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Georges Bank Scallop Stock Assessment - 1988

By

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ABSTRACT

The Canadian Georges Bank scallop catch for 1988 was 4,336 t., a 36% decrease over last year. There was a slight increase in effort and catch-rates decreased by almost 40%. This is confirmed by the research data which indicated that recent year-classes have not been as strong as the 1982 year-class.

1988 was the third and last year of the experimental management plan using enterprise allocations. Under this plan, a heavy targetting of effort was seen on age 5 animals. The research surveys show poor survivorship above this age.

Yield per recruit and resultant stock projections estimated for 1988 a $F_{0.1}$ catch level of 4,800 t. The TAC was set at 5,400 t which may be compared to the catch of 4,336 t. The increased targeting on 5 year olds required a new partial recruitment vector and the re-estimation of $F_{0.1}$. The new value of $F_{0.1}$ is 0.594 compared to the old value of 0.402.

The stock projections are performed with starting numbers derived from the cohort analysis, aged forward to January 1989. The $F_{0.1}$.catch level for 1989 is 3,300 t.

RESUME

Les prises canadiennes de pétoncles sur le banc Georges pour 1988 sont de l'ordre de 4,336 t, une réduction de 36 % d'après l'an dernier. Il y a eu une légère augmentation de l'effort et les taux de capture ont diminué de presque 40 %. Les données de recherche indiquent aussi que les classes d'âge récentes n'ont pas été aussi fortes que la classe d'âge 1982.

1988 était la troisième et dernière année du plan expérimental de gestion d'allocations par entreprise. Sous ce régime on a vu beaucoup d'effort dirigé sur les animaux de 5 ans. Les résultats de recherche montrent une mortalité élevée pour les plus de 5 ans.

Le rendement par recrue et les projections de stock résultantes avaient estimés pour 1988 un niveau des prises à $F_{0.1}$ de 4,800 t. La TPA fut établie à 5,400 t, ce qui se compare aux prises de 4,336 t. L'effort dirigé sur les animaux de 5 ans a exigé un nouveau vecteur de recrutement partiel et une ré-évaluation de $F_{0.1}$. La nouvelle valeur de $F_{0.1}$ est de 0.594 comparé à 0.402 précédemment.

Les projections de stock sont établies avec des valeurs initiales dérivées de l'analyse de cohortes, âgées en avance à Janvier 1989. Le niveau $F_{0.1}$ de prises pour 1989 est 3,300 t.

INTRODUCTION

The strong year-classes of 1957 and 1972 produced major peaks in landings in the last 30 years of the Georges Bank scallop fishery (Figure 1 and Table 1). The more recent peak occurred in 1977 and 1978 with landings of over 17,000 t. Landings fell to about 10,000 t in 1980 but increased to 16,000 t in 1981 as a result of increased Canadian and U.S. fishing effort and a relaxation of the enforcement of the meat count regulation on the Canadian fleet. U.S. catch levels have shown an upward trend since the early 1970's to over 8,000 t in 1981, representing an increase of 400% from 1976 to 1981 and a parallel increase in effort. From 1982 on, landings by the Canadian fleet decreased steadily to 1,945 t in 1984, its lowest level since 1959. Then catches increased steadily to 6,800 t in 1987 before lowering again in 1988. Effort increased slightly from 1987 to 1988. Given the reduction of older age groups and relatively stable abundance of pre-recruits, the fishery performance is not expected to show great improvements in the near future.

As anticipated, the 1988 catches went down, by 36 % from the previous year to 4,336 t while catch-rates decreased by 40 %. 1988 marked the last year of the experimental Enterprise Allocations plan. This was also the last year that the Bay of Fundy fleet was granted a share of the Georges Bank TAC following the Inshore / Offshore Agreement; that fleet took about 15 t.

METHODS

Catch and effort data are compiled from logbooks. Logs with complete effort data are called Class 1 and are used to determine catch-rates. The Class 1 data represent more than 90% of the total (Table 2). Also, data on size distribution of meats from the commercial fleet are derived from port samples. Canadian port sampling data were applied to the Canadian and U.S. total catch east of the ICJ line. This assumes similar fishing practices for both fleets. The annual changes in fishing practice can be seen in Table 3, which contains weight distribution in 2-gram intervals for the last ten years. Changes by month within 1988 are shown in the same manner in Table 4. Figure 2 shows the monthly catches and CPUE's for the last four years.

Catch in numbers-at-age (Table 10) for the cohort analysis are derived from the port sampling data and the sum of U.S. and Canadian catches in the Canadian zone. For more details on the method used to derive catch-at-age see Roddick and Mohn (1985). The total catch (U.S. and Canadian) from the Canadian zone is decomposed into weight frequencies. The weights were converted to shell heights using the allometric relationship derived from 1982 -1985 research and commercial data (Robert et al., 1987). The values expressing meat weight as a function of shell height use the parameters 9.102E-6 for the constant and 3.097 for the exponent of height. These values agree closely with those of Serchuck et al. (1982) for the same stock. Von Bertalanffy growth coefficients relating shell height and age were taken from Brown et al. (1972).

Traditionally, catch statistics are compiled on an annual basis and recruitment to a fishery is discussed in terms of year-class strength. It is generally accepted that Georges Bank scallops are born in October and the first annual ring is laid down the following spring. This is typically less than 10 mm and becomes difficult to discern as the animal grows. For this reason the ring, which is approximately 25 mm from the umbo is often referred to as the first annulus (see, for example, 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 5, 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 5, as well as all other age data, uses this convention, with correction of ring sizes back to January 1. For use in age / weight programs and projections, the actual weights used are mid-quarter values.

As for recent years, a research survey was carried out on Georges Bank during August 1988. The design of the survey was based on a stratification by commercial effort (Robert and Jamieson, 1986). The logbooks of the commercial fleet in the preceding 9 months were analyzed to determine areas of high and low fishing intensity. The areas of high intensity were sampled more heavily as they represent the area most important to the fleet (and presumably the areas of greatest abundance). The average number of animals at age per tow is given in Table 6. The details of the survey results on a per stratum basis are given in Table 8.

In addition to establishing a stratified mean number per tow, the data were contoured to represent the spatial distribution of the scallop aggregations and integrated to estimate total numbers (Table 7). Data points describe a three dimensional surface with latitude, longitude, and density to be plotted. A surface is formed by defining triangles (Delaunay) where the data points form the vertices of triangles connecting neighbouring points. The algorithm used to define the triangles is found in Watson (1982). Collectively, the triangles form a surface. The surface between adjacent contour levels (abundance of scallops) is illustrated by varying shades of grey. Smoothing of the contours may be performed by interpolating the surface using inverse weighting of gradients (perpendicular to the planes of the triangles). The interpolation points are found by dividing the sides of the Delaunay triangle into equal segments. For example, dividing the sides into 4 segments produces 16 subtriangles. Interpolation is performed on all the new vertices. This method assumes that the data points near the point in question contribute more than distant points (Watson and Philip 1985). The summation of the volumes of all triangles (integration) under the contoured surface approximates the total volume, here the abundance estimate for the survey area. The degree of interpolation will affect the volume estimates. For the Georges Bank survey data, the effect was generally less than 5%. The estimates stabilize using 4 or more segments (16 or more subtriangles). To assure the abundance estimates from similar areas are compared, only those points east of the ICJ line are used. A method to more accurately define a common overlapping area for comparison is still under development. A more complete description of the contouring method and volume (total abundance) estimation may be found in Black (MS 1988).

