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Georges Bank Scallop Stock Assessment - 1987

By

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ABSTRACT

The Canadian Georges Bank scallop catch for 1987 was 6,800 t, a 45% increase over last year and the highest of the last six years. This continues the recovery from 1984 landings, which were the worst since 1959, and is due to the strong 1982 and good 1981 and 1983 year-classes. The biomass at the end of 1987 is the highest it has been since the peak of 1977-1978. Research data indicates that recent year-classes have not been as strong, and therefore catches will not continue at this level in 1988.

In 1987, the second year for a TAC divided into enterprise allocations, the strong 1982 year-class was of a size that allowed it to be blended with smaller animals. CPUE continued to fall from a peak in mid 1986 as the strong year-class was being depleted, but the annual rate remains well above the average for the past 16 years.

Yield per recruit and resultant stock projections estimated a $F_{0.1}$ catch level of 6,500 t for 1987 which compares well with the estimated 6,800 removals. However, the F level was significantly higher than $F_{0.1}$. Although quota controls were in place, the higher F is due to an effort increase of about 50% from 1986 to 1987 combined with a selectivity change in response to the size composition of the stock. Effort was focused more on age 4 and 5 animals, perhaps because older animals were not needed for blending.

The stock projections are performed with starting numbers derived from the cohort analysis, aged forward to January 1988. The $F_{0.1}$ catch level for 1988 is 4,800 t.

RÉSUMÉ

Les prises canadiennes de pétoncles sur le banc Georges sont estimées à 6,800 t en 1987, une augmentation de 45% comparée à l'année précédente et les prises les plus élevées durant les six dernières années. Les débarquements continuent de s'améliorer depuis 1984 losqu'ils avaient atteint le niveau le plus bas jamais enregistré (1959). Cette performance est attribuable à la forte classe d'âge de 1982 et aux bonnes années de 1981 et de 1983. La biomasse établie à la fin de 1987 est la plus élevée qu'elle a été depuis le plateau de 1977-78. Les données de recherche indiquent que les plus récentes classes d'âge ne sont pas aussi fortes que celle de 1982 et que les prises ne pourront continuer à ce niveau en 1988.

En 1987, la 2ième année du régime d'allocations par entreprise, l'importante classe d'âge de 1982 avait atteint une taille qui permettait de la mélanger avec des animaux plus petits. Les PUE continuèrent à baisser du pic de la mi-1986 à mesure que l'importante classe d'âge diminuait mais le taux annuel demeure au-dessus de la moyenne pour les 16 dernières années.

D'après une analyse de rendement par recrue et une projection de stock on estima un niveau de prises de 6,500 t. à $F_{0.1}$ pour 1987; ce qui se compare bien avec les 6,800 t qu'on suppose débarquées. Cependant, le niveau de F était significativement plus élevé que $F_{0.1}$. Même si les prises étaient contrôlées, le F plus grand est dû à une augmentation de l'effort d'à peu près 50 % de 1986 à 1987 en plus d'un changement de la sélectivité suscité par la structure du stock. L'effort était dirigé davantage vers des animaux de 4 et 5 ans, peut-être parce que des animaux plus vieux n'étaient pas requis pour renconter le compte de viandes.

Pour les projections de stock, les nombres de départ provenant de l'analyse de cohortes sont âgés d'avance à Janvier 1988. Le niveau des prises avec $F_{0.1}$ pour 1988 est de 4,800 t.

INTRODUCTION

Two strong year-classes, those 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 by almost 6,000 t 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. Marked improvements in catches and catch-rates characterize the fishery in the last two years, however, as landings reached 4,900 t in 1986, a 250% increase over 1984 and 6,800 t for 1987. The last two year-classes have not been strong and catches and catch rates are expected to fall in 1988.

In 1987 the deep-sea fleet (vessels over 19.8m L.O.A.) fished under a meat count of 33 per 500 g, which had been implemented on January 1st, 1986, and other management measures as per 1985. 1987 marked the second year of the three year experimental fishing plan based on enterprise allocations. Following the Inshore/Offshore Agreement of 1986, the Bay of Fundy fleet was entitled to 8% (548 t) of the Georges Bank allocation for 1987. This fleet fished all of its allotment, but in an orderly fashion compared to 1986. According to the agreement, their entitlement for 1988 will be 4% of the Georges Bank TAC.

METHODS

Catch and effort data are compiled from logbooks. Those logs with complete effort data are called Class 1 and are used to determine catch rates (Table 2). The Class 1 data represent more than 90% of the total. 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 seven years. Changes within 1987 are shown in the same manner in Table 4, which has the monthly distributions. Figure 2 shows the monthly catches and CPUE's for the last four years.

Catch in numbers at age (Table 5) 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) as had been done previously.

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. 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. The annual growth rates for weights, given in Table 6, are converted into rates for heights and this results in a 16% reduction of the ring size being used for the January 1 size. For example, an animal born in the fall of 1978 is of the 1978 year-class and will be approximately 25 mm on its second birthday (January 1, 1980) although the ring would not be deposited for a few months. Table 6, as well as all other age data, uses this convention, with correction of ring sizes back to January 1. For use in age/weight 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 1987. The design of the survey was based on a stratification by commercial effort. 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 estimate of abundance was formed by contouring the catch rates at age of the survey tows and expanding the mean by the area enclosed by a given contour (Robert et al. 1986). The average number of animals at age per tow is given in Table 7. The numbers per tow are converted into indices of abundance by weighting them by the appropriate contour areas. The indices are shown in Table 8. The details of the surveys on a per stratum basis are given in Table 9.

A Thompson-Bell type yield per recruit analysis was carried out (Mohn et al. 1987) breaking growth down into quarters and using 1986 selectivity values, corrected to reflect the meat count of 33 meats/500 g. This was done in order to take into account the dynamic growth of the younger age-classes of scallops. This method also takes into account the average quarterly distribution of effort. However, this method cannot include the effects of blending. This analysis is still applicable and was not recalculated herein.

The regulations operant on the offshore fleet are that the catch should average no more than 33 meats per 500 g which corresponds to an average weight of 15 g per meat. Placing a limitation on the average instead of stipulating a minimum means that the fishermen may take small animals and then balance them with larger ones. Such a practice, called blending, renders the use of most yield models 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 in 1984 (Mohn et al. 1984) in which the mortality on the animals beneath the stipulated average 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 19, 35, 29 and 17%, which reflects the 1987 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 1987 cohort estimates to Jan. 1988.

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. Selectivity 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 1987. 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 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 VPA is carried out in the normal manner. The results of the trial VPA could be used to retune the age determination. Significant discrepancies were not found so retuning was not carried out. The interdependence of the catch-at-age tuning and subsequent VPA tuning are a concern and research is underway to address this problem.

The VPA is tuned against a number of independent, and sometimes contradictory, sets of observations. The most important is the commercial CPUE. Research estimates are also used. F versus effort does not aid in the tuning process. Tuning selectivity is more difficult in scallop data than for most fisheries. This is because the VPA 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. The older (6+) animals seem to be experiencing less effort directed against them in the last two years than was previously the case. This may be because the meat count has not been restrictive with the large 1982 year-class becoming fully recruited. 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. The terminal F (annual rate) ranged from 0.6 to 1.6 for the purposes of tuning. A range of this magnitude was required to drive the residuals in the research vs VPA biomass across the regression line. The residuals of the last two year's data and the correlation coefficient were used as criteria (Table 10). 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. The cohort biomass vs CPUE tuning was internally consistent in that the residuals came closest to the regression line at the approximate maximum correlation (F = 0.8).

