DFO Atlantic Fisheries
Research Document 95/140

MPO Pêches de l'Atlantique
Document de recherche 95/140

Georges Bank Scallop Stock Assessment - 1994

By

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

[1]This series documents the scientific basis for the evaluation of fisheries resources in Atlantic Canada. As such, it addresses the issues of the day in the time frames required and the 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.

[1]La présente série documente les bases scientifiques des évaluations des ressources halieutiques sur la côte atlantique du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs 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 dans le manuscrit envoyé au secrétariat.

ABSTRACT

The 1994 TAC of 5,000 tons was less than 1993 (6,200 tons). Industry advised a cautious approach since the incoming year class (1990) was weaker than the previous 2 year classes (1988 and 1989). A declining biomass could not sustain high catch-rates in 1994. From June to September the catch-rate experienced a 45% drop and did not recover. Survey results for 1994 indicate that the abundance of recruited age groups has been decreasing and that they have been replaced by weak age classes. Biomass estimates, which had been rising since the mid 1980's, have been decreasing from the recent peak in 1992. The overall biomass has decreased 19% from 1993 to 1994; the target biomass (ages 4 to 6), by 32%.

Different fishing scenarios are presented for 1995. Even with a good 1992 year class, it will take a few years and improving recruitment to replenish stock biomass. High effort levels in 1995 could lead to a situation where the fishery is recruitment driven.

RESUME

Le TPA de 5,000 tonnes pour 1994 était inférieur à celui de 1993 (6,200 tonnes). L'industrie avait recommandé une approche conservatrice vu que la classe d'age recrutant à la pêche (1990) était plus faible que les 2 classes d'age qui l'avait précédée (1988 et 1989). Une biomasse en voie de réduction ne put soutenir des taux de capture élevés en 1994. De Juin à Septembre, les taux de capture ont subi une baisse de 45 % et sont restés à ce niveau. Les résultats d'inventaire de recherche indiquent que l'abondance des groupes d'ages recrutés a diminué et que ceux qui les remplacent sont faibles. Les estimés de biomasse, qui avaient augmenté depuis le milieu des années 1980, sont descendus du pic de 1992. La biomasse totale a diminué de 19 % de 1993 à 1994 alors que la biomasse cible (ages 4 - 6) a plongé à 32 %.

On présente différents scénarios de pêche pour 1995. On aura besoin de quelques années et d'un meilleur recrutement pour remonter la biomasse du stock même si la classe de 1992 est une bonne année. Un taux d'effort élevé en 1995 pourrait conduire à une situation où la pêche dépend exclusivement sur le recrutement.

INTRODUCTION

After the jurisdiction for fisheries on Georges Bank (Fig. 1) had been settled by the World Court (October 1984), the Canadian scallop industry focused on stock rehabilitation through better harvesting of the resource. An Enterprise Allocation (EA) regime was implemented in 1986 partly to reduce fishing effort. There were 77 active license holders in 1984. Today, about half the initial number of license holders are actively involved in the Georges Bank fishery. The meat count (size limit) was also lowered to 33 meats per 500 g in January 1986 to direct exploitation toward slightly larger scallops.

Since 1986, catches have fluctuated between 4,300 and 6,800 tons, a narrower range than the pre-1986 period when the fishery was competitive (Table 1). Catches follow TAC levels in most years. In 1992 and 1993 catches were over 6,000 tons as the fishery was exploiting 2 strong year classes, the 1988 and 1989 year classes. In 1994, industry recommended a TAC of 5,000 tons although TAC levels could have been higher according to the scenarios proposed (Robert et al MS 1994). A cautious approach was justified since the 2 strong year classes were contributing less to the fishery and the 1990 year class is considerably weaker. Catches exceeded the TAC slightly.

Almost 30% of the annual catches came from the first quarter of the year both in 1993 and 1994. Such a high ratio for winter catches is triple the traditional levels for the first quarter in previous years. Annual catch-rates since 1990 are in the medium to high range, peaking in 1993 (Table 2). There has been a 20% drop in the annual rate for 1994 from the year previous. Although catch-rates experienced a small decline due to spawning in 1992 and 1993 (Fig. 2), the available biomass allowed monthly variations to be minor and catch-rates to rebound. In 1994 however, a declining biomass could not sustain CPUE in the high range. From June to September, rates experienced a 45% drop and did not recover from these low values. A detailed geographical distribution of CPUE's for 1994 (Fig. 3) shows a fragmented distribution of areas with CPUE's over 1 kg/crhm in contrast with the last 2 years when fragmentation was much less pronounced (Robert et al MS 1994). Fishing also took place over a greater area of the Northeast Peak, near longitude 66 degrees west.

The average monthly meat weight in the catch increased from 1993 (Table 3) reflecting the weakness of the 1990 year class recruiting to the fishery. The quarterly distribution of meat weights for 1994 (Table 4) shows the sizable contribution of meats over 30 g to the catch. This pattern had not been observed in the recent past. Concurrently, numbers of meats belonging to the 1990 year class in the 11 - 15 g weight interval are relatively low. The availability of big meats also allowed for blending of very small meats (5 - 9 g interval) in the catch.

METHODS

Fishery data

Catch and effort data were compiled from commercial logbooks. Logs with complete effort data are called Class 1 and were used to estimate catch-rates. The Class 1 data represent more than 90% of the total logs available (Table 2). Effort is measured in towed hours (h) and towed hours times the width of the 2 drags used times the number of crew (crhm). Catch-rate is presented as catch (kg) per hour and per crew-hour-meter. Catch per h considers only the period that gear was actively fishing. It does not consider how wide the gear is to estimate how much ground is covered by the tow. Gear width may vary from 8.5 to 15.5 m. Scallop meats caught have to be shucked at sea; the smaller the meats, the more crew needed to shuck. Common fishing practices will first change the number of crew if effort has to be modified. CPUE in kg / h is used in the cohort tuning analysis. Over the period 1981 - 1994, catch-rates determined as kg/hour were highly correlated to catch-rates in kg/crewhourmeter (r=0.987). 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 were derived from port samples. Only one or two company fleet(s) have regularly contributed the information.The 8 companies fishing Georges Bank under EA's use different harvesting strategies that are reflected in the profile of meat weight distribution of their catch. Data is being collected to incorporate in the database to give a better representation of the patterns in the overall catch. Canadian port sampling data were applied to the Canadian and U.S. total catch east of the ICJ line prior to 1985. This assumes similar fishing practices for both fleets. Table 5 lists the frequency distribution of meats on an annual basis. There has been a gradual shift toward larger meats in the catch over the last 10 years, reflecting the implementation of a lower meat count in 1986. For the first time in the last 10 years, the 1994 catch consists of about 10% in numbers of age 7+ (29+ g) scallops. While ages 4 and 5 (9-24 g range) made up about 90% of the catch in 1993, the figure dropped to 75% in 1994. The incoming 1990 year class at age 4 is weak and not contributing much to the catch.

Catch in numbers-at-age (Table 6) for the cohort analysis are derived from the port sampling data and the sum of U.S. and Canadian catches in NAFO SA 5Zc. The total catch (U.S. prior to 1985 and Canadian) from the Canadian zone is decomposed into 2 - g weight frequencies. The weights were converted to shell heights using the allometric relationship derived from 1982 - 1985 research and commercial data (Robert and Lundy MS 1987). The values expressing meat weight as a function of shell height use the parameters 9.102^{-6} for the regression coefficient and 3.097 for the exponent of height. These values agree closely with those of Serchuck et al. (1982) for the same stock. Shell heights were clustered into age groups according to a Von Bertalanffy growth equation (Brown et al. 1972, cf. Table 7).

Traditionally, catch statistics are compiled on an annual basis and recruitment to a fishery is discussed in terms of year class strength. It is generally accepted that, in any given year the majority of Georges Bank scallops are born in October and the first annual ring is laid down the following spring. This is typically less than 10 mm and becomes difficult to discern as the animal grows. For this reason the ring, which is approximately 25 mm from the umbo is often referred to as the first annulus (Naidu 1970). The convention which we shall adopt is that animals born in the fall of a year will be of that year class and it will be further assumed that they were born on January 1 of that year (cohort ages). The deposition of the ring less than 10 mm will take place during the first year of life. The date of the deposition will be assumed to take place on April 1. A back calculation is then made to estimate the shell height for January 1 (eg. cohort age 3 has a shell height of 61 mm on January 1st, while its biological age is 2.25 years). The annual growth rates for weights, given in Table 7, are converted into rates for heights and this results in a 16% reduction of the ring size being used for the January 1 size. For example, an animal born in the fall of 1988 is of the 1988 year class and will be approximately 25 mm on its second birthday (January

1, 1990) although the ring would not be deposited for a few months. Table 7, as well as all other age data, uses this convention, with correction of ring sizes back to January 1. The actual weights used are mid-quarter values in age - weight analyses and projections.

Research survey data

The annual research survey was carried out on Georges Bank during August 1994. 1994 marks the beginning of a new survey data series. This is reported elsewhere (Rodgers, MS). 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). A very high stratum was added in 1991 to reduce the variability of the high stratum. The range of catch-rate values encountered has increased markedly. Since 1992 40% of the total catch-rate points used were over 1 kg / crhm, the minimum benchmark of the high stratum. The maximum value in the data set peaked at 10 kg/crhm in 1993; it is down to 7.3 in 1994. The steady rise in catch-rates has turned the opposite way. The average number of scallops at age per tow is given in Table 8. The details of the survey results on a per stratum basis are given in Table 9.

In addition to establishing a stratified mean number per tow, the data are contoured to represent the spatial distribution of the scallop aggregations (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 10a for ages 3 to 6. The degree of interpolation will affect the volume estimates. For the Georges Bank survey data, the estimates stabilize using 16 or more subtriangles when they vary less than 5%. A more complete description of the contouring method and volume estimation may be found in Black (MS 1993).

