers-at-age of the last quarter from the 1993 cohort analysis aged forward to the first quarter of 1994. The projections for a one year period assume a recruitment level of only 250 millions scallops to reflect the low densities observed in the research survey results and anecdotal information from the fleet. Average recruitment would be 400 millions approximately.The partial recruitment vector used : 0.02, 0.41, 1.00, 0.49, 0.32, 0.22, 0.19, 0.15, and 0.07; last year was: 0.02, 0.45, 1.00, 0.43, 0.26, 0.18, 0.18, 0.16, and 0.09. The new vector is highly similar on the left (age 4), age 5 acting as the pivot, while the slope of the 1992 vector was slightly steeper for ages 6 and 7 on the right side.

Considering the patterns of high fishing mortality rates on ages 4 to 6 in recent years, an average of 0.77, and the probability that the 1989 year class is not as strong as first indicated, yet the main target at age 5 in 1994, catch projections at $F_{0.1}$ and F_{max} with a terminal F_{Q4} at 0.13 were run for 1994. They are 4,100 t and 5,550 t respectively (Table 15). The meat count will be met without difficulties; the mean weight of the catch being 17.7 g at its lowest value in the winter fishery. The mean weight of the catch is on the rise as year classes coming into the fishery are not as abundant. Under the assumed recruitment pattern, the projected biomass increases by 7 % under $F_{0.1}$ and decreases by 3 % under the F_{max} scenario. This also reflects the declining trend in recruitment.

Other fishing scenarios are given in table 16. They encompass a wide range of catch levels (4,100 to 6,200 t) and F values (0.70 to 1.32). Some options are fairly similar to each other; namely, the 1993 scenario, same TAC or same effort. These 2 options produced the highest catch projections.

CONCLUSIONS

Stock biomass and catches have been rising gradually over the last five years from 12,000 to 15,000 t (Tables 2 and 13). A build-up of biomass and significant contributions from the strong 1988 and 1989 year classes were responsible for this rising trend in the fishery performance. It would appear that the process might have peaked. The outlook for 1994 is of a slow decline in performance since the main age classes available are the leftovers of the 1988 year class and the 1989 year class which at age 5 is fully exploited. 1995 will deal with the leftovers of the 1989 year class but the bulk of the biomass will come from the weaker 1990 year class. The stock biomass will adopt a declining trend; so far, there has been no observations of a strong recruitment to reverse this trend.

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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.

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	5218	5218
1991	0	5805	5805
1992	0	6151	6151
1993	0	6183	6183

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

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/ fd*	kg/ h*	kg/crhm
1972	2746	5404	75	9220	508.14	36.61	0.298
1973	1975	3716	54	6333	531.49	36.67	0.312
1974	4541	6071	90	10810	747.98	50.46	0.420
1975	6524	7234	105	13389	901.85	62.13	0.487
1976	7809	6129	90	12222	1274.11	86.77	0.639
1977	11126	7386	82	11051	1506.36	135.68	1.007
1978	10970	7692	100	13686	1426.16	109.70	0.802
1979	7642	7327	105	14372	1042.99	72.78	0.532
1980	4751	6232	86	11785	762.36	55.24	0.403
1981	7612	8020	100	14484	949.13	76.12	0.526
1982	3918	5564	73	9977	704.17	53.67	0.393
1983	2418	4825	67	8690	501.14	36.09	0.278
1984	1945	5716	70	8598	340.27	27.79	0.226
1985	3812	7376	105	12644	516.81	36.31	0.301
1986	4900	3915	52	6957	1251.60	94.23	0.704
1987	6793	5736	78	10808	1184.27	87.09	0.629
1988	4336	5853	85	11283	740.82	51.01	0.385
1989	4676	5154	78	10774	907.26	59.96	0.434
1990	5218	4724	72	10570	1104.57	72.09	0.494
1991	5805	4272	66	9687	1358.90	88.40	0.599
1992	6151	4697	73	10957	1309.52	84.10	0.561
1993	6183	4043	64	9868	1529.18	96.76	0.627

* crew-hour-meter; fishing day; hour

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

%	catch examined	meat weight (g)				n meats
	catch landed	mean	min	max	s.e.	
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
1992	0.00532					
January		16.81	6.68	50.99	0.07	1022
February		16.61	5.90	49.00	0.06	1287
March		16.49	4.33	49.69	0.04	2692
April		16.62	6.22	61.76	0.05	2480
May		16.71	5.76	62.80	0.09	837
June		17.51	6.85	43.54	0.08	817
July		16.91	8.07	51.74	0.07	886
August		16.81	6.08	58.48	0.05	2377
September		16.43	6.30	44.70	0.05	1323
October		15.94	5.12	51.62	0.04	3126
November		15.44	5.41	52.79	0.04	2576
December		15.69	6.91	47.64	0.08	535
1993	0.00485					
January		16.40	7.64	44.20	0.04	1740
February		---	---	---	---	0
March		16.84	5.43	51.04	0.05	1204
April		16.35	6.44	58.27	0.04	2158
May		17.07	6.51	55.99	0.04	2353
June		15.90	7.00	37.00	0.05	943
July		16.74	7.51	36.10	0.06	898
August		16.69	7.21	44.49	0.05	1807
September		16.26	5.67	39.13	0.04	2163
October		16.28	5.36	46.89	0.04	2166
November		15.97	5.88	47.33	0.04	2201
December		16.54	6.85	37.66	0.08	585

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

Grams	1990	Q1	Q2	Q3	Q4	1991	Q1	Q2	Q3	Q4
1		0	0	0	0		0	0	0	0
3		0	0	0	0		0	0	0	0
5		4	0	0	1		1	0	0	2
7		50	10	15	18		11	6	8	12
9		161	57	76	83		73	45	58	70
11		221	134	151	146		147	140	150	121
13		195	178	178	158		170	210	184	147
15		133	155	152	146		148	177	167	139
17		86	128	123	117		131	117	132	133
19		56	95	86	86		105	76	95	114
21		37	79	63	71		68	53	66	76
23		22	52	49	49		41	39	50	53
25		13	39	36	36		30	29	22	35
27		8	25	21	24		19	20	16	20
29		4	14	16	19		17	22	14	16
31		3	11	11	13		12	13	6	12
33		2	6	8	9		8	12	8	11
35		2	6	5	6		5	10	4	6
37		1	4	2	5		5	7	6	9
39		1	1	2	5		3	5	1	6
41		0	3	2	2		2	5	4	6
43		0	1	1	2		1	3	3	3
45		0	1	1	1		1	5	2	2
47		0	0	0	1		1	1	2	2
49		0	0	0	1		0	2	2	2

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	1		0	0	0	0
7		6	8	8	8		2	4	4	11
9		41	60	43	59		19	23	45	57
11		112	151	121	160		81	108	125	137
13		188	201	176	218		192	200	186	176
15		191	168	182	186		220	219	173	175
17		158	106	147	128		192	156	149	137
19		107	83	103	89		120	96	115	115
21		68	47	80	49		77	63	67	76
23		49	42	46	33		39	41	46	44
25		26	34	33	18		23	37	34	29
27		17	29	18	15		14	19	20	17
29		13	18	15	8		5	11	13	8
31		8	13	9	7		6	10	10	7
33		6	8	6	6		4	5	7	3
35		3	7	4	5		1	4	3	3
37		3	4	2	3		0	1	1	2
39		1	5	3	2		1	1	1	1
41		1	3	1	1		1	1	0	0
43		1	5	0	1		1	0	0	0
45		1	1	1	1		0	0	0	0
47		0	2	1	1		0	0	0	0
49		1	1	0	0		0	1	0	0

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

	Year									
Grams	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	0	0	0	0	0	0	0	0	0	0
3	7	1	0	0	0	0	0	0	0	0
5	96	20	0	2	3	1	2	1	0	0
7	205	112	6	17	28	14	24	9	8	6
9	169	211	41	79	98	83	96	60	51	38
11	108	197	125	150	163	179	164	139	137	116
13	69	136	209	175	179	219	177	181	197	188
15	55	87	225	168	152	182	146	159	182	195
17	46	57	160	129	104	117	113	127	135	155
19	41	42	96	89	75	72	80	95	95	110
21	37	30	55	59	54	43	62	64	60	70
23	30	21	28	44	36	30	43	44	42	43
25	25	17	17	29	27	18	30	29	27	32
27	20	13	11	18	22	14	19	19	19	18
29	18	11	8	12	16	7	13	18	13	10
31	15	9	3	9	11	6	9	11	9	9
33	12	7	3	6	9	4	6	10	6	5
35	11	6	3	4	6	4	5	7	5	3
37	8	5	2	3	5	2	3	7	3	1
39	6	4	1	2	4	2	2	4	2	1
41	5	3	2	1	3	1	2	4	2	0
43	4	3	1	1	2	1	1	3	2	0
45	3	2	0	0	1	1	1	3	1	0
47	2	2	0	0	1	0	0	1	1	0
49	2	1	0	1	1	0	0	2	1	0
51	2	1	1	0	1	0	0	1	0	0
53	1	1	0	0	0	0	0	1	0	0
55	1	1	0	0	0	0	0	1	0	0
57	1	0	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0	0	0
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	1	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.- 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	177	191	24	5	2	1	0	0	0
1982	26	49	23	6	1	0	0	0	0
1983	44	31	18	5	1	1	0	0	0
1984	271	35	14	3	1	0	0	0	0
1985	104	206	18	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
1991	359	103	49	13	3	1	0	0	0
1992	83	195	108	23	6	2	0	0	0
1993	10	42	46	24	7	2	0	0	0

Table 8a.- 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

Table 8b.- Indices of abundance of scallop age-classes by volume estimates: numbers-at-age (10^6), minimum dredgeable biomass at survey time (t of meats) from tow data inside a minimum polygon.