The VPA biomass and the research survey biomass are used as a secondary criteria for tuning. Over the range of F's (except the highest value) the last two year's residuals are always positive and the correlation coefficient does not attain a minimum. This relationship is deemed to be less important because of the fleet's concentration in areas of high abundance and on a few age classes when compared to the research surveys broader coverage. Plots of the regressions used in the tuning process are presented in Figures 3, 4 and 5 at terminal F's of 0.8 and 1.0. The VPA biomass vs CPUE shows a linear distribution with the last two years being well above the mean (Figure 3). The high agreement between these two gives them a stronger value in the tuning process. The VPA vs research biomass (Figure 4) shows a cluster of points and one outlier (1978) which dominates the regression. The early research results are not considered to be reliable and hence the weighting given to this relationship is subordinate to CPUE. F vs effort is given in Figure 5. The correlation is quite low and decreased as the residuals for 1986 and 1987 approach the regression line. Therefore, these data were not used in the VPA tuning. Both the CPUE and research biomass, the independent data used for tuning, show a fall in abundance from 1986 to 1987. We could not duplicate this trend in the VPA using reasonable terminal F's. The best estimate for terminal F, if one heavily weights the CPUE tuning, is at F = 0.8. Depending on how much importance one wishes to give to the research biomass based tuning, the terminal F moves increasingly upward. A reasonable upper limit might be an F of 1.0, which is the upper edge of the CPUE regression minimum (Table 10).

RESULTS

Survey catch rates (Tables 7 and 8) indicate that stock rebuilding is taking place. For the first time in 4 years, age 7 scallops have appeared in the research survey and a sizeable quantity of age 6 animals were also seen. Survey catch rates indicate a significant reduction in the abundance of age 5's when compared to the 1986 survey results, likely due to fishing activity. Pre-recruits are estimated to have decreased compared to the strong 1982 year-class, but are still important. Noticeable concentrations of this strong year-class (age 5 in 1987) are still found and the abundance of this age is the strongest seen for 6 years. Survey results are also shown in a graphical representation (Figures 6 and 7) in which darker shading depicts higher abundance. These figures show the aggregated nature of the resource in the survey area on Georges Bank. Figure 6 is at a lower resolution and contains the distribution of the numbers of 2, 3 and 4 year olds for 1985 to 1987, as well as the total biomass. Figure 7 is at a higher resolution and shows older animals that have survived form the strong 1982 year-class (age 5) as well as the age 4's.

The cohort analysis results are given in terms of numbers-, F-, and biomass-at-age (Tables 11a,b, 12a,b and 13a,b) which have been combined into annual values from quarterly analysis for the two terminal F levels under consideration. For either terminal F the 1982 year-class is almost twice the size of those seen since 1981. The annual F's for 1986 and 1987 are the lowest (F_{term} = 0.8) or among the lowest (F_{term} = 1.0) in the 16 year period covered by the VPA. These two years are also the only ones which are under quota control. Effort increased from 1986 to 1987 which is also evidenced in the average F's. In 1987, in contrast to 1985 and 1986, age 4 animals are the hardest fished. This may reflect high local concentrations of the age 4's as well as the relative (compared to recent years) abundance of older animals for blending. The principal effects of the two different terminal F's are in the abundances (and F's) in the terminal year. The lower terminal F results in a 17% higher biomass (18,420 viz 15,906 t of meats)

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 F_{max} was estimated to be at an F of 0.630 and $F_{0.1}$ at 0.402. These values differ from assessments earlier than 1986 as the selectivity pattern has changed with the introduction of a lower meat count. The same selectivity is used in projections which are carried out at F_{max} and $F_{0.1}$ using each of the two cohort analysis results (Tables 14 and 15). This partial recruitment is not quite as domed as the 1987 VPA result as the 1987 value reflects the specific size distribution and fishing pattern for that year. The annual values for the partial recruitment for ages 3 to 11 are 0.10, 0.75, 1.0, 0.71, 0.50, 0.37, 0.37, 0.35, 0.32. The projections are for a three year period and assume a recruitment level of 400 million animals, a level which is low but not extreme. The $F_{0.1}$ and F_{max} catch levels for a terminal F of 0.8 are 4,800 and 6,900 t respectively. The mean weights of catch are projected to be well above the legal limit of 33 meats per 500 g. The biomass is essentially stable under F_{max} and increases about 10% per annum under $F_{0.1}$ and the assumed recruitment pattern. The catch levels are about 20% lower when a terminal F of 1.0 is used for the VPA.

Figure 8 shows the apparent lack of a stock recruit relationship as described by traditional models. This may indicate that environmental factors, or dynamics not accounted for in conventional models, determine year-class strength.

CONCLUSIONS

A relatively strong recruitment was seen in the 1986 fishery. This is evidenced by the change in the monthly CPUE of 1986 compared to 1985 (Figure 2). Fishing early in the year means a loss of yield, and may affect the cohort analysis. The fishery required less blending as the season progressed and the CPUE, although slightly lower than in 1986, is still above the long term average. The 1987 research survey indicates that the strong recruiting year-class of 1982 will be followed by less abundant ones which will not support the fishery at the 1987 level. These conclusions are supported by the cohort analysis which is principally tuned to CPUE. At $F_{0.1}$ the recommended catch level for 1988 is 4,800 t.

The scallop stock on Georges Bank is still undergoing rebuilding. Therefore, it is still strongly dependent on recruiting year-classes. As the pre-recruits are first seen as 2 year olds 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 VPA process. This assessment uses techniques which are still under research and being refined.

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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	9070
1987	8800*	6800*	15600*

* Preliminary

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	4670	3730	50	6641	0.704
1987	6800	5740	78	10822	0.628

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

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

Table 4.- 1987 meat weight port sampling data. Numbers at weight in 2 gram intervals normalized to 1000. Sample sizes are given in 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	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
5	0	1	2	0	0	0	0	1	5	3	2	1
7	2	9	25	8	1	0	3	9	21	28	20	44
9	40	44	99	71	14	5	23	42	85	119	120	165
11	130	110	192	206	87	38	110	120	172	176	173	182
13	128	141	171	201	189	104	204	229	182	163	184	141
15	181	160	110	147	250	203	249	221	159	139	152	106
17	195	149	100	82	176	143	195	137	127	101	112	83
19	105	107	76	72	95	82	105	90	78	90	91	72
21	67	89	62	64	58	93	50	46	54	58	47	54
23	50	69	59	55	41	159	29	37	36	42	32	29
25	35	45	40	42	24	77	17	20	22	25	25	33
27	32	31	23	17	16	55	6	14	18	18	10	18
29	7	21	13	9	11	22	4	11	12	9	13	14
31	13	11	11	9	13	16	1	6	10	9	7	11
33	12	7	4	6	8	0	2	6	5	7	5	9
35	3	2	4	5	7	0	1	4	4	3	3	9
37	0	1	6	2	4	0	1	3	4	2	1	5
39	0	2	1	1	1	0	0	2	3	3	0	3
41	2	1	2	0	2	0	0	1	1	1	1	4
43	0	0	0	0	1	0	0	1	0	1	1	4
45	0	0	1	1	0	0	0	1	0	1	0	1
47	0	1	0	0	0	0	0	0	0	0	0	1
49	0	0	1	0	0	0	0	0	1	1	1	2
51	0	0	0	0	0	0	0	1	0	0	0	1
53	0	1	0	0	0	0	0	0	0	0	0	2
55	0	0	0	0	0	0	0	0	0	0	0	3
57	0	0	0	1	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0	0	0	0	1
63	0	0	0	0	0	0	0	0	0	0	0	1
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	601	1987	1510	862	1595	182	1527	1637	2450	3295	1450	1392

Table 5.- Catch at age.

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

Table 6.- 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 7.- Total weighted average number of scallops at age per tow.

Sampling dates	Age (years)								
	2	3	4	5	6	7	8	9	10+
1979	26	108	31	20	9	4	2	1	4
1980	432	56	34	6	2	1	0	0	1
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

Table 8.- Indices of abundance of scallop age-classes by contour analysis; numbers at age (10^6).

Sampling dates	Age (years)						
	2	3	4	5	6	7	8
1978	781.15	370.39	834.23	326.25	95.21	36.39	11.74
1979	106.18	327.06	184.39	137.46	44.97	22.71	8.25
1980	350.50	181.55	38.58	19.54	14.37		
1981	548.31	551.89	137.31	66.98			
1982	241.77	430.42	98.11	23.43	5.09		
1983	204.16	115.75	97.88	24.27	9.52		
1984	1166.26	183.36	48.08	11.06	3.59		
1985	737.04	779.10	83.09	8.74			
1986	574.29	710.64	221.56	30.26			
1987	418.20	440.61	215.43	33.29	8.94		

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

Stratum	Sampling dates	Age (years) 2	3	4	5	6	7	8	9	10+	N	s.d.
Very Low	1979	3	18	6	9	8	4	2	1	5	39	40
	1980	39	5	6	4	2	2	1	1	2	62	92
	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
Low	1979	17	36	26	26	9	4	3	2	7	130	229
	1980	65	28	18	8	3	1	1	0	1	125	256
	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
Medium	1979	41	117	39	21	9	5	2	1	3	238	234
	1980	550	74	36	10	2	1	0	0	0	674	1725
	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
High	1979	27	147	42	19	9	3	1	0	1	249	231
	1980	727	104	66	6	2	1	0	0	1	908	1256
	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

Table 10.- Tuning criteria, regressions of cohort biomass versus both CPUE, and research survey biomass estimates.

