

Not to be cited without  
author's permission.

CAFSAC Res. Doc. 78/17

AN INTERPRETATION OF BIOLOGICAL FACTORS  
IMPORTANT IN THE MANAGEMENT OF  
THE NORTHWESTERN ATLANTIC MACKEREL STOCK

BY

PATRICK F. LETT

and

WILLIAM H. MARSHALL

FISHERIES SYSTEMS AND DATA PROCESSING GROUP

MARINE FISH DIVISION, RESOURCE BRANCH

DEPARTMENT OF THE ENVIRONMENT

BEDFORD INSTITUTE OF OCEANOGRAPHY

DARTMOUTH, NOVA SCOTIA

## Introduction

It has been known since the turn of the century that mackerel inhabit the waters on the continental shelf from Cape Hatteras to Southern Newfoundland. Overwintering areas are thought to be on the edge of the continental shelf in the deeper warmer water from Long Island to Sable Island (Sette, 1950; Anderson and Almeida, 1976). In the spring the schools move inshore and northward to spawn in the warmer waters of the Gulf of St. Lawrence. Another group, the so called southern component, spawns in the vicinity of Long Island then moves as far north as the Gulf of Maine (Anderson and Almeida, 1977). Sette (1950) suggested that this southern component was the major portion of the stock, however, current scientific opinion would disagree with this statement. It should be noted though, to date there has been no successful attempt to separate these two components and until this question is resolved the entire stock is considered to be one. Recent tagging experiments done by Beckett et al (1974) and Parsons and Moores (1974) indicate that there is mixing of the two components to some degree.

Recently Kulka (1977) has presented an interesting hypothesis concerning mackerel migration. It is his conviction that 0 group mackerel spawned in the Gulf of St. Lawrence migrate to an overwintering ground on the edge of the Scotian Shelf. In the spring these fish move inshore and remain resident along the coast of Nova Scotia gradually working their way north. However, few 1 group mackerel enter the Gulf of St. Lawrence as evidenced by the length

frequency distribution (see Kulka 1977 Fig. 10). Thus, those 0 and 1 group mackerel remaining on the Scotian Shelf throughout the year are immature, and this area serves as a nursery ground. After age one, these fish join the main schools of mature mackerel vacating the Gulf of St. Lawrence on their way south.

Mackerel are a valuable commercial species, but perhaps their value as an ecological forcing and stabilizing function is even more important. Recently, Lett and Kohler (1976), Winters (1976) and Lett (1977) have presented sufficient data to show <sup>that</sup> mackerel have an extreme effect on the management on Gulf of St. Lawrence cod and herring stocks. In addition, there is some evidence that 0 group mackerel yearclass size influences the formation of yearclasses belonging to 4X haddock.

Given the above scenarios, it is easily seen that assessment of mackerel has far reaching implications. One of the recurrent problems in the assessment of this stock using conventional virtual population techniques, is the estimation of the starting fishing mortality (F) values. Since the initial population estimates vary as  $1/F$ , the lack of prior knowledge of fishing mortality suggest that any management decision depends on a certain degree of guess work, since for mackerel, use of commercial effort statistics is virtually impossible. Recently, Anderson (MS 1977) has presented what appears to be credible effort data, with which there are undoubtedly problems, although it does track changes in the exploitation rate quite well. Since this data is based on an index fishery the problems of changing catchability are somewhat circumvented. However, surveys were designed to sample for juvenile herring and not mackerel, and therefore may miss concentrations of mackerel since the distribution boundaries of the two species do not overlap significantly (Anderson and Almeida, 1977).

Although data has been accumulating, and a number of attempts have been made to assess this stock, all attempts have to date been on a fairly weak foundation. Thus it is the purpose of this paper to present some new data which when analysed will help clarify some of the more relevant issues as they relate to this stock. In addition, to elucidating present stock and yearclass size, the paper presents a stochastic simulation to study the system as a whole. Furthermore this model will permit extrapolation of present knowledge into the future and may thus be used to predict the future consequences of present management strategies.

Results of Egg and Larval surveys in the Gulf of St. Lawrence and on the Scotian Shelf.

In 1965 an investigation of the distribution of eggs and larvae in the southern Gulf of St. Lawrence was initiated and has subsequently been continued. In 1967, 1968, 1969, 1976 and 1977 at least one cruise was designed to coincide with the peak of spawning. In addition to those surveys covering the entire southern Gulf of St. Lawrence, a more intensive study was begun in St. Georges Bay, at the southeastern corner of the southern Gulf. This investigation has continued since 1973, and to some extent, events occurring in Georges Bay may be extrapolated to interpret egg production for the entire Gulf. However, egg production in St. Georges Bay is in no way related to overall egg production by some simple area ratio, because of the patchy distribution of eggs and local areas of concentration. (Figs 1 & 2). Furthermore, only with a highly stratified system of current and temperature would this be possible.

The gear type analysed for the surveys covering the entire Gulf of St. Lawrence were 1-meter surface nets towed at 4.63 km/hr for 30 minutes. Volumes of water strained were measured with T.S.K. flowmeters. After each tow, the nets were

washed down with salt water to remove gelatinous neston or anything else which could prevent the nets from functioning properly.

It has been known for some time that mackerel are very temperature specific (Sette 1950) and this factor is very important when interpreting the egg data. During peak spawning 60-80% of the variation in the logarithm of egg abundance between stations is explained by temperature. The response is quadratic with the optimal temperature occuring where most of the eggs were found. There are usually 2 or 3 areas in the Gulf where egg concentrations are exceedingly high where catches reach  $1.8 \times 10^6$  eggs per half hour tow although eggs are caught at all stations, even those with low temperatures ( $8^{\circ}\text{C}$ ). The biological basis of this penomena is explained by mackerel searching for an optimal spawning temperature, and statistically the effect easily removed through an analysis of covariance.

At similar temperatures the arithmetic mean catch of eggs is not normally distributed with low catches being predominate over high catches. For this reason the logarithm of egg abundance was used in the analysis of covariance, temperature being the covariate. This analysis substantially decreased the variance of the geometric mean egg abundance.

The spawning cycle of mackerel in the Gulf of St. Lawrence follows a normal distribution in relation to temperature for the reasons already discussed. The duration of spawning is well defined, beginning in mid-June and ending in late-July, however when more eggs are deposited the cycle is slightly more protracted. The height of model egg production can vary dramatically on an annual basis depending on the biological state of the stock.

During 1966-1969 at least 5 cruises occurred yearly, and of these at least 4 caught makerel eggs in the surface meter nets. A curve was fitted to these values using the model,

$$(1) E = \beta_0 \text{EXP} [\beta_1 T - \beta_2 T^2]$$

where E is the catch of eggs/100,000 meters of water strained and T is temperature on the cruise in °C. It is assumed residual values resulted from variation in production of the adult stock. The temperature of maximum egg production was determined by solving for the first derivative of the  $\log_e$  of egg catch. The temperature of maximum egg production was 12.27. Although all cruises occurred during peak spawning, the duration of the cruise would put the geometric mean value slightly on the left or the right hand side of the real peak. Thus the  $\log_e$  of egg abundance could be corrected to a value corresponding with that of the optimal temperature. This peak value then is an index of the overall egg production, or the area under the production curve, since the yearly duration of spawning varies little.

$\log_e$  Peak abundance / 100,000 m  
in G. of St. Lawrence,  $\pm 1$ (SE)

<u>YEAR</u>	
1967	11.18 $\pm$ 0.842
1968	12.41 $\pm$ 0.490
1969	13.39 $\pm$ 0.279
1970	*13.63
1973	*13.69
1976	13.94 $\pm$ 0.148
1977	(not completely analysed).

\* correction here was quite large since cruise did not occur at times of peak spawning.

It would seem from these figures that egg production in the Gulf of St. Lawrence has steadily been increasing. However, although the 1977 counting and sorting is not complete, it is the opinion of the first author that 1977 egg production fell slightly short of 1976.

The Gulf of St. Lawrence survey was extended out of the Gulf of St. Lawrence in 1977 to see if spawning was also occurring in this area when peak spawning occurred in the Gulf. Stations were 30 miles apart and covered Banquereau and northern extent of Sable Island Bank. No mackerel eggs were found at this time, but in 1976 an August survey on the Shelf caught mackerel larvae (Figs. 3A and 3B). However, the catches were so minimal in comparison with those in the Gulf, it is our conclusion that the major spawning of the Northern contingent of the mackerel stock occurs in the Gulf of St. Lawrence. It is assumed that some fairly constant proportion of the Northwestern Atlantic mackerel stock enters the Gulf of St. Lawrence to spawn.

#### Mackerel 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 (1976, 1977), Lett and Kohler (1976), Lett et al (1975) and Tyler and Dunn (1976) 'ad nauseam'. More recently DeVeen (1976) has presented data showing a continual increase of fecundity at length for sole because of a decrease in stock size, an increase in food or both. Bagenal (1973) has also noted the same type of change for North Sea plaice. MacKay (1976) has presented rather conclusive evidence for this mackerel stock that gonad weight is a power function of fork length with the exponent being greater than one. Furthermore our analysis indicates that the value of the exponent in different years is positively correlated ( $r = 0.97, 3df$ ) with the instantaneous growth rate of the mature stock. This agrees with results from a fecundity study for Pacific horse mackerel.