Sampling dates	Age (years)				
	3	4	5	6	Biomass
1981	275.70	48.38	7.46	3.22	1445
1982	90.38	33.94	13.34	4.47	770
1983	36.19	30.50	11.44	5.36	546
1984	73.41	16.65	6.13	1.79	470
1985	645.15	48.84	5.69	1.32	2705
1986	186.67	279.18	33.69	3.58	3074
1987	177.77	95.77	46.90	16.35	2053
1988	307.43	96.69	22.93	5.87	2108
1989	349.41	128.73	24.31	5.13	2490
1990	195.88	98.80	36.81	9.66	1934
1991	208.26	112.10	36.92	10.34	2084
1992	443.25	275.57	52.10	15.27	4318
1993	165.58	102.58	57.21	19.61	2217

Table 8c.- 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

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.e.
		2	3	4	5	6	7	8	9	10+		
Very low	1988	39	104	67	9	1	0	0	0	0	236	104
	1989	50	55	95	16	2	0	0	0	0	225	64
	1990	40	41	33	19	5	1	0	0	0	148	34
	1991	132	15	21	10	3	1	0	0	0	185	121
	1992	22	105	86	28	6	2	1	0	0	250	143
	1993	4	197	90	18	8	2	0	0	0	321	174
Low	1988	50	116	57	12	2	0	0	0	0	250	52
	1989	44	68	73	13	2	1	0	0	0	203	77
	1990	70	39	27	10	5	1	0	0	0	161	61
	1991	411	49	40	17	4	1	0	0	1	532	165
	1992	32	86	72	28	10	1	0	0	0	230	74
	1993	3	26	30	14	6	2	1	0	0	83	22
Medium	1988	17	45	37	9	3	1	0	0	0	112	39
	1989	155	143	88	22	3	0	0	0	0	412	96
	1990	105	142	21	13	3	1	0	0	0	290	116
	1991	378	95	53	16	3	1	0	0	0	555	166
	1992	56	167	92	44	11	2	0	0	0	372	67
	1993	7	59	38	21	1	4	1	0	0	144	40
High	1988	141	113	48	10	2	1	0	0	0	317	30
	1989	138	161	57	9	2	1	0	0	0	369	51
	1990	131	99	47	15	3	1	0	0	0	298	32
	1991	305	68	43	12	3	1	0	0	0	476	153
	1992	85	171	104	19	6	2	0	0	0	387	47
	1993	11	23	36	20	7	2	1	0	0	101	14
Very high	1991	408	157	58	12	3	1	0	0	0	672	142
	1992	111	263	127	15	4	1	0	0	0	521	74
	1993	11	29	48	28	6	1	0	0	0	124	8

Table 10. - Tuning criteria for the regressions of cohort biomass, cohort numbers ages 4-6, and cohort biomass ages 4-6 on CPUE (upper section of table); of cohort biomass on research survey biomass estimates, of fishing mortality on effort, and fishable biomass on CPUE (middle section); of cohort biomass on survey biomass estimates from inside a minimum polygon (lower section) for selected F_{Q4}.

	Coh Biom vs CPUE			Coh N vs CPUE			Biom 4-6 vs CPUE		
F_{Q4}	R^2	1992*	1993*	R^2	1992*	1993*	R^2	1992*	1993*
0.05	0.735	-3352	-6841	0.777	-21	-498	0.803	-382	-6218
0.06	0.769	-1874	-3774	0.835	9	-339	0.858	83	-4127
0.07	0.772	-819	-1583	0.864	29	-225	0.885	416	-2634
0.08	0.759	-28	60	0.876	45	-140	0.894	665	-1514
0.09	0.739	587	1337	0.878	57	-74	0.893	859	-643
0.10	0.717	1080	2359	0.873	67	-20	0.886	1014	54
0.11	0.694	1482	3196	0.865	75	23	0.876	1141	624
0.12	0.673	1818	3892	0.856	81	59	0.865	1247	1099
0.13	0.653	2102	4482	0.845	87	90	0.853	1336	1501
0.14	0.635	2345	4987	0.835	92	116	0.842	1413	1845
0.15	0.619	2556	5425	0.825	96	139	0.831	1480	2144

	Coh Biom vs Res Biom			F vs Effort			Fish Biom vs CPUE		
F_{Q4}	R^2	1992*	1993*	R^2	1992*	1993*	R^2	1992*	1993*
0.05	0.235	-3104	-14747	0.567	0.04	0.09	0.679	1077	595
0.06	0.286	-2116	-11060	0.553	0.01	0.07	0.645	1434	1432
0.07	0.342	-1410	-8427	0.535	-0.01	0.05	0.617	1689	2030
0.08	0.401	-880	-6453	0.514	-0.03	0.04	0.594	1879	2478
0.09	0.462	-469	-4917	0.491	-0.04	0.02	0.576	2027	2826
0.10	0.518	-139	-3688	0.466	-0.06	0.00	0.561	2144	3104
0.11	0.565	130	-2683	0.440	-0.07	-0.02	0.548	2240	3332
0.12	0.598	355	-1846	0.414	-0.08	-0.03	0.537	2320	3521
0.13	0.616	545	-1137	0.388	-0.10	-0.05	0.528	2387	3681
0.14	0.620	708	-530	0.362	-0.11	-0.07	0.520	2445	3818
0.15	0.610	849	-4	0.336	-0.12	-0.08	0.513	2494	3936

	Coh Biom vs Min.Polygon		
F_{Q4}	R^2	1992*	1993*
0.05	0.362	-1038	-13600
0.06	0.410	-529	-10079
0.07	0.461	-166	-7565
0.08	0.511	107	-5680
0.09	0.556	319	-4213
0.10	0.590	488	-3040
0.11	0.612	627	-2080
0.12	0.617	743	-1281
0.13	0.607	840	-604
0.14	0.584	924	-24
0.15	0.551	997	479

* 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	1991	1992	1993
3	11	11	15	6
4	173	151	180	180
5	124	140	133	158
6	13	19	26	19
7	8	6	7	7
8	5	6	2	2
9	1	7	3	1
10	0	3	4	1
11	0	1	1	1
Total	335	344	371	375

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 0.10.

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	232	211	448	622	421	337	424	472
4	672	309	167	160	343	500	379	284	363
5	112	145	118	66	80	173	276	164	142
6	33	30	43	46	28	37	54	74	58
7	25	15	15	26	22	15	23	34	46
8	43	15	7	10	15	11	11	18	26
9	16	34	11	5	8	10	8	8	16
10	6	11	28	8	3	6	9	5	6
11	3	3	7	22	6	2	5	6	3
Total	1563	794	607	790	1126	1173	1102	1017	1132

Ages	1990	1991	1992	1993
3	426	522	705	379
4	412	375	462	623
5	177	210	195	246
6	32	44	58	51
7	35	17	22	28
8	34	24	10	13
9	22	26	16	7
10	14	19	17	12
11	5	12	15	12
Total	1158	1248	1500	1371

Table 13.- Biomass Q2 (t of meats) east of the ICJ line from cohort analysis using a terminal F_{Q4} of 0.10.