A Thompson-Bell type yield per recruit analysis was carried out (Mohn et al. 1987) with quarterly time steps and using a newly defined partial recruitment pattern for 1988. A quarterly based time step is required to take into account the dynamic growth of the younger age-classes of scallops. However, this method cannot include the effects of blending. Because of a recent change in fishing strategy, the yield per recruit was re-calculated this year.

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. 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 because of the very rapid growth of the young scallops. The annual growth is divided into quarterly components of 10, 35, 35 and 20% and annual effort is partitioned into quarters by the rates of 10, 40, 40 and 10%, which reflects the 1988 fishery. Selectivity for the projections follows the pattern of the fishery as revealed from the cohort analysis instead of that of the gear (Caddy 1972). Starting numbers-at-age for the projections were derived by aging ahead the fourth quarter 1988 cohort estimates to January 1989.

Because cohort analyses deal only with the removals from a cohort and not the growth of the animals it is not appropriate to use data collected on an annual basis for a dynamic species like scallops. In the first year of recruitment the animals experience approximately a 300% increase in weight. In order to reduce the magnitude of the errors caused by ignoring growth effects, the cohort analysis was carried out on a quarterly basis. This required that catch-at-age be determined on a quarterly basis. Also, the above mentioned quarterly distribution of effort had to be taken into account. Partial recruitment had to be determined on a quarterly basis also. This was done by adjusting the recent two year's selectivity pattern to reflect the port sampling data for the last quarter of 1988. This pattern, multiplied by the F determined from tuning for the last quarter year, was used as a starting vector for the quarterly cohort analysis. Natural mortality was set at .025 per quarter and no attempt was made to include a seasonal, age or time dependent effect.

Tuning must be applied to both the catch-at-age determination and to the cohort analysis. Because age-length keys are not available for the scallop fishery (actually they would have to be age-meat weight keys) a growth model was developed to convert port sampled weight distributions (Tables 3 and 4) into numbers caught per quarter (Roddick and Mohn, 1985). The model is tuned against the port sampling data. A matrix of residuals is examined for local patterns and longer term trends. The total residual is also used in the tuning process. Relative year-class strengths and survivorship are adjusted in the tuning process. The catch-at-age is fairly stable to the tuning except in the older ages when year-classes overlap in size. Fortunately, there are few animals caught above age 6 and the increased sensitivity does not significantly affect the results. Once a stable catch-at-age matrix is produced, a SPA is carried out in the normal manner. The results of the trial SPA could be used to re-tune the age determination. Significant discrepancies were not found so re-tuning was not carried out. The interdependence of the catch-at-age tuning and subsequent SPA tuning are a concern and research is underway to address this problem.

The SPA is tuned against a number of independent, and sometimes contradictory, sets of observations. The most important are the commercial CPUE and the research estimates. F versus effort is also used to aid in the tuning process. Tuning selectivity is more difficult in scallop data than for most fisheries. This is because the SPA is done on a quarterly basis and the F's on the most recent year affect only the last quarter. Thus one cannot 'dial up' the exact numbers or F's one might want for the most recent year as can be done with annually collated data. F on the oldest animals was found by multiplying the effort pattern by the mean terminal F from the older ages. Because the selectivity is highly domed, these values are not critical and the normal iterative determination was not undertaken. (At the recent retrospective analysis workshop it was shown that iteratively estimating the terminal F from younger ages diverged rather than converged.) For the purposes of tuning, the terminal F (annual rate) ranged from 0.4 to 1.2 (Table 9). A range of this magnitude was required to drive the residuals in the research survey vs SPA biomass across the regression line. The residuals of the last two year's data and the correlation coefficient were used as criteria. As expected, the correlation coefficient was not very sensitive. The + signs in this table denote that the residual is above the regression line and the minus sign, below. Both the correlation coefficient and residuals for the last 2 years are used in the tuning. It should be noted that the research survey biomass estimates are derived from the average weights of the 3rd quarters. These are compared to 3rd quarter biomasses from the SPA. The annual CPUE values are compared to 1st quarter biomasses.

The CPUE vs SPA biomass estimates had a maximum R^2 at F = 0.5 and the 1988 point crossed the regression line at an F of 0.7. The research survey biomass and the SPA biomass are used as a second criteria for tuning, although the regressions were not as good as for the CPUE based tuning. The residual crosses the regression line at an F of 0.8. The tuning of effort vs F had a weak correlation and the residual for 1988 crossed the regression line at an F of 0.9. Plots of the regressions used in the tuning process are presented in Figure 3. The CPUE vs SPA biomass shows a linear pattern of points with the last year being on the regression line and the two before that being beneath the regression. (Figure 3). The research survey biomass vs SPA biomass (Figure 3) shows a strong linear distribution. The approximate agreement between tuning of CPUE and research biomass against the SPA results gives us a measure of confidence that the correct terminal F is in the vicinity of 0.7-0.8. Both the CPUE and research biomass, the independent data used for tuning, show a fall in abundance from 1986 to 1988. We could not duplicate this trend in the SPA using reasonable terminal F's. Although the correlation is lower in the research biomass tuning, it is felt to be a more reliable data series and terminal F is set at 0.8. This is because of changes in the fishery over the 17-year period include changes in size regulations. Also, the lower (F= 0.7) value did not track recent biomass estimates, nor the recruitment indices from the research surveys, as well. Although a weak indication, the F vs effort tuning, suggested a higher terminal F (= 0.9). The pattern shown in the efforts for the last 5 years are similar to the average F's with a terminal F of 0.8. On balance, the 0.8 value seemed best.

"Shortcut" methods have been proposed by ICES (Anon. 1985) and others when traditional assessments are impossible or impractical. An implementation of these methods was developed and applied to the Georges Bank data. Shortcut methods are essentially a predicted catch from a (multiple) regression model. They are usually denoted by an anagram-based name; for example, SHOT, Shepherd's HangOver Technique, which is based on a regression of yield in year y+1 from yield and a recruitment index in year y. The purpose of reviewing shortcut techniques here is the problem of producing a provisional TAC for the fleet in advance of the full assessment results. This has been the practice and a requirement for Georges Bank scallops since the inception of EA's.

The simplest shortcut estimate would be the average catch. Over the period of cohort analysis the average annual catch for 5Ze, east of the ICJ line is just over 6,300 t and for the period since reliable research numbers are available the average is 5,100 t. The appropriate average catch could be partitioned into a fraction for the portion of the year (January to April) required until the Advisory Document is released. However,the shortcut methods should afford a better estimate. Regression variables for potential fitting are shown in Table 15. They are the yield, effort, research recruitment index, SPA recruitment index, catch and an environmental factor. Excepting the environmental factor, all of these, and in various combinations have been suggested by various authors (Anon. 1985). The environmental factor has been included to take advantage of the strong periodicity of landings which correlates with an 18.6-year tidal cycle (Cabilio et al. 1987). The factor is a simple 18.6-year sinusoid with a phase to match its peak to the peak in landings of 1977. Regressions were done for the full 17-year period of the cohort analysis and for the shorter 11-year period for which research recruitment indices are available. The index used is the mean numbers per tow of three-year olds. The research survey values were extended to the period 1972 to 1978 by inserting the mean values of the recruitment series.

