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CAFSAC Res. Doc. 78/21

A multispecies simulation for the management of the  
southern Gulf of St. Lawrence cod stock

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Introduction

Cod (*Gadus morhua* L.) have been fished in the Gulf of St. Lawrence for more than a century during the ice-free summer months. Prior to the mid-forties the fishery was primarily by baited hook or jigger, and it was not until otter trawls were first introduced by Canadian fishermen that any significant changes took place in this fishery. The introduction of foreign otter trawls in the mid-fifties had a major effect on the fishery.

This cod stock, delineated in three tagging studies has been shown to occupy only ICNAF Division 4T and Subdivision 4Vn (McCracken 1959; Martin and Kohler 1964; Kohler MS 1975). There are two main areas where the fish appear to congregate and where the fishery on them is concentrated: first, the Magdalen Shallows between the Magdalen Islands and the Gaspé-Bay Chaleur; and second, the edge of the Laurentian Channel off the northeast coast of Cape Breton. The annual migratory pattern is from the Magdalen Shallows in the fall to the area of dense winter concentration in the so-called Sydney Bight. In May, following "break-up", they again migrate to spawn in the highly productive shallows of the southern Gulf (Palohiemo and Kohler 1968). This stock supports two fisheries, the summer fishery in the southern Gulf of St. Lawrence and the winter fishery off Cape Breton. Traditionally, increases in fishing effort have been associated with increased foreign interest in the winter fishery.

Between 1936 and 1953 the average catch from this fishery was approximately 33,000 M.T., a figure which fishermen at the time thought was optimal for a sustained fishery. The fishery would probably have continued at this level if it had not been for the onset of the epizootic disease (Sinderman 1958).

The epizootic disease had catastrophic effects on the Gulf of St. Lawrence ecosystem by virtually decimating the entire pelagic fish community. From a scientific point of view it was rather opportune since this violent perturbation allowed for a wide fluctuation in the stock-dependent variables controlling the cod production system. Thus, as in good experimental design variations in the independent variables became great enough that significant changes in the dependent variables could be noted.

Furthermore, the "die-off" of the pelagic biomass facilitate the growth of cod Kohler (1964), improved recruitment (Lett and Doubleday 1976) and generally led to an increase in the exploitable cod biomass. During the period between 1954 and 1957 there were four year-classes of aged 3 fish in excess of  $10^8$ . These sort of changes have also been noted in the North Sea where the increase in cod biomass is attributable to the decline in the pelagic biomass (Jones MS 1976).

In the late fifties the pelagic biomass in the Gulf of St. Lawrence began to recover with two large, 1958-59, herring (*Clupea harengus harengus*) year-classes being produced in conjunction with the 1959 year-class of mackerel. As the pelagic biomass increased the 3+ cod biomass declined rapidly from a high of 560,000 M.T. in 1955 to a low of 156,000 M.T. by 1967; in part due to a substantial increase in fishing effort. During this period the average catch of the Southern Gulf stock was 78,000 M.T. with the peak catch in 1956 being 110,000 M.T.

However, a preliminary analysis of the data would show that the management of this stock is only partially reliant on the manipulation of fishing effort. Indeed, the calculation of fishing mortality between 1960 and 1975 indicates that the exploitation rate is much lower than has been experienced by other cod stocks fished in a sustainable manner. Thus the present critically low level of stock biomass is probably more the result of interactions with other fish stocks than the effects of so-called single-species-model exploitation.

This paper attempts to interpret the effects of multispecies interaction in the light of the internal dynamics of the cod stock as it relates to its management. Two previous papers (Lett et. al. 1975 and Lett and Doubleday 1976) have set the framework for this further attempt. It is anticipated that some earlier confusion related to the bioenergetics can be clarified and the very important relationships between population energetics and stock management will be elucidated.

### The Basic Data for Assessment

#### Catch-at-age data

A detailed discussion of the basic data between 1960 and 1970 has previously been presented by Halliday (1972), however it is probably worthwhile to present a brief summary. Six categories of landings are considered: otter trawl landings in the periods January-April, May-August, and September-December, seine, line, and gillnet landings. Biological sampling for length and age composition of landings in these categories in

the 1960-76 period are good only from the Magdalen Shallows "summer trawl fishery". It was considered more appropriate to treat the winter Sydney Bight fishery separately despite poor sampling by all countries. Coverage of this fishery since 1970 has vastly improved especially since the fishery is now largely Canadian. Danish and Scottish seine landings were treated separately when samples were available and combined with otter trawl landings when there were no seine samples. While seine landings differed slightly from trawl caught fish, being smaller and younger they formed such a small part of the total that the error introduced by combining seine with trawl landings is small, but presently this is not the case (Table 1). However, gillnet and line landings could not be combined with trawl landings since the selection pattern in this fishery differs markedly from that for otter trawls. When there were no length frequency samples from line or gillnet landings in a particular year, those of the preceding and subsequent years were combined and some 1971 samples were applied in this way to the immediately preceding years. Since 1970, the sampling of all fisheries has been thorough and no interpolating from other years was necessary (Table 1).

Catch-at-age data between 1950 and 1960 should be treated with some caution since sampling information is only available for the winter trawl fishery for the entire period (Palohiemo and Kohler 1968). Long and handlines and some gillnets made up a substantial proportion of the fishery during this period in addition to an inshore otter trawl fleet of small vessels. In years when samples were available for these gear types they were weighted into the overall catch-at-age frequency accordingly, but in years when samples were lacking an average catch-at-age frequency for that gear type was used. A substantial amount of discarding, from 1950 until the mesh regulations were strictly enforced in 1957, was practised especially of 3- and 4-year old fish. No detailed sampling of the discard is available to weight up the samples, but calculations show that the average estimation of year-class size during this period could not be underestimated by more than 10%. Catch-at-age data for the period from 1950 to 1976 is presented in Table 2.

#### Effort Data

The previous discussion indicates that the Gulf of St. Lawrence cod fishery is indeed diverse and between the period 1950-1976 the gear types, fishing power and gear efficiency changed dramatically. The only gear type for which effort data is consistently available is the 26-50 ton otter trawl fishery. Therefore this gear type has been used as the standard for the period. One aspect that detracts from

from its usefulness, upon first inspection, is that only ~7% of total catch is made by it as compared with 75% in early 50's. However, the correlation between the catch per unit effort (C.U.E.) of 26-50 ton vessels and 51-100 ton vessels from 1962 to the present is very good suggesting that the catch rate in this fishery still reflects the catch rates in the overall fishery.

#### Changes in efficiency

The efficiency and fishing power of the Gulf of St. Lawrence fleet most certainly has changed since the otter trawl fishery first began in 1947. The progressive build up of larger trawlers and the decline in prominence of the gillnet and longline fishery are only a few of these changes. To analyse for an alteration in gear efficiency a trend was sought between fishing mortality per unit effort (F.U.E.) and time. The fishing mortality values were those generated by virtual population analysis. It was noted that F.U.E. increased exponentially with time suggesting that efficiency was increasing at a constant rate. A relationship of this sort had previously been hypothesized (Halliday and Doubleday 1976) for Scotian Shelf stocks in general. Their conclusion was arrived at by an indirect method, resulting from an iterative fitting of general production models.

The relationship hypothesis for analysis was

$$(1) \text{ F.U.E.} = \beta_0 \text{ EXP } [\beta_1 \Delta t]$$

The reduction in the total sums of squares after fitting the mean due to exponential of  $\Delta t$  was 39% while  $\beta_1$  was equal to 0.0313. This would suggest then that effort for this fishery was increasing at a rate of 3.13% per year since at least after 1957 when the proper mesh selections were enforced. Effort values were then adjusted by multiplying them by  $\text{EXP } [0.0313 \Delta t]$  where 1950 was considered year zero.

In 1976 the southern Gulf of St. Lawrence was closed to fishing by vessels >100'. In addition, the number of large vessels fishing in 4Vn was substantially reduced. This probably ended the continual gain in efficiency with the virtual closing of the 4Vn fishery in 1977 the efficiency is probably equivalent to that in the early 60's. Many of the small inshore vessels fishing now were built during this period, thus it would seem the fishery has reverted back to its nature in former times.

<u>YEAR</u>	<u>EFFORT/TRIPS</u>	<u>CATCH/M.T.</u>	<u>C.U.E.</u>
1950	3289	44023	13.38
1951	2771	34827	12.57
1952	3516	41956	11.93
1953	6572	58911	8.96
1954	6879	63901	9.29
1955	7592	65227	8.59
1956	10004	104469	10.44
1957	8917	89131	10.00
1958	10804	86582	8.01
1959	7706	70720	9.18
1960	12846	66013	5.14
1961	9144	65583	7.17
1962	8585	66664	7.77
1963	9846	70202	7.13
1964	9638	60547	6.28
1965	10786	63027	5.84
1966	15039	54851	3.65
1967	9562	41314	4.32
1968	7146	46551	6.51
1969	6438	47512	7.38
1970	8874	64459	7.26
1971	11305	56375	4.99
1972	13598	67733	4.98
1973	13446	50635	3.77
1974	19340	48746	2.52
1975	13741	39085	2.84
1976	No data analysed		
1977	4221	21096	4.99
Gear selection			

Because of the diverse nature of this fishery and its affinity for constant change a valid sequential population analysis could not be performed until something was known about selection, so that proper starting fishing mortality (F) values can be determined. Virtual population estimates will always vary in the proper direction when incorrect starting values are used, however these values cannot be considered correct until the selection is known. Since 1957 the 4 1/2" otter trawl mesh standard has been strictly enforced although the author is not naive enough to believe the violations of this standard would not lead to some biases within the data. The only selection experiments were carried out on otter trawl selection. The selection ogive was the cumulative distribution function of a normally distributed random variate (Fig. 1) with mean 40 cm and standard deviation 7.5 cm derived from the data in Holden [ed.] (1971).

$$(2) \quad \theta_a = \frac{1}{7.5 \sqrt{2\pi\sigma}} \text{EXP} ( -[(X-40) \times 7.5]^2 ) dx$$

In the case of long and handline selection and gillnet selection it was necessary to turn to the commercial catch sampling data. The strong 1959 year-class was chosen to follow through between ages 4 and 14 so the year-class effects would not confound the analysis. The fraction of the total catch attributable to each 30 cm length class was accumulated over the years between 1960 and 1974 as the year-class grew in length and passed through the fishery. These accumulated fractions gave a selection curve but were confounded with the effects of the abundance at given lengths.

For this reason a relationship was found between the cohort numbers at age and the average length of the cohort as it grew older. A predictive equation was developed and abundance levels for each 3 cm length grouping were estimated. By dividing these estimates into the accumulated percentages a more unbiased estimate of selection could be determined assumingly with the effects of varying abundance removed. Polynomials were fit to these relationships of the form

$$(3) \quad \theta_a = \beta_o \text{EXP} [\beta_1 L_a - \beta_2 L_a^2]$$

and the maximum of the curve was given as selection of one (Figure 1). Selection in the otter trawl fishery begins at approximately 22 cm while in the longline fishery selection begins at 37 cm and 49 cm for the gillnets. Full selection in the otter trawl fishery occurs at 61 cm, 73 in in the long and handline and 86 cm in the gillnet. Danish seine selection is assumed to be the same as otter trawl selection.

It is rather peculiar that the selection in the long and handline fishery falls away so symmetrically, however this response has been noted for other line fisheries. It would seem that the cod no longer prefer the bait in addition to the fact that the hook size may become inefficient. It is doubtful that they are not merely available to the gear since the division between size groups of fish seems to be more related to maturity. Furthermore, research surveys indicate that cod over 73 cm are available in areas of longline fishing.

These three selection curves were combined such that an overall selection for each year since 1960 could be determined for the fishery. Weighting factors were calculated for each age group and combined based on the overall catch in numbers of that age group within the gear type; the mean length of the age group dictating the selection. The results of these calculations are shown in Table 3.

#### Sequential population analysis

Cohort analysis (Pope 1972) was utilized to determine the numbers at age. Starting values were determined using an iterative process. First a guess was made for starting F values in 1975 and this was distributed over age according to the selection factors in that year. The starting F for the terminal ages in the different years was 0.2. Natural mortality (M) was held constant at 0.2 for all age groups. A preliminary study using Palohiemo's method indicated this to be correct for ages 3 to 14 when the C.U.E. was divided by the selection factors. However, this is not to say natural mortality does not vary with age, it is merely an average value when the geometric mean regression is used for bivariate normal data (Ricker 1973).

Estimates from cohort analysis improve as F values accumulate, thus after the initial run the average F was determined for fully recruit age class and F values for terminal years were determined by multiplying these average F's by the appropriate selection factor. The F value in 1975 was determined from a plot of fishing mortality vs effective effort. The analysis was again run, and the same procedure was followed with the exception being that the total average F for ages 3 to 15 was now correlated with effective effort until the deviation of 1974 plus 1975 from the G.M. regression line was minimized (Fig. 2). Since no selection factors were available prior to 1960 an average value of 0.28 was used in the terminal years.

The correlation between  $F_{3-16}$  and effective effort is quite good and does indicate that management of fishing effort can have substantial impact on the resultant mortality rates within the cod stock. The lack of trends in the residual would indicate errors are occurring randomly and there are no between year effects in natural mortality although nothing can be said for this relationship about age effects. The correlation of effort x selection against F does show a trend in the residual and this may be attributed to age specific natural mortality. Numbers at age and F values are shown in tables 4 and 5.

The relationship in Fig. 2 supports the idea of an increase in efficiency up until 1975. However, it does not indicate that the numbers at age are completely correct, especially in most recent years. The check on this relationship, the numbers of 3+ fish from VPA in year t+1 were plotted against the catch of 2+ fish from the Gulf surveys in year t. The reason for the 1 year lag is that the standard Gulf cruise occurs in



October when the fishing is almost over and the birthdate for virtual population analysis is January 1st.

The abundance levels were taken from fixed stations in the Shediac Valley, Bay of Chaleur area. This is the area of highest cod abundance according to the stratified random survey over the entire Gulf of St. Lawrence (Fig. 4). Two facts are important when interpreting this relationship. First the correlation is excellent indicating that the virtual population analysis corresponds very well with catches in the survey especially since the data is not a time series. Therefore, it is very likely that the numbers at age from virtual population analysis actually are close to the real numbers at age. The second aspect is that this relationship does not go through the origin suggesting that perhaps numbers at age are in fact over-estimated. However, since ages 2, 3 and some of 4 are not fully recruited to the research gear, the CUE is an underestimate of the real CUE if all fish were available.