Ages	1972	1973	1974	1975	1976	1977	1978	1979	1980
3	2145	2324	3250	5298	5574	3447	2184	1838	3909
4	1733	2210	3424	4858	7394	10227	5449	3383	3217
5	1997	1208	2007	1963	2852	4937	5481	2741	1879
6	251	1778	1131	1540	1320	1591	3032	2700	1181
7	341	184	1851	1074	1467	1037	1333	1488	1815
8	51	303	165	1813	1025	1305	897	608	827
9	32	32	286	145	1735	914	1190	455	331
10	16	22	23	262	124	1549	812	791	241
11	13	9	16	14	237	67	1396	473	563
Total	6579	8070	12154	16968	21729	25074	21773	14477	13963

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	2891	1038	909	2002	2780	1883	1505	1895	2113
4	6637	3224	1534	1718	3755	5479	3993	3052	3776
5	1854	2345	1852	1125	1433	3072	4071	2776	2074
6	768	707	1048	1068	689	893	1218	1747	1304
7	723	422	450	737	660	433	679	1011	1306
8	1447	518	255	345	525	361	343	624	884
9	574	1259	397	168	282	378	277	278	577
10	200	425	1089	291	113	224	326	171	227
11	126	109	299	892	224	64	202	253	92
Total	15220	10048	7834	8348	10462	12787	12614	11808	12354

Ages	1990	1991	1992	1993
3	1905	2334	3153	1694
4	3846	3914	4861	6619
5	2238	3027	2665	3359
6	719	982	1279	1150
7	1002	459	613	801
8	1109	772	312	434
9	824	900	581	237
10	541	730	634	455
11	202	491	590	470
Total	12386	13611	14687	15218

Table 14.- Annualised fishing mortality east of the ICJ line from cohort analysis using a terminal F_{Q4} of 0.10.

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	0.23	0.18	0.17	0.12	0.01	0.07	0.05	0.04
4	1.44	0.86	0.83	0.59	0.59	0.49	0.74	0.59	0.62
5	1.21	1.11	0.85	0.75	0.68	1.06	1.22	0.94	1.38
6	0.72	0.60	0.42	0.62	0.56	0.35	0.36	0.37	0.40
7	0.39	0.57	0.27	0.40	0.63	0.22	0.14	0.17	0.21
8	0.14	0.26	0.35	0.21	0.31	0.18	0.21	0.06	0.06
9	0.30	0.11	0.23	0.40	0.18	0.08	0.43	0.17	0.02
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
Mean	0.69	0.52	0.41	0.38	0.42	0.28	0.38	0.34	0.34

Ages	1990	1991	1992	1993
3	0.03	0.02	0.02	0.02
4	0.58	0.55	0.53	0.36
5	1.29	1.18	1.24	1.09
6	0.57	0.60	0.62	0.48
7	0.28	0.43	0.41	0.29
8	0.17	0.29	0.29	0.18
9	0.07	0.32	0.21	0.15
10	0.03	0.16	0.25	0.11
11	0.09	0.07	0.09	0.11
Mean	0.34	0.40	0.41	0.31

Table 15 .-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 0.13.

F = 0.70	1994_{Q1}	1994_{Q2}	1994_{Q3}	1994_{Q4}
Rate on smalls	1.00	1.00	1.00	1.00
Mean Wgt. Catch	17.77	18.09	19.91	23.25
Catch (Mill.)	59.13	90.14	40.04	26.13
Catch (t)	1,051	1,630	797	607
Cum. Catch (t)	1,051	2,681	3,478	4,085
Biomass	11,624	11,433	11,596	12,440

F = 1.10	1994_{Q1}	1994_{Q2}	1994_{Q3}	1994_{Q4}
Rate on smalls	1.00	1.00	1.00	1.00
Mean Wgt. Catch	17.77	17.98	19.68	23.10
Catch (Mill.)	89.16	124.47	51.24	31.85
Catch (t)	1,585	2,238	1,009	736
Cum. Catch (t)	1,585	3,823	4,832	5,568
Biomass	11,051	10,125	9,976	10,686

Table 16.- Fishing scenarios established for 1994 given different options of fishing mortality rate. Biomass figures are for the end of 1994. Catch figures are rounded off to the nearest 50 t.

No.	Options	Fvalues	Biomass (t)	Catch (t)
1	$F_{0.1}$	0.70	12,440	4,100
2	$F_{replacement}$ yield	0.85	11,720	4,700
3	F_{max}	1.10	10,686	5,550
4	F_{1993} effort	1.29	10,015	6,150
5	F_{1993} TAC	1.32	9,917	6,200

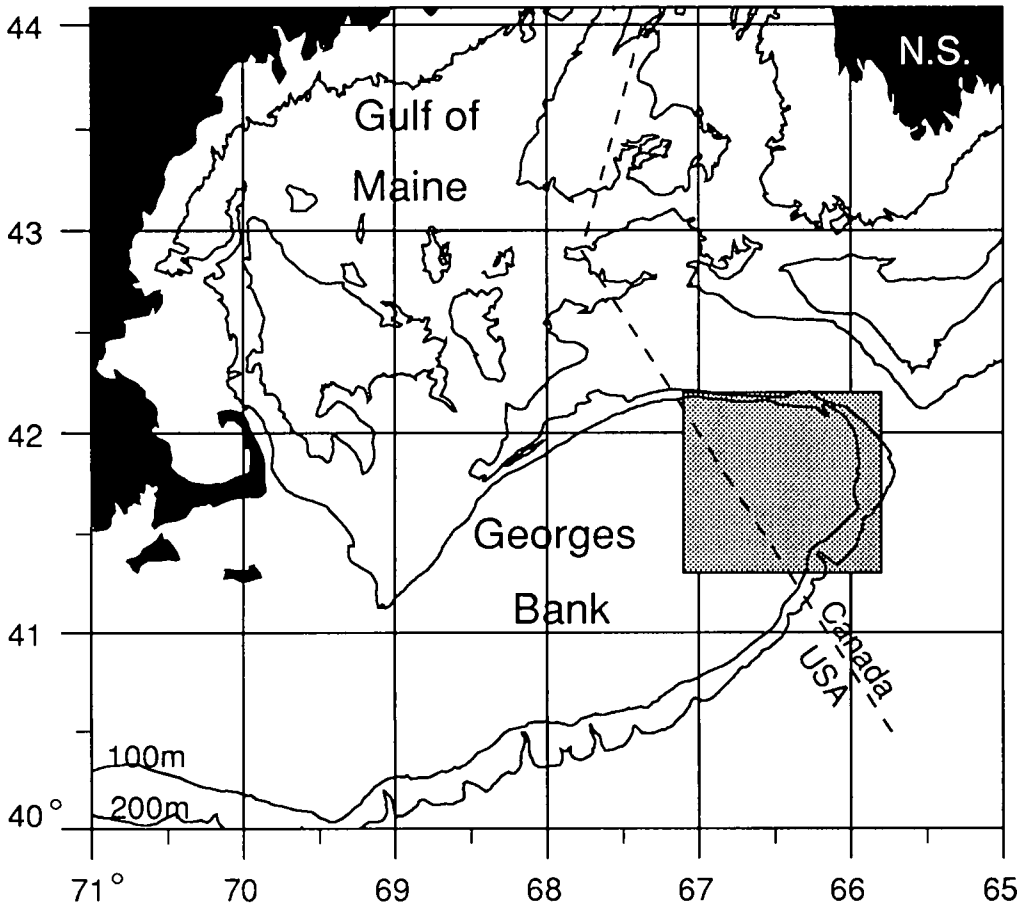

Figure 1.- Georges Bank and surrounding areas. The dashed line represents the international boundary between Canada and USA waters, the International Court of Justice line. The grey box refers to the area shown in figures 3 to 6.

