Northwest Atlantic Fisheries Organization

Serial No. N143

NAFO SCR Doc. 80/VI/89

SCIENTIFIC COUNCIL MEETING - JUNE 1980

Dynamics and Assessment of the Labrador-Northeast Newfoundland Cod Stock Complex (Divisions 2J and 3KL)

by

J.P. Minet, A. Forest and J.C. Poulard
Institut Scientifique et Technique des Pêches Maritimes
Centre de Recherches
Saint-Pierre et Miquelon

INTRODUCTION

The Labrador-Northeast Newfoundland cod stock complex is composed of several substocks intermingling inside the NAFO Divisions 2J, 3K and 3L (Templeman, 1962). Although the migration patterns were identified (Templeman, 1974), these substocks cannot be separated due to the lack of biological data. So, for the purpose of managment, it is now usual (Pinhorn and Wells, 1972) to consider this complex as an homogeneous stock.

Historical catches on this stock complex have greatly changed during the last twenty years (ICNAF, 1960 to 1979). A progressive increase occurs from 1958 (217,000 metric tons) to 1968 when a pick is reached at 784,000 tons. After 1968 the catches progressively drop down to the level of 136,000 tons in 1978 (provisional report). The nominal catches of the last ten years (1968-1977) are given in Table 1 by country and by division. The average catch of the last five years (1974 to 1978) is about 240,000 tons when it is about 430,000 tons for the last twenty years (1958-1978).

Due to the importance of this historical fishery many works were done on this cod stock complex. Among them, the most important and recent studies were carried out by Fleming (1960) ; Hodder (1965) ; May, Pinhorn, Wells and Fleming (1965) ; May (1966a); Wells and Pinhorn (1970) ; Pinhorn (1975).

The present study, based on surveys carried out during five years (1976 to 1980) involves the analysis of complementary data on the dynamics of this stock complex and provides a yield assessment from research material completed by commercial data.

MATERIALS AND METHODS

The material used in this study was collected during five research surveys in Div. 2J, 3K and 3L with the research vessel Cryos during the winters (January-February) of 1976 to 1980.

The basic biological data were obtained from catches made with a polyamide research bottom trawl with 31.2 m headrope, 17.7 m footrope, 140 mm mesh in the wings and body and 50 mm mesh in the codend.

The length and age composition of the stock in each year were determined from 40,524 fish measured (total length) and 3,082 otoliths sampled at 234 trawling stations occupied during the 1976-1980 period.

Since no consistent trend in growth was observed during the 1976-80 period, the mean length-at-age data for all years were used to calculate the von Bertalanffy growth curve by the method of Walford (1946). The length-weight relationship based on the measurement of 952 specimens collected during the survey of 1980 was used to obtain the corresponding von Bertalanffy curve of growth by weight.

The mean length at 50 % maturity (L_{50}) was calculated for both sexes using the regression of the experimental probits versus the total length, on 6,214 fish examined during the 1980 survey.

During the 1980 survey, selectivity studies were carried out in Div. 2J using the research trawl with alternatively 50 mm mesh and 140 mm mesh in the codend, at 6 stations each. From the length frequencies of cod caught per half-hour with each gear, the percentages retained at each length by the 140 mm mesh trawl were determined using a conversion coefficient between the two gears. The selection curve was then fitted by the probit method and the mean length at entry to the catch (L_c) was determined from the 50 % retention length. In addition, from 1,430 cod measured on the catches of the 140 mm mesh trawl and from the 1980 age-length key, the length and age composition of the exploited portion of the stock were determined for 1980.

Catch curves and the calculation of total mortality coefficients (Z) for fully recruited age-groups were obtained from frequencies of each age-group caught during the 1976-1980 period. The corresponding values of the fishing mortality coefficients (F) were obtained for each year using the estimate of the natural mortality coefficient M = 0.18 (Pinhorn, 1975).

The values of the basic parameters, calculated as indicated above, were used in the Beverton and Holt (1957) yield-per-recruit model. Variations in yield-per-recruit were studied in relation to different values of the

fishing mortality coefficient (F), and the mean age at recruitment to the exploited phase (t_c).

The fishing efforts (f) were calculated for 1958 to 1977 from commercial data, using the Portuguese trawlers (OTB1-6) as standard (ICNAF, 1960 to 1979). For 1978, the value of f was derived from data provided by Wells (1980), by converting Spanish CPUE to Portuguese CPUE. These values of f, with the corresponding values of total catches, were included in the Schaefer (1957) general production model. In addition, the relationship between Z and f was established from the values calculated for 1976, 1977 and 1978, taking M = 0.18.

CALCULATION OF PARAMETERS

Length and age composition.

The length and age compositions of the Labrador-Northeast Newfoundland cod stock complex in 1976-1980 are shown in Fig. 1.

