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Dynamics and yield assessment of the northern Gulf of St. Lawrence cod stock (ICNAF Div. 4R-4S-3Pn)

by

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I. Introduction.

The northern Gulf of Saint Lawrence cod stock is migratory, as indicated by results from various tagging experiments (TEMPLEMAN, 1974 ; MINET, 1977). It stays in the northern part of the Gulf (ICNAF Divisions 4 S and 4 R-north) during the summer period, migrating to overwinter along the south-western coast of Newfoundland (ICNAF Division 4 R-south and Subdivision 3 Pn).

From ICNAF Statistical Bulletin for the years 1965-1975, it appears that the monthly evolution of catches in each division corresponds with the seasonal variation of the stock geographical boundaries. From January to April (maximum in March), most of the catches are made in Division 4 R and Subdivision 3 Pn. After a general drop in May, catches increase again from June to September-October (maximum in July) in Divisions 4 R and 4 S. So, catches made in Divisions 4 R and 4 S for the whole year and those made in Subdivision 3 Pn for the months January to April inclusive are referred to this stock (Table 1).

Total catches ranged approximatively from 60,000 to 80,000 metric tons during the 1965-69 period, reached a maximum of 103,000 metric tons in 1970 and averaged 60,000 metric tons again from 1973 to 1975. Most of the catches (72 p.cent) are made in Division 4 R while 13 p.cent come from Division 4 S and 15 p.cent from Subdivision 3 Pn (January to April). The Canadian catches, which slightly diminished during this period, represent about 50 p.cent of the total. Catches by France average 28 p.cent and those by others countries (mainly Portugal and Spain) have represented 22 p.cent up to 1975.

Catches of the offshore fisheries, carried on mainly by Canadian, French, Portuguese and Spanish trawlers, represented almost 70 p.cent of the total during this period while 30 p.cent came from the Canadian (Newfoundland, Québec) inshore fisheries using various types of gears (long-lines, gillnets, traps, hand-lines and jiggers).

A detailed study of this stock by WILES and MAY (1968) for the 1953-1966 period provided numerous data on the fishery (composition of catches, efforts, catch-per-unit-effort) and on the biology of cod (mortality, growth, maturity and spawning).

The present paper tends to bring complementary data on the dynamics of this stock (length and age composition, mortality, growth, length and age at first maturity and at recruitment to the exploited phase) and on variations of yield-per-recruit in relation to fishing mortality and age at first capture from research surveys carried out by the ISTPM Laboratory in St Pierre and Miquelon during the 1973-1976 period.

II. Material and methods.

The material used in this paper was collected during five research surveys carried out in ICNAF Divisions 4 R-S and Subdivision 3 Pn with R/V Thalassa in July-August 1975 and R/V Cryos during the winters (January-March) of 1973 to 1976.

From 1973 to 1975, the basic data were obtained from catches made by a polyamide research bottom-trawl (Lofoten) with 31.2 m headline, 17.7 m footrope, 140 mm mesh in the wings and body and 50 mm mesh in the codend, in order to collect biological samples.

On the contrary, the winter 1976 data were collected using two types of gears : the Lofoten research trawl and a polyamide commercial bottom-trawl used by the French (Metropolitan and St. Pierre) stern-trawlers with 33.0 m headline, 12.0 m footrope, 140 mm mesh in the wings and body and also 140 mm mesh in the codend. The catches made with this trawl were similar to those made by the commercial trawlers fishing in the same area at the same period.

1. Research trawl data.

Length and age compositions of the stock in each year were determined from 27,663 fish measured and 2,134 otoliths sampled at 312 trawling stations occupied during the 1973-76 period in the 4 R-S - 3 Pn area.

Research catch curves and calculation of instantaneous coefficient of total mortality (Z) of fully recruited age-groups were obtained from numbers of each age-group caught per half-hour from 1973 to 1976.

Estimates of natural mortality (M) were obtained first from 1976 data on cod recaptures after tagging experiment by the method developed by RICKER (1958) and then by plotting the 1973-74-75 values of Z against fishing effort (f) of the corresponding years calculated by standardizing efforts of the tonnage class 6 (1000-2000 gross tons).

Since no consistent trends were observed from 1973 to 1976, the average values of mean length at age were used to calculate the von BERTALANFFY growth curve equation by the WALFORD (1946) method. The length-weight relationship equation, calculated from 757 pairs of data collected in winter and summer of 1975, was used to obtain the corresponding von BERTALANFFY growth in weight equation.

From observations on sexual stages of 3,379 males and 3,120 females made in winter 1973, the mean length at 50 p.cent maturity (L_{50}) was calculated for both sexes using the method described by BLISS (1935).

2. Commercial trawl data.

Length and age compositions of the exploited portion of the stock in Div. 4 R-S-3 Pn were determined from 3,231 cod measured and 498 otoliths sampled in the winter 1976 catches with the commercial trawl.

During this survey, selectivity studies were undertaken in Division 4 R with the two types of trawls described above and using the alternate haul method (17 hauls of 30 minutes duration with each gear). The length frequencies of cod caught per hour with the research trawl (codend mesh size of 50 mm) and with the commercial trawl (codend mesh size of 140 mm) were analysed. The percentages retained at each length by the commercial trawl were determined using a conversion coefficient between the two trawls. The selection curve of the commercial trawl was fitted. The length at 50 p.cent retained fish, calculated by the BLISS (1935) method, gave the value of the mean length of entry to the catch (Lc).

1.4

3. Use of parameters.

The values of the basic parameters calculated as indicated in earlier sections were integrated in the yield-per-recruit BEVERTON and HOLT (1957) model. Variations of yield-per-recruit were studied in relation to different values of the instantaneous coefficient of fishing mortality (F), of the mean age at recruitment to the exploited phase (tc), and of F and tc simultaneously.

III - Results.

1. Length and age compositions.

Length and age compositions of the 4 R-S - 3 Pn cod stock for the years 1973 to 1976 are shown in fig. 1. The 1966 and 1968 year-classes were abundant in the 1973-74 research catches. The 1968 year-class, still abundant in 1975, was followed by the strong 1971 year-class which became the most important class in the 1976 research catches in which a good 1973 year-class appeared.

Length and age compositions observed in 1976 from research and commercial trawl catches are shown in fig. 2. Ages 2 and 3 are totally absent in the commercial catch, ages 4 and 5 are partly recruited to the fishery and full recruitment occurs at age 6.

2. Calculation of total mortality (Z).

The four catch curves obtained for the years 1973 to 1976 (fig. 3) yielded annual values of Z (6-11) of respectively 0.67, 0.50, 0.50 and 0.57.

Regression of natural logarithms of the average number caught in each fully recruited age-group, during the 1973-76 period (fig. 4) givesan average value of Z (6-11) = 0.57 (r = 0.948).

This value is inferior to the one found for the 1962-66 period (Z (7-15) = 0.65) for cod caught in Divisions 4 R-S by small-mesh otter trawl (WILES and MAY, 1968).

3. Estimates of natural mortality (M).

From the 1976 data on the number of cod recaptured during 3 four-months intervals after tagging, the following estimates were obtained for the year 1976 :

$$(F + M) = 0.48$$
$$F = 0.28$$

The F value, obviously underestimated, is due to incomplete reporting of tags recaptured by fishermen and mainly from French trawlers during the January-April period as indicated from results on returns compared to catches (RICKER's type A error).

On the other hand, the M value deducted from these results (M = 0.20) may be slightly overestimated, due to additional causes of mortality after tagging (traumatisms, predation, etc...).

With the second method, the annual values of Z found from 1973 to 1976 were plotted against the fishing efforts (f) calculated in days fished for the years 1972 to 1975. Regression of the Z values on corresponding f values is expressed in the equation :

$$Z = 1.67 \times 10^{-4} . f + 0.15$$

from which the estimate of M = 0.15 can be yielded.