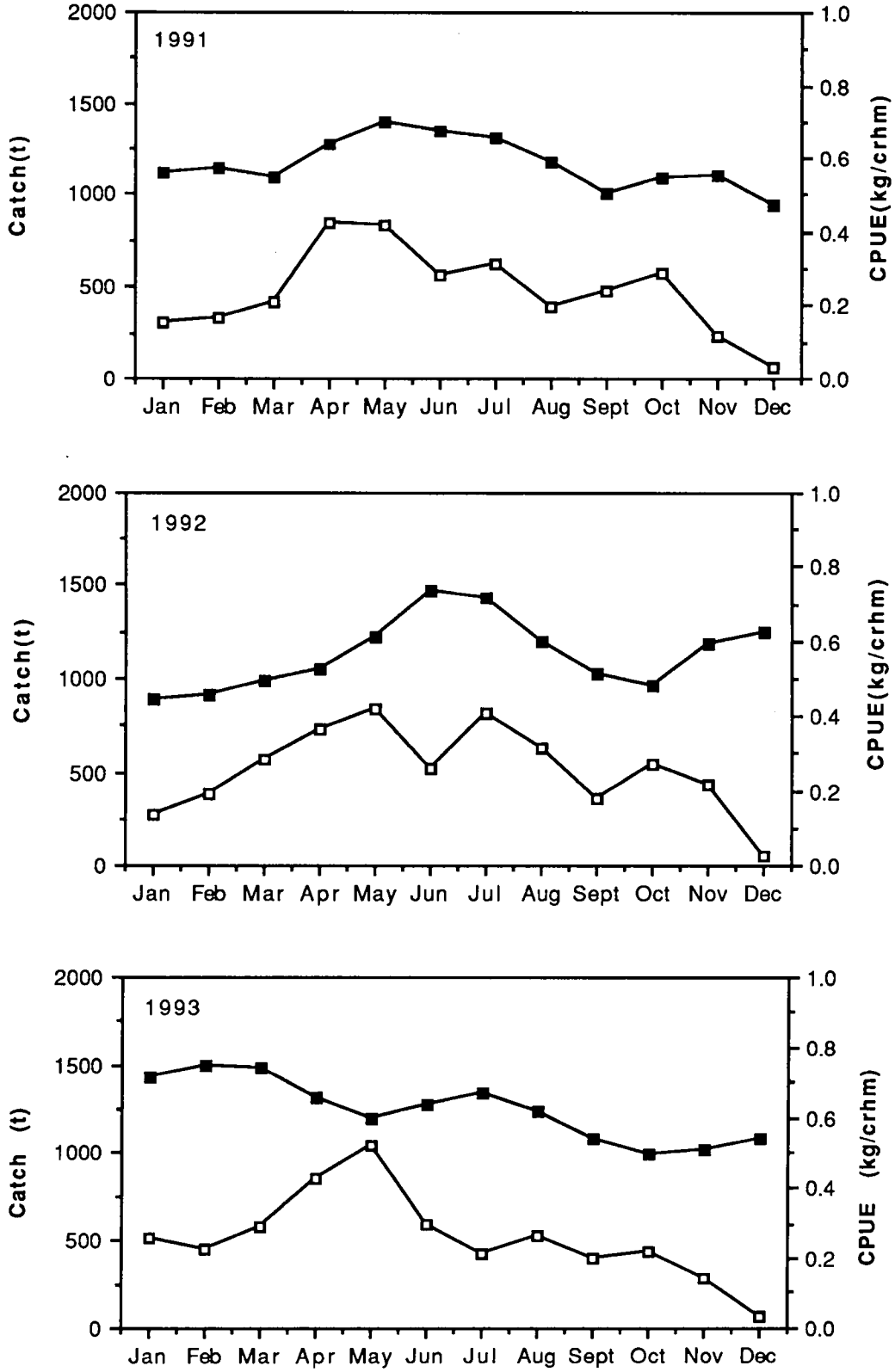

Figure 2.- Monthly CPUE (filled square) and catch in tons of meats (open square) for the deep-sea fleet fishing Georges Bank.

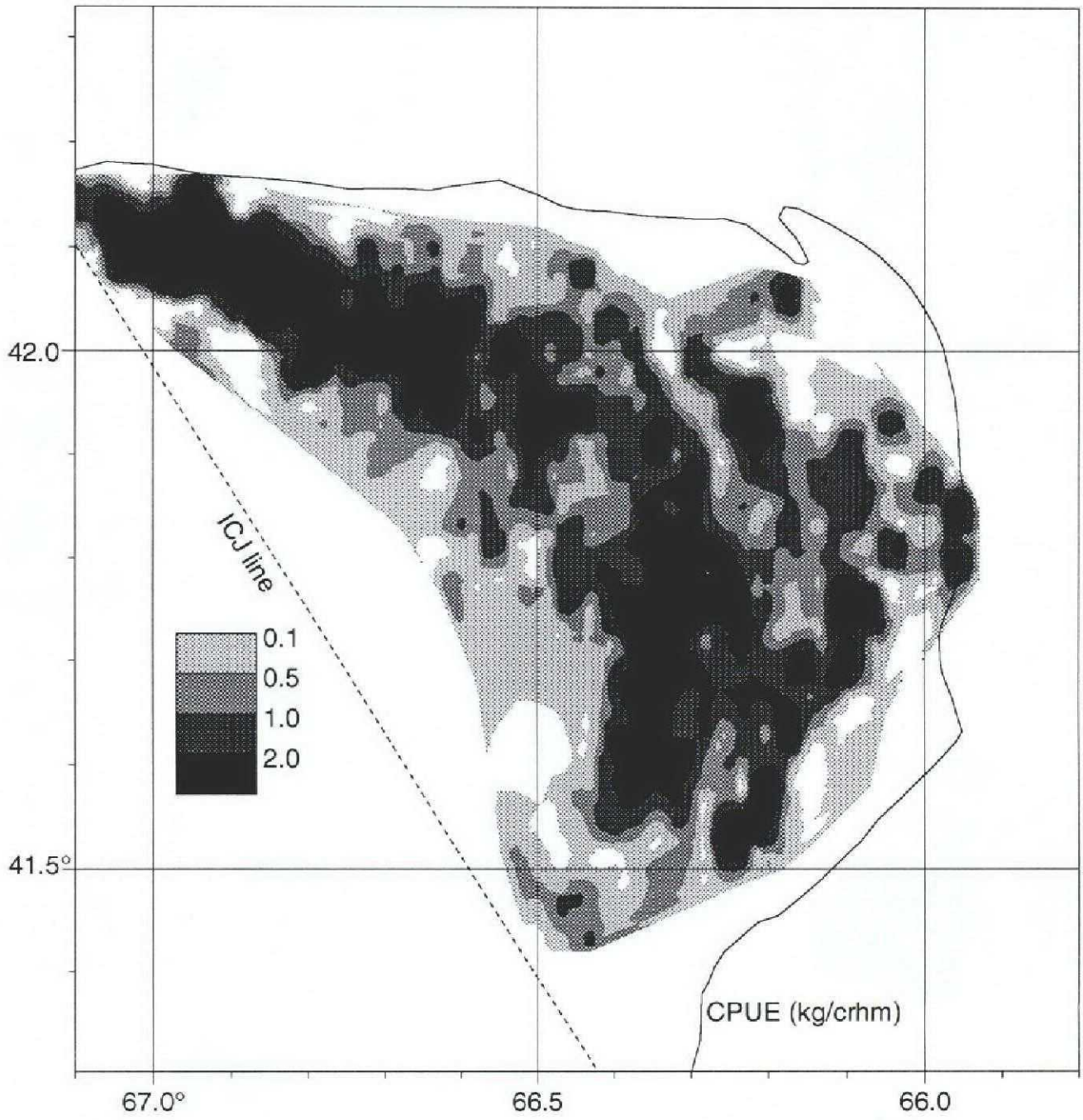

Figure 3.- Catch-rates encountered on Georges Bank in 1993. The scale of grey shades represents an ascending catch-rate up to 2+ kg / crhm.