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

$$(11) E = \left[ \begin{array}{l} n = a + t \\ \Sigma \partial_a^c x N_a \\ n = a \end{array} \right] \times (\Delta W)^Y$$

where E is the egg catch in the Gulf of St. Lawrence surveys per  $10^5 M^{-3}$  of water strained and N is the number of mature fish and  $\Delta W$  is weighted growth rate of the mature stock. The exponent,  $\gamma$ , is the rate at which surplus energy is being channelled to the gonad in relation to the overall surplus energy, represented by a change in weight. The maturity at age, is determined from a cumulative normal distribution of percentage mature with length. Inspection of the maturity data from 1966 to the present shows no shift of maturity with length.

It was assumed that stock sizes in 1967, 1968, and 1969 would not vary substantially in the face of different starting fishing mortalities in 1976. Thus  $N_a$  are the numbers at age given by the most recent assessment (ICNAF 1977).

Length at age between 1962 - 1976 was determined from the Canadian 4X catch statistics and data from MacKay (see MacKay, 1976). In years when MacKay's data and the Canadian sampling data overlapped the average lengths at age were determined, giving the proper weights in accordance with sample sizes. The data between 1965 and 1976 is presented in Table 1. The 4X samples were used since it was the only consistent set of data over the entire period. Length-weight relationships were available in individual years from MacKay (per. comm.) as from the Canadian samples. These relationships were used to convert length to weight (Table 2). No sampling was carried out in 1972 and the values were interpolated using a Walford plot, however, using this method it is impossible to get a length for fish in the first year, since the curve becomes non linear at this extent. In 1973 there seemed to be a problem with ageing, this being the first year a substantial effort was put into sampling the Canadian 4X fishery since 1968, thus personal ageing the material had changed.



Weighted mean growth rates were calculated between 1966 and 1975 by the following calculation

$$\Delta W = \frac{\left[ \begin{array}{l} n = a + t \\ \sum \partial_a \times N_a \times \Delta W_a \\ n = a \end{array} \right]}{\left[ \begin{array}{l} n = a + t \\ \sum \partial_a \times N_a \\ n = a \end{array} \right]}$$

where  $N_a$  is taken from virtual population analysis to yield the following

YEAR	Ages 2 to 9		Eggs/100,000 m <sup>-3</sup>
	$\Delta W$	Mature N	
1966 - 1967	0.040	869	71905
1967 - 1968	0.053	1090	245755
1968 - 1969	0.072	1353	652194
1969 - 1970	0.093	2774	*830680
1970 - 1971	0.025	2183	
1971 - 1972	0.066		
1972 - 1973	0.098		
1973 - 1974	0.054	remaining values change depending on starting F	*880997
1974 - 1975	0.140		
1975 - 1976	0.086		1,135,998

\* large adjustments necessary to determine these values

MATURITY AT LENGTH

L. LENGTH	26	28	30	32	34	36	38	40	42	cm
MATURITY ( $\partial$ )	1.5	7.0	20.0	44.0	77.0	89.0	97.0	99.0	99.9	%

In order to fit the exponent of gonad production  $\gamma_1$  the relation

$$\log_e \left[ \frac{E}{\partial_a N_a} \right] = \gamma_0 + \gamma_1 \log_e \Delta W$$

to yield the following equation

$$(III) E = 1.303 \times 10^6 N (\Delta W)^{2.985}$$

using the 1967 - 69 data (Fig. 4).

Although the 1973 and 1970 points are shown in the Fig. 4 they were not used in the regression since the points are subject to considerable adjustment, thus error. However, these points are consistent with the theory being advanced.

The predicted number of eggs caught /100,000 m<sup>-3</sup> of water per mature fish in 1976 was 860. With a total catch of 1,135,998 eggs/100,000 m<sup>-3</sup> these means that there are 1,321 x 10<sup>-6</sup> mature mackerel. If  $C$  is a vector of catches from ages 2 to 9,  $S$  is the selection and  $\partial$  the maturity, the vector of numbers at age  $N$  is predictable by the following model,

$$\text{? } \overline{\text{IV}} N_{76} = [1321 \times (C / S \times \partial) / \Sigma (C / S \times \partial)] / \partial$$

$n = a + t$   
 $n = a$

thus

<u>AGE</u>	<u>N<sub>76</sub></u>
2	1661
3	783
4	203
5	182
6	97
7	94
8	94
9	2

where partial recruitment is assumed to be 67% for 2 year olds and 100% thereafter.

It would seem that the high number of eggs caught in the Gulf in 1976 is related to the high maturity rate of the younger fish. In 1976, 21% of the age 2 fish are mature as opposed to only 13% on average. In addition, the maturity 3, 4 and 5 year old fish is approximately 10% higher than it has been in the late 1960's.

Estimates of stock size and starting fishingMortality values:

One of the recurrent problems in the management of fish stocks is the estimation of stock size in the current areas. The usual approach is through find a correlation between  $F$  values from VPA analysis and effort. However, this method is extremely dangerous if 1) there are not many observation and 2) if the data forms a time series. In other words the method is most reliable when there are wide variations in effort from year to year. Anderson (MS 1977) presents a highly correlated relation between VPA  $F$  and his effort index, but the data is a time series. Thus a significant correlation could be found between effort and fishing mortality for a wide range of starting values. Because of the rather low fishing mortality values over the last few years, errors in the initial starting values are not significantly damped (Pope, 1972) and almost a good correlation can be obtained for terminal  $F_s$  between 0.8 and 0.4, or a half or doubling of the population in 1976.

Based upon our calculation, the population numbers in 1976 produce a starting fishing mortality value for fully recruited age classes of 0.48, not much different from Andersons (MS 1977) values of 0.616. However, we feel that our calculation is better than that of Anderson since 1) it is based on an additional almost completely independent piece of data and 2) the calculation is independent of assumptions made about stock size in 1976.

Our virtual population analysis, assuming a natural mortality,  $M$ , of 0.3, is presented in table 2 with associated  $F$  values in table 3. We have plotted the relation between  $F$  for ages 3 to 8 and Anderson's effort index (Fig. 5) and it can be seen that our goodness of fit is equivalent to his, when using a GM regression (Ricker, 1973). Andersons reports on  $R^2$  of 0.98 while ours is 0.96, with the basic difference being if the 1976 point is included or excluded. Indeed, the two regressions can not be separated statistically.

Anderson (1977) presents effort data for 1977, based upon an assumed catch of 110,000 metric tons, or the present TAC. Both of us have difficulty with the 1977 value, since the use of this value gives an average  $F$  of 0.713 to Anderson in 1976, and when we project ahead our 1976 population to 1977 and use the 1977 catch to determine fishing mortality rates the answer is 0.26 well below the predicted value of 0.37. When 0.37 was set for 1977, the 1976 value generated was 0.63. We believe Anderson's 1977 catch data is incorrect and we will have to wait until the final statistics are complete before concluding a valid analysis.

Density dependent growth and the influence of environmental factors

Density dependent growth has been noted for a number of fish stocks, however, elucidation of this relationship consistently falls short of attempts. Varying growth rates following maturity are usually difficult to determine since it is usually more ecologically advantageous for fish to remain on a particular growth schedule that coincides with different particle sizes of food items, and partition surplus energy in gonad production. This is especially true for schooling fish such as herring and mackerel where an optimal foraging size is extremely important (Ware 1975). Therefore it is not unusual that Lett (1977) can detect density dependent growth for Gulf of St. Lawrence cod but not herring (Lett and Kohler, 1976).

Furthermore, no correlation could be found between mackerel instantaneous growth rate and stock biomass (even though mackerel growth varies widely). In addition, temperature was not found to be significant in explaining variations in growth. This is not surprising since mackerel do most of their growing within the first year. So it should be within the first year that density dependent<sup>ly</sup> is detectable (Fig. 6).

The mechanism by which growth in the first year of life is density dependent has previously been discussed by Iles (1973), Lett (1977) and Lett and Kohler (1976). Indeed, the concept is well established as a mechanism in the recruitment process (Burd, 1972) and one which produces stability (Lett and Kohler, 1976) in stocks where density-dependent is not apparent in the older age groups.

The values used to calculate this relationship were measured length of one year olds from the 4X fishery (Table 1) and the 0 group year class size from virtual population analysis. No values were available for the 1971, and 1972 yearclasses for the previously mentioned reasons. The relationship looked to be almost linear, but the non-linear form gave the best fit,

$$\bar{V}_1 = 279.94 \text{ EXP } [-2.531 \times 10^{-5} N_0]. \quad R^2 = .73$$

where  $N_0$  is the size of the 0 group yearclass. Environmental factors were also tested for significant correlations with growth but no relation was found. This differs from results obtained by Lett (1977) for cod.

To some extent this relationship confirms the starting values used in the VPA, however, the precision is certainly not good enough to differentiate between a starting F of 0.48 and 0.616 in 1976. However, the relationship may be useful later in predicting yearclass size. Kulka's (1977) findings indicate that the (1 group) mackerel moving inshore during the summer are indeed those spawned in the Gulf of St. Lawrence and therefore this correlation, which may not exist for other fisheries, is to be expected. To go on, it also suggests that a large portion of the overall mackerel stock must spawn within the Gulf since the catch data used in the VPA analysis represents the entire fishery.

### Factors Affecting Yearclass Formation

A strongly density-dependent  $l_1$  relationship implies the stock-recruitment curve should be dome shape (Cushing and Harris, 1973). Because of cannibalism among mackerel larvae of 11-50mm length (Arnold 1970), it is not difficult to hypothesize how such a mechanism could be set up. Furthermore, Ware (1975) has found the mortality rate among larval and juvenile mackerel to be considerably higher than other fish species.

Temperature effects the growth rate, and thus the mortality rate of larval and juvenile mackerel (Ware 1975). However, such effects are not as detectable in the  $l_1$  length-yearclass size relationship since both growth and mortality respondant nearly the same rate (Ware, 1975) to temperature fluctuations.

