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Georges Bank Scallop Stock Assessment - 1989

by

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ABSTRACT

After the lowest fishery performance on record in 1984, under 3,000 t caught, catches started to increase until 1987 when the TAC of 6,800 t was caught. Then catches dropped to 4,336 t in 1988 and 4,676 in 1989 with a moderate CPUE at 0.434 kg / crhm (crew-hour-meter). Research survey results suggest only a moderate recruitment since the 1982 year class. Scallops also show poor survival above age 5. There is a high degree of similarity in abundance-at-age (3 - 5) numbers in the last 3 surveys. Sequential population analysis was carried out and established an average fishing mortality rate of 0.41 for 1989. A one-year stock projection was performed which predicts a catch of 3,300 t for 1990 if fishing at $F_{0.1}$ and a catch of 4,800 t if fishing at F_{max}.

RESUME

Après la pire performance de pêche enregistrée en 1984 lorsque moins de 3,000 t furent capturées, les prises ont commencé à augmenter jusqu'en 1987 quand le TPA de 6,800 t a été pris. Par la suite les prises ont baissé à 4,336 t en 1988 et 4,676 t en 1989 avec une PPUE moyenne de 0.434 kg / crhm (équipage-heure-mètre). Les inventaires de recherche ne suggèrent qu'un recrutement de taille moyenne depuis la classe d'âge 1982; ils démontrent aussi des taux de survie peu élevés au-dessus de l'âge 5. Un haut niveau de similarité existe entre les indices d'abondance-à-l'âge (3 - 5) pour les trois derniers inventaires. Une analyse de population virtuelle a établi un taux moyen de mortalité dû à la pêche de 0.41 pour 1989. Une projection de stock pour un an prédit une prise de 3,300 t pour 1990 si on pêche à $F_{0.1}$ et 4,800 t si on pêche à F_{max}.

INTRODUCTION

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

During the post-1985 period catches have stabilised in the range of 4,300 - 6,800 t while catch-rates have varied between 0.4 - 0.7 kg/crhm. This is less variation than the one that was experienced during the decade 1975 - 85 (Table 2). Research survey indices also suggest a dampening of the large variation previously experienced in the stock recruitment. The Total Allowable Catch for 1990 is recommended to be the same as for 1989 since cohort analysis suggests little change in the population biomass.

METHODS

Fishery data

Catch and effort data are compiled from logbooks. Logs with complete effort data are called Class 1 and are used to determine catch-rates. The Class 1 data represent more than 90% of the total (Table 2). Effort is measured in towed hours times the width of the 2 drags used times the number of crew (crhm). Scallop meats caught have to be shucked at sea; the smaller the meats, the more crew needed to shuck. Common fishing practices will first change the number of crew if effort has to be modified. Data on size distribution of meats from the commercial fleet are derived from port samples. Characteristics of monthly meat weight frequencies for selected years are given in Table 3. Canadian port sampling data were applied to the Canadian and U.S. total catch east of the ICJ line. This assumes similar fishing practices for both fleets. The annual changes in fishing practice can be seen in Table 4, which contains weight distributions in 2-gram intervals for the last ten years. Changes by month within 1989 are shown in the same manner in Table 5. Catch sampling was not carried out during the third quarter of 1989 although 18 % of the annual catch was landed during that period. Therefore, the catch-at-age matrix does not have any catch information for the third quarter. It was modified by duplicating the port sampling information of the second quarter to also represent the third quarter. Figure 1 shows the monthly catches and CPUE's for the last three years.

Catch in numbers-at-age (Table 11) for the cohort analysis are derived from the port sampling data and the sum of U.S. and Canadian catches in NAFO SA 5Zc. For more details on the method used to derive catch-at-age see Roddick and Mohn (1985). The total catch (U.S. ,prior to 1985 and Canadian) from the Canadian zone is decomposed into weight frequencies. The weights were converted to shell heights using the allometric relationship derived from 1982 -1985 research and commercial data (Robert et al 1987). The values expressing meat weight as a function of shell height use the parameters 9.102E-6 for the regression coefficient and 3.097 for the exponent of height. These values agree closely with those of Serchuck et al. (1982) for the same stock. Von Bertalanffy growth coefficients relating shell height and age were taken from Brown et al. (1972).

Traditionally, catch statistics are compiled on an annual basis and recruitment to a fishery is discussed in terms of year class strength. It is generally accepted that Georges Bank scallops are born in October and the first annual ring is laid down the following spring. This is typically less than 10 mm and becomes difficult to discern as the animal grows. For this reason the ring, which is approximately 25 mm from the umbo is often referred to as the first annulus (Naidu 1970). The convention which we shall adopt is that animals born in the fall of a year will be of that year class and it will be further assumed that they were born on January 1 of that year (cohort ages). The deposition of the ring less than 10 mm will take place during the first year of life. The date of the deposition will be assumed to take place on April 1. A back calculation is then made to estimate the shell height for January 1 (eg. cohort age 3 has a shell height of 61 mm on January 1st, while its biological age is 2.25 years). The annual growth rates for weights, given in Table 6, are converted into rates for heights and this results in a 16% reduction of the ring size being used for the January 1 size. For example, an animal born in the fall of 1978 is of the 1978 year class and will be approximately 25 mm on its second birthday (January 1, 1980) although the ring would not be deposited for a few months. Table 6, as well as all other age data, uses this convention, with correction of ring sizes back to January 1. For use in age / weight analyses and projections, the actual weights used are mid-quarter values.

Research survey data

A research survey was carried out on Georges Bank during August 1989. The design of the survey was based on a stratification by commercial effort (Robert and Jamieson 1986). The logbooks of the commercial fleet in the preceding 9 months were analyzed to determine areas of high and low catch-rates (Fig. 2). The areas of high catch-rates were sampled more heavily as they represent the area most important to the fleet (and presumably the areas of greatest abundance). The average number of scallops at age per tow is given in Table 7. The details of the survey results on a per stratum basis are given in Table 9.

In addition to establishing a stratified mean number per tow, the data were contoured to represent the spatial distribution of the scallop aggregations and integrated to estimate total numbers (Table 8). Data points describe a three dimensional surface with latitude, longitude, and density to be plotted. A surface is formed by defining Delaunay triangles where the data points form the vertices of triangles connecting neighbouring points. The algorithm used to define the triangles is found in Watson (1982). Collectively, the triangles form a surface. The surface between adjacent contour levels (abundance of scallops) is illustrated by varying shades of grey. Smoothing of the contours may be performed by interpolating the surface using inverse weighting of gradients (perpendicular to the planes of the triangles). The interpolation points are found by dividing the sides of the triangle into equal segments. Dividing the sides into 4 segments produces 16 subtriangles. Interpolation is performed on all the new vertices. This method assumes that the data points near the point in question contribute more than distant points (Watson and Philip 1985). The summation of the volumes of all triangles (integration) under the contoured surface approximates the total volume, here the abundance estimate for the survey area. The degree of interpolation will affect the volume estimates. For the Georges Bank survey data, the estimates stabilize using 16 or more subtriangles when they vary less than 5%. To assure the abundance estimates from similar areas are compared, only those points east of the ICJ line are used. A method to more accurately define a common overlapping area for comparison is still under development. A more complete description of the contouring method and volume estimation may be found in Black (MS 1988).

Stock analysis

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 does not include the effects of blending. Because of a recent change in fishing strategy to adapt to the lower meat count, the yield per recruit was re-calculated last year (Mohn et al 1989). Although it was examined this year, there was no need for a reevaluation as the fishing strategy remained the same.