RESULTS

Sampling locations of the 1988 research survey are plotted in Figure 4 (See plot of age 6 animals). A few stations are deeper than the 100-m isobath. These latest results indicate that age groups over age 5 have decreased by half since 1987. The main recruiting age (4) has also decreased while pre-recruits have remained at practically the same level (Tables 6 and 7). The serious reduction in recruited age groups occurred principally in the stratum of highest commercial catches (Table 8). Figure 4 illustrates the main scallop aggregations on an age basis, the highest concentrations having the darkest shading. The representation for ages 4 and 5 shows discrete patches (over 100 animals/tow for age 4; over 20 for age 5) in a more or less continuous strip, 5 nautical miles wide, within the 100-m isobath on the north and northeastern sides of the Bank.

The cohort analysis results are given in terms of numbers-at-age, biomass-at-age, and F-at-age (Tables 11 to 13) which have been combined into annual values from quarterly analysis for the terminal F level of 0.8. The 1982 year-class is the largest seen in the last 8 years. There is very little survivorship above age 6 seen in Table 11. Examination of the F estimates shows that the last three years had a targeting of effort on 5 year-olds. This corresponds to the introduction of EA's and the 33 meats per 500 grams size regulation. The average F values show some degree of recent stabilization compared to the earlier years. It is interesting to note that the starting F in the last quarter of 1988 on age 5 was 0.8, but the total over the year for that age was 1.14. Again, this shows the targetting on age 5 scallops.

The quarterly based yield per recruit analysis used mid-quarter meat weights and the quarterly expanded selectivity derived from the cohort analysis (See Mohn et al. 1987). The assessments from the previous two years had an F_{max} which was estimated to be at an F of 0.630 and $F_{0.1}$ at 0.402. This year's re-analysis gives values of 0.966 and 0.594 respectively. The same selectivity is used in the cohort analysis, yield per recruit, and the stock projections (Table 14) which are carried out at F_{max} and $F_{0.1}$ using the cohort analysis results. This partial recruitment is more domed than used before; the annual values for the partial recruitment for ages 3 to 11 were 0.10, 0.75, 1.0, 0.71, 0.50, 0.37, 0.37, 0.35, and 0.32. The new values are 0.04, 0.52. 1.00, 0.63, 0.36, 0.21, 0.17, 0.10, and 0.05. The projections are for a two year period and assume a recruitment level of 400 million animals, a level which is low and commensurate with recently estimated values. The $F_{0.1}$ and F_{max} catch levels for a terminal F of 0.8 are 3,300 and 4,700 t respectively. The mean weights of the catch are projected to be well above the legal limit of 33 meats per 500 grams, except for the second quarter (Table 14). The biomass is essentially stable under F_{max} and increases about 10% per annum under $F_{0.1}$ and the assumed recruitment pattern.

The shortcut analyses were conducted for 2 periods. For the period 1979-1987, the only encouraging regression coefficients are those involving the SPA recruitment indices. As they require a full age-structured analysis calling them 'shortcut' is not entirely appropriate. The estimates of 1989 yield from the three relationships having an R^2 above 0.4, range from 4,500 to 4,700 t. (Table 16). Using the full data series in Table 15, gives higher regression coefficients and R-squares get just over 0.8 for yield as a function of the previous year's yield and SPA recruitment index. They also predict a 1989 catch in the vicinity of 4,600 t. It is interesting to note that they seriously overestimate the 1988 catch which was 4,336 t.. On the basis of these analyses, it appears that the shortcut methods offer only a slight advantage when compared to the mean values.

CONCLUSIONS

A relatively strong recruitment was seen in the 1986 and 1987 fishery. This is evidenced by the change in the monthly CPUE of 1986 compared to 1985 (Figure 2). Such fishing early in the year means a loss of yield, and may affect the cohort analysis. 1988 showed relatively modest catches and CPUE's were well beneath the long term average. Figure 2 also did not show a strong recruitment pulse (in terms of catch-rates) during the summer. The 1988 research survey indicates that recruitment has stabilized at a level approximately one half the strong 1982 year-class. These conclusions are supported by the cohort analysis. At $F_{0.1}$ the recommended catch level for 1989 is 3,300 t.

The tuning with CPUE minimized the 1988 residual at an F of 0.7. Tuning with research biomass minimized the residual at 0.8. The latter value was chosen for the projections for reasons summarized under Methods. An additional factor is that retrospectively, the terminal biomass estimates from the SPA's were over-estimated.

The scallop stock on Georges Bank still requires rebuilding. Therefore, it is still strongly dependent on recruiting year-classes. Targeting of effort has reduced survivorship above age 5. As the pre-recruits are first seen as 2 year olds in the research gear in non-reliable quantities and are fully recruited two years later, it is not possible to predict stock status with any confidence more than a year into the future.

A cautionary note is appended as a closing comment. There are special problems in applying traditional assessment techniques to scallop stocks. One example is the tuning which is required for both the generation of catch-at-age and in the SPA process. This assessment uses techniques which are still under research and being refined.

REFERENCES

Anon. 1985. Report of the Working Group on Methods of Fish Stock Assessments. I.C.E.S. Coop. Res. Rep. No. 133. 56p.

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

Bourne, N. 1964. Scallops and the offshore fishery of the Maritimes. Bull. Fish. Res. Board Can. No. 145: 60 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.

Cabilio, P., D.L. DeWolfe, and G.R. Daborn. 1987. Fish catches and long-term tidal cycles in Northwest Atlantic fisheries: a nonlinear regression approach. Can. J. Fish. Aquat. Sci. 44: 1890-1897.

Caddy, J.F. 1972. Size selectivity of the Georges Bank offshore dredge and mortality estimate for scallops from the northern edge of Georges in the period June 1970 to 1971. Int. Comm.

Northw. Atl. Fish. Res. Doc. 72/5: 10p.

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

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

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

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

Roddick, D.L. and R.K. Mohn. 1985. A method for the generation of catch-at-age data. Int. Cons. Explor. Mer C.M. 1985/D14: 21 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.- Catch statistics (t of meats) from Georges Bank, NAFO subdivision 5Ze. For Canada: Statistics from SA 5Z not separated into 5Ze and 5Zw prior to 1967. Source: Pre-1961, Bourne (1964); 1961-on, ICNAF and NAFO Statistical Bulletins.

YEAR	USA	CANADA	TOTAL
1953	7392	148	7540
1954	7029	103	7132
1955	8299	120	8419
1956	7937	318	8255
1957	7846	766	8612
1958	6531	1179	7710
1959	8910	1950	10860
1960	10039	3402	13441
1961	10698	4565	15263
1962	9725	5715	15440
1963	7938	5898	13836
1964	6322	5922	12244
1965	1515	4434	5949
1966	905	4878	5783
1967	1234	5011	6245
1968	998	4820	5818
1969	1329	4318	5647
1970	1420	4097	5517
1971	1334	3908	5242
1972	824	4161	4985
1973	1084	4223	5307
1974	929	6137	7066
1975	860	7414	8274
1976	1777	9675	11452
1977	4823	13089	17912
1978	5589	12189	17778
1979	6412	9207	15619
1980	5477	5221	10698
1981	8443	8013	16456
1982	6523	4307	10830
1983	4328	2748	7076
1984	3071	1945	5016
1985	2949	3812	6761
1986	4400	4670	9110
1987	8800	6793	15593
1988	n/a	4336	4336

Table 2.- Catch and effort data. Canadian catches (t of meats) in NAFO subdivision 5Ze. Total effort is derived from effort from Class 1 data.