These two estimates of natural mortality are relatively close to the M values found for other cod stocks in ICNAF area (PINHORN, 1975) ; they can reasonably be taken as limit values for M in this particular stock. Keeping in mind that M = 0.20 is probably too high, an estimate of M = 0.18 could be closer to the real value.

From these values of M and results of the previous section, the values of the fishing mortality F can be estimated to range from 0.37 to 0.42 with best estimate at F = 0.39.

4. Growth.

From analysis of average total length at age (3 to 12) for the 1973-76 period, the resulting von BERTALANFFY growth curve equation (fig. 5) is :

$$L_t = 91.9 \left(1 - e^{-0.13 (t - 0.20)}\right)$$

The length-weight relationship (fig. 6), as determined from the regression of log of the mean total weights (in grams) on log of total lengths (in centimeters), is expressed by the equation :

$$\log W = 2.96 \log L - 1.98$$

or after conversion :

$$W = 0.01047\ L^{2.96}$$

This relationship, applied to the growth in length equation, leads to the following von BERTALANFFY growth in weight curve equation (fig. 7) :

$$W_t = 6\ 783\ (1 - e^{-0.13\ (t - 0.20)})^{2.96}$$

The growth parameters calculated here for the 4 R-S - 3 Pn cod stock during the 1973-76 period are very close to the results obtained by WILES and MAY (1968) for the 4 R-S cod during the 1953-64 period :

$$L_t = 91\ (1 - e^{-0.14\ (t + 0.30)})$$

$$\log W = 3.01 \log L - 4.68$$

Our values of L_∞ (91.9 cm total length) and K (0.13) are indeed very close to the respective values of 91 cm fork -length and 0.14 given by these authors. The present value of n (2.96) obtained from total length measurements is also similar to their value of 3.01, obtained from fork-length measurements. In the same way, our value of a (-1.98) that seems different from their value (-4.68) gives, when our weights data are converted from grams to pounds, the value of -4.64.

5. Length and age at sexual maturity.

The sigmoid curves, fitted by the BLISS method to the proportion of mature males and females numbered at each length, are shown in fig. 8. The mean length and the corresponding mean age at which 50 p.cent of males and 50 p.cent of females become mature are as follows :

	male	female	combined
L_{50} (total length cm)	45.7	51.9	48.8
t_{50} (years)	5.5	6.6	6.0

Here again, these 1973 values are very close to those provided by WILES and MAY (1968) for the 1947-66 period which are respectively :

male : 45.5 cm and age 5.1
female : 49.7 cm and age 6.1
combined : 47.5 cm and age 5.6

6. Length and age at entry to the fishery.

The selection curve (fig. 9) is obtained from the 1976 studies on selectivity of the French commercial polyamide trawl (codend mesh size m = 140 mm).

The mean length (Lc) at which 50 p.cent of fish are retained in the commercial catch, calculated by the BLISS method, is 44.2 cm total length and the corresponding mean age at entry to the fishery (tc) is 5.25 years.

The values of m and Lc yield a selection factor (b) of 3.16.

This selection factor (3.16) related to the mean length at 50 p.cent maturity found earlier for sexes combined (L_{50} = 48.8 cm) indicates that a minimum mesh size of 155 mm would be necessary to avoid catch of immature fish.

7. Yield-per-recruit.

The values of parameters calculated before are substituted in the BEVERTON and HOLT yield-per-recruit model as follows :

$Z = 0.57$
$K = 0.13$
$t_o = 0.20$
$L_\infty = 91.9$ cm
$W_\infty = 6783$ g
$t_r = 2.00$ years (age at recruitment to the fishing area)
tc = 5.25 years
b = 3.16

a. Effects of change in fishing mortality.

The value of mesh size is constant (m = 140 mm) and so tc = 5.25 years.

According to the estimates of instantaneous natural mortality previously calculated, the values M = 0.15, M = 0.18 and M = 0.20 are used in the yield equation giving the results shown in fig. 10.

Assuming M = 0.15 (F = 0.42) maximum yield-per-recruit is obtained from this stock at F = 0.20, meaning that the stock is considerably overexploited.

If M = 0.20 (F = 0.37), maximum yield-per-recruit is obtained at F = 0.45, meaning that the 4 R-S - 3 Pn cod stock is slightly underexploited (present yield = 96 p.cent maximum).

Finally, taking the intermediate value of M = 0.18 (F = 0.39) considered to be a better estimate, maximum yield-per-recruit is obtained at F = 0.35, slightly lower than the 1973-76 value.

The theoretical mean weight of cod in the catch ($\overline{W}$ = 1.40 kg) calculated for M = 0.18 and F = 0.39, is the closest value to the experimental mean weight of cod ($\overline{W}$ = 1.45 kg) obtained in catches of the 140 mm mesh trawl. It confirms that the estimate M = 0.18 can be taken into consideration for further calculations.

b. Effects of change in mesh size.

The value of M (0.18) and F (0.39) are constant and the selection factor b = 3.16.

Variations of yield-per-recruit in relation to mesh sizes (m) and corresponding values of mean length (Lc) and age (tc) at first capture are shown in fig. 11.

Maximum yield-per-recruit is obtained for a codend mesh size m = 155 mm at Lc = 49.0 cm and tc = 6.0 years. An increase from 140 mm to 155 mm mesh size provides an increase of 9.5 p.cent of the yield-per-recruit.

c. Effects of simultaneous changes in fishing mortality and mesh size.

Results on variations of yield-per-recruit in relation to fishing mortality and to mesh size (and consequently to tc) are indicated in Table 2. Yield-per-recruit curves fitted to these data are shown in fig. 12.

To each increase of fishing mortality, maximum yield-per-recruit is obtained with a greater mesh size (older age at first capture). So, for each value of F, the optimum mesh size can be used to obtain the maximum yield from the stock ; for instance, at F = 0.40, maximum is obtained with 155 mm mesh size, tc = 6.0 years.

The values of maximum yield-per-recruit increase with F ; however, increases become progressively smaller towards an asymptotic value (fig. 13). Values of F going from 0.10 to 0.20 bring an increase of 27 p.cent in the maximum yield-per-recruit. Values of F going from 0.20 to 0.40 bring an increase of 11 p.cent. When F increases from 0.40 to 0.80 and to 1.20, the respective increases of yield are only of 3 p.cent and 0.3 p.cent. So, after the value of 0.40, no advantages could be obtained by an increase of fishing intensity.

From results indicated in Table 2, the yield isopleth diagram is obtained for this stock (fig. 14). The average 1973-76 position of exploitation is located on this diagram at F = 0.39 and tc = 5.25 years.

IV. Conclusion.

Results presented here indicate that the 4 R-S - 3 Pn cod stock stayed relatively stable during the last twenty years. Values of biological parameters found for the 1973-76 period are in fact very close to those obtained by WILES and MAY (1968) during the 1947-66 period. This stability is mainly observed on values of total mortality, growth in length and in weight, and length and age at first sexual maturity.

Although somewhat irregular, recruitment seems relatively good over the period of investigation. Strong year-classes appear each two or three years in the stock and in 1976 the young ones seem particularly well represented.

Yield-per-recruit analysis indicates that, during the period of research and taking M = 0.18 as the best estimate of natural mortality, the stock has been exploited very close to the maximum yield-per-recruit (F_{max} = 0.35) and even slightly over (F = 0.39).

The BEVERTON and HOLT model predicts that no economical benefit could be obtained from this stock by an increase of fishing intensity F. However, an increase of length and age at first capture by a change in trawl mesh size could bring long-term increases of yield-per-recruit. A mesh size of 155 mm was found to be the optimum value to obtain the maximum yield from the 4 R-S - 3 Pn cod stock, the length and age at recruitment to the fishery being respectively 49.0 cm and 6.0 years.

