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Georges Bank Scallop Stock Assessment - 1983

by

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Abstract

The 1983 fishery reflected another year of depletion of the resource which has not experienced good recruitment since the 1977 year class. The Canadian catch was 2751 t, which is the lowest catch for the Canadian fleet since 1959. This was taken from a biomass that is estimated to be the lowest since research surveys were initiated. Yield per recruit and stock projections show that the stock is seriously overfished. The effects of the currently used catch restriction of an average of 35 meats/pound and the proposed American minimum size of 40/pound are compared to assess their conservation impact. Neither of these management objectives is adequate to significantly aid stock reconstruction.

Résumé

La pêche de 1983 a représenté une autre année de diminution de la ressource, qui n'a pas connu de bon recrutement depuis la classe d'âge de 1977. Les prises canadiennes ont été de 2 751 t, ce qui est le plus bas total pour la flotte canadienne depuis 1959. Les prises ont été réalisées sur une biomasse que l'on estime être à son plus bas niveau depuis le début des relevés de recherche. Le rendement par recrue et les projections concernant le stock montrent que ce stock est fortement surexploité. On compare les effets de la limite de prise en vigueur, 35 chairs/livre (mélange) et la mesure proposée par les Américains, une taille minimale équivalente à 40 chairs/livre pour en évaluer l'influence sur la conservation de la ressource. Ni l'un ni l'autre de ces objectifs de gestion n'est suffisant pour contribuer de façon significative la reconstitution du stock.

Introduction

Two strong year classes, those of 1957 and 1972, produced major peaks in landings in the last 30 yr of the Georges Bank scallop fishery (Table 1a). The more recent peak occurred in 1977 to 1978 with landings of over 17000 t. Landings fell to about 10000 t in 1980 but increased by almost 6000 t to 16000 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. In 1981, the Georeges Bank scallop fishery relied on age 4 scallops for 60% of its catch, older scallops becoming scarcer through the year. In 1982, the fishery relied mainly on the 1977 year class, and landings by the Canadian fleet decreased by 50% in comparison to 1981. U.S. catch levels have shown an upward trend since the early 1970's to over 8000 t in 1981, representing an increase of 400% from 1976 to 1981 and a parallel increase in effort. Effort in 1983 was slightly lower than 1982, and the Canadian catch fell to 2748 t, its lowest level since 1959.

For this document, the standard assessment techniques (research survey abundance, yield per recruit analysis, cohort anlaysis, and stock projections) are applied to the Georges Bank scallops. It is shown that the stock is depleted and that the currently discussed management options are inadequate for stock reconstruction.

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 (see Table 1b). 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 Canadian line. This assumes similar fishing practices for both fleets. The change in fishing practice can be seen in Table 2 which contains weight distribution in 2 g intervals for the last 5 yr. Month-by-month port sampling data are given in Table 3.

Catch in numbers at age (Table 4) for the cohort analysis are derived from these port sampling data and the sum of U.S. and Canadian catches in the Canadian zone. The total catch from the Canadian zone is decomposed into weight frequencies. The weights were converted to shell heights using the allometric relationship derived from 1982 research cruise data. The values expressing meat weight as a function of shell height use the parameters 1.027E-5 for the constant and 3.090 for the exponent of height. The 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) having the values of 145.5, 1.5, and 0.38

respectively for L_∞, T_O, and k. The distribution for each year, now expressed in heights, are then converted to ages and accumulated for each year class.

Traditionally, catch statistics are compiled on an annual basis and recruitment to a fishery is discussed in terms of year class strengths. It is generally accepted that Georges Bank scallops are born in October and the first annual ring is laid down the following March. This ring 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 mark the first birthday and the approximately 25 mm annulus will mark the second birthday. The date of the deposition will be assumed to take place also on January 1. There is therefore a deliberate error introduced which is of the amount of growth from January 1 to the formation of the ring. This error is assumed to be small, as the animals are not growing rapidly during this period. 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 occur for a few months. Table 5, as well as all other age data, uses this convention.

The values for the column of ovary weights as a function of size, given in Table 5, are derived from data published in Serchuck et al. (1982). An allometric equation was fit from the logs of shell height and ovary weight giving 3.875E-7 for the constant and 3.617 for the exponent. These values may be compared with values derived from Naidu (1970) (8.069 and 3.3463 respectively) for animals from Port au Port Bay, Newfoundland. The similarity is interesting in light of the different environments the animals are facing.

The standard cohort analysis was augmented by the separable VPA of Pope and Shepherd (1982). This SVPA is an extension of the ideas presented by Doubleday (1976) wherein the F matrix was decomposed into age effects (selectivities, S_i) and year effects (overall fishing mortality, F_j). This separation into age and year effects was done to reduce the underdetermined nature of the VPA. By making the separability assumption SVPA allows the estimation of population numbers and fishing mortality from only catch at age data and four additional numbers. The first of these is the natural mortality, the second is the age of maximum selectivity, and the last two are starting values for the oldest age's selectivity and the most recent year's fishing mortality. The program then optimizes the fit of the resultant outer product F matrix to the catch data.

Actually the catch data are not directly used but rather the log of the catch ratio down cohorts. This is done to remove variable year class strength effects. The resultant S_i and F_j represent the best fit to the data and assumed four values. Unfortunately the residual to the fit is insensitive to the starting values and cannot be used to discriminate amongst them. The matrix of the residuals (Table 6) is useful for detecting changes in the fishery, and the fit S_i and F_j may be tried as starting values in conventional VPA. The SVPA does not depend on tuning as does the conventional approach, but on the other hand it cannot be tuned in this manner either.

A research survey was carried out on Georges Bank during August 1983. The design of the survey was based on a stratification by commercial effort. The logbooks of the commercial fleet in the preceeding 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. 1982).

A Thompson-Bell yield per recruit analysis was carried out (Fig. 2 and Table 7) with yield in units of meat weight from the smoothed values in Table 5. Also, an index of the reproductive potential of the stock was produced with smoothed pre-spawning ovary weights. In this case the yield was not defined as the summation of the product of the catch and weight at age but rather as the product of the numbers at age and ovary weight at age. Such a function is of course not domed as the standard yield per recruit but monotonically decreases with increasing F.