YEAR	CATCH	EFFORT			CPUE
		days	hours 10^3	crhm* 10^3	kg/crhm
1972	4161	8188	114	13971	0.298
1973	4223	7946	115	13541	0.312
1974	6137	8205	121	14610	0.420
1975	7414	8221	119	15216	0.487
1976	9675	7593	112	15142	0.639
1977	13089	8689	97	13001	1.007
1978	12189	8547	111	15207	0.802
1979	9207	8827	126	17315	0.532
1980	5221	6848	95	12951	0.403
1981	8013	8443	105	15247	0.526
1982	4307	6116	80	10968	0.393
1983	2748	5483	76	9876	0.278
1984	1945	5716	70	8598	0.226
1985	3812	7376	105	12644	0.301
1986	4900	3915	52	6957	0.704
1987	6793	5736	78	10808	0.629
1988	4336	5853	85	11283	0.385

* crew-hour-meter

Table 3.- Frequencies of numbers at weight in 2-g intervals (normalized to 1000) by year.

	YEAR									
Grams	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
1	0	0	0	0	0	0	0	0	0	0
3	2	15	16	2	12	7	1	0	0	0
5	32	99	84	26	66	96	20	0	2	3
7	97	172	204	99	110	205	112	6	17	28
9	136	169	253	146	118	169	211	41	7	98
11	137	128	177	159	125	108	197	125	150	163
13	110	92	96	132	111	69	136	209	175	179
15	85	67	52	103	90	55	87	225	168	152
17	65	51	31	73	70	46	57	160	129	104
19	50	38	20	55	53	41	42	96	89	75
21	43	32	15	45	44	37	30	55	59	54
23	38	24	11	33	36	30	21	28	44	36
25	31	20	8	27	27	25	17	17	29	27
27	25	17	6	21	23	20	13	11	18	22
29	24	13	5	17	18	18	11	8	12	16
31	21	11	4	13	15	15	9	3	9	11
33	17	9	3	11	13	12	7	3	6	9
35	16	7	3	8	10	11	6	3	4	6
37	13	6	2	6	8	8	5	2	3	5
39	11	5	2	5	8	6	4	1	2	4
41	9	4	1	4	6	5	3	2	1	3
43	7	3	1	3	6	4	3	1	1	2
45	7	3	1	2	5	3	2	0	0	1
47	5	3	1	2	4	2	2	0	0	1
49	4	2	1	1	4	2	1	0	1	1
51	3	2	1	1	2	2	1	1	0	1
53	3	2	1	1	3	1	1	0	0	0
55	2	1	1	1	3	1	1	0	0	0
57	1	1	0	0	1	1	0	0	0	0
59	1	1	0	1	2	0	0	0	0	0
61	1	1	0	0	2	0	0	0	0	0
63	1	1	0	0	1	0	0	0	0	0
65	1	0	0	0	2	0	0	0	0	0
67	0	0	0	0	1	0	0	0	0	0
69	0	0	0	0	1	0	0	0	0	0
71	0	0	0	0	0	0	0	0	0	0
73	0	0	0	0	1	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0	0
77	0	0	0	1	0	0	0	0	0	0
79	0	0	0	0	0	0	0	0	0	0

Table 4.- Frequencies of numbers at weight in 2-g intervals (normalized to 1000) by month for 1988. Sample sizes are given in the last row.

Grams	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	0	0	0	0	1	0	0
3	0	0	0	0	0	1	0	0	0	0	0	0
5	0	6	0	2	2	1	3	6	0	4	3	0
7	0	37	25	34	13	13	28	37	0	37	34	15
9	0	118	134	133	54	57	83	112	0	116	140	55
11	0	165	298	168	133	128	157	172	0	167	202	147
13	0	140	198	163	168	186	179	180	0	184	183	222
15	0	96	74	123	177	182	157	141	0	146	145	195
17	0	89	51	76	117	133	103	93	0	91	103	145
19	0	53	51	56	85	89	80	71	0	79	61	80
21	0	68	35	56	51	65	57	48	0	58	42	43
23	0	40	58	40	49	38	35	39	0	36	23	26
25	0	32	26	32	41	33	29	25	0	19	20	19
27	0	32	32	38	27	23	22	24	0	19	11	13
29	0	25	10	21	25	15	17	16	0	14	9	9
31	0	18	16	16	19	10	12	12	0	8	8	6
33	0	23	10	15	12	9	9	6	0	5	8	6
35	0	9	0	6	13	5	8	5	0	4	3	5
37	0	9	6	6	5	3	6	3	0	4	5	6
39	0	9	0	8	4	3	4	3	0	3	2	3
41	0	11	3	0	3	2	3	2	0	2	3	6
43	0	4	0	1	1	2	2	1	0	2	1	1
45	0	3	0	1	0	1	2	1	0	2	1	0
47	0	4	0	5	0	2	2	0	0	0	0	1
49	0	2	0	0	0	0	1	0	0	0	1	0
51	0	4	0	1	0	0	1	0	0	2	0	2
53	0	2	0	0	0	0	1	0	0	0	0	0
55	0	0	0	0	0	0	1	0	0	0	0	0
57	0	0	0	1	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	1	0	0	0	0	0
61	0	1	0	0	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0	0	0	0
77	0	0	0	0	0	0	0	0	0	0	0	0
79	0	0	0	0	0	0	0	0	0	0	0	0
N	0	1107	321	1310	2348	3698	4002	4095	0	3116	3530	865

Table 5.- Shell height (mm), meat weight (g) and meat count per 500 grams at age as used by projection and age/weight programs. 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 6.- Total weighted average (by stratum) number of scallops at age per tow.

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

Table 7.- Indices of abundance of scallop age-classes by contour analysis: numbers-at-age (10^6), biomass (t of meat), area (km^2) used in abundance estimation.

Sampling dates	Age (years)					
	3	4	5	6	Biomass	Area
1981	279.47	53.60	9.34	3.48	6112	3987
1982	121.76	56.95	15.47	3.43	3835	6161
1983	99.32	50.76	14.31	5.28	3361	5839
1984	85.74	30.32	8.08	2.21	2386	5812
1985	557.64	45.29	5.88	1.26	10207	5943
1986	309.16	225.53	26.46	3.81	11071	5025
1987	214.58	145.50	41.78	11.27	8400	4997
1988	238.53	105.06	23.45	5.05	7107	5115

Table 8.- Stratified average number of scallops at age per tow and stratified total number of scallops per tow, N.