An increase in mesh size from 140 mm to 155 mm would bring a long term increase of 9.5 p.cent in the yield-per-recruit with an immediate loss of 8 p.cent. A change from 130 mm to 155 mm could give a long term increase of 15 p.cent in the yield with an immediate loss of 11 p.cent.

Besides, such an increase to 155 mm mesh size would have the advantage to avoid capture of immature fish and so to favour a better recruitment.

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Table 1.- ICNAF Divisions 4 R-S and Subdivision 3 Pn (January-April) cod - Catches (metric tons) by country and division, 1965-75.
(others : mainly Portugal and Spain).

Year	Canada	France	Others	Total	4 R	4 S	3 Pn
1965	35,431	15,634	15,631	66,696	43,839	8,355	14,502
1966	35,065	13,708	13,062	61,835	44,208	7,253	10,374
1967	35,346	17,105	18,433	70,884	49,941	8,943	12,000
1968	48,394	26,344	11,716	86,454	70,029	7,721	8,704
1969	48,507	16,536	4,167	69,210	56,632	9,591	2,987
1970	46,116	30,457	26,726	103,299	91,146	9,114	3,039
1971	33,038	24,458	24,010	81,506	66,362	9,604	5,540
1972	27,345	13,326	14,017	54,688	37,583	10,297	6,808
1973	26,862	17,642	17,794	62,298	43,094	11,411	7,793
1974	33,094	16,614	14,297	64,005	39,446	12,977	11,582
1975	27,461	17,154	14,477	59,092	41,569	12,431	5,092

Table 2.- Effects of simultaneous changes in mesh size and fishing mortality (F) on yield-per-recruit for the 4 R-S - 3 Pn cod stock.
Values of maximum yield-per-recruit are underlined.

Mesh size (mm)	Lc (cm)	tc (years)	Yield-per-recruit (g) for :				
			F = 0.10	F = 0.20	F = 0.40	F = 0.80	F = 1.20
120	37.9	4.3	396	476	474	468	378
140	44.2	5.2	<u>403</u>	501	518	486	456
150	47.4	5.9	400	<u>510</u>	544	544	532
155	49.0	6.0	396	509	<u>567</u>	555	554
165	52.1	6.7	387	498	560	<u>586</u>	563
180	56.9	7.7	367	485	554	568	<u>588</u>
200	63.2	9.2	337	459	542	552	578
250	79.0	15.3	164	234	294	336	355

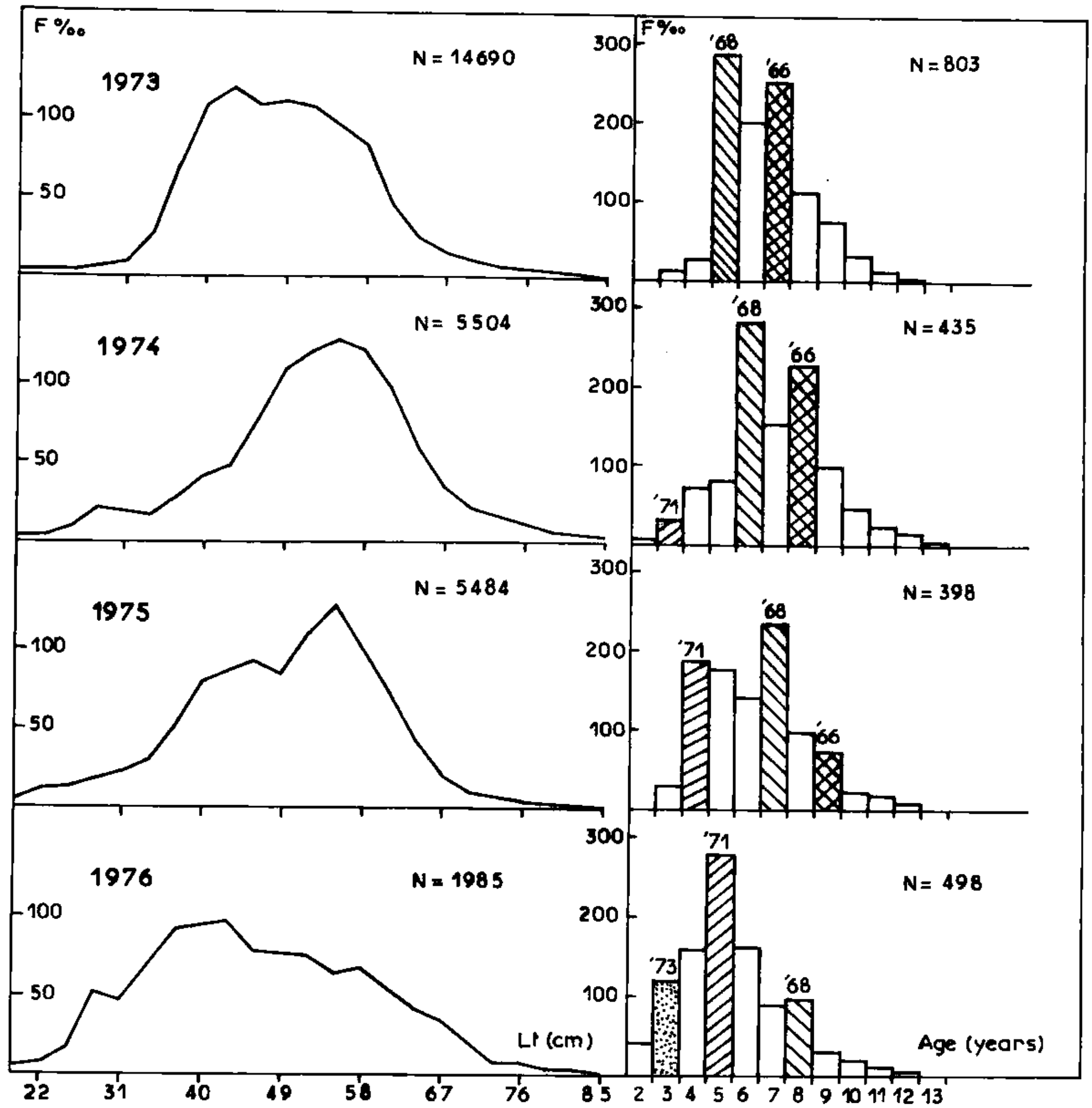

Fig. 1. - Length and age compositions of the 4 R-S - 3 Pn cod stock from research trawl catches, 1973-76.

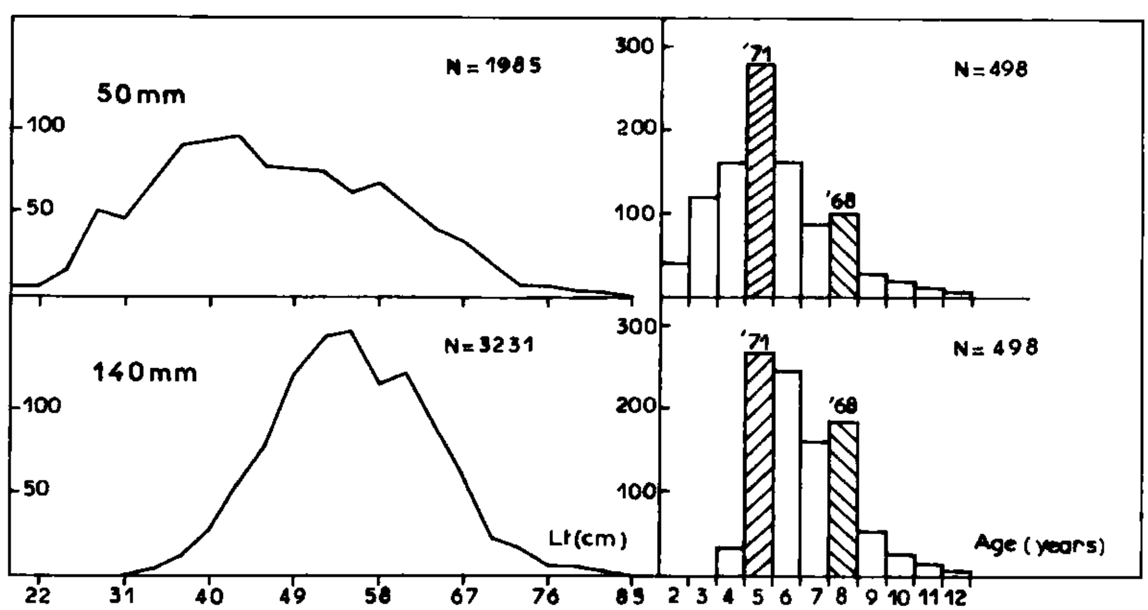

Fig. 2. - Length and age compositions of cod in ICNAF Div. 4 R-S - 3 Pn from research trawl (50 mm codend mesh) and commercial trawl (140 mm) catches in 1976.

