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ASSESSMENT OF GEORGES BANK (ICNAF SUBDIVISION 5Ze) SCALLOP STOCK 1972-76 INCORPORATED

BY

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ABSTRACT

Cohort analysis of Canadian and U.S. size composition data for 1972-76 was attempted after conversion to equivalent age using existing von Bertalanffy growth parameters and length-weight relationships. Analysis under two different sets of assumptions as to availability at age gives similar results: Peak mortality at ages 4-5 of $F \simeq 0.6$ declines with age to $F \simeq 0.2$-0.3 for ages 6+, reflecting the fishing strategy of the Canadian fleet; namely, to look for high-density patches of age 3-4 recruits in preference to lower densities of older scallops.

Landing trends in the fishery over the last decade are explicable in terms of yield-per-recruit considerations and recruitment variation. A steady rise in landings from 4,000 MT in 1970-72 to 7,484 MT in 1975 parallels a steady increase in mean age at first capture from 3 to 4, partly as a result of Canadian regulations on average landed meat count. This is of the same order of magnitude as predicted from yield-per-recruit considerations. Increases in landings since 1975 are apparently a consequence of above-average recruitment in 1972; and it is predicted that landings will remain above average in 1978, judging from recent resource surveys.

With long-term average recruitment estimated at 707×10^6, the predicted sustained yield is approximately 8,286 MT with current fishing strategy. Theoretically, under Beverton and Holt knife-edge recruitment assumptions, sustained yield with fishing mortality of 0.6 will be increased by raising age at first capture to 7, to around 14,776 MT at long-term levels of recruitment. An alternative estimate of potential yield is 9,693 MT with 1974-75 levels of effort, plus recent mortality vector modified to postpone availability until age 4.

INTRODUCTION

Over the last 20 years, Georges Bank scallop fishery has experienced two periods of high landings; the first from 1959-63 when combined U.S. and Canadian landings reached a record high of around 15,000 MT; dropping in 1965-74 to 5,000-6,000 MT before rising again in 1975-76 to approximately 8,000 to 10,000 MT respectively. Projected Canadian landings in 1977 are 12,285 MT, meats; and with a reported American catch approximating 4,000 MT, the total catch projection for 1977 is in the vicinity of 16,200 MT (Table 1).

Both peaks in landings are attributable to years of exceptionally good recruitment, in 1959-60 and 1971-72 respectively, and both were preceeded by years (1958 and 1975) in which the nominal catches and efforts (Fig. 1) as well as the average meat count for the greater part of the catch (around 30-35 meats/lb.), were almost identical. Superficially at least, the fishery has returned to a situation similar to that prevailing prior to 1958, with the exception that Canadian domestic regulations are now in effect, limiting landed meat count, fleet size, and more recently, maximum catch per trip and allowable catch per four-month period. Regulations introduced in the Canadian fishery with dates are in Table 2.

To a large extent, the increase in landings from 1973-75 must be a consequence of the higher yield-per-recruit resulting from the decrease in average meat count of the Canadian fleet from between 40 and 50 meats/lb. in the early 1970's, to meat counts in the 30's over the last three years.

This relationship is illustrated diagrammatically in Figure 1, where the catch-effort points before 1958, and in subsequent years when meat counts have been 25-35/lb. appear to fall along the upper eye-fitted curve, whereas the period 1970-73 when meat counts were much higher (40-50/lb.) seems to represent a separate equilibrium situation at a lower sustained yield. This has been represented by a second line drawn parallel to the first, but a catch level roughly 30% lower. This is similar to the decline forecast from yield-per-recruit considerations for a drop in age at first capture from 4.5 to 3.0 years ($F = 0.6$).

MATERIAL AND METHODS

Since 1972, data on meat size landed in Canada from ICNAF Div. 5Ze have been collected regularly at the principal ports of landing. Comparable U.S. data (Woods Hole, pers. comm.) in the form of shell size frequencies, were converted to equivalent meat sizes, using the annual relationship for Georges Bank scallops given in Haynes (1966). The two data series were adjusted to give a catch by weight category equivalent to the reported total annual catch (Table 3). Since no obvious modes can be detected in the resulting size frequencies, combined Canadian and U.S. data were simply partitioned into age groups, using weight intervals derived from von Bertalanffy growth parameters given in Brown et al. (1972); namely,

$$W = 46.6 \text{ g}$$
$$t_o = 1.5$$
$$K = 0.38$$
$$EXP = 3.0$$

The resulting estimates of age frequency (Table 4) were then used as the basis for cohort analysis (Pope, 1971): the convention being adopted that age is equivalent to the number of non-marginal winter rings on the shell.

Sensitivity of Cohort Analysis to Initial Mortality Estimates

The rather approximate method required to arrive at the age matrix in Table 4 evidently permits errors in conversion from size to age, both due to the different initial form of the U.S. and Canadian data (that is, due to variations in length-weight relationship; Haynes, 1966), and due to variance in size-at-age. These errors are likely to be accentuated with age, making choice of the initial value of F for the oldest age group used as input to Pope's (1971) cohort analysis, as well as the number of age groups included, somewhat problematical. The short data series also means that choice of final F's and partial selection factors may have a significant influence on population size and mortality estimation.

Trials were carried out with Pope's method on data in Table 4, with or without the 13+ age group. This last group, incidentally, contains a mixture of year classes, and more individuals than the immediately preceeding group. Retaining the 13+ category in the cohort analysis almost eliminates the effect of the initial F used, because of the erratic relationship between number of individuals in the 12 and 13+ age group, and therefore further cohort analysis was carried out omitting this group from the age matrix. Undoubtedly, this underestimates back-calculation of the number of recruits, but appeared to have relatively little influence on mortality at age for the earlier (2-5) ring groups (Fig. 2). Further discussion will be confined to conclusions based on analysis of the reduced (2-12 ring) age matrix.