Stratum	Sampling dates	Age (years) 2	3	4	5	6	7	8	9	10+	N	s.d.
Very low	1981	71	92	48	6	1	1	0	0	0	239	325
	1982	6	6	20	10	1	0	0	0	0	64	200
	1983	26	19	8	3	2	1	0	0	0	69	175
	1984	74	14	8	2	1	0	0	0	0	125	295
	1985	32	79	6	1	0	0	0	0	0	170	375
	1986	42	154	50	5	1	0	0	0	0	292	582
	1987	43	171	76	10	1	0	0	0	0	301	595
	1988	39	104	67	9	1	0	0	0	0	236	417
Low	1981	24	26	9	2	1	1	0	0	0	78	102
	1982	14	18	20	5	1	0	0	0	0	86	138
	1983	81	59	19	5	2	1	0	0	0	172	230
	1984	151	27	11	2	1	0	0	0	0	253	445
	1985	74	64	11	2	0	0	0	0	0	188	324
	1986	165	143	49	14	2	0	0	0	0	376	769
	1987	61	56	71	17	2	1	0	0	0	208	277
	1988	50	116	57	12	2	0	0	0	0	250	328
Medium	1981	377	279	24	7	2	1	0	0	0	712	1025
	1982	24	37	18	4	1	0	0	0	0	90	143
	1983	16	28	15	4	2	1	0	0	0	69	88
	1984	449	35	12	2	0	0	0	0	0	636	931
	1985	173	511	22	2	0	0	0	0	0	710	1164
	1986	70	35	63	14	2	0	0	0	0	185	139
	1987	90	29	33	17	3	1	0	0	0	173	171
	1988	17	45	37	9	3	1	0	0	0	112	103
High	1981	133	285	32	5	2	1	0	0	0	458	674
	1982	30	68	21	4	1	0	0	0	0	129	143
	1983	60	24	20	5	1	0	0	0	0	112	113
	1984	215	52	8	1	1	0	0	0	0	277	400
	1985	110	255	22	2	0	0	0	0	0	392	481
	1986	309	144	232	14	1	0	0	0	0	702	854
	1987	108	109	65	18	6	2	0	0	0	315	347
	1988	141	113	48	10	2	1	0	0	0	317	272

Table 9. - Tuning criteria, regressions of cohort biomass on CPUE, and on research survey biomass estimates.

	CPUE			Research Survey Biomass		
F	R^2	1987*	1988*	R^2	1987*	1988*
0.4	0.86	–	+	0.53	+	+
0.5	0.87	–	+	0.57	+	+
0.6	0.86	–	+	0.58	+	+
0.7	0.86	–	0	0.56	+	+
0.8	0.85	–	–	0.52	–	0
0.9	0.84	–	–	0.47	–	–
1	0.84	–	–	0.43	–	–
1.1	0.83	–	–	0.39	–	–
1.2	0.83	–	–	0.36	–	–

* Position of point relative to regression line.

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

Age	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
3	231	151	194	381	149	180	115	62	114	297	48	38	60	61	2	23	18
4	102	83	198	273	372	568	320	201	186	465	203	107	67	145	184	185	127
5	32	17	45	50	94	141	198	115	74	71	112	78	33	38	108	187	89
6	3	4	6	8	16	13	70	44	21	15	16	17	20	12	10	16	22
7	2	1	3	2	6	4	25	23	13	8	7	4	8	10	3	3	5
8	1	0	1	1	3	2	13	8	6	5	4	3	2	4	2	2	1
9	0	0	0	0	3	1	10	5	3	4	4	3	1	1	1	3	1
10	0	0	0	0	1	1	8	5	2	2	3	4	1	1	0	1	2
11	0	0	0	0	1	0	8	3	2	2	1	3	2	1	0	0	1
Total	371	256	447	717	645	911	768	466	421	869	398	255	195	274	311	421	266

Table 11. - Population numbers (10^6) east of the ICJ line from cohort analysis using a terminal F of 0.8.

Age	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
3	475	529	732	1197	1220	780	497	416	860	733	253	195	417	578	387	356	455
4	179	208	333	474	714	960	530	337	317	669	375	182	141	319	463	347	299
5	113	66	110	113	170	293	326	175	115	112	166	148	64	63	150	244	137
6	11	72	44	57	55	66	132	107	50	34	34	45	61	27	21	34	44
7	10	6	62	34	44	35	47	53	55	25	16	16	25	36	14	9	16
8	2	7	5	53	28	34	28	18	26	37	16	8	10	15	23	10	5
9	1	1	6	4	47	23	29	13	9	17	29	10	5	8	10	19	7
10	0	1	1	5	3	39	20	17	6	6	12	23	7	3	6	8	15
11	0	0	0	0	5	2	35	10	11	3	3	8	17	5	2	5	6
Σ	790	890	1293	1937	2287	2231	1642	1145	1448	1638	905	635	747	1054	1075	1032	985

Table 12. - Biomass (t of meats) east of ICJ line from cohort analysis, terminal F of 0.8.

Age	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
3	1555	1733	2399	3919	3996	2553	1626	1363	2818	2401	828	639	1366	1892	1266	1166	1491
4	1730	2007	3223	4584	6900	9281	5124	3263	3066	6473	3629	1761	1359	3087	4480	3360	2895
5	1938	1130	1887	1948	2927	5040	5592	3003	1968	1920	2859	2538	1105	1086	2585	4186	2358
6	256	1737	1055	1382	1326	1586	3185	2576	1200	830	815	1095	1467	655	502	818	1066
7	287	188	1843	1003	1327	1042	1407	1573	1638	758	493	472	751	1079	404	268	474
8	54	248	170	1823	968	1168	946	631	892	1287	544	278	359	522	795	329	185
9	34	33	234	151	1765	858	1093	471	345	658	1090	394	185	291	375	727	257
10	17	23	24	213	133	1578	784	670	248	223	487	900	282	123	233	333	596
11	12	10	17	15	194	72	1447	424	441	139	119	333	703	210	73	212	258
Σ	5884	7110	10852	15035	19536	23178	21205	13974	12615	14691	10865	8411	7577	8946	10711	11398	9581

Table 13. - Fishing mortality east of ICJ line from cohort analysis, terminal F of 0.8.

Age	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
3	0.73	0.36	0.34	0.42	0.14	0.29	0.29	0.17	0.15	0.57	0.23	0.23	0.17	0.12	0.01	0.07	0.04
4	0.90	0.54	0.98	0.92	0.79	0.98	1.01	0.98	0.94	1.29	0.83	0.94	0.70	0.65	0.54	0.83	0.60
5	0.35	0.31	0.55	0.63	0.85	0.70	1.02	1.16	1.10	1.10	1.20	0.79	0.76	1.01	1.39	1.61	1.14
6	0.42	0.05	0.16	0.15	0.36	0.23	0.82	0.57	0.57	0.64	0.66	0.49	0.42	0.60	0.74	0.66	0.72
7	0.19	0.14	0.05	0.07	0.17	0.13	0.84	0.61	0.28	0.37	0.61	0.31	0.40	0.34	0.24	0.41	0.41
8	0.47	0.05	0.11	0.02	0.11	0.06	0.69	0.60	0.30	0.16	0.31	0.40	0.20	0.32	0.08	0.24	0.24
9	0.36	0.30	0.06	0.08	0.07	0.05	0.45	0.60	0.40	0.26	0.15	0.29	0.37	0.18	0.08	0.16	0.19
10	0.44	0.21	0.41	0.03	0.55	0.03	0.56	0.36	0.52	0.57	0.32	0.19	0.24	0.47	0.03	0.20	0.14
11	0.35	0.33	0.27	0.28	0.27	0.20	0.30	0.45	0.20	0.66	0.78	0.48	0.10	0.24	0.07	0.08	0.21
$\bar{X}$	0.47	0.25	0.32	0.29	0.37	0.30	0.66	0.61	0.50	0.62	0.57	0.46	0.37	0.44	0.35	0.47	0.41

Table 14. - Stock projections on a quaterly basis at current F_{MAX} (0.966) and at $F_{0.1}$ (0.594) using starting numbers from cohort analysis with a terminal F of 0.8.