The regulations in effect on the offshore fleet are that the catch should average no more than 33 meats per 500 grams which corresponds to an average weight of 15 grams per meat. Placing a limitation on the average instead of stipulating a minimum means that the fishermen may take small animals and then balance them with larger ones. Such a practice, called blending, renders the use of most yield models and stock projections inappropriate. If there are not enough larger animals to blend in, then the mortality on the small ones will have to be reduced. Thus, the partial recruitment is a function of abundance-at-age. In order to take this practice into account, a stock projection program was written (Mohn et al. 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 15, 45, 27 and 13%, which reflects the 1988 and 1989 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 1989 cohort estimates to January 1990.

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, effort distribution, and partial recruitment be determined on a quarterly basis. This was done by adjusting the most recent two year's selectivity pattern to reflect the port sampling data for the last quarter of 1989. This pattern, multiplied by the F determined from tuning for the last quarter year (F_{Q4} 1989), was used as a starting vector for the quarterly cohort analysis. Natural mortality was set at .025 per quarter (M = 0.1 on an annual basis, Dickie 1955; Merrill and Posgay 1964) and no attempt was made to include a seasonal, age or time dependent effects.

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 SPA is carried out in the normal manner.

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 1989 CAFSAC retrospective analysis workshop it was shown that iteratively estimating the terminal F from younger ages diverged rather than converged.) For the purposes of tuning, the terminal F (quarterly rate) ranged from 0.10 to 0.18 (Table 10). *A range of this magnitude was required to drive the residuals in the research survey vs* cohort biomass across the regression line. The residuals of the last two year's data and the correlation coefficient were used as tuning criteria. As expected, the correlation coefficient was not very sensitive. The positive residual values in table 10 denote that the residuals are below the regression line and the negative ones, above. It should be noted that the research survey biomass estimates are derived from the average weights at the third quarter. These are compared to third quarter biomasses from the cohort analysis. The annual CPUE values are compared to first quarter biomasses.

The CPUE vs cohort biomass estimates had a maximum R^2 at F_{Q4} = 0.11 and the 1989 point crossed the regression line at an F_{Q4} of 0.13. The research survey biomass vs the cohort biomass are also used, although the regressions were not as good as for the CPUE based tuning. The residual crosses the regression line at an F_{Q4} of 0.14 - 0.15 (but smaller 1989 residual with 0.14, see table 10); the maximum R^2 occurred at F_{Q4} = 0.11. The tuning of effort vs F had a slightly weaker correlation and the residual for 1989 crossed the regression line at an F_{Q4} of 0.12. Plots of the regressions used in the tuning process are presented in Figure 3. The CPUE vs cohort biomass shows a linear pattern of points with the last year being slightly below the regression line and the two before that being beneath the regression. (Figure 3). The unusual years 1977 - 1978 fit the regression line with difficulty. The research survey biomass vs cohort biomass (Figure 3) shows a strong linear distribution. The approximate agreement between tuning of CPUE and research biomass against the cohort analysis results and of effort against F gives us a measure of confidence that the correct terminal F_{Q4} is in the vicinity of 0.12 - 0.15. Both the CPUE and research biomass, the independent data used for tuning, show a fall in abundance from 1986 to 1988 with a small resurgence in 1989. Although the correlation is lower in the research biomass tuning, it is felt to be a more reliable data series and a stronger independent variable; therefore terminal F_{Q4} is set at 0.14. This is because of changes in the fishery over the 18-year period include changes in size regulations. Although a weak indication, the effort vs F tuning, suggested a similar terminal F_{Q4} (= 0.12). The pattern shown in the efforts for the last 5 years are similar to the average F's with a terminal F_{Q4} of 0.14.

At the request of the CAFSAC Steering Committee and in collaboration with R.K. Mohn an attempt was made to fit a production model (Gulland 1961) to the data to establish a MSY.

RESULTS

Research surveys

The commercial catch-rate data that led to the survey stratification is plotted as CPUE isopleths in Figure 2. The overall area covered by the survey (Figure 4) matches closely the total area of commercial cath-rates distribution depicted in Figure 2.

Sampling locations of the 1989 research survey are plotted in Figure 4. Station locations are indicated in the plot for age 6. A few stations are deeper than the 100-m isobath. Basically, there is a high degree of similarity between the survey results of 1988 and 1989 with slightly higher numbers of pre-recruits in 1989 (Table 6). Over the 1980 decade the 1989 survey abundances-at-age are in the moderate range (Table 8) with a rather high biomass although the area covered was one of the smallest. The medium stratum had a sizable input of pre-recruits compared to the last 3 years (Table 9). Minor changes occurred in the other strata. 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, within the 100-m isobath on the north and especially the northeastern side of the Bank.

Relative survey catch-rates established as number of scallops per standard tow are compared to absolute survey catch-rates derived from volume estimates of a smoothing interpolation technique by subtriangulation. In both cases, the estimates have been normalised by the maximum annual value for each index. Estimates for pre-recruits (age 3) and 3 recruited classes (ages 4 - 6) are graphically represented in Figure 5.

There are small differences between abundance as n / tow and abundance as volume estimate. Ages 3 and 4 estimates do not follow the same trend after 1986 while the older age groups follow each other quite closely.

Cohort analysis

The cohort analysis results are given in terms of numbers-at-age, biomass-at-age, and F-at-age (Tables 12 to 14) which have been combined into annual values from quarterly analysis for the terminal F_{Q4} level of 0.14 when the residual values of the cohort biomass on research survey biomass cross the regression line (Figure 6). The 1982 year-class is the largest seen in the last 9 years although the 1985 and 1986 year classes are next in rank. There is usually very little survivorship above age 6 seen in table 12. The F-at-age estimates show the shift in targeted ages from 1985 to 1986 with the drop in meat counts to 33 meats per 500 g forcing the targeted age to be of an older, bigger scallop while there is almost no fishing directed on age 3. Age 5 is very strongly targeted; F-at-age 5 equals 1.36 for 1989. The average F values show some degree of recent stabilization compared to the earlier years.

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 last year had an F_{max} which was estimated to be at an F of 0.966 and $F_{0.1}$ at 0.592. This year's re-analysis gives similar values of 1.07 and 0.665 respectively. The same selectivity is used in the cohort analysis, yield per recruit, and the stock projections (Table 15) which are carried out at F_{max} and $F_{0.1}$ using the cohort analysis numbers-at-age of the last quarter aged forward to the first quarter of the new year. This partial recruitment is more domed than the one used before; the annual values for the partial recruitment for ages 3 to 11 were 0.04, 0.52, 1.00, 0.63, 0.36, 0.21, 0.17, 0.10, and 0.05. The new values are 0.02, 0.28, 1.00, 0.47, 0.28, 0.19, 0.23, 0.23, and 0.13. The projections are given for a one 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_{Q4} of 0.14 are 3,300 and 4,755 t respectively. The mean weights of the catch are projected to be well above the legal limit of 33 meats per 500 grams, (Table 15). The projected biomass is essentially stable under F_{max} and increases about 10% per annum under $F_{0.1}$ and the assumed recruitment pattern.