The CUE from the Gulf surveys are variable from year to year. Therefore, these numbers are smoothed using a 3 year running average since it is really the average of 2, 3 and 4 year olds that make up the bulk of the index.

YEAR	CUE 2+ cod Gulf survey year t	CUE 3 year average	Numbers of 3+ from VPA year t+1
1962	189	170	266,945
63	133	156	235,666
64	145	125	208,242
1965	95	112	192,111
66	95	161	231,893
67	291	181	261,517
68	155	181	245,352
69	95	132	228,406
1970	144	96	227,120
71	48	92	189,026
72	84	62	161,273
73	52	58	161,729
74	37	61	149,755
1975	94	87	174,837
76	128	149	202,569
77	223	191	-

Using the smoothed value for 1977 gives a predicted numbers at age in 1978 of approximately  $2.6 \times 10^8$  3+. The catch projection from 1977 using the catches generated in that year gives a total of  $1.6 \times 10^8$  4+ cod in 1978. Thus by subtraction the estimated 1975 year class size is  $1.1 \times 10^8$  in 1978.

Juvenile surveys and the prediction of year class size.

Previously a correlation was found by Hare and Kohler (1975) between the logarithm of the CUE of juveniles and year class size as estimated from virtual population analysis. Further analysis of this data indicates that the transformation is unwarranted, thus the geometric mean is used here. Since the juvenile surveys in former years did not cover the entire Gulf of St. Lawrence, and were conducted with different mesh and vessel sizes, the two surveys needed to be inter-calibrated.

The correlation between the catch per tow of the old and new surveys was almost perfect for 1971 to 1973. The values from the old surveys between 1957 and 1970 were now corrected to be equivalent to the new random stratified surveys.

YEAR CLASS	CUE AGE 2	VPA ESTIMATED AT AGE 3 x 10 <sup>3</sup>
1957	17.32	134,847
58	3.10	46,119
59	3.53	60,134
1960	3.68	41,739
61	4.86	61,261
62	3.63	52,501
63	4.58	61,429
64	16.87	107,042
1965	6.92	95,111
66	7.53	56,944
67	2.04	50,480
68	6.96	74,245
69	0.62	23,460
1970	3.63	45,780
71	6.98	69,137
72	2.54	42,135
73	8.90	80,814
74	9.41	83,915
1975	26.42	187,363

The correlation between the numbers at age 3 from VPA and the catch of age 2 cod of the same year class from the juvenile surveys, was indeed high ( $r = 0.90$ ). The equation for the geometric regression was as follows:

$$(4) \quad N_3 = 6081.58 \text{ C.U.E.}_2 + 26687$$

Because of the contagious nature in which cod are distributed and the fact there is a segregation of small cod from larger cod, it is quite possible to overestimate the catch per unit of effort for young cod when they are abundant. The survey has not been stratified, or randomized for the matter, for the distribution of different age classes of cod. These young fish are mainly concentrated around Miramichi Bay (Fig. 4) and spread out from there in diminishing numbers. In 1977 large catches of small fish occurred throughout this region.

The basic data for the assessment presented here is now complete, but very little of the actual biology of these relationships has been discussed. Before further analysis is performed, a detailed biological analysis will be presented, and a simulation built for further prediction.

### The Biological Background to the Assessment

#### Density Dependent Growth

The instantaneous growth rate of cod ages 2-15 was defined as  $G = \frac{dw}{dtw}$  and calculated from weight at age data

from commercial catch sampling between 1950 and 1975 (Table 5). These samples were all taken between January and April when the cod are not growing. The instantaneous growth rate can be calculated by the natural logarithm of the ratio of weights in successive years (Ricker 1958).

Lett and Doubleday (1976) have previously shown that the growth rate of cod between ages 5 and 8 in the Gulf of St. Lawrence is inversely related to the biomass, and that the biomass indeed reflects the density since no changes in catchability have been noted during the period. However, since this is an average rate it is difficult to apply it to the overall stock. According to Kerr (1974) the instantaneous growth fishes should be an inverse power function of their weight. In theory this is fine. however one wonders to what degree the fit of such a relationship is due to the auto correlation of the independent and dependent variables. Laboratory experiments have shown that the basal metabolic rate of fish drops with size (Beamish et. al. 1975) suggesting that this relationship is indeed correct; thus it would seem appropriate to linearize the data using a double logarithmic transformation for hypothesis testing.

Another variable, which does not vary in a continuous manner overtime, are the accumulation of events which occurred during the epizootic disease in the Gulf of St. Lawrence (Sinderman 1958). During the period from 1945 to 1958 the biomasses of mackerel and herring were almost totally decimated. The disease which started gradually and caused catastrophic mortalities near its termination may be related to higher than average water temperature which prevailed during this time. The growth rate of cod was increased since they were eating diseased herring which could easily be captured. Furthermore, more energy was possibly being transferred directly into the

This would increase the carrying capacity of the benthos, and the number of available food items for young and old cod alike. This situation in the Gulf of St. Lawrence is similar to that noted in the North Sea where the pelagic biomass is now at a very low level because of over-exploitation, but substantial increases have been noted in the cod biomass. Jones (MS 1976) has presented a preliminary investigation of possible energy flows in the North Sea system which elucidate the partitioning of energy such that the measured changes could occur.

Palohiemo and Dickie (1966) suggest the metabolic exponent is constant while the proportionality constant varies to environmental condition. Farmer et. al. (1977) found this was not true for the growth of sea lamprey since both the exponent and proportionality constants were acted on by environmental variables. For this reason the following form of equation is put forward to describe the growth of cod:

$$(6) \quad \frac{dw}{dtw} = \beta_0 \cdot B^{-\gamma_1} \cdot W^{-\gamma_2} \cdot B$$

where B is the biomass of cod before the summer fishery begins and W is the weight of cod in kg.

Multiple regression was used to determine parameter values and a dummy variable D represents the collective effects of the epizootic disease on growth. The dummy variable is zero when there is no epizootic and one when it is occurring. The following adequately describes the instantaneous growth rate of cod:

$$(7) \quad \log_e G = -0.0517 \log_e B \times \log_e W - 0.2515 \log_e B + \\ 0.1472 \log_e W \times D + 1.88691$$

<u>Variable</u>	<u>Coeff.</u>	<u>S.E.</u>
$\log_e B$	-0.2515	0.0922
$\log_e B \times \log_e W$	-0.0517	0.0050
$\log_e W \times D$	0.1471	0.0803

The coefficient of multiple determination ( $R^2$ ) is 0.47 while F (significant at  $P < 0.05$ ) for regression is 65.32 ( $F^1_{3,221} / 2.60$ ).

The significant interaction between weight and the dummy variable indicates that when the epizootic is not occurring weight is more influential on growth rate. This would suggest that the epizootic infact increased the energy intake of cod which seems to be the case. Since the epizootic is not a "normal" event in the management of cod the most useful equation would be:

$$(8) \quad G = 6.6000B^{-0.2515} \times W^{-0.0517} \log_e B$$

As the weight of cod increases the growth rate declines rapidly (Fig. 6) with the growth rates of smaller fish being more effected by shifts in biomass than older fish. This would make density dependent growth in most fish stocks extremely hard to detect.

#### Seasonal Growth of Cod

The seasonal growth pattern for cod is very difficult to determine from field data because of sampling errors and biomass. In addition, the collection of the data is expensive and probably substantially out weighs its value when the degree of uncertainty is considered. Thus monthly growth rates were determined by Waiwood (1978) for laboratory held fish at different temperatures and fed varying rations. It was found that growth rate followed appetite extremely well, and this was evident in a seasonal pattern. Using this data and considering the cumulative growth was calculated as a proportion of the maximum growth rate (Fig. 7). Growth rate declines during the initial part of the year and actually became negative in April to May prior to spawning. A maximum growth rate was reached in October with a further decline being evident in November and December. Thus, by using this data, it would be possible to calculate monthly catches when something is known about the seasonality of the fishery.

#### Density dependent $z_1$ growth

The occurrence of density-dependent growth during the first year of life in the Gulf of St. Lawrence cod stock was investigated using the back calculation of 2500 otoliths taken from commercial sample surveys for the years 1960-1975. For each year, 150 otoliths covering all available age groups were read according to the established methods of Kohler (1964) and May (1967). The

left otolith from each fish was broken across the sulcus, both halves were smoothed with emery paper when necessary, placed into a plasticene substrate, covered with alcohol and examined at 25 x magnification under a binocular microscope. The interface between the outside edge of the opaque band and the inside edge of the hyaline zone was taken to be an annulus. The distances between the focus and each respective annulus were measured with the aid of an ocular micrometer in a radius perpendicular to the otoliths longitudinal axis. These distances were tabulated with the fishes length; values for crystallized or unreadable otoliths were not used. The regression between fish length (L) and otolith radius ( $R_0$ ) was  $L = 0.628 R_0^{1.227}$  with an  $R^2$  of 0.73. According to age and year of capture, the otolith measurements for each fish were sorted into year-classes. The sample sizes ranged from 32 for 1950 year-class to 183 for 1964 and 27 for 1972. The mean length in centimeters for each year of growth for all year classes was tabulated.

Density-dependent  $Z_1$  growth has been shown to exist for clupeids (Marr 1960, Iles 1968, Lett and Kohler 1976) and for gadoids (Raitt 1939, Doubleday et al 1976). The information of the first annulus has been argued by Lett and Kohler (1976) as being a response to carrying capacity, environmental heterogeneity and predatory pressure. This predation is not a direct but secondary one, leading to the consumption of larvae and juveniles which are weakened by starvation (Jones, 1973). Both temperature and a holistic variable representing the change in the carrying capacity as a result of the epizootic disease should therefore significantly alter the information of  $Z_1$  length. The hypothesis was the  $Z_1$  length was a power function of year-class size and the exponent could be altered by the logarithm of temperature. Again a dummy variable was used to represent the ep-zootic, 1 when it was occurring and 0 when not. The following equation described much of the variation in  $Z_1$  length:

$$(9) \log_e Z_1 = 0.2999 \log_e N_3 + 0.27251 \log_e N_3 \times D - 2.9395 \times D + 0.02201 \log_e N_3 \times \log_e T_p + 4.71572$$

<u>Variable</u>	<u>Coeff.</u>	<u>S.E.</u>
$\log_e N_3$	-0.2999	0.0459
$\log_e N_3 \times D$	0.2725	0.0931
D	-2.9395	1.0486
$\log_e N_3 \times T_p$	0.02202	0.0132

The coefficient of multiple determination ( $R^2$ ) was 0.71 while F (significant at  $P < 0.05$ ) for regression is 10.79 ( $F'_{4,18} / 2.29$ ).

$N_3$  is the numbers in a particular year class  $\times 10^{-3}$  at age 3, while  $L_1$  is the length of the fish at the time of formation of the first annulus and  $T_p$  is the spring temperature at Grande Riviere on May 25.

As year class size increases, there is an exponential decline in  $L_1$  length. The shape of this relationship agrees well with the exponential decline in  $L_1$  length for silver hake in response to year class size noted by Doubleday et al. (1976).

A more useful form of the equation when the epizootic is not occurring is:

$$(10) \quad L_1 = 5.907 N_3 [0.5724 + 0.0222 \times \log_e T_p]$$

The yearly fluctuations in the first year of growth are most interesting. The variations could not be explained by either Lee's phenomenon or an increase in experimental error, in fact statistical confidence was highest for the first year growth measurements. The relationship between this crucial growth period and the ensuing recruiting stock size seemed to satisfactorily account for much of the variation. Concomitant with density dependent first year growth is a suggestion of growth compensation in the second and third years; where first year growth was low, second year growth was usually high, with the converse always being true.

The phenomenon of density dependent growth has been viewed as obvious by some and dubious by others Cushing (MS 1976), but is certainly suggested by this study. This is probably because changes in the rate of accumulation of surplus energy are more manifested in fluctuations in gonadal rather than somatic weight in mature fish, making changes in body weight much harder to detect as fish get older.

#### Shifts in maturity with length

Maturity for some time has been considered a fixed function of length. However, the recent works of Daan (1974) and DeVeen (1976) indicate that this biological trait is dynamic for cod and plaice. Shifts in the maturity ogive have also been noted

for Gulf of St. Lawrence cod (Fig. 8) with the mean length of maturity dropping 13 cm since 1959. Small shifts in maturity can have an extreme impact on the total egg production of the population this it would seem that a trait as powerful as this one should have some biological significance. In addition, it is not intuitively obvious why maturity should shift with length.

It has been noted by Beverton (1959) that maturity usually occurs at the inflection of the relationship of growth over time. That is to say, when the rate at which fish are gaining weight over time begins to decline the fish reaches maturity. Therefore it would seem that the length at which maximal growth rate is achieved determines the onset of maturity.

It has been noted in mammalian populations that growth determines the age of maturity in addition to the size. Personal observation has shown that, rainbow trout fed a maximum diet will mature in the first year of life at a length far less than wild fish. For this reason, it was hypothesized that the growth rate of cod during the first year probably strongly influences the length at which they mature. Indeed, this does seem to be the relationship (Fig. 9). A mechanism such as this has strong homeostatic value in relation to maintaining population stability. A strong year-class grows more slowly in the first year of life and matures at a larger size. Thus the effect of this good year-class on the reproductive biomass does not as quickly as a small year-class. However, if a stock is collapsing and year-class size is beginning to diminish then these fish will mature much sooner than if the ogive were fixed, augmenting the size of the reproductive biomass quite dramatically. The effect of this relationship on the population stability and subsequent stock management will be discussed later.

#### Cod Adult Stock Production and Egg Production

The mechanism by which the egg production of a fish stock is related to the production of the adult stock has been discussed by Lett (MS 1976), Lett and Kohler (1976), Lett et al (1975) and Tyler and Dunn (1976). Recently De Veen (1976) has presented data showing a continual increase of fecundity at length for sole either because of a decrease in stock or an increase in food or both. Bagenal (1973) has also not the same types of changes for North Sea plaice. Waiwood (1978) has presented data showing the egg production can be related to growth rate for cod.

The hypothesis being put forward in this paper is that fecundity is related to the food intake and the partitioning of the proportion of surplus energy into gonad is reliant on the total available surplus energy. Mathematically this paradigm can be represented by the equation:



$$(11) \quad E = N \times (\Delta W)^\gamma$$

where E is the egg catch in the Gulf of St. Lawrence surveys per 100,000 m<sup>-3</sup> of water, N is the number of mature fish and  $\Delta W$  is the weighted growth rate of the mature stock. The exponent,  $\gamma$ , is the rate at which surplus energy is being channeled to gonad in relation to the overall surplus energy represented by a change in weight. The distribution of eggs in the Gulf of St. Lawrence is shown in Figure 10.