Thus we propose the following model for the recruitment of mackerel

$$\underline{VI} \quad N_o = \beta_o \times E \times \text{EXP} [ \beta_1 T + \beta_2 E + \beta_3 T \times E ]$$

where a test will be made for an interaction term in the exponent.

Using equation III the number of eggs was predicted. Temperature was the average temperature on the Magdellan shallows during the summer months.

<u>YEAR</u>	<u>E</u>	<u>T</u>	<u><math>N_o \times 10^{-6}</math></u>
1967	75527	16.83	9879
1968	21925	15.87	4015
1969	704762	15.43	4278
1970	3165479	15.93	2350
1971	49473	15.90	2670
1972	1055259	15.20	1740
1973	2991200	16.70	2953
1974	348257	15.43	3543
1975	4741371	15.89	2102

The model being proposed suggests that temperature has a far greater impact when egg numbers are low than when egg numbers are high, basically because density dependence among the larvae becomes the dominate factor in determining survival.

The autocorrelated statistical model was used to fit equation V1

$$\text{VII} \log_e [N_o/E] = 2.148 T + 1.099 N_o^{-5} E - 7.537 \times 10^{-7} \text{EXT} - 37.825$$

<u>Variable</u>	<u>T Value</u>	<u>Variation</u>
T	3.84	13.37
E	1.86	75.86
EXT	2.04	4.90

However, these statistics are rather misleading since the equation is autocorrelated. A better appreciation of the goodness of fit can be gained by the examination of Fig. 7. Here yearclass sizes are plotted after being corrected to an arbitrary temperature (16.25 °C). The residual values are small indicating that temperature explains much of the variation in yearclass size and is a powerful enough factor to completely mask any conventional stock-recruitment relationship. Moreover, without some prior knowledge of temperature on the Magdellan Shallows, it is impossible to predict yearclass size with any certainty.

Temperatures on the Magdallen Shallows are log normally distributed with a mean of 2.75 (15.64 °C) and standard deviation of 0.0391. Thus, the high temperatures which produce exceptionally large yearclasses occur infrequently, less than 10% of the time.

CONSTRUCTION OF SIMULATION

The simulation was run using the APL programming language. Two programs were written each containing essentially the same model but differing in operational characteristics. The first program runs the simulation 10 times with 10 different user specified fishing mortalities. The second program will run the simulation 10 times with the same parameters each time. The second program allows the user to either set the fishing mortality at a specified level or to fix the 1+ biomass at a fixed level.

The input to each of the programs consists of the 1977 numbers at age in millions, the 1976 lengths at age in centimeters, the predicted length of the 1-group Mackerel in 1977 in centimeters and the range of years over which the simulation is to be run.

The output from each program consists of table of predicted catch, 1+ biomass, mature biomass, 0-group recruitment values and fishing mortalities. For the first program the mean and standard deviation for each of the 10 runs was calculated separately over the last 20 years of the simulation. For the second program the mean and standard deviation of the 10 runs was calculated for each year of the simulation.

The logic of the biological aspects of the model is depicted in the flowchart (fig. 11). At the start of each year of the simulation the population numbers for that year, the lengths for the previous year and the length of the one year olds for the current year are known.

The first step is then to calculate the change in weight ( $\Delta W$ ) between this years weights and the previous years weights. This is done by converting the previous year lengths (cms) to weights (kgs) using the relationship:

$$W_{t-1} = 2.908 \times 10^{-6} \times L_{t-1}^{3.384} \quad (1)$$

There is a relationship between the increase in weight divided by the previous years weight and the previous years weight as depicted in Fig. 12. A linear



interpolation routine is used to obtain the value for  $\frac{\Delta W}{W_{t-1}}$  and the current years weights are calculated as:

$$W_t = W_{t-1} \times \left( 1 + \frac{\Delta W}{W_{t-1}} \right) \quad (2)$$

The change in weights is then calculated as:

$$\Delta W = W_t - W_{t-1} \quad (3)$$

The next step consists of calculating the number mature at age. The percentage maturity is dependent on length and so the weights at age for the current year (equation 2) are converted to length.

$$L_t = \left( \frac{W_t}{2.908 \times 10^{-6}} \right)^{\frac{1}{2.927}} \quad (4)$$

The percentage maturity at age is distributed as a cumulative normal variate with mean 32.4 and standard deviation 2.927. The number mature at age (M) and is then simply the percentage mature times the numbers at age.

The next step consists of calculating the number of 0-group fish which will be produced and predicting their lengths when they reach age one. The egg production is calculated as:

$$E = \sum 1303000 \times M \times \Delta W^{2.985} \quad (5)$$

with the summation being over all age groups. The number of 0-group Mackerel depends on the number of eggs and the temperature. A random temperature (T) is calculated based on the long term observed temperature distribution (Fig. 13). The number of 0-group fish is then calculated as:

$$N_0 = 3.739 \times 10^{-17} \times E \times \exp \left[ (1.099 \times 10^{-5} \times E) + (2.1484 \times T) - (7.537 \times 10^{-7} \times E \times T) \right] \quad (6)$$

There is a relationship between the number of 0-group fish and their length at age one ( $L_1$ ). The length at age one is predicted as:

$$L_1 = 27.894 \times \exp (-2.531 \times 10^{-5} \times N_0) \quad (7)$$

The final step in each year then consists of calculating the catch using the standard Beverton-Holt catch equation

$$C = \sum N \times \left( \frac{F}{F + .3} \right) \times [1 - \exp(-F - .3)] \quad (8)$$

where the summation is over all age groups.

The population numbers for the next year are then updated by taking the number of 0-group fish multiplied by  $\exp(-.3)$  and concatenating this to the front of the population vector for the older age groups which is calculated by multiplying the current population vector by  $\exp(-F - .3)$ . This assumes that there is no fishing mortality on 0-group Mackerel. The partial recruitment factors for older Mackerel are entered as a global variable to the simulation. The current years lengths (equation 4) are then saved as the previous years lengths, the year counter is updated and if there are more years to be run the whole process is repeated.

RESULTS OF THE SIMULATION

The simulation was run ahead at different levels of fishing mortality until the population reaches a sort of stable limit cycle, or a situation which represented a kind of equilibrium. The mean catch, biomass and recruitment were calculated for the last 20 years.

The object of this exercise was to determine the MSY stock size and catch level as a reference point of stock management. The MSY  $l^+$  biomass was calculated to be  $2.2 \times 10^6$  MT (Fig. 8) and the biomass corresponding to  $2/3 F_{MSY}$  is approximately  $3.5 \times 10^6$  MT. Although the mean values do describe a typical Graham-Shaeffer type curve, the amount of confidence associated with any value along the curve is indeed limited. The variance in catch increases as stock size declines basically due to the much greater impact temperature has on recruitment at these low stock levels. Variations are so great, that conventional management strategies are not sufficient.

The simulated results were also useful in describing a relationship between fishing effort and catch (Fig. 9). It would seem that total stock collapses are not inherent in the biological components used in building the model. Basically, this is due to the very strong stabilizing influence of a density dependent  $l_1$  relationship (Fig. 6) and the important influence of temperature on yearclass formation.

The fact that large yearclasses mature later because they are shorter to begin with, and the opposite occurs for small yearclasses, greatly influences the number of eggs which are broadcasted by mackerel. For mackerel it would be very difficult to define a critical biomass.

At fishing mortalities greater than 0.3 the catch declines slowly. The major problem is with the variance that is associated with these catches. Variance is so high that it is impossible to predict catches more than 1 year in advance.  $F_{0.1}$  has previously been calculated to be 0.35. Our model

would predict a value closer to 0.18 with an associated catch of 325,000 MT.

The present management strategy of fish at  $F = 0.35$  will produce a catch of 279,000 MT in 1978 and a sustained catch of 310,000 MT. However, at this level of fishing the stock biomass will stabilize around a value of  $1.65 \times 10^6$  MT. Fishing at an  $F$  of 0.01 will sustain a biomass of  $3.50 \times 10^6$  MT.

Given the importance of mackerel in the management of Gulf of St. Lawrence fisheries (Lett and Kohler, 1976, Lett, 1977) it is not advisable to maintain a mackerel biomass over  $1.3 \times 10^6$  MT. It has been demonstrated a number of times that optimal levels of harvest cannot be maintained for species within a multispecies fishery. This matter is important, since it is quite clear that major changes within the Gulf of St. Lawrence fishery are almost independent of shifts in fishing effort and rely more on events within the mackerel biomass. In other words, to manage the Gulf of St. Lawrence fish stocks, mackerel must first be managed.