Production model

Attempts were made at fitting the 5Ze Canadian catch data and corresponding effort in terms of days fished and crew-hour-meters (crhm) covering the period 1972 to 1988 to Gulland's production model. Whether days or crhm are used for effort, this data set gives a negative MSY and does not fit the model even when the data was lagged up to 5 years. This is graphically shown in Figure 7 where the catch on effort (days and crhm) does not plot the expected parabola. Furthermore, CPUE on effort should have a negative slope but such is not the case. This stock and its fishery may be too dynamic to use this type of model or they are responding to exogeneous factors.

CONCLUSIONS

In many respects, there are similarities between the 1988 and 1989 fishery with a slightly better performance in 1989. The catch-rate rose by 13 % but it was a lot more stable throughout 1989 than 1988 (Figure 1). However, the seasonal summer rise in catches was not sustained in 1989. The targeting of very few year classes, always focussed on age 5 since the change in meat counts in 1986, was even sharper than last year. This led to a highly domed selectivity. Research survey indices of the last two years also revealed similar trends with slightly more scallops in 1989. Although cohort analysis indicated a lower terminal F for 1989, the mean F were also quite similar (0.44 in 1988; 0.41 in 1989). And the recommended catch levels for 1990 remained the same as the ones proposed for 1989.

The tuning with CPUE minimized the 1989 residual at an F_{O4} of 0.13. Tuning with research biomass minimized the residual at 0.14. The latter value was chosen for the projections because it is an independent variable from the catch.

The scallop stock on Georges Bank is still strongly dependent on recruiting year classes. Targeting of effort has markedly 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.

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. Other possible methods that are statistically more rigorous such as the ADAPT method based on scallop meat weight frequencies to bypass the conversion problems of meat weight frequency distribution into age frequency distribution are being looked into. Under this approach the meat weight frequencies from the commercial catch are compared to the meat weight frequencies derived from the research survey indices. Preliminary analyses indicate good correlation between SPA determination and ADAPT results. This work is being pursued.

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Table 1.- Estimated (pre-1985) catches (t of meats) from Georges Bank, NAFO subarea 5Zc. Since October 1984 the ICJ line separates fishing areas for both countries.

Year	U.S.A.	Canada	Total
1957	3562	732	4294
1958	3024	1167	4191
1959	2601	2235	4836
1960	2008	2568	4576
1961	4472	4382	8854
1962	3200	5315	8515
1963	1953	5270	7223
1964	462	5034	5496
1965	24	3059	3083
1966	25	2537	2562
1967	34	3212	3246
1968	41	3904	3945
1969	97	3368	3465
1970	51	2868	2919
1971	3	2345	2348
1972	26	2746	2772
1973	5	1975	1980
1974	0	4541	4541
1975	0	6524	6524
1976	0	7809	7809
1977	77	11126	11203
1978	212	10970	11182
1979	314	7642	7956
1980	761	4751	5512
1981	2000	7612	9612
1982	1054	3918	4972
1983	714	2418	3132
1984	889	1945	2834
1985	0	3812	3812
1986	0	4900	4900
1987	0	6793	6793
1988	0	4336	4336
1989	0	4676	4676

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

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

* crew-hour-meter

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

	% catch examined / catch landed	meat weight (g) mean	min	max	s.e.	n meats
1981	0.01306					
January		0.00	0.00	0.00	0.00	0
February		8.96	3.26	53.21	0.06	1386
March		11.00	2.58	65.10	0.05	3673
April		10.19	4.70	54.38	0.08	402
May		11.56	3.37	76.60	0.02	19036
June		12.15	2.26	79.87	0.02	24514
July		11.44	2.55	73.25	0.02	16301
August		10.50	2.37	74.49	0.02	15204
September		9.90	2.23	59.09	0.03	4321
October		7.28	2.37	56.52	0.03	3165
November		8.13	2.10	54.47	0.03	4146
December		8.56	2.30	53.68	0.04	3004
1985	0.01101					
January		0.00	0.00	0.00	0.00	0
February		0.00	0.00	0.00	0.00	0
March		14.30	2.65	61.81	0.07	2037
April		14.77	3.56	60.90	0.05	4425
May		14.10	3.05	74.54	0.04	4604
June		13.75	4.58	69.04	0.05	2576
July		13.49	3.01	70.00	0.05	3049
August		14.05	4.92	62.11	0.05	3604
September		14.22	5.37	55.35	0.06	2137
October		12.60	4.09	68.03	0.04	4293
November		12.85	5.26	73.82	0.06	1566
December		12.69	4.33	53.19	0.04	2250
1989	0.00724					
January		15.46	5.19	45.89	0.05	1722
February		15.54	5.57	53.99	0.05	2090
March		15.23	6.05	60.15	0.05	2687
April		14.89	5.93	52.64	0.03	3640
May		15.39	5.41	67.19	0.03	4849
June		16.17	6.34	53.16	0.04	2027
July		0.00	0.00	0.00	0.00	0
August		0.00	0.00	0.00	0.00	0
September		0.00	0.00	0.00	0.00	0
October		12.60	5.16	43.86	0.03	2849
November		12.85	4.12	68.34	0.05	1818
December		12.69	5.92	31.46	0.06	713

Table 4.- Frequencies of numbers at weight in 2-g intervals (normalized to 1000) by year.

	Year									
Grams	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
1	0	0	0	0	0	0	0	0	0	0
3	15	16	2	12	7	1	0	0	0	0
5	99	84	26	66	96	20	0	2	3	1
7	172	204	99	110	205	112	6	17	28	14
9	169	253	146	118	169	211	41	7	98	83
11	128	177	159	125	108	197	125	150	163	179
13	92	96	132	111	69	136	209	175	179	219
15	67	52	103	90	55	87	225	168	152	182
17	51	31	73	70	46	57	160	129	104	117
19	38	20	55	53	41	42	96	89	75	72
21	32	15	45	44	37	30	55	59	54	43
23	24	11	33	36	30	21	28	44	36	30
25	20	8	27	27	25	17	17	29	27	18
27	17	6	21	23	20	13	11	18	22	14
29	13	5	17	18	18	11	8	12	16	7
31	11	4	13	15	15	9	3	9	11	6
33	9	3	11	13	12	7	3	6	9	4
35	7	3	8	10	11	6	3	4	6	4
37	6	2	6	8	8	5	2	3	5	2
39	5	2	5	8	6	4	1	2	4	2
41	4	1	4	6	5	3	2	1	3	1
43	3	1	3	6	4	3	1	1	2	1
45	3	1	2	5	3	2	0	0	1	1
47	3	1	2	4	2	2	0	0	1	0
49	2	1	1	4	2	1	0	1	1	0
51	2	1	1	2	2	1	1	0	1	0
53	2	1	1	3	1	1	0	0	0	0
55	1	1	1	3	1	1	0	0	0	0
57	1	0	0	1	1	0	0	0	0	0
59	1	0	1	2	0	0	0	0	0	0
61	1	0	0	2	0	0	0	0	0	0
63	1	0	0	1	0	0	0	0	0	0
65	0	0	0	2	0	0	0	0	0	0
67	0	0	0	1	0	0	0	0	0	0
69	0	0	0	1	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0	0	0
73	0	0	0	1	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0	0
77	0	0	1	0	0	0	0	0	0	0
79	0	0	0	0	0	0	0	0	0	0

Table 5.- Frequencies of numbers at weight in 2-g intervals (normalized to 1000) by month for 1989. Sample sizes are given in the last row.