The regulations operant on the offshore fleet are that the average weight of samples taken from the catch cannot be less than 13 g, which corresponds to 35 meats/pound. Placing a limitation on the average instead of stipulating a minimum means that the fishermen may take small animals and then balance them out 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 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 young scallops. The annual growth is divided into quarterly components of 10, 35, 35, and 20%. The annual effort is also partitioned into quarters at the rates of 15, 40, 30, and 15%. Selectivity for the projections follows the pattern of the fishery as revealed from the cohort analysis instead of that of the gear (Caddy 1972). The divergence between the two partial recruitments can be seen by comparing Figures 2a and 2b.

Results

The catch at age matrix (Table 4) does not extend back beyond 1972 because of the lack of reliable data. The growth rate falls off with age and animals above age 13 are combined into one age class. The results of the cohort analysis are given in Table 8 and show that the stock was in a very depressed state in 1983. The last apparent good recruitment was the 1977 year class; and subsequent recruitment, as defined by the 3 yr olds in Table 8, has been very poor. The fishing mortality has been highest on the 5 yr olds in recent years, and the high mortality of 4 yr olds in 1981 reflects the relaxation of regulations in the fishery for that year. It is interesting to note the difference between the selectivity of the gear (Caddy 1972) and fishing mortality as a function of age as determined by the cohort analysis. The difference in patterns is a result of the behaviour of the fishermen who direct their effort against the younger animals because they occur in higher densities. In tuning the VPA, F was regressed against effort as defined in terms of hours and crew-hours-meters (crhm) as given in Table 1. The F was unweighted and the fit virtually non existent ($r<0.3$) for both indices. The relatively good fit obtained in last year's assessment was with average F's weighted by numbers, a method recommended against by Mohn (1983). The estimated biomass was also used in tuning against the CPUE. The regression coefficient between biomass of ages 4 to 9 and CPUE as defined by crhm was 0.8 with the last two points falling just above the regression line. Forcing them down to the line would require larger starting F's for 1983 while the effort dropped from 1982 to 1983. The numbers at age estimated from the research survey (Tables 9 and 10) for 3+ also drop approximately by a factor of two. Selectivity and annual F's from the SVPA showed very similar results and did not represent a significant improvement. The log catch ratio residuals in Table 6 show the shift in the fishery on young animals from 1980/81 to 1981/82. Also, the high residuals observed for the youngest age reflect the uncertainty associated with this only weakly recruited, but highly contagious, age class. The numbers at age from the SVPA (when divided by 10) and the VPA do not agree well. The 4+ biomass from the cohort analysis and the recruitment from the year class are plotted in Figure 1 to display (the lack of) a stock-recruit relationship.

The research survey data (Table 10) show the depletion of the stock which has taken place in recent years. The survey results are not considered to be reliable for age 2 animals because of their low partial recruitment to the research gear and should not be considered as always an accurate predictor of the following year's recruitment. The biomass estimates from the research data are not corrected for efficiency of the gear. The 3+ biomass from the research surveys and the cohort analysis follow.

3+ Biomass estimates (10^3 t).

	1978	1979	1980	1981	1982	1983
Research	28.4	11.2	2.7	8.9	6.3	3.6
Cohort	279	264	318	279	125	70

The projections from the standing stock estimated from the research surveys are shown in Tables 11, 12, and 13. The first of these tables is a 2 yr projection under the current management requirement of 35 meats/pound. It has been assumed that the fishing pressure will be similar to 1983 and that recruitment will be as indicated from the research estimates of 2 yr olds in 1983, aged ahead to January 1984. The bulk of the annual recruitment takes place in the fourth quarter of the year (note the influx of smaller animals in October in Table 3). The projections show a catch for 1984 of about two-thirds of 1983 - a disastrous prognosis for the fishery. Because of the recent relatively poor recruitment there are enough large animals in the population such that effort on the smaller animals will not have to be curtailed. If subsequent recruitment is similar to that estimated for 1984 the biomass will only slightly recover.

The results in Table 12 are for a similar scenario except that the selectivity is changed so that no animals under 11.4 g are taken. This management strategy is being initiated by the U.S. as a consequence of the destruction of a relatively strong year class in the Great South Channel area in a few months while they were still well below optimum size (see Fig. 2). The catch after the first year is 15% smaller than that under the current regulations and the standing stock is 12% larger. The catch in the second year is approximately equal, but the biomass is 19% greater.

The projection in Table 13 is included to show the effects if an unexpectedly large recruitment were to take place this year. The level chosen for good recruitment was 400 million age 3 on January 1. The projection shows that only 85% of the young animals available could be harvested because of the requirement that the average catch be greater than 13 g. This good recruitment would not affect the fishery appreciably until 1985.

The yield per recruit analysis had an $F_{0.1}$ at 0.56 and F_{max} at 0.89 (Table 7). These levels are beneath the recently observed fishing mortalities which are on the order of unity on fully selected age classes. Figure 2a uses the partial recruitment derived from the SVPA which reflects the fishing habits of the fleet and suggests an optimum age of recruitment of approximately 6. On the other hand, Figure 2b uses the selectivity of the gear and is more intense on older animals than is Figure 2a. These show that at lower fishing mortalities the potential yield would be much higher. It would also be beneficial to delay age of capture to age 6. The relative amounts of ovary pre-spawning biomass in a stable age distribution at various fishing levels are:

F	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
B (%)	100	59	37	25	18	13	10	8	7	6	5

Conclusions

All indices show that the 5Ze stock is at or near an all-time low level. Fishing mortality on young animals approaches unity and has been at this level for years, resulting in a depleted stock. All relevant indices show that fishing mortality is at too intense a level for this stock. This is compounded by the failure of a strong year class to appear in the last few years. The data available suggest that 1984 will be an even worse year than 1983. The proposed change in regulations by the U.S. would not help in the short run. Also, data are not currently available to assess the impact of such a regime; for example, what will be the survivorship of the returned culls.

The separable VPA was found to be a useful adjunct to conventional cohort analysis. The main use in this study was in tuning the selectivity. Of course this method would be more valuable in cases where effort data are not available.

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Table 1a. Catch statistics (t meats) from Georges Bank (Subdiv. 5Ze) 1953-1983.

Year	USA	Canada	Total
1953	7392	136	7528
1954	7029	91	7120
1955	8299	136	8435
1956	7937	317	8254
1957	7846	771	8617
1958	6531	1179	7710
1959	8910	2378	11288
1960	10039	3470	13509
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	5019	6253
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	9761	11538
1977	4823	13089	17912
1978	5589	12189	17778
1979	6412	9207	15619
1980	5477	5221	10698
1981	8443	8013	16456
1982*	6100	4306	10406
1983**	3500	2748	6248

* Estimated value.
** It is estimated that 700 t of this estimate are east of the Canadian line.