	CPUE			Research Survey Biomass		
F	1986*	1987*	R	1986*	1987*	R
0.6	-	+	.90	+	+	.47
0.7	-	+	.92	+	+	.59
0.8	-	+	.92	+	+	.69
0.9	-	0	.92	+	+	.76
1.0	-	-	.92	+	+	.81
1.1	-	-	.91	+	+	.85
1.2	-	-	.90	+	+	.87
1.4	-	-	.88	+	0	.88
1.6	-	-	.87	-	-	.88

*Position of point relative to regression line.

Table 11a.- Population numbers (10^6) east of 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
3	475	529	732	1197	1220	780	497	416	888	761	270	211	471	836	409	483
4	179	208	333	474	714	960	530	337	317	695	400	198	155	368	697	368
5	113	66	110	113	170	293	326	175	115	112	189	170	78	77	194	456
6	11	72	44	57	55	66	132	107	50	34	34	66	81	40	33	74
7	10	6	62	34	44	35	47	53	55	25	16	16	44	55	25	20
8	2	7	5	53	28	34	28	18	26	37	16	8	10	32	40	20
9	1	1	6	4	47	23	29	13	9	17	29	10	5	8	25	34
10	0	1	1	5	3	39	20	17	6	6	12	23	7	3	6	22
11	0	0	0	0	5	2	35	10	11	3	3	8	17	5	2	5
Σ	790	890	1293	1937	2287	2231	1642	1145	1476	1691	970	710	869	1423	1431	1482

Table 11b.- Population numbers (10^6) east of ICJ line from cohort analysis using a terminal F of 1.0.

Age	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
3	475	529	732	1197	1220	780	497	416	880	749	264	206	455	771	367	390
4	179	208	333	474	714	960	530	337	317	687	390	192	151	354	638	330
5	113	66	110	113	170	293	326	175	115	112	183	161	74	72	182	402
6	11	72	44	57	55	66	132	107	50	34	34	60	73	35	29	62
7	10	6	62	34	44	35	47	53	55	25	16	16	38	47	21	16
8	2	7	5	53	28	34	28	18	26	37	16	8	10	27	33	16
9	1	1	6	4	47	23	29	13	9	17	29	10	5	8	21	28
10	0	1	1	5	3	39	20	17	6	6	12	23	7	3	6	18
11	0	0	0	0	5	2	35	10	11	3	3	8	17	5	2	5
Σ	790	890	1293	1937	2287	2231	1642	1145	1468	1672	947	684	829	1322	1297	1267

Table 12a.- Fishing mortality east of ICJ line from cohort analysis using a terminal F of 0.8.

Age	Year															
	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
3	.73	.36	.34	.42	.14	.29	.29	.17	.15	.54	.21	.21	.15	.08	.01	.05
4	.90	.54	.98	.92	.79	.98	1.01	.98	.94	1.20	.75	.83	.61	.54	.33	.76
5	.35	.31	.55	.63	.85	.70	1.02	1.16	1.10	1.10	.95	.64	.58	.75	.87	.56
6	.42	.06	.17	.16	.36	.23	.82	.57	.57	.64	.66	.31	.30	.37	.40	.25
7	.19	.14	.05	.07	.17	.14	.84	.61	.28	.37	.61	.32	.21	.21	.12	.17
8	.47	.05	.11	.02	.11	.06	.69	.60	.30	.16	.31	.40	.20	.14	.05	.11
9	.36	.30	.06	.08	.07	.05	.45	.60	.40	.26	.15	.29	.37	.19	.03	.09
10	.44	.22	.41	.03	.55	.03	.56	.36	.52	.57	.32	.19	.24	.47	.03	.07
11	.35	.33	.27	.28	.27	.20	.30	.45	.20	.66	.78	.48	.10	.24	.07	.08
A	.47	.25	.33	.29	.37	.30	.66	.61	.50	.61	.53	.41	.31	.33	.21	.24

Table 12b.- Fishing mortality east of ICJ line from cohort analysis using a terminal F of 1.0.

Age	Year															
	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
3	.73	.36	.34	.42	.14	.29	.29	.17	.15	.55	.21	.22	.15	.09	.01	.07
4	.90	.54	.98	.92	.79	.98	1.01	.98	.94	1.23	.79	.86	.63	.57	.36	.90
5	.35	.31	.55	.63	.85	.70	1.02	1.16	1.10	1.10	1.02	.70	.63	.81	.98	.66
6	.42	.06	.17	.16	.36	.23	.82	.57	.57	.64	.66	.35	.34	.42	.47	.31
7	.19	.14	.05	.07	.17	.14	.84	.61	.28	.37	.61	.31	.25	.25	.15	.20
8	.47	.05	.11	.02	.11	.06	.69	.60	.30	.16	.31	.40	.20	.17	.06	.13
9	.36	.30	.06	.08	.07	.05	.45	.60	.40	.27	.15	.29	.37	.19	.04	.11
10	.44	.22	.41	.03	.55	.03	.56	.36	.52	.57	.32	.19	.24	.47	.03	.09
11	.37	.33	.27	.28	.27	.20	.30	.45	.20	.66	.78	.48	.10	.24	.07	.08
A	.47	.25	.33	.29	.37	.30	.66	.61	.50	.61	.53	.42	.32	.36	.24	.28

Table 13a.- 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
3	1555	1733	2399	3919	3996	2553	1626	1363	2910	2492	885	693	1541	2739	1340	1583
4	1730	2007	3223	4584	6900	9281	5124	3263	3066	6718	3871	1912	1501	3555	6744	3557
5	1938	1130	1887	1948	2927	5040	5592	3003	0968	1920	3253	2926	1347	1314	3337	7824
6	256	1737	1055	1382	1326	1586	3185	2576	1200	830	815	1597	1961	963	793	1776
7	287	188	1843	1003	1327	1042	1407	1573	1638	758	493	472	1313	1633	749	594
8	54	248	170	1823	968	1168	946	631	892	1287	544	278	359	1106	1370	687
9	34	33	234	151	1765	858	1093	471	345	658	1090	394	185	291	954	1297
10	17	23	24	213	133	1578	784	670	248	223	487	900	282	123	233	890
11	12	10	17	15	194	72	1447	424	441	139	119	333	703	210	73	212
Total	5884	7110	10852	15035	19536	23178	21205	13974	12707	15026	11557	9504	9193	11936	15591	18420

Table 13b.- Biomass (t of meats) east of ICJ line from cohort analysis, terminal F of 1.0.

Age	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
3	1555	1733	2399	3919	3996	2553	1626	1363	2882	2454	865	676	1490	2524	1201	1277
4	1730	2007	3223	4584	6900	9281	5124	3263	3066	6645	3769	1859	1457	3418	6169	3187
5	1938	1130	1887	1948	2927	5040	5592	3003	1968	1920	3035	2763	1263	1243	3117	6900
6	256	1737	1055	1382	1326	1586	3185	2576	1200	830	815	1446	1753	856	702	1496
7	287	188	1843	1003	1327	1042	1407	1573	1638	758	493	472	1144	1400	629	492
8	54	248	170	1823	968	1168	946	631	892	1287	544	278	359	931	1128	562
9	34	33	234	151	1765	858	1093	471	345	658	1090	394	185	291	780	1057
10	17	23	24	213	133	1578	784	670	248	223	487	900	282	123	233	723
11	12	10	17	15	194	72	1447	424	441	139	119	333	703	210	73	212
Total	5884	7110	10852	15035	19536	23178	21205	13974	12680	14915	11318	9121	8637	10997	14032	15906

Table 14.- Stock projections at current F_{MAX} (0.63) and at $F_{0.1}$ (0.40) using starting numbers from cohort analysis with a terminal F of 0.8.