F = 0.966	1989	1989	1989	1989	1990	1990	1990	1990
Rate on smalls	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mean Wgt. Catch (g)	16.9	15.2	16.7	19.5	17.2	16.0	17.4	19.3
Catch (Mill.)	21.4	123.9	114.3	27.7	26.9	134.7	118.6	27.1
Catch (t)	361	1,879	1,907	541	463	2,154	2,068	524
Cum. Catch (t)	361	2,240	4,147	4,688	463	2,617	4,685	5,209
Biomass (t)	11,247	11,099	10,242	11,064	11,789	11,363	10,339	11,408

F = 0.594	1989	1989	1989	1989	1990	1990	1990	1990
Rate on smalls	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mean Wgt. Catch (g)	16.9	15.3	16.9	19.6	17.6	16.7	18.2	20.0
Catch (Mill.)	13.4	81.2	82.1	21.0	20.5	102.2	96.9	23.3
Catch (t)	225	1,240	1,385	411	361	1,704	1,765	466
Cum. Catch (t)	225	1,465	2,851	3,262	361	2,065	3,830	4,296
Biomass (t)	11,393	11,995	11,787	12,758	13,672	13,917	13,381	14,554

Table 15. - Values used in "shortcut" predictions of scallop yields.

Year	Yield(t)	Effort(h)	Recruitment (Res)	Recruitment(SPA)	Catch(#)	Environ.
1972	4161	114	93*	475	371	-0.168
1973	4223	115	93	529	256	0.168
1974	6137	121	93	732	447	0.485
1975	7414	119	93	1197	717	0.748
1976	9675	112	93	1220	645	0.925
1977	13089	97	93	780	911	0.999
1978	12189	111	93	497	768	0.959
1979	9207	126	108	416	466	0.811
1980	5221	95	56	860	421	0.571
1981	8013	105	179	733	869	0.267
1982	4307	80	41	253	398	-0.068
1983	2748	76	26	195	255	-0.394
1984	1945	70	25	417	195	-0.677
1985	3812	105	165	578	274	-0.882
1986	4670	50	136	387	311	-0.988
1987	6800	78	98	356	421	-0.983
1988	4313**	85	110	455	266	-0.866

* Average value of recruitment from research surveys for the period 1979-1988.
** Estimated value

Table 16. - Predicted yields for 1987, 1988 and 1989 from "shortcut" analysis. The numbers under the dependent variables refer to columns in the above table. That is, 2+4 means that yield and recruitment form the research series were used in the regression. The predicted values for 1987 and 1988 may be compared to the actual values in the above table.

Period	Dep. Variables	R^2	Y_{1987}	Y_{1988}	Y_{1989}
1979-87	2	.09	4526	5022	4443
"	3	.01	4431	4594	4635
"	4	.10	5089	4702	4824
"	5	.47	4180	3997	4582
"	6	.01	4557	4668	4512
"	7	.05	4217	4220	4289
"	2+3	.11	5075	5325	4394
"	2+4	.13	4886	4906	4651
"	2+5	.48	4161	4146	4518
"	2+6	.12	4678	5233	4655
"	2+7	.09	4398	4828	4351
"	2+4+7	.16	4638	4101	4439
"	2+5+7	.50	4446	4557	4749
1972-87	2	.53	5178	6720	4920
"	3	.12	3947	5416	5783
"	4	.02	6934	6539	6664
"	5	.63	4654	4390	5234
"	6	.40	4949	5933	4547
"	7	.47	3097	3112	3473
"	2+3	.53	4839	6553	4863
"	2+4	.53	4860	6695	4758
"	2+5	.81	4278	5081	4541
"	2+6	.53	5207	6758	4959
"	2+7	.58	3985	5017	3995
"	2+4+7	.58	4007	4982	3999
"	2+5+7	.81	4439	5299	4676

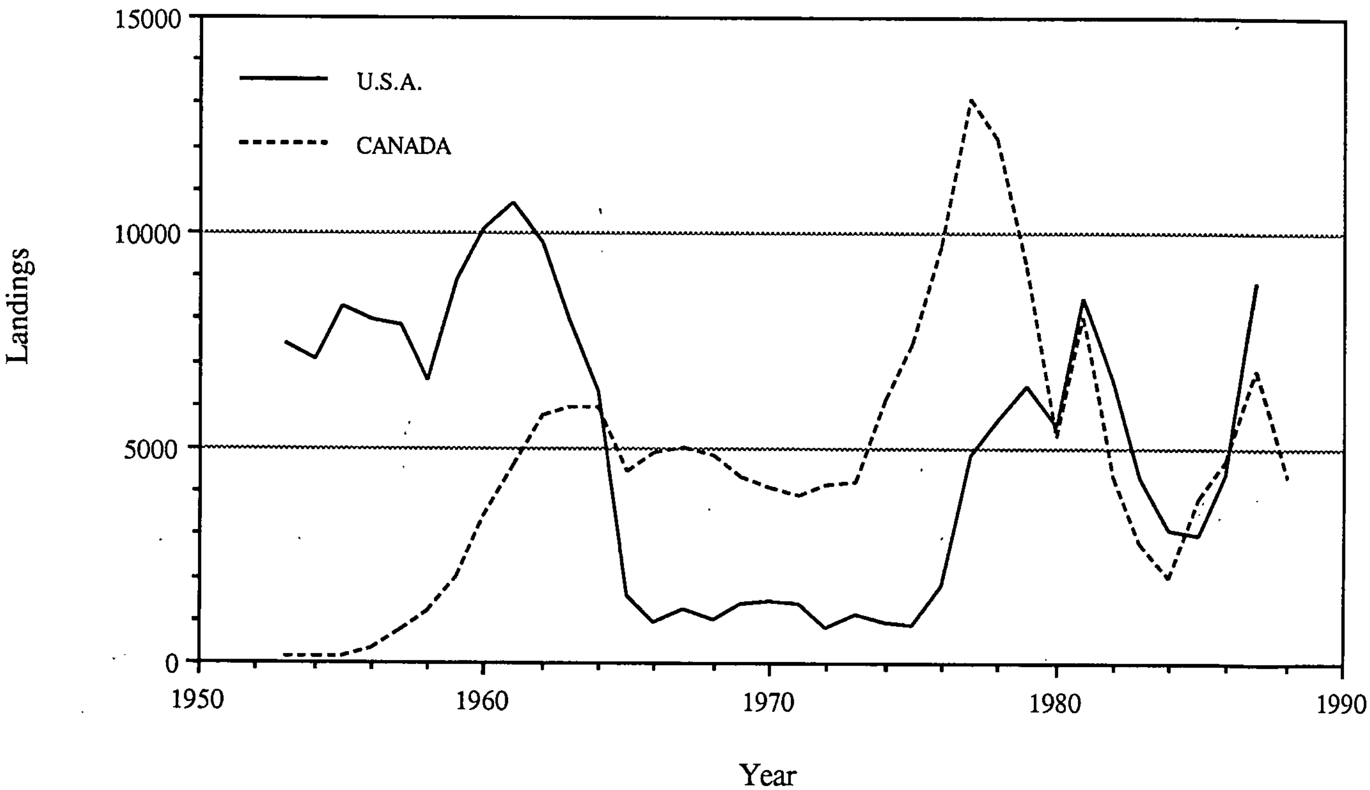

Figure 1.- Landings (t of meats) from NAFO subdivision 5Ze.