Table 1b. Catch and effort data. Canadian catches (t of meats) in Subarea 5Z/5Ze. Total effort is derived from effort from Class 1 data.

Year	Catch	Days	Hrs 10^3	crhm 10^3	C/crhm
1972	4161	8188	114	13971	0.298
1973	4223	7946	115	13541	0.312
1974	6137	8207	121	14613	0.42
1975	7414	8221	119	15216	0.487
1976	9726	7633	113	15222	0.639
1977	13089	8689	97	13001	1.007
1978	12189	8547	111	15209	0.801
1979	9207	8826	126	17313	0.532
1980	5221	6848	96	13016	0.401
1981	8013	8443	105	15247	0.526
1982	4306	6115	80	10965	0.393
1983	2748	5492	73	9505	0.289

Table 2. Cumulative percent of catch by weight from port sampling, 1979-1983.

Grams	1979	1980	1981	1982	1983
2	0.0	0.0	0.0	0.0	0.0
4	0.0	0.4	0.5	0.0	0.3
6	1.0	4.2	4.4	1.0	2.3
8	5.0	13.1	17.5	5.5	7.1
10	12.2	24.3	38.0	14.1	13.6
12	21.2	34.7	55.5	25.5	22.0
14	29.7	43.6	66.7	36.7	30.8
16	37.2	51.0	73.7	46.7	39.1
18	43.8	57.4	78.3	54.8	46.4
20	49.3	62.8	81.8	61.6	52.5
22	54.5	67.7	84.6	67.7	58.1
24	59.5	71.7	86.8	72.7	63.2
26	64.0	75.3	88.7	77.1	67.4
28	67.9	78.7	90.3	80.8	71.1
30	71.8	81.6	91.5	84.0	74.3
32	75.5	84.1	92.5	86.5	77.1
34	78.7	86.3	93.6	88.9	79.7
36	81.8	88.2	94.4	90.7	81.9
38	84.5	89.9	95.2	92.2	83.8
40	86.9	91.4	95.8	93.4	85.6
42	89.0	92.5	96.3	94.4	87.2
44	90.8	93.5	96.8	95.3	88.7
46	92.7	94.5	97.2	96.0	90.0
48	94.1	95.4	97.7	96.4	91.3
50	95.2	96.1	98.0	96.8	92.4
52	96.1	96.7	98.4	97.1	93.2
54	97.0	97.3	98.7	97.5	94.1
56	97.6	97.8	99.0	97.7	95.1
58	98.0	98.2	99.2	97.9	95.6
60	98.5	98.6	99.3	98.2	96.2
62	98.8	98.9	99.5	98.3	96.8
64	99.0	99.1	99.7	98.5	97.3
66	99.2	99.3	99.8	98.7	98.0
68	99.4	99.5	99.8	98.8	98.5
70	99.5	99.6	99.9	99.0	98.8
72	99.6	99.7	99.9	99.1	99.0
74	99.7	99.8	99.9	99.2	99.2
76	99.8	99.8	100.0	99.4	99.5
78	99.9	99.9	100.0	99.7	99.6
80	99.9	99.9	100.0	99.8	99.7
82	100.0	99.9	100.0	99.9	99.8
84	100.0	99.9	100.0	99.9	99.8
86	100.0	100.0	100.0	99.9	99.9
88	100.0	100.0	100.0	100.0	99.9
90	100.0	100.0	100.0	100.0	99.9
92	100.0	100.0	100.0	100.0	99.9
94	100.0	100.0	100.0	100.0	99.9
96	100.0	100.0	100.0	100.0	100.0
98	100.0	100.0	100.0	100.0	100.0
**	100.0	100.0	100.0	100.0	100.0

Table 3. Cumulative percent by weight by month from port sampling in 1983.

Grams	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0
4	6.0	1.1	0.5	0.4	1.2	0.4	0.6	9.9	0.3	0.3
6	27.2	11.2	5.2	4.6	9.6	3.2	6.9	32.2	3.2	3.2
8	48.7	32.6	20.6	13.9	20.8	9.0	22.0	49.4	8.8	10.9
10	63.4	49.9	39.3	26.5	30.5	17.3	38.4	65.1	15.1	21.5
12	78.6	62.2	57.5	39.2	42.2	27.1	50.8	80.6	25.7	39.5
14	89.0	72.8	71.2	50.5	53.3	37.9	60.0	87.6	39.5	53.7
16	95.0	80.4	80.3	59.2	63.0	47.7	67.4	91.4	54.3	65.4
18	97.5	86.2	86.1	66.2	70.3	55.7	72.6	94.9	67.0	74.9
20	99.0	90.1	90.5	71.9	75.7	61.5	76.7	96.2	75.1	81.7
22	99.4	92.3	92.6	76.6	80.1	67.3	82.4	97.3	81.7	87.1
24	99.6	93.9	94.7	80.7	83.2	72.9	86.2	98.2	86.4	90.4
26	99.8	96.0	95.9	84.1	85.1	76.6	88.9	99.0	90.0	92.5
28	99.9	96.8	97.3	87.1	86.7	80.0	91.5	99.3	92.4	94.2
30	99.9	97.2	98.0	89.4	88.1	82.4	92.6	99.8	94.3	96.8
32	100.0	97.8	98.6	91.4	89.4	84.4	94.6	100.0	95.5	97.7
34	100.0	98.3	99.1	93.0	90.7	86.4	95.1	100.0	96.6	98.2
36	100.0	98.8	99.6	94.1	91.6	88.0	96.7	100.0	97.6	99.2
38	100.0	99.0	99.8	95.2	92.3	89.3	97.8	100.0	98.3	99.8
40	100.0	99.1	99.8	96.3	93.1	90.4	98.3	100.0	99.0	99.9
42	100.0	99.2	99.9	97.1	93.9	91.5	98.6	100.0	99.1	99.9
44	100.0	99.4	100.0	97.6	94.7	92.4	99.0	100.0	99.1	99.9
46	100.0	99.7	100.0	98.0	95.6	93.1	99.2	100.0	99.3	99.9
48	100.0	99.8	100.0	98.4	96.3	94.0	99.3	100.0	99.7	100.0
50	100.0	99.9	100.0	98.7	96.9	94.6	99.6	100.0	99.8	100.0
52	100.0	99.9	100.0	98.9	97.3	95.1	99.6	100.0	99.9	100.0
54	100.0	99.9	100.0	99.1	97.9	95.6	99.8	100.0	99.9	100.0
56	100.0	99.9	100.0	99.3	98.4	96.4	99.9	100.0	99.9	100.0
58	100.0	100.0	100.0	99.3	98.7	96.6	99.9	100.0	100.0	100.0
60	100.0	100.0	100.0	99.4	98.9	97.1	99.9	100.0	100.0	100.0
62	100.0	100.0	100.0	99.6	99.1	97.6	99.9	100.0	100.0	100.0
64	100.0	100.0	100.0	99.7	99.2	97.9	99.9	100.0	100.0	100.0
66	100.0	100.0	100.0	99.7	99.3	98.8	99.9	100.0	100.0	100.0
68	100.0	100.0	100.0	99.8	99.4	99.3	99.9	100.0	100.0	100.0
70	100.0	100.0	100.0	99.8	99.5	99.5	100.0	100.0	100.0	100.0
72	100.0	100.0	100.0	99.8	99.6	99.6	100.0	100.0	100.0	100.0
74	100.0	100.0	100.0	99.9	99.7	99.7	100.0	100.0	100.0	100.0
76	100.0	100.0	100.0	99.9	99.8	99.8	100.0	100.0	100.0	100.0
78	100.0	100.0	100.0	99.9	99.9	99.9	100.0	100.0	100.0	100.0
80	100.0	100.0	100.0	99.9	99.9	99.9	100.0	100.0	100.0	100.0