Grams	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1	0	0	0	3	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
5	3	1	0	1	2	0	0	0	0	5	79	2
7	26	18	52	45	15	15	0	0	0	68	63	22
9	145	132	310	290	175	84	0	0	0	346	230	141
11	285	385	572	722	685	246	0	0	0	585	338	198
13	352	476	588	785	1242	389	0	0	0	604	344	135
15	283	394	355	630	1149	438	0	0	0	438	302	86
17	208	204	215	462	706	314	0	0	0	293	172	41
19	147	136	152	273	335	216	0	0	0	200	126	36
21	89	106	103	162	177	106	0	0	0	123	86	19
23	63	80	93	100	121	75	0	0	0	63	55	20
25	42	46	63	54	68	40	0	0	0	49	38	7
27	23	32	54	41	50	44	0	0	0	35	22	3
29	15	22	23	22	26	17	0	0	0	14	5	2
31	15	17	22	18	32	13	0	0	0	14	13	1
33	6	10	15	8	25	9	0	0	0	4	3	0
35	5	8	22	15	14	10	0	0	0	5	1	0
37	3	5	10	2	8	3	0	0	0	1	2	0
39	8	8	7	6	7	4	0	0	0	1	4	0
41	1	1	10	2	4	1	0	0	0	0	2	0
43	1	5	6	0	0	0	0	0	0	1	1	0
45	1	1	7	0	3	1	0	0	0	0	0	0
47	0	2	1	0	0	1	0	0	0	0	1	0
49	0	0	2	0	0	0	0	0	0	0	1	0
51	0	0	2	1	1	0	0	0	0	0	0	0
53	0	1	0	1	0	1	0	0	0	0	1	0
55	0	0	0	0	0	0	0	0	0	0	0	0
57	0	0	1	0	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0	0	0	0	0
61	0	0	2	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	1	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0	1	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	1722	2090	2687	3640	4849	2027	0	0	0	2849	1818	713

Table 6.- Shell height (mm), meat weight (g) and meat count per 500 grams at age, biological and cohort. Height and weight as of first day of quarter.

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

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

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

Table 8.- Indices of abundance of scallop age-classes by volume estimates: numbers-at-age (10^6), biomass at survey time (t of meats), 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	2965	3987
1982	121.76	56.95	15.47	3.43	2056	6161
1983	99.32	50.76	14.31	5.28	1841	5839
1984	85.74	30.32	8.08	2.21	1245	5812
1985	557.64	45.29	5.88	1.26	4628	5943
1986	309.16	225.53	26.46	3.81	5942	5025
1987	214.58	145.50	41.78	11.27	4704	4997
1988	238.53	105.06	23.45	5.05	3744	5115
1989	266.38	161.01	31.79	5.24	4899	4414

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

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

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

	CPUE			Research Survey Biomass			Effort		
F_{Q4}	R^2	1988*	1989*	R^2	1988*	1989*	R^2	1988*	1989*
0.10	0.773	-746	-2134	0.524	-1486	-2740	0.450	+0.02	+0.05
0.11	0.774	-410	-1329	0.535	-1190	-1930	0.438	+0.01	+0.03
0.12	0.773	-130	-658	0.531	-944	-1256	0.423	-0.00	+0.01
0.13	0.769	+107	-90	0.512	-735	-685	0.408	-0.02	-0.01
0.14	0.765	+310	+396	0.478	-557	-195	0.391	-0.02	-0.03
0.15	0.761	+486	+817	0.434	-402	+229	0.374	-0.03	-0.04
0.16	0.756	+640	+1186	0.385	-266	+600	0.357	-0.04	-0.06
0.17	0.751	+775	+1512	0.336	-147	+927	0.339	-0.05	-0.07
0.18	0.747	+896	+1801	0.289	-41	+1218	0.322	-0.06	-0.09

* Position of residual value with respect to regression line

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

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

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	289	45	33	65	65	2	21	21	16
4	492	170	90	68	144	185	186	119	162
5	75	93	65	33	37	108	188	96	101
6	16	13	14	20	11	10	16	22	18
7	8	6	3	8	10	3	3	5	8
8	5	3	2	2	4	2	2	1	1
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

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 0.14.

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

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	651	230	188	424	635	384	334	482	506
4	672	308	164	139	321	512	345	281	416
5	112	145	118	64	61	153	287	134	140
6	33	30	43	45	26	20	37	83	30
7	25	15	15	26	22	13	8	18	55
8	43	15	7	10	15	10	9	5	12
9	16	34	11	5	8	10	8	6	3
10	6	11	28	8	3	6	9	4	5
11	3	3	7	22	6	2	5	6	2
Total	1562	790	581	743	1097	1109	1041	1020	1169

Table 13.- Biomass (t of meats) east of the ICJ line from cohort analysis using a terminal F_{Q4} of 0.14.

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

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	2133	752	617	1390	2080	1256	1094	1578	1658
4	6503	2981	1586	1348	3105	4950	3335	2722	4019
5	1921	2486	2023	1094	1052	2630	4933	2295	2408
6	797	729	1039	1094	629	481	884	2013	729
7	753	435	448	765	651	380	246	548	1639
8	1486	527	256	355	531	355	304	161	406
9	611	1278	401	179	286	386	291	233	121
10	220	434	1105	305	116	229	344	177	181
11	140	112	305	920	230	67	209	268	92
Total	14563	9735	7780	7449	8680	10734	11639	9994	11252

Table 14.- Annualised fishing mortality east of the ICJ line from cohort analysis using a terminal F_{Q4} of 0.14.

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

Ages	1981	1982	1983	1984	1985	1986	1987	1988	1989
3	0.65	0.24	0.20	0.18	0.12	0.01	0.07	0.05	0.04
4	1.44	0.86	0.85	0.72	0.64	0.48	0.85	0.60	0.53
5	1.21	1.11	0.86	0.79	1.02	1.33	1.14	1.39	1.36
6	0.72	0.60	0.42	0.63	0.62	0.79	0.59	0.32	0.98
7	0.39	0.57	0.27	0.40	0.65	0.26	0.46	0.34	0.17
8	0.14	0.26	0.35	0.21	0.31	0.19	0.26	0.28	0.14
9	0.30	0.11	0.23	0.40	0.18	0.08	0.46	0.21	0.12
10	0.62	0.29	0.12	0.22	0.49	0.03	0.19	0.60	0.09
11	0.71	0.65	0.43	0.08	0.21	0.08	0.08	0.20	0.30
Mean	0.69	0.52	0.41	0.40	0.47	0.36	0.45	0.44	0.41

Table 15.-.Stock projections at current F_{max} (0.966) and at $F_{0.1}$ (0.594) using starting numbers from cohort analysis with a terminal F_{Q4} of 0.14.