Biomass indices (Table 10b) from aerial expansion of numbers of scallops per standard tow have been computed using weights at age for the middle of the third quarter (August) found in table 7. These estimates correspond to a minimum dredgeable biomass as they are not adjusted for the survey gear efficiency. Data prior to the establishment of the ICJ line, from 1981 to 1985 inclusive, have been recomputed (Tables 8 and 10) to provide density and biomass estimates for the Canadian side of Georges Bank only.

Stock analysis

In the first year of recruitment the animals experience approximately a 300% increase in weight. To reduce the magnitude of the errors caused by ignoring growth effects, the cohort analysis was carried out on a quarterly basis. This required that catch-at-age, effort distribution, and partial recruitment be determined on a quarterly basis. This was done by adjusting recent year's selectivity pattern to reflect the port sampling data for the last quarter of 1994. This pattern, multiplied by the F determined from tuning for the last quarter year (F_{Q4} 1994), was used as a starting vector for the quarterly cohort analysis.

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

The SPA is tuned against a number of independent, and sometimes contradictory, sets of observations. The most important are the commercial CPUE and research survey estimates. F versus effort is used in the tuning process but of lesser importance.Tuning selectivity is more difficult in scallop data than for most fisheries. This is because the SPA is done on a quarterly basis and the F's on the most recent year affect only the last quarter. Thus one cannot 'dial up' in an iterative fashion the exact numbers of F's one might want for the most recent year as can be done with annually collated data. F on the oldest animals was found by multiplying the effort pattern by the mean terminal F from the older ages. Because the selectivity is highly domed toward ages 4 and 5, these values are not critical and the normal iterative determination was not undertaken. (At the 1989 CAFSAC retrospective analysis workshop it was shown that iteratively estimating the terminal F from younger ages diverged rather than converged.) In addition to tuning for cohort biomass as a whole, over ages 3 to 11, iterations were carried out on cohort biomass for certain age groups. Relative indices of abundance in the research surveys best represent ages 3 to 6; indices for ages 3 - 6 was used to calibrate a cohort biomass for these ages. Since 1986, ages 4 to 6 represent 50% or more of the biomass in the stock compared to the other ages. Fishable biomass was also tuned against CPUE. A better fit was achieved when tuning fishable biomass for ages 4 to 6, likely due to the importance of this age group.

Tuning iterations estimated a quarterly rate for terminal F in a narrow range (0.10-0.13). A few more F values and estimated variables are presented in table 11 to give a better perspective. The tuning of cohort biomass on CPUE in terms of hours gave a slightly stronger multiple correlation coefficient than CPUE expressed in crewhourmeter for the same terminal F. The tuning of cohort biomass on research biomass relative index established via area expansion (the one shown here) had a slightly stronger multiple correlation coefficient than research biomass index derived from volume estimates; both tune for the same value of terminal F.

Regression of cohort biomass on CPUE: the maximum multiple correlation coefficient, 0.699, for the regression of cohort biomass on CPUE corresponded to an F_{Q4} of 0.10. That terminal F provides for both the 1993 and 1994 residual points to be close to the regression line.

Cohort ages 3 - 6 on research biomass ages 3 - 6: A maximum multiple correlation coefficient of 0.742 occurs at F_{Q4} equal to 0.13. A slightly lower F_{Q4} of 0.10 provides a very small residual for 1994 with a weaker coefficient at 0.708. The 1993 residual point is away from the line; it crosses at a much higher F. Ages 3 to 6 are well represented in the survey data; they offer a better match to corresponding ages in the stock biomass compared to matching the stock biomass for all ages to the ages represented (ages 3 to 6 mainly) in the research data.

F versus effort: The multiple correlation coefficient does not vary much over the range of terminal F's considered. Although not necessarily maximum, the coefficient is still high, 0.750, at F_{Q4} equal to 0.10 when the 1994 residual point is on the regression line with the 1993 point close behind.

Fishable biomass on CPUE: The relationship is much weaker and a poor fit for maximum correlation under the range of F selected. But the 1994 residual point is almost on the regression line at F_{Q4} equal to 0.11 with the 1993 point below the line; correlation is then 0.320.

The residual points of the last two year's data and the multiple correlation coefficient were used as tuning criteria. The positive residual values in table 11 denote that the residual points are below the regression line and the negative ones, above. It should be noted that the annual CPUE values are compared to the second quarter biomasses. Q2 corresponds to the quarter where the largest catches are encountered, from 40 to 50% of the total annual catch. This also holds true for regression of fishable biomass for ages 4 to 6. The research survey biomass estimates are derived from the average weights at the third quarter. These are compared to third quarter biomasses from the cohort analysis.

Strong correlations of cohort biomass on CPUE and F versus effort occurred at an F_{Q4} of 0.10. 70 to 75% of the variability could be explained when the cohort biomass was tuned against CPUE or F versus effort with the last 2 years residual points in close proximity to the regression line (Fig. 5). A similar degree of variability (71%) was explained when a particular age group, ages 3 to 6, was compared between cohort biomass and research survey biomass index. In this instance, the 1994 point was almost on the regression line (Fig. 5). But the maximum coefficient explaining 74% of the variability over the time period considered is at an F_{Q4} of 0.13; the most recent residual point is slightly below the line. The regression of fishable biomass of the age group 4 to 6 which is the main target of the fishery, on CPUE gave a best fit for the last year residual at a terminal F of 0.11 but the relationship is rather weak (only 32% of variability explained).

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

A Thompson-Bell type yield per recruit analysis with quarterly time steps is used to take into account the dynamic growth of the younger age groups of scallops. However, this method does not include the effects of blending. A change in fishing strategy to adapt to the 33 meat count regulation required a re-calculation of the yield per recruit in the 1988 stock evaluation (Mohn et al MS 1989) and redefinition of the partial recruitment pattern. Subsequently, the yield per recruit was re-examined but there was no need for a re-evaluation as the fishing strategy, hence partial recruitment remained practically the same. Improvements in the fishery in 1991 - 1992 required a re-evaluation as older age groups (>age 7) became more represented in the catch (Table 4). The 1994 fishing strategy remained practically unchanged from previous years. The yield per recruit was examined for change in partial recruitment. A difference of 10% did not warrant any changes being made to the model.

The regulations in effect on the offshore fleet are that the catch should average no more than 33 meats per 500 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 20, 35, 30, and 15%, which reflects the fishery in the last four years but with a slower start for 1995. 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.

Catch projections and fishing scenarios under the current meat count were carried out for different rates of F including $F_{0.1}$ and F_{max}, to present TAC options and their respective implications on the stock biomass.

RESULTS

Research surveys

Sampling locations of the 1994 research survey are plotted in Figure 4. Station locations are indicated in the plot for age 6. A few survey stations were allocated to waters over 100 m on the Northeast Peak. In early summer of 1994, the fleet ventured to marginal areas that had not been exploited to date to maintain high catch-rates despite the anticipated decline in fishery performance. Abundance of young recruited age groups (ages 4 and 5) has been declining (Table 8) even though numbers of older recruits (age 6+) have been quite stable so far. For the first time in the last 15 years, age 8 scallops are recorded in the survey; they were present in all strata except the very high stratum (Table 9). Ages 6 and 7 scallops were also present in each stratum. Numbers of age 5, the 1989 year class, are much lower than the 1988 year class had been last year. There were some indications that the 1989 year class might have been important (surveys from previous years and VPA results of the 1993 analysis; Robert et al MS 1994); but it was smaller than the 1988 year class. Observations that the 1990 year class is weak, first reported in previous surveys, are certainly confirmed by the very low abundance of age 4 scallops throughout the surveyed area. Maximum isopleth contoured is only 25 animals per tow (Fig. 4).

Abundance of prerecruits offers a mixed picture. The 1991 year class (age 3) is one of the weakest recruitment pulse according to survey results. It is almost completely absent from the southern part of Georges Bank (Fig. 4). The 1992 year class (age 2), observed for the first time in the 1994 survey appears to have set in very good quantities on the Northern Edge (Fig. 6) but with extremely low occurrences in the southern Bank. Successive low recruitment inputs will not allow replenishment of the fishable biomass in the southern half of the Bank. The mean number per tow of age 2 scallops in the 1994 survey (Table 8) was less than the long term average (127 for age 2) estimated for the whole survey area. However, when survey data for the southern half of the Bank were excluded, abundance of age 2's increased by at least a factor of 2 and may be qualified as a good year class, but only on the Northern Edge.

The relative indices of biomass (Tables 10) have experienced important declines especially for the targeted age groups, 4-6, given the reduced 1988 and 1989 year classes due to fishing and the incoming but weak 1990 year class.

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 0.13. In terms of numbers at age, the early 1990's have seen the passage of 2 good year classes in the stock with over 500 million scallops at age 3 each (Table 12 and Fig. 7). Numbers at age 3 in the research surveys coincide well with the strength of these same year classes in the population estimates. Survey numbers at age 2 may only be used as a trend indicator; they do not reflect the actual strength of every year class (Fig. 7). Overall numbers in the 1994 population estimate are considerably lower than previous years(Table 12); old (age 7+) scallops are present in fair numbers but the age 3 and age 4 densities are very low, somewhat comparable to the early 1980's especially for age 3 (see Fig. 7 also). Similarly, biomass estimates (Table 13, Fig. 8) have been decreasing substantially from the recent peak in 1992. Annual fishing mortality rates are presented in table 14. Overall F on ages 3-11 has varied little since 1988 and is much lower than before the implementation of EA's (pre-1986) (Fig. 10 bottom). There has been a slight increase from 1993 to 1994. The fishing mortality at age 3 (F3) had peaked in 1981 when the meat count regulation had been relaxed and the strong 1978 year class was recruiting to the fishery. It has become minimal with the meat count reduction to 33 per 500 g in 1986. Average F on the targeted ages 4 to 6 has been quite stable at 0.68 since 1989 and increased slightly from 1993 to 1994; F at age 4 increased and F at age 5 decreased in 1994 in a repositioning of individual F's.