F=0.63	1988	1988	1988	1988	1989	1989
Rate on smalls	1.00	1.00	1.00	1.00	1.00	1.00
Mean Wgt. Catch	18.26	18.08	18.85	22.79	18.14	18.11
Catch (Mill.)	65.05	123.90	105.52	65.13	61.50	114.93
Catch (t)	1187.62	2239.87	1988.77	1484.47	1115.60	2081.86
Cum. Catch (t)	1187.62	3427.49	5416.26	6900.73	1115.60	3197.46
Biomass (t)	18396.30	18158.40	17417.50	17416.50	17497.00	17281.90
	1989	1989	1990	1990	1990	1990
Rate on smalls	1.00	1.00	1.00	1.00	1.00	1.00
Mean Wgt. Catch	19.16	23.45	18.10	17.97	18.93	21.48
Catch (Mill.)	96.85	61.61	56.97	107.94	91.74	53.76
Catch (t)	1855.11	1444.83	1030.83	1939.53	1736.59	1154.75
Cum. Catch (t)	5052.57	6497.40	1030.83	2970.36	4706.95	5861.70
Biomass (t)	16591.60	16572.90	16697.70	16569.40	15966.70	16393.50

F=0.40	1988	1988	1988	1988	1989	1989
Rate on smalls	1.00	1.00	1.00	1.00	1.00	1.00
Mean Wgt. Catch	18.27	18.14	18.91	23.35	18.49	18.60
Catch (Mill.)	41.99	83.11	74.47	48.77	45.30	86.61
Catch (t)	767.23	1507.96	1408.66	1138.71	837.60	1610.94
Cum. Catch (t)	767.23	2275.19	3683.85	4822.56	837.60	2448.54
Biomass (t)	18844.30	19458.60	19423.00	19727.00	20184.10	20667.20
	1989	1989	1990	1990	1990	1990
Rate on smalls	1.00	1.00	1.00	1.00	1.00	1.00
Mean Wgt. Catch	19.65	24.42	19.00	19.02	19.91	22.80
Catch (Mill.)	75.50	50.71	44.87	86.03	74.62	45.62
Catch (t)	1483.15	1238.36	852.45	1636.11	1486.03	1039.94
Cum. Catch (t)	3931.69	5170.05	852.45	2488.56	3974.59	5014.53
Biomass (t)	20529.70	20640.10	21056.50	21488.40	21327.60	21844.10

Table 15.- Stock projections at current F_{MAX} (0.63) and at $F_{0.1}$ (0.40) using starting numbers from cohort analysis with a terminal F of 1.0.

F=0.63	1988	1988	1988	1988	1989	1989
Rate on smalls	1.00	1.00	1.00	1.00	1.00	1.00
Mean Wgt. Catch	18.13	17.85	18.65	22.41	17.48	17.34
Catch (Mill.)	51.91	99.77	84.97	53.22	52.48	100.82
Catch (t)	941.13	1781.00	1584.97	1192.88	917.20	1748.53
Cum. Catch (t)	941.13	2722.13	4307.10	5499.98	917.20	2665.73
Biomass (t)	14964.60	14936.30	14459.10	14765.30	14985.60	15013.10

	1989	1989	1990	1990	1990	1990
Rate on smalls	1.00	1.00	1.00	1.00	1.00	1.00
Mean Wgt. Catch	18.42	22.45	17.37	17.27	18.34	20.69
Catch (Mill.)	87.34	55.00	53.31	101.99	87.71	50.92
Catch (t)	1608.58	1234.69	926.04	1761.77	1608.17	1053.59
Cum. Catch (t)	4274.31	5509.00	926.04	2687.81	4295.98	5349.57
Biomass (t)	14523.40	14770.80	14989.10	15010.40	14525.70	15086.70

F=0.40	1988	1988	1988	1988	1989	1989
Rate on smalls	1.00	1.00	1.00	1.00	1.00	1.00
Mean Wgt. Catch	18.15	17.93	18.84	23.01	17.87	17.87
Catch (Mill.)	33.50	66.86	59.87	39.70	38.35	75.18
Catch (t)	607.95	1198.59	1121.77	913.63	685.39	1343.14
Cum. Catch (t)	607.95	1806.54	2928.31	3841.94	685.39	2028.53
Biomass (t)	15319.80	15970.80	16057.70	16611.30	17146.00	17773.20

	1989	1989	1990	1990	1990	1990
Rate on smalls	1.00	1.00	1.00	1.00	1.00	1.00
Mean Wgt. Catch	18.92	23.45	18.25	18.28	19.27	21.95
Catch (Mill.)	67.34	44.71	41.50	80.36	70.65	42.72
Catch (t)	1274.10	1048.46	757.35	1469.17	1361.11	937.98
Cum. Catch (t)	3302.63	4351.09	757.35	2226.52	3587.63	4525.61
Biomass (t)	17777.10	18156.10	18648.00	19199.80	19143.70	19812.20

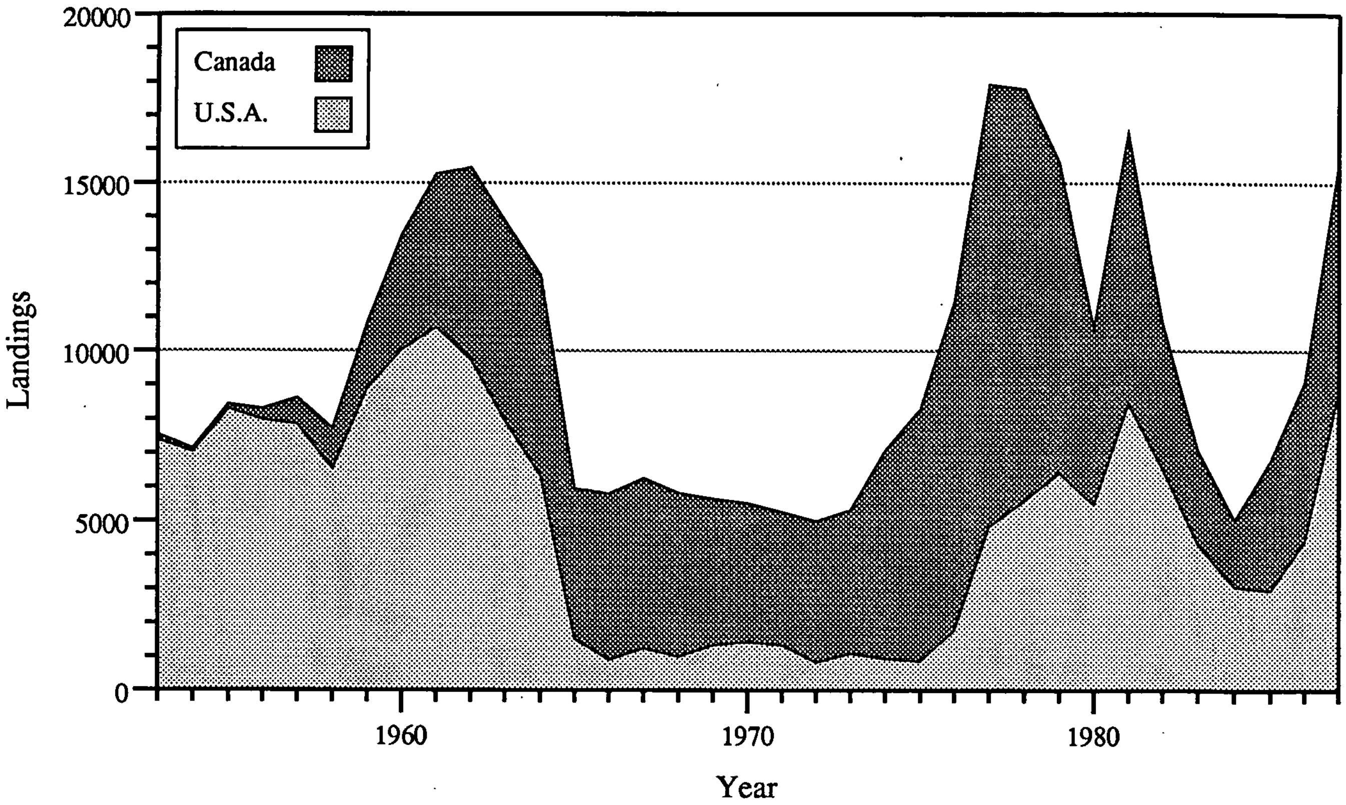


Figure 1.- Landings (t of meats) from NAFO subdivision 5Ze.