Two approaches to cohort analysis were used, both assuming $M = 0.1$, and constant fishing mortality at full exploitation (fishing effort in 1972-76, averaged 9,569 days, and varied by only 3% from this mean value).

Analysis of the catch age matrix (Table 5) was carried out with uniform input F's both for last year in the fishery, and as input values for mortality at age in 1976. Mean values for mortality at age resulting from this procedure were then used as inputs for F at age in 1976, and the procedure repeated. The fishing mortality at age for various input F's with this procedure is illustrated in Figure 2A.

This procedure shows good convergence of F estimates for the more important younger age classes (2-6 ring scallops) for all initial values of F used (F_{12} = 0.1-1.0), but progressive divergence for later age groups. Mean F at age for all years combined rose from low levels for 2-3 ring scallops to a peak around 0.53 for F_{4-5} before declining to a trough between F = 0.2 → 0.3 for ring groups 6-11.

We have estimates of the mortality rate for 1958-63 (Posgay, 1972) of 0.71, corresponding to a mean annual effort of 11,087 days fished. Nominal effort for 1972-76 was 15% lower, and assuming no change in catchability, this suggests a fully exploited F of approximately 0.6. Estimates of selectivity at age (Table 6) are available from gear observation experiments (Caddy, 1972), and suggest that partial recruitment occurs over a wide range of ages, increasing rapidly from negligible retention at age 9. However, these experiments were carried out with a small dredge (2.4 m wide) using 1-2 links per ring and short tows (15-20 min.) as compared with tows to saturation of 0.5+ hours with commercial gear (4 m wide) using 3-5 links per ring, which may be expected to retain a larger proportion of small scallops.

Judging from catch at age (Table 5), relatively few age 2 scallops are retained in the cull, but by age 4 retention is almost complete.

The second analysis was therefore run with the lower set of selection factors in Table 6 applied to input F's for the last year in the fishery (Fig. 2B), which represents a first estimate of the selectivity of commercial gear. This second approach is more dependent on parameter inputs than the earlier analysis, but may be expected to be more accurate. The results of this second analysis are used in the following sections.

The outputs from this second analysis (Tables 8a & 8b) are broadly similar to the first (Tables 7a & 7b); however, peak F is somewhat larger and occurs with 5-year-old scallops rather than 4 year olds.

Estimation of Mortality at Age

An explanation for the apparent decline in F values after age 5 requires some explanation. Three obvious mechanisms may be postulated as underlying this phenomenon:

1. Errors in conversion from size to age. This may affect some age-class catches but is a less satisfactory explanation for the decline in F immediately after ages 4-5, since this is close to the inflexion in the von Bertalanffy growth curve when less overlap between sizes of adjacent groups is likely.

2. Natural mortality rate decreases subsequent to ages 4-5. What biological evidence there is available supports a relatively low, if anything, decreasing natural mortality rate with age, at least up to some maximum age, variously estimated at 10 to 16 years. when the possibility of shell disease and other senescents - related phenomena may lead to increase in M. Predation on commercial sizes seems limited, although early pre-recruits (0-1 ring scallops) may be found in stomach contents of bottom fish. No sign of debilitating parasitism or disease have been reported that would suggest that M = 0.1 is an overestimate for most of the commercial size range.

3. The strategy of fishing described for the Canadian fleet by Caddy (1975) is relevant here: new recruits (3-4 ring scallops) occur locally at high densities ($4\text{-}5/m^2$) consisting predominantly of 1 or 2 age classes (Caddy, 1971). Concentration of effort onto these patches results in local stock depletion so that older (5+) age groups tend to occur at densities $< 0.5/m^2$ dispersed over relatively larger areas of the Bank. With introduction of a Canadian size limit of 60 meats/lb. on the minimum landed meat count in 1972, and further Canadian decreases in allowable count to 40 meats/lb. in 1975, there has been a tendency by the Canadian fleet to adjust the effort spent respectively on more densely populated recruits, and on more sparsely populated areas of older scallops, so as to maintain the catch below the legal meat count. Evidently this type of "aimed fishing" for an essentially sedentary species contravenes the usual dynamic pool assumptions and has been predicted (Gales and Caddy, 1975) from independent evidence to result in a decline in F subsequent to the "target" ages, similar to that obtained by the cohort analysis described here. With fishing strategy aimes at maintaining a high CPUE, Gales' and Caddy's model predicts for the Georges Bank scallop population that in the absence of size limits, the peak fishing mortality rate will occur at a progressively earlier age with increasing effort levels before declining for older age groups. The possibility that fishing mortality might again increase on the older age groups if effort allocation per unit area is determined by local abundance was also predicted by the model. This could be explained if there is a tendency for the remnants of an earlier year class to be spatially coincident with an abundant new year class attracting heavy fishing effort. This has not been demonstrated for the Georges Bank stock, but may be in accord with the apparent 9-year cycles of production noted for certain inshore grounds (Caddy, in press).

Estimation of Fishing Mortality at Age

In conclusion, the peak fishing mortality at ages 4-5 and the subsequent decline in F with age is consistent with the observed fishing strategy; namely, to concentrate on high density (newly recruited patches) of scallops, to the maximum extent compatible with maintaining scallop meat count below the regulated maximum. Since older scallops tend to be dispersed over low-density areas of the bank, while younger scallops occur locally in high density patches maximum F's would be expected for younger scallops. The final selection of input F_{12} of 0.5 is consistent with the expectation that peak F value occurs for the first fully vulnerable age groups (ages 4+5) at around F = 0.6. Higher values for input F are not in accord with this expectation (Fig. 2).