REFERENCES

- ANDERSON, E. D. MS 1977. Assessment of the Northwest Atlantic Mackerel Stock. mimeo. 30p
- ANDERSON, E. D. and F. ALMEIDA. 1976. Distribution of Atlantic mackerel in ICNAF Subarea 5 and Statistical Area 6 based on research vessel spring trawl surveys, 1968-1975. Int. Comm. Northw. Atl. Fish. Res. Doc. 76/VI/I3 Ser. No. 3782
- ARNOLD, P. W. 1970. Spawning and aspects of the early life history of the Atlantic mackerel, *Scomber scombrus* L., in the Gulf of St. Lawrence. BS thesis, Acadia University, 73 p.
- BECKETT, J. S., W.T. STOBO AND C.A. DICKSON. MS1974. South westerly migration of Atlantic mackerel, *Scomber scombrus*, tagged off Nova Scotia. Int. Comm. Northw. Atl. Fish. Res. Doc. 74/94, Ser. No 3330, 2p.
- BERGERON, J. 1961. Repoort preliminaire des travaux sur la biologie du Maquereau (*Scomber scombrus* L.) du Golfe Saint-Laurent. Rapp. Ann. 1960. Sta. Biol. Mar. Grande-Riviere: 77-85.
- BURD, A. C. 1962. Growth and recruitment in the herring of the southern North Sea. Fish. Invest. Minist. Agric. Fish. Food (G.Br.) Ser. 11 Salmon Freshwater Fish 23: 5 p.
- ILES, T. D. 1973. Interactions of environment and parent stock size in determining recruitment in Pacific sardine as revealed by analysis of density-dependent O-group growth. Rapp. P.V. Raun., Cons. Int. Explor. Mer. 164: 228-240.
- KULKA, D. 1977. An hypothesis concerning the migration and distribution of Atlantic mackerel (*Scomber scombrus*) CAFSAC Res. Doc. 77/7
- LETT, P. F. 1977. A preliminary discussion of the relationship between population energetics and the management of southern Gulf of St. Lawrence cod CAFSAC Res. Doc 77/8
- LETT, P. F. and W.G. DOUBLEDAY. 1975. The influence of Fluctuations in Recruitment on Fisheries Management Strategies, with Special Reference to Southern Gulf of St. Lawrence Cod. Int. Comm. Northwest Atl. Res. Doc. 75/140.
- LETT, P. F. and A.C. KOHLER. 1976. Recruitment: A Problem of Multispecies Interaction and Environmental Perturbations with Special Reference to Gulf of St. Lawrence Atlantic Herring (*Clupea harengus harengus*). J. Fish. Res. Board Can. 33: 1353-1371.
- LETT, P. F., A.C. KOHLER and D.M. FITZGERALD. 1975. Role of Stock Biomass and Temperature in Recruitment of Southern Gulf of St. Lawrence Atlantic cod, *Gadus morhua*. J. Fish. Res. Board Can. 32: 1613-1627.
- MACKAY, K. T. 1976. Population biology and aspects of energy use of the northern population of Atlantic mackerel, *Scomber scombrus* L. Ph.D. thesis, Dalhousie University.
- PARSONS, L. S. and J.A. MOORES. 1974. Long distance migration of Atlantic mackerel (*Scomber scombrus*). J. Fish. Res. Bd. Canada 31: 1521-1522.

- SETTE, O. E. 1950. Biology of the Atlantic mackerel (*Scomber scombrus*) of North America. Part. II. Migrations and Habits. Ibid 49 (51): 251-358
- WARE, D. M. 1975. Relationship between egg size, growth and natural mortality of larval fish. J. Fish. Res. Board Can. 32: 2503-2512
- WARE, D. M. 1975. Growth, metabolism and optimal swimming speed of a pelagic fish. J. Fish. Res. Board. Can 32: 33-41.
- WINTERS, G. H. 1976. Recruitment mechanisms of Southern Gulf of St. Lawrence Atlantic herring (*Clupea harengus harengus*). J. Fish Res. Board Can. 33: 1751-1763.

TABLE 1. MACKEREL LENGTH AT AGE (MM) 4X DURING JULY, AUGUST AND SEPTEMBER

AGE	1965	1966	1967	1968	1969	1970	1971	1972 <sup>1</sup>	1973 <sup>2</sup>	1974	1975	1976
1	265	281	264	221	253	250	260	(no value)	(no value)	242	239	265
2	320	309	296	287	272	299	291	310	293	259	280	301
3	341	336	333	328	314	316	305	320	321	321	320	320
4	350	341	345	342	337	330	319	335	336	339	343	343
5	355	356	355	352	355	345	333	334	345	350	363	355
6	352	360	357	356	354	358	348	336	348	358	369	369
7	-	355	364	361	368	358	368	360	362	361	373	374
8	-	356	369	369	383	381	366	380	369	370	388	379
9	-	-	-	384	380	387	385	376	392	385	396	382
10	-	-	-	390	385	382	400	400	388	393	388	385
11	-	-	-	-	-	-	-	-	-	403	409	394

<sup>1</sup> lengths\* interpolated from Walford Plot.

<sup>2</sup> age of these mackerel is uncertain since it seemed ageing was incorrect by one year.

22

TABLE 2. WEIGHT AT AGE (grams) FOR MACKEREL SAMPLES IN 4X FISHERY DURING JULY, AUGUST AND SEPTEMBER

AGE	1965	1966	1967	1968	1969	1970	1971	1972 <sup>1</sup>	1973 <sup>2</sup>	1974	1975	1976
1	181.9	218.8	179.7	102.6	152.2	151.3	171.2	(no value)	(no value)	129.9	137.7	186.0
2	329.7	295.2	257.8	233.9	193.7	266.1	244.9	296.0	265.4	168.3	234.1	287.5
3	402.9	384.5	373.8	356.4	312.1	316.9	284.4	325.0	359.7	346.7	365.7	354.3
4	437.4	402.9	418.0	406.6	394.8	363.3	328.1	371.9	418.5	416.8	463.6	449.2
5	457.4	461.5	457.4	445.3	469.3	418.0	376.1	368.7	461.1	463.8	558.3	505.2
6	445.3	478.0	465.6	461.5	464.9	469.7	432.7	375.2	474.0	503.1	593.2	576.7
7	-	457.4	495.0	482.2	528.9	469.7	516.8	459.7	540.8	519.0	613.4	603.8
8	-	461.5	516.7	516.7	604.0	571.6	508.0	539.1	575.4	564.1	702.0	631.8
9	-	-	-	585.9	588.5	600.5	596.7	522.5	705.4	653.8	752.1	649.1
10	-	-	-	615.3	614.6	576.3	673.8	627.0	679.8	697.5	704.9	666.7
11	-	-	-	-	-	-	-	-	-	759.6	843.1	721.5

23

<sup>1</sup> lengths interpolated from Walford Plot.

<sup>2</sup> age of these mackerel is uncertain since it seemed ageing was incorrect by one year..



TABLE 3. NUMBERS AT AGE X10-6 USING CATCH DATA FROM ICNAF91977) AND A NATURAL MORTALITY, M, OF 0.3

AGE	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
0	513	510	689	1405	3974	9879	4015	4278	2350	2670	1740	2953	3543	2102	<sup>6500</sup> 1159
1	826	380	378	510	1041	2944	7317	2974	3166	1737	1976	1288	2184	2623	1555
2	672	603	281	272	372	754	2181	5310	2198	2190	1226	1446	817	1538	1627
3	653	496	444	204	199	268	538	1567	3728	1584	1380	837	834	402	775
4	-	475	367	327	149	144	183	352	1035	2342	1069	810	381	395	202
5	-	-	336	270	239	109	104	106	210	636	1275	726	404	197	208
6	-	-	-	237	196	174	78	66	74	133	304	620	377	203	97
7	-	-	-	-	163	140	125	53	47	49	70	153	294	185	94
8	-	-	-	-	-	105	99	92	38	31	29	32	87	127	94
9	-	-	-	-	-	-	53	73	66	20	20	18	15	43	52
10	-	-	-	-	-	-	-	35	52	41	12	8	10	6	22
11	-	-	-	-	-	-	-	-	19	36	24	6	3	6	2

42

TABLE 4. FISHING MORTALITY VALUES FROM COHORT ANALYSIS

AGE	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
0	.000	.000	.000	.000	.000	.000	.000	.001	.002	.001	.002	.002	.001	.002	.001
1	.016	.002	.028	.016	.022	.000	.021	.003	.069	.049	.013	.154	.051	.177	.048
2	.003	.006	.020	.012	.030	.037	.030	.054	.027	.162	.082	.251	.411	.386	.300
3	.019	.002	.008	.013	.026	.079	.124	.115	.165	.094	.233	.487	.447	.391	.480
4	-	.046	.009	.011	.017	.025	.250	.220	.187	.309	.086	.395	.361	.345	.480
5	-	-	.048	.018	.019	.032	.159	.059	.155	.440	.421	.357	.388	.416	.480
6	-	-	-	.079	.040	.031	.094	.049	.110	.342	.390	.447	.412	.480	.480
7	-	-	-	-	.139	.046	.006	.041	.131	.226	.488	.264	.543	.386	.480
8	-	-	-	-	.520	.381	.011	.036	.337	.141	.180	.491	.411	.608	.480
9	-	-	-	-	-	-	.131	.033	.180	.276	.645	.301	.710	.405	.480
10	-	-	-	-	-	-	.690	.296	.082	.252	.473	.849	.334	.667	.480
11	-	-	-	-	-	-	-	1.000	.172	.254	.308	.443	.485	.250	.480

25

Figure 1 Histograms of different mackerel egg stages with different density distributions within the Gulf of St. Lawrence.