Lett et al. (1976) have shown that temperature ( $T_p$ ) influences the survival of eggs and influences the catches on the egg and larval cruises. In addition, it has been shown that temperature acts in a quadratic manner which agrees with the findings of Forrester and Alderdice (1966) and Bonnet (1939). There the following equation was fit using multiple regression to represent the catch of eggs during the time of peak spawning.

$$(12) \quad \log_e E/N = \beta_1 \log_e \Delta W + \beta_2 T_p + \beta_3 T^2 + \beta_0$$

<u>Parameter</u>	<u>Value</u>	<u>St. Error</u>
$\beta_1$	1.2221	0.3640
$\beta_2$	1.6769	1.1114
$\beta_3$	-0.1655	0.1071
$\beta_0$	1.780	

The reduction in the total sums of squares, after fitting the mean, due to regression was 77.3%, with an  $F = 6.8$  ( $F^1_{3.6} / 4.76$ ). The equation can be rearranged to the following form.

$$(13) \quad E = 5.93 \times \text{EXP} [1.677T_p - 0.166 T_p^2] \times N(\Delta W)^{1.222}$$

where  $T_p$  is the mean sea surface temperature occurring on

the cruise. Although neither  $\beta_2$  or  $\beta_3$  are significant the combined effects of the fitting of these two parameters led to an improvement to the overall fit of 9%. Most of the variation in egg catch per mature individual is explainable by the growth rate, 69% or the production of surplus energy by individual fish (Fig. 11).

The existing dogma relates eggs production to the mature stock biomass and this is usually converted to eggs by the multiplication of some fixed fecundity length relationship. Equation (13) shows that clearly for cod this is not the case. However, for a stock where  $\Delta W$  did not change then there would be a linear relationship between biomass and egg production, but this has limited biological meaning. Twice (Lett et al. 1975), (Lett and Doubleday 1976) a dome shaped egg production curve has been presented as a function of biomass. It was hypothesised at that time that density dependent growth led to the production of this dome shaped curve. Equation (13) certainly supports this conclusion since according to equation (8)  $\Delta W$  should decrease as  $N$  increases and the rate at which egg produce declines with density depends on the exponent of  $\Delta W$ .

#### The Production of Larvae

The survival of fish larvae has been a topic of particular concern to fisheries biologists for the past century. A number of notable papers have been produced relating the survival to environmental effects (Hjort 1916, Hempel 1965, Postuma and Zijlstra 1974 and Cushing 1975) and the density dependent effects (Beverton and Holt 1957, Beverton 1962, Cushing and Harris 1973, Jones 1973, Cushing 1975) however, few papers consider the combined effects of the environment and density dependence presenting the results in a quantitative manner. Exceptions to this however are the works of Ware (1975), Lett et al. (1975) and Lett and Kohler (1976).

The model being developed in this paper incorporates the two effects and presents a quantitative model. The normal assumption concerning the survival of fish is that:

$$(14) \quad \frac{dN}{dt} = \beta_0 N$$

or that the instantaneous growth rate is constant. Cushing (1975) and Ware (1975) found this was not an adequate model for explaining both the mortality of fish larvae in addition

to older stages of fish. Cushing decided that instantaneous growth was indeed density dependent and reformulated the survivorship equation as:

$$(15) \quad \frac{dN}{dt} = \beta_0 N^2$$

Ware's (1975) sophistication of the problem hypothesizes that mortality is related to the growth rate an agreement which seems well supported by the data. Unfortunately, the data is not yet available on the growth of juvenile and larval cod so in this study it is proposed that the mortality rate responds to density.

It is assumed that the structure of the relationship between density is not known. A plot of the instantaneous mortality verses numbers over the period when larvae are available is an asymptotic relationship with population density such that:

$$(16) \quad \frac{dN}{dtN} = \beta_1 \log_e N + \beta_2 [\log_e N] \times T_p + \beta_0$$

<u>Parameter</u>	<u>Value</u>	<u>S.E.</u>
$\beta_1$	$1.639 \times 10^{-2}$	$2.470 \times 10^{-3}$
$\beta_2$	$1.751 \times 10^{-5}$	$1.000 \times 10^{-5}$
$\beta_0$	-0.0485	

where  $T_p$  is the annual monthly maximum temperature. The reduction in the total sums of squares, after fitting the mean, due to regression is 88.7% with an F of 35.3 ( $F^1_{2,9} / 4.26$ ). What the equation implies is that if the number of eggs is known and the temperature, the number of surviving larvae is predictable at a later date. Of all models considered equation 16 gave the best fit. This equation must be solved iteratively since there is no closed form for intergration. Thus the equation in the following form must be solved iteratively:

$$(17) \, dN = [1.639 \times 10^{-2} \log_e N (1 - 1.0683 \times 10^{-3} T_p^2) - 0.0485] \times N_0 \times dt$$

$$(18) \, N^1 = N_0 + dN$$

$$(19) \, N_0 \leftarrow N^1$$

where  $N_0$  is the initial number of animals and  $N^1$  is the number remaining after the time step  $dt$ . The solutions of the equation are extremely stable when the  $dt$  is one day. The number of larvae are estimated after 50 days and the results are the same as previous preliminary analysis (Lett et al 1975). The final number of larvae seems to vary less than the initial number of eggs which indicates that competition among cod larvae tends to thin the population out such that carrying capacity of the environment can be met. Temperature in turn probably is modifying the food supply such that when temperature is high and more plankton is available there is less competition, thus greater survival. This same type of density dependent relationship has been noted for mackerel larvae (Lett et al MS 1975b) and is an important stabilizing force in the recruitment mechanism. Large variations in egg production and survival at this stage can be severely damped through this process. Harding and Talbot (1973) present a number of survivorship curves for plaice which indicates the same response, that is the number of surviving larvae is much more invariable than the number of eggs.

The simulated relationship between the numbers of eggs at peak spawning and larvae is shown in Fig. 12 when temperature is varied. It can be seen that at higher egg numbers the effect of temperature is more influential in determining the numbers of larvae because of temperatures proportional influence. In addition, with a density dependent mechanism operating these larvae may be in a weakened state thus more susceptible to the influence of temperature.

#### Factors effecting year-class size information

Previous attempts to derive an equation describing the formation of year-classes from larval abundance have incorporated the effects of predation of older cod on juvenile cod as they become demersal (Lett and Doubleday, 1976). However, this equation did not adequately explain the data, especially in the description of the most recent year-classes. The conclusion that Lett and Doubleday (1976) came to was that an important variable was missing.

This most recent analysis indicates that the missing variable is possibly the impact of mackerel predation of cod larvae since mackerel enter the Gulf when cod are beginning to hatch in large numbers and remain in the same areas that cod larvae are found for the entire summer. It is known mackerel eat other fish larvae (Mackay 1976), and there is no reason to believe cod represent a special case. Mackerel have been shown to effect year-class formation of Gulf of St. Lawrence herring (Lett and Kohler 1976, Winters 1976). In fact, Lett et al. (1975) have suggested that mackerel are extremely influenced on the recruitment of any fish stock with which they co-habitat. Unfortunately, no stomach content data exists for mackerel while resident in the Gulf of St. Lawrence showing the consumption of cod larvae, however stomach content from the Scotian Shelf indicate gadoid larvae are consumed (Kulka, 1977).

The relationship between year class size,  $N_3$ , at age 3 ( $\times 10^{-3}$ ), 3+ cod biomass (mt),  $C_D$ , and 2+ mackerel  $M_k$ , biomass (mt) is represented by the following equation. The cod biomass is the average when coincident year class is 0 and 1 group. Previously, it has been stated that the lag was 3 years, however it is apparent from the relationship between 2 year olds in surveys and 3 year olds from the VPA that year class size is formed by the second year (Fig. 5).  $L_R$  is the abundance of larvae on day fifty after peak spawning as predicted by equations (13) and (16-18).

$$(20) \quad N_3 = 4.22 \times 10^{-3} \cdot L_R \cdot \text{EXP} [(-1.4096 \times 10^{-8} \cdot C_D \cdot M_k^{0.5}) + (1.457 \times 10^{-11} \times C_D \times M_k^{0.5} \times L_R) + (2.584 \times 10^{-9} \times L_R \times C_D)]$$

The mackerel biomass  $M_k$  is taken to the exponent 0.5, since it was found by nonlinear regression that this exponent gave the best fit. What this means then, is the rate at which mackerel feed on cod larvae, if this is indeed the way the interaction works, is about 1/2 as effective as an equivalent biomass of cod feeding juveniles.

<u>Variable</u>	<u>Coefficient</u>	<u>Variation Explained</u>
$C_D \times M_k^{0.5}$	$-1.410 \times 10^{-8}$	0.559
$L_R$	$-5.160 \times 10^{-3}$	0.087
$C_D \times M_k^{0.5} \times L_R$	$1.457 \times 10^{-11}$	0.028
$L_R \times C_D$	$2.584 \times 10^{-9}$	0.109

The coefficient for multiple determination was 0.781 while F for regression is 12.5.

Although an auto-correlated function was used to fit the data most of the variation is explained by the interaction of cod and mackerel as competitors for the feeding on larval and juvenile cod. Thus the equation fits very well (Fig. 13). The 1964 year class was not well explained, which was a good year class for cod along the Atlantic seaboard, thus information is still missing here, but a substantial proportion of the variation among year classes can be explained by this relationship. Furthermore, the equation indicates that as mackerel and/or cod decline, or that their interaction declines, year class size should improve. Only the data between 1954 and 1972 were used to fit this curve. However, if the 1973, 1974 and 1975 year classes were also used the equation would have fit much better. Surveys indicate that these year classes have been increasing in size (see juvenile surveys section), and this has happened as both cod and mackerel have declined. A first estimate indicates that the 1975 year class is one of the largest on record for this stock, when cod and mackerel predatory biomasses were at a minimum, thus the equation seems to be working. This is the only way of substantiating any of these relationships and really only time will tell if we are on the correct track.

<u>Year</u>	<u>Observed <math>N_3 \times 10^3</math></u>	<u>Estimated <math>N_3 \times 10^3</math></u>
1954	106,681	129,949
55	110,471	106,851
56	143,344	133,810
57	134,847	120,288
58	46,119	49,883
59	60,119	59,118
1960	41,739	51,151
61	61,261	51,589
62	56,163	60,634
63	61,261	63,933
64	107,042	75,327
1965	95,111	78,275
66	56,944	83,675
67	50,480	64,991
68	74,245	52,787
69	23,460	30,443
1970	45,780	57,786
71	69,137	41,877
72	42,135	44,931

The relationship between larvae and year class size is indeed unclear (Fig. 15). There is very little relationship between the two above the production of 200 larvae per 100,000 m<sup>3</sup> of water. In fact it is hard to imagine that a relationship exists between parent stock and recruitment for cod over a wide range of stock sizes. A relationship can only be elucidated as the stock begins to decline - a similar result noted for herring (Lett and Kohler 1976). The important relationship in a so-called stock recruitment relationship is not the parent stock but the predatory stock as cod become demersal. Thus, the changes of a good year class increase as the stock declines until some critical level is reached.

### Construction of simulation model

The simulation model was initially written in APL for "debugging" and testing purposes and later rewritten in FORTRAN. The stochastic nature of the model and the many runs necessary to calculate the correct means and deviation for the different fishing strategies made the printing capabilities of APL extremely time consuming and uneconomical. However, the explanation of how the simulation was constructed will relate to the APL model because of the ease of scientific type programming in this language.

The actual model is a group of subprograms dealing with different aspects of the simulation procedure. That is to say, that one subprogram is a group of algorithms to facilitate linear interpolations, (AFGEN), sampling from normal (GAUSS) distributions and a procedure whereby a probability is put in and a deviation is retrieved (INVGAUSS). The AFGEN algorithm is particularly useful since it allows the programmer to sample from any functional relationship. The second subprogram COD0 is merely a description of variables utilized throughout the model. The next subprogram COD1 initializes the cod simulation.

COD1 begins by asking for the mackerel biomass to be run in metric tons, and fishing mortalities in the winter and summer otter trawl fisheries, gillnet fishery and line fisheries. Furthermore, questions are asked concerning the length of time the simulation is to run, the number of runs and types of output expected. Matrices are set up for the AFGEN program concerning the selection of the different gear types within the fishery. Later some calculations are made concerning  $L_1$  size, standing biomass and growth. In addition, the number-at-age and 1000's are entered. The simulation is now passed onto the next subprogram COD3.

Since the initial writing of the program it has been updated so that the winter and summer fisheries can be conducted in seasonal manner. This utilized the seasonal growth information (Fig. 7) and the seasonal distribution of the fishery (Fig. 15). Thus a number of questions relevant to management of the stock could be elucidated.

COD3 is the main body of the simulation and contains the mathematical representation of the population energetic response of the southern Gulf of St. Lawrence cod stock. First the model begins to calculate the length, L, based on the weight, W, using the following equation:

$$L = [1.0902 \times 10^5 w]^{0.333}$$



where the growth rate at age a in year t is:

$$\text{VIII. } {}_t\Delta W_a = 6.6 \times {}_tBS^{-0.252} \times {}_tW_a^{-0.052} \times \ln {}_tBS \times {}_tW_a$$

and  ${}_tBS$  is the summer biomass after the winter fishery in year t.

The  ${}_tMGR$  is now used to calculate the catch of cod eggs per 100,000 m<sup>3</sup> of water when coupled with previously mentioned spring water temperatures and  ${}_tMSN$ .

$$\text{IX. } {}_tEGGS = 5.93 \times {}_tMGR^{1.22} \times \text{EXP} (1.678TP1 - 0.167TP1^2) \times {}_tMSN \times 10^{-3}$$

From this equation it is evident that there is an optimal temperature for egg survival and that temperature is indeed very important in determining final egg numbers.

It has previously been determined by Lett and Doubleday (1976) that temperature improves the survival of cod larvae. The following equation was developed to determine the number of cod larvae, LR, after a specific period of time:

$$\text{X. } \Delta LR = (1.639 \times 10^{-2} \ln LR \times (1 - 1.0683TP2^2) - 0.04854) \times LR \times \Delta t$$

where initially:

$$\text{XI. } LR \leftarrow {}_tEGGS$$

therefore:

$$\text{XII} \quad {}_{t+\Delta t} \text{LR} \leftarrow {}_t \text{LR} + \Delta \text{LR}$$

for a particular time step  $\Delta t$ .