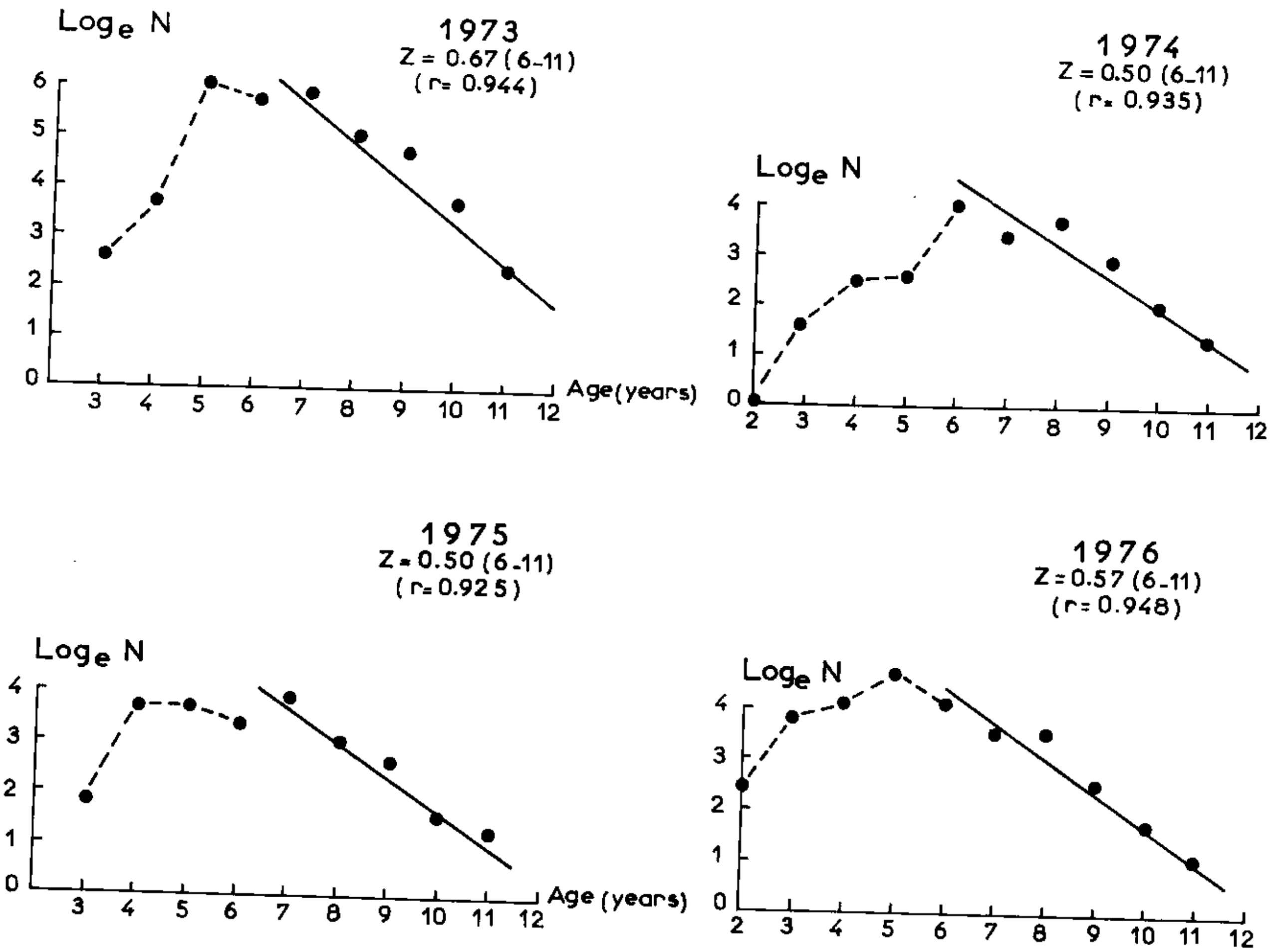

Fig. 3. - Research catch curves for cod in ICNAF Div. 4 R-S-3 Pn from 1973 to 1976.

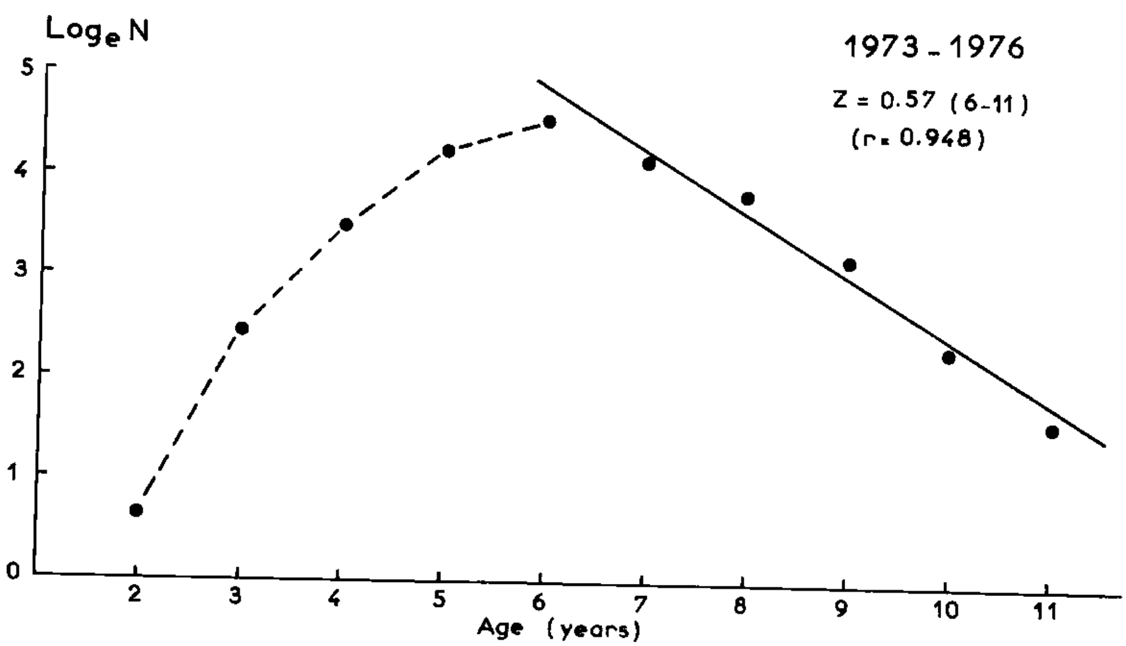

Fig. 4. - Average catch curve for cod in ICNAF Div. 4 R-S - 3 Pn during the 1973-76 period.