The ADAPT model estimated F at age 5 for the last quarter of 1994 calibrating with CPUE in the second quarter and the research survey data as in the first tuning procedure. Ages included in the tuning are from 3 to 6. All other variables are identical to the first tuning. The statistical diagnostics are as follows:

relative change in phi parameter = < 0.0001
mean square of the residual = 0.0666
$F_5 = 0.1349$ s.e. = 0.0285 CV = 0.2113

A partitioned search (Robert et al MS 1994) estimated the minimum residual for F_5 to be at a terminal F value equal to 0.1325. The search improved the estimate slightly. F_5 estimate fits well with the value established with the first tuning procedure. The coefficient of variation is equal to 21%. A retrospective analysis of the average fishing mortality rate and biomass for ages 3 to 6 was carried out on the last 5 year's data. Figure 9 shows quarterly patterns for selected F and biomass. There is no apparent trend of persistent under or over estimation of the 2 variables. They oscillate in a narrow range of values. Table 15 details the biomass estimates adding one set of data per year for the last 5 years (peels). Looking down each column shows the generally small fluctuations but no specific trends. No constraint was put on the terminal population to initiate the stock projection given the lack of pattern shown in the retrospective analysis.

The quarterly based yield per recruit analysis uses mid-quarter meat weights and the quarterly expanded selectivity derived from the cohort analysis (See Mohn et al. MS 1987). The 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 1.10 for F_{max} and 0.70 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. No change were necessary in the 1993 assessment. The yield per recruit model was reevaluated with the 1994 data. A change of 10% or less in the values for F_{max} and $F_{0.1}$ did not justify modification of the estimates for F_{max} and $F_{0.1}$. The same selectivity was used in the cohort analysis, yield per recruit, and the catch projections. The projections are carried out at $F_{0.1}$, F_{max} and other selected F values using the numbers-at-age of the last quarter from the 1994 cohort analysis aged forward to the first quarter of 1995. The projections for a one year period assume a recruitment level of 300 million scallops to reflect the improvement in recruitment with the 1992 year class. It is estimated to be a bit below average (geometric mean around 450 million, see figure 7) since its presence was not noticed in the southern half of the Bank. The partial recruitment vector used : 0.04, 0.53, 1.00, 0.35, 0.20, 0.13, 0.11, 0.18, 0.10; last year was: 0.02, 0.41, 1.00, 0.49, 0.32, 0.22, 0.19, 0.15, and 0.07. The selectivity is greater on age 4 but smaller on ages 6 and 7 than last year. Age 5 selectivity still acts as the inflexion point for the selectivity curve; the slope changes on each side of age 5.

Given the monthly profile of CPUE's in 1994 when they dropped significantly by mid-year to remain low afterward and the poor recruitment patterns found in survey results, catch projections were carried out for 1995 with a terminal F_{Q4} at 0.13. The quarterly catch pattern for 1995 was set with a decreased level of activity during the winter fishery to reflect that the offshore fleet has somewhat reduced the recent levels of effort put on Georges Bank stock during the first quarter. Biomass projections for selected fishing scenarios are lower than for recent years. Highest biomass (all ages) levels, around 11,250 t, are obtained under the $F_{0.1}$ scenario for 1995 (Table 16). However, the biomass figure for ages 4 to 6 is more important since these particular ages are the target of the fishery. Under this scenario, the TAC (or a catch of 1,900 t for 1995) represents 41% of the target biomass. These biomass figures are for the end of 1995; therefore, after a new year class, assumed at long term average strength would have recruited to the fishery. If recruitment is below par, as indicated before, the 1992 year class is good but absent for the southern part of the Bank, the biomass would likely be smaller. Catches at the level of the interim TAC of 2,000 t would represent 44% of the target biomass (Table 17). Given the relatively large presence of old scallops in the stock, the meat count regulation is not an issue as very small scallops may be blended in. F_{annual} at age 5 in 1994 was equal to 1.04. Keeping the same effort levels from 1994 to 1995 would predict catches around 2,600 t (Table17); that would represent 60% of the target biomass. Under an F_{max} scenario, the total biomass drops to 10,400 t during 1995 (Table16) but catches would account for 65 % of the target biomass. Total F_{max} catches are projected at 2,700 t. Other fishing scenarios such as keeping the TAC constant, could put F values to very high levels, 2.9 and seriously deplete stock biomass, especially the target age groups. There is a 30% change in total biomass between fishing at $F_{0.1}$ (conservative) and fishing at the 1994 TAC level (aggressive) strategy. Catches have a more important effect on the target biomass.

CONCLUSIONS

In the early 1980's, Georges Bank scallop stock experienced a gradual and important reduction in biomass due to very high fishing mortality rates targeting young scallops in a highly competitive fishery (Fig. 8). Very low recruitment made for a slow recovery. With the implementation of EA's in 1986, F decreased markedly. Age 3 scallops were no longer targeted by the fleet to any great extent. Since 1989, F on the target age group, ages 4 to 6, has been quite stable. With good to excellent recruitment pulses provided by the 1986, 1988, and 1989 year classes, biomass had steadily increased to peak in 1992. There has been only a small increase in overall F (ages 3 to 11) from 1993 to 1994 but the biomass has dropped. The main age groups in the biomass (ages 4 to 7) for 1995 are the remnants of the strong 1988, 1989 year classes but mostly the 1990 and 1991 year classes which belong to the weakest category of recruiting year classes, being less than 200 million scallops (at age 3).

With the prospects of a 1992 year class at average levels at best overall, it will take a few years and improving recruitment patterns to replenish stock biomass. High catch levels in 1995 would only aggravate the low biomass levels; especially, when the target biomass of ages 4 to 6 is considered. During the latter part of 1995, the young 1992 year class will recruit to the fishery. There will be no difficulty whatsoever in blending these small (5 to 10 g or 100 to 50 count) scallops with available larger (older) scallops. They will be targeted because the high densities of these unfished aggregations bring high catch-rates and because of the low densities of the 1990 and 1991 year classes. Through the process, significant yield from the 1992 year class will be lost. High effort levels during the 1995 fishery could lead to a stock status where future catch levels would depend very heavily on the incoming year class. Simply put, this is the recruitment driven fishery as experienced before 1986 when high levels of effort were operating on a competitive basis.

REFERENCES

Black, G.A.P. MS 1993. - ACON - Data visualization software (Version 7.14) 35 p.

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: 10 p.

Gavaris, S. 1988. An adaptive framework for the estimation of population size. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 88/29: 12 p.

Mohn, R.K., G. Robert, and D.L. Roddick. MS 1984. 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. MS 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. MS 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. MS 1987. Shell height-meat weight allometry for Georges Bank scallop (*Placopecten magellanicus*) stocks. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 87/40: 39 p.

Robert, G., G.A.P. Black, and M.A.E. Butler. MS 1994. Georges Bank scallop stock assessment - 1994. DFO Atl. Fish. Res. Doc. 94/97: 42 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	5218	5218
1991	0	5805	5805
1992	0	6151	6151
1993	0	6183	6183
1994	0	5003	5003

Year	Recommended TAC	Set TAC	Catch
1986	–	4300	4900
1987	6500	6850	6793
1988	4800	5400	4336
1989	4700	4700	4676
1990	4800	5200	5218
1991	5200	5800	5805
1992	5800	6200	6151
1993	6200	6200	6183
1994	5000	5000	5003

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

Year	Catch	Effort		CPUE	
	tons	hours 10^3	crhm* 10^3	kg/h*	kg/crhm
1972	2746	75	9220	36.61	0.298
1973	1975	54	6333	36.67	0.312
1974	4541	90	10810	50.46	0.420
1975	6524	105	13389	62.13	0.487
1976	7809	90	12222	86.77	0.639
1977	11126	82	11051	135.68	1.007
1978	10970	100	13686	109.70	0.802
1979	7642	105	14372	72.78	0.532
1980	4751	86	11785	55.24	0.403
1981	7612	100	14484	76.12	0.526
1982	3918	73	9977	53.67	0.393
1983	2418	67	8690	36.09	0.278
1984	1945	70	8598	27.79	0.226
1985	3812	105	12644	36.31	0.301
1986	4900	52	6957	94.23	0.704
1987	6793	78	10808	87.09	0.629
1988	4336	85	11283	51.01	0.385
1989	4676	78	10774	59.96	0.434
1990	5218	72	10570	72.09	0.494
1991	5805	66	9687	88.40	0.599
1992	6151	73	10957	84.10	0.561
1993	6183	64	9874	96.76	0.627
1994	5003	64	9566	78.12	0.523

* crew-hour-meter; hour

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

	% catch examined / catch landed	meat weight (g) mean	min	max	s.e.	n meats
1981	0.01306					
January		—	—	—	—	0
February		8.96	3.26	53.21	0.06	1386
March		11.00	2.58	65.10	0.05	3673
April		10.19	4.70	54.38	0.08	402
May		11.56	3.37	76.60	0.02	19036
June		12.15	2.26	79.87	0.02	24514
July		11.44	2.55	73.25	0.02	16301
August		10.50	2.37	74.49	0.02	15204
September		9.90	2.23	59.09	0.03	4321
October		7.28	2.37	56.52	0.03	3165
November		8.13	2.10	54.47	0.03	4146
December		8.56	2.30	53.68	0.04	3004
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
1994	0.00605					
January		17.39	6.70	43.55	0.05	1444
February		17.36	5.85	49.13	0.05	2028
March		17.67	5.09	47.15	0.07	1422
April		18.86	5.25	62.26	0.09	1068
May		18.39	5.42	64.86	0.06	2195
June		16.17	4.47	42.92	0.11	622
July		19.35	5.30	47.46	0.14	520
August		17.91	5.93	57.03	0.08	1126
September		18.46	5.15	53.40	0.07	1635
October		18.39	4.07	53.31	0.06	1932
November		20.99	4.63	59.09	0.09	1686
December		18.50	4.77	55.43	0.12	827