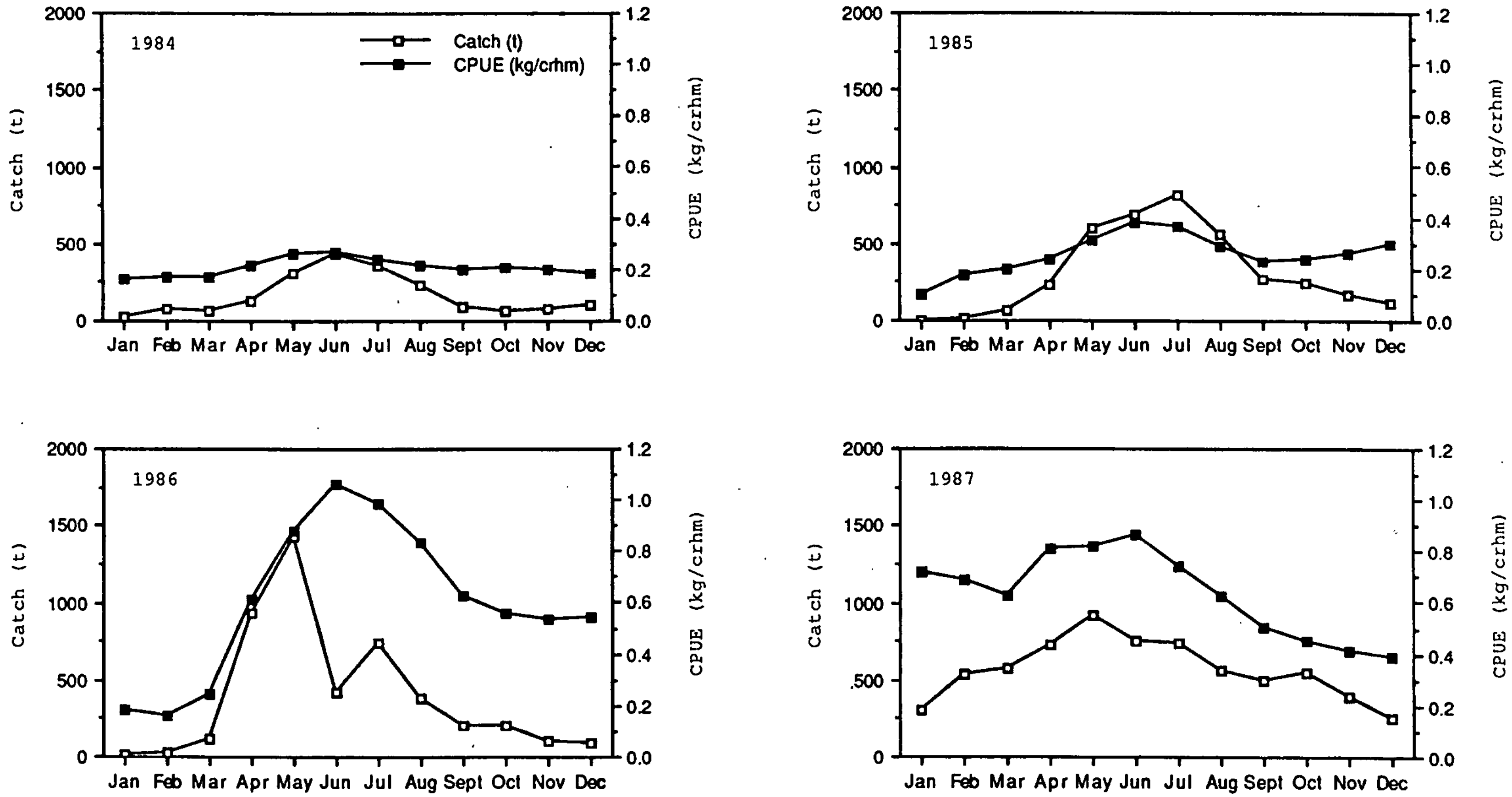


Figure 2.- Monthly CPUE and catch (t of meats) for vessels over 19.8 m L.O.A. fishing Georges Bank

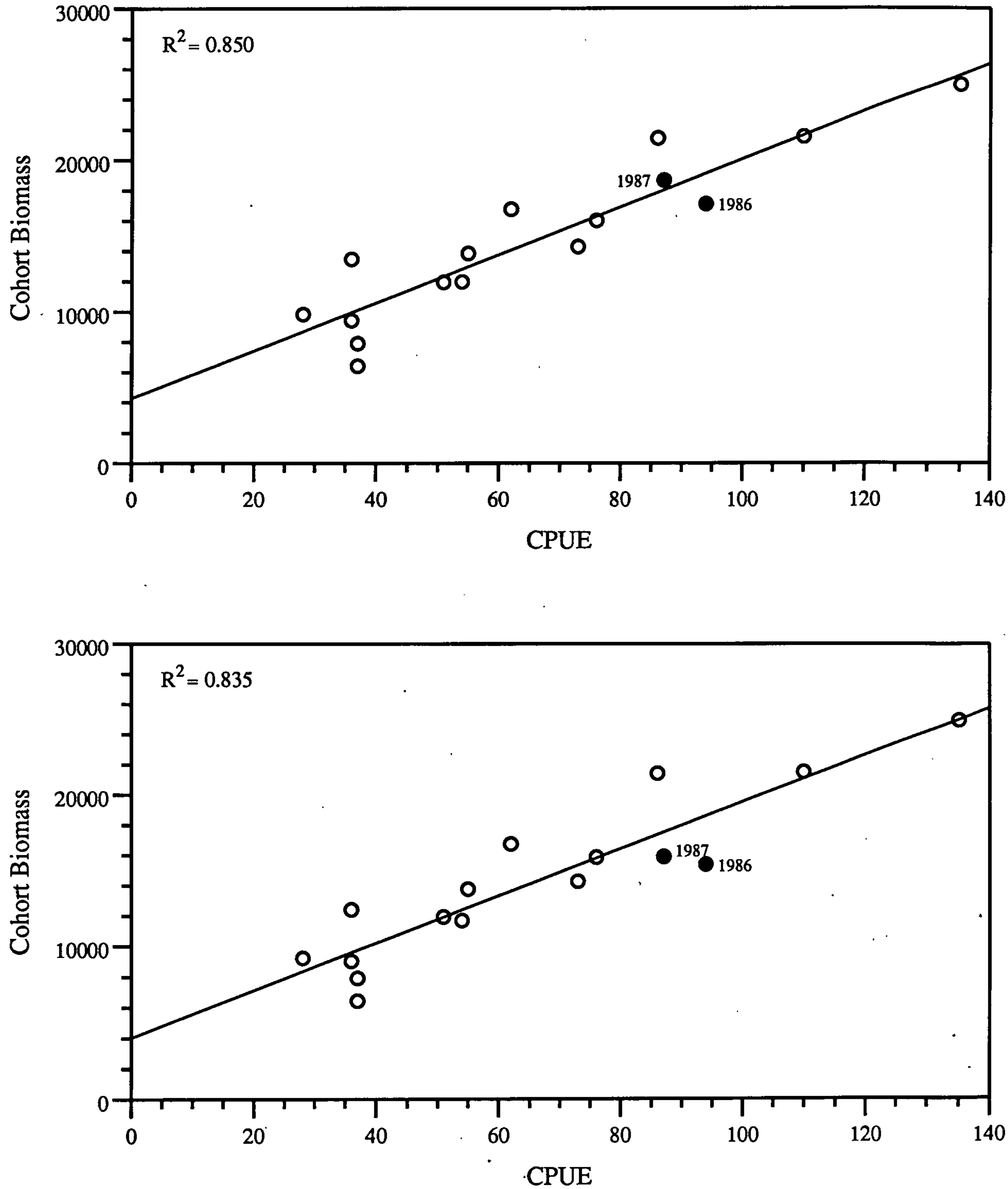
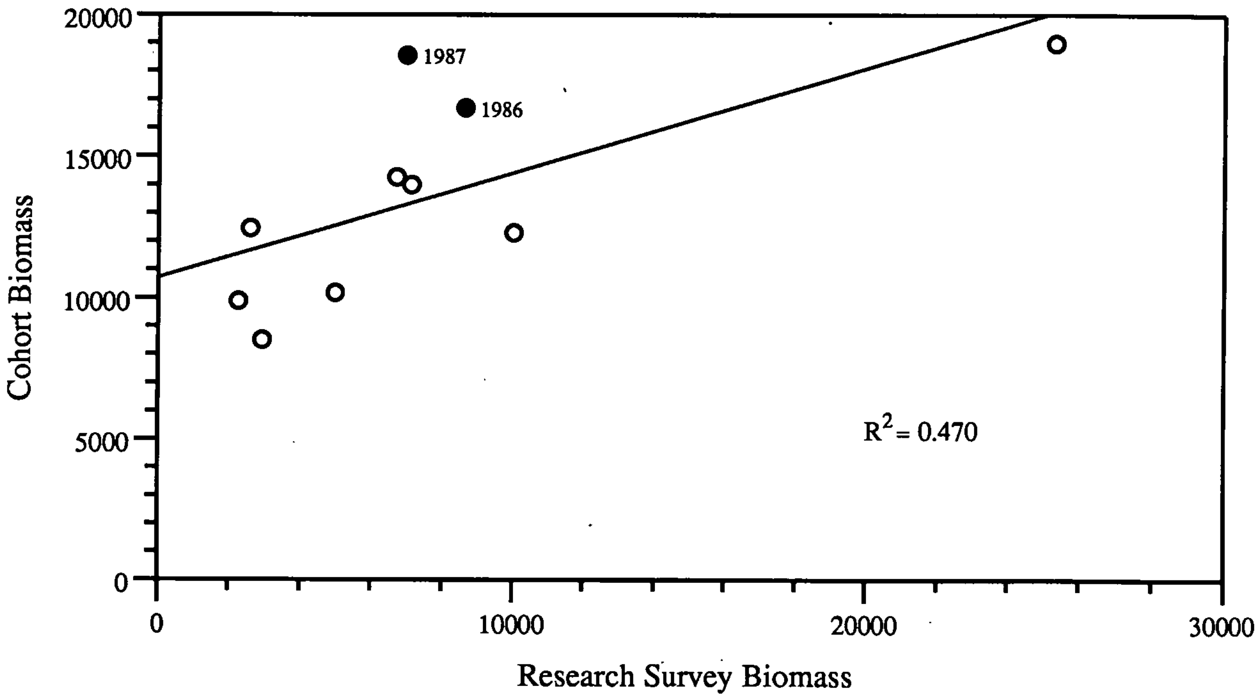