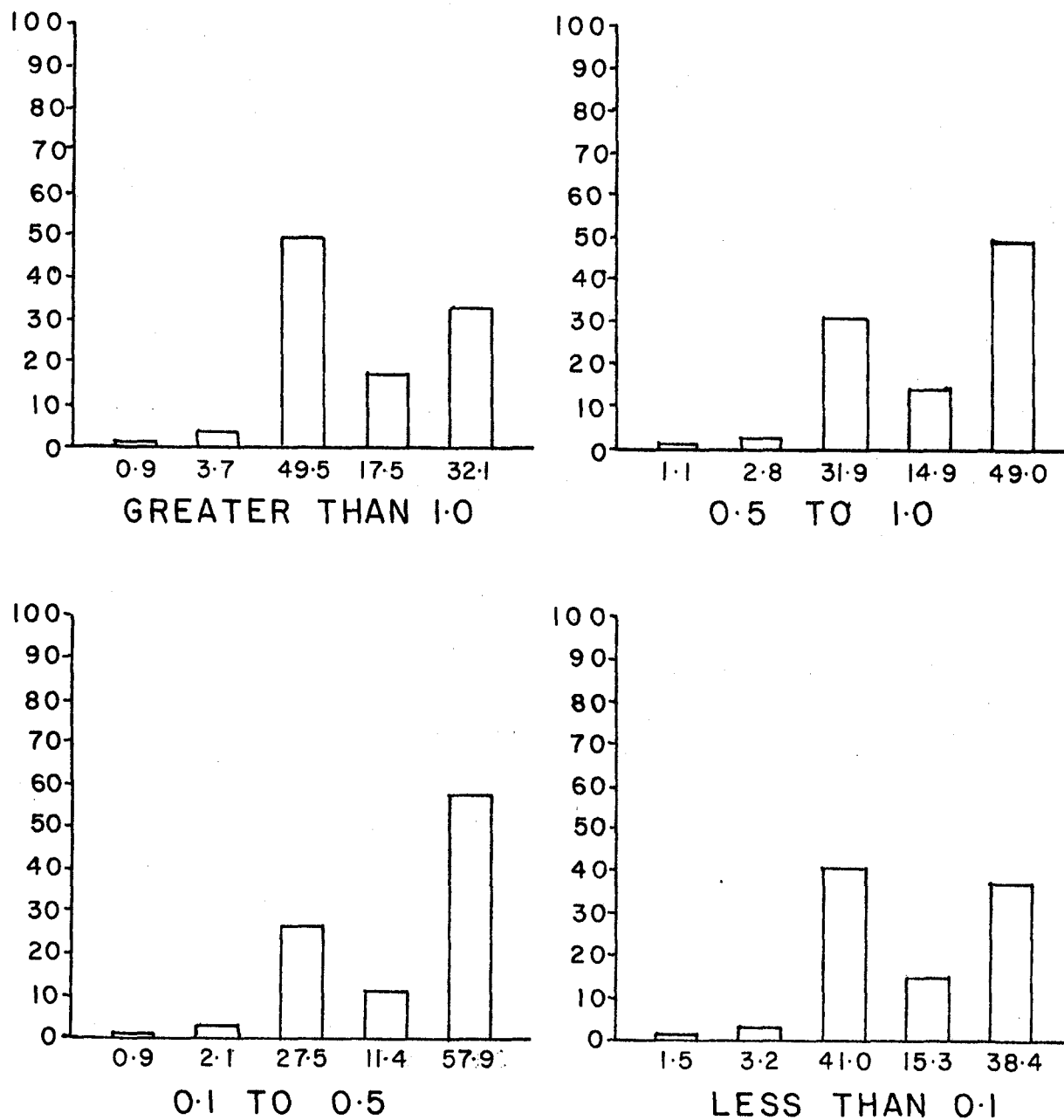


Figure 2 Contour map of mackerel egg densities in the Gulf of St. Lawrence.



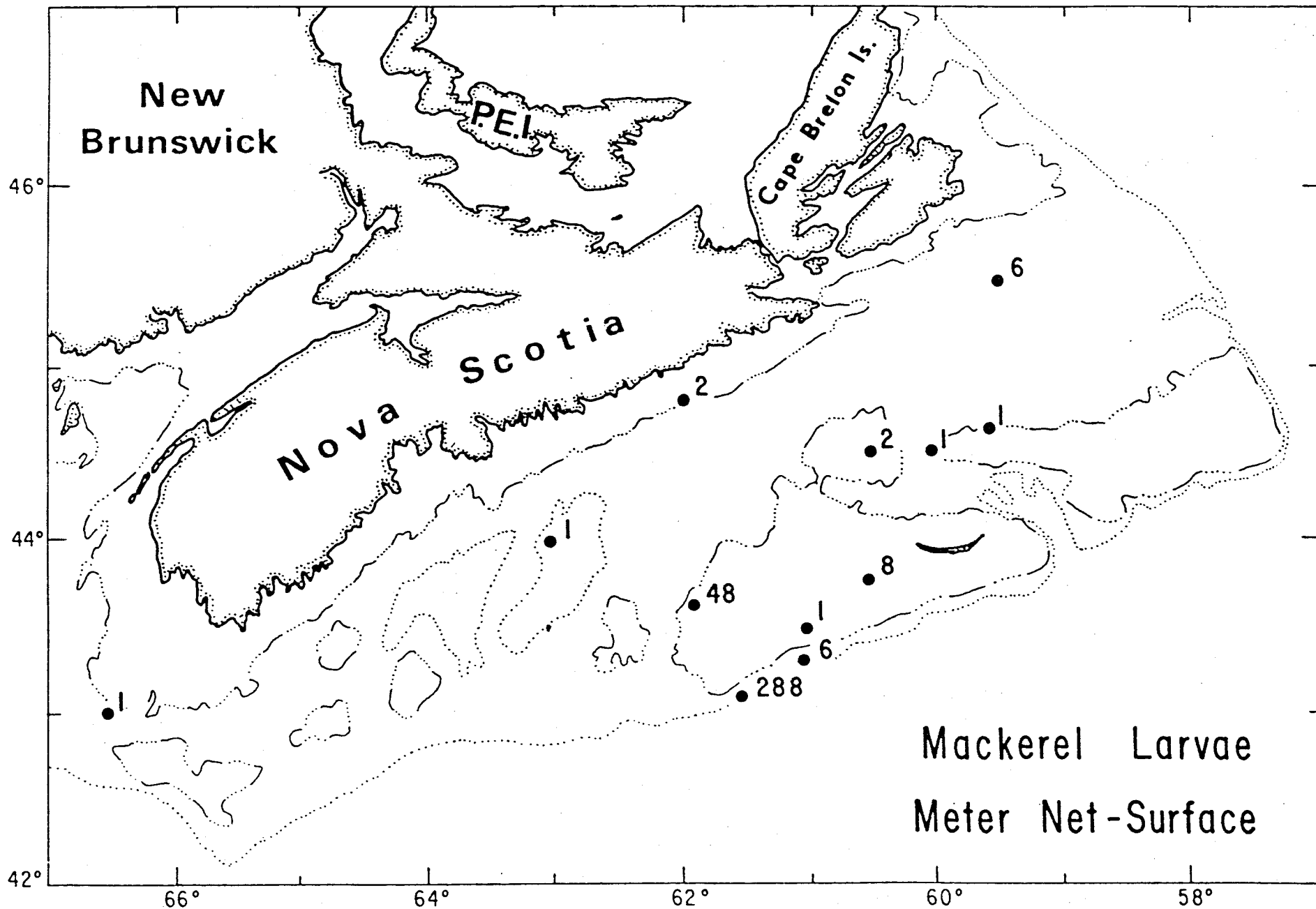
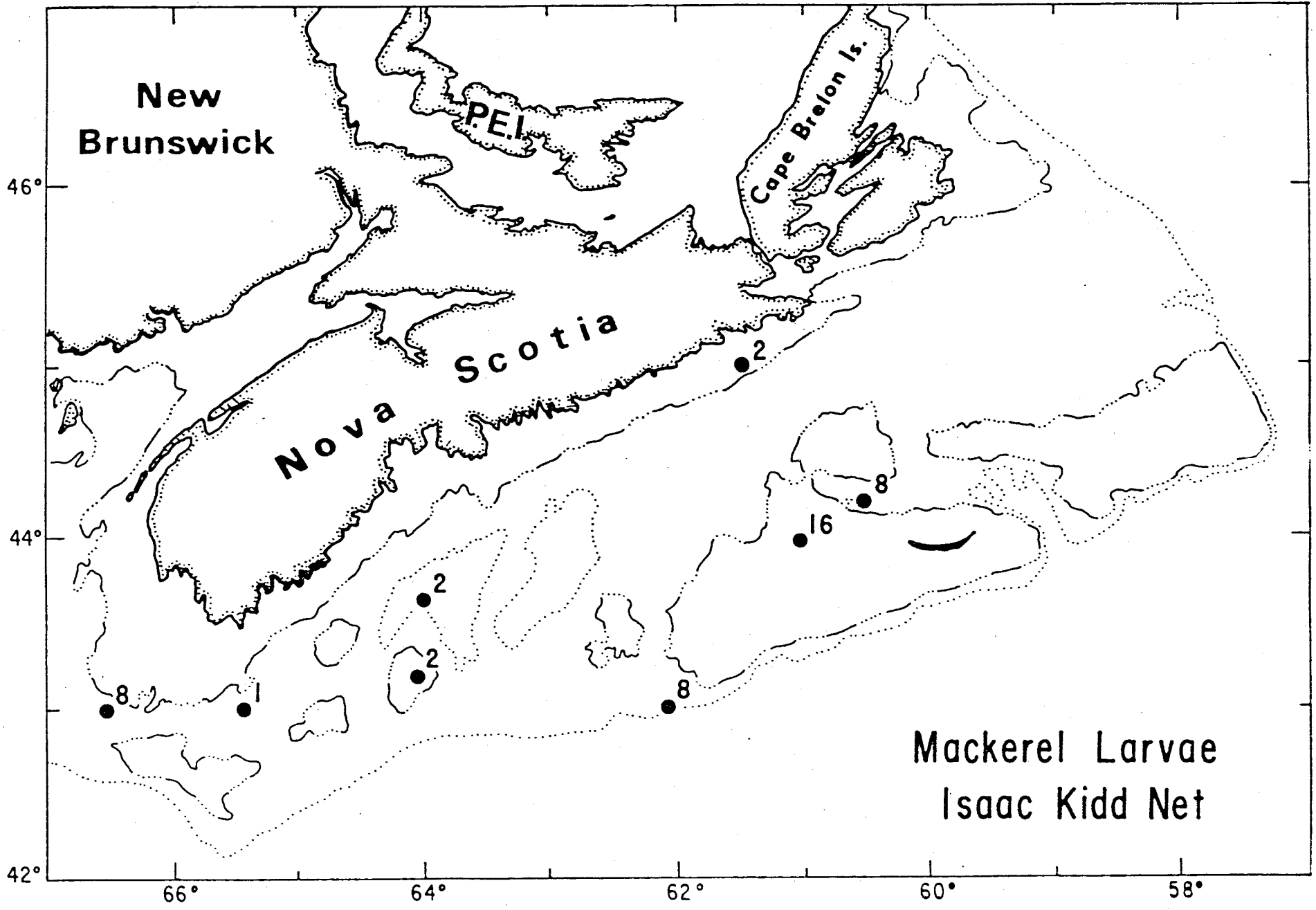


Figure 3A Catches of mackerel larvae on the Scotian Shelf in meter nets.