F = 0.966	1990	1990	1990	1990
Rate on smalls	1.00	1.00	1.00	1.00
Mean Wgt. Catch	17.54	16.64	17.58	21.09
Catch (Mill.)	38.34	129.99	77.97	26.02
Catch (t)	672	2,163	1,371	549
Cum. Catch (t)	672	2,835	4,206	4,755
Biomass	13,164	12,934	12,821	13,998

F = 0.594	1990	1990	1990	1990
Rate on smalls	1.00	1.00	1.00	1.00
Mean Wgt. Catch	17.54	16.76	17.85	21.48
Catch (Mill.)	24.11	87.02	55.68	19.73
Catch (t)	423	1,459	994	424
Cum. Catch (t)	423	1,882	2,875	3,299
Biomass	13,432	14,026	14,406	15,734

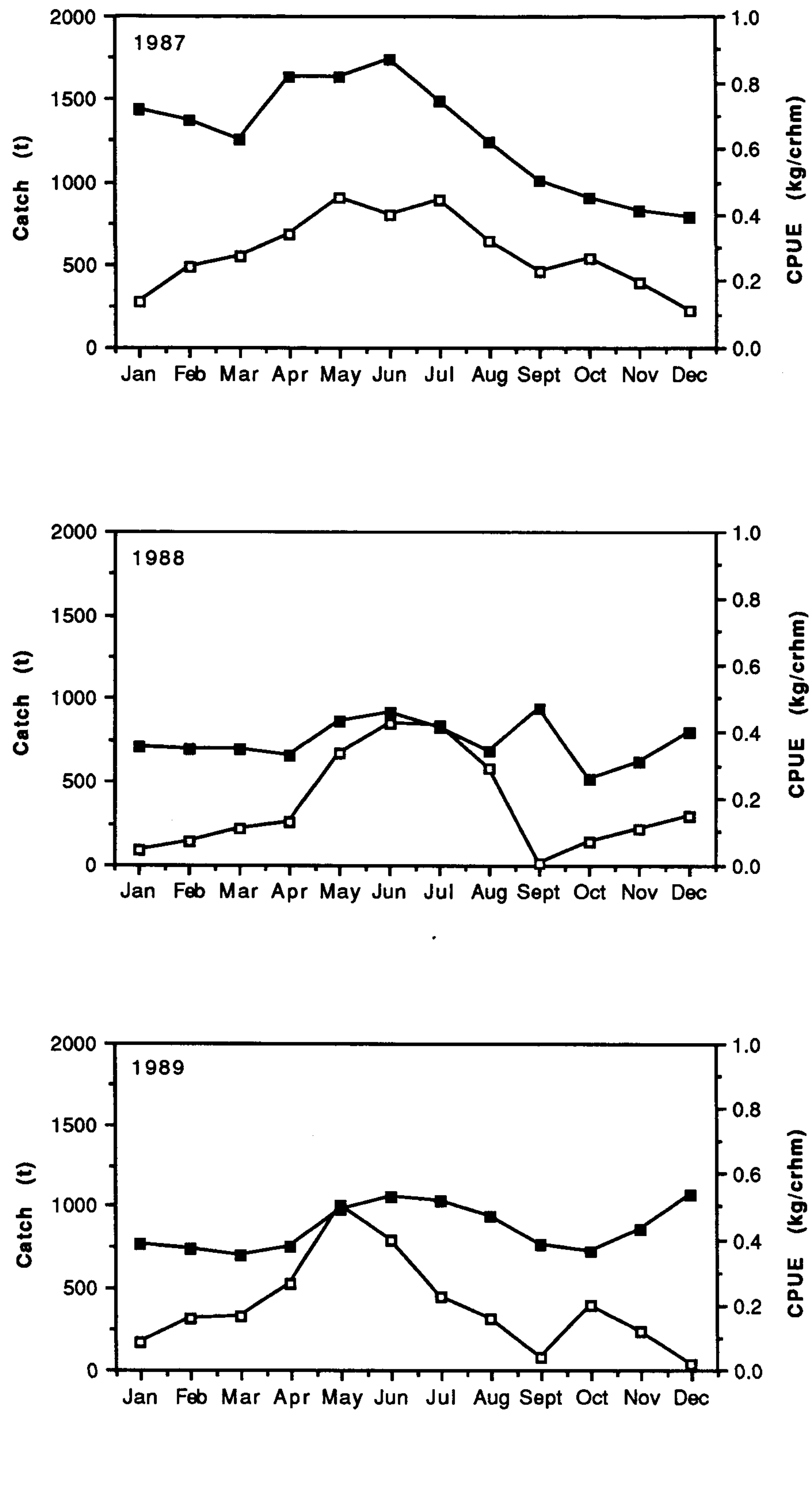


Figure 1.- Monthly CPUE (filled square) and catch in tons of meats (open square) for the deep-sea fleet fishing Georges Bank.