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

Grams	1991	Q1	Q2	Q3	Q4	1992	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	2		0	0	0	1
7		11	6	8	12		6	8	8	8
9		73	45	58	70		41	60	43	59
11		147	140	150	121		112	151	121	160
13		170	210	184	147		188	201	176	218
15		148	177	167	139		191	168	182	186
17		131	117	132	133		158	106	147	128
19		105	76	95	114		107	83	103	89
21		68	53	66	76		68	47	80	49
23		41	39	50	53		49	42	46	33
25		30	29	22	35		26	34	33	18
27		19	20	16	20		17	29	18	15
29		17	22	14	16		13	18	15	8
31		12	13	6	12		8	13	9	7
33		8	12	8	11		6	8	6	6
35		5	10	4	6		3	7	4	5
37		5	7	6	9		3	4	2	3
39		3	5	1	6		1	5	3	2
41		2	5	4	6		1	3	1	1
43		1	3	3	3		1	5	0	1
45		1	5	2	2		1	1	1	1
47		1	1	2	2		0	2	1	1
49		0	2	2	2		1	1	0	0

Grams	1993	Q1	Q2	Q3	Q4	1994	Q1	Q2	Q3	Q4
1		0	0	0	0		0	0	0	0
3		0	0	0	0		0	0	0	0
5		0	0	0	0		1	3	3	9
7		2	4	4	11		6	17	22	34
9		19	23	45	57		45	65	68	76
11		81	108	125	137		124	109	112	100
13		192	200	186	176		157	132	119	91
15		220	219	173	175		144	134	110	88
17		192	156	149	137		134	117	95	81
19		120	96	115	115		108	92	99	94
21		77	63	67	76		84	86	93	87
23		39	41	46	44		62	64	79	78
25		23	37	34	29		39	43	59	59
27		14	19	20	17		30	35	43	49
29		5	11	13	8		19	27	33	39
31		6	10	10	7		16	21	21	29
33		4	5	7	3		11	14	9	26
35		1	4	3	3		9	12	12	17
37		0	1	1	2		5	11	8	15
39		1	1	1	1		2	7	5	9
41		1	1	0	0		2	4	4	7
43		1	0	0	0		2	3	5	4
45		0	0	0	0		0	1	1	4
47		0	0	0	0		0	1	1	2
49		0	1	0	0		0	1	1	2

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

	Year									
Grams	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	0	0	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0	0	0
5	20	0	2	3	1	2	1	0	0	4
7	112	6	17	28	14	24	9	8	6	19
9	211	41	79	98	83	96	60	51	38	63
11	197	125	150	163	179	164	139	137	116	112
13	136	209	175	179	219	177	181	197	188	126
15	87	225	168	152	182	146	159	182	195	120
17	57	160	129	104	117	113	127	135	155	108
19	42	96	89	75	72	80	95	95	110	99
21	30	55	59	54	43	62	64	60	70	87
23	21	28	44	36	30	43	44	42	43	70
25	17	17	29	27	18	30	29	27	32	49
27	13	11	18	22	14	19	19	19	18	39
29	11	8	12	16	7	13	18	13	10	29
31	9	3	9	11	6	9	11	9	9	22
33	7	3	6	9	4	6	10	6	5	16
35	6	3	4	6	4	5	7	5	3	12
37	5	2	3	5	2	3	7	3	1	10
39	4	1	2	4	2	2	4	2	1	6
41	3	2	1	3	1	2	4	2	0	4
43	3	1	1	2	1	1	3	2	0	3
45	2	0	0	1	1	1	3	1	0	2
47	2	0	0	1	0	0	1	1	0	1
49	1	0	1	1	0	0	2	1	0	1
51	1	1	0	1	0	0	1	0	0	0
53	1	0	0	0	0	0	1	0	0	0
55	1	0	0	0	0	0	1	0	0	0
57	0	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	0	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0	0
77	0	0	0	0	0	0	0	0	0	0
79	0	0	0	0	0	0	0	0	0	0

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

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	289	45	33	65	65	2	21	21	16
4	492	170	90	68	144	185	186	119	159
5	75	93	65	33	37	108	188	96	103
6	16	13	14	20	11	10	16	22	19
7	8	6	3	8	10	3	3	5	9
8	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	1994
3	11	11	15	5	7
4	173	151	180	177	64
5	124	140	133	162	165
6	13	19	26	19	20
7	8	6	7	7	7
8	5	6	2	2	5
9	1	7	3	1	3
10	0	3	4	1	2
11	0	1	1	1	2
Total	335	344	371	375	275

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

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

Table 8.- Total weighted average (by stratum) number of scallops at age per tow.

Sampling dates	Age (years)								
	2	3	4	5	6	7	8	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
1994*	90	24	24	14	5	2	1	0	0

* new survey series

Table 9.- Stratified average number of scallops at age per tow and stratified total number of scallops per tow, N. A new survey series starts in 1994.

Stratum	Sampling dates	Age (years)									N	s.e.
		2	3	4	5	6	7	8	9	10+		
Very low	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
	1994*	49	6	21	23	7	3	1	0	0	114	53
Low	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
	1994*	111	5	5	11	7	2	1	0	0	143	111
Medium	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
	1994*	25	6	10	14	6	2	1	0	0	65	15
High	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
	1994*	82	19	24	13	5	2	1	0	0	148	33
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
	1994*	132	43	35	16	5	1	0	0	0	234	40

* new survey series

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

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

* new survey series

Table 10b.- Minimum dredgeable biomass at age (t of meats) using aerial expansion as per number of scallops per standard tow. Weights at age for the middle of the third quarter (August) are used.

Sampling dates	Age (years)				
	3	4	5	6	Total biomass
1981	3,435.56	876.56	277.26	143.74	4,733.12
1982	881.37	840.04	332.71	71.87	2,126.00
1983	557.60	657.42	277.26	71.87	1,564.15
1984	629.55	511.33	166.36	71.87	1,379.11
1985	3,705.36	657.42	110.90	35.94	4,509.63
1986	2,446.25	5,295.89	665.36	71.75	8,479.25
1987	1,762.72	2,301.00	942.78	359.29	5,365.79
1988	1,978.62	1,899.22	554.43	143.77	4,576.04
1989	2,356.33	2,593.11	720.93	143.77	5,814.14
1990	1,600.84	1,424.38	831.86	287.55	4,144.63
1991	1,852.68	1,789.70	720.93	215.52	4,578.83
1992	3,507.50	3,944.53	1,275.39	431.22	9,158.65
1993	755.46	1,680.08	1,330.84	503.09	4,269.47
1994*	431.69	876.56	776.33	359.35	2,443.93

* new survey series

Table 11. - Tuning criteria for the regressions of cohort biomass on CPUE in kg/hour, cohort biomass ages 3-6 on research survey biomass estimates ages 3-6, of fishing mortality (F) on effort (hours), and fishable biomass ages 4-6 on CPUE in kg/hour for selected F_{Q4}.

	Coh Biom vs CPUE			Coh Biom ages 3-6 vs Res Biom ages 3-6		
F_{Q4}	R^2	1993*	1994*	R^2	1993*	1994*
0.08	0.672	-931	-1815	0.630	-2381	-1183
0.09	0.692	-472	-800	0.677	-1912	-502
0.10	0.699	-106	11	0.708	-1537	43
0.11	0.695	194	675	0.728	-1230	489
0.12	0.681	444	1229	0.738	-974	860
0.13	0.659	656	1697	0.742	-757	1175
0.14	0.632	837	2098	0.741	-572	1444
0.15	0.602	994	2446	0.737	-411	1678

	F vs effort			Fish Biom ages 4-6 vs CPUE		
F_{Q4}	R^2	1993*	1994*	R^2	1993*	1994*
0.08	0.755	0.02	0.02	0.393	442	-693
0.09	0.754	0.01	0.01	0.370	536	-391
0.10	0.750	0.01	0.00	0.345	611	-149
0.11	0.742	0.01	-0.02	0.320	673	49
0.12	0.731	0.00	-0.03	0.296	724	213
0.13	0.717	0.00	-0.04	0.275	768	353
0.14	0.699	0.00	-0.06	0.255	806	472
0.14	0.679	-0.01	-0.07	0.238	838	575

* Residual value with respect to regression line

Table 12.- Population numbers (at beginning of the first quarter) (10^6) east of the ICJ line from cohort analysis using a terminal F_{Q4} of 0.13.

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	652	232	211	448	615	458	351	438	500
4	672	309	167	160	343	494	412	297	376
5	112	145	118	66	80	173	271	194	154
6	33	30	43	46	28	37	54	69	85
7	25	15	15	26	22	15	23	34	41
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	1120	1204	1143	1069	1207

Ages	1990	1991	1992	1993	1994
3	449	515	545	154	135
4	437	396	455	479	134
5	189	232	214	240	265
6	43	55	79	69	66
7	59	26	32	47	44
8	29	46	18	22	36
9	22	22	36	14	18
10	14	19	13	30	12
11	5	12	15	9	26
Total	1249	1324	1408	1063	736

Table 13.- Biomass Q2 (t of meats) east of the ICJ line from cohort analysis using a terminal F_{Q4} of 0.13.

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	2891	1038	909	2002	2750	2047	1569	1960	2236
4	6637	3224	1534	1718	3755	5412	4359	3191	3921
5	1854	2345	1852	1125	1433	3072	3970	3326	2283
6	768	707	1048	1068	689	893	1218	1623	1979
7	723	422	450	737	660	433	679	1011	1170
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
Biom3-11	15220	10048	7834	8348	10432	12884	12941	12437	13370
Biom4-6	9259	6277	4434	3911	5878	9377	9547	8140	8184

Ages	1990	1991	1992	1993	1994
3	2010	2304	2437	688	602
4	4122	4148	4793	4990	1355
5	2455	3441	3016	3122	3711
6	977	1249	1788	1567	1513
7	1744	742	906	1353	1277
8	969	1533	602	732	1172
9	824	762	1330	521	637
10	541	730	502	1170	460
11	202	491	590	344	1046
Biom3-11	13843	15402	15964	14487	11773
Biom4-6	7554	8839	9597	9678	6578

Table 14.- Annual fishing mortality east of the ICJ line from cohort analysis using a terminal F_{Q4} of 0.13.