The total time period in the simulation was 50 days and  $\Delta t$  equally 1 day. TP2 is the maximum summer temperature in the Gulf, normally distributed with mean 14.39 C and standard deviation 1.28 C.

Predation by a mackerel biomass  ${}_t \text{MB}$  and cannibalism by a 3+ cod biomass,  ${}_{t+3} \text{BC}$ , three years later are shown to be important in conjunction with the abundance of cod larvae to be important in the recruitment of cod. The recruitment of cod is predicted at age 3 since this is the first year of sampling data. The equation

$$\text{XIII.} \quad N = 2191.4 \times {}_{t-3} \text{LR} \times \text{EXP}(-6.1024 \times 10^{-7} {}_{t-3} \text{MB} - 5.7506 \times 10^{-6} {}_t \text{BC} - 2.8070 \times 10^{-3} {}_{t-3} \text{LR})$$

where  ${}_t \text{LR}$  was placed in the first position of the numbers at age vector and had to wait 3 simulated years before being utilized in equation XIII.

Following the calculation of yearclass size the  $l_1$  size of cod is determined by the following equation which included a spring temperature slightly higher than that used to determine the mortality of eggs.

$$\text{XIV.} \quad {}_t l_1 = 111.69 \times {}_t N_3^{0.022} \times \ln \text{TP3} - 0.300$$

where  $\text{TP3} \leftarrow \text{TP1} + 0.92$

After the recruitment and other biological factors are determined, the model calculates catches in the summer fishery. This fishery contains three gear types; lines (LL), gillnets (GN) and trawls (OT), which all compete with one another. Selection for each of these fisheries

are calculated using lengths to linearly interpolate in the AFGEN algorithm. The total fishing mortality is calculated as follows.

$$\text{XV. } FTOT_a = (\partial OT_a \times F_{WOT_a}) + (\partial GN_a \times FGN_a) + (\partial LL_a \times FLL_a)$$

where  $\partial$  is the selection and  $F$  is the instantaneous fishing mortality for age  $a$ . Thus the total fraction of fish caught in this fishery is  $(FTOT_a / (FTOT_a + MS))$  where  $MS$  is the natural mortality in the summer fishery.  $MS$  is equal to 0.117 since this fishery only lasts 7 months. Thus catch each of the winter fisheries is given by the catch equation.

$$\text{XVI. } CS_a^t(OT, GN, LL) = \frac{N_a^W (1 - \exp(-(FTOT_a + MS))) \times F(OT, GN, LL)}{FTOT_a + MS}$$

$a=15$   
 $a=3$

After the winter fishery is complete the model goes through an update phase. The instantaneous growth rate is calculated by rearranging equation VIII such that.

$$\text{XVII. } t_a = 6.6 \times t_{BS}^{-0.252} \times t_a^W^{-0.052} \times \ln_t BS$$

Weight is updated by

$$\text{XVIII. } t_{a+1}^W \leftarrow t_a^W \cdot \exp G_{t_a}$$

A new weight is determined from the  $l_1$  length and placed on the front of the length vector and the age 16 fish are dropped from the vector. Next the numbers at age are updated by the expression,

$$t_{a+1}^N \leftarrow t_a^N \exp - (FTOT + MS)$$

and the number of larvae are put on the front of the abundance vector, while age 16 year old fish are dropped.

At this point in the model a number of biological factors are accumulated to be subsequently printed out. The next subprogram COD is responsible for formulating the output into matrices and calculating means and standard deviations.

these lengths are used to determine a vector of ottertrawl mesh selections  $\partial_a$  determined by the relationship in Fig. , using the AFGEN algorithm. The catch in the winter ottertrawl fishery is determined by the catch equation (Beverton and Holt 1957).

$$\text{II} \quad a^{CW}_t = \sum_{a=3}^{a=15} \frac{N_a^W (1 - \text{EXP}(-\partial_a \text{WOT} + M_W)) \times \partial_a F_{\text{WOT}_a}}{\partial_a F_{\text{WOT}_a} + M_W}$$

where  $F_{\text{WOT}}$  is the instantaneous fishing mortality in the winter otter trawl fishery and  $M_w$  is the instantaneous natural mortality during the winter fishery and is assigned a value of 0.083 since this fishery only lasts 5 months of the year (Halliday 1972). In addition natural mortality is assumed invariate with age. After the winter fishery is complete the numbers in the abundance vector are updated in accordance with the catch.

The biomass before the winter fishery, or on the "conventional" January 1 birthdate is calculated by the following equation:

$$\text{III} \quad t^{BW} = \sum_{a=13}^{a=15} t_a^W \times t_a^N$$

After the calculation concerning the catches and biomass in the winter otter trawl fishery the recruitment portion of the model is activated. Since environmental factors effect the survival of cod eggs, spring temperatures (May 25th as a convention) by sampling from a normal distribution with mean 4.84 and standard deviation 0.95. For this procedure, the algorithm GAUSS is used. In addition to temperature, the position of the maturity

ogive in relation to length and age is important. It was shown earlier that the length of first maturity was related to the growth rate in the first year. The following equations describe shifts in the maturity ogive relation to  $l_1$  growth rate:

$$\text{IV. } {}_t\text{MLM} = (99.09 \times \text{EXP} (-0.5571 \times \ln {}_t l_1)) + 13.0$$

where MLM is the mean length at maturity and  $l_1$  is the length at the end of the first year. It was found that on average the mean length at maturity of 13 cm greater than the length at first maturity, therefore equation IV only supplies an approximation to the real situation. Since the mean length at maturity on deviation, 8 cm, are known actual maturities at age can be calculated by the relationship:

$$\text{V. } {}_t\text{MAT}_a \leftarrow \text{INVGAUSS} ({}_t L_a - {}_t\text{MLM}) \div 8$$

assuming a cumulative normal distribution.

The mature stock numbers are now calculated:

$$\text{VI. } {}_t\text{MSN} \leftarrow \sum_{a=13}^{a=15} {}_t\text{MAT}_a \times {}_t N_a$$

and used to calculate the weighted average growth rate,  ${}_t\text{MGR}$

$$\text{VII. } {}_t\text{MGR} \leftarrow \left[ \sum_{a=3}^{a=15} {}_t \Delta W_a \times {}_t N_a \times {}_t\text{MAT}_a \right] \div {}_t\text{MSN}$$

Table 1 . Number of cod samples in 4T - 4Vn (Jan - April) for the various fisheries. Values across the bottom are total catches (mt) and number values down the right hand side are total numbers at age, caught after the appropriate weighing factors have been applied.

Age	Gulf OT	Bight OT	Danish Seine	Long Lines	Gill Nets	Catch at Age x 10 <sup>3</sup>
3	113	5	712	240	12	547
4	847	225	2582	732	62	2733
5	1005	910	1763	1012	48	3134
6	732	704	1097	475	212	2266
7	457	316	490	302	347	1496
8	101	76	100	49	166	400
9	46	113	48	30	132	269
10	39	41	47	7	106	193
11	22	34	13	5	57	107
12	7	56	6	1	24	59
13	7	19	1	1	26	43
14	0	12	1	0	2	8
15	0	3	0	0	0	2
16+	1	30	0	0	2	16

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Numbers of cod x 10 <sup>3</sup>	5542	1046	2218	1405	1051.4	11354.4
	France	92				
Tons of cod	9420.9	2267.1	3016.3	2248.5	3942.8	21095.6
	France	200				

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able *200*. Catch removed at age.

Age	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
3	173	133	192	294	412	324	396	359	506	535	75	1	16	255
4	728	638	1034	2120	2968	2336	2612	2372	3341	3535	3967	3304	1720	2123
5	1559	1462	1915	5596	7832	6165	6727	6109	8607	9107	8983	13921	10887	4352
6	2703	2113	3104	5037	7049	5549	6648	6037	8506	9000	12515	9475	1889	16021
7	2772	2127	3065	4713	6596	5191	6331	5750	8101	8571	7144	8313	7870	14742
8	2495	1874	2643	3799	5319	4186	5223	4743	6683	7071	1736	2661	4290	6390
9	3327	2365	3141	3593	5029	3959	5381	4887	6885	7286	795	777	1480	3180
10	2183	1582	2146	2680	3751	2952	3878	3522	4961	5250	1812	506	589	984
11	901	638	843	942	1319	1038	1424	1293	1823	1929	388	741	153	392
12	478	351	483	636	890	701	902	819	1153	1221	279	385	178	137
13	138	106	153	235	329	259	316	287	405	428	76	188	37	102
14	128	94	130	173	243	191	245	222	314	332	93	174	26	37
15	79	58	80	106	148	117	150	136	192	203	51	33	36	50

Age	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
3	100	464	1498	700	310	327	26	2	1541	378	1229	2379	332	547
4	970	5504	7055	7068	8140	4936	3395	2476	14294	4396	3170	9902	4059	2733
5	6728	6148	10689	5503	8086	12530	14972	7313	11326	11878	3862	6096	9089	3134
6	5863	9292	4505	4586	4674	3571	11925	8941	7193	5982	9851	2350	4996	2266
7	12038	4481	3423	3040	2916	2516	4194	6127	8479	4492	3631	3173	1513	1496
8	9261	8524	1841	1735	1276	2136	1905	2567	5128	3455	2188	1250	834	400
9	2760	5534	2262	407	753	917	1444	1237	1370	2204	2081	1033	423	269
10	1133	1845	1890	1021	434	785	727	554	719	740	1186	738	220	193
11	347	1004	867	901	899	212	569	156	452	380	300	571	143	107
12	149	423	357	383	698	283	360	432	127	130	178	113	106	59
13	103	150	242	171	259	292	239	42	92	63	74	47	34	43
14	88	52	76	82	139	55	139	103	34	35	26	40	17	8
15	24	124	42	23	65	21	30	144	72	14	4	5	11	2

Table 3. Selection at age for the weighted combination of the different gear types.

Age	1960	1961	1962	1963	1964	1965	1966	1967
3	0.619	0.000	0.022	0.236	0.330	0.748	0.572	0.301
4	0.753	0.678	0.385	0.343	0.562	0.696	0.664	0.722
5	0.891	0.722	0.593	0.615	0.696	0.750	0.846	0.857
6	0.356	0.859	0.764	0.801	0.776	0.810	0.899	0.871
7	0.989	0.964	0.909	0.894	0.894	0.906	0.962	0.938
8	0.989	1.000	0.992	0.969	0.972	0.943	0.982	0.952
9	0.956	0.992	1.000	1.000	1.000	0.995	1.000	0.931
10	0.975	0.872	0.807	0.939	0.929	1.000	0.988	0.977
11	0.754	0.776	0.386	0.810	0.740	0.934	0.908	1.000
12	0.299	0.457	0.817	0.603	0.775	0.769	0.766	0.993
13	0.247	0.271	0.527	0.887	0.337	0.535	0.544	0.817
14	0.113	0.167	0.287	0.611	0.551	0.789	0.441	0.885
15	0.598	0.324	0.092	0.934	0.287	0.734	0.394	0.531

Age	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
3	0.252	0.225	0.041	0.081	0.204	0.139	0.196	0.201		0.118
4	0.616	0.563	0.590	0.651	0.437	0.470	0.615	0.606		0.467
5	0.876	0.842	0.752	0.818	0.744	0.774	0.851	0.849		0.831
6	0.968	0.942	0.909	0.891	0.912	0.901	0.973	0.972		0.814
7	0.969	0.954	0.940	0.912	0.939	0.961	1.000	0.997		0.724
8	0.953	0.988	0.918	0.932	1.000	0.995	0.994	0.995		0.831
9	0.957	0.969	0.941	0.960	0.964	1.000	0.930	0.938		0.747
10	1.000	1.000	0.931	0.941	0.913	0.976	0.998	1.000		0.943
11	0.999	0.952	0.958	0.931	0.779	0.920	0.880	0.889		0.905
12	0.983	0.871	0.925	0.893	0.778	0.802	0.811	0.820		0.953
13	0.941	0.685	0.841	1.000	0.779	0.507	0.651	0.663		0.963
14	0.931	0.955	0.765	0.604	0.838	0.945	0.055	0.055		0.995
15	0.471	0.741	1.000	0.823	0.919	0.671	0.198	0.197	NOT analysed to Date	1.000

Table 4. Cohort Analysis Numbers at Age X 10<sup>3</sup> M = 0.2

AGE	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
3	113987	109640	113532	108046	78707	70001	83924	106681	110471	143344	134847	46119	60134	41747	61261	52155
4	76132	93168	89645	92779	88195	64067	57019	68353	87018	89988	116876	110335	37758	49219	33949	50066
5	62446	61673	75703	72460	74043	69522	50340	44320	53817	68221	70478	92101	87345	29357	38376	26917
6	41633	49716	49171	60247	54262	53534	51342	35128	30758	36274	47615	49574	62809	61662	20098	25332
7	27950	31641	38792	37449	44769	38048	38809	36020	23298	17486	21555	27660	32015	49715	35988	11150
8	17732	20376	23981	28987	26396	30685	26454	26046	24288	11745	6561	11184	15124	19090	27364	18572
9	12106	12260	14987	17243	20295	16799	21336	16933	17033	13838	3218	3801	6749	8501	9848	14024
10	6572	6901	7898	9428	10866	12066	10172	12599	9442	7116	4737	1915	2409	4186	4148	4661
11	3552	3405	4219	4524	5294	5502	7208	4819	7129	3241	1567	2239	1110	1440	2537	2371
12	1755	2093	2211	2691	2852	3141	3566	4613	2775	4187	908	932	1163	771	824	1763
13	817	1004	1396	1373	1628	1530	1937	2103	3036	1229	2323	491	415	791	507	540
14	461	544	726	1005	912	1035	1018	1300	1463	2119	619	1833	232	306	555	322
15	346	261	360	477	666	527	675	612	864	913	1435	423	1344	167	217	375

AGE	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
3	61216	106187	94971	57488	53455	76274	30455	52562	60673	42499	76794	79630
4	42281	48764	86305	77476	46771	43742	62446	23540	42692	48563	32642	62574
5	36010	28233	33529	63295	58965	35221	33573	38193	15296	32085	30800	23053
6	16475	19811	18136	20135	40484	34730	22220	17239	20522	9029	20753	16993
7	12332	9413	12070	10619	13254	22356	20344	11684	8701	7889	5266	12471
8	5074	7000	4956	7244	6418	7057	12759	8984	5501	3839	3588	2942
9	7493	2489	4161	2903	3998	3531	3455	5807	4230	2524	2012	2183
10	6475	4088	1669	2726	1547	1967	1772	1589	2760	1580	1132	1265
11	2147	3591	2423	974	1521	609	1109	800	631	1187	626	728
12	1033	973	2125	1171	606	731	357	499	311	246	455	383
13	1061	523	450	1108	702	170	208	178	291	94	99	277
14	306	650	273	134	643	359	102	87	89	172	34	50
15	217	182	458	98	60	401	201	53	39	49	104	13