To estimate the relative size of annual recruitment for 1975-78 from the 1977 resource survey (Table 9), it was assumed that the relative abundance of ages 2-5 scallops determined from the 1977 stratified random resource survey accurately reflects relative year class strength on the grounds. Further, it was assumed that the mean values for F_n for 1974-75 will apply over the period 1975-78 in calculating forwards and backwards the numbers at age 3 in 1978, 1976, and 1975.

$$\text{Thus, } {}_{78}N_3 = {}_{77}N_2 \exp(-0.1-F_2)$$
$${}_{76}N_3 = {}_{77}N_4 \exp(F_3 + 0.1)$$
$${}_{75}N_3 = {}_{77}N_5 \exp(F_3 + F_4 + 0.2)$$

Effects of Recent Changes in Size Limit on Fishing Mortality

A major factor affecting the mean landed size of scallops since 1972 has been the Canadian domestic regulations of landed meat count. These changes are also reflected in the yearly mortality at age vector derived from cohort analysis (Fig. 3). Although cohort analysis appears to show marked changes in annual F vector from year to year (which may be due either to errors in the short data series used or to changes in fishing strategy), a steady movement in peak F can be observed from age 3 in 1972 to age 4 in 1973 and 1974, while in 1975 peak F occurred at age 5. This would appear to parallel change in Canadian meat size regulations over the same time period.

Assessment of Recent Changes in Recruitment

The cohort analysis permits some first estimates of the relative order of magnitude or recruitment over the period 1972-76. It is believed that age 3 catches provides the best estimate of recruited year-class strength, since 2-ring scallops are only fractionally retained by the gear. They also occur in highly contagious unfished concentrations, and in recent years have been very lightly exploited compared with the early 1970's. Cohort analysis suggests that age 3 abundance increased between 1972-75 from 570×10^6 to $1,346 \times 10^6$, before declining to 681×10^6 in 1976 (Table 8).

Both cohort analysis and resource survey reveal an increase in level of recruitment (age 3) from 1972-75, but while cohort analysis suggests that recruitment falls off in 1976, the resource survey appears to reveal a continued increase in level of recruitment into 1976, before declining to a still relatively high level in 1977, followed by a projected decline in abundance of age 3 in 1978.

Yield-Per-Recruit Considerations and Fishing Strategy

Mean age at first harvest as judged from the cohort analysis has increased from around age 3 in the early 1970's to approximately age 4 in 1975; and the general upward trend in landings (69%) from 1972-75 (Fig. 1) are in accord with the predicted increase in yield-per-recruit of 37% with age at first capture increased (Table 10). It is quite apparent from Table 10, however, that a reduction in effort at the present size at first capture, or increase in size at first capture at current levels of F, or optimally, a combination of the two strategies will further improve yield. Considering fishing mortality rates of $F < 0.6$ as approximating the recent level of F exerted in this fishery, Table 10 predicts that an increase in yield-per-recruit of up to 8% is possible through effort reduction with existing size limit. Assuming no influence of density-dependent recruitment at the mean level of age 3 abundance for 1972-76 suggested by cohort analysis of 829.1×10^6 and with present yield estimates (Table 11A), this provides an upper estimate of sustained yield at current effort levels of 9,717 MT. Using long-term estimates of average recruitment (1944-74) resulting from simulation (Caddy, 1975) of 689.4×10^6 age 3 scallops per annum, this reduces our best estimate of long-term recruitment to 707×10^6 per annum; equivalent to a sustained yield of 828.6 MT with current yield estimates (Table 11A), close to the long-term average catch.

The analysis of Brown et al. (1972) given in Table 10 assumes knife-edge recruitment and full availability subsequently. An assessment of the potential yield-per-recruit with the average mortality vector derived from cohort analysis for 1974-75 was attempted in Table 11. This suggests that yield-per-recruit with the 1974-75 fishing strategy is not much higher than predicted under knife-edge recruitment at age 3 ($F = 0.6$). This may be partly a consequence of the recruitment at age 2 assumed in Table 11 as opposed to age 3 in Table 10, but confirms that the present fishing strategy with relatively high mortality at age 3 provides a relatively low yield-per-recruit. Recognizing that the mortality vector used is likely to vary dependent on age composition of the stock, the predicted mean meat count of 28.1/lb. is very close to that reported through fishery officer's meat counts in 1976 (28.2/lb.) and biological meat sampling which suggests the mean meat count in 1976 was 30.6/lb.

While recognizing that the regulation setting an upper limit to average meat count in the catch depends on population age structure, and cannot be directly converted into changes in fishing mortality at age (or vice versa), the effects of several changes to the current mortality vector are presented in Table 11. This predicts that a decrease in mean meat count in the landings to 22 meats/lb. as a result of increasing age at first capture to 4 years, will provide a 17% increase in yield-per-recruit. In contrast, a 25% decrease in effort with the current mortality vector will increase yield-per-recruit by just 2%. Thus, an approach based on truncation of the 1974-75 F vector with first capture at age 4 is predicted to yield 9,693 MT, with a mean meat count of 22 meats/lb. in the whole catch. (This will necessitate an average meat count regulation in the vicinity of 25 meats/lb.)

This is in agreement with Brown et al. (1972) and stresses that with recruitment at age 3 and peak F at 0.6, yield-per-recruit can be best increased through management of mean age at first harvest rather than through effort control. However, it should be also recognized that, although effort regulation has a lesser effect on yield, an increase in effort will reduce catch per-unit-effort and hence affect the economics of the fishery.