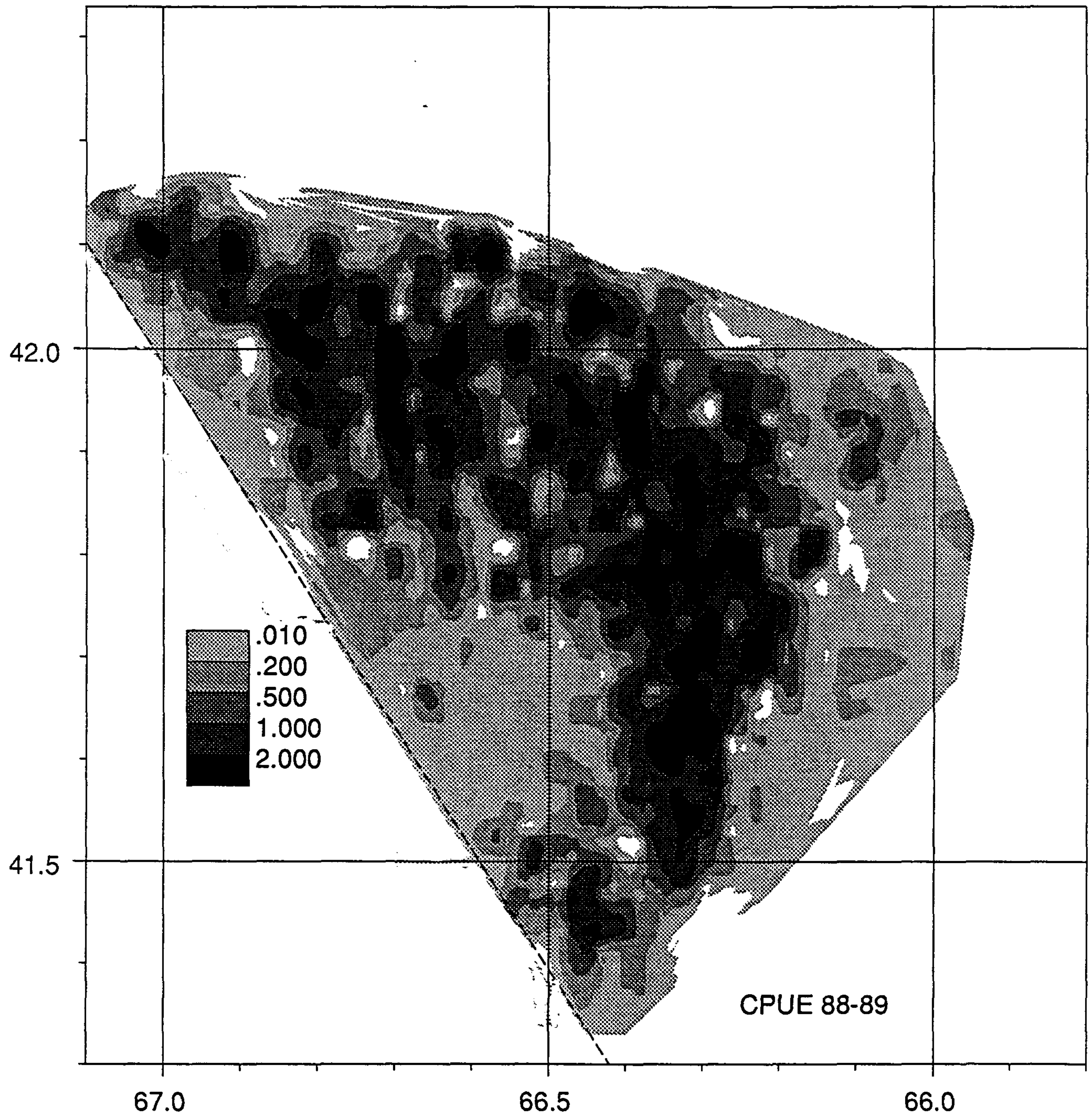
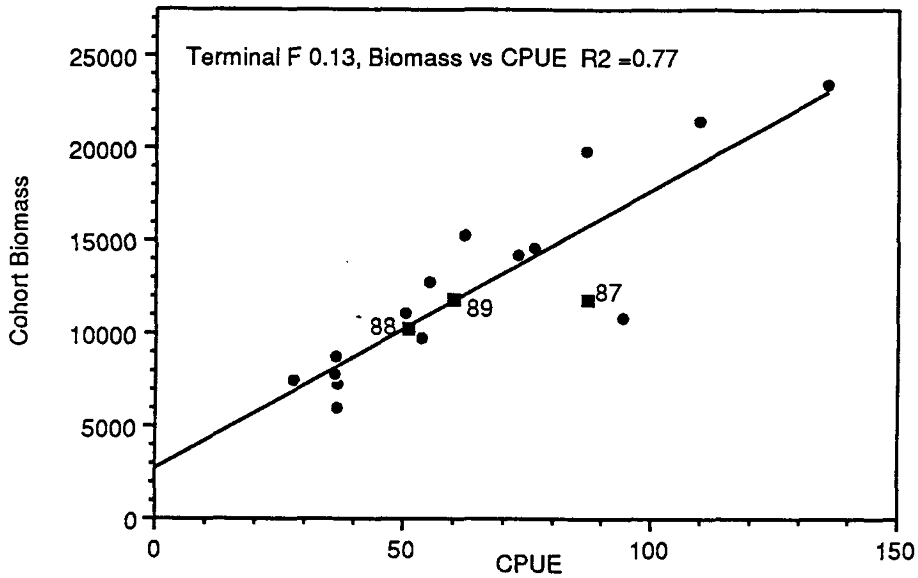
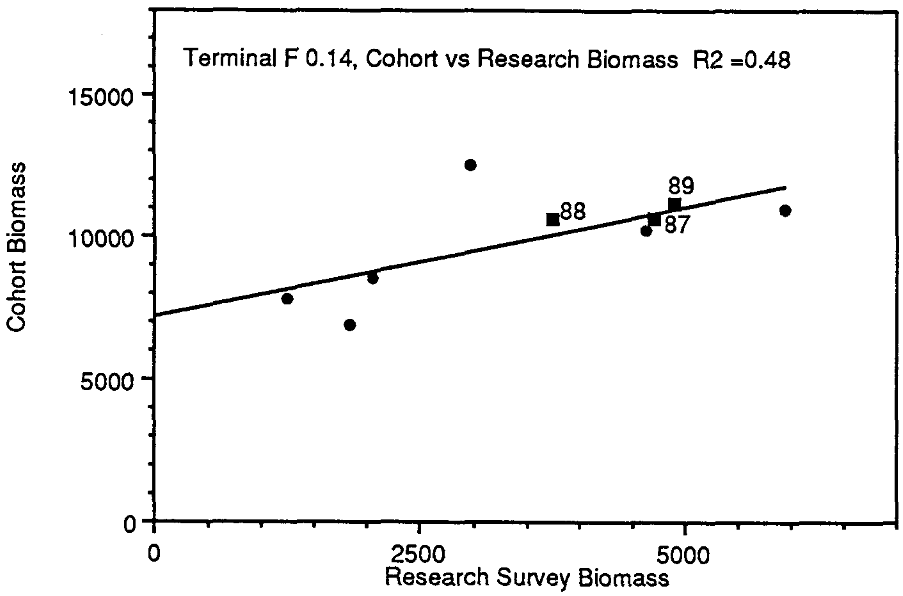


Figure 2.- The distribution of catch-rates in the last 9 months preceding the survey. CPUEs in kg/crhm as per grey scale to the left of the plot corresponds to the survey strata: less than 0.2 kg/crhm is very low; 0.2 - 0.49 low; 0.5 - 0.99 medium, and 1.00 or greater high stratum.





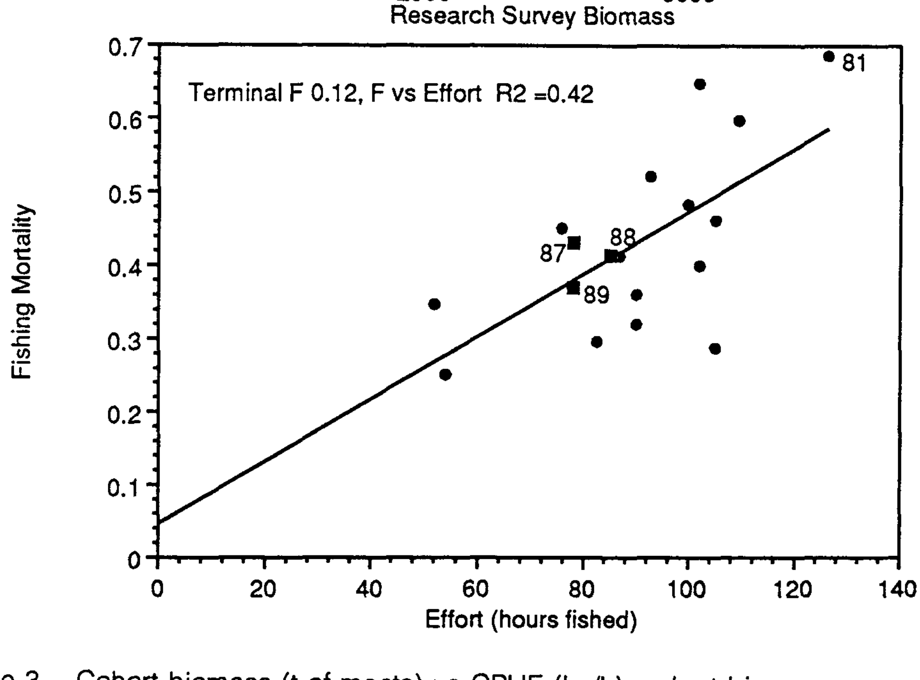


Figure 3 .- Cohort biomass (t of meats) vs CPUE (kg/h), cohort biomass vs research survey biomass (t of meats), and fishing mortality vs effort (hours fished) using terminal F_{Q4} as shown above.