TABLE 5. Fishing Mortality (F) from Cohort Analysis M= 0.2

AGE	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964
3	.002	.001	.002	.003	.006	.005	.005	.004	.005	.004	.001	.000	.000	.007	.002
4	.011	.088	.013	.026	.038	.041	.052	.039	.043	.044	.038	.034	.052	.049	.032
5	.028	.027	.028	.089	.124	.103	.160	.165	.194	.160	.152	.183	.148	.179	.215
6	.074	.048	.072	.097	.155	.122	.154	.211	.365	.320	.343	.237	.034	.338	.389
7	.116	.077	.091	.150	.178	.163	.199	.194	.485	.78-	.456	.404	.317	.397	.462
8	.169	.107	.130	.156	.252	.163	.246	.225	.363	1.095	.346	.305	.376	.462	.468
9	.362.	.240	.263	.262	.320	.302	.327	.384	.592	.872	.319	.256	.278	.518	.548
10	.458	.292	.357	.377	.481	.315	.541	.370	.869	1.394	.550	.345	.315	.301	.359
11	.329	.232	.250	.262	.322	.234	.246	.352	.332	1.072	.320	.455	.165	.358	.164
12	.358	.205	.276	.303	.423	.283	.328	.218	.615	.389	.415	.610	.185	.219	.223
13	.207	.124	.129	.210	.253	.207	.199	.163	.160	.486	.037	.550	.104	.154	.254
14	.367	.212	.221	.211	.349	.228	.309	.209	.271	.190	.182	.111	.132	.144	.193
15	.289	.280	.280	.280	.280	.280	.280	.280	.280	.280	.040	.090	.030	.400	.130
AGE	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977		
3	.010	.027	.007	.004	.006	.001	.000	.058	.008	.023	.064	.005	.008		
4	.130	.204	.175	.110	.073	.084	.065	.292	.231	.086	.255	.148	.049		
5	.291	.398	.243	.310	.247	.329	.261	.467	.421	.327	.236	.395	.162		
6	.520	.360	.296	.335	.218	.394	.335	.443	.484	.756	.339	.309	.159		
7	.587	.366	.442	.311	.304	.430	.361	.617	.553	.618	.588	.382	.141		
8	.708	.513	.320	.335	.394	.398	.514	.587	.553	.579	.446	.297	.162		
9	.573	.406	.199	.223	.430	.509	.490	.577	.544	.785	.602	.265	.146		
10	.575	.390	.323	.339	.383	.733	.373	.595	.723	.644	.726	.242	.184		
11	.631	.591	.325	.528	.275	.534	.333	.599	.745	.745	.759	.291	.177		
12	.308	.482	.571	.451	.311	1.071	1.061	.500	.340	1.002	.712	.298	.186		
13	.367	.291	.449	1.012	.344	.472	.319	.676	.499	.330	.812	.481	.188		
14	.197	.321	.150	.829	.605	.273	.382	.465	.595	.394	.299	.806	.194		
15	.450	.240	.150	.170	.270	.790	.500	.500	.350	.120	.120	.124	.195		

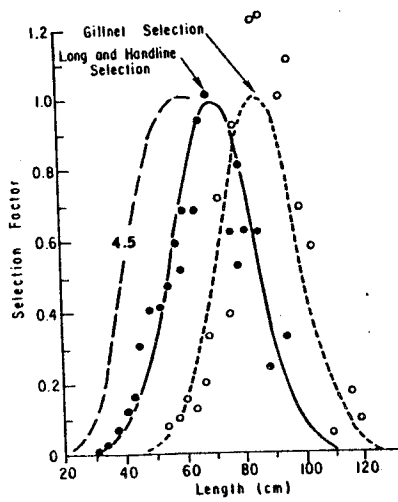


Fig. 1. Selection of different gear types within the 4T-4Vn (January-April) cod fishery.

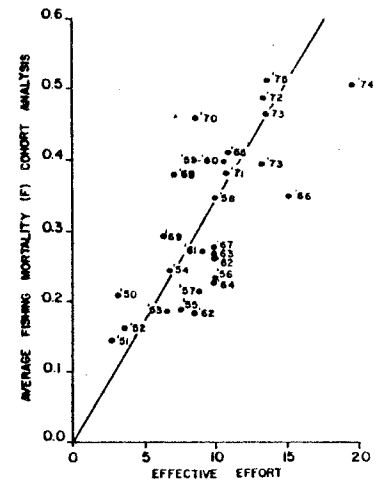


Fig. 2. Average fishing mortality from VPA age 3-15 versus fishing effort.

34.

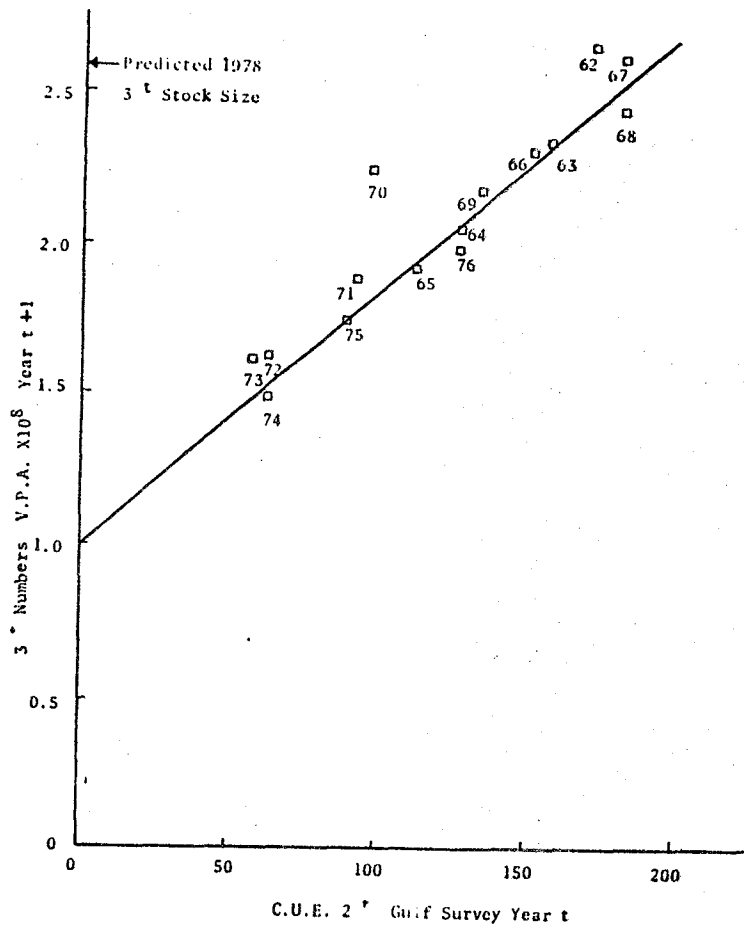


Fig. 3. Relationship between the cod of 3+ from VPA and 2+ cod the fall before from Gulf surveys.

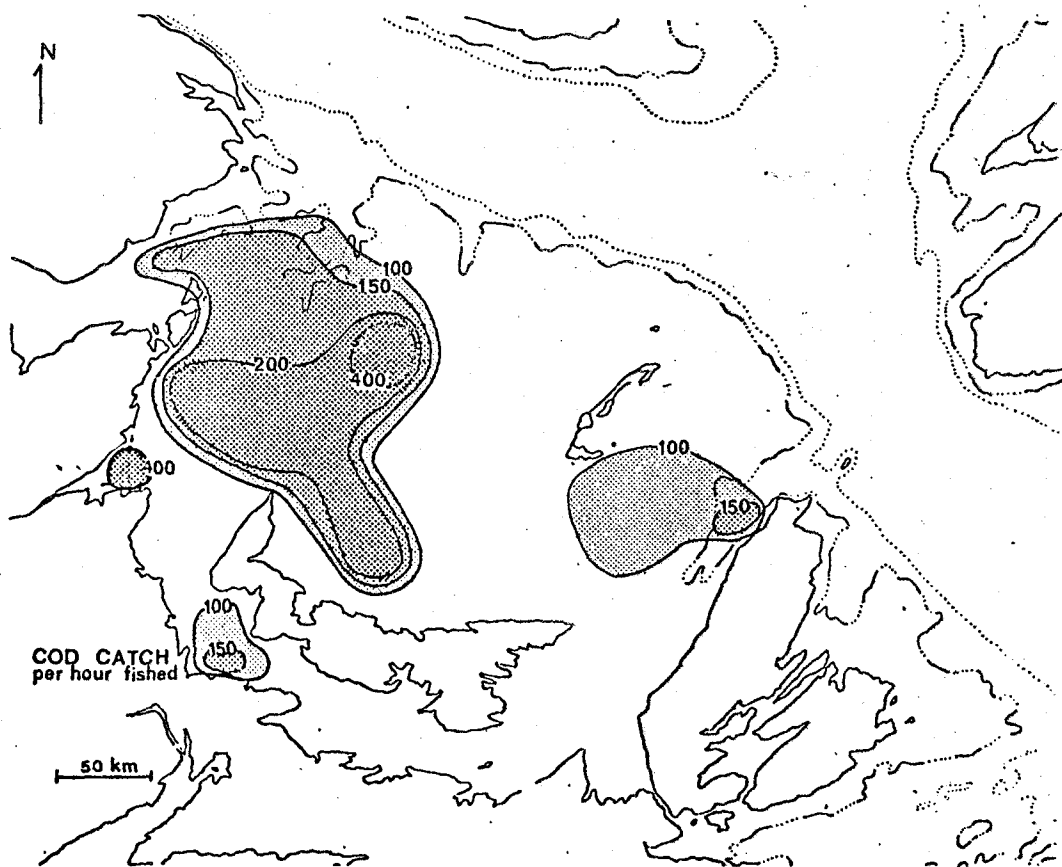


Fig. 4. Average catch per hour fished from research vessel survey between 1971 and 1977 in October.

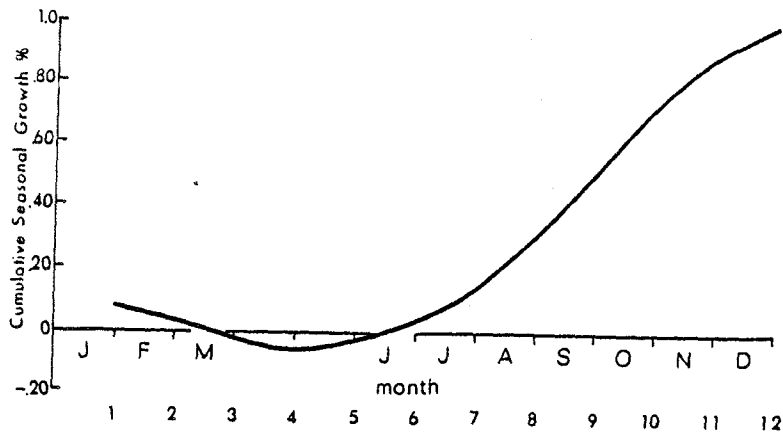


Fig. 7. Seasonal growth of cod (cumulative) based on laboratory experimentation.

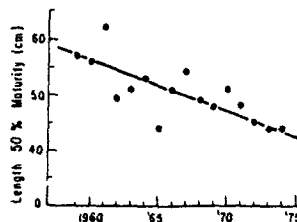
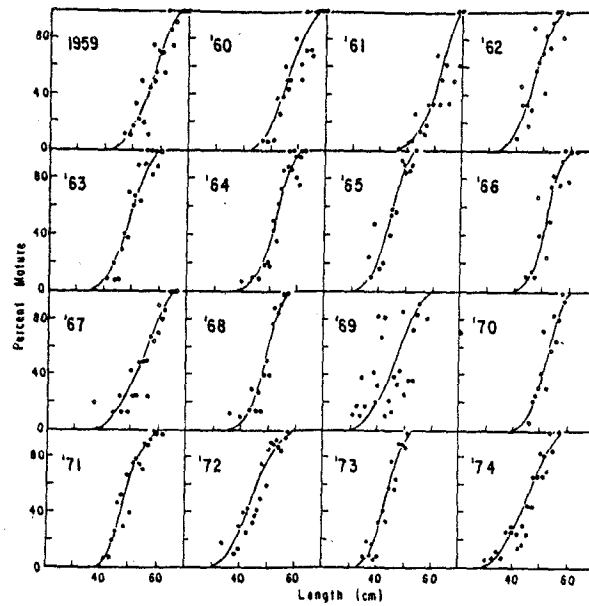


Fig. 8. Maturity ogives for females between 1959-74.

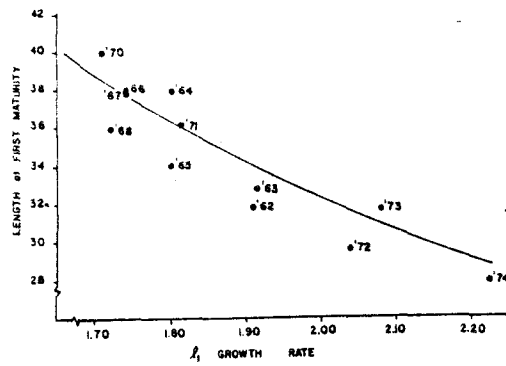


Fig. 9. The mean age of maturity as a function of the  $l_1$  growth rate.



Fig. 10. Distribution of cod eggs in the Gulf of St. Lawrence during peak spawning (May-June).

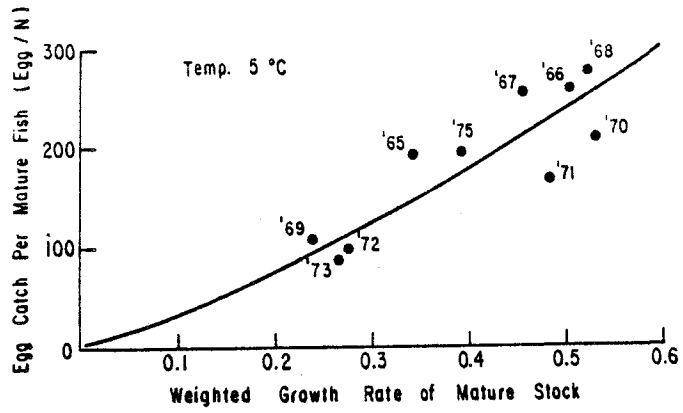


Fig. 11. The relationship between weighted mean growth rate for mature fish egg catch per mature individual. The relationship has been corrected to 5°C.