The polymodal length distribution in 1976 (modes at 35 cm, 50 cm and 64 cm LT) is very different from distributions observed in the following years where one main modal length is dominant : 40 cm LT in 1977 and 1978 and 50 or 52 cm LT in 1979 and 1980. The age composition in the research catches of 1976 indicates the presence of several equivalent year-classes from the 1967 to the 1973 ones. After this year, the relatively abundant 1972 and 1973 year-classes are still present in the catches followed by the relatively good 1974 and 1975 year-classes which both appear at age 3 and dominate in 1980.

These results indicate that if the medium level of the 1974 and 1975 year-classes has insured a fair recruitment, the relatively poor 1976 and 1977 year-classes (as shown at age 3 in 1979 and 1980) may provide a very bad recruitment in the next two years. The weakness of the 1976 year-class, already noted last year (ICNAF, 1979), is also indicated by Postolaky (1980). The weakness of the following year-class (1977), as shown here, can only contribute to this decrease in the recruitment level.

The same general trends in the age composition of commercial catches from 1976 to 1979 are observed by Postolaky (1980) : in 1976, presence of almost equivalent 1967 to 1973 year-classes and in the 1977-79 period a predominance of the 1972 and 1973 year-classes and a relative strength of the 1974 one. However his results indicate a relatively poor 1975 year-class.

The length and age compositions of the catches obtained in 1980 respectively with a 50 mm and a 140 mm codend mesh are shown in Fig. 2.

The modal length at 52 cm LT and the 1975 dominant year-class observed with the small mesh gear, is replaced by a mode at 63 cm LT and a corresponding 1974 dominant year-class with the large mesh gear which is more comparable to the commercial trawls used in the fishing area.

Growth.

From analysis of mean length-at-age data (ages 3-17) for the 1976-80 period, the von Bertalanffy growth curve (Fig. 3) is expressed by the equation :

$$L_t = 111.7 \left[1 - e^{-0.151\ (t\ -\ 0.88)}\right]$$

The length-weight relationship (Fig. 4), as determined from the log-log regression of mean weight (grams) on total length (cm), is expressed by the equation :

$$\log WT = 3.146 \log LT - 2.336$$

This relationship, when applied to the growth-in-length equation, leads to the following equation for the growth-in-weight curve (Fig. 5) :

$$W_t = 12{,}783 \left[1 - e^{-0.151\ (t\ -\ 0.88)}\right]^{3.146}$$

These results on growth-in-length are difficult to compare with those given by May et al. (1965) for the 1960-62 period, by May (1966a) for 1963 and by Wells and Pinhorn (1970) for the 1964-68 period, since provided for divisions 2J, 3K and 3L separately. Also, the length-weight relationships calculated by May (1966b) concerned only division 2J.

Length and age at sexual maturity.

The sigmoid curves, fitted to the proportions of mature males and females at each length in 1980 samples are shown in Fig. 6. The mean length and the corresponding mean age at which 50 % of the male and female cod become mature are as follows :

Parameters	Male	Female	Combined
L_{50} (total length, cm)	46.1	52.1	49.1
t_{50} (years)	4.4	5.0	4.7

Here again, the values provided by Fleming (1960) for the 1947-1950 period are difficult to compare to the results of this study since they are separated by division. However, the four values of t_{50} given, ranging between 5.4 and 6.3 years, are slightly larger than ours.

Length and age at entry to the fishery.

The selection curve (Fig. 7) was derived from the 1980 selectivity experiment of the research trawl with a codend mesh size of 140 mm. The mean length (L_c) at which 50 % of the fish are retained is 53.4 cm total length and the corresponding mean age at entry to the fishery (t_c) is 5.2 years. The selection factor (b) for cod taken by this trawl is therefore 3.81. The application of this selection factor to the mean length at 50 % maturity for both sexes (L_{50} = 49.1 cm) indicates that a minimum mesh size of 130 mm would be necessary to avoid the capture of many immature cod.

This value of t_c is very similar to the results of Pinhorn and Wells (1972) who found t_c = 5.4 years for Div. 2J-3KL.

Fishing mortality and effort.

Calculation of the fishing mortality coefficient (F).

The five catch-curves based on data for the years 1976 to 1980 (Fig. 8) yielded values of the total mortality coefficient (Z) of 0.60, 0.78, 0.65, 0.69 and 0.54 respectively. Using the calculation of M = 0.18 (Pinhorn, 1975) these values lead to the following values of F :

1976 - F = 0.42
1977 - F = 0.60
1978 - F = 0.47
1979 - F = 0.51
1980 - F = 0.36

The F-values obtained by Wells (1978, 1980) for the years 1976, 1977, 1978 in Div. 2J-3K-L from other methods, are different from these results.

Correlation between F and the fishing effort (f).

The regression of the Z-values on the corresponding f-values calculated for 1976, 1977 and 1978, is shown in Fig. 9 and expressed by the equation :

$$Z = 1.39 \cdot 10^{-6} \cdot f + 0.18$$

The value of M = 0.18 being taken, this regression shows a very good correlation between the values of F calculated in 1976, 77 and 78 from our research material and the values of f obtained from the commercial data.