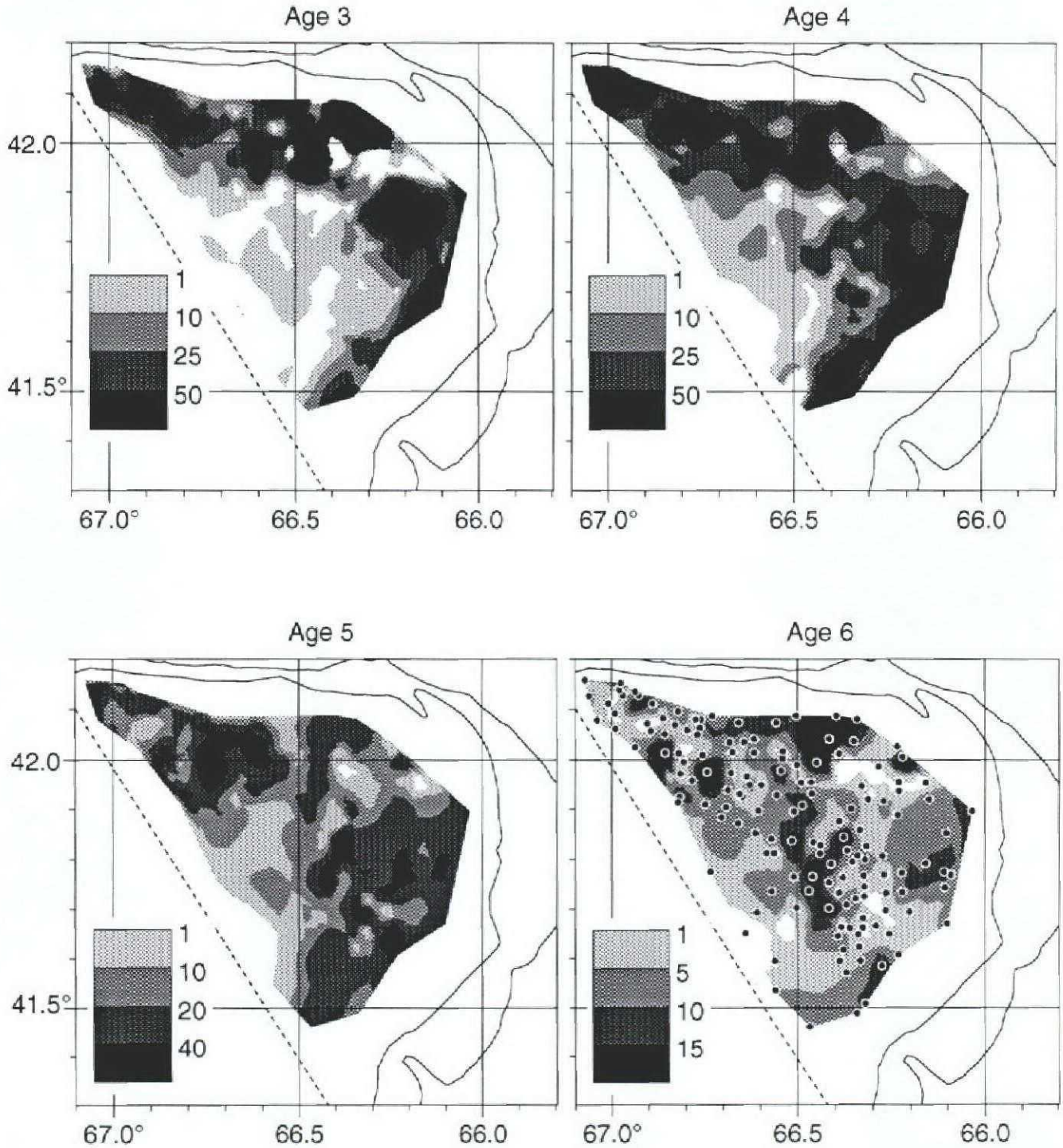

Figure 4.- Scallop distribution according to age from the research survey of August 1993. Location of sampling stations is indicated on the graph for age 6 scallops. The shading scale represents number of scallops per standard tow.

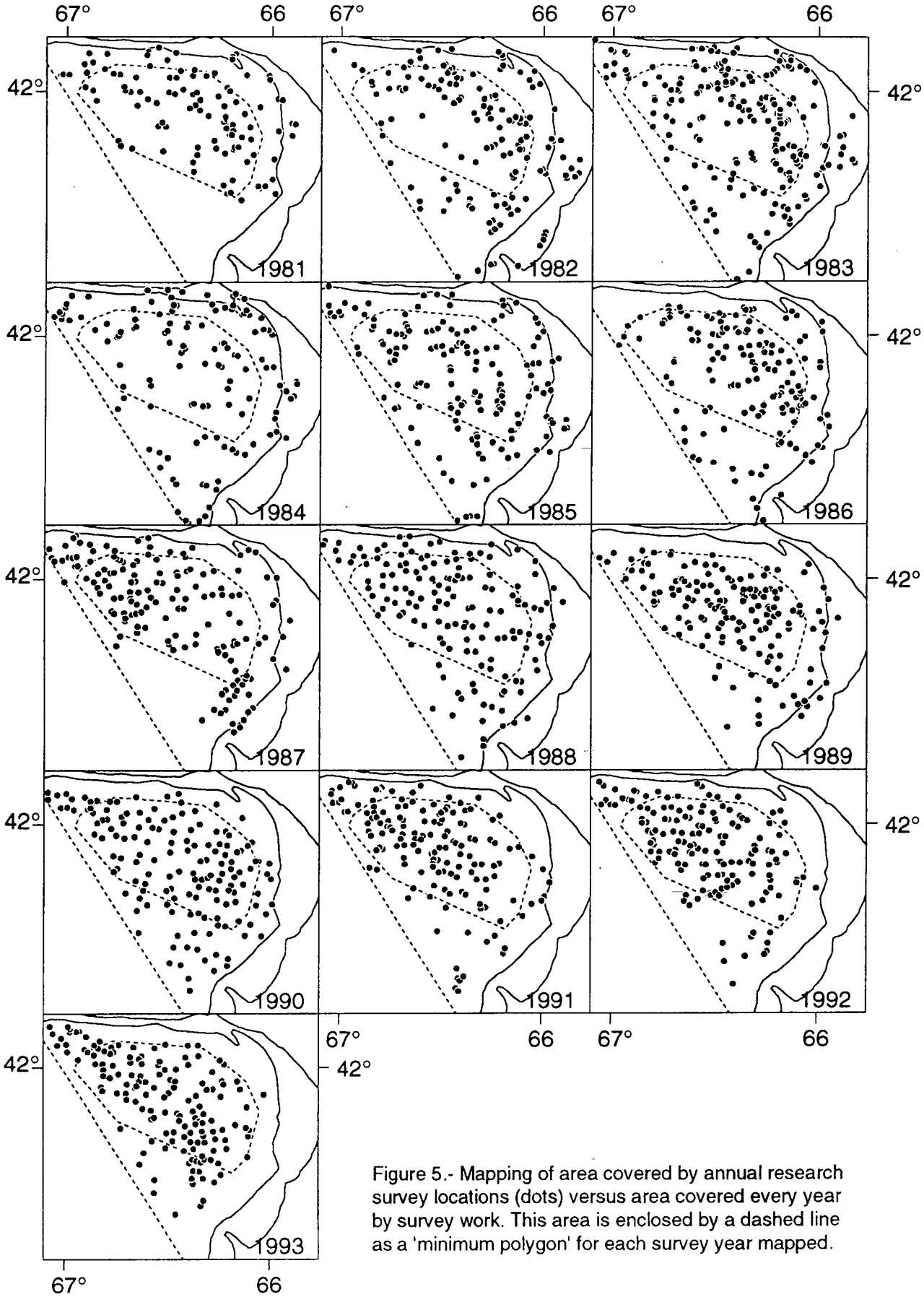

Figure 5.- Mapping of area covered by annual research survey locations (dots) versus area covered every year by survey work. This area is enclosed by a dashed line as a 'minimum polygon' for each survey year mapped.