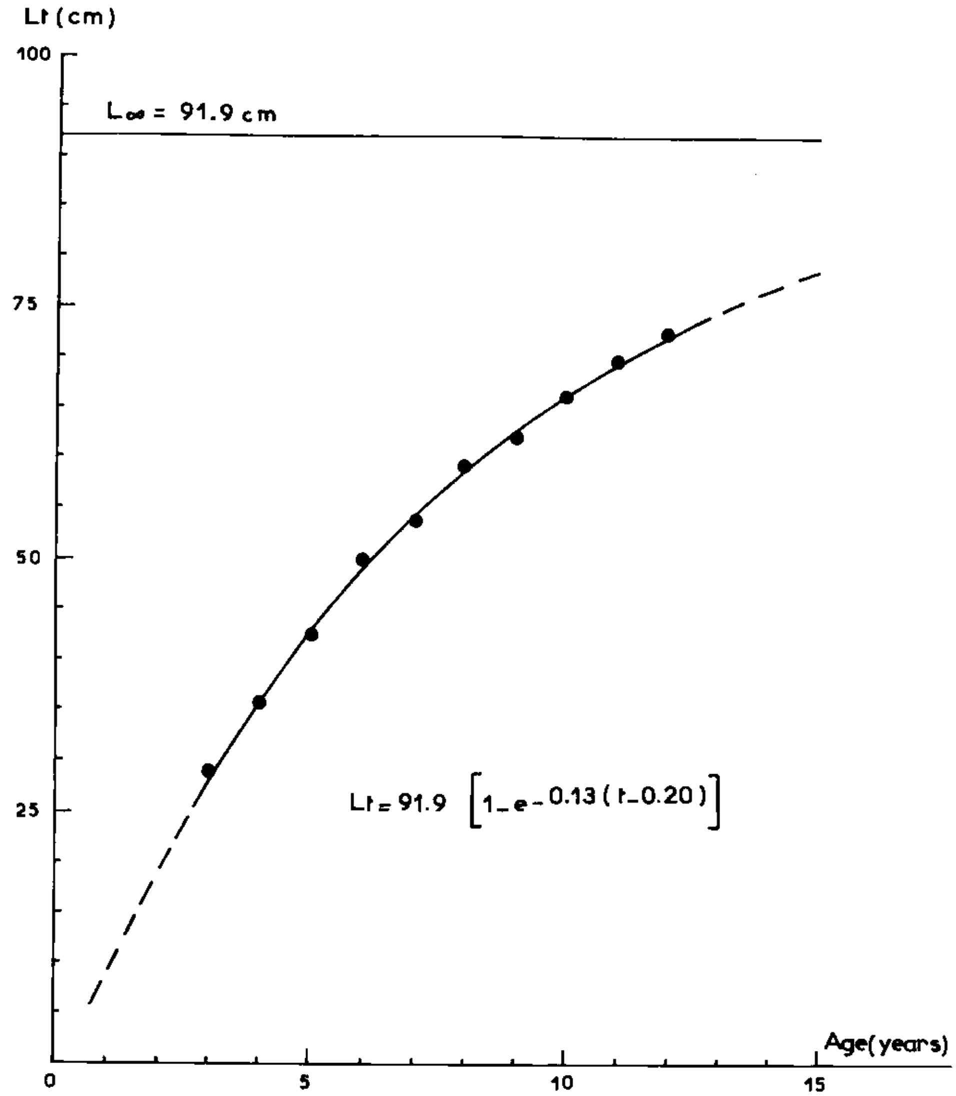

Fig. 5. - Von BERTALANFFY growth in length curve for the 4 R-S - 3 Pn cod stock, 1973-76.
Dots represent experimental values.

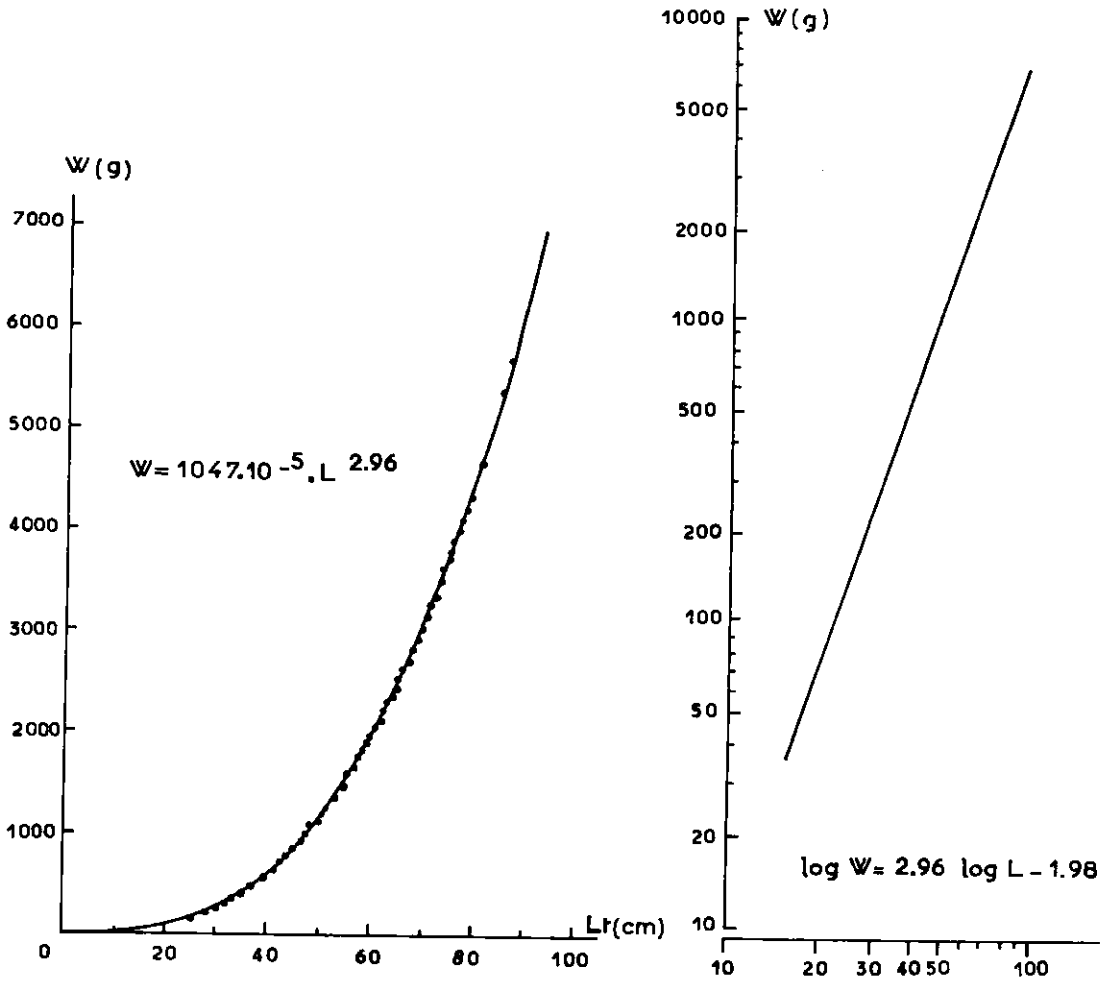

Fig. 6. - Length-weight relationship (arithmetic and logarithmic) for the 4 R-S - 3 Pn cod stock, 1975.