RESULT OF THE ASSESSMENT

The calculated parameters are introduced in the Beverton and Holt (1957) yield-per-recruit model, as follows :

$K = 0.151$	$t_r = 2.00$ years
$L_\infty = 111.7$ cm	$t_c = 5.20$ years
$W_\infty = 12,783$ g	$b = 3.81$
$t_o = 0.88$ year	$t_\lambda = 18$ years

where t_r is the age at recruitment to the fishing area and t_λ the estimated last age of contribution to the fishery.

Taking the value of M = 0.18 in the yield equation, the resulting yield-per-recruit curve is shown in Fig. 10. The maximum yield-per-recruit is obtained at F = 0.37, and the optimum at F = 0.20. So :

$$F_{max} = 0.37$$
$$F_{0.1} = 0.20$$

These values are very close from those found by Pinhorn and Wells in 1972 ($F_{max} = 0.40$ and $F_{0.1} = 0.23$). Also, since 1976, $F_{0.1} = 0.20$ is the usual value taken in the stock assessments. These results indicate however that in the past four years (1976 to 1979) this cod stock complex has been exploited over the F_{max} level and that in 1980, even if the F-value (0.36) is sligthly lower than F_{max}, the stock is still exploited over the $F_{0.1}$ level, which was recommanded as a management strategy for this particular stock.

The effects of simultaneous changes in fishing mortality and in mesh size (and consequently in age t_c at first capture) on the yield-per-recruit are expressed in Table 2 and Fig. 11. From these results, it is obvious that there is no significant advantage to increase the fishing intensity over F_{max}, even with trawl mesh size up to 200 mm : a long-term increase in yield of 15 % from $F_{0.1}$ (0.20) to F_{max} (0.37) and only 8 % from F_{max} to F = 1.20.

The yield isopleth diagram for this cod stock complex is shown in Fig. 12. The point corresponding to the level of exploitation in 1980 is plotted on this diagram ($F = 0.36$, $t_c = 5.20$).

CONCLUSION AND DISCUSSION

The yield assessment presented above allows to draw conclusions on the status of the Labrador-Northeast Newfoundland cod stock complex, in recent years.

The yield-per-recruit analysis indicates that the stock was exploited during the 1976-80 period at a level superior or close to F_{max} (0.37). The model indicates that no biological and economic benefits could be obtained from this stock by increasing the fishing intensity over F_{max}. On the contrary, it shows that the status of the stock could improve by an exploitation at the $F_{0.1}$ level (0.20).

All these estimates are based on the hypothesis of a constant recruitment, but it was clearly indicated that the recruitment in this stock complex is irregular and seems to be poor for the next two years. It was also shown how a minimum trawl codend mesh size of 130 mm could improve the recruitment by decreasing substantially the capture of immature fish.

In order to allow the stock complex to recover and to obtain a sustainable yield, it is necessary that the spawning biomass can reach a satisfactory level. The following calculations may lead to estimate this level.

The Schaefer (1957) production model, established from the standard efforts calculated above from 1958 to 1977 and from the corresponding total catches during this period, is expressed in Fig. 13. With a stock at the equilibrium level, this production model indicates a MSY = 470,000 metric tons for an effort of 280,000 hours fished. Using the F - f relationship calculated in this study :

$$F = 1.39 \cdot 10^{-6} \cdot f,$$

the value of $F_{MSY} = 0.39$ is obtained, which is very close to the value of $F_{max} = 0.37$ found with the yield-per-recruit model. These results indicate a good correlation between the two models and consequently between the biological and the commercial data.

Because of this agreement between the values of F_{MSY} and F_{max}, it is possible to obtain an estimation of the average level of recruitment

in this stock complex, at the level of F_{max}, for t_c = 5.2 years. At F_{max}, the yield-per-recruit value is :

$$\frac{Y}{R} = 1069 \text{ g}$$

and the average recruitment at age 2 (t_r = 2 years) is :

$$\bar{R}_2 = \frac{470,000}{1069.10^{-6}} = 440.10^6 \text{ individuals}$$

At age 4 (with M = 0.18), $\bar{R}_4 = 304.10^6$ individuals which is very close to the results given by Wells (1980) : average recruitment of 332.10^6 fish at age 4 during the 1972-78 period.

From the average number of recruits at age 2, the spawning biomass of the cod stock complex was estimated at the F_{max} and $F_{0.1}$ levels (Table 3). The target values found range between 1500.10^3 to 2400.10^3 metric tons which is slightly over the values (1200 to 1800.10^3) usually taken (ICNAF, 1977) as a target in the assessments. Results by Wells (1980), assuming a poor 1976 year-class but a relatively good 1977 year-class, indicate that this objective could be achieved in 1982. However, taking into account the apparent weakness of the 1977 year-class, as shown in this study, it seems difficult to reach this target within the next two years.

REFERENCES

BEVERTON, R.J.H., and S.J. HOLT. 1957. On the dynamics of exploited fish populations. Fish. Invest., Lond. (2), 19, 533 p.

FLEMING, A.M. 1960. Age, growth and sexual maturity of cod (Gadus morhua L.) in the Newfoundland area, 1947-1950. J. Fish. Res. Bd. Canada, 17 (6) : 774-809.