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TABLE 1

CATCH STATISTICS FOR CANADIAN AND U.S. SEA SCALLOP FLEETS FISHING GEORGES BANK, 1944-76, INCLUSIVE

	LANDINGS OF SCALLOP MEATS (metric tons)			EFFORT IN DAYS ON THE GROUNDS		
Year	U.S.	Canada	Total	U.S.	Canada	Total
						-/- (Can.units)
1944	1,814	-	1,814	2,223	-	2,039
1945	1,769	-	1,769	2,391	-	2,194
1946	4,036	-	4,036	4,934	-	4,527
1947	4,853	-	4,853	6,434	-	5,903
1948	4,580	-	4,580	7,613	-	6,984
1949	5,306	-	5,306	8,428	-	7,732
1950	5,442	-	5,442	7,349	-	6,742
1951	5,714	91	5,805	7,626	(123)	7,119
1952	5,488	91	5,579	7,742	(128)	7,231
1953	7,392	136	7,528	10,031	(185)	9,388
1954	7,029	91	7,120	9,343	(121)	8,693
1955	8,299	136	8,435	11,619	(190)	10,850
1956	7,937	317	8,254	12,246	(490)	11,725
1957	7,846	771	8,617	10,500	1,197	10,830
1958	6,531	1,179	7,710	8,775	1,598	9,648
1959	8,481	1,950	10,431	8,556	2,098	9,948
1960	9,932	3,401	13,333	8,039	2,601	9,976
1961	10,703	4,580	15,283	8,671	3,147	11,102
1962	9,932	5,669	15,601	8,959	4,642	12,861
1963	7,982	5,941	13,923	7,718	5,905	12,986
1964	6.122	5,986	12,108	6,662	6,723	12,835
1965	1,497	4,580	6,077	2,156	5,749	7,727
1966	998	4,853	5,851	1,001	5,524	6,442
1967	1,315	5,034	6,349	1,870	6,785	8,501
1968	1,179	4,807	5,986	1,938	6,972	8,750
1969	1,769	4,354	6,123	2,800	6,684	9,253
1970	1,497	4,036	5,533	2,706	7,615	10,098
1971	1,406	3,946	5,352	2,577	7,688	10,052
1972	797	4,128	4,925	1,691	8,264	9,815
1973	777	4,218	4,995	1,701	8,082	9,643
1974	880	5,987	6,867	1,263	8,185	9,344
1975	839	7,484	8,323	1,028	8,531	9,474
1976	*1,767	*9,682	*11,449	*1,560	* 7,535	*8,966
1977	+<4,000	*12,276	+16,276			

* Preliminary figures

\+ See text

-/- Can. unit (f) = 1.09 U.S. unit (f) (Caddy 1975)

Table 2. Canadian Domestic Regulations on the Offshore Georges Bank Fishery

DATE OF INTRODUCTION	REGULATION
June 1973	Maximum of 60 meats/lb in the landed catch*
May 1974	Maximum of 50 meats/lb in the landed catch*
June 1975	Maximum of 45 meats/lb in the landed catch*
May 1976	Maximum of 40 meats/lb in the landed catch*
March 15, 1977	Maximum catch of 30,000 lbs (13.608 m.t.) of shucked scallops taken per trip of 12 days maximum duration dock to dock
March 15, 1977	Maximum landed weight per boat over a 4-month period of 180,000 lbs (81.648 m.t.). Date of landing determines 4-month period towards which the particular catch is counted (agreement in effect to end of next 4-month period on March 15, 1978.
*FOOTNOTE	Mean meat count per trip is based on no less than 9 independent representative samples per catch. A tolerance of 10% is allowed over the maximum allowable count.

Table 3. Scallop landings by 2 gm intervals (U.S. + Canada Separate and Combined) for Georges Bank (ICNAF area 5Ze) (Nos x 10^{-6})

	U.S.	Can.	Comb	U.S.	Can.	Comb	U.S.	Can.	Comb	U.S.	Can.	Comb	U.S.	Can.	Comb
0.0 - 1.9	-			-	0.06	0.06	-	0.02	0.02	-					
2.0 - 3.9	-	14.5	14.5	-	6.3	6.3	-	2.7	2.7	0.03	0.9	0.9			
4.0 - 5.9	0.4	81.4	81.8	0.2	39.2	39.4	0.2	18.3	18.5	0.07	29.5	29.6	0.04	5.7	5.7
6.0 - 7.9	1.6	81.8	83.4	2.2	71.8	74.0	1.4	60.5	61.9	0.1	106.7	106.8	0.4	30.2	30.6
8.0 - 9.9	1.9	48.5	50.4	3.4	63.8	67.2	2.3	97.4	99.7	0.5	137.1	137.6	6.6	92.3	98.9
10.0 - 11.9	2.8	34.4	37.2	6.7	48.7	55.4	4.6	79.1	83.7	1.7	73.1	74.8	14.6	110.4	125.0
12.0 - 13.9	2.1	24.2	26.3	5.2	36.2	41.4	3.9	49.6	53.5	2.7	55.0	57.7	20.6	82.2	102.8
14.0 - 15.9	1.7	14.0	15.7	3.6	24.7	28.3	4.1	38.4	42.5	4.1	46.6	50.7	16.4	61.0	77.4
16.0 - 17.9	1.4	11.3	12.7	2.5	14.6	17.1	3.9	30.1	34.0	6.1	34.8	40.9	6.6	45.7	52.3
18.0 - 19.9	1.6	9.0	10.6	2.1	8.7	10.8	3.6	22.2	25.8	4.4	23.9	28.3	1.7	31.8	33.5
20.0 - 21.9	1.9	8.3	10.2	2.1	5.9	8.0	2.7	15.7	18.4	3.7	19.3	23.0	0.9	25.5	26.4
22.0 - 23.9	1.9	6.9	8.8	2.1	5.9	8.0	2.1	13.3	15.4	3.2	15.7	18.9	0.6	31.4	32.0
24.0 - 25.9	1.8	7.9	9.7	2.1	4.1	6.2	1.5	9.7	11.2	2.5	10.7	13.2	0.4	14.9	15.3
26.0 - 27.9	1.2	7.0	8.2	2.1	4.6	6.7	1.3	7.7	9.0	1.8	9.3	11.1	0.5	15.6	16.1
28.0 - 29.9	1.0	6.1	7.1	2.1	3.8	5.9	1.1	4.8	5.9	1.6	5.3	6.9	0.5	8.3	8.8
30.0 - 31.9	1.1	3.9	5.0	1.6	3.1	4.7	1.1	2.6	3.7	1.3	5.0	6.3	0.7	7.3	8.0
32.0 - 33.9	1.0	3.2	4.2	1.4	2.8	4.2	1.0	2.8	3.8	1.2	4.0	5.2	0.7	6.8	7.5
34.0 - 35.9	0.9	3.4	3.3	1.1	2.0	3.1	0.8	2.0	2.8	0.9	2.4	3.3	1.0	4.5	5.5
36.0 - 37.9	0.9	0.6	1.5	1.0	1.8	2.8	0.8	1.5	2.3	0.8	1.7	2.5	1.0	5.4	6.4
38.0 - 39.9	0.7	1.1	1.8	0.7	1.8	2.5	0.5	1.8	2.3	0.6	1.8	2.4	1.1	4.1	5.2
40.0 - 41.9	0.7	1.2	1.9	0.6	1.0	1.6	0.5	1.0	1.5	0.5	1.3	1.8	1.0	3.2	4.2
42.0 - 43.9	0.5	0.8	1.3	0.4	1.2	1.6	0.4	0.6	1.0	0.4	0.6	1.0	0.5	3.1	3.6
44.0 - 45.9	0.5	0.4	0.9	0.4	1.8	1.2	0.5	0.2	0.7	0.4	0.5	0.9	0.5	2.1	2.6
46.0 - 47.9	0.4	0.1	0.5	0.2	0.3	0.5	0.2	0.3	0.5	0.2	0.6	0.8	0.3	2.9	3.2
48.0 - 49.9	0.4		0.4	0.2	0.2	0.4	0.1	0.1	0.2	0.2	0.1	0.3	0.2	2.2	2.4
50.0+	2.8	0.2	3.0	2.0	0.3	0.3	0.2	0.6	0.8	0.1	0.3	0.4	0.3	9.6	9.9