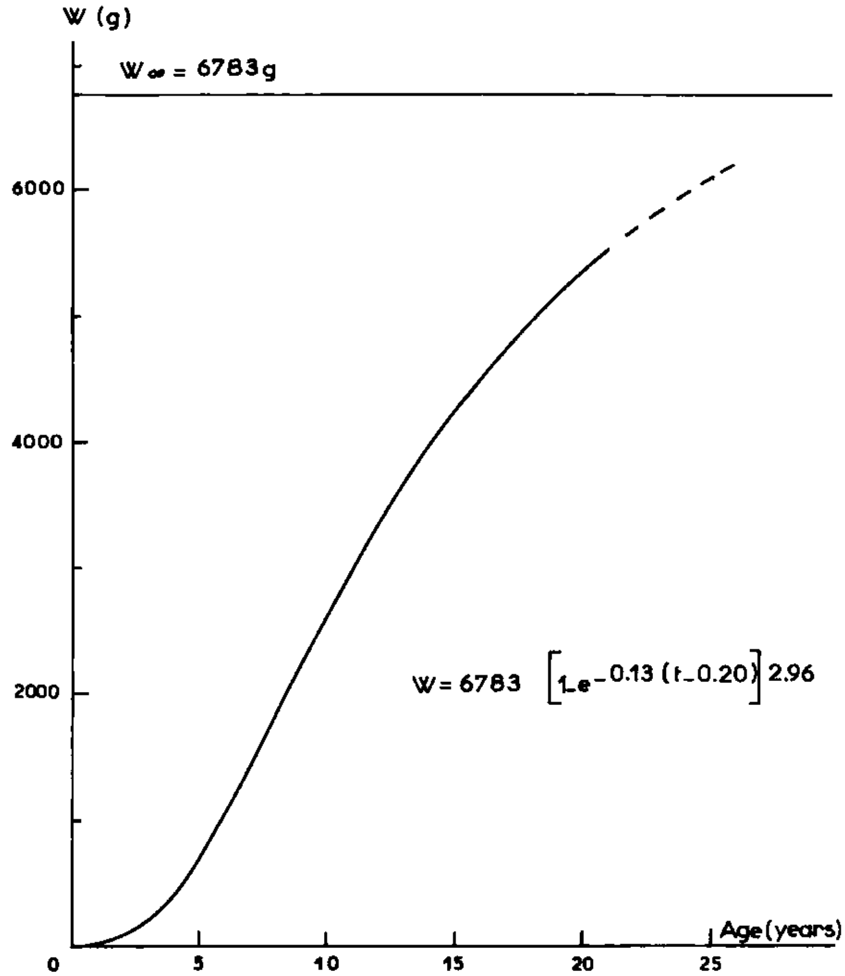

Fig. 7. - Von BERTALANFFY growth in weight curve for the 4 R-S - 3 Pn cod stock, 1973-76.

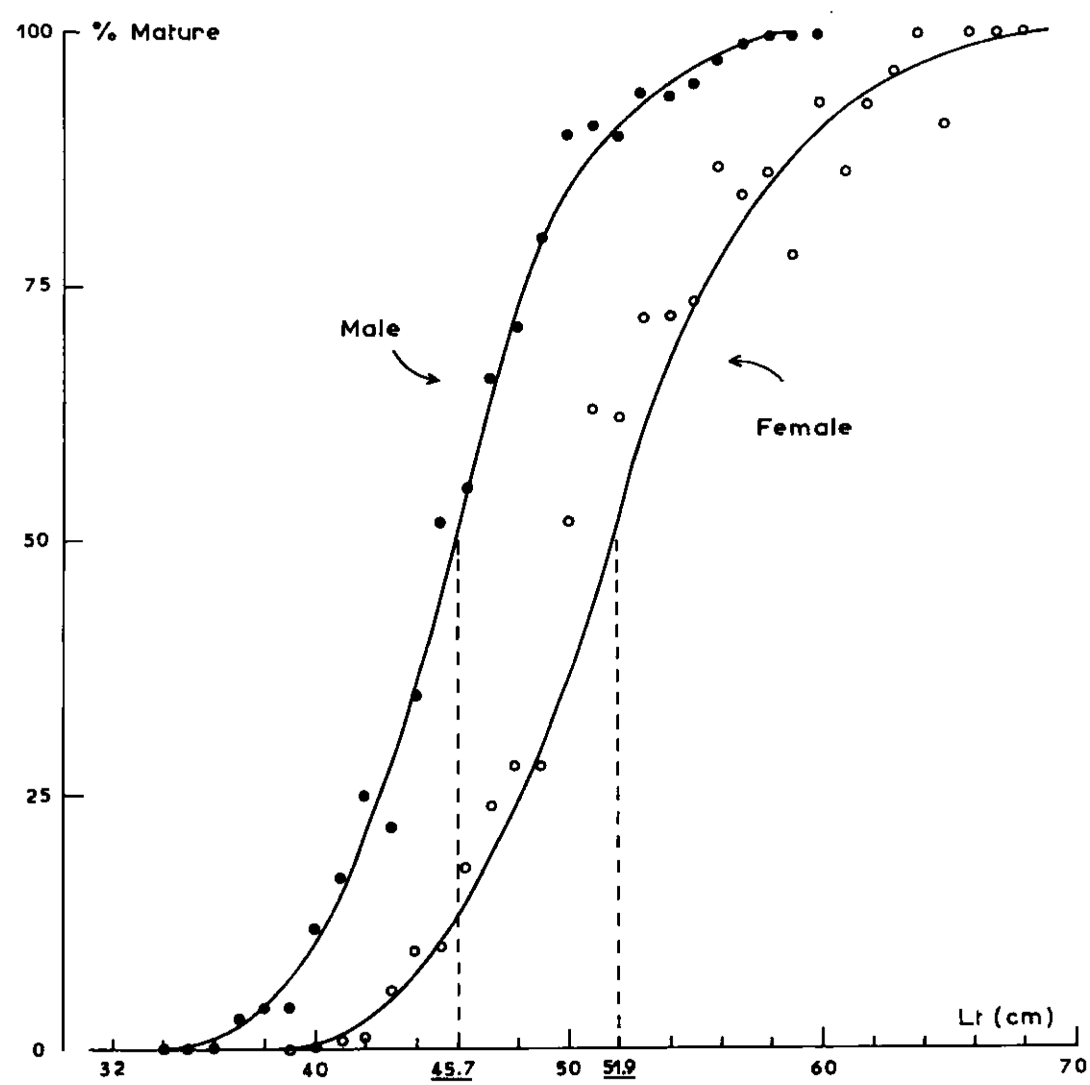

Fig. 8. - Fitted sigmoid curves of length at sexual maturity for male and female 4 R-S - 3 Pn cod, 1973. Dots represent experimental values.