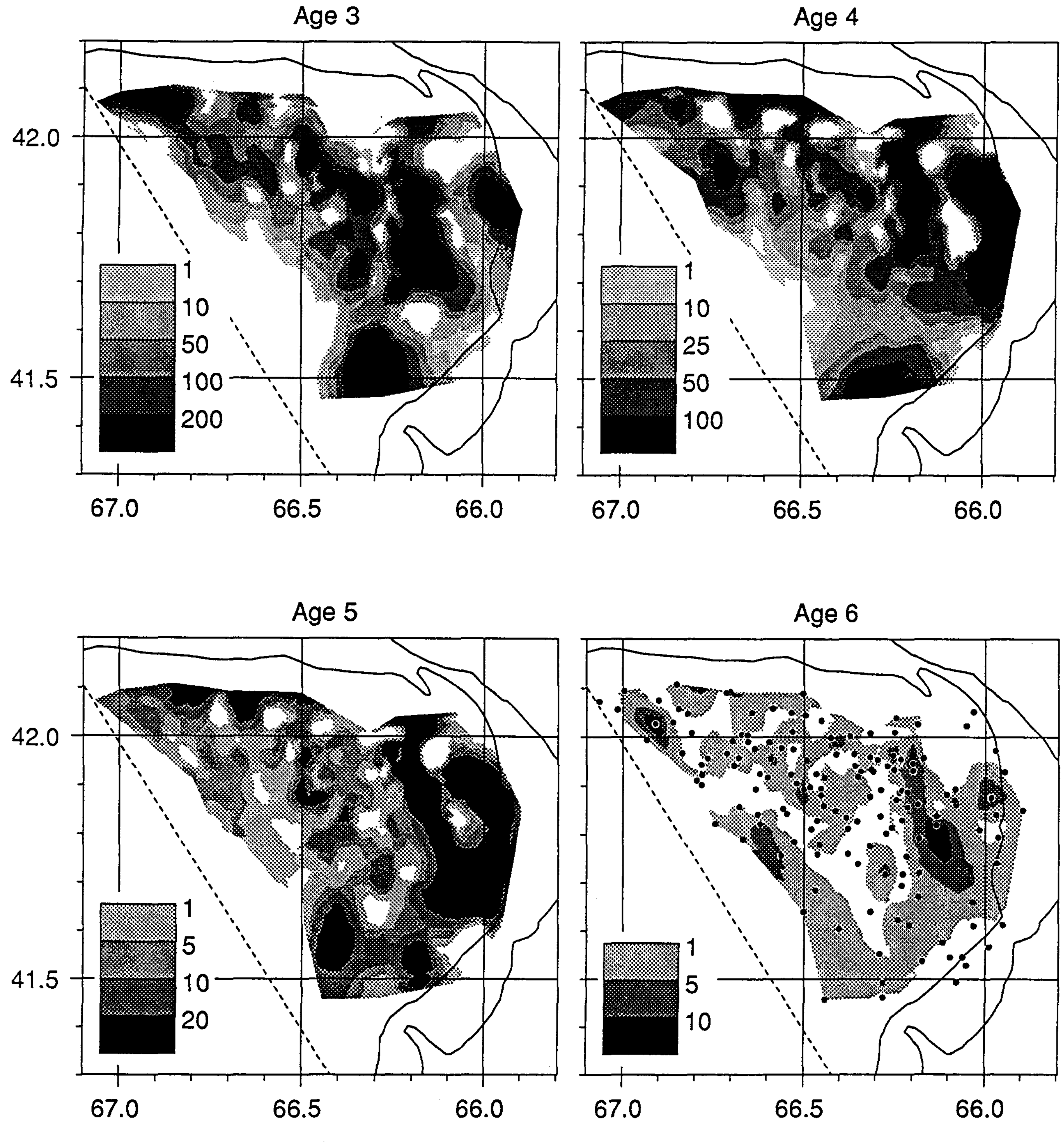


Figure 4.- Scallop distribution according to age from the research survey of August 1989. Location of sampling stations is indicated on the graph for age 6 scallops.The shading scale (lower left corner of graph) represents number of animals per standard tow.

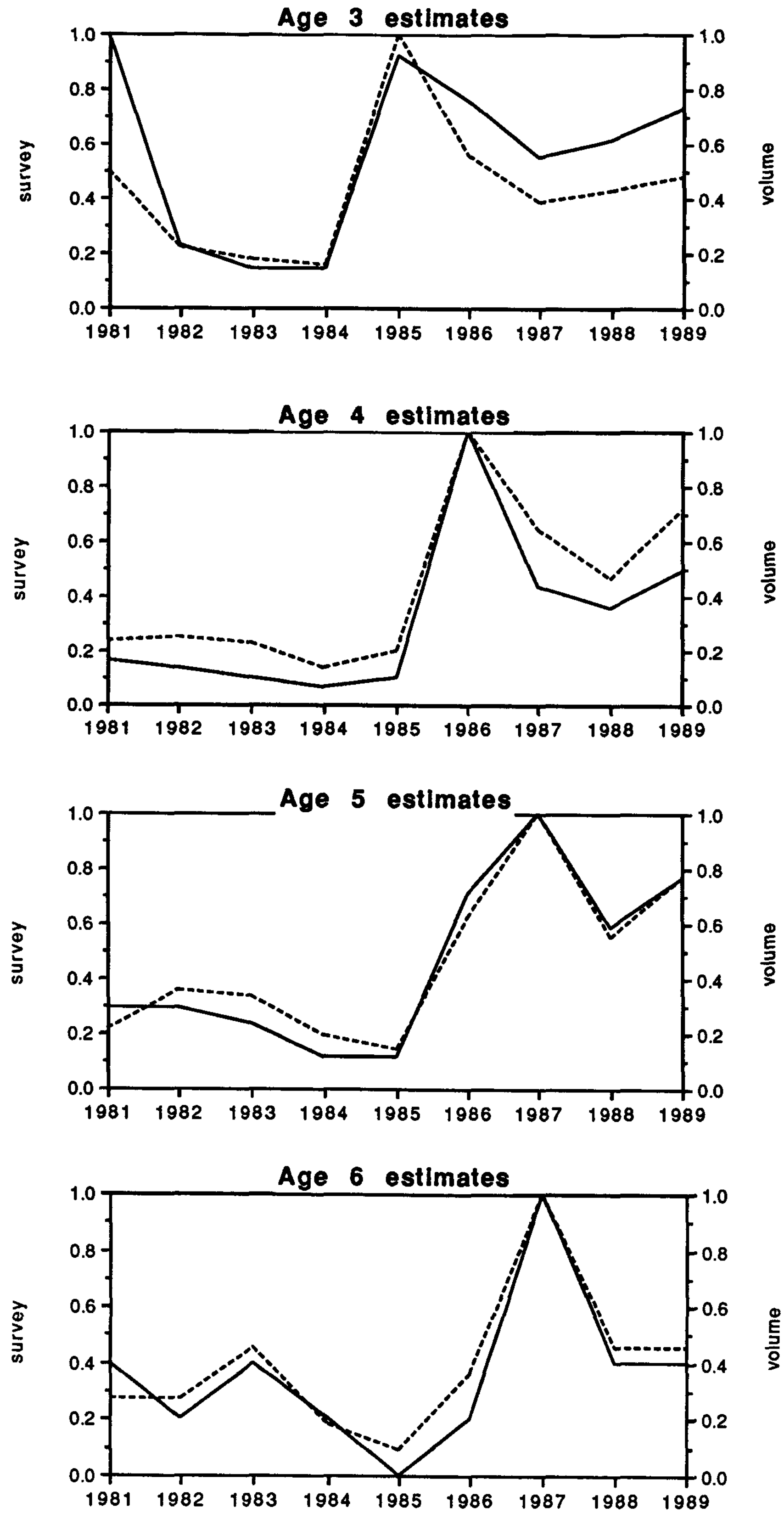


Figure 5 .- Comparison of abundance estimates, 1981 - 1989. Estimates have been normalised by the maximum annual value for each index. The survey index, no. per standard tow, is drawn with a smooth line. The volume index, no. in millions, as per Delaunay triangulation, is expressed with a dashed line.