Table 4. Estimated number of scallops at age (U.S. and Canada) landed annually from Georges Bank (ICNAF area 5Ze) (nos. landed x 10^6).

	1972			1973			1974			1975			1976		
Age	U.S.	Can.	Total	U.S.	Can.	Total	U.S.	Can.	Total	U.S.	Can.	Total	U.S.	Can.	Total
2	0	12.2	12.2	0	5.4	5.4	0	2.3	2.3	.02	.8	.8	0	0	0
3	5.0	226.8	231.8	8.5	195.3	203.8	5.8	210.3	216.1	1.2	302.7	303.9	11.2	169.0	180.2
4	7.2	73.3	80.5	15.9	107.3	123.2	15.6	169.6	185.2	14.2	187.2	201.4	54.4	267.0	321.4
5	6.5	28.4	34.9	7.6	21.1	28.7	8.7	52.8	61.5	12.1	61.4	73.5	3.1	91.9	95.0
6	2.8	15.6	18.4	5.0	9.8	14.8	2.9	15.4	18.3	4.2	16.7	20.9	1.2	28.5	29.7
7	2.7	8.4	11.1	3.7	7.0	10.7	2.6	6.4	9.0	3.0	10.3	13.3	2.1	16.6	18.7
8	1.3	1.4	2.7	1.5	2.7	4.2	1.1	2.5	3.6	1.2	2.7	3.9	1.7	7.8	9.5
9	.8	1.5	2.3	.8	1.8	2.6	.6	1.6	2.2	.6	1.9	2.5	1.3	4.4	5.7
10	.5	.8	1.3	.4	.8	1.2	.4	.6	1.0	.4	.8	1.2	.5	2.4	2.9
11	.3	.3	.6	.2	.7	.9	.2	.4	.6	.2	.2	.4	.3	1.8	2.1
12	.2	.1	.3	.2	.3	.5	.2	.2	.4	.2	.4	.6	.2	.6	.8
13+	3.8	.6	4.4	2.6	1.3	3.9	.7	1.0	1.7	.7	1.2	1.9	1.1	16.1	17.2
Total			400.5			399.9			501.9			624.3			683.2

Table 5. Estimated age composition of Canada + U.S. catches 1972-76 (x 10^{-3}).

Age	72	73	74	75	76
2	12178	5390	2288	780	0
3	231793	203738	216032	303978	180250
4	80487	123216	185246	201472	321497
5	34902	28688	61456	73534	95082
6	18412	14870	18274	20892	29648
7	11117	10708	9063	13290	18743
8	2754	4169	3667	3875	9466
9	2285	2564	2208	2558	5706
10	1228	1232	947	1160	2920
11	626	874	593	401	2110
12	340	428	359	530	873

Table 6. Partial selection factors (offshore scallop dredge

	Age										
	2	3	4	5	6	7	8	9	10	11	12
1) Experimental dredge (Caddy, 1972):	.03	.20	.40	.72	.79	.89	.95	.97	1.00	1.00	1.00
2) Deduced from catch curve:	.01	.65	.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 7a. Matrix of estimated population (x 10^{-6}) (Hypothesis I, input F = 0.5)

	Year				
Age	72	73	74	75	76
2	751.3	887.6	1322.3	642.0	0
3	582.4	668.3	798.0	1194.2	580.2
4	217.2	306.5	410.9	516.6	791.4
5	95.9	120.0	160.1	195.5	275.8
6	52.1	53.6	81.3	86.4	107.0
7	27.6	29.6	34.4	56.1	58.3
8	9.2	14.4	16.6	22.5	38.2
9	5.5	5.7	9.0	11.6	16.6
10	2.8	2.8	2.7	6.1	8.0
11	1.2	1.4	1.3	1.6	4.4
12	0.4	0.5	0.4	0.6	1.0