Table 4. CATCH AT AGE (10^6)

	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	59.8	38.0	6.8	11.2	36.0	3.2	7.3	1.3	7.5	15.5	0.8	2.3
4	376.0	269.3	327.4	563.7	341.0	401.9	290.2	212.4	277.7	689.7	143.8	74.7
5	55.3	55.4	139.5	149.5	290.2	557.3	386.6	237.4	167.3	316.1	177.9	78.0
6	14.8	8.0	26.1	26.0	50.5	61.9	150.3	90.6	54.0	49.8	56.9	29.1
7	5.5	3.0	4.9	6.2	13.1	13.4	42.1	43.3	21.9	15.5	20.1	11.2
8	1.3	1.0	1.5	1.7	5.2	4.0	13.2	22.5	9.7	7.1	8.1	5.1
9	0.6	0.5	0.8	0.7	2.7	1.9	5.1	11.4	4.6	3.4	3.4	2.7
10	0.2	0.3	0.3	0.2	1.4	1.0	2.5	6.2	2.4	1.9	1.7	1.6
11	0.1	0.1	0.1	0.1	0.7	0.4	1.1	4.0	1.4	1.0	0.9	0.9
12	0.0	0.0	0.0	0.0	0.3	0.1	0.4	1.6	0.5	0.4	0.3	0.4
13	0.1	0.1	0.2	0.1	3.8	0.9	3.8	15.0	7.6	6.2	4.4	6.0

Table 5. Smoothed growth characteristics. Height is in mm, weight of meat and ovary in grams and count is per 500 g.

AGE	HEIGHT	WEIGHT	COUNT	PRE-SPAWNING OVARY WEIGHT AS A FUNCTION OF HEIGHT
2	25.2	0.2	2286.	0.
2.25	36.1	0.7	751.9	0.2
2.5	46.	1.4	355.1	0.4
2.75	55.	2.4	204.2	0.8
3	63.2	3.8	132.9	1.3
3.25	70.6	5.3	94.2	1.9
3.5	77.4	7.	71.	2.6
3.75	83.6	8.9	56.	3.5
4	89.2	10.9	45.8	4.4
4.25	94.3	13.	38.6	5.4
4.5	98.9	15.	33.3	6.4
4.75	103.1	17.1	29.3	7.4
5	106.9	19.1	26.1	8.5
5.25	110.4	21.1	23.7	9.5
5.5	113.6	23.1	21.7	10.5
5.75	116.5	24.9	20.1	11.5
6	119.1	26.7	18.7	12.5
6.25	121.5	28.4	17.6	13.4
6.5	123.7	30.	16.7	14.3
6.75	125.6	31.5	15.9	15.2
7	127.4	32.9	15.2	16.
7.25	129.	34.2	14.6	16.7
7.5	130.5	35.4	14.1	17.4
7.75	131.9	36.6	13.7	18.1
8	133.1	37.6	13.3	18.7
8.25	134.2	38.6	13.	19.3
8.5	135.2	39.5	12.7	19.8
8.75	136.2	40.3	12.4	20.3
9	137.	41.1	12.2	20.7

Table 6. Results of separable VPA.

ITERATION	SSQ
1	339.5482
5	57.2462
10	27.9314
15	25.3193
20	24.8154
25	24.7528
30	24.7798

APPROX.COEFF. VARIATION OF CATCH DATA = 45.4%

YEAR	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
F(I)	1.3701	.7730	.7283	.5407	.7730	.5355	.9511	1.2048	1.1409	1.3926	1.1378	1.0000

AGE	3	4	5	6	7	8	9	10
S(J)	.0126	.6198	1.0000	.5810	.3355	.1975	.1413	.1000

LOG CATCH RATIO RESIDUALS

	72/73	73/74	74/75	75/76	76/77	77/78	78/79	79/80	80/81	81/82	82/83	
3/ 4	1.4877	1.3674	-1.0844	.5137	.8561	-.4224	.3117	-1.9319	-.9254	1.0324	-1.2015	.0034
4/ 5	-.6957	.3870	.3731	.8696	-.9844	.3878	-.0312	-.3476	-.5372	.5553	.0316	.0083
5/ 6	-.2636	-.5675	.1976	.3007	-.0315	.6986	.1995	-.1971	-.2360	-.2243	.1347	.0112
6/ 7	-.1711	-.5839	.1848	.1030	-.0137	-.0053	.3474	.1584	.2257	-.5624	.3317	.0145
7/ 8	.1806	-.2206	-.0118	-.2766	-.0075	-.2239	-.0487	.4908	.3604	-.5367	.3078	.0139
8/ 9	-.2304	-.4125	-.0830	-.6630	.0865	-.2008	-.2349	.9049	.6117	-.1100	.3459	.0143
9/10	-.2707	.0572	.4363	-.8439	.0936	-.2361	-.5452	.9225	.5020	-.1524	.0513	.0147
	.0368	.0271	.0127	.0035	-.0010	-.0020	-.0013	-.0001	.0012	.0019	.0014	.0803

Table 6 (Contd...)