67

Figure 3B Catches of mackerel larvae on Scotian Shelf in Isaacs Kidd trawl.

Figure 4 Relationship between eggs/mature fish and weighted growth rate  
circle points not included in regression.

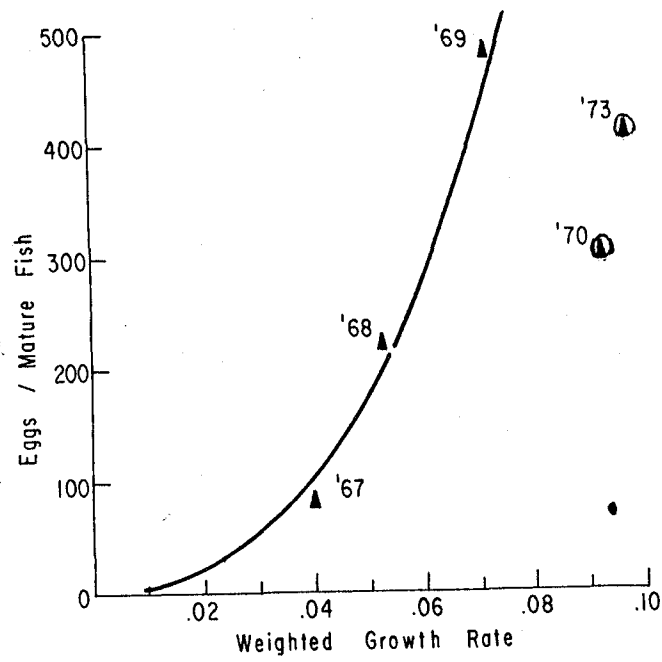


Figure 5 Relationship between fishing mortality from VPA and Andersons fishing effort.

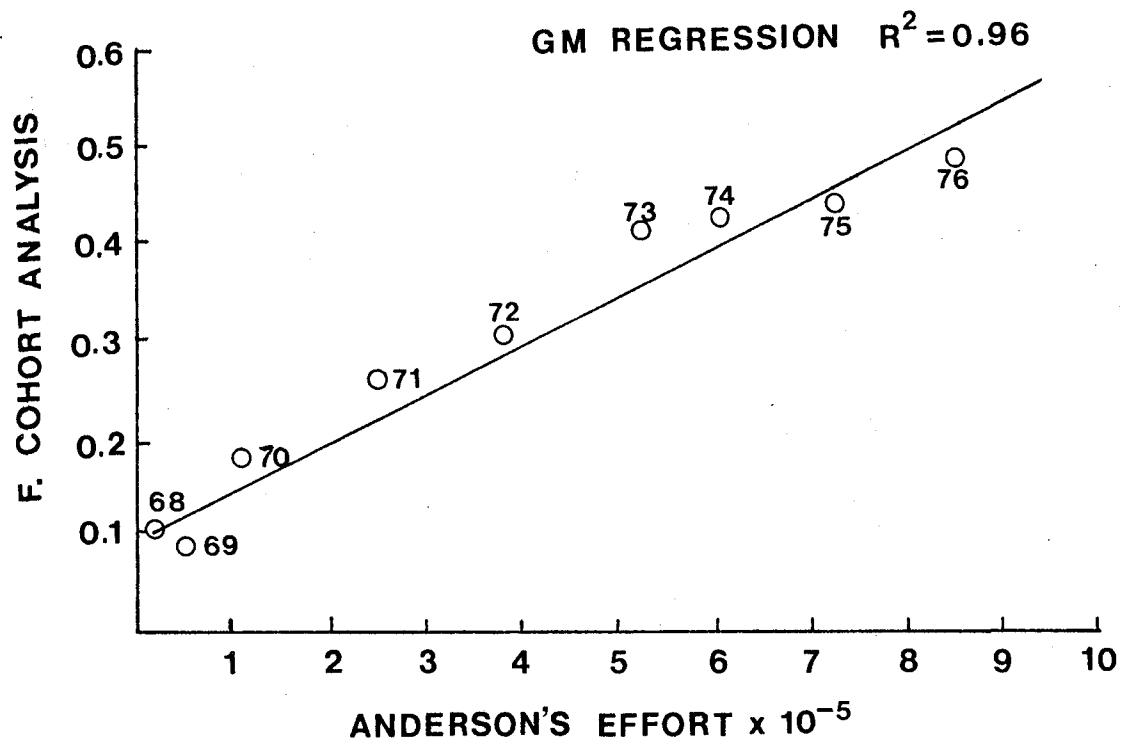




Figure 6 Relationship between  $l_1$  length and 0 group yearclass size  
1976 point is a predicted yearclass size based on equation VII  
and a measure  $l_1$  size. Point was not used in the regression.

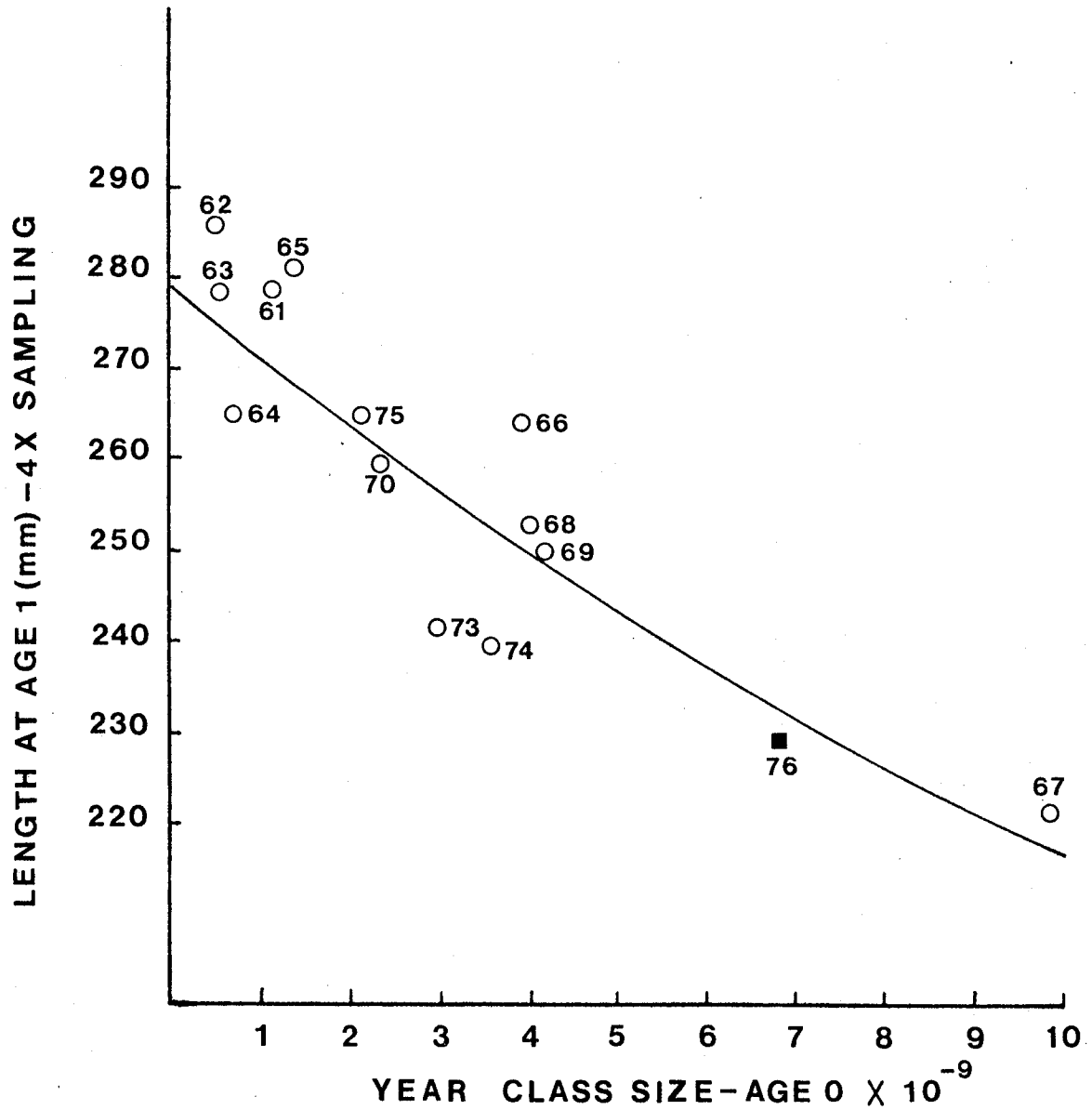


Figure 7 Relationship between eggs and yearclass size when variation due to temperature is removed.