Figure 3.- Cohort biomass (t of meats) vs CPUE (kg/hr), using terminal F's of 0.8 (top) and 1.0 (bottom).



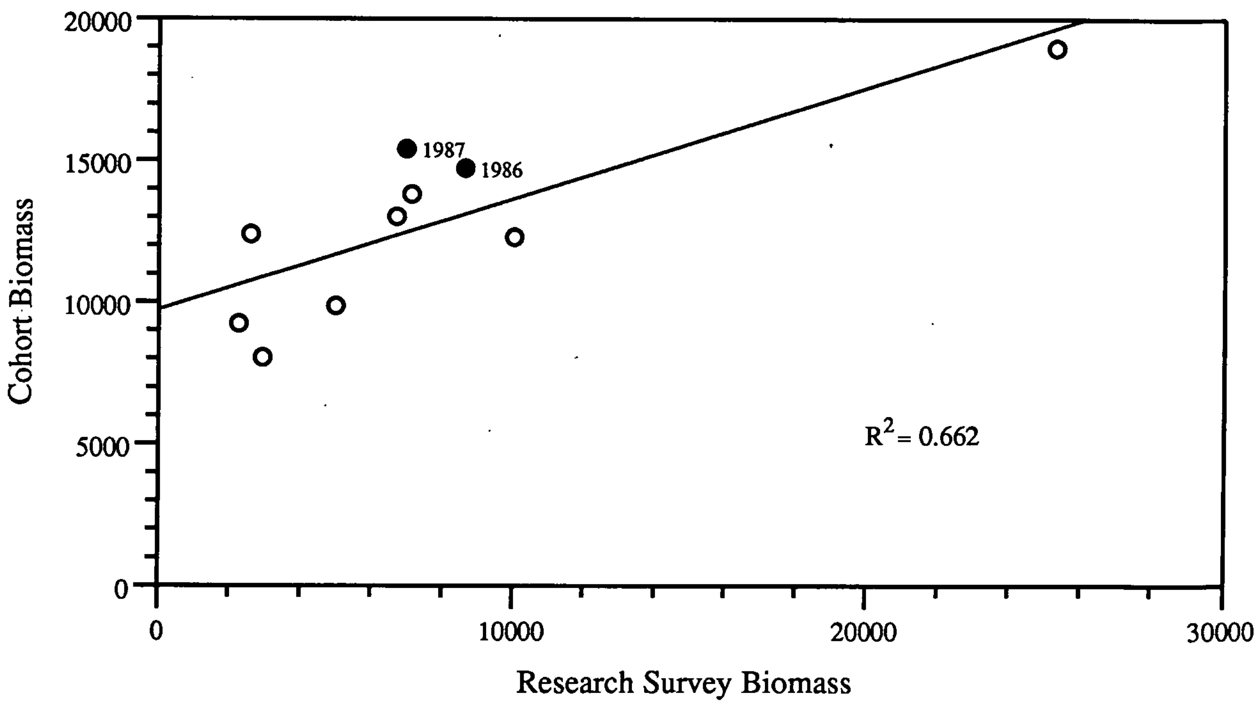
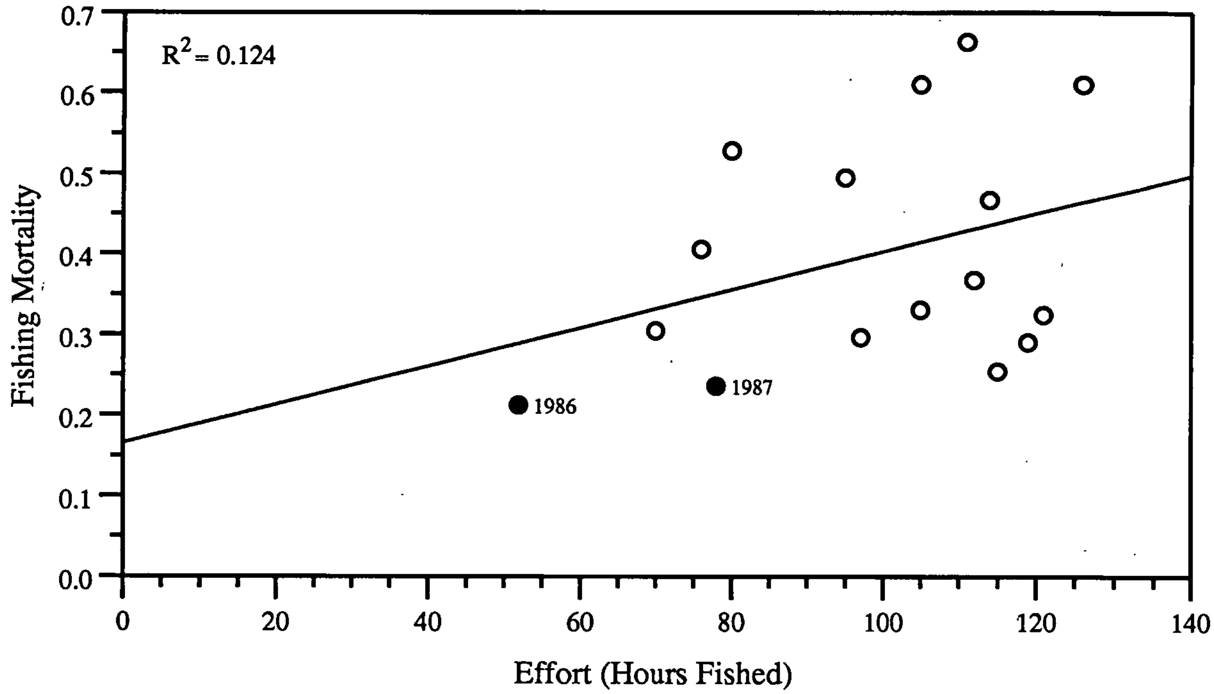


Figure 4.- Cohort biomass (t of meats) vs research survey biomass, using terminal F's 0.8 (top) and 1.0 (bottom).