Table 7b. Matrix of estimated fishing mortalities

	Year				
Age	72	73	74	75	76
2	.017	.006	.002	.001	.007
3	.542	.386	.335	.311	.394
4	.494	.549	.642	.528	.553
5	.482	.290	.517	.503	.448
6	.464	.345	.270	.293	.343
7	.552	.478	.325	.286	.410
8	.377	.364	.264	.200	.301
9	.581	.636	.297	.265	.445
10	.608	.633	.451	.224	.479
11	.770	.075	.635	.310	.498
12	.500	.500	.500	.500	.500

Table 8a. Matrix of estimated populations (x 10^{-6}) (Hypothesis II, input F = 0.5)

Age	Year 72	73	74	75	76
2	709.4	856.7	1490.1	753.2	0
3	569.8	630.3	770.1	1346.1	680.8
4	197.8	295.1	376.5	491.3	928.8
5	93.7	102.4	149.8	164.5	252.9
6	51.7	51.6	65.4	77.1	78.9
7	29.4	29.3	32.6	41.8	49.9
8	9.2	16.0	16.3	20.8	25.2
9	5.5	5.7	10.5	11.3	15.2
10	2.8	2.8	2.7	7.4	7.8
11	1.2	1.4	1.3	1.6	5.6
12	0.4	0.5	0.4	0.6	1.0

Table 8b. Matrix of estimated fishing mortalities (Hypothesis II, input F = 0.5)

Age	Year 72	73	74	75	76	$\bar{F}_{74-75}$
2	.018	.007	.002	.001	.005	.002
3	.558	.415	.349	.271	.325	.310
4	.558	.578	.728	.564	.450	.646
5	.498	.349	.565	.635	.500	.600
6	.469	.361	.348	.336	.500	.342
7	.507	.485	.346	.407	.500	.377
8	.377	.320	.270	.217	.500	.244
9	.581	.636	.249	.273	.500	.261
10	.608	.633	.451	.180	.500	.316
11	.770	1.075	.635	.311	.500	.473
12	.500	.500	.500	.500	.500	

Table 9. Relative size of recruitment by cohort analysis and resource survey (age 3).

	RESOURCE SURVEY				COHORT ANALYSIS	
Age	# Individual in SR Survey (%)	Virtual Pop. (age 3) (Arbitrary Units)	Abundance Ratio, age 3 (1975 = 1.0)	Year	Estimated # at age 3 (cohort analysis) x 10^{-6}	Abundance Ratio (age 3) (1975 = 1.0)
0	3					
1	7					
2	1646(12.8)	1345	0.319	1978		
3	5236(40.8)	5236	1.241	1977		
4	3777(29.4)	6395	1.515	1976	680.7	0.505
5	1277(9.9)	4221	1.000	1975	1346.1	1.000
6	477(3.7)	2872	0.680	1974	770.1	0.572
7	282(2.2)	2507	0.594	1973	630.3	0.468
8	140(1.1)	1823	0.432	1972	569.8	0.423

Table 10. Kg Yield/recruit (10,000) at age 3 (M = 0.1) (After Brown et al. 1972)

Mean Age at First Harvest	F 0.3	0.4	0.5	0.6	0.7	0.8
3.0	143	134	125	116*	109	103
3.5	158	153	146	139	133	128
4.0	171	169	164	159**	155	151
4.5	181	162	179	176	173	170
5.0	188	191	191	189	188	186
5.5	192	197	199	199	198	197
6.0	194	201	204	205	205	205
6.5	194	202	206	208	209	210
7.0	192	201	206	209	211	212
7.5	189	199	204	208	210	212
8.0	185	195	201	205	207	209
8.5	180	190	197	201	204	206
9.0	175	185	191	196	199	201
9.5	169	179	185	190	193	195
10.0	163	173	179	184	187	189
10.5	158	166	173	177	180	183
11.0	150	160	166	170	173	176
11.5	144	153	159	163	166	169
12.0	138	147	153	157	160	162

*Early 1970's

** 1975

Table 11. Projected yields/1,000 recruits (age 2) with 5 different fishing strategies.

		A			B			C			D			E		
		Fished with F_{74-75}			No fishing age 2: $F_3 - F_3/2$			No fishing age 2 + 3			Fishing at F = 0.75 (F_{74-75})			No fishing age 2: F = 0.75 (F_{74-75}) F_3 = 0.5 F'		
Age	$\bar{W}k$	$\bar{F}_{74-75}$	Catch	Survive	F	Catch	Survive	F	Catch	Survive	F	Catch	Survive	F	Catch	Survive
2	2.0	.002	1.9	903.0	-	-	904.8	-	-	904.8	.002	1.9	903.0	-	-	904.8
3	7.3	.310	229.6	599.3	.155	123.7	700.5	-	-	818.0	.233	179.0	647.2	.116	94.3	728.4
4	14.7	.646	272.7	284.1	.646	318.7	332.0	.646	372.0	387.5	.485	237.6	360.4	.485	267.3	405.6
5	22.1	.600	122.5	141.0	.600	142.8	164.4	.600	167.0	192.2	.450	124.6	207.7	.450	140.2	233.7
6	28.5	.342	39.0	90.6	.342	45.3	105.4	.342	53.1	123.4	.257	44.7	144.9	.257	50.4	163.0
7	33.6	.377	27.0	55.9	.377	31.5	65.2	.377	36.9	76.3	.283	33.9	98.2	.283	38.3	111.1
8	37.3	.244	11.4	39.0	.244	13.4	46.1	.244	15.7	53.9	.183	15.6	73.8	.183	17.7	83.6
9	40.1	.261	8.3	26.5	.261	10.1	32.1	.261	11.6	36.9	.196	12.4	54.3	.196	14.1	61.7
10	42.1	.316	6.7	17.2	.316	8.3	21.1	.316	9.3	23.7	.237	10.9	38.6	.237	12.3	43.5
11	43.5	.473	6.1	9.6	.473	7.6	11.8	.473	8.3	13.0	.355	10.8	24.1	.355	12.3	27.3