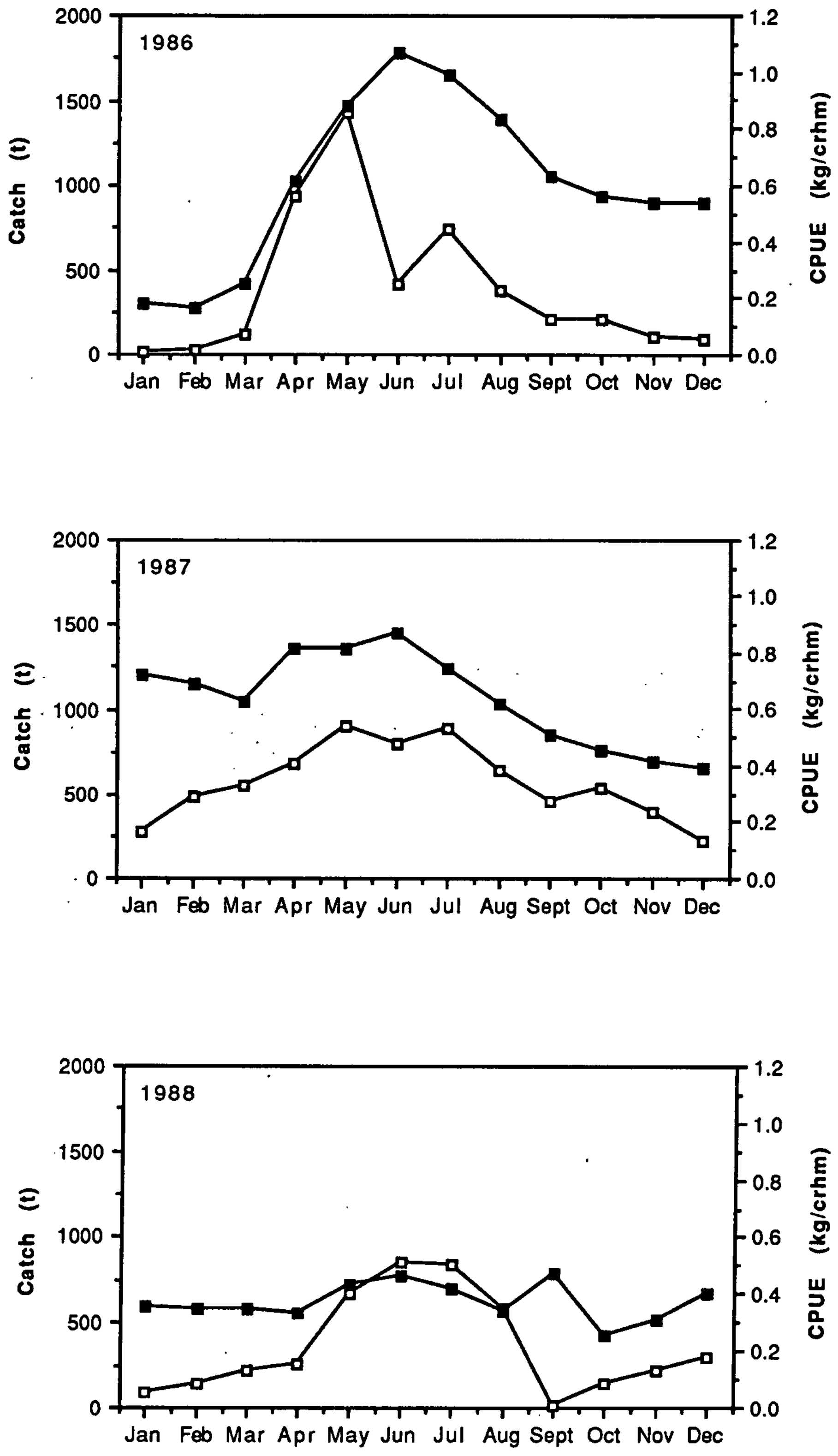

Figure 2.- Monthly CPUE (filled square) and catch in tons of meats (open square) for vessels over 19.8 m L.O.A. fishing Georges Bank.

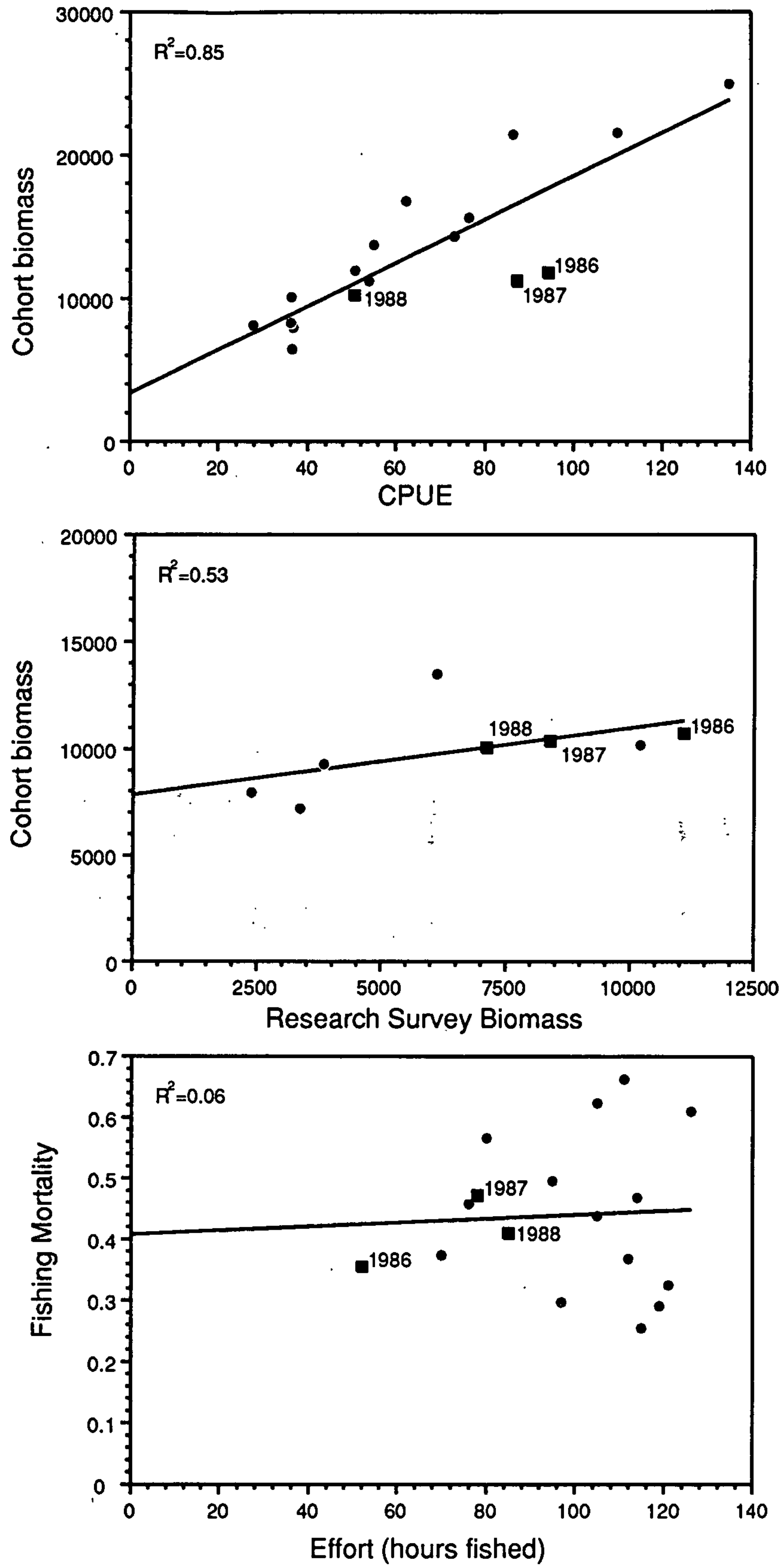

Figure 3.- Cohort biomass (t of meats) vs CPUE (kg/hour), cohort biomass vs research survey biomass (t of meats), and fishing mortality vs effort (hours fished) using a terminal F of 0.8.