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	0.65	0.23	0.18	0.17	0.12	0.01	0.07	0.05	0.03
4	1.44	0.86	0.83	0.59	0.59	0.50	0.65	0.56	0.59
5	1.21	1.11	0.85	0.75	0.68	1.06	1.27	0.73	1.18
6	0.72	0.60	0.42	0.62	0.56	0.35	0.36	0.40	0.26
7	0.39	0.57	0.27	0.40	0.63	0.22	0.14	0.17	0.24
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
F ages3-11	0.69	0.52	0.41	0.38	0.42	0.28	0.38	0.32	0.30
F ages4-6	1.12	0.86	0.70	0.66	0.61	0.64	0.76	0.56	0.68

Ages	1990	1991	1992	1993	1994
3	0.03	0.02	0.03	0.04	0.06
4	0.53	0.51	0.54	0.49	0.70
5	1.14	0.98	1.04	1.19	1.04
6	0.40	0.45	0.42	0.34	0.37
7	0.15	0.25	0.26	0.17	0.19
8	0.20	0.14	0.14	0.11	0.16
9	0.07	0.38	0.09	0.07	0.19
10	0.03	0.16	0.33	0.04	0.15
11	0.09	0.07	0.09	0.15	0.10
F ages3-11	0.29	0.33	0.33	0.29	0.33
F ages4-6	0.69	0.65	0.67	0.67	0.70

Table 15.- Retrospective analysis of biomass (10^2 tons) for the first quarter of the year, ages 3 to 6. The analysis was carried out for the last 5 years as per row label.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1990	11.0	6.6	5.1	5.0	7.0	9.7	11.2	9.9	10.0	9.0				
1991	11.0	6.5	5.0	5.0	7.3	10.4	11.8	10.1	10.2	10.3	9.8			
1992	11.0	6.5	4.9	4.8	6.9	9.7	11.0	9.2	9.5	10.2	11.6	12.6		
1993	11.0	6.5	4.9	4.7	6.6	9.1	10.1	8.5	8.7	9.2	10.1	11.3	11.0	
1994	11.0	6.5	4.9	4.7	6.5	9.1	10.3	8.9	9.9	9.9	10.7	11.6	10.7	7.7

Table 16 .-Stock projections at $F_{0.1}$ (0.70) and at F_{max} (1.10) using starting numbers from cohort analysis with a terminal F_{Q4} of 0.13.

F = 0.70	1995_{Q1}	1995_{Q2}	1995_{Q3}	1995_{Q4}
Rate on smalls	1.00	1.00	1.00	1.00
Mean Wgt. Catch	20.31	19.49	21.07	25.60
Catch (Mill.)	16.79	33.01	25.97	13.90
Catch (t)	341	643	547	356
Cum. Catch (t)	341	984	1,531	1,887
Biomass	9,782	10,170	10,303	11,245

F = 1.10	1995_{Q1}	1995_{Q2}	1995_{Q3}	1995_{Q4}
Rate on smalls	1.00	1.00	1.00	1.00
Mean Wgt. Catch	20.35	19.54	21.10	25.33
Catch (Mill.)	25.78	48.14	35.72	18.56
Catch (t)	525	940	754	470
Cum. Catch (t)	525	1,465	2,219	2,689
Biomass	9,588	9,636	9,522	10,379

Table 17.- Fishing scenarios established for 1995 given different options of fishing mortality rate. Biomass figures are for the end of 1995. Under the biomass for ages 4 to 6, the percentage that the catch represents from that biomass is in parenthesis. Catch figures are rounded off to the nearest 50 t.

No.	Options	Fvalues	Biomass (t)	Biomass 4 -6	Catch (t)
1	$F_{0.1}$	0.70	11,245	4,610 (41 %)	1,900
2	$F_{interim}$	0.75	11,128	4,562 (44 %)	2,000
3	$F_{1994\ effort}$	1.04	10,491	4,301 (60 %)	2,600
4	F_{max}	1.10	10,379	4,152 (65 %)	2,700
5	$F_{replacement\ yield}$	1.58	9,523	3,809 (91 %)	3,500
6	$F_{1994\ TAC}$	2.90	7,839	3,214 (156 %)	5,000

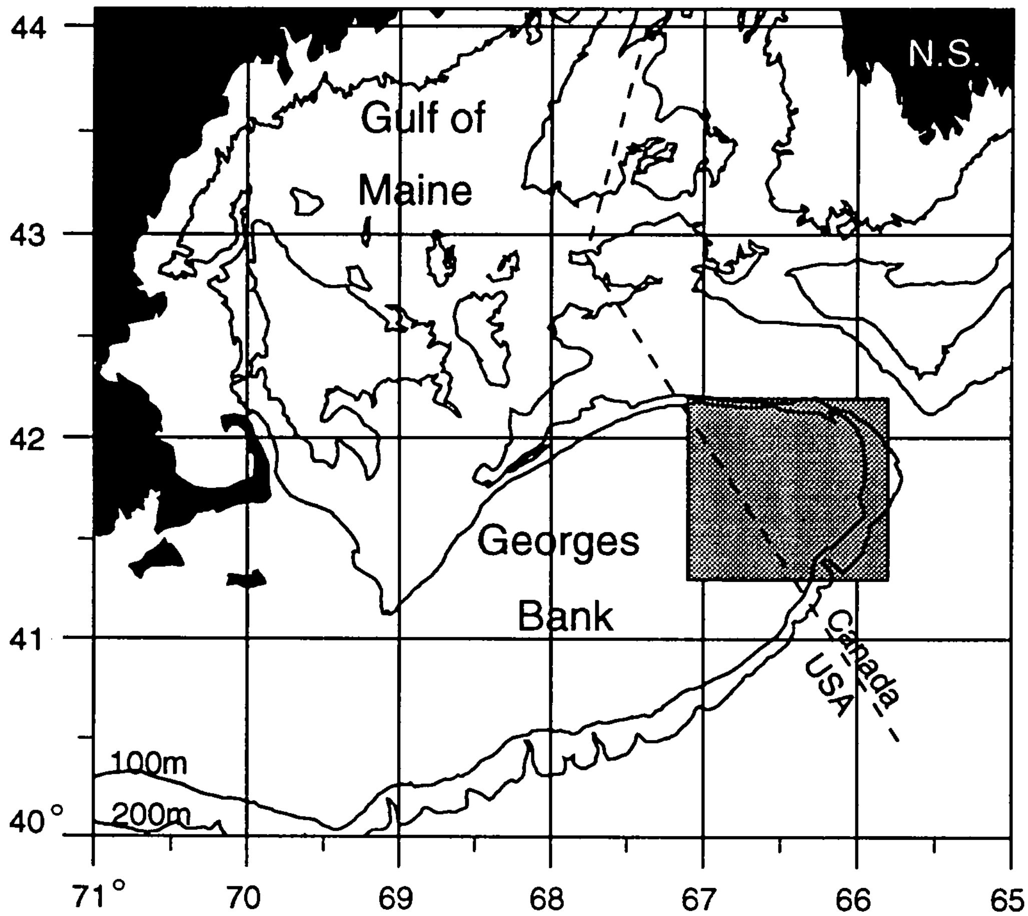

Figure 1.- Georges Bank and surrounding areas. The dashed line represents the international boundary between Canada and USA waters as determined by the International Court of Justice. Inset: see figures 3 to 6.