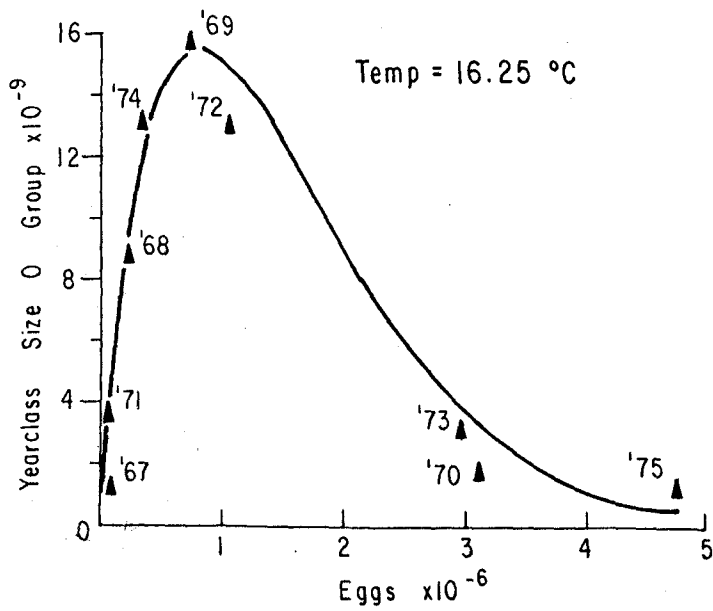


Figure 8 Simulated relationship between catch and biomass

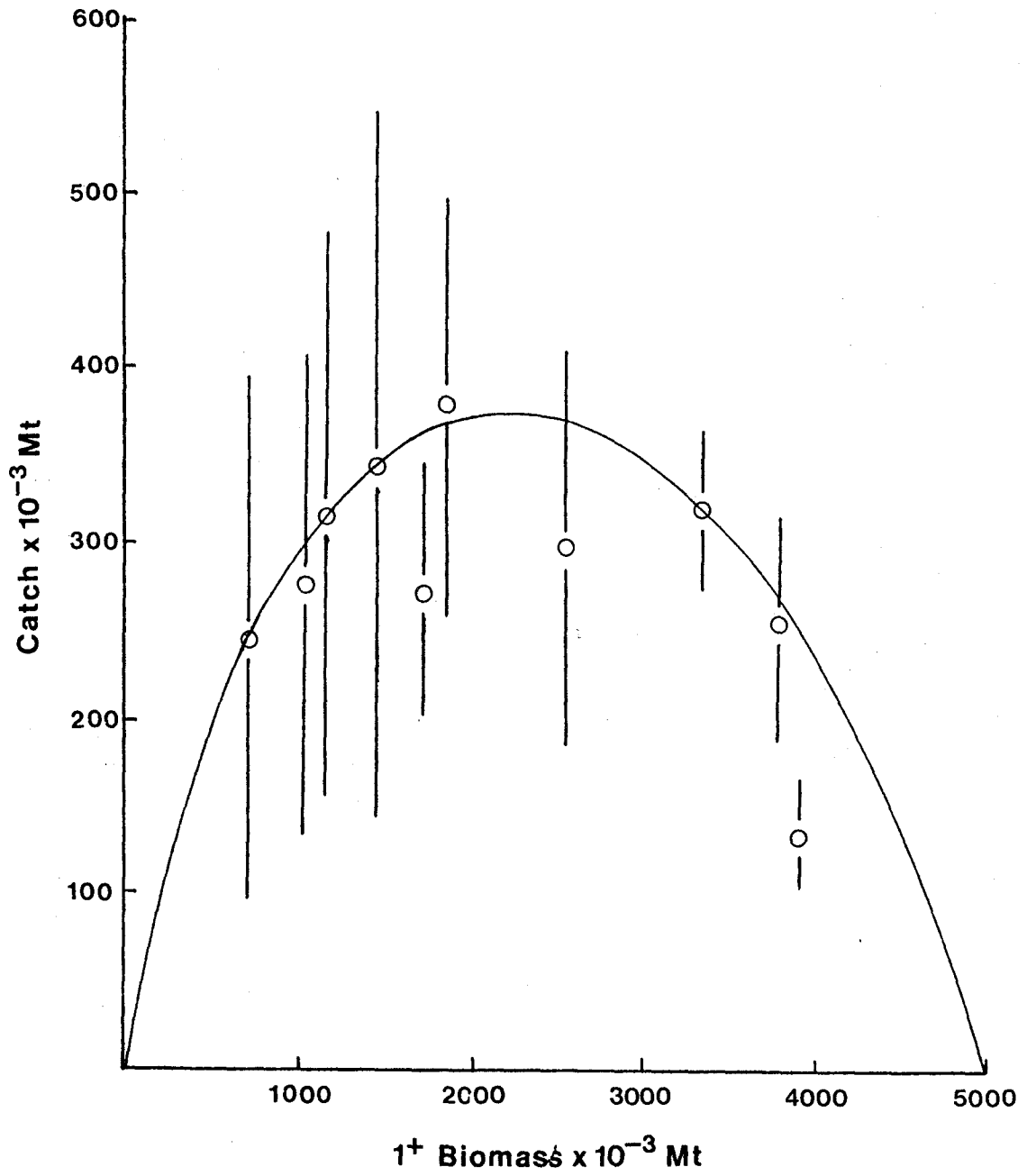


Figure 9 Simulated relationship between catch and fish mortality.

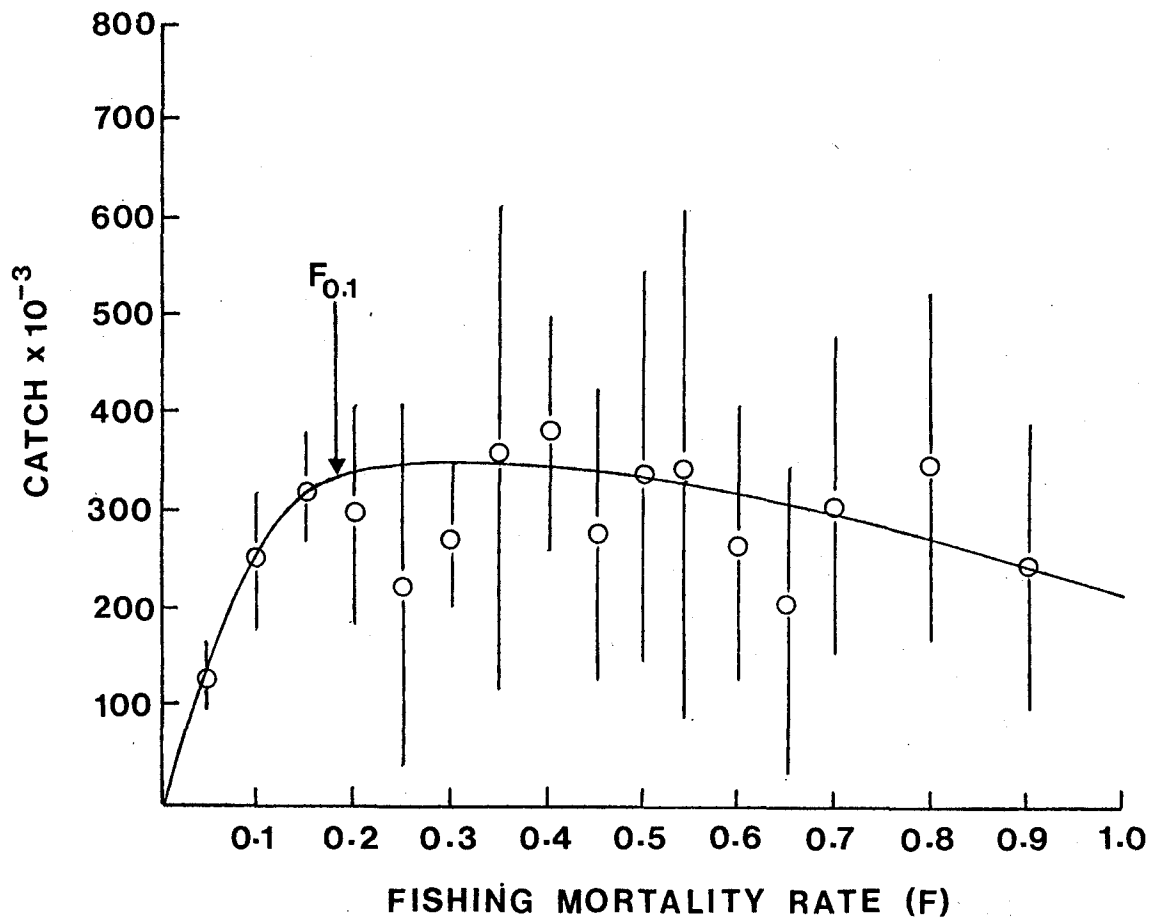


Figure 10 Flowchart of APL simulation model.