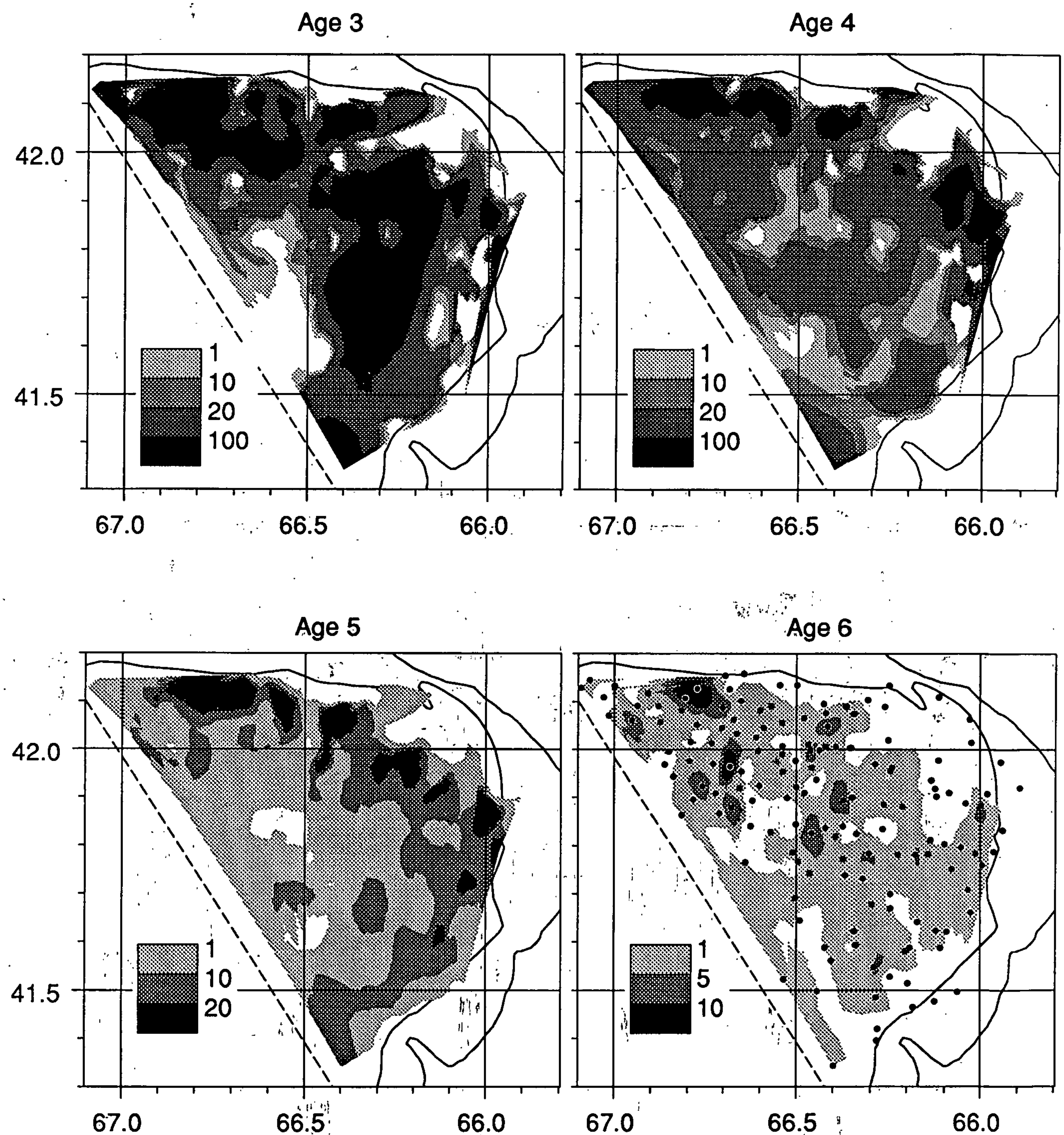

Figure 4 .- Scallop distribution according to age from the research survey of August 1988. Location of sampling stations is indicated on the graph for age 6 scallops. The shading scale (lower left corner of graph) represents number of animals per standard tow.

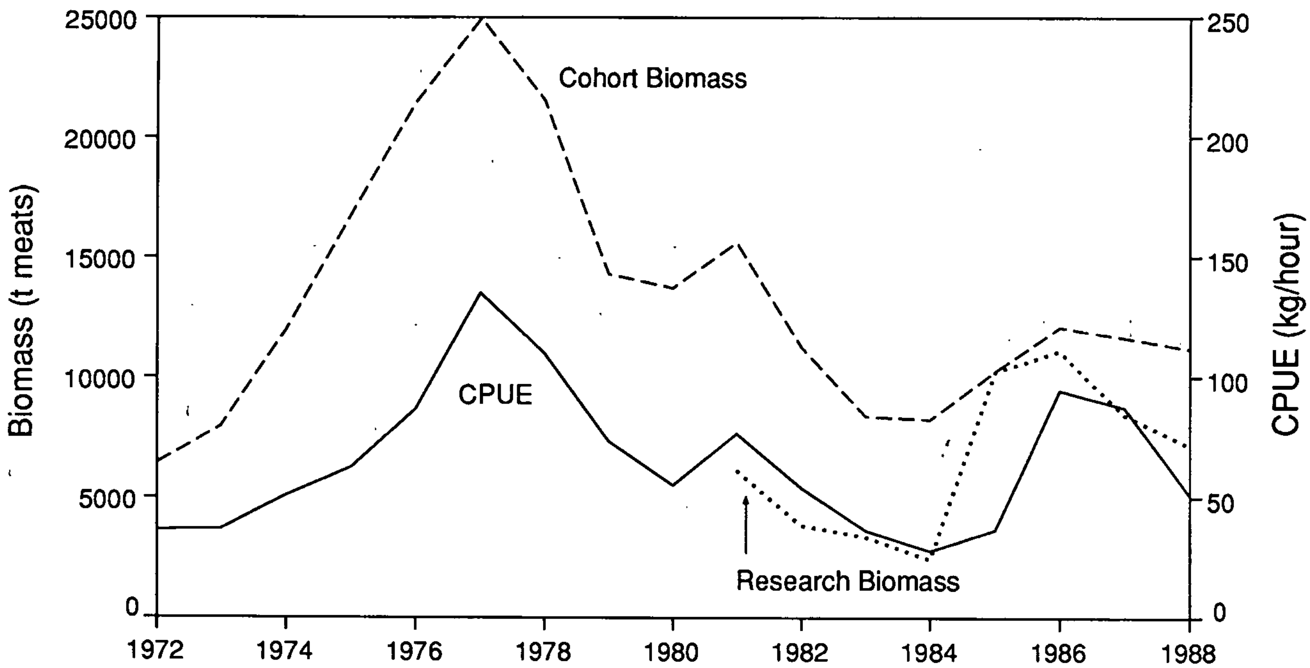

Figure 5. - Time series of indices of abundance and estimated biomass from SPA with terminal F of 0.8.