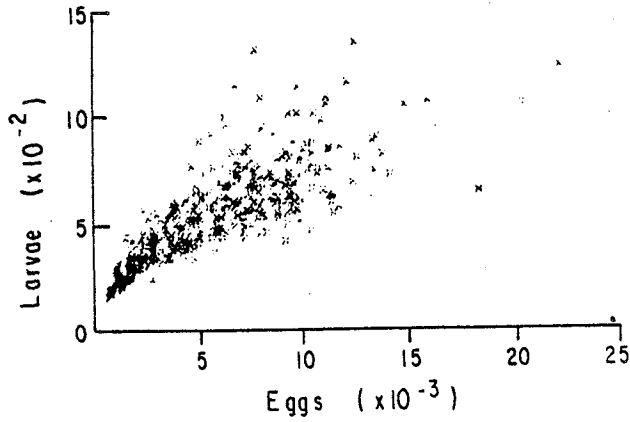


Figure 12. Simulated relationship between the number of eggs at peak spawning and the numbers of larvae 50 days later.

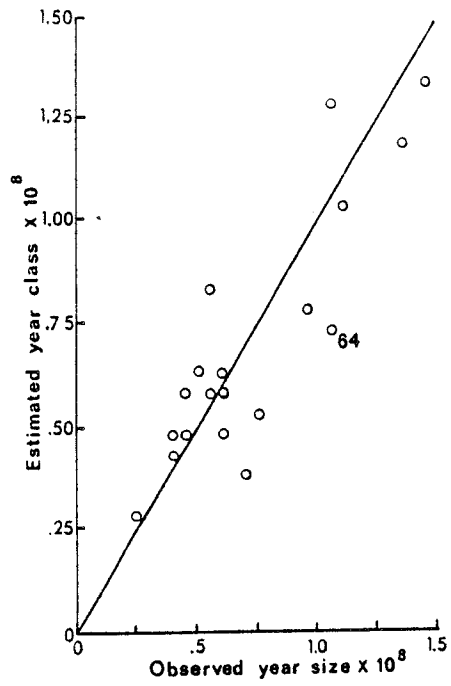


Fig. 13. The relationship between observed and estimated year-class size using equation (20).

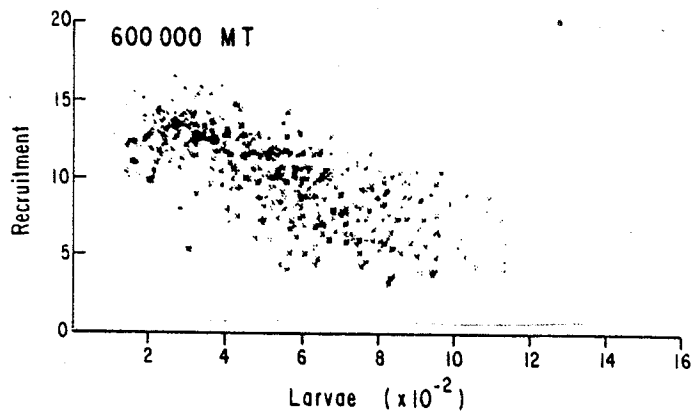


Fig. 14. Relationship between year-class size x 10<sup>7</sup> and larvae for a fixed mackerel biomass and varying cod biomass.

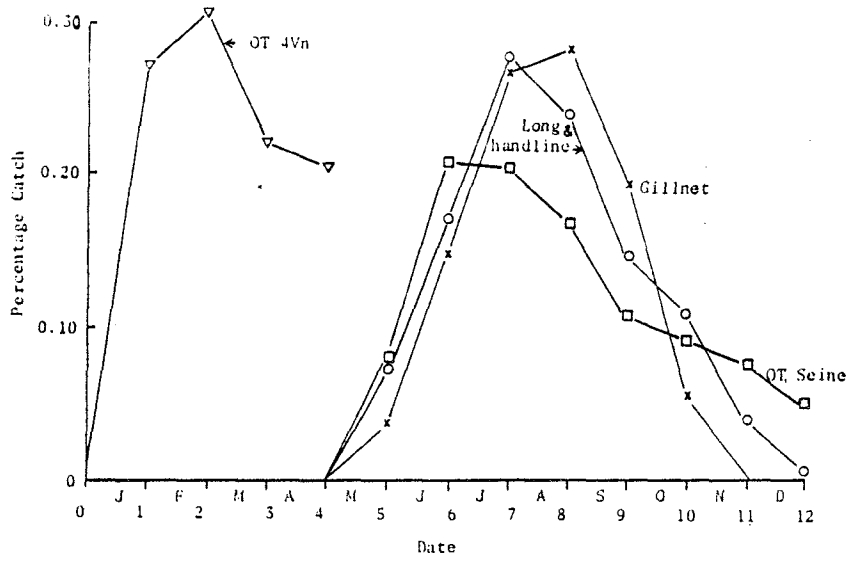


Fig. 15. Seasonal distribution of fishery between 1960 and 1976.

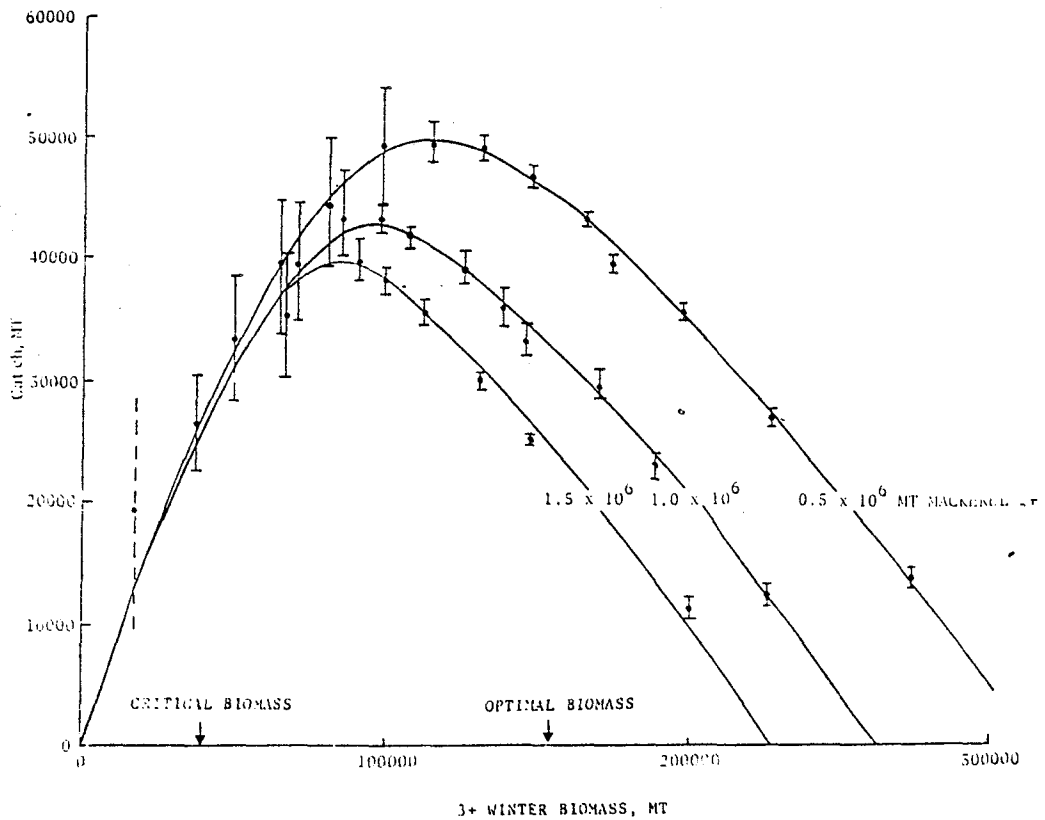


Fig. 16. Relationship between catch and biomass at different levels of mackerel biomass.



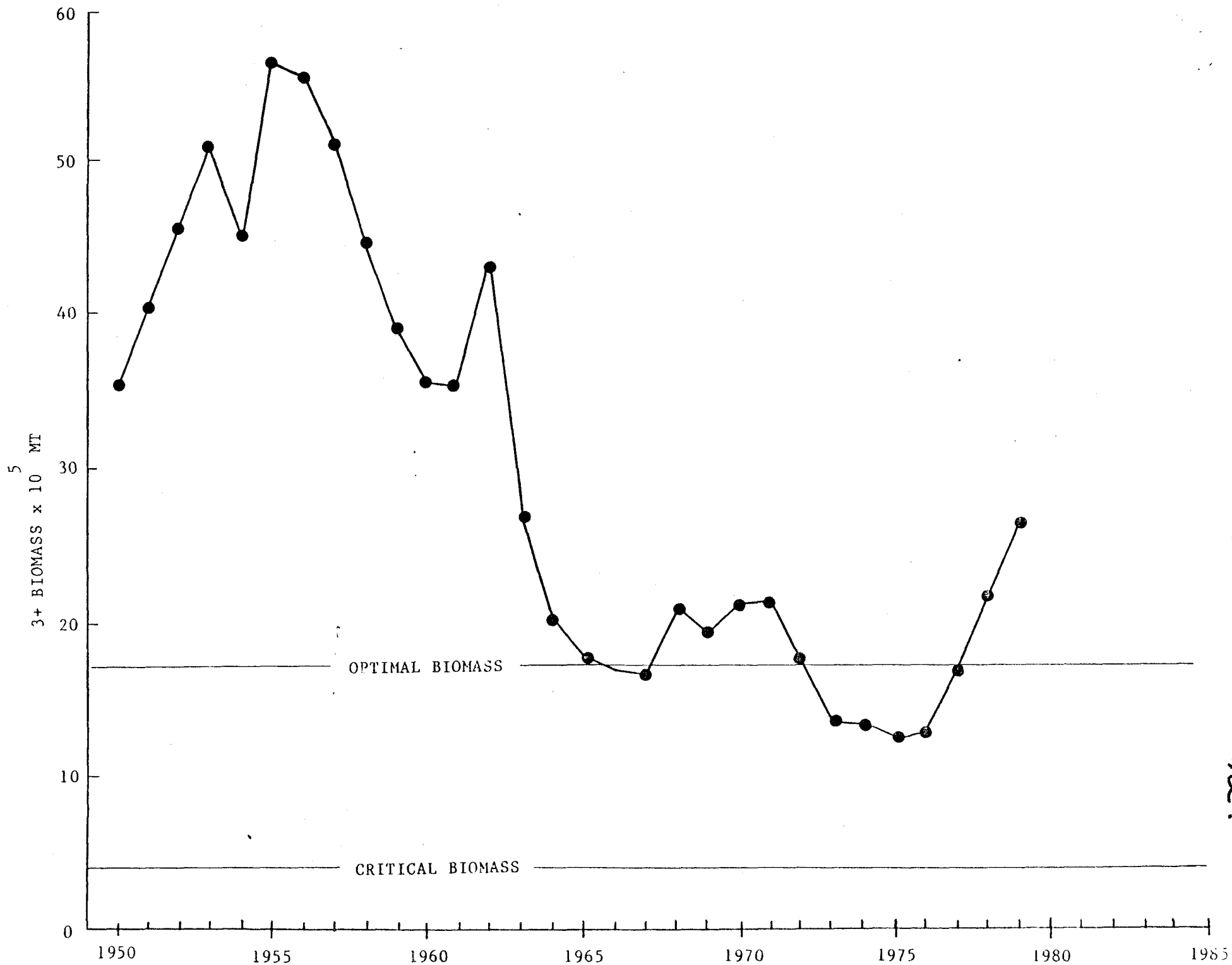


Fig. 17. Relationship between time and biomass.

112.

## APPENDIX

Table 1A . Nominal catches (mt) for Canadian cod fishery in 4T by month and gear.

Catch	4T Cod												Total Catch
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	
Traps	-	-	-	-	1.7	10.1	12.2	-	-	4.2	-	-	28.1
Drift Nets	-	-	-	-	2.4	2.3	48.1	72.4	4.6	-	-	-	150.0
Fixed Gill Nets	-	-	-	5.5	193.0	792.6	1163.1	883.3	520.7	166.4	68.2	-	3792.8
Handlines	-	-	-	-	37.0	199.3	302.8	223.9	154.1	97.4	94.6	5.2	1114.3
Misc.	-	-	-	-	103.3	138.6	155.2	126.1	74.6	81.8	17.4	-	696.9
Unspec.	-	-	-	-	8.7	45.8	13.5	12.5	30.2	50.7	52.6	-	214.1
Shrimp Trawl	-	-	-	-	19.6	1.0	4.2	5.4	9.3	48.5	45.2	-	133.2
Side OT	-	-	-	9.4	1614.6	1427.2	1367.4	1400.5	730.3	933.7	1392.3	32.7	8908.0
Stern OT	-	-	10.9	4.6	111.4	0.4	1.1	7.1	11.5	103.1	106.2	0.5	356.7
Longlines	-	-	-	-	-	10.1	78.2	28.5	15.0	16.5	32.8	11.1	192.1
Purse Seine	-	-	-	-	-	0.8	0.8	-	-	-	-	-	1.6
Danish Seine	-	-	-	-	312.8	266.8	298.1	408.6	364.8	299.2	708.7	12.3	2671.3
Scottish Seine	-	-	-	-	39.0	31.3	83.0	35.1	47.2	13.0	70.8	14.1	333.5
Midwater	-	-	-	-	-	-	1.4	1.5	-	-	-	20.1	23.0
Pair Seine	-	-	-	-	-	-	1.6	0.4	-	-	-	-	2.0

Table 1B . Nominal catches (mt) for Canadian cod fishery in 4Vn from January - April by gear.

Catch	4Vn Jan - April				Total
	Jan	Feb	Mar	Apr	
Side OT	361.3	358.2	13.9	48.2	781.6
Stern OT	388.9	414.2	676.4	6.0	1485.5
Longline	-	-	-	3.0	3.0
Danish Seine	-	-	-	6.3	6.3
Midwater	-	-	1.6	-	1.6

Table 2A. Catch, effort and CUE for Canadian and Foreign vessels in area 4T.