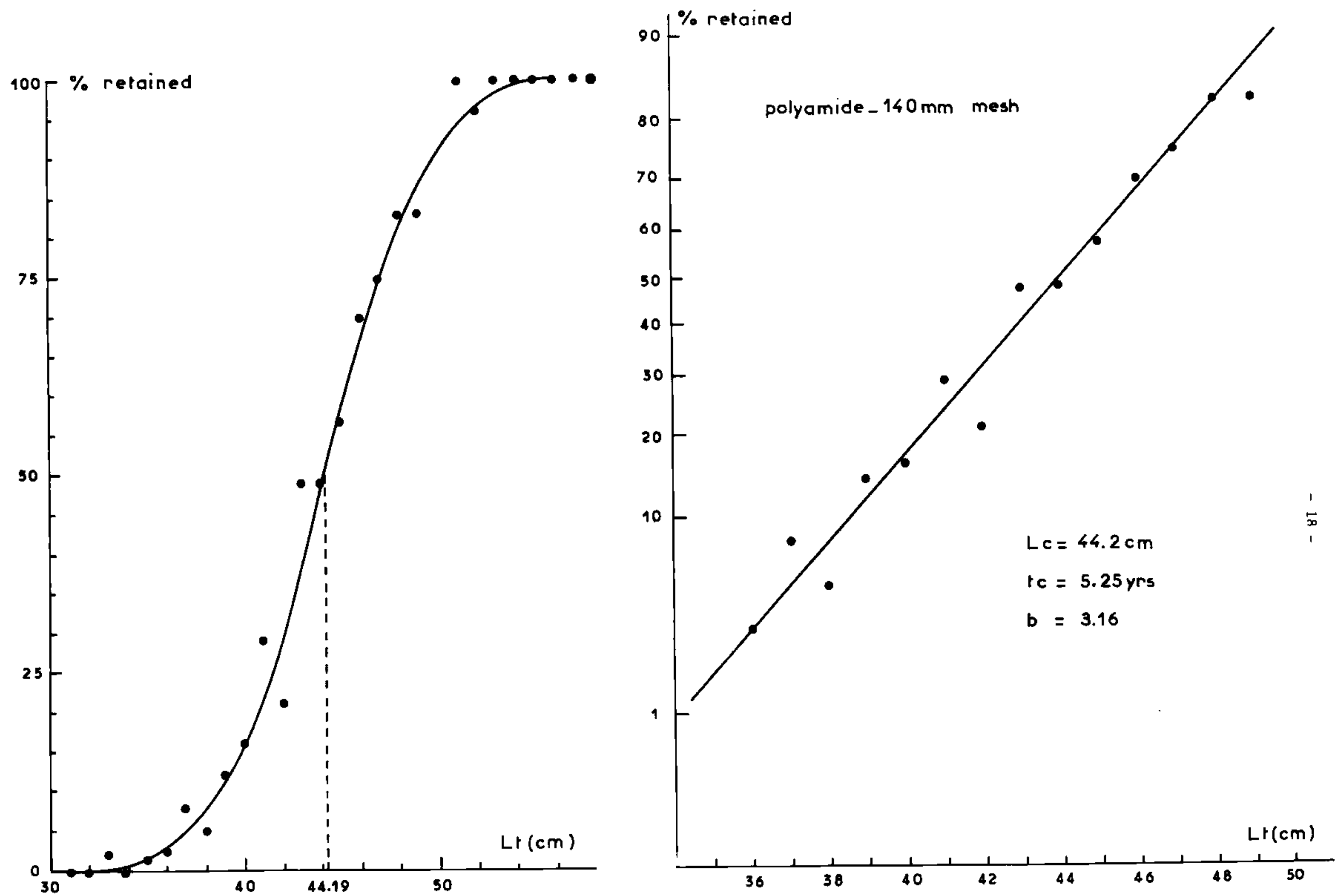

Fig 9. - Fitted selection curve and line obtained for 4 R-S - 3 Pn cod by commercial polyamide trawl (140 mm codend mesh size), 1976. Dots represent experimental values.

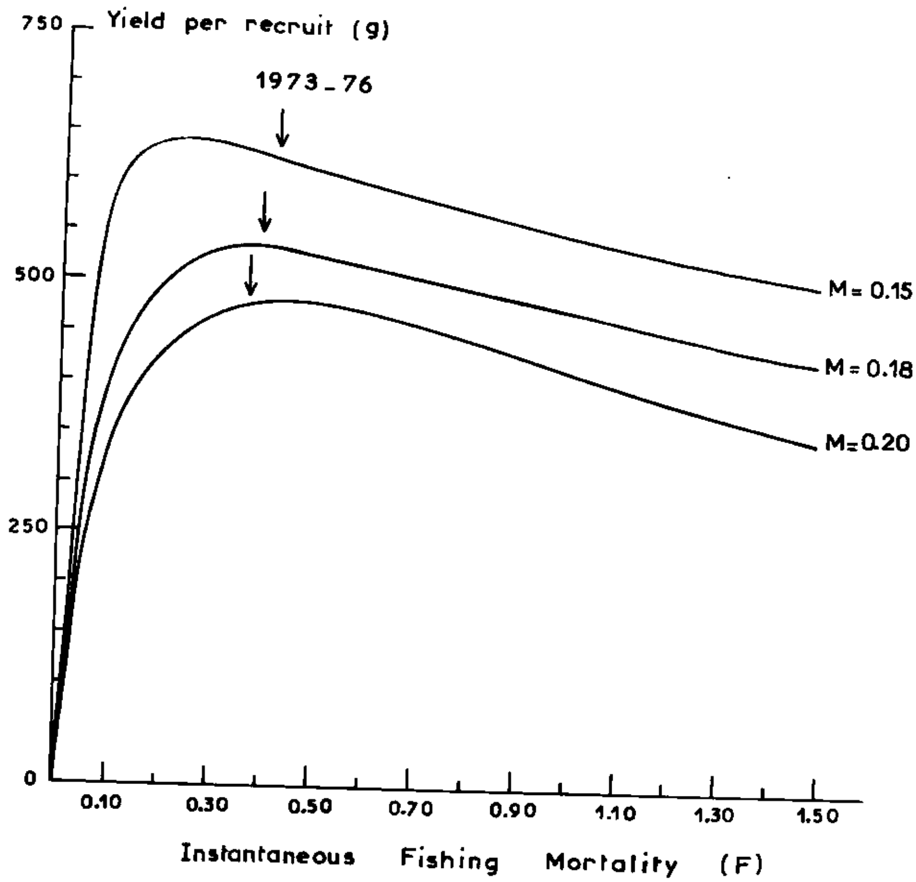

Fig. 10. - Yield curves for the 4 R-S - 3 Pn cod stock with three values of natural mortality (M), 1973-76. The average 1973-76 position is indicated by arrows.

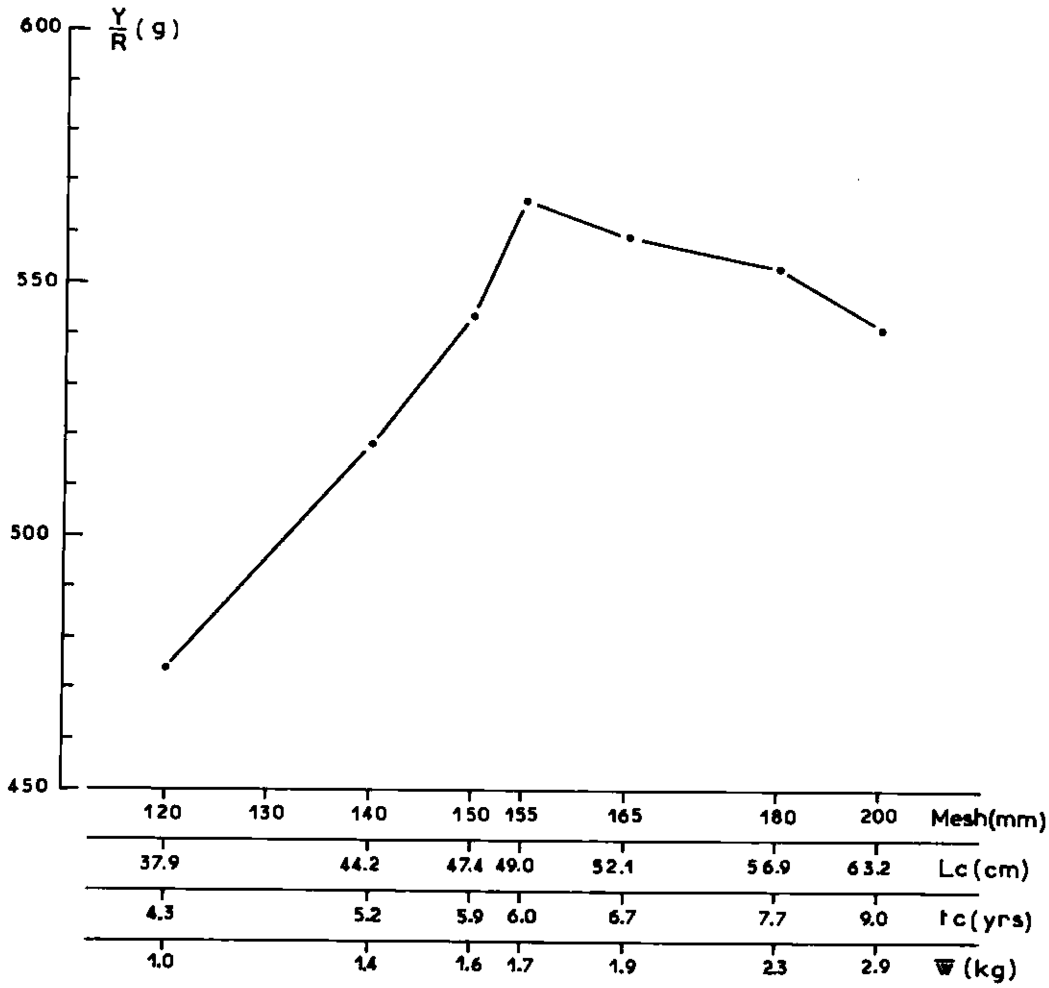

Fig. 11. - Yield-per-recruit for the 4 R-S - 3 Pn cod stock in relation to change in mesh size and corresponding mean lengths and ages at recruitment to the fishery.