RESULTS FROM SEPARABLE ANALYSIS

POPULATION NUMBERS

AGE	YEAR 1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
3	7107.	8099.	8211.	9199.	10074.	8226.	8076.	6166.	8110.	4661.	1040.	1911.	-I
4	3856.	6321.	7257.	7362.	8267.	9027.	7394.	7221.	5496.	7234.	4144.	927.	1707.
5	1748.	1493.	3543.	4181.	4765.	4633.	5861.	3710.	3096.	2452.	2761.	1852.	452.
6	452.	402.	623.	1547.	2203.	1990.	2454.	2049.	1006.	895.	551.	801.	617.
7	150.	185.	232.	370.	1023.	1272.	1319.	1278.	921.	469.	361.	257.	405.
8	67.	85.	129.	165.	279.	714.	962.	868.	772.	568.	266.	223.	167.
9	43.	46.	66.	101.	134.	217.	581.	721.	619.	557.	390.	192.	165.
10	17.	32.	37.	54.	85.	109.	182.	460.	551.	477.	414.	301.	151.
11	???	14.	27.	31.	46.	71.	93.	150.	369.	444.	375.	335.	246.

?? NOTE CATCH NUMBERS REDUCED BY 10**1 ??

?? ALL POPULATION NUMBERS AND BIOMASSES SHOULD BE RAISED BY THIS FACTOR ??

FISHING MORTALITY

AGE	YEAR 1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
3	.017	.010	.009	.007	.010	.007	.012	.015	.014	.017	.014	.013
4	.849	.479	.451	.335	.479	.332	.589	.747	.707	.863	.705	.620
5	1.370	.773	.728	.541	.773	.536	.951	1.205	1.141	1.393	1.138	1.000
6	.796	.449	.423	.314	.449	.311	.553	.700	.663	.809	.661	.581
7	.460	.259	.244	.181	.259	.180	.319	.404	.383	.467	.382	.335
8	.271	.153	.144	.107	.153	.106	.188	.238	.225	.275	.225	.197
9	.194	.109	.103	.076	.109	.076	.134	.170	.161	.197	.161	.141
10	.137	.077	.073	.054	.077	.054	.095	.120	.114	.139	.114	.100
WEIGHTED F	.582	.329	.310	.230	.329	.228	.404	.512	.485	.592	.484	.425

Table 7. Results of yield per recruit analysis.

	FISHING MORTALITY	CATCH (NUMBER)	YIELD (KG)	AVG. WEIGHT (KG)	YIELD PER UNIT EFFORT	WGT. F
	0.080	0.16022	3.518	22.0	43.969	0.031
	0.160	0.28836	6.148	21.3	38.427	0.063
	0.240	0.39107	8.099	20.7	33.744	0.097
	0.320	0.47360	9.528	20.1	29.775	0.132
	0.400	0.54010	10.560	19.6	26.400	0.167
	0.480	0.59384	11.289	19.0	23.519	0.202
	0.560	0.63742	11.790	18.5	21.053	0.238
F0.1---	0.562	0.63839	11.800	18.5	20.999	0.238
	0.640	0.67290	12.117	18.0	18.933	0.273
	0.720	0.70189	12.316	17.5	17.105	0.307
	0.800	0.72568	12.418	17.1	15.523	0.341
	0.880	0.74532	12.450	16.7	14.148	0.374
FMAX---	0.887	0.74685	12.450	16.7	14.037	0.376
	0.960	0.76160	12.431	16.3	12.949	0.406
	1.040	0.77518	12.375	16.0	11.899	0.437
	1.120	0.78657	12.294	15.6	10.977	0.467
	1.200	0.79619	12.196	15.3	10.163	0.496
	1.280	0.80437	12.087	15.0	9.443	0.525
	1.360	0.81137	11.972	14.8	8.803	0.553
	1.440	0.81740	11.855	14.5	8.233	0.580
	1.520	0.82264	11.737	14.3	7.722	0.606
	1.600	0.82722	11.621	14.0	7.263	0.631

Table 8. Results of cohort analysis.

POPULATION NUMBERS ($\times 10^6$)

	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
3	662	780	1259	1452	1213	798	609	866	1129	337	159	120
4	547	542	670	1133	1303	1063	719	544	782	1014	291	143
5	109	137	234	295	489	855	579	375	290	443	262	126
6	62	46	72	79	124	166	243	157	113	103	101	67
7	18	42	34	40	47	64	91	77	55	51	46	37
8	5	11	35	27	30	30	46	43	29	29	32	23
9	9	3	9	30	22	22	23	29	17	17	20	21
10	1	7	2	8	27	18	18	16	15	11	12	15
11	0	0	6	2	7	23	15	14	9	11	8	9
12	0	0	0	6	2	5	20	13	9	7	9	7
13	0	0	0	0	5	1	5	18	10	8	6	8
	1413	1570	2322	3070	3268	3046	2370	2151	2458	2033	945	576

FISHING MORTALITY

	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
3	0.100	0.053	0.006	0.008	0.032	0.004	0.013	0.002	0.007	0.049	0.005	0.020
4	1.281	0.739	0.722	0.741	0.322	0.507	0.552	0.529	0.467	1.255	0.734	0.786
5	0.757	0.552	0.984	0.763	0.979	1.157	1.209	1.095	0.932	1.383	1.256	1.033
6	0.291	0.199	0.483	0.422	0.556	0.497	1.049	0.938	0.695	0.706	0.902	0.601
7	0.381	0.078	0.163	0.177	0.347	0.247	0.663	0.891	0.536	0.381	0.611	0.383
8	0.334	0.099	0.047	0.068	0.201	0.153	0.363	0.812	0.441	0.294	0.312	0.271
9	0.080	0.182	0.098	0.025	0.133	0.094	0.258	0.543	0.330	0.239	0.197	0.145
10	0.494	0.038	0.121	0.033	0.057	0.060	0.156	0.512	0.182	0.193	0.168	0.120
11	0.235	0.490	0.014	0.041	0.123	0.018	0.083	0.344	0.183	0.101	0.123	0.113
12	0.206	0.121	0.186	0.005	0.185	0.024	0.022	0.141	0.063	0.062	0.038	0.057
13	0.416	0.256	0.283	0.226	0.286	0.266	0.409	0.520	0.328	0.399	0.348	0.293
	0.416	0.255	0.282	0.228	0.293	0.275	0.434	0.575	0.379	0.460	0.427	0.348

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

Stratum	Sampling dates	Age (yr)									N	s.d.
		2+	3+	4+	5+	6+	7+	8+	9+	10+		
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
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
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
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
Total weighted average	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		

Table 10. Indices of abundance of scallop age-classes determined by contour analysis; number at age (10^{-6}).