Year	CANADA			FOREIGN		
	CATCH (mt)	EFFORT (days fished)	CATCH/DAY (CUE)	CATCH (mt)	EFFORT (days fished)	CATCH/DAY (CUE)
<b>OT &lt; 50</b>						
1970	8087	3232	2.50	-	-	-
71	12939	3483	3.71	-	-	-
72	5398	3111	1.74	0	0	0
73	3849	2737	1.41	-	-	-
74	2086	2047	1.41	-	-	-
75	2868	1969	1.46	-	-	-
76	1900	1328	1.43	-	-	-
77	-	-	-	-	-	-
<b>OT &gt; 50 (3), i.e. 51 - 150</b>						
1970	4561	1355	3.43	-	-	-
71	4863	1773	2.74	-	-	-
72	5554	1751	2.74	0	0	0
73	2560	1163	2.20	-	-	-
74	1481	909	1.63	-	-	-
75	3078	1278	2.40	-	-	-
76	1151	689	1.67	-	-	-
77	-	-	-	-	-	-
<b>OT &gt; 50 (4), i.e. 151 - 500</b>						
1970	4175	400	10.44	-	-	-
71	4990	520	9.60	-	-	-
72	7692	774	9.64	-	-	-
73	2916	407	7.16	-	-	-
74	2288	373	6.13	-	-	-
75	1911	308	6.20	-	-	-
76	2036	222	9.17	-	-	-
77	-	-	-	-	-	-
<b>OT &gt; 50 (5), i.e. 501 - 900</b>						
<b>OT &gt; 50 (6,7), i.e. 901 - 1500; &gt;1500</b>						
1970	2028	109	18.56	773	38	20.34
71	1501	123	12.20	23	3	7.67
72	4834	325	14.87	1270	79	16.08
73	758	97	7.81	636	30	20.20
74	1163	115	10.11	8538	305	27.99
75	1513	185	8.18	3251	163	19.94
76	1241	136	9.12	58	5	11.60
77	-	-	-	-	-	-
$\text{Weighted CUE} = \frac{\sum \text{effort}_i \text{catch}_i \times \text{CUE}_i}{\text{Total effort catch}}$						
<b>Σ OT &gt; 50</b>						
	CANADA			FOREIGN		
1970	8.95			20.34		
71	7.00			7.67		
72	9.17			16.08		
73	5.20			20.20		
74	5.71			27.99		
75	4.86			19.94		
76	8.68			11.60		
77	-			-		

Table 2B. (cont'd) 4T

YEAR	CANADA			FOREIGN		
	CATCH (mt)	EFFORT (days fished)	CATCH/DAY (CUE)	CATCH (mt)	EFFORT (days fished)	CATCH/DAY (CUE)
<b>Longline and Handline</b>						
1970	957	447	2.14	-	-	-
71	1352	620	2.18	-	-	-
72	494	352	1.40	-	-	-
73	154	98	1.57	-	-	-
74	39	31	1.26	686	125	5.49
75	48	74	0.65	-	-	-
76	-	-	-	-	-	-
77	-	-	-	-	-	-
<b>Gillnet</b>						
1970	1030	363	2.84	-	-	-
71	757	246	3.08	-	-	-
72	786	284	2.77	-	-	-
73	623	256	2.43	-	-	-
74	-	-	-	-	-	-
75	-	-	-	-	-	-
76	-	-	-	-	-	-
77	-	-	-	-	-	-
<b>Seine</b>						
1970	962	337	2.85	-	-	-
71	1153	581	1.98	-	-	-
72	1188	407	2.92	-	-	-
73	890	408	2.18	-	-	-
74	-	-	-	-	-	-
75	-	-	-	-	-	-
76	151	65	2.32	-	-	-
77	-	-	-	-	-	-

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Table 3A Catch, effort and CUE for Canadian and Foreign vessels in area 4Vn.

Year	CANADA			FOREIGN		
	CATCH (mt)	EFFORT (days fished)	CATCH/DAY (CUE)	CATCH (mt)	EFFORT (days fished)	CATCH/DAY (CUE)
<b>OT &lt; 50</b>						
1970	-	-	-	-	-	-
71	-	-	-	-	-	-
72	-	-	-	-	-	-
73	-	-	-	-	-	-
74	-	-	-	-	-	-
75	-	-	-	-	-	-
76	-	-	-	-	-	-
77	-	-	-	-	-	-
<b>OT &gt; 50 (3), 51-150</b>						
1970	-	-	-	-	-	-
71	56	13	4.31	-	-	-
72	44	24	1.83	-	-	-
73	-	-	-	-	-	-
74	3	4	.75	-	-	-
75	-	-	-	-	-	-
76	18	8	2.25	-	-	-
77	-	-	-	-	-	-
<b>OT &gt; 50 (4), 151-500</b>						
1970	3085	354	8.71	-	-	-
71	3549	448	7.92	-	-	-
72	3435	375	9.16	73	11	6.64
73	3844	464	8.28	-	-	-
74	3752	477	7.87	-	-	-
75	2605	296	8.80	-	-	-
76	4692	474	9.90	-	-	-
77	-	-	-	-	-	-
<b>OT &gt; 50 (5), 501-900</b>						
1970	923	68	13.57	11559	414	27.92
71	2504	225	11.13	4646	245	18.96
72	2740	257	10.66	12559	748	16.79
73	3270	280	11.68	11663	773	15.09
74	5665	559	10.13	6504	331	19.65
75	4021	435	9.40	9347	228	19.07
76	6102	595	10.26	1762	178	9.90
77	-	-	-	-	-	-
<b>OT &gt; 50 (6,7) 901-1500; &gt;1500</b>						
1970	923	68	13.57	11559	414	27.92
71	2504	225	11.13	4646	245	18.96
72	2740	257	10.66	12559	748	16.79
73	3270	280	11.68	11663	773	15.09
74	5665	559	10.13	6504	331	19.65
75	4021	435	9.40	9347	228	19.07
76	6102	595	10.26	1762	178	9.90
77	-	-	-	-	-	-
$\text{WEIGHTED CUE} = \frac{\text{effort catch}_i \times \text{CUE}_i}{\text{Total effort catch}}$						
<b>I OT &gt; 50</b>						
1970	CANADA			FOREIGN		
71	9.83			27.92		
72	9.20			18.96		
73	9.79			16.73		
74	9.84			15.09		
75	9.22			19.65		
76	9.16			19.07		
77	10.10			9.90		

Table 3B (cont'd) 4Vn

Year	CANADA			FOREIGN		
	CATCH (mt)	EFFORT (days fished)	CATCH/DAY (CUE)	CATCH (mt)	EFFORT (days fished)	CATCH/DAY (CUE)
<b>Longline and Handline</b>						
1970	223	48	4.65	-	-	-
71	117	24	4.88	-	-	-
72	27	7	3.86	-	-	-
73	3	2	1.50	-	-	-
74	58	21	1.81	15	7	2.14
75	2	2	1.00	-	-	-
76	-	-	-	-	-	-
77	-	-	-	-	-	-
<b>Gillnet</b>						
1970	-	-	-	-	-	-
71	-	-	-	-	-	-
72	-	-	-	-	-	-
73	-	-	-	-	-	-
74	-	-	-	-	-	-
75	-	-	-	-	-	-
76	-	-	-	-	-	-
77	-	-	-	-	-	-
<b>Seine</b>						
1970	-	-	-	-	-	-
71	6	1	6.0	-	-	-
72	-	-	-	-	-	-
73	40	14	3.08	-	-	-
74	3	2	1.50	-	-	-
75	-	-	-	-	-	-
76	7	2	3.50	-	-	-
77	-	-	-	-	-	-

45.

Table 4 . Total catches (mt) and percentage catch for different gear and vessel types within months.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
4W, OT < 50	85	13	8	862	950	745	50	30	94	54	22	54	2892
%	3	.4	.2	30	33	26	2	1	3	2	.8	2	100
4W, OT > 50	27393	31942	23137	21541	15643	9270	1700	2112	3392	2269	2530	11278	148775
%	18.4	21.5	15.6	14.5	10.5	6.2	1.1	1.4	2.3	1.5	1.6	7.6	100
4T, OT < 50	58	0	0	553	18930	30893	34268	23944	21191	17029	10003	773	157793
%	-	-	-	.3	12	19.6	21.7	15.2	13.4	10.8	6.3	.5	100
4T, OT > 50	21431	5628	1325	17476	16516	21213	13512	9388	7905	16600	12291	20388	178656
%	12	3.2	.7	9.8	9.2	11.9	7.6	5.2	4.4	9.3	6.9	11.4	100
4T, Gillnet	5	1	4	58	3970	15101	26855	28798	19516	5748	742	151	101146
%	0	0	0	.06	3.92	14.9	26.6	28.5	19.3	5.68	.73	.15	100
4T, Longline	0	2	18	134	7397	17564	27939	24041	14738	10803	3960	727	107337
%	0	0	0	.12	6.9	16.4	26.0	22.4	13.7	10.1	3.69	.68	100

Table 5. 3+ Biomass, 3 and 4+ Numbers and Average 3+ Weight

DATE	3+ NUMBERS	3+ BIOMASS MT	AVERAGE WEIGHT W	4+ NUMBERS
1950	365491	354429	.970	251505
1951	392676	405232	1.032	283037
1952	422614	456011	1.079	309083
1953	436703	509540	1.167	328658
1954	408879	449670	1.100	330172
1955	366452	562851	1.536	296451
1956	353794	554863	1.568	269870
1957	359521	511663	1.423	252841
1958	371385	446118	1.201	260914
1959	400296	391884	.979	256953
1960	412732	356253	.863	277886
1961	348601	353630	1.014	302483
1962	308600	434382	1.408	248467
1963	266945	263725	.988	225198
1964	235666	202722	.860	174406
1965	208242	189278	.909	156088
1966	192111	172822	.900	130898
1967	231893	166481	.718	125708
1968	261517	206075	.788	166548
1969	245352	194929	.794	187873
1970	228406	212886	.932	174955
1971	227120	216833	.955	150856
1972	189026	179494	.950	158522
1973	161273	138469	.859	108673
1974	161729	138304	.855	101112
1975	149755	128058	.855	107248
1976	174837	130720	.748	97512
1977	202569	169495	.836	122939



Table 8 Nominal catches by Canada for Gillinets in 4T and 4Vn in different years and months.

	CANADA												TOTAL
	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	
4T													
1960					0	0	2	0	2	0	0	0	4
1961					0	6	66	30	53	15	1	0	171
1962					18	103	246	266	398	105	8	2	1146
1963					7	342	1115	693	218	18	3	0	2396
1964													
1965				5	26	497	1238	997	646	130	31	1	3571
1966				0	86	1792	2108	2697	2330	248	104	49	9414
1967				0	85	1522	2703	3479	1735	378	38	2	9942
1968				0	616	1421	3442	3745	3021	649	39	0	12933
1969				10	315	1327	2692	2878	1655	554	128	19	9578
1970				5	451	730	2573	2912	1778	1188	92	60	9789
1971				2	354	1766	2192	2731	1937	383	11	0	9376
1972	0		2	20	487	1002	2030	2143	1424	694	51	9	7862
1973	4		1	0	88	1492	2015	2461	1490	541	39	0	8131
1974				0	65	905	2083	1480	1107	315	102	0	6057
1975				6	1089	1089	1336	1439	1064	235	60	9	6327
1976				10	283	1107	1214	847	658	295	35	0	4449
4Vn													
1960	0	0	0	0	0	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	4	5	7	0	0	0	16
1962	0	0	0	0	0	0	3	2	27	1	0	1	34
1963	0	0	0	0	3	4	15	53	23	12	0	0	110
1964													
1965	0	0	0	0	0	0	33	49	28	0	0	0	110
1966	0	0	0	0	0	5	47	30	19	4	0	0	105
1967	0	0	0	0	0	0	12	71	46	4	6	0	139
1968	0	0	0	0	0	15	32	28	23	12	0	0	110
1969	0	0	0	0	0	0	22	43	35	12	3	0	115
1970	0	0	0	6	0	1	12	37	20	5	0	0	81
1971	0	0	0	0	0	4	1	14	18	4	0	0	41
1972	0	0	0	0	2	0	1	39	67	106	33	0	248
1973	0	0	0	0	0	3	139	180	147	86	67	27	649
1974	0	0	0	0	0	132	120	88	147	156	61	10	714
1975	0	0	0	0	99	58	99	199	109	37	3	0	604
1976	0	0	0	0	9	19	48	118	57	53	10	0	314
1977													

Table 9 Catches by Canadian vessels in 4T and 4Vn by month and tonnage class.

	> 50 TONS (VESSEL)												TOTAL
	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	
4T													
1960	340	18	6	62	624	569	673	408	374	392	532	218	4216
1961	859	0	0	224	698	1247	690	718	591	408	454	149	6038
1962	30	0	0	210	1702	1225	1329	865	1115	1253	511	339	8579
1963	884	100	0	235	3429	2183	1956	1824	1177	696	451	149	13084
1964	141	0	0	355	2120	1796	2360	1268	843	461	440	466	10270
1965	1429	864	0	1531	3847	2211	929	531	503	591	960	2442	15838
1966	1121	149	94	1448	1391	922	213	381	301	530	1348	1401	9299
1967	1684	205	0	145	2026	1403	435	125	191	349	563	1290	8416
1968	1088	0	0	2429	3025	862	683	536	337	654	564	1719	11897
1969	1795	830	1083	2242	1840	897	850	510	387	435	1021	1611	13501
1970	3115	1637	99	1122	2166	1019	795	465	335	493	747	953	12946
1971	1740	1228	30	2358	2447	1180	862	379	414	382	713	1346	13079
1972	3928	318	0	1936	5938	3413	501	267	227	227	768	2056	19579
1973	430	0	0	1067	1346	885	372	252	125	228	698	1609	7012
1974	882	0	0	536	1298	370	103	94	154	328	688	2382	6835
1975	68	1	0	253	2790	467	181	194	165	530	782	2205	7636
1976	1890	279	10	1301	2014	446	522	468	592	291	124	33	7970
	6.5	0	3.3	22.3	683	118	59.7	103	72.3	446.5	926.8	19.8	2461
4Vn													
1960	162	420	49	242	650	507	4	10	0	1	31	7	2083
1961	202	58	0	51	391	283	31	9	0	126	22	38	1211
1962	35	696	121	368	457	1669	242	46	2	236	17	56	3945
1963	955	536	512	820	1622	689	23	10	12	109	78	113	5479
1964	1146	1430	4877	1527	2538	936	184	195	305	2	83	420	11173
1965	689	4415	2005	3589	1508	1263	124	21	93	66	142	257	14172
1966	1906	2708	2221	3420	748	810	243	202	38	75	50	285	12706
1967	685	737	416	0	166	254	131	265	216	171	104	527	3672
1968	2308	1699	476	1573	655	397	41	0	22	0	63	663	7897
1969	1149	1871	1244	531	1296	499	55	112	899	140	110	329	8235
1970	886	2196	1017	321	585	705	477	394	51	899	73	493	8097
1971	806	2201	897	2779	403	376	28	475	986	112	113	637	9813
1972	2705	1501	499	2018	1227	106	19	57	627	36	188	235	9218
1973	4517	969	93	2052	1077	135	50	8	8	90	93	302	9394
1974	2101	4122	2588	994	1072	295	27	34	7	46	26	371	11683
1975	2190	2320	1962	402	504	173	8	7	84	23	59	524	8266
1976	4187	3266	3480	786	322	136	2	1	33	87	511	3036	15847
1977	764	797	610	68	422	37	11	266	9.2	50.4	566.7	2685	5884

187

Table 10. Catches by Canadian vessels < 50 tons in 4T and 4Vn by month.