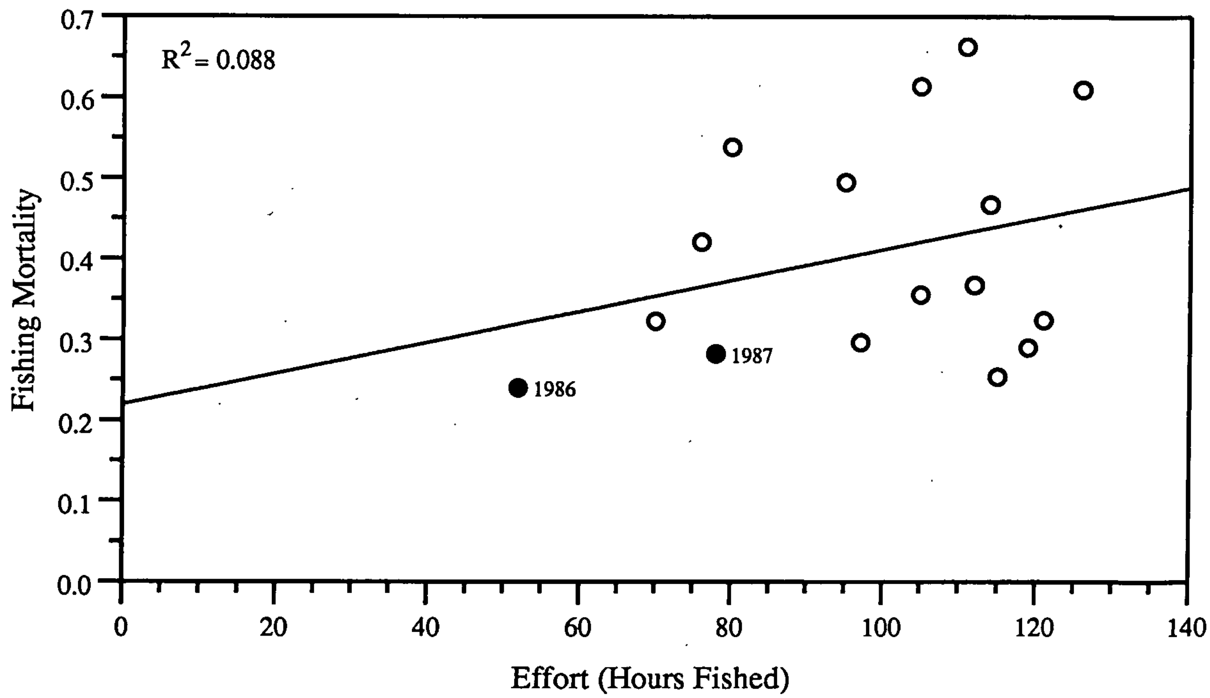
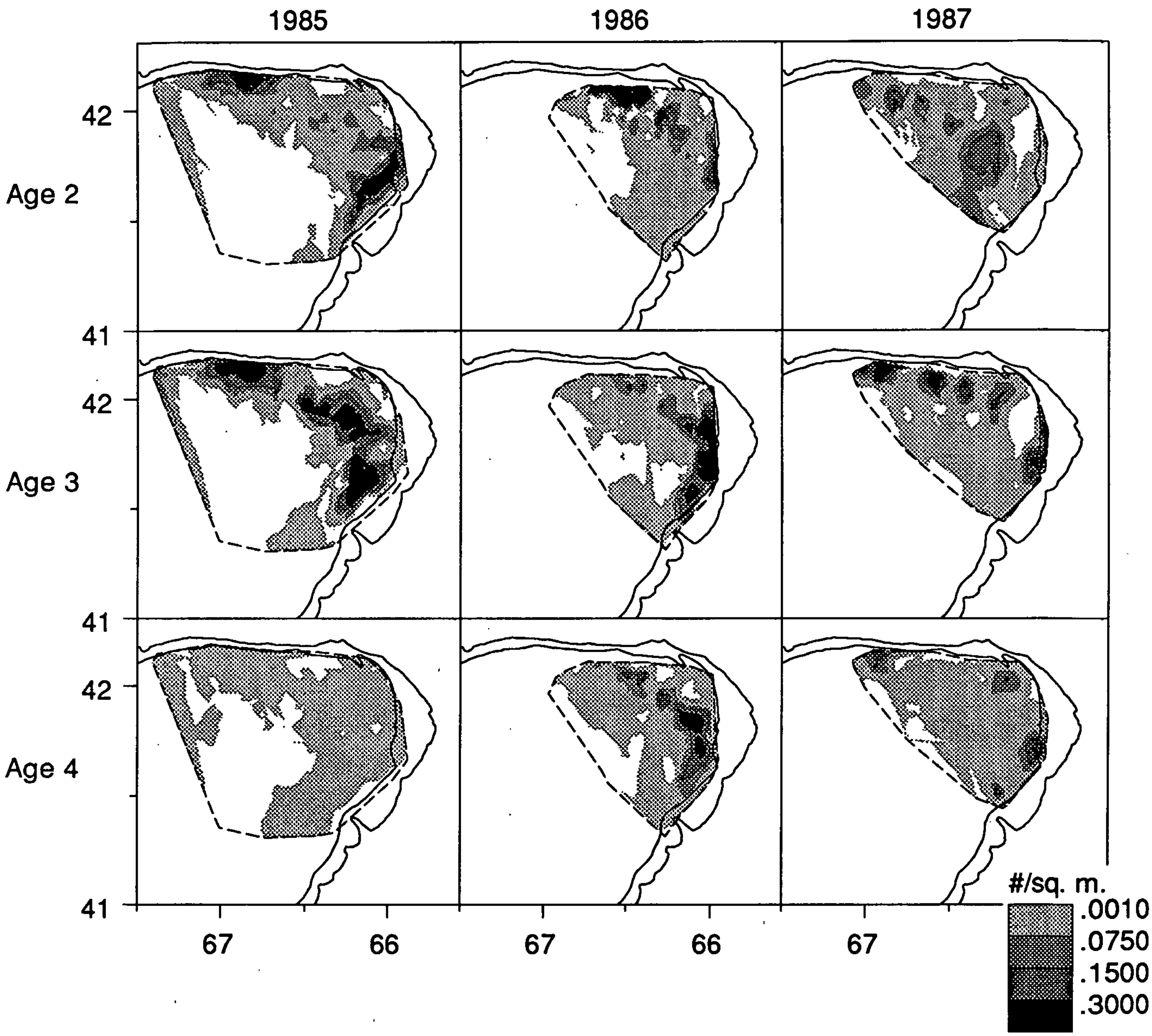


Figure 5.- Fishing mortality versus effort, using terminal F's of 0.8 (top) and 1.0 (bottom).



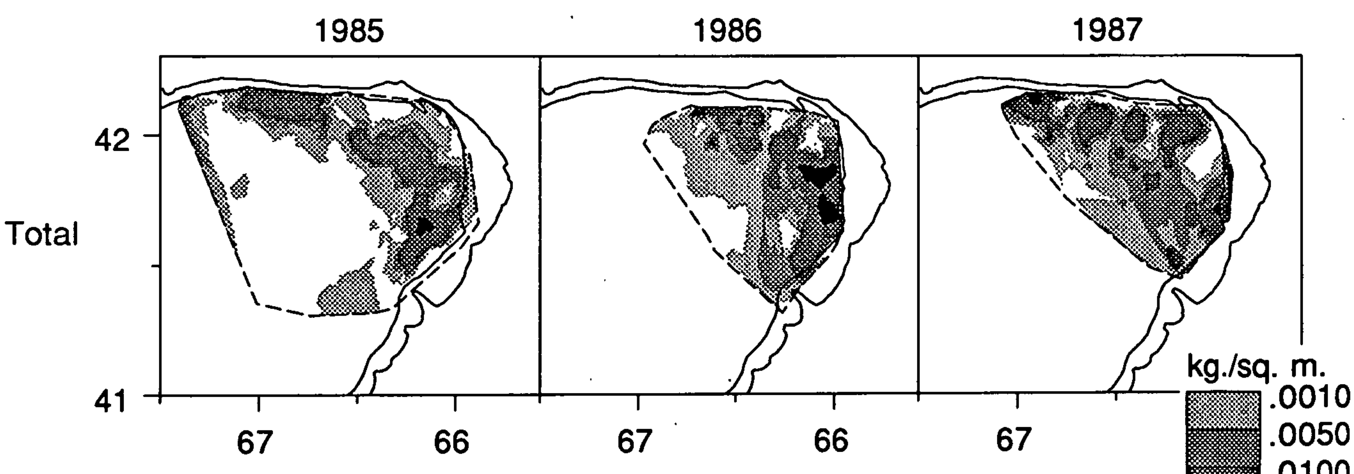


Figure 6.- Graphical representation by contour analysis of numbers of 2,3 and 4 year old scallops and total biomass on the Canadian portion of Georges Bank for 1985 to 1987.