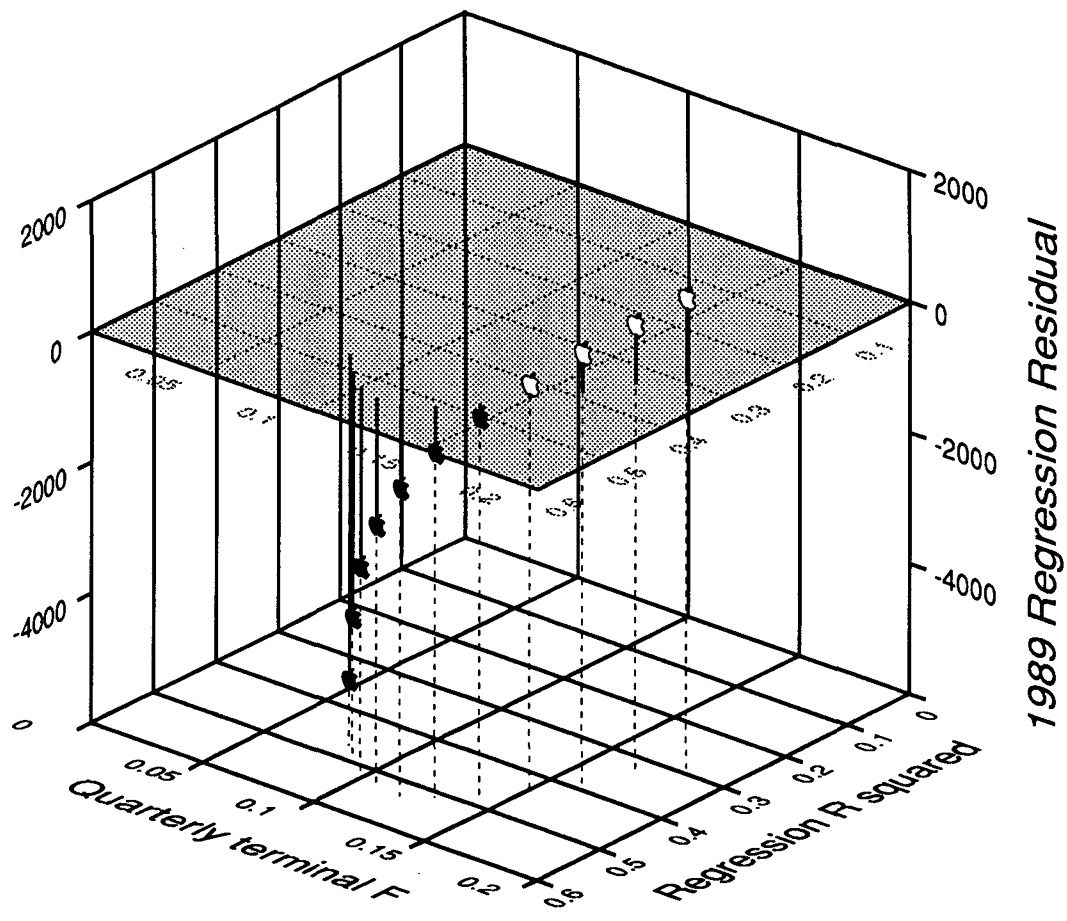


Figure 6 .- Three-dimensional representation of regression R^2 on the x-axis, F_{Q4} on the y-axis, and residual values on the z-axis. The z-surface with a residual value of zero (i.e. at the regression line) is shaded in light grey. Residuals above the surface (line) are noted by white 'apples'; residuals below by dark 'apples'. The best fit is at the transitional coordinates between dark and white.

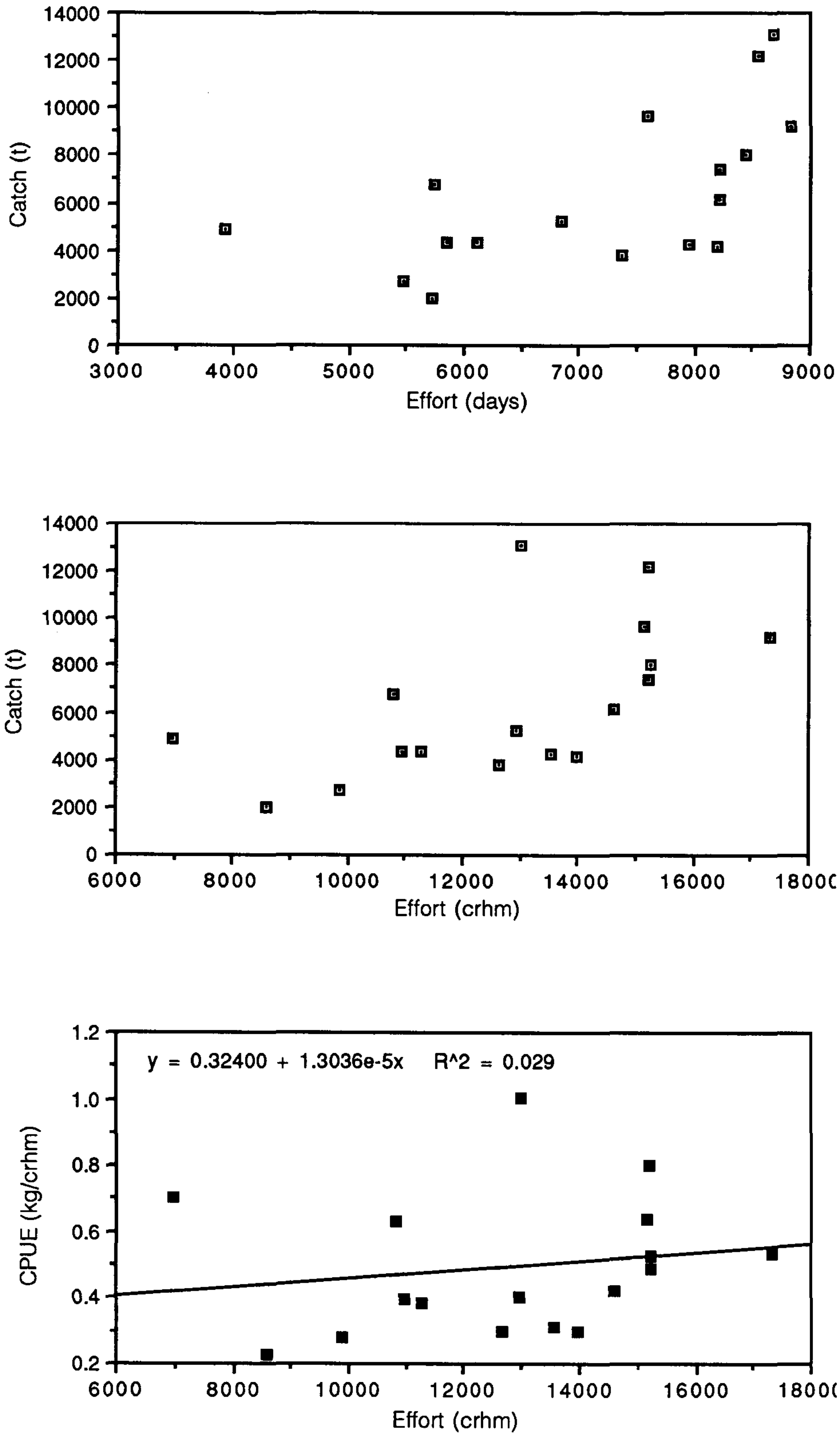


Figure 7 .- Graphs of the catch on effort (days and crew-hour-meters) show the lack of parabolic shape in the data set. The slope of CPUE on effort is positive when the model expects a negative one.