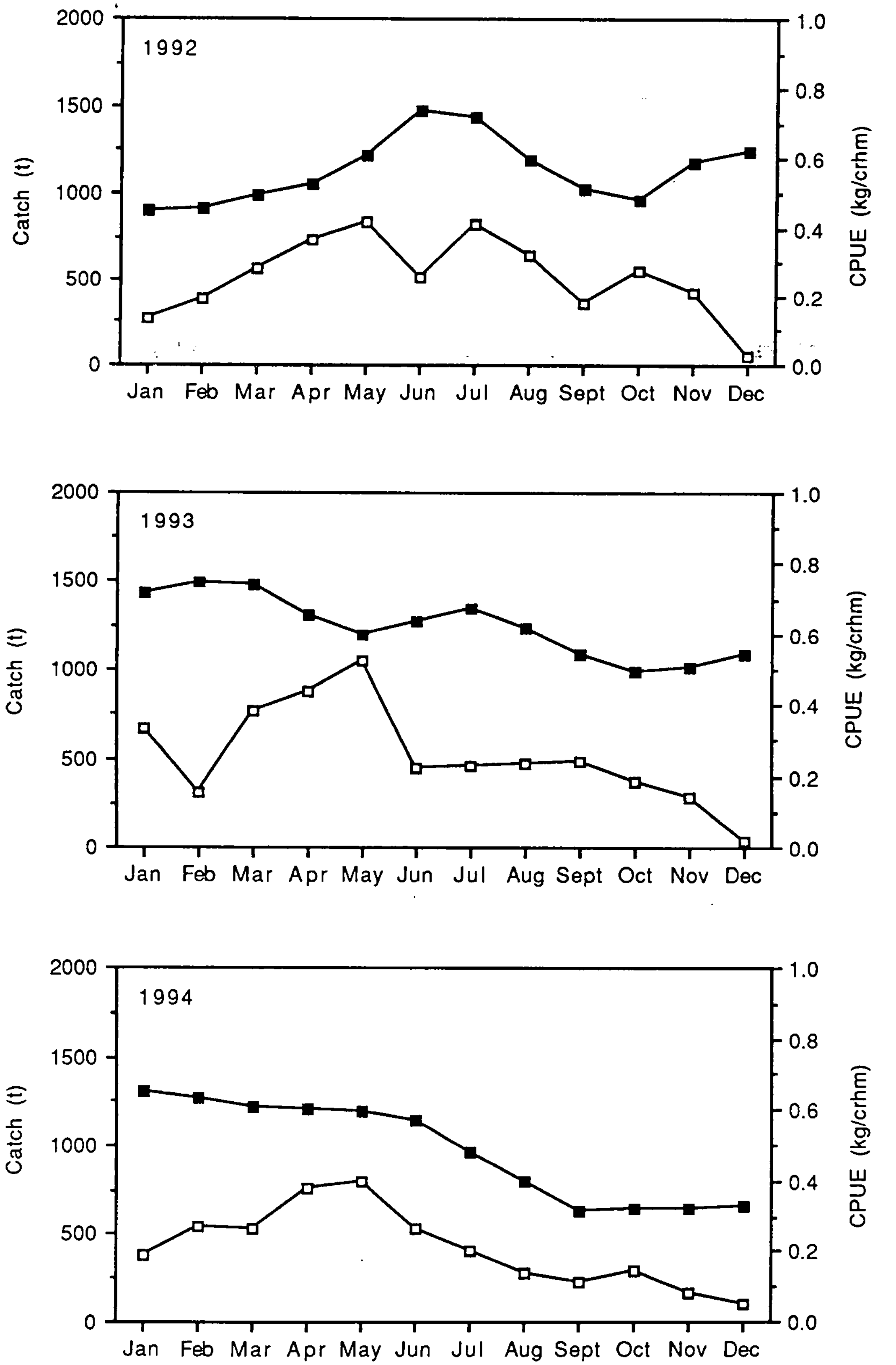

Figure 2.- Monthly CPUE (filled square) and catch in tons of meats (open square) for the deep-sea fleet fishing Georges Bank.

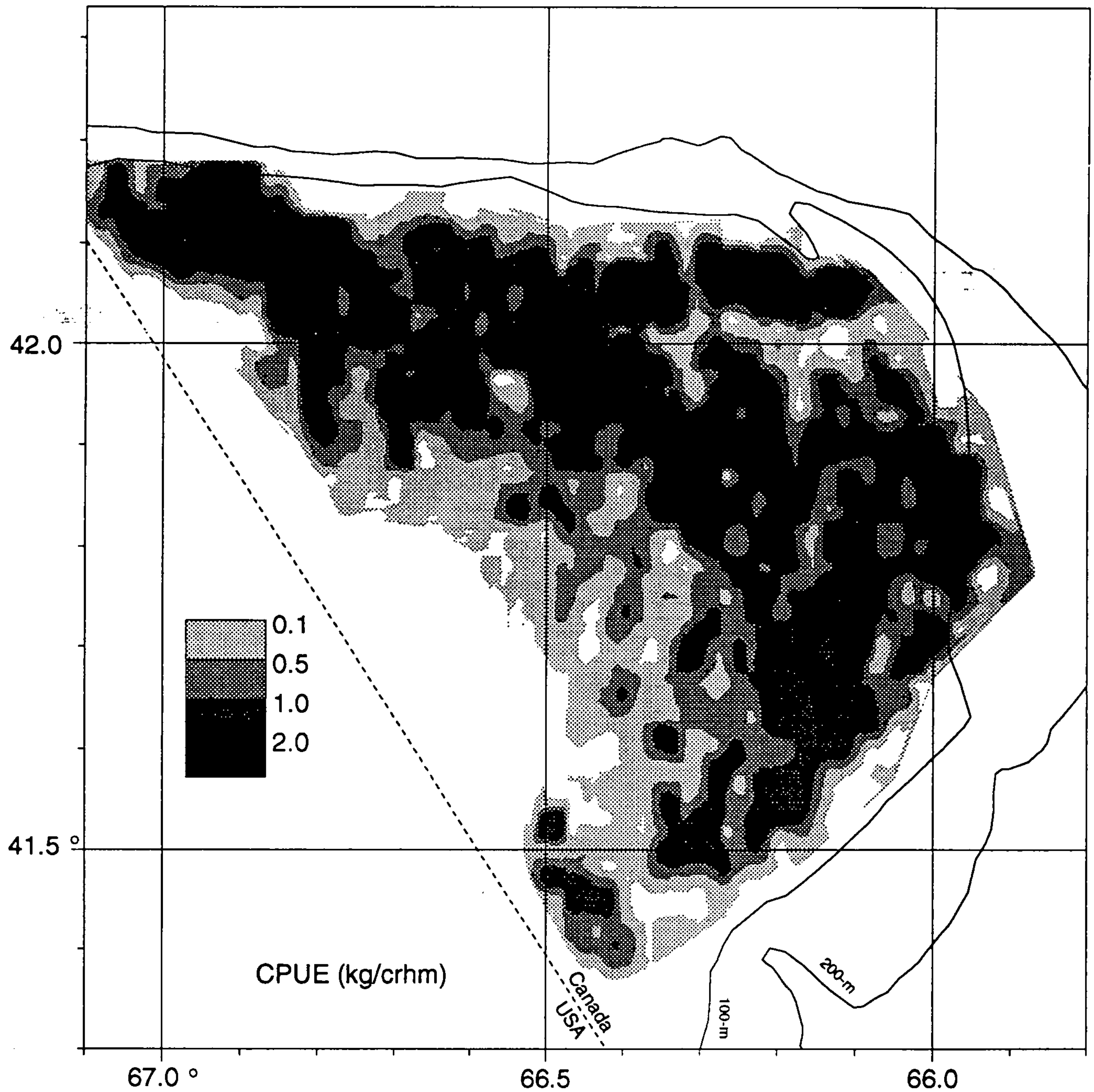

Figure 3.- Catch-rates encountered on Georges Bank in 1994. The scale of grey shades represents an ascending catch-rate up to 2+ kg / crhm.

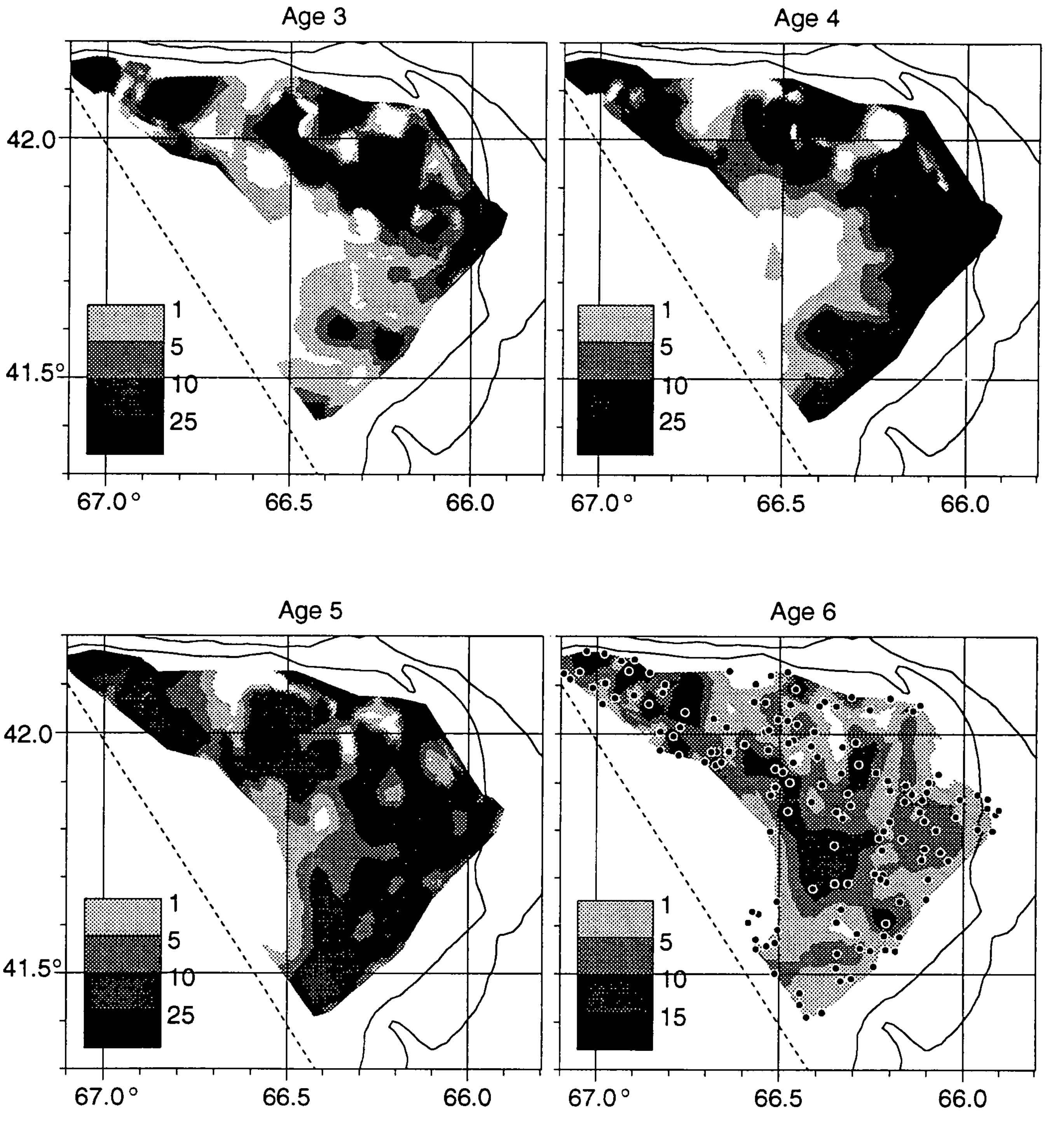

Figure 4.- Scallop distribution according to age from the research survey of August 1994. Location of sampling stations is indicated on the graph for age 6 scallops. The shading scale represents number of scallops per standard tow.