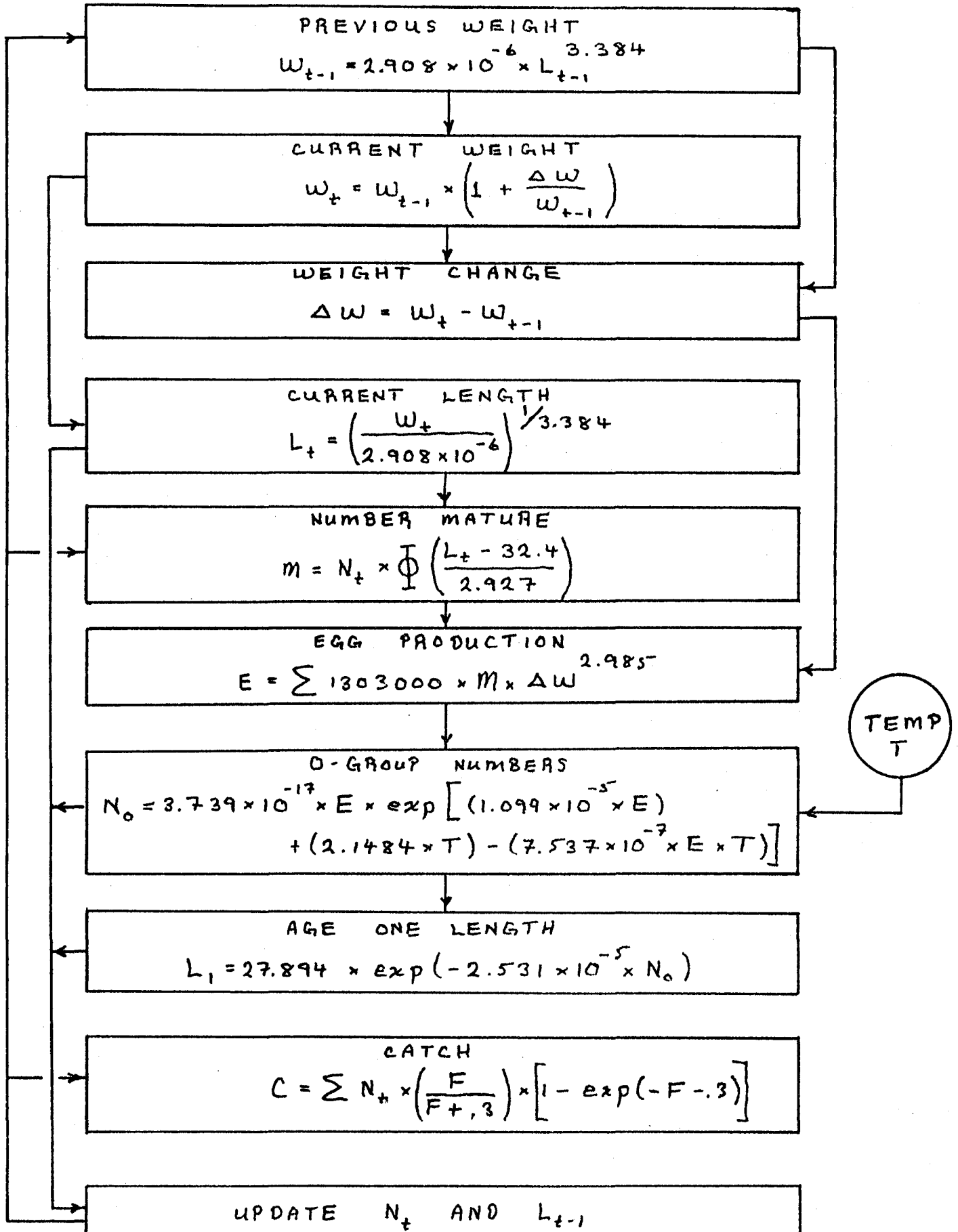


Figure 11 Relationship between change in weight divided by weight in previous year  $\frac{\Delta W}{W}$  and weight in previous year (W)

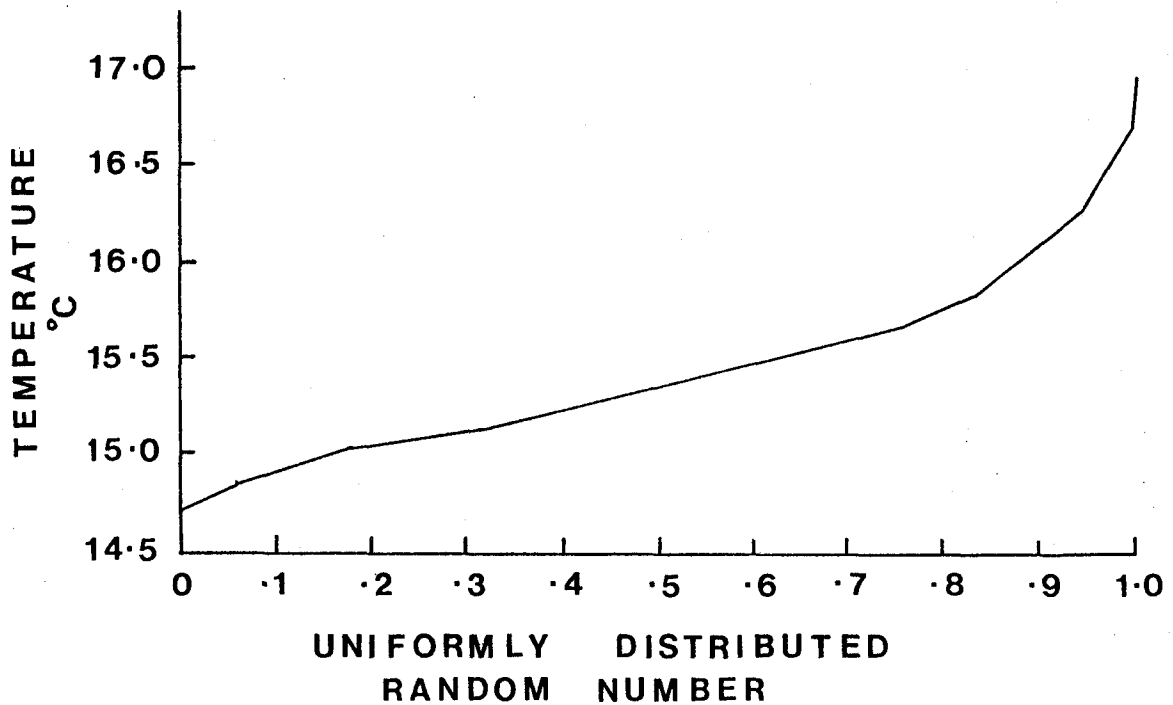
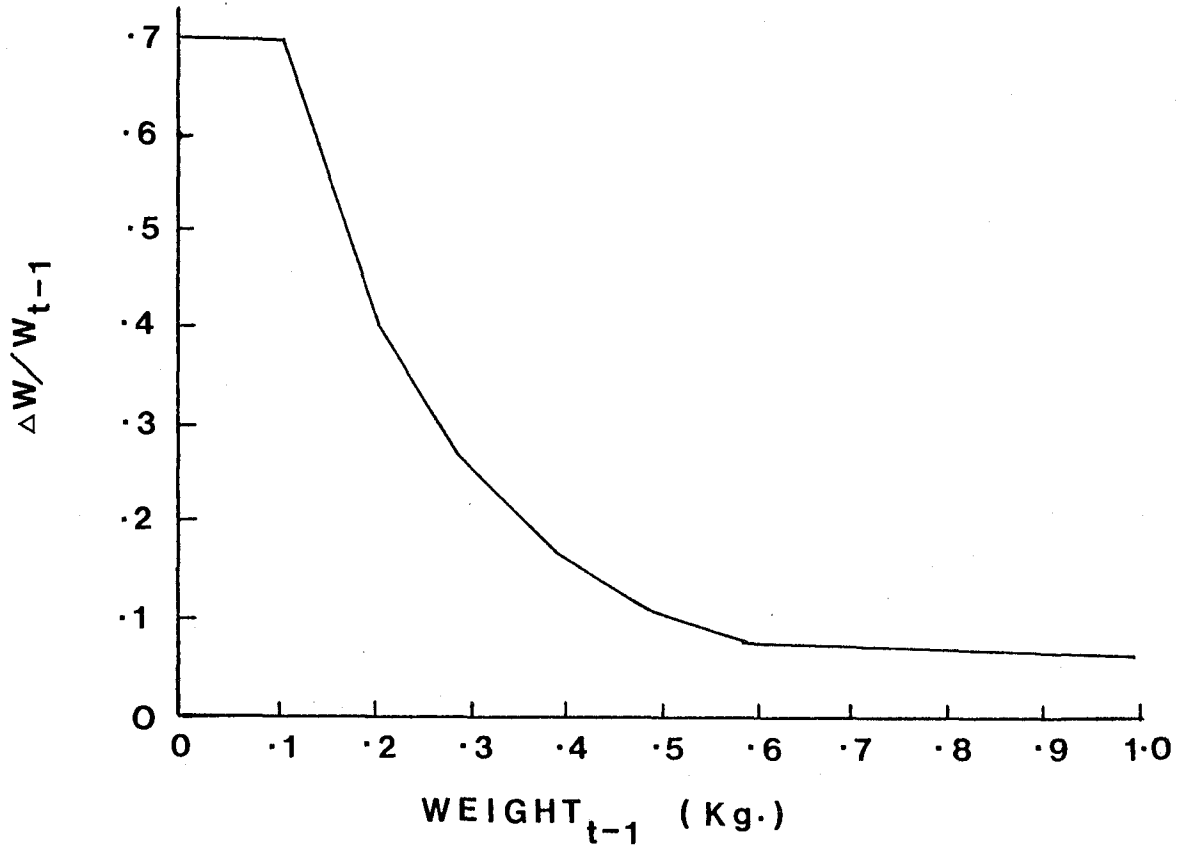


Figure 12 Observed temperature distribution as measured at Magdelan Shallows expressed as a cumulative distribution. Temperatures are averages for July, August and September. Temperature used in model is calculated by entering a uniformly distributed random variable on the x - axis and reading off the corresponding temperature variable from the y - axis.