HODDER, V.M. 1965. Trends in the cod fishery off the East coast of Newfoundland and Labrador. Res. Bull. int. Comm. Northw. Atlant. Fish., No.2 : 31-41.

ICNAF. 1960-1979. Stat. Bull. int. Comm. Northw. Atlant. Fish., Vol. 8-27.

— 1977. Report of Assessments Subcomittee. Int. Comm. Northw. Atlant. Fish., Redbook 1977 : 49-64.

— 1979. Report of Assessments Subcomittee. Int. Comm. Northw. Atlant. Fish., Redbook 1979 : 63-84.

MAY, A.W. 1966a. Increase in growth of Labrador cod. Annu. Meet. int. Comm. Northw. Atlant. Fish. 1966, Res.Doc. No. 66/24, Serial No. 1632.

— 1966b. Length-weight relation in Labrador cod. Annu. Meet. int. Comm. Northw. Atlant. Fish. 1966, Res.Doc. No. 66/25, Serial No. 1633.

MAY, A.W., A.T. PINHORN, R. WELLS and A.M. FLEMING. 1965. Cod growth and temperature in the Newfoundland area. Spec. Publ. int. Comm. Northw. Atlant. Fish., No. 6 : 545-555.

PINHORN, A.T. 1975. Estimates of natural mortality for the cod stock complex in ICNAF Divisions 2J, 3K and 3L. Res. Bull. int. Comm. Northw. Atlant. Fish., No. 11 : 31-36.

PINHORN, A.T., and R. WELLS. 1972. Combined virtual population assessment for ICNAF Divisions 2J, 3K and 3L cod. Int. Comm. Northw. Atlant. Fish., Redbook 1972, Part III : 35-38.

POSTOLAKY, A.I. 1980. State of the cod stocks off Labrador. Scient. Coun. Meet. Northw. Atlant. Fish. Organ., June 1980, SCR.Doc. 80/VI/61, Serial No. N100.

SCHAEFER, M.B. 1957. A study of the dynamics of the fishery for yellowfin tuna in the eastern tropical Pacific ocean. Bull. Inter-Am. Trop. Tuna Comm., 2 : 245-285.

TEMPLEMAN, W. 1962. Divisions of cod stocks in the Northwest Atlantic. Int. Comm. Northw. Atlant. Fish., Redbook 1962, Part III, No. 8 : 79-123.

— 1974. Migrations and intermingling of atlantic cod (Gadus morhua) stocks of the Newfoundland area. J. Fish. Res. Bd. Canada, 31 (6) : 1073-1092.

WALFORD, L.A. 1946. A new graphic method of describing the growth of animals. Biol. Bull., 90 (2) : 141-147.

WELLS, R. 1978. Status of the cod stock in Divisions 2J, 3KL. Annu. Meet. int. Comm. Northw. Atlant. Fish. 1978, Res.Doc. No. 78/VI/66, Serial No. 5236.

___ 1980. Status of the cod stock in Divisions 2J + 3KL in 1978. Scient. Coun. Meet. Northw. Atlant. Fish. Organ., June 1980, SCR.Doc. No. 80/VI/63, Serial No. N102.

WELLS, R. and A.T. PINHORN. 1970. Growth and mortality changes in cod from ICNAF Subareas 2 and 3. Annu. Meet. int. Comm. Northw. Atlant. Fish. 1970, Res.Doc. No. 70/88, Serial No. 4239.

	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
CANADA	123,320	115,565	91,151	74,546	66,439	44,137	36,080	42,482	62,991	79,561
FRANCE	81,966	49,822	20,866	9,422	14,034	5,728	2,116	2,642	6,087	5,385
FRG	47,868	60,620	56,906	28,646	29,533	35,655	35,520	27,065	17,353	14,661
GDR	0	0	0	0	27,022	23,815	25,115	22,265	11,816	4,300
POLAND	69,587	59,528	43,207	27,514	39,128	27,514	31,583	15,203	18,493	7,429
PORTUGAL	152,473	146,428	116,282	109,706	65,536	76,004	83,849	47,302	37,539	18,695
SPAIN	130,972	102,161	70,929	64,478	59,100	42,823	55,972	38,471	10,784	20,725
USSR	117,559	147,855	77,368	79,141	143,451	81,794	96,071	88,311	45,996	18,850
UK	32,598	4,098	3,065	4,634	6,911	3,634	884	473	216	1,641
OTHERS (a)	27,461	3,389	6,571	22,430	3,436	13,403	5,457	3,294	2,945	1,460
TOTAL	783,804	689,466	486,345	420,517	454,590	354,507	372,647	287,508	214,220	172,707
2 J	359,177	360,908	198,786	150,216	149,763	57,724	121,266	81,988	34,636	43,611
3 K	157,883	99,375	91,000	79,546	146,183	172,951	159,951	128,385	101,190	56,649
3 L	266,744	229,183	196,559	190,755	158,644	123,832	91,430	77,135	78,394	72,447

(a) Mainly Denmark (F), Norway and Romania

Table 1. Nominal catches (metric tons) of cod from the Labrador-Northeast Newfoundland cod stock complex (Div. 2J + 3KL), 1968-1977.