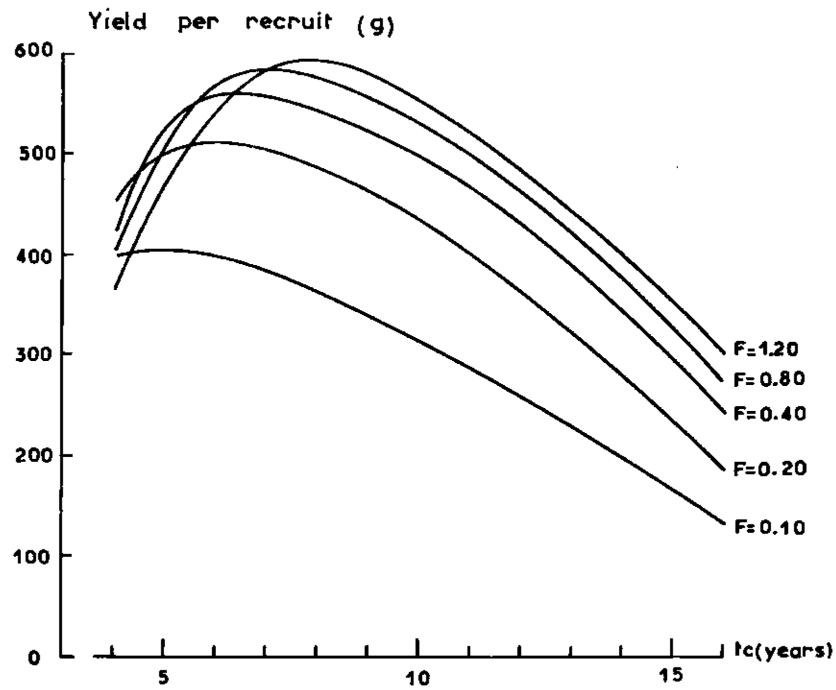

Fig. 12. - Yield-per-recruit curves for the 4 R-S - 3 Pn cod stock in relation to age at recruitment to the fishery and fishing mortality.

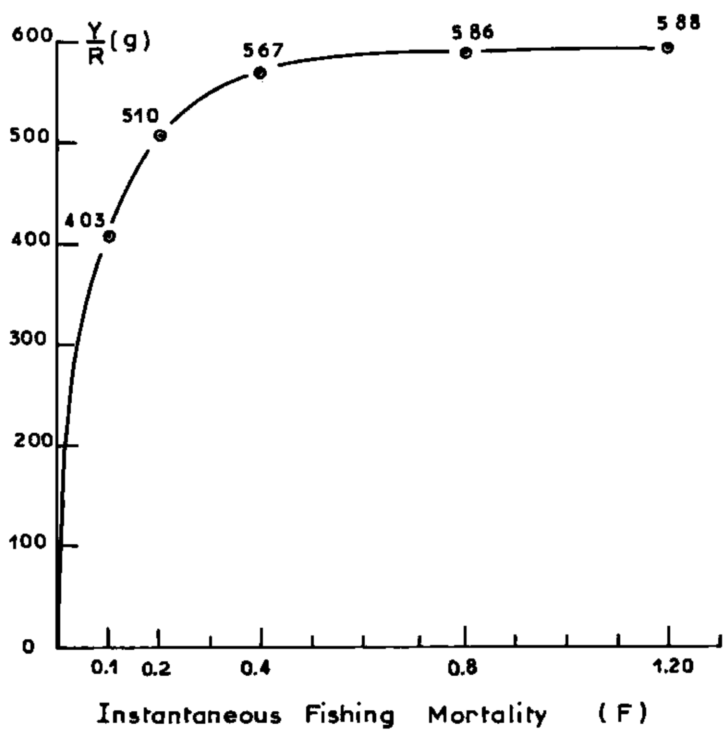

Fig. 13. - Eumetric yield curve for the 4 R-S - 3 Pn cod stock.

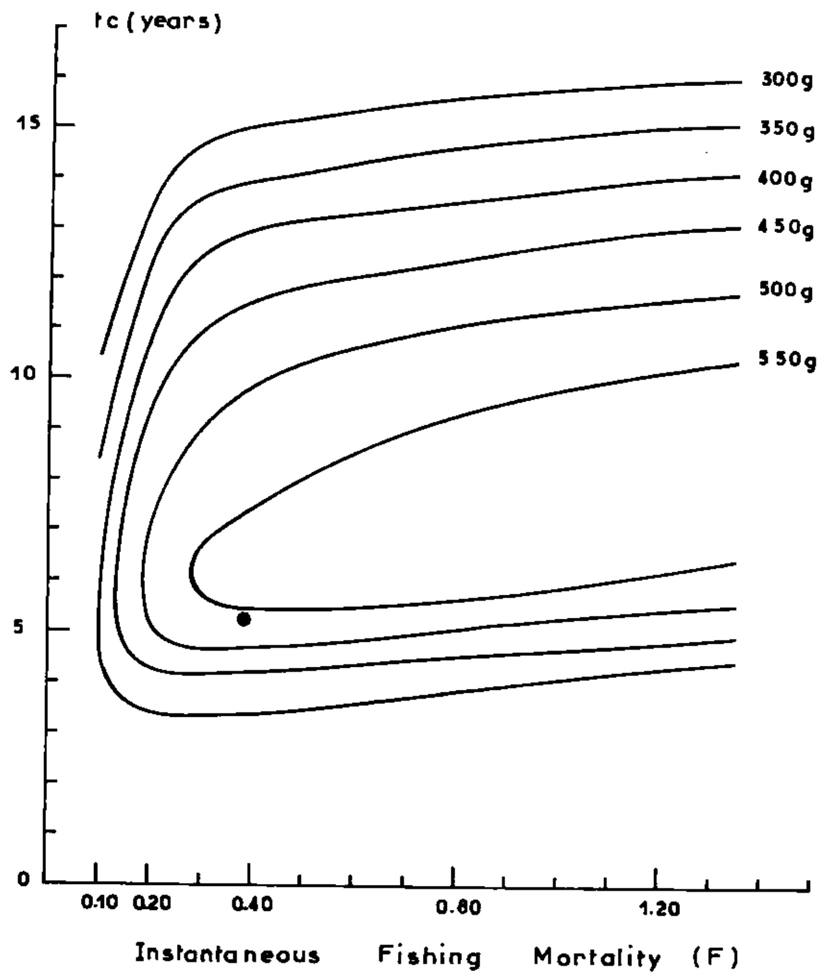

Fig. 14. - Yield isopleth diagram for the 4 R-S - 3 Pn cod stock.
Dot indicates average 1973-76 position.