O.T. < 50 TONS (VESSEL)													
	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
<b>4T</b>													
1960	16	0	0	154	1302	1443	1772	1448	1325	1248	999	97	9804
61	13	0	0	0	815	2998	2459	2145	2081	1470	1218	82	13281
62	0	0	0	0	1668	3685	4014	2479	2975	2745	841	277	18684
63	0	0	0	0	1807	3833	4327	3637	2551	1371	780	54	18360
64	0	0	0	0	1642	2676	4296	2850	2071	1323	645	16	15519
65	0	0	0	99	3686	3123	3189	1574	1766	1044	664	42	15187
66	0	0	0	353	1221	2044	1090	1524	1532	1221	866	72	9923
67	0	0	0	0	859	1929	1994	851	718	640	523	22	7536
68	0	0	0	24	689	1290	1406	1296	1162	1117	590	2	7576
69	0	0	0	56	378	1457	1766	1307	901	647	519	17	7048
70	0	0	0	21	723	1565	2377	1284	978	1039	503	44	8534
71	29	0	0	0	731	1283	1917	897	663	887	468	6	6881
72	0	0	0	0	1047	1512	894	689	621	477	402	33	5673
73	0	0	0	0	297	709	974	626	526	593	448	0	4173
74	0	0	0	0	309	381	372	321	398	459	318	4	2562
75	0	0	0	0	1104	620	697	669	458	493	185	5	4231
76	0	0	0	0	596	293	678	329	408	194	15	0	2513
77	0	0	0	0	56.3	52.2	46	18.1	55.6	60.6	19.2	0	308
<b>4Vn</b>													
1960	25	13	0	140	84	76	3	0	3	1	6	20	371
61	47	0	0	0	97	73	1	0	1	0	2	6	227
62	0	0	0	33	212	63	4	0	0	4	0	5	321
63	13	0	5	24	238	74	0	0	0	0	11	0	365
64	0	0	0	0	68	0	0	0	55	0	0	0	123 12.3
65	0	0	0	0	86	159	8	5	0	0	0	5	263
66	0	0	0	21	134	261	12	22	0	2	4	0	456
67	0	0	3	641	0	8	1	0	0	0	0	0	653
68	0	0	0	0	0	13	0	0	0	42	0	0	55
69	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0	1	1	0	0	2
74	0	0	0	0	13	10	7	1	4	1	0	5	31
75	0	0	0	0	1	2	13	2	0	2	0	0	20
76	0	0	0	3	3	3	0	0	30	1	0	4	44
77	0	0	0	0	14.4	4.6	1	0	0	0	0	8.7	28.9

Table 11. Catches by Foreign vessels >50 tons in 4T and 4Vn by month.

> TONS (VESSEL)													
	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
<b>4T</b>													
1960	0	348	1537	3006	130	0	0	0	0	0	0	1	5021
1961	0	79	69	8067	36	0	0	0	0	0	4	0	8255
1962	0	418	108	111	0	0	0	0	0	0	0	0	637
1963	141	68	0	0	0	0	1	0	0	0	0	0	209
1964	0	0	130	0	290	2	0	0	0	0	0	0	422
1965	23	0	573	297	75	3	0	0	0	0	0	0	971
1966	0	12	997	0	0	0	0	0	0	0	0	0	1009
1967	69	58	757	0	0	0	0	0	0	0	0	0	884
1968	3	0	0	116	0	0	0	0	0	0	0	0	119
1969	2	135	72	0	0	0	0	0	0	0	0	0	209
1970	0	0	498	275	0	0	0	0	0	0	0	0	773
1971	0	0	25	0	0	0	0	0	0	0	0	0	25
1972	30	249	95	884	51	0	0	0	0	0	0	0	1309
1973	446	0	0	256	5	0	0	0	0	0	0	0	5
1974	7432	6	0	1100	106	0	0	0	0	0	0	0	42
1975	903	1413	67	1264	95	1	8	0	0	0	31	509	8686
1976	984	0	0	118	2	0	0	0	0	0	247	314	4283
1977													1665
<b>4Vn</b>													
1960	35	2439	12639	5532	18	2	0	18	1	1	0	1	20686
1961	0	1127	5200	6867	1	1	0	0	0	0	0	0	13196
1962	0	1504	8795	1243	855	0	0	0	0	0	0	0	12397
1963	207	8254	6227	1017	18	0	9	0	4	0	0	0	15736
1964	690	6887	1580	495	707	0	0	0	61	3	0	0	10359
1965	565	964	1153	1799	0	2045	167	168	18	216	32	0	7127
1966	761	574	2168	502	60	257	57	159	202	18	0	0	4758
1967	223	91	946	1923	0	0	0	14	0	1	0	0	3198
1968	0	168	871	27	13	0	0	0	0	1	0	4	1083
1969	0	0	704	0	0	0	129	0	0	0	0	71	904
1970	0	603	7264	3682	0	0	0	0	0	203	19	0	11771
1971	54	835	2481	1281	0	0	0	0	1851	85	58	0	6645
1972	1846	5273	4711	944	3	0	0	0	805	342	0	0	13988
1973	814	4058	6873	118	0	0	0	0	0	0	0	0	11936
1974	2290	4280	19	85	0	0	61	0	0	14	0	0	7249
1975	1442	2050	813	222	0	83	118	104	55	0	0	0	4887
1976	1949	514	225	0	0	0	0	0	0	0	0	211	2899
1977													

149.



50 - orig.

OPTIMAL BIOMASS OBTAINED IN 1980

Catch	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Longlines	4856	2808	1866	1396	1183	1105	1086	1117	1189	1231
Gillnets	3778	1991	1122	703	476	356	300	272	255	251
WNTR OT	-	-	-	-	-	-	-	-	-	-
SUMR OT	107,900	68,750	46,740	37,020	34,570	33,700	33,790	36,580	39,580	39,870
TOTAL	116,500	73,550	49,730	39,110	36,230	35,160	35,180	37,970	41,030	41,350
WINTER BIOMASS	26,430	164,600	113,100	95,000	92,240	92,650	96,980	103,800	110,300	112,900

NO WINTER FISHERY

OPTIMAL BIOMASS - OBTAINED IN 1980

Catch	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Longlines	3,879	2,212	1,483	1,126	951	860	883	999	1,115	1,154
Gillnets	2,994	1,522	836	527	365	278	226	197	199	215
WNTR OT	68,240	41,610	27,390	20,260	17,940	16,570	18,890	22,630	24,380	23,590
SUMR OT	49,300	31,480	21,060	16,910	15,240	15,040	18,130	20,800	21,310	20,700
TOTAL	124,400	78,820	50,780	38,820	34,500	32,750	38,130	44,620	47,000	45,660
Winter Biomass	264,300	162,500	110,500	89,940	86,280	92,800	109,400	119,900	121,200	118,300

SUMMER TO WINTER OTTER TRAWL EFFORT APPROXIMATELY .60 to .40

OPTIMAL BIOMASS OBTAINED IN 1980

Catch	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Longlines	4472	2580	1725	1299	1103	1028	1037	1102	1170	1230
Gillnets	3470	1812	1015	639	436	327	274	248	241	242
WNTR OT	28,190	17,300	71,500	8533	7711	7459	7792	8498	8959	9465
SUMR OT	83,070	53,120	36,010	28,710	26,850	26,650	28,620	30,730	32,320	33,590
TOTAL	119,200	74,810	50,260	39,180	36,100	35,460	37,730	40,580	42,690	44,530
WINTER BIOMASS	264,300	164,300	112,700	94,230	92,240	96,330	103,500	110,000	114,900	118,600

SUMMER TO WINTER OTTER TRAWL EFFORT APPROXIMATELY .80 to .20.

OPTIMAL BIOMASS OBTAINED IN 1985

Catch	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Longlines	6086	5471	5126	4835	4607	4253	3903	3592	3430	3399
Gillnets	4789	4104	3577	3188	2927	2762	2631	2490	2305	2172
WNTR OT	-	-	-	-	-	-	-	-	-	-
SUMR OT	39,040	36,390	33,170	29,930	27,310	24,780	23,330	22,770	22,500	23,050
TOTAL	49,910	45,960	41,870	37,960	34,850	31,790	29,870	28,850	28,240	28,620
WINTER BIOMASS	264,300	237,900	213,700	194,200	177,500	164,900	158,700	155,800	156,400	159,900

NO WINTER FISHERY

OPTIMAL BIOMASS OBTAINED IN 1985

Catch	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Longlines	5743	5156	4847	4569	4350	4011	3655	3360	3213	3212
Gillnets	4509	3852	3344	2992	2745	2598	2475	2343	2165	2027
WNTR OT	21,720	20,170	18,540	16,670	15,190	13,760	12,650	12,280	12,210	12,300
SUMR OT	19,900	18,570	16,870	15,210	13,860	12,580	11,770	11,570	11,550	11,680
TOTAL	51,870	47,750	43,600	39,440	36,150	32,940	30,550	29,550	29,130	29,220
WINTER BIOMASS	264,300	237,900	213,400	193,500	177,100	163,900	157,500	155,800	155,500	158,800

SUMMER TO WINTER OTTER TRAWL CATCHES 40 to 60%.

OPTIMAL BIOMASS OBTAINED IN 1985

Catch	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Longlines	5988	5431	5134	4872	4665	4323	3977	3665	3486	3426
Gillnets	4709	4072	3578	3217	2973	2822	2700	2571	2394	2260
WNTR OT	8148	7630	7070	6407	5869	5346	4961	4790	4625	4698
SUMR OT	30,040	28,250	25,900	23,490	21,530	19,670	18,540	17,910	17,540	17,970
TOTAL	48,890	45,380	41,680	37,990	35,040	32,160	30,180	28,930	28,050	28,350
WINTER BIOMASS	264,300	239,800	216,700	198,000	182,000	169,700	161,900	157,600	158,300	161,500

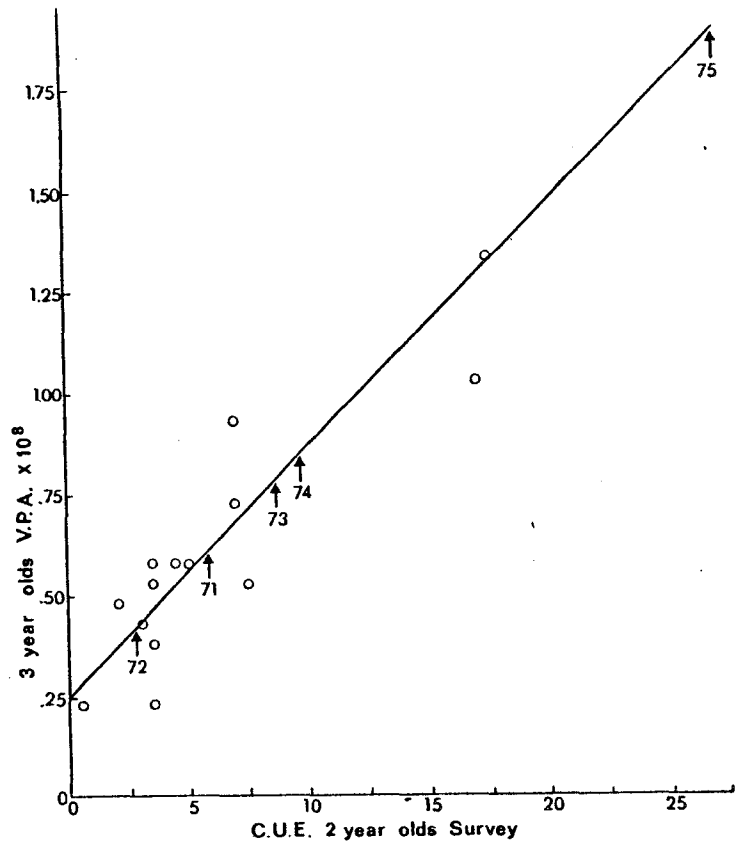


Fig. 5. Relationship between the catch of 2-year-olds in the Gulf surveys and the year-class size at age from virtual population analysis.

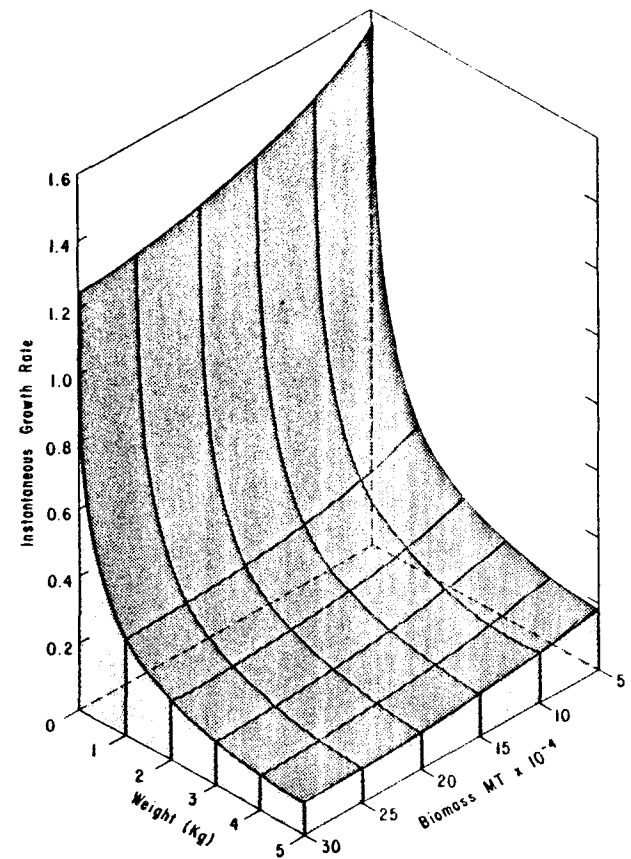


Fig. 6. Relationship among instantaneous growth rate, biomass and weight showing density-dependent growth.