Mesh size (mm)	Lc (cm)	tc (years)	Yield-per-recruit (g) for					
			F = 0.10	F = 0.20	F = 0.37	F = 0.60	F = 0.80	F = 1.20
120	45.7	4.4	760	953	970	903	851	780
130	49.5	4.8	765	979	1024	976	933	872
140	53.4	5.2	766	999	1069	1040	1006	956
160	61.0	6.1	754	1021	1141	1151	1137	1108
180	68.6	7.2	716	1006	1171	1221	1228	1224
200	76.2	8.5	645	941	1140	1223	1248	1266
240	91.4	12.2	380	611	823	946	995	1039

Table 2. The effects of simultaneous changes in mesh size and fishing mortality (F) on yield-per-recruit for the cod stock complex in Div. 2J + 3KL. (Maximum yield-per-recruit values are underlined).

Age	% recruitment	% mature	W_t (kg)	F_{max} = 0.37			$F_{0.1}$ = 0.20		
				Z	Population number ($Nx10^{-6}$)	Spawning Biomass ($Tx10^{-3}$)	Z	Population number ($Nx10^{-6}$)	Spawning Biomass ($Tx10^{-3}$)
2	0	0	0.037	0.18	440	-	0.18	440	-
3	2	0	0.218	0.19	368	-	0.18	368	-
4	14	6	0.588	0.23	304	11	0.21	307	11
5	40	68	1.135	0.33	241	186	0.26	249	192
6	73	98	1.823	0.45	174	311	0.33	192	343
7	90	100	2.605	0.51	111	289	0.36	138	359
8	96	100	3.438	0.54	66	227	0.37	96	330
9	99	100	4.286	0.55	39	167	0.38	67	287
10	100	100	5.121	0.55	22	113	0.38	45	230
11	100	100	5.923	0.55	13	77	0.38	31	184
12	100	100	6.677	0.55	7	47	0.38	21	140
13	100	100	7.375	0.55	4	30	0.38	15	111
14	100	100	8.015	0.55	2	16	0.38	10	80
15	100	100	8.594	0.55	1	9	0.38	7	60
16	100	100	9.114	0.55	1	9	0.38	5	46
17	100	100	9.578	0.55	0.5	5	0.38	3	29
18	100	100	9.990	0.55	0.3	3	0.38	2	20
TOTAL						1500			2422

Table 3. Estimation of the spawning biomass of cod in Div. 2J + 3KL at F_{max} and $F_{0.1}$ levels for average recruitment conditions.