	A	B	C	D	E
Weight catch (kg):	11.72	12.68	13.71	11.98	12.71
Average Meat count:	28.1/lb	25.1/lb	22.3/lb	25.4/lb	23.1/lb
% increase in yield v. 1974-75 strategy:		8%	16.8%	2.2%	7.2%

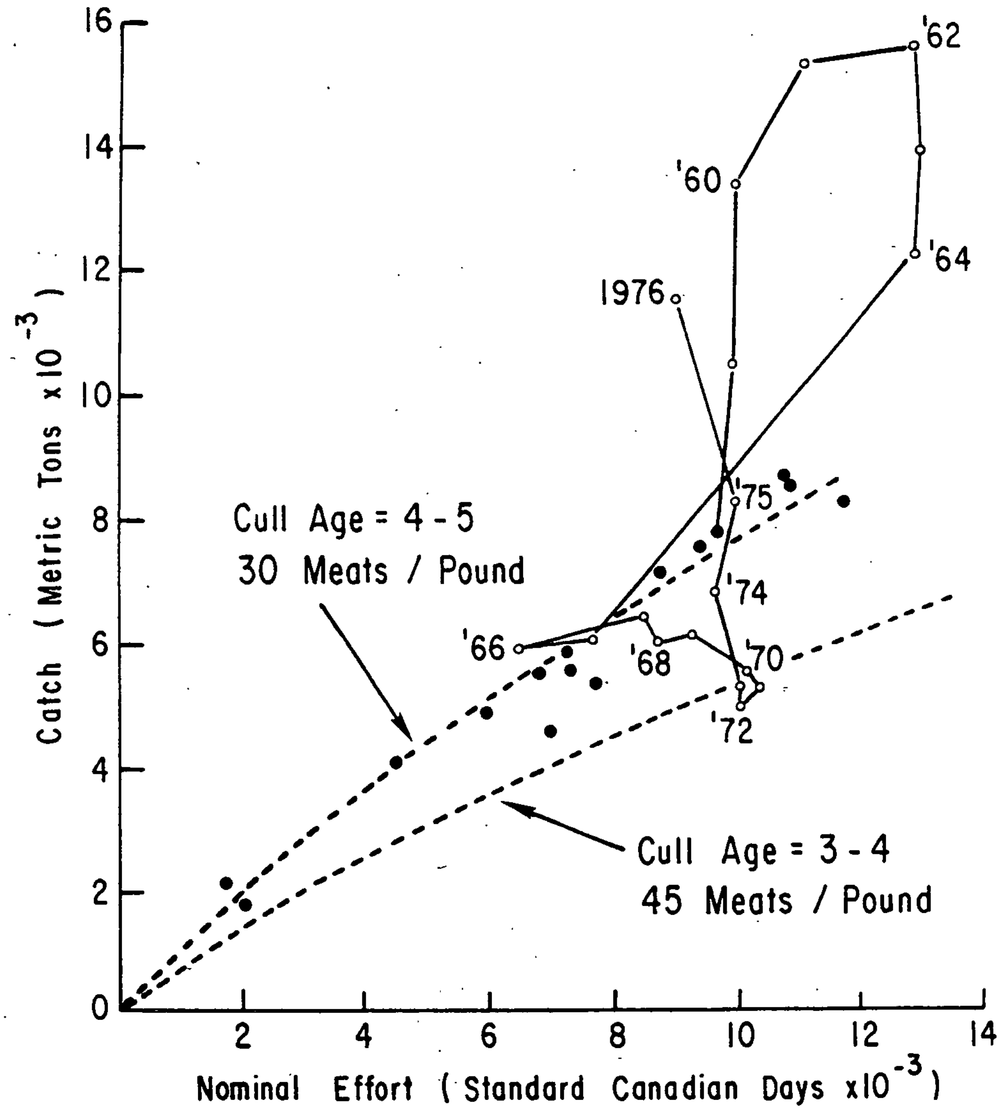

Fig. 1. Relationship between catch (US+CAN) and nominal effort.