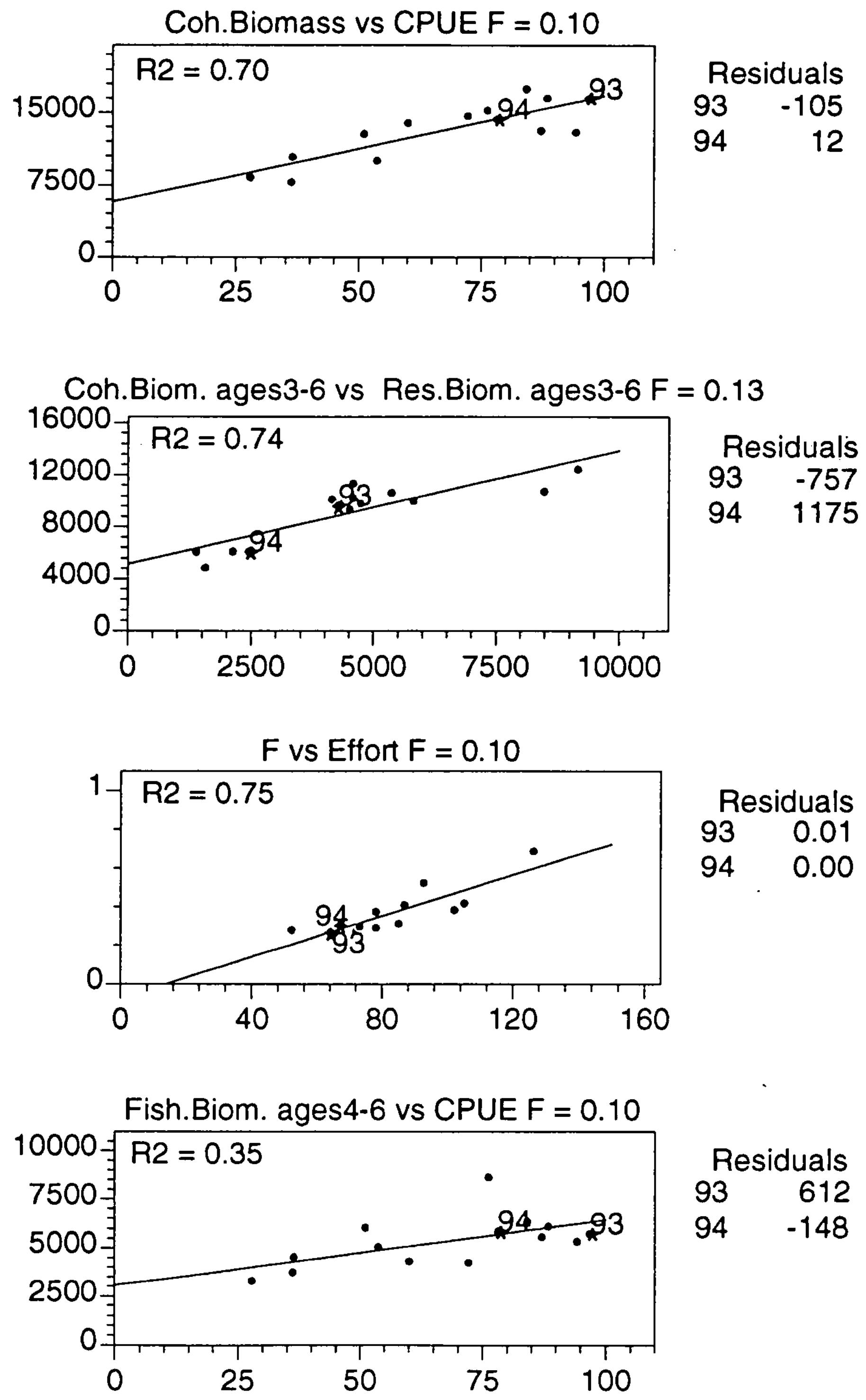

Figure 5.- Cohort biomass (t of meats) versus CPUE (kg / h) , cohort biomass for ages 3-6 versus research survey biomass for ages 3-6 (t of meats) , F versus effort, and fishable biomass for ages 4 to 6 versus CPUE (kg / h) using a terminal F_{Q4} as shown.

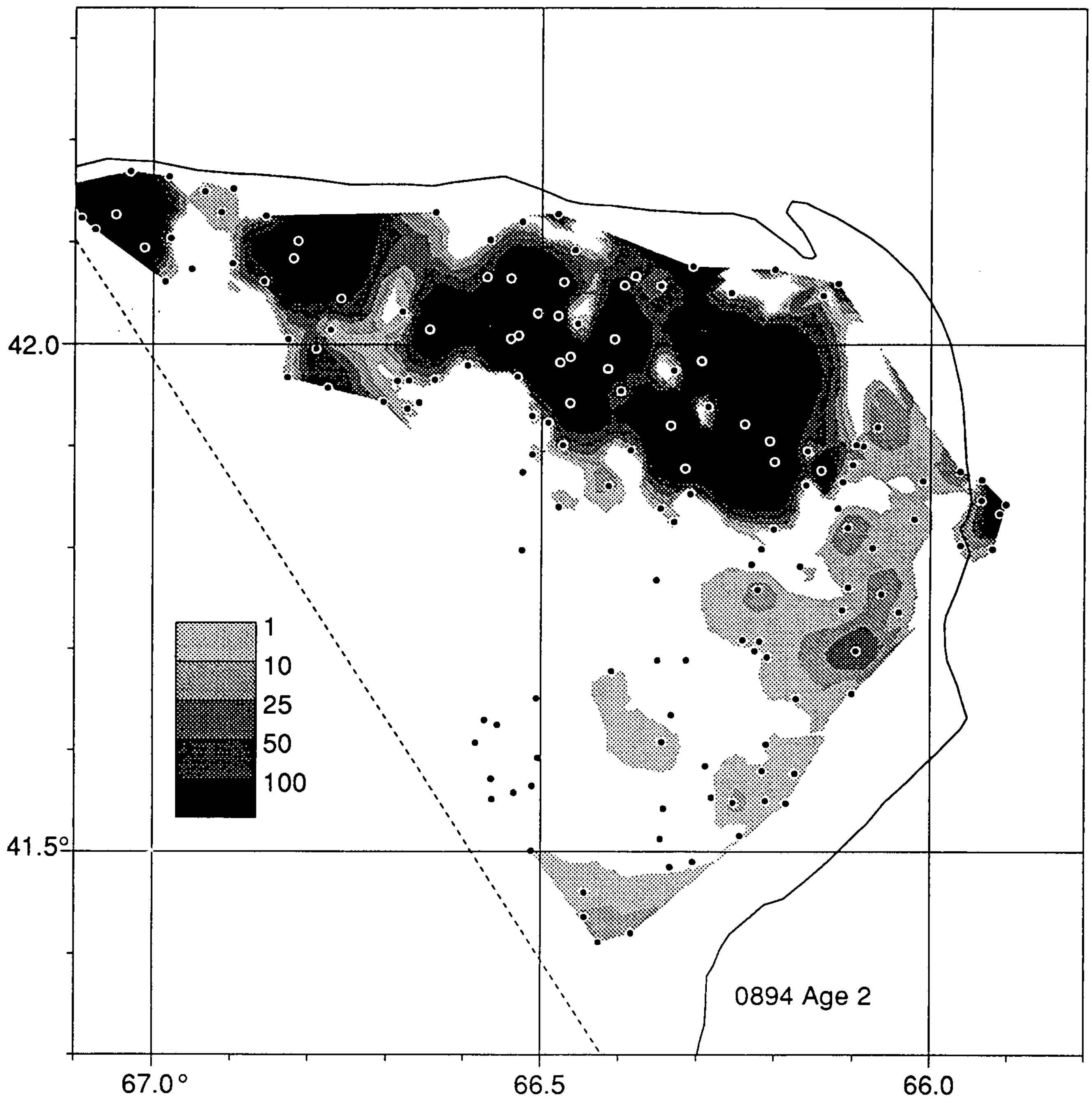

Figure 6.- Distribution of the 1992 year class at age 2 in the 1994 stock survey. Dots represent sampling locations. The 100-m isobath (smooth line) and the ICJ line (dashed) are indicated.