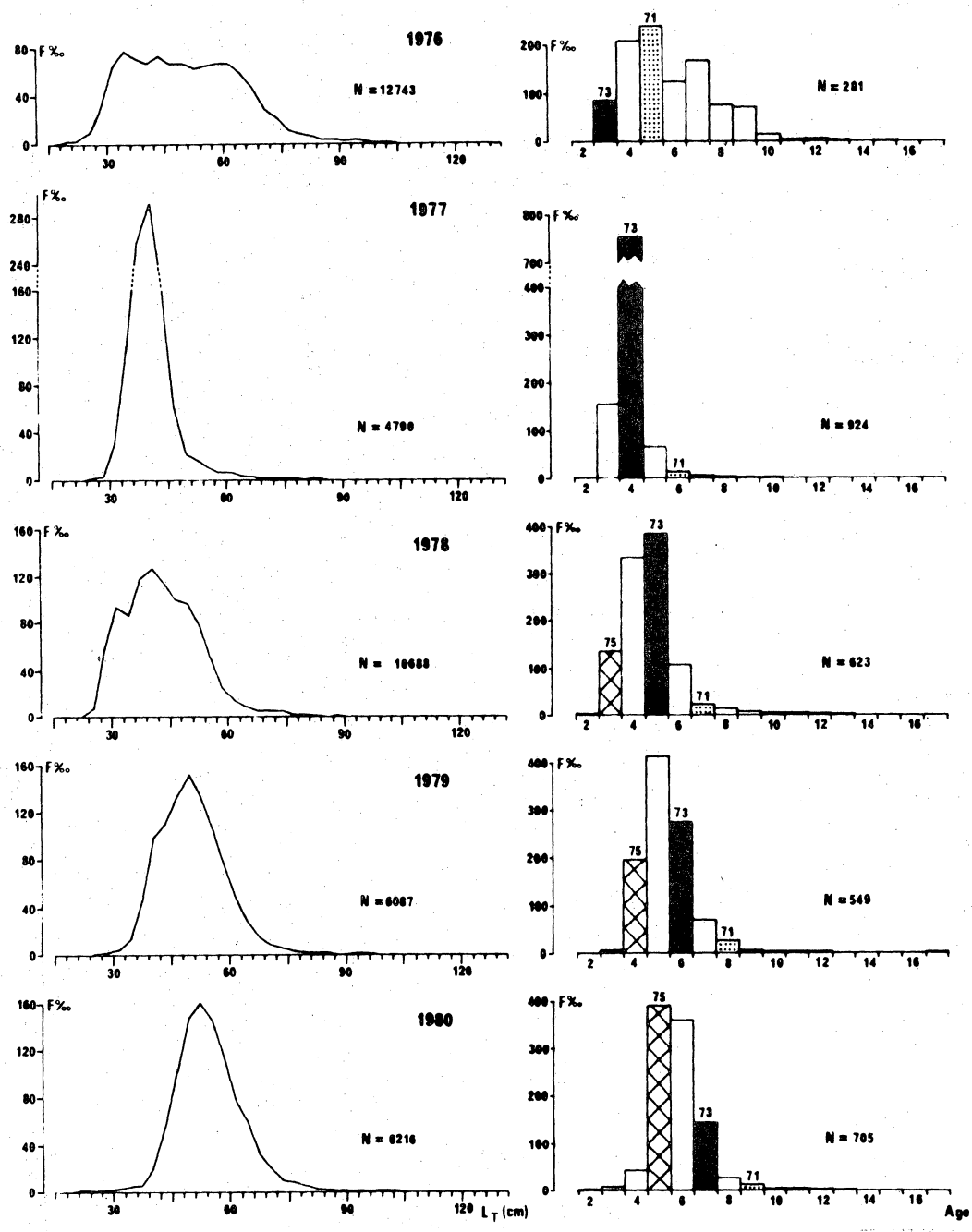

Fig. 1 Length and age compositions of cod from research trawl (50 mm codend mesh) catches in Div. 2J + 3KL, 1976-1980.

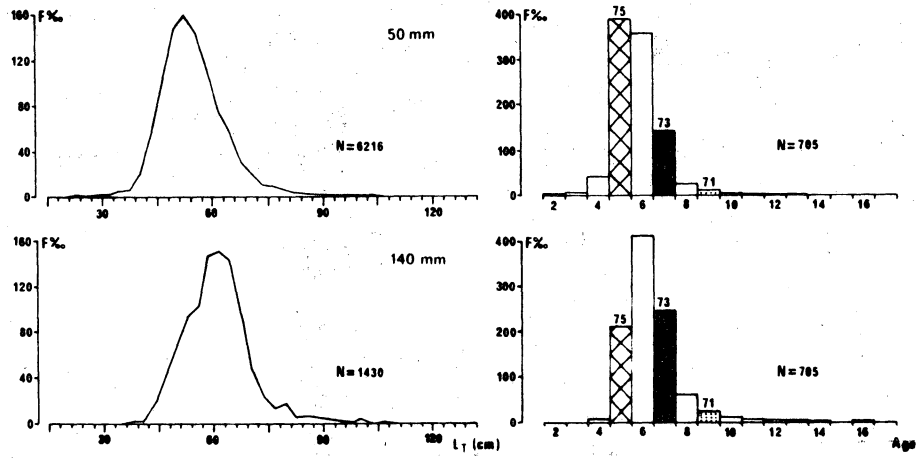

Fig. 2 Length and age compositions of cod from research trawl (50 mm and 140 mm codend mesh) catches in Div. 2J + 3KL, 1980.