Sampling dates	Age						
	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		

Table 11. Stock projection results. Management strategy is 35 meats/pound.

```
      SCAP4
 STARTING NUMBERS NR
 WEIGHTS AT AGE WR
 SELECTIVITY AT AGE SGIN
 RECRUITMENT TO YOUNGEST AGE RR
 FISHING INTENSITY ER
 BLENDING (Y OR N)
Y
```

CATCH (NUMBERS 10^6)

	1984	1984	1984	1984	1985	1985	1985	1985
3	1	6	11	22	1	7	12	24
4	7	21	15	6	11	33	23	10
5	6	15	11	4	3	7	5	2
6	1	3	2	1	1	3	3	1
7	0	1	1	3	2	4	3	6
	15	46	39	37	19	54	46	43

YIELD (T)

	1984	1984	1984	1984	1985	1985	1985	1985
3	3	23	43	85	4	25	46	92
4	80	232	160	67	125	360	248	104
5	107	292	201	85	49	136	93	39
6	23	67	53	25	30	91	72	34
7	7	23	20	98	81	121	103	183
	220	638	476	360	289	733	562	453

POPULATION (NUMBERS 10^6)

	1984	1984	1984	1984	1985	1985	1985	1985	1986
3	185	179	169	154	200	194	183	166	200
4	82	73	50	35	128	113	78	53	138
5	59	52	36	25	28	24	17	11	43
6	15	14	11	8	20	18	14	11	9
7	6	5	5	4	11	10	9	7	16
	347	324	270	225	386	360	300	250	406

Table 11 (Contd...)

BIOMASS DISTRIBUTION (o/o)

	1984	1984	1984	1984	1985	1985	1985	1985	1986
3	21.2	22.6	27.7	32.7	21.3	22.7	27.5	32.0	19.7
4	27.1	26.4	23.7	21.1	39.1	37.9	33.5	29.5	39.0
5	34.2	33.2	29.7	26.5	14.8	14.3	12.6	11.1	21.1
6	11.8	11.9	12.3	12.6	14.8	14.9	15.2	15.3	6.3
7	5.8	5.9	6.6	7.2	10.0	10.2	11.2	12.1	13.9
	3318.0	3019.0	2314.0	1787.0	3562.0	3255.0	2528.0	1977.0	3865.0

FISHING SUMMARY

	1984	1984	1984	1984	1985	1985	1985	1985
MAX. BLEND AGE	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
RATE ON SMALLS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
MEAN WT. CATCH	14.76	15.85	15.95	15.00	15.96	15.67	16.07	15.78
CATCH (MILL.)	14.94	45.95	39.05	36.97	18.59	53.82	45.60	42.74
CATCH (MT)	220.48	728.15	622.73	554.47	296.69	843.41	732.73	674.28
CUM. CATCH (MT)	220.48	948.63	1571.36	2125.83	296.69	1140.10	1872.83	2547.11

MORE RUNS WITH THIS DATA
N

Table 12. Stock projection results. Management strategy is 11.4 grams minimum meat weight.

```
     SCAP4
 STARTING NUMBERS NR
 WEIGHTS AT AGE WR
 SELECTIVITY AT AGE SUS
 RECRUITMENT TO YOUNGEST AGE RF
 FISHING INTENSITY ER
 BLENDING (Y OR N)
N
```

CATCH (NUMBERS 10^6)

	1984	1984	1984	1984	1985	1985	1985	1985
3	0	0	0	0	0	0	0	0
4	6	22	15	6	13	44	30	13
5	6	15	11	4	3	7	5	2
6	1	3	2	1	1	3	3	1
7	0	1	1	3	2	4	3	6
	13	40	28	15	19	58	41	22

YIELD (T)

	1984	1984	1984	1984	1985	1985	1985	1985
3	0	0	0	0	0	0	0	0
4	68	236	162	68	138	479	329	139
5	107	292	201	85	50	138	95	40
6	23	67	53	25	30	91	72	34
7	7	23	20	98	81	121	103	183
	205	619	436	276	300	828	598	395

POPULATION (NUMBERS 10^6)

	1984	1984	1984	1984	1985	1985	1985	1985	1986
3	185	180	176	171	200	195	190	186	200
4	82	74	51	35	167	151	103	71	181
5	59	52	36	25	28	25	17	12	57
6	15	14	11	8	20	18	14	11	9
7	6	5	5	4	11	10	9	7	16
	347	326	278	244	426	399	334	287	463

Table 12 (Contd...)

BIOMASS DISTRIBUTION (o/o)

	1984	1984	1984	1984	1985	1985	1985	1985	1986
3	21.2	22.6	28.4	35.0	19.0	20.2	25.4	31.4	16.5
4	27.1	26.7	23.7	20.5	45.6	44.7	39.7	34.5	42.8
5	34.2	33.0	29.3	25.4	13.4	12.8	11.4	9.9	23.6
6	11.8	11.9	12.1	12.1	13.2	13.2	13.5	13.5	5.4
7	5.8	5.9	6.5	6.9	8.9	9.1	10.0	10.7	11.7
	3318.0	3034.0	2349.0	1860.0	4001.0	3672.0	2841.0	2246.0	4605.0

FISHING SUMMARY

	1984	1984	1984	1984	1985	1985	1985	1985
MAX. BLEND AGE	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75
RATE ON SMALLS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
MEAN WT. CATCH	15.86	17.42	19.55	24.36	16.26	16.36	18.59	23.70
CATCH (MILL.)	12.91	40.18	27.99	14.63	18.91	58.23	40.96	21.65
CATCH (T)	204.83	700.06	547.11	356.40	307.56	952.38	761.32	512.97
CUM. CATCH (T)	204.83	904.89	1452.00	1808.40	307.56	1259.94	2021.26	2534.23

MORE RUNS WITH THIS DATA

Table 13. Stock projection results. Management strategy is 35 meats/pound with recruitment pulse in 1984.

```
   SCAP4
STARTING NUMBERS NR
WEIGHTS AT AGE WR
SELECTIVITY AT AGE SGIN
RECRUITMENT TO YOUNGEST AGE 4↑RR
FISHING INTENSITY 4↑ER
BLENDING (Y OR N)
Y
```

CATCH (NUMBERS 10^6)

	1984	1984	1984	1984
3	2	13	24	42
4	7	21	15	6
5	6	15	11	4
6	1	3	2	1
7	0	1	1	3
	16	53	52	56

YIELD (T)

	1984	1984	1984	1984
3	7	50	93	159
4	80	232	160	67
5	107	292	201	85
6	23	67	53	25
7	7	23	20	98
	225	665	526	434

POPULATION (NUMBERS 10^6)

	1984	1984	1984	1984	1985
3	400	388	366	332	200
4	82	73	50	35	283
5	59	52	36	25	28
6	15	14	11	8	20
7	6	5	5	4	11
	562	533	467	404	541

BIOMASS DISTRIBUTION (°/°)

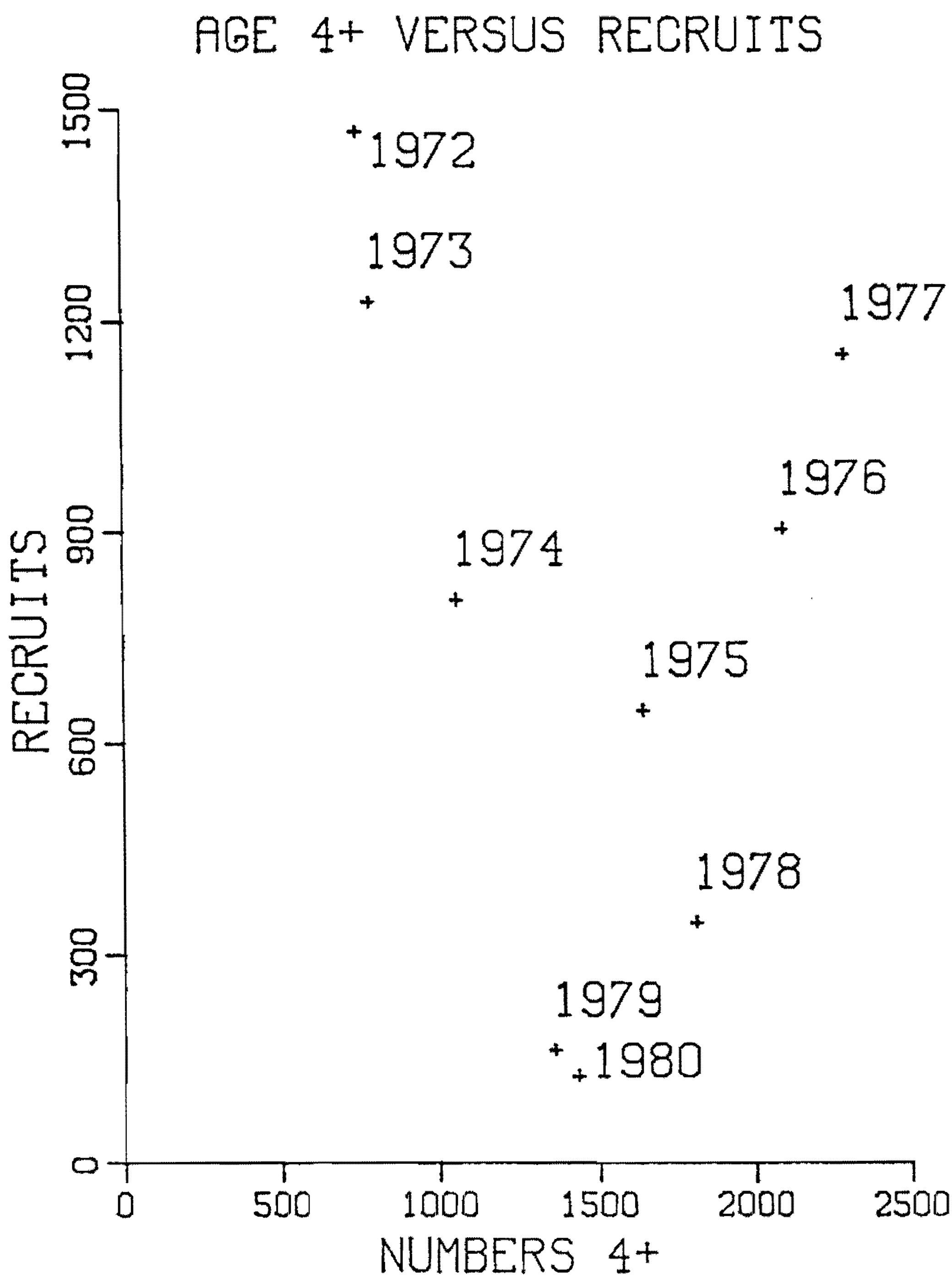
	1984	1984	1984	1984	1985
3	36.8	38.7	45.4	51.2	14.5
4	21.7	20.9	17.9	15.3	58.7
5	27.4	26.3	22.5	19.2	10.0
6	9.5	9.5	9.3	9.1	10.0
7	4.6	4.7	5.0	5.2	6.8
	4136.0	3812.0	3061.0	2466.0	5254.0

FISHING SUMMARY

	1984	1984	1984	1984
MAX. BLEND AGE	4.00	4.00	4.00	4.00
RATE ON SMALLS	1.00	1.00	1.00	0.85
MEAN WT. CATCH	14.03	14.44	13.70	12.90
CATCH (MILL.)	16.00	53.04	52.18	56.41
CATCH (T)	224.51	765.75	714.67	727.50
CUM. CATCH (T)	224.51	990.26	1704.93	2432.43

```
MORE RUNS WITH THIS DATA
N
```

Figure 1. Stock recruitment relationship.



YIELD PER RECRUIT AND YIELD ISOPLETHS
(Grams Per Individual)

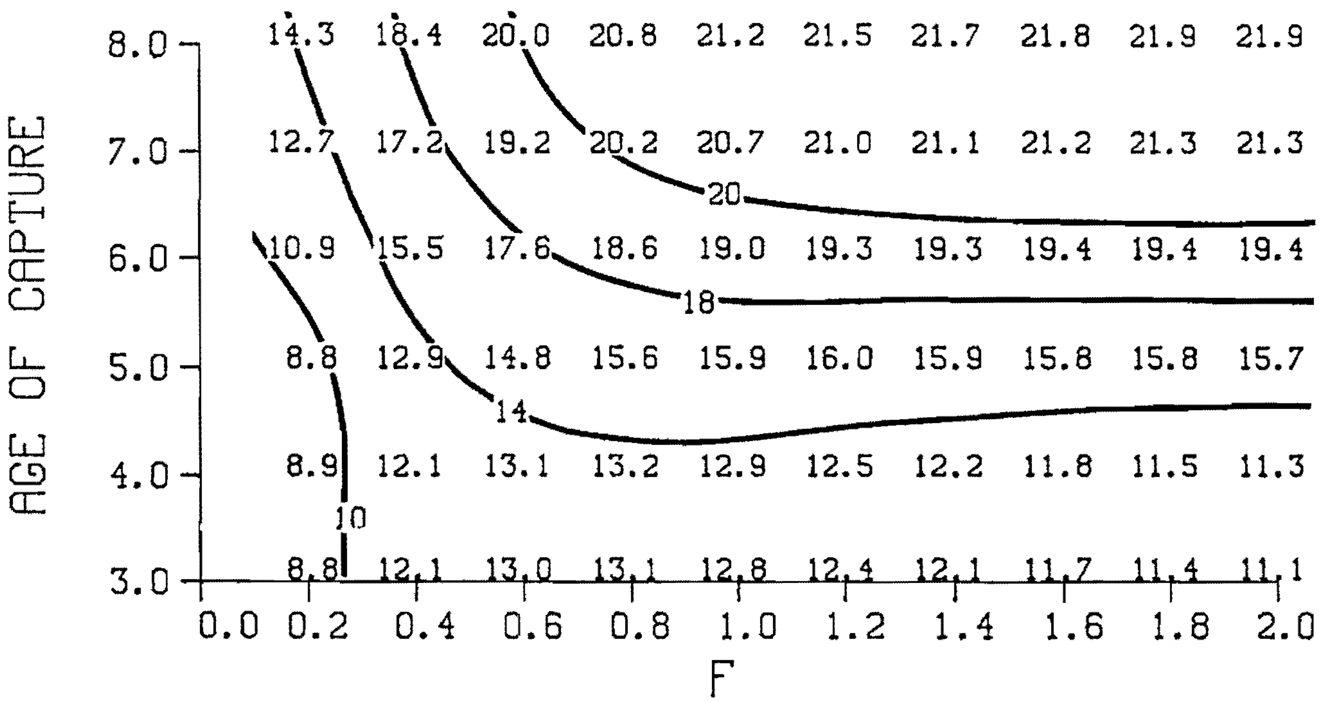


FIG. 2A YIELD PER RECRUIT, SELECTIVITY FROM SVPA

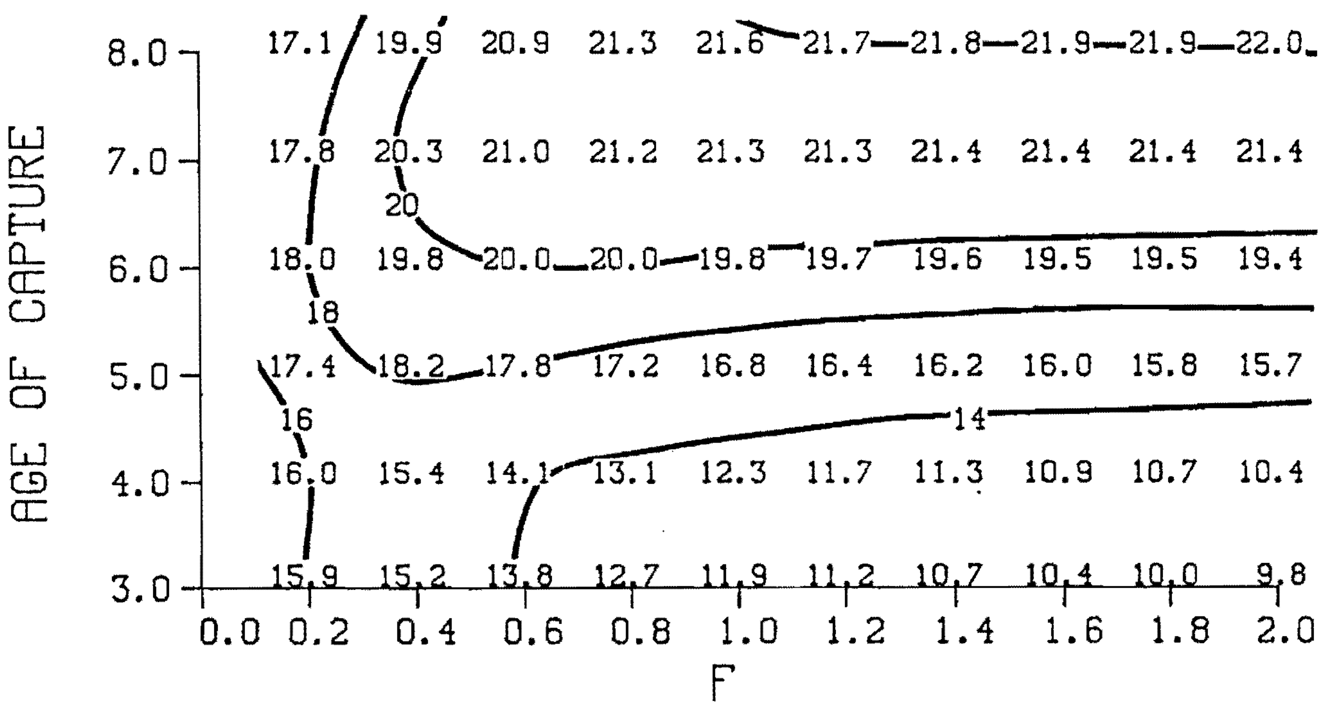


FIG. 2B YIELD PER RECRUIT, SELECTIVITY OF GEAR