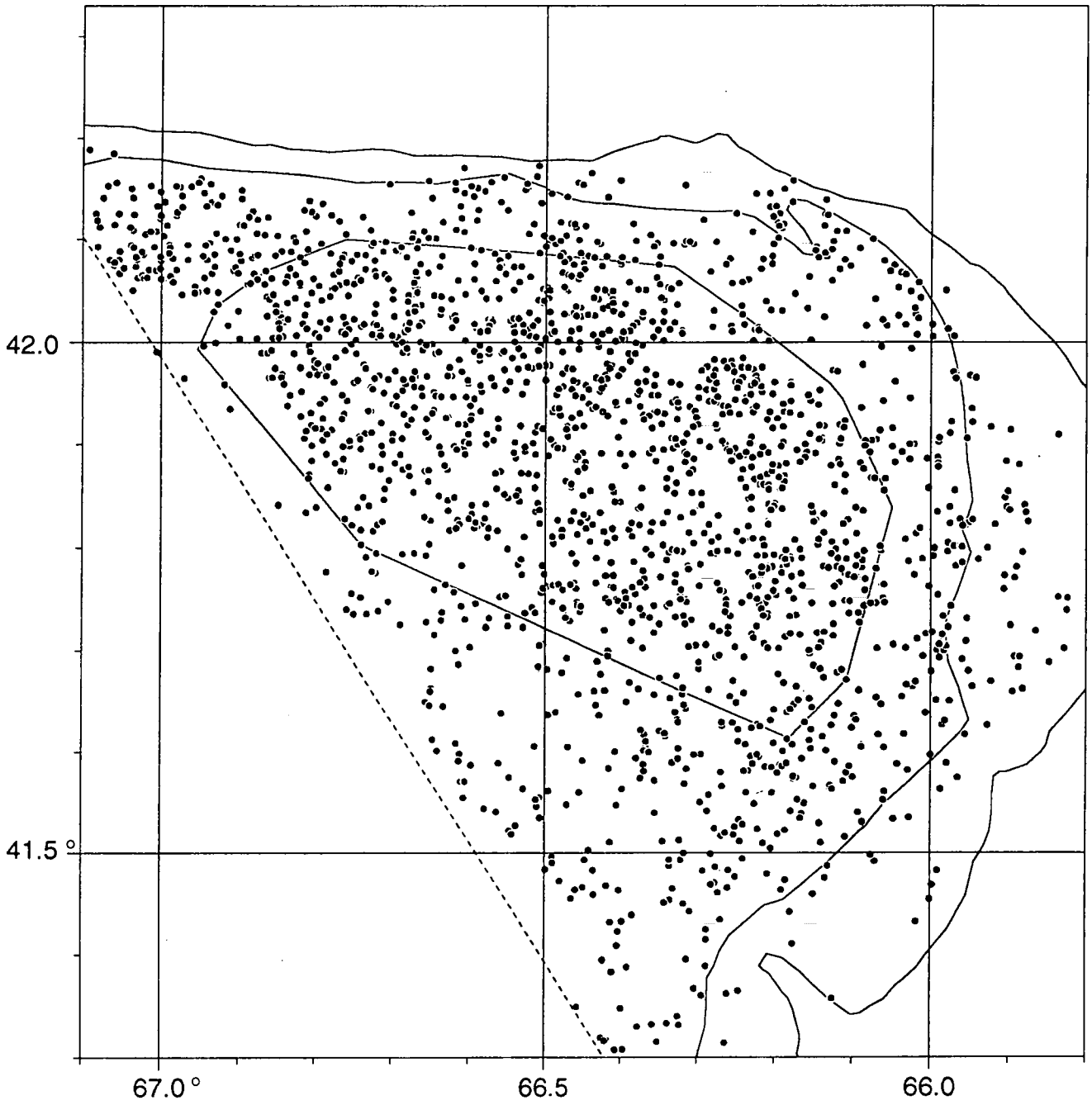

Figure 6.- Mapping of all locations surveyed east of the ICJ line (dashed) between 1981 and 1993. Locations within the polygon are the only ones surveyed every year. A fairly large area of Georges Bank lays outside the polygon.

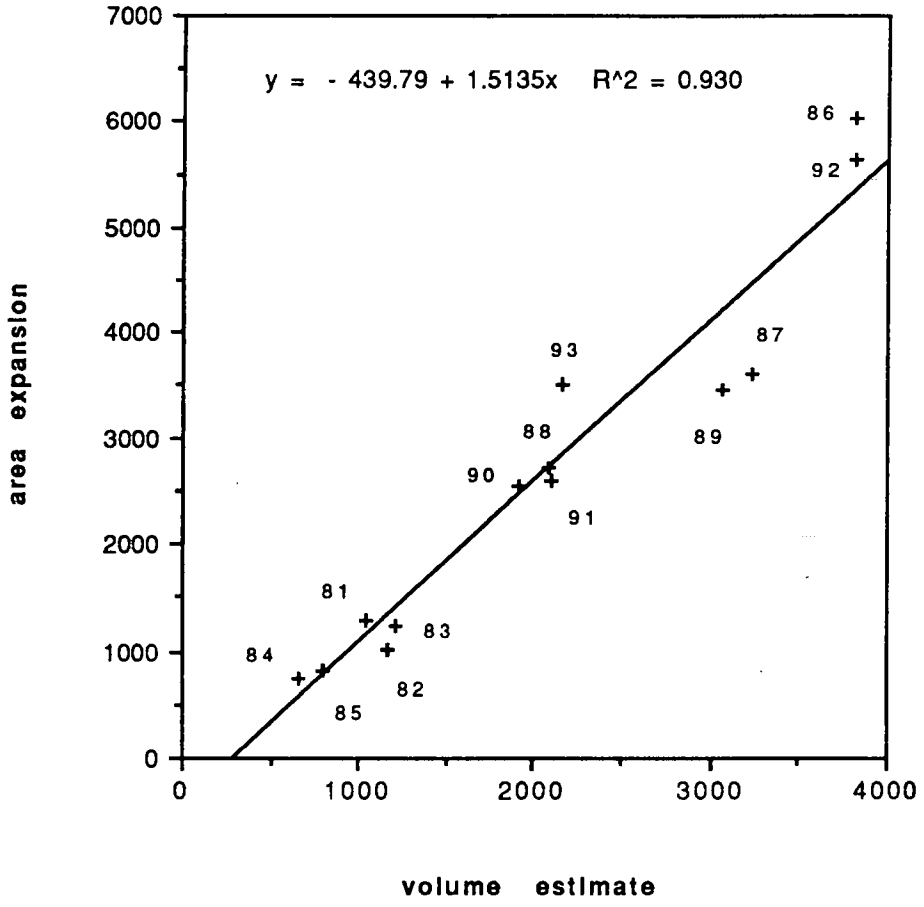

Figure 7.- Relationship between survey biomass for recruited ages 4 - 6 computed by aerial expansion and by volume estimates for the period 1981 to 1993.

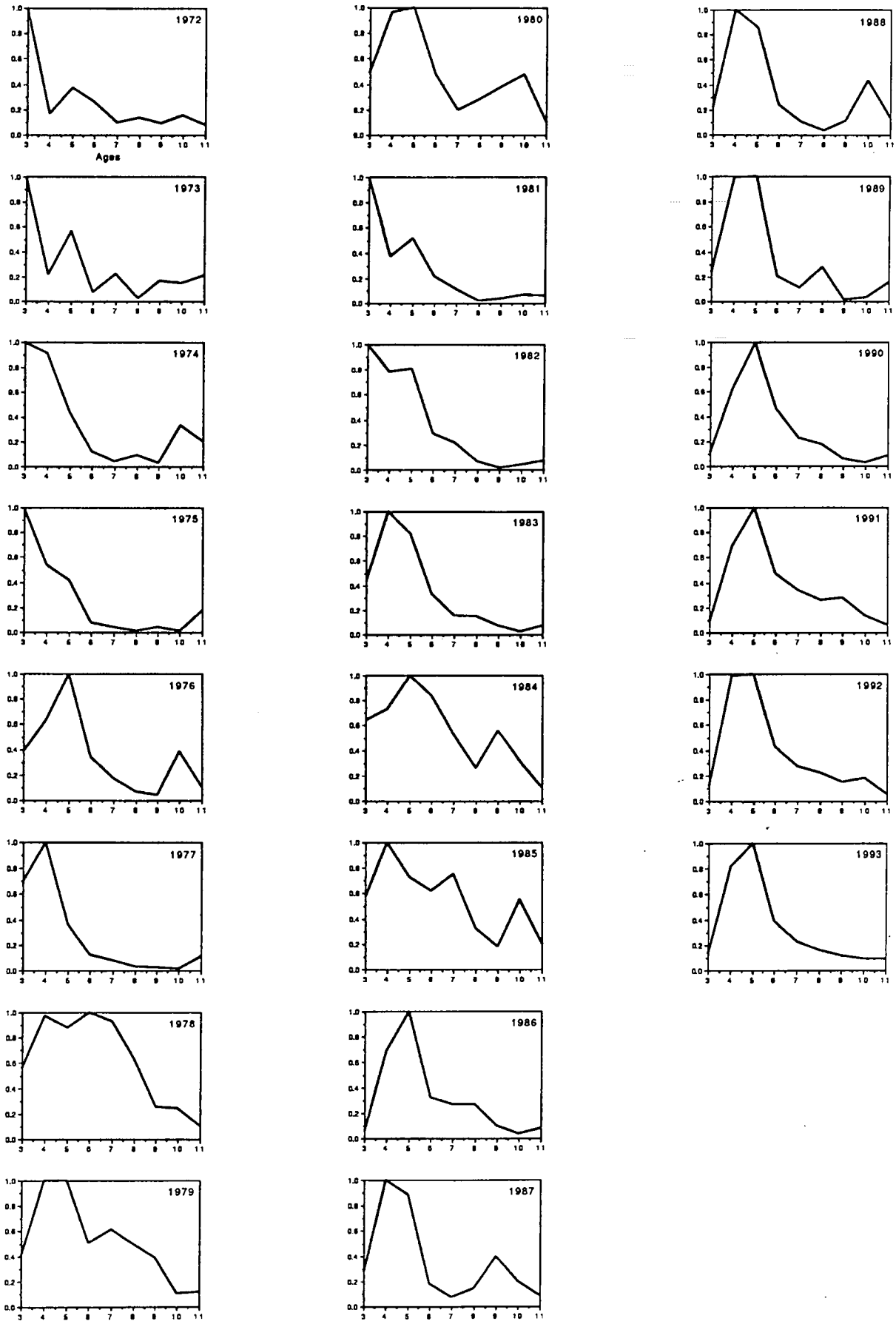

Figure 8.- Profile of selectivity-at-age from 1972 to 1993.