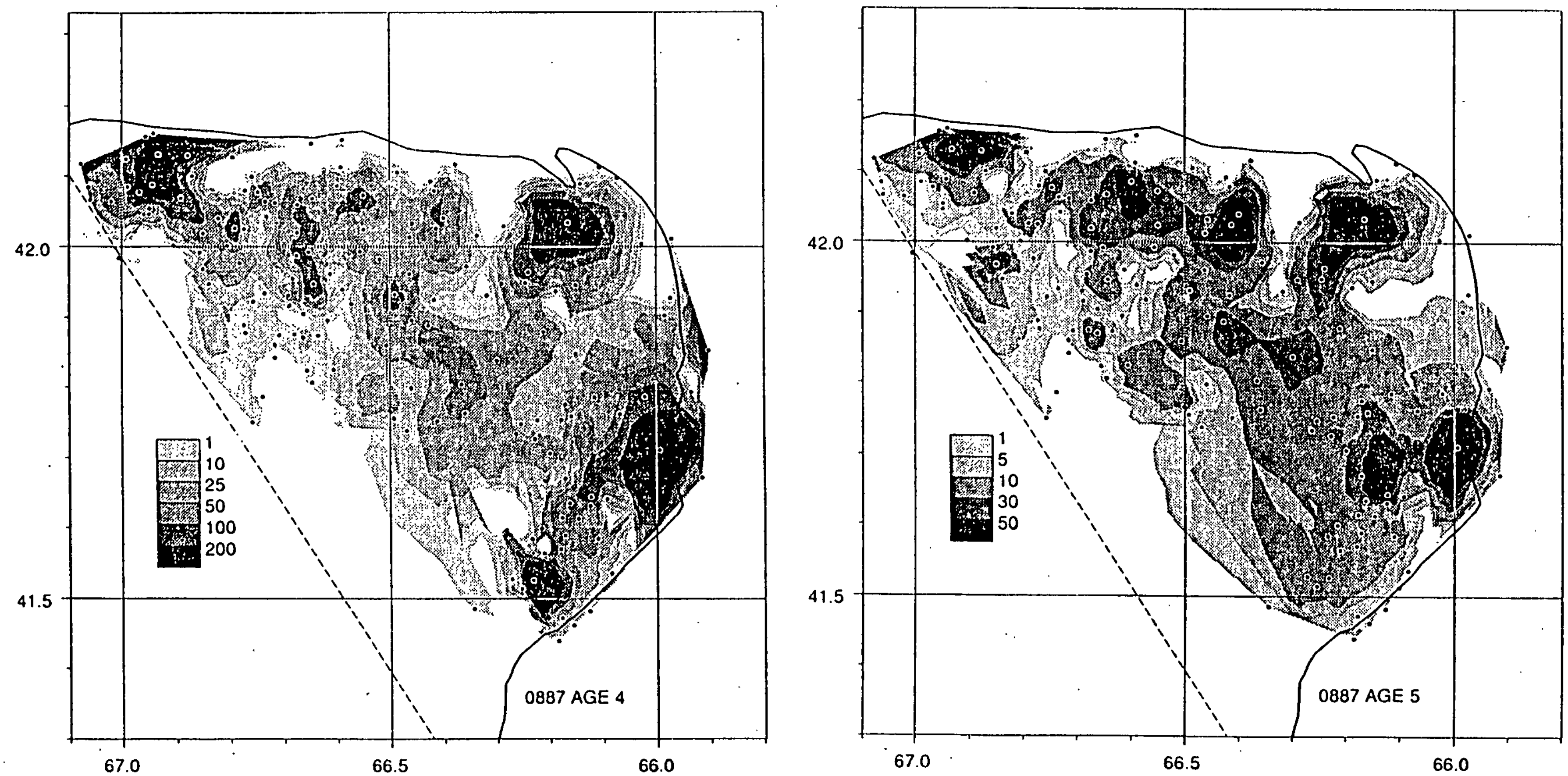


Figure 7.- Distribution of ages 4 and 5 scallop concentrations from the 1987 research survey represented by shaded contours from 1 to 200 scallops per tow (age 4) and from 1 to 50 for age 5.

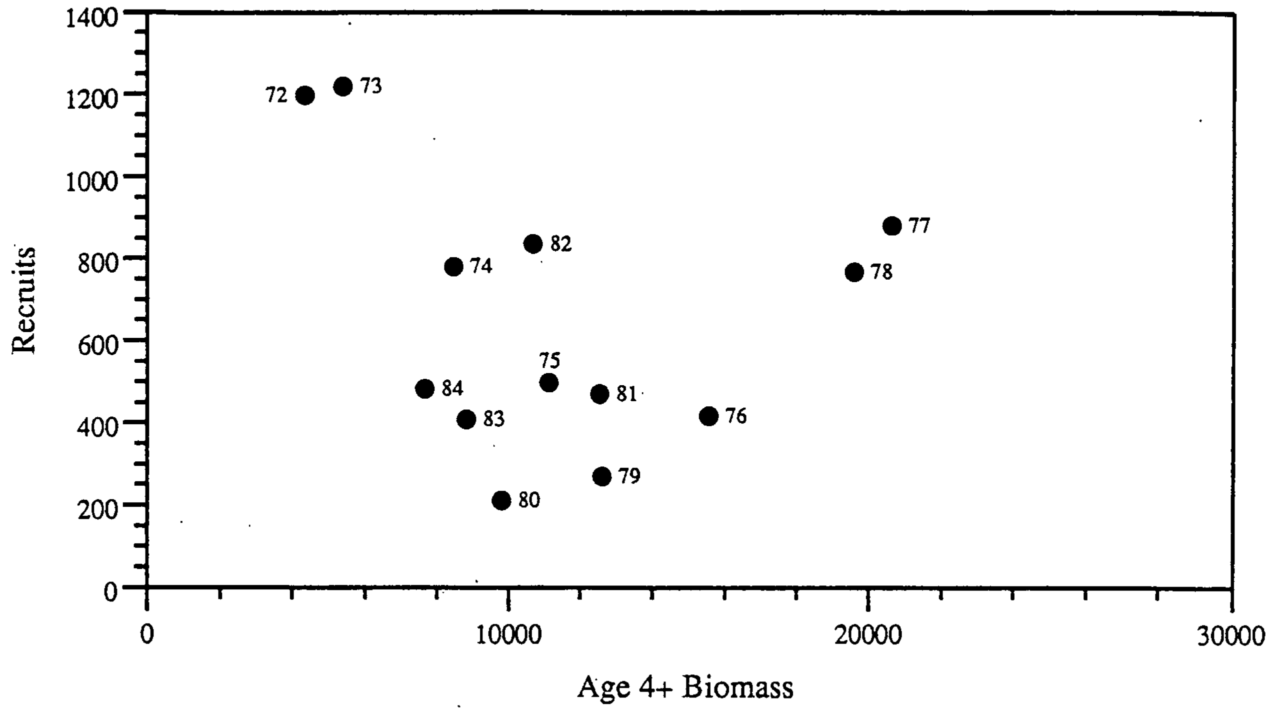


Figure 8.- Age 4+ biomass (t) versus recruits (lagged three years).