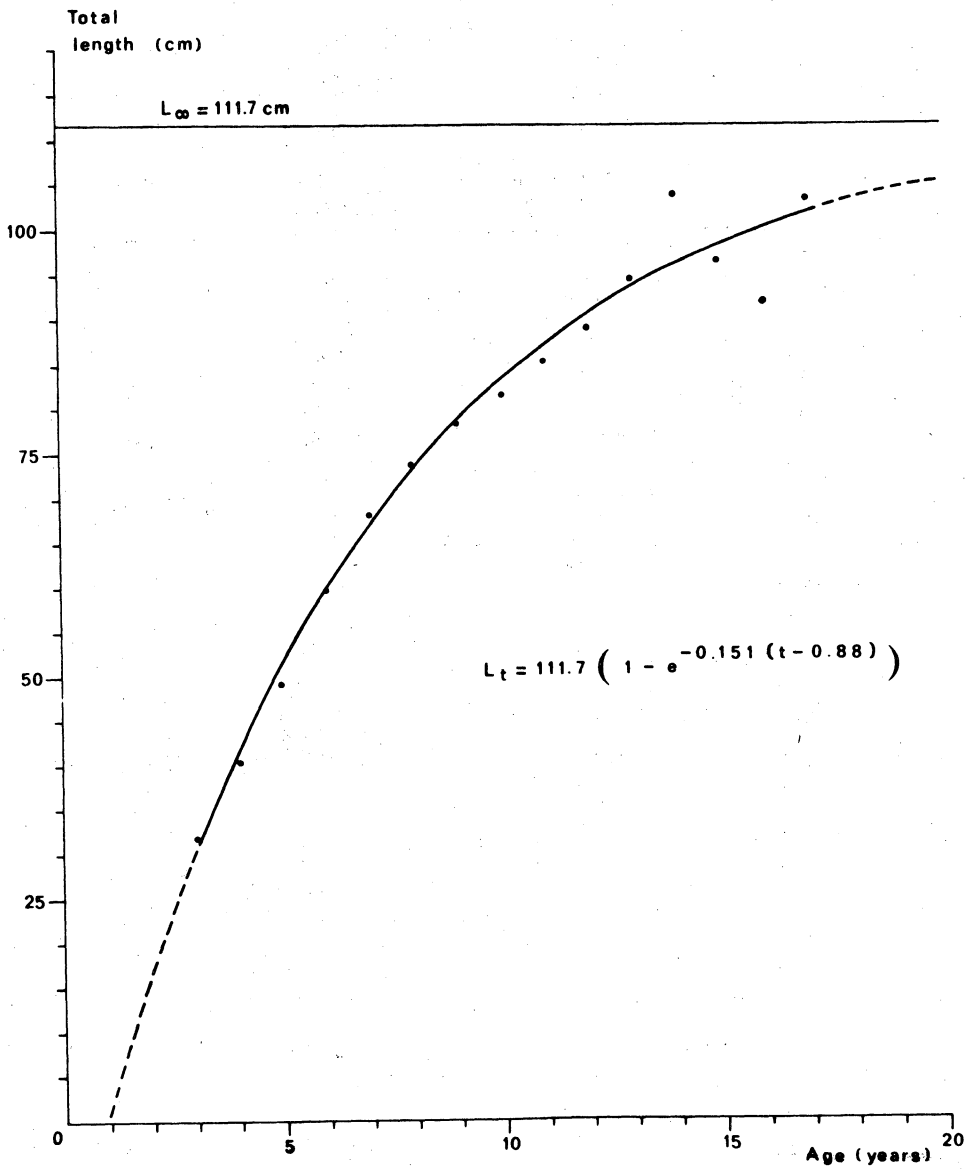

Fig. 3 Von Bertalanffy growth-in-length curve for the cod stock complex in Div. 2J + 3KL, 1976-1980 (Dots are actual mean length-at-age values).