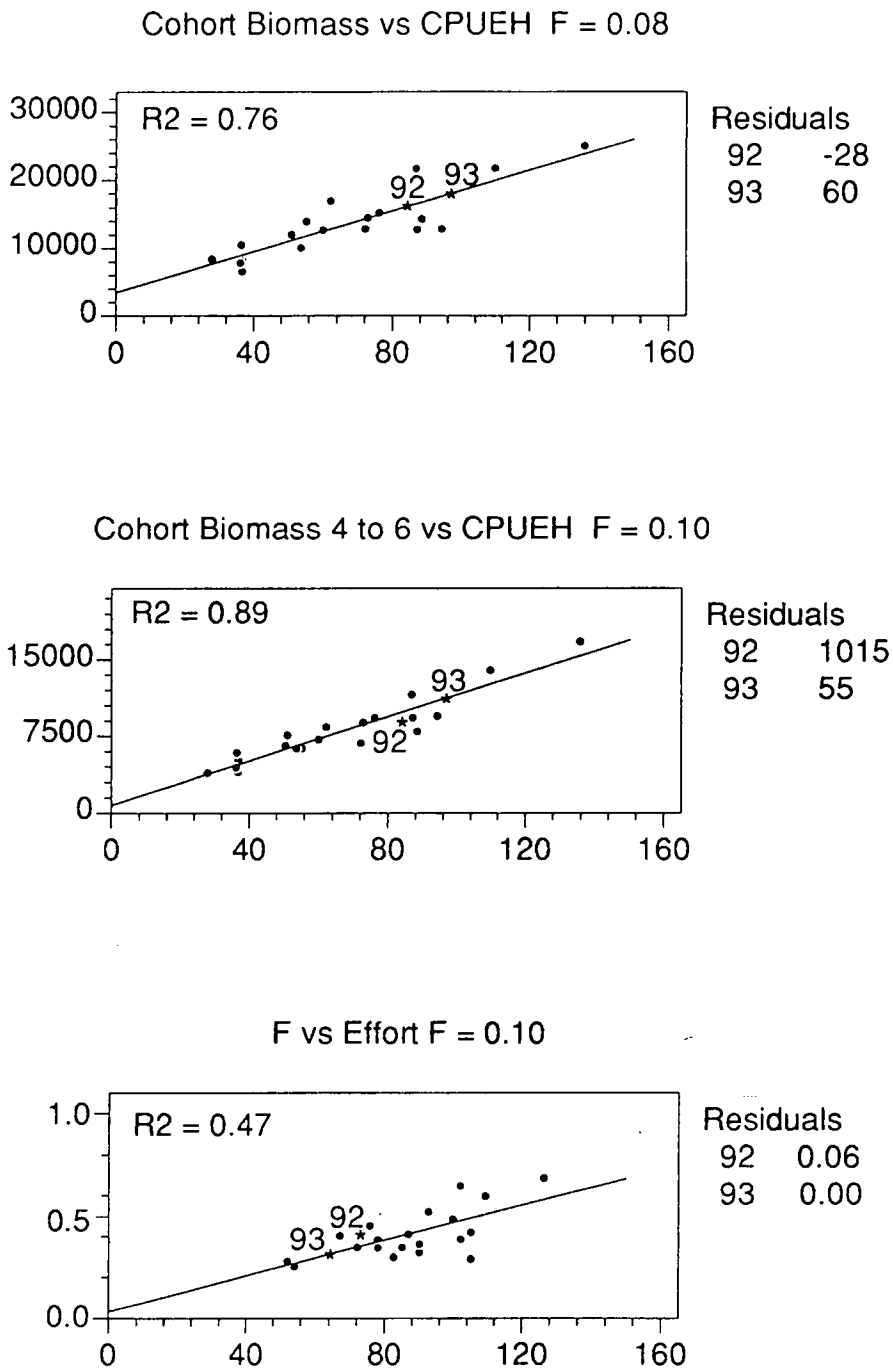

Figure 9.- Cohort biomass (t of meats), cohort biomass for ages 4 - 6 versus CPUE (kg / h), and F versus effort (hours) using a terminal F_{Q4} as shown.

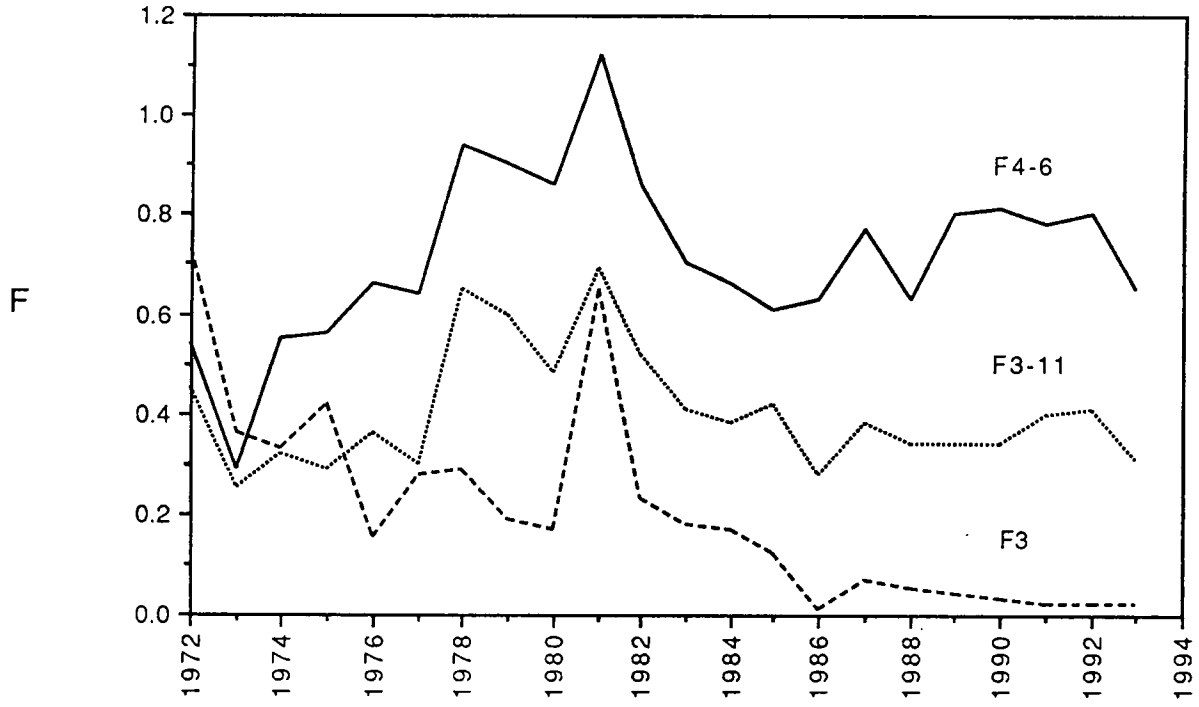

Figure 10.- Annualised fishing mortality rates. F3 is F at age 3. F3-11 is the average value for ages 3 to 11. F4-6 is the average for ages 4, 5, and 6.

Appendix

NLLS - ADAPT Methodology

Sequential Population Analysis was also carried out using non linear least square regression (ADAPT). The model is running on a quarterly basis. Data relating to catch-at-age, weights-at-age, and natural mortality rate are identical to the ones used in the VPA via linear regression. Data used are from the period 1981 onward. A log transformation has been applied to the residuals. Independent estimates selected are annual value of CPUE, quarterly values for CPUE, and research survey abundance indices.

Independent estimate: Annual CPUE allocated in Q2

Multiple estimated parameters

Mean square of the residuals: 0.057

Estimated parameter		s.e.	c.v.
Age 4	0.135	0.430	3.187
Age 5	0.061	0.428	7.074
Age 6	0.018	0.111	6.293

Correlation Matrix

	Age 4	Age 5	Age 6
Age 4	1	-0.871	0.501
Age 5	-0.871	1	-0.849
Age 6	0.501	-0.849	1

Single estimated parameter

Mean square of the residuals: 0.048

Estimated parameter		s.e.	c.v.
Age 5	0.098	0.026	0.267

Correlation Matrix

	Age 5
Age 5	1

Partitioned Search established a minimum residual (0.585) for a parameter value of 0.096. See graph A1.

Independent estimates: CPUE in Q3 and Research survey index (volume)

Multiple estimated parameters

Mean square of the residuals: 0.087

Estimated parameter		s.e.	c.v.
Age 4	0.129	0.161	1.251
Age 5	0.104	0.343	3.304
Age 6	0.105	0.516	4.924

Correlation Matrix

	Age 4	Age 5	Age 6
Age 4	1	-0.794	0.173
Age 5	-0.794	1	-0.700
Age 6	0.173	-0.700	1

Single estimated parameter

Mean square of the residuals: 0.081

Estimated parameter		s.e.	c.v.
Age 5	0.147	0.030	0.203

Correlation Matrix

	Age 5
Age 5	1

Optimising terminal f changes F5 from 0.14691 to 0.14688.