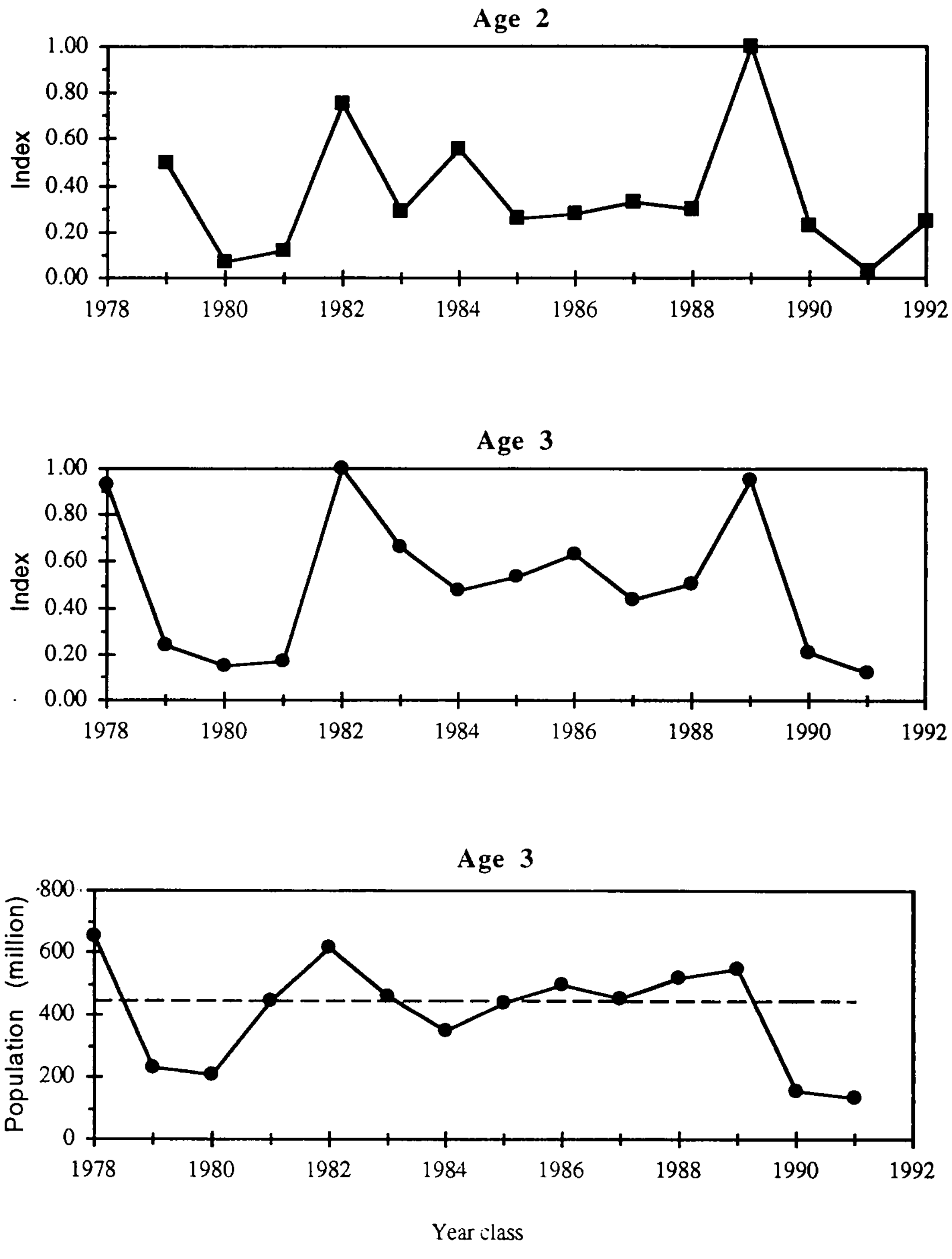

Figure 7.- Time series of normalised abundance indices from research surveys for ages 2 and 3 (top and middle graph) and estimated population numbers at age 3 in million (bottom graph). The dashed line shows the geometric mean for recruitment. Year classes are labeled on the X-axis.

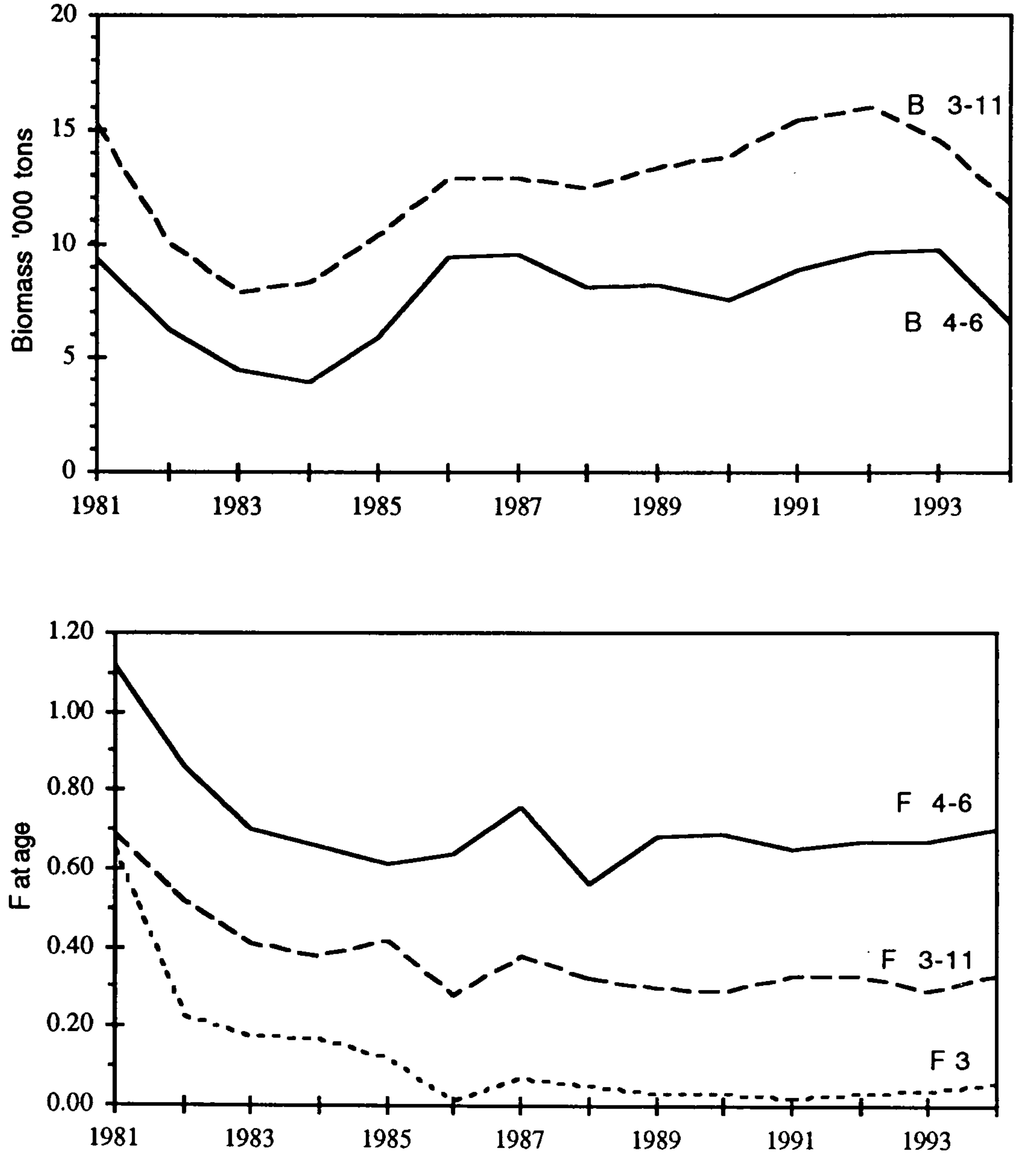

Figure 8.- Trends in biomass and fishing mortality rates. Fishing mortality rates are the mean for the ages indicated in the F label.

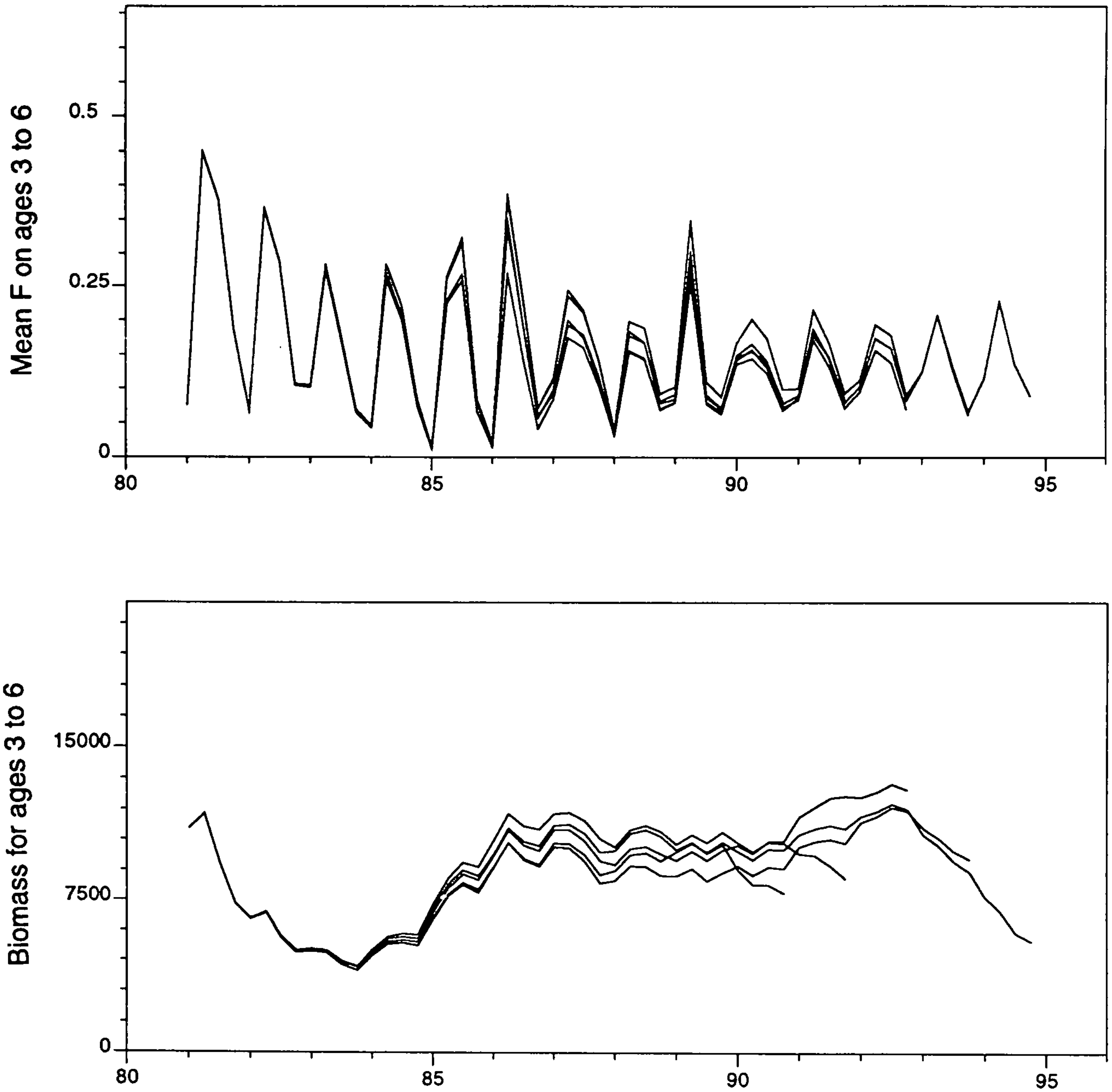

Figure 9.- Retrospective analysis patterns for fishing mortality rates and biomass for ages 3 to 6 peeling by sequences of 4 quarters (1 year) over the last 5 years.