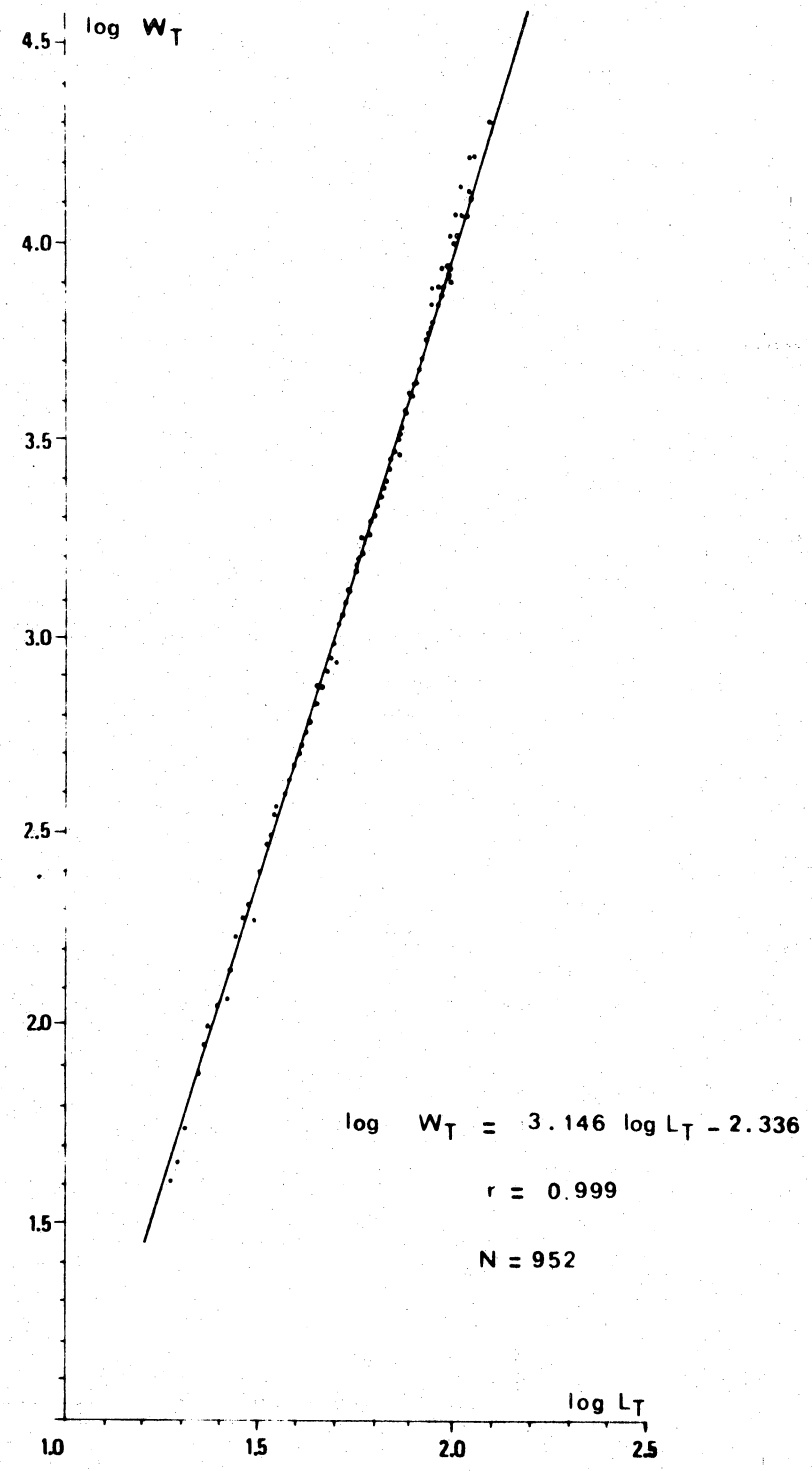

Fig. 4 Length-weight logarithmic relationship for the cod stock complex in Div. 2J + 3KL, 1980.

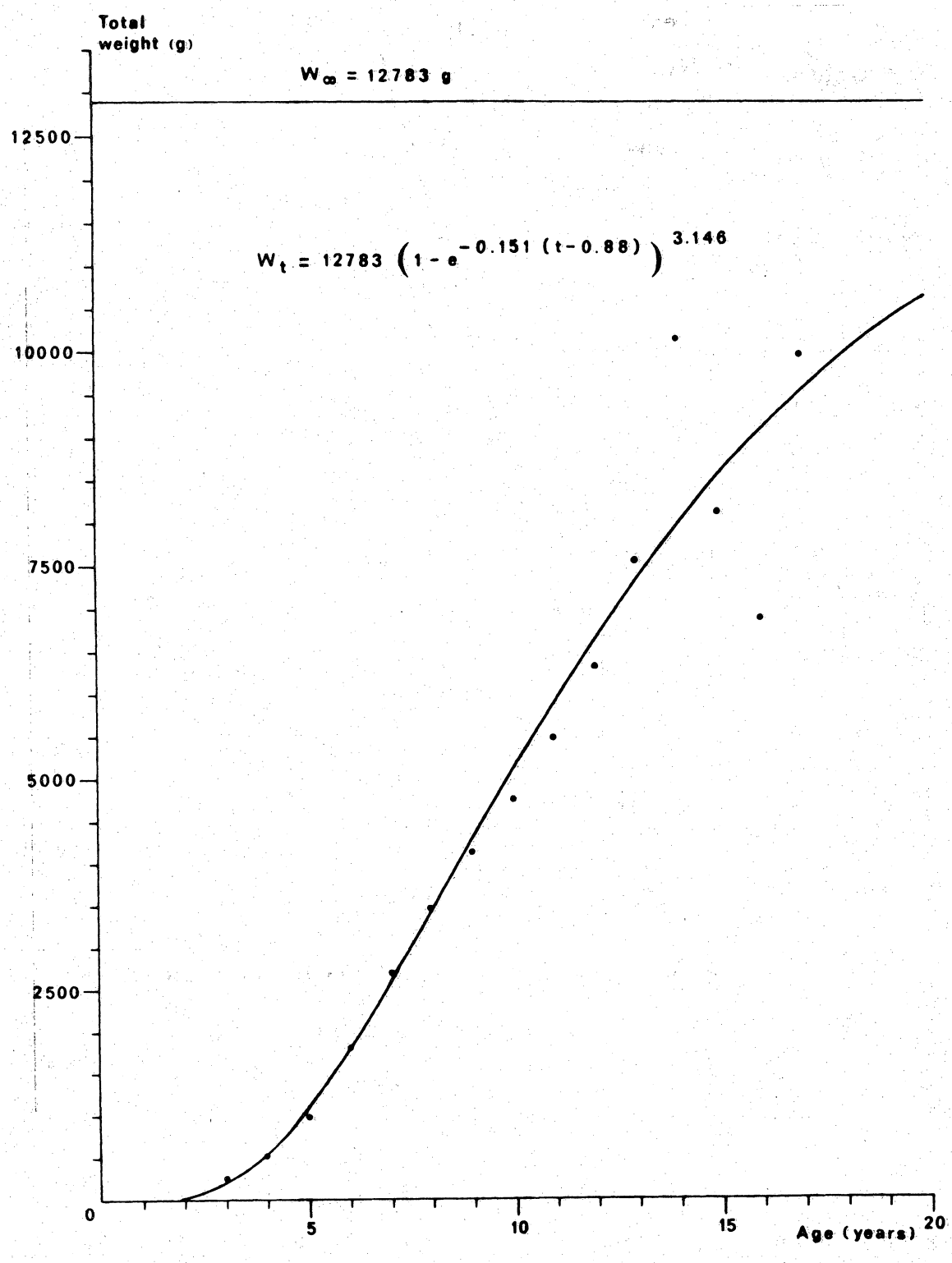

Fig. 5 Von Bertalanffy growth-in-weight curve for cod stock complex in Div. 2J + 3KL, 1976-1980 (Dots are actual mean weight-at-age values).