Independent estimates: CPUE quarterly values in each Q and Research survey indices

Multiple estimated parameters

Mean square of the residuals: 0.088

Estimated parameter		s.e.	c.v.
Age 4	0.135	0.121	0.896
Age 5	0.072	0.143	2.003
Age 6	0.043	0.142	3.315

Correlation Matrix

	Age 4	Age 5	Age 6
Age 4	1	-0.742	0.175
Age 5	-0.742	1	-0.764
Age 6	0.175	-0.764	1

Single estimated parameter

Mean square of the residuals: 0.105

Estimated parameter	s.e.	c.v.

Age 5 Inner Loop Limit

Partitioned Search established a minimum residual (6.7043) for a parameter value of 0.1176. See graph A2.

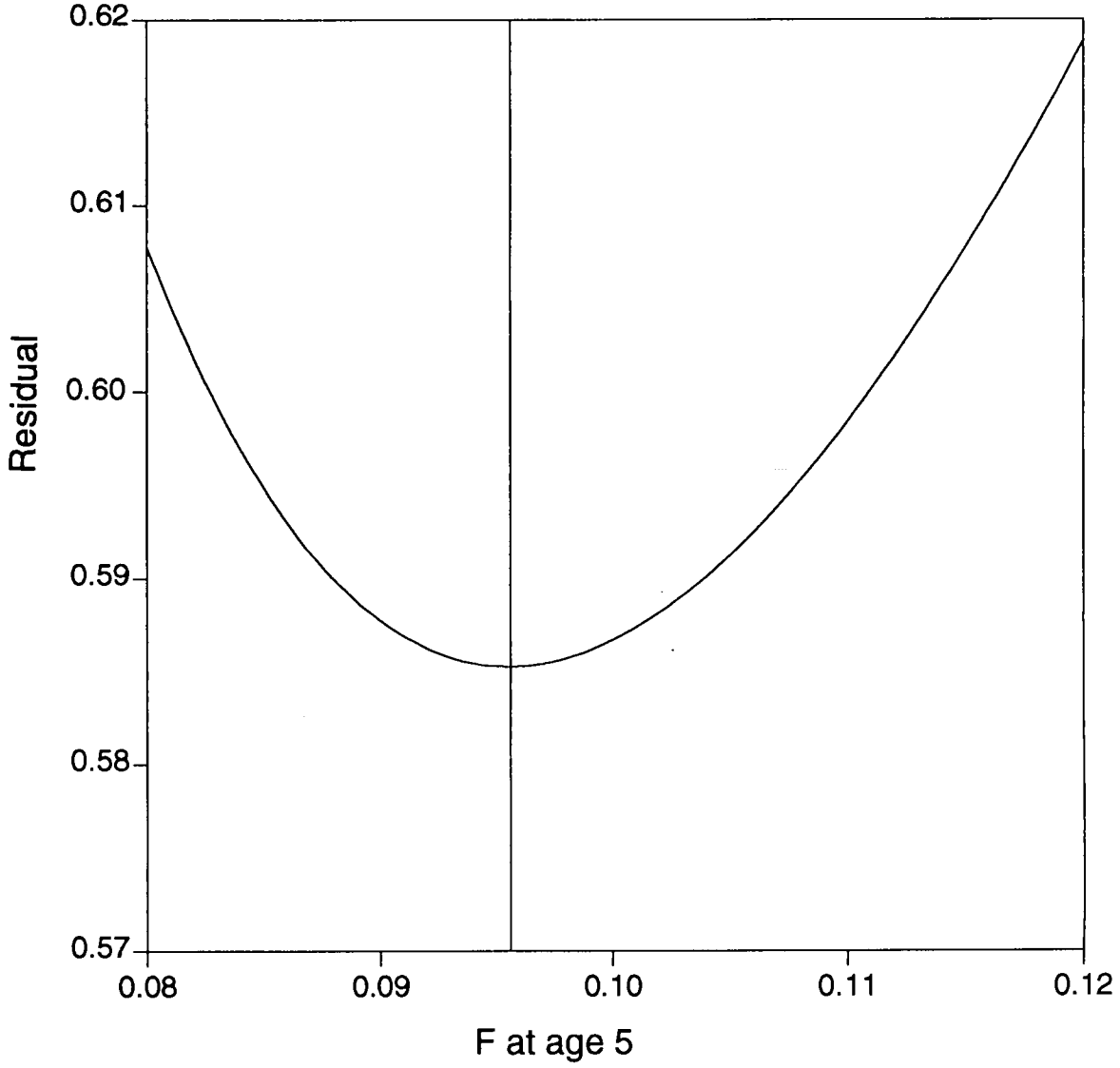

Figure A1.- F at age 5 versus residuals from a partitioned search with annual CPUE as independent estimate. The vertical line marks the F value corresponding to the minimum residual.

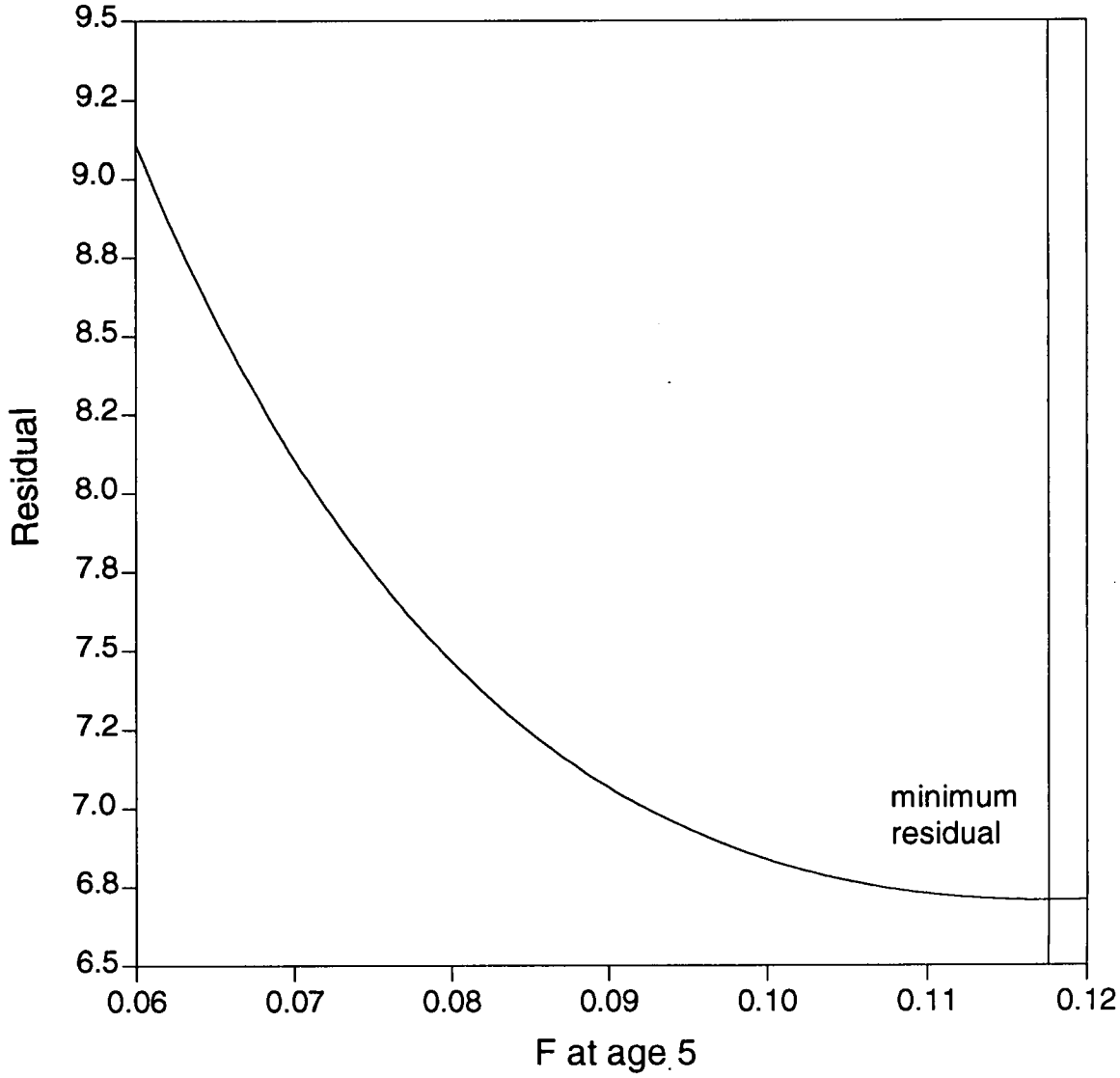

Figure A2.- F at age 5 versus residuals from a partitioned search with CPUE quarterly values in each Q and research survey indices as independent estimates. The vertical line marks the F value corresponding to the minimum residual.