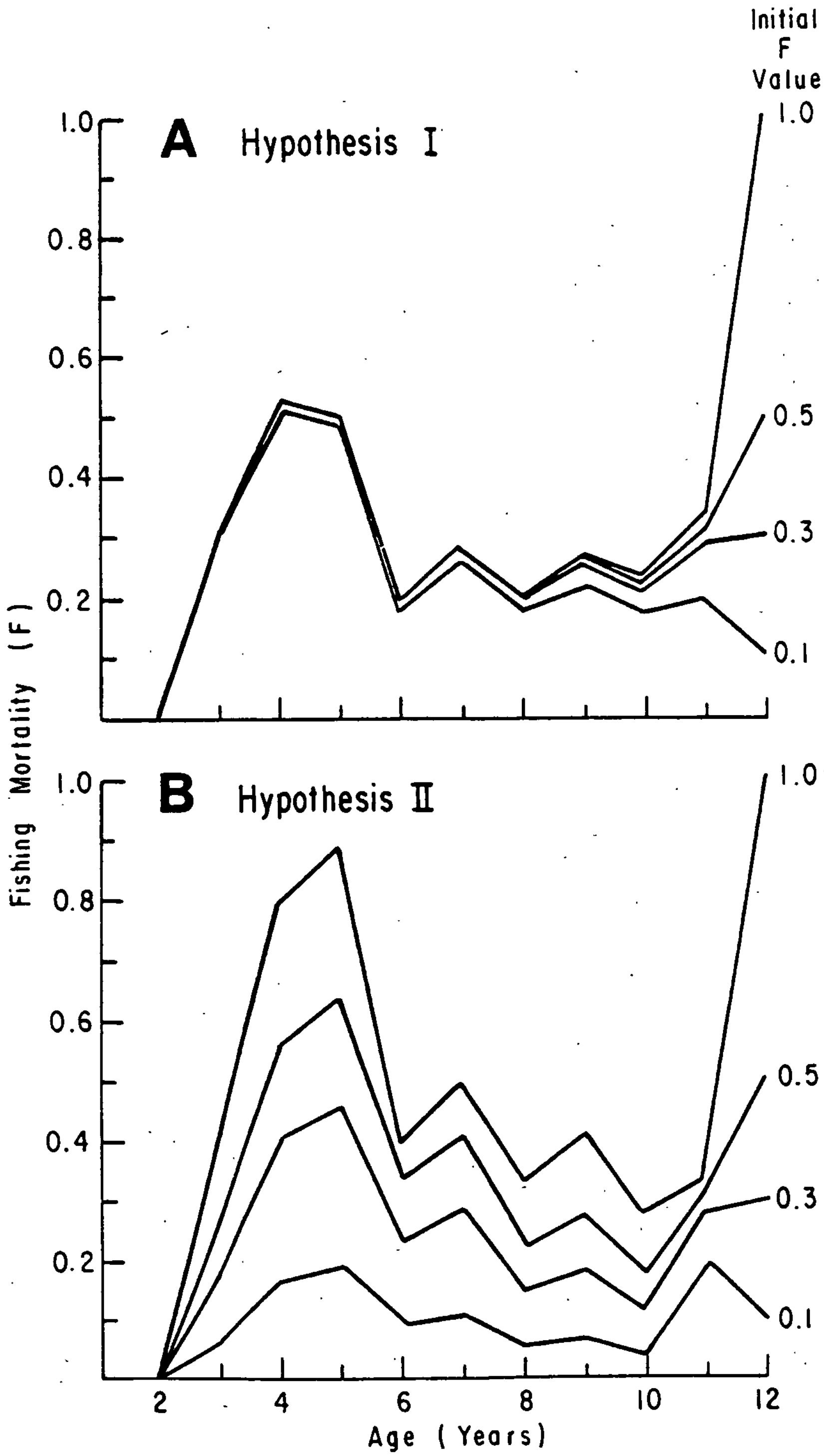

Fig. 2. F-vectors for different values of input F in cohort analysis.

A - constant F.

B - variable F with age.

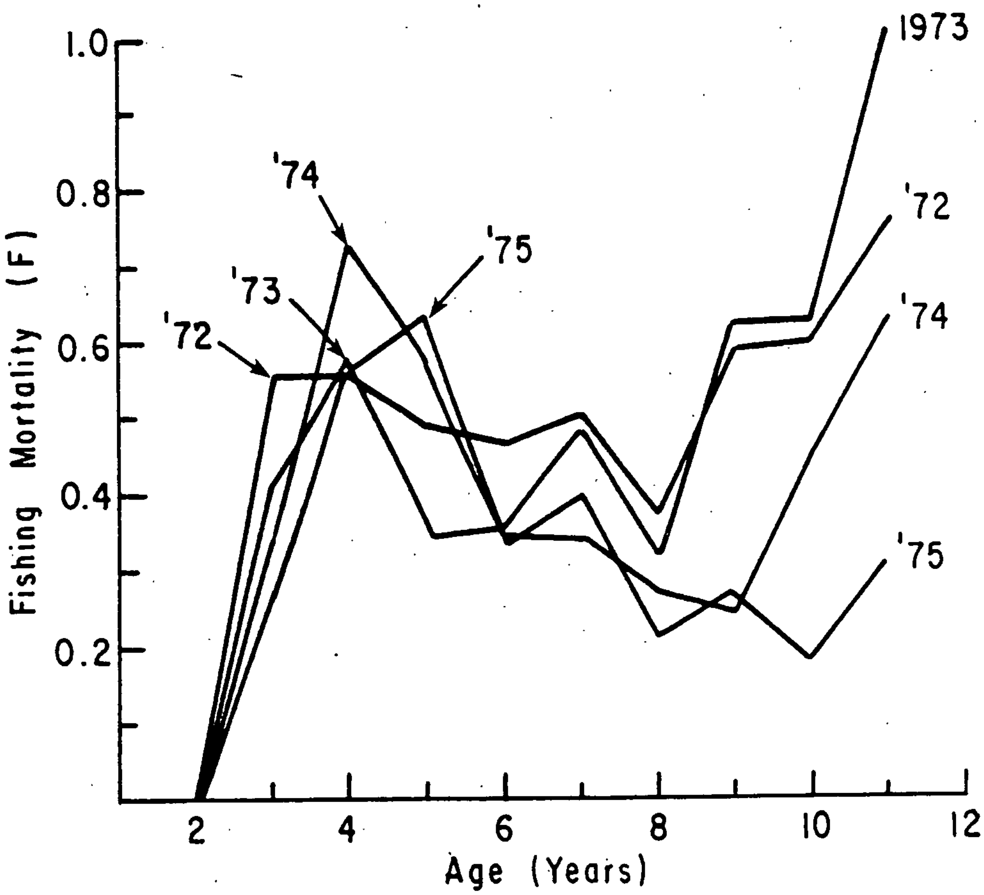

Fig. 3. F-vectors from cohort analysis for different years with an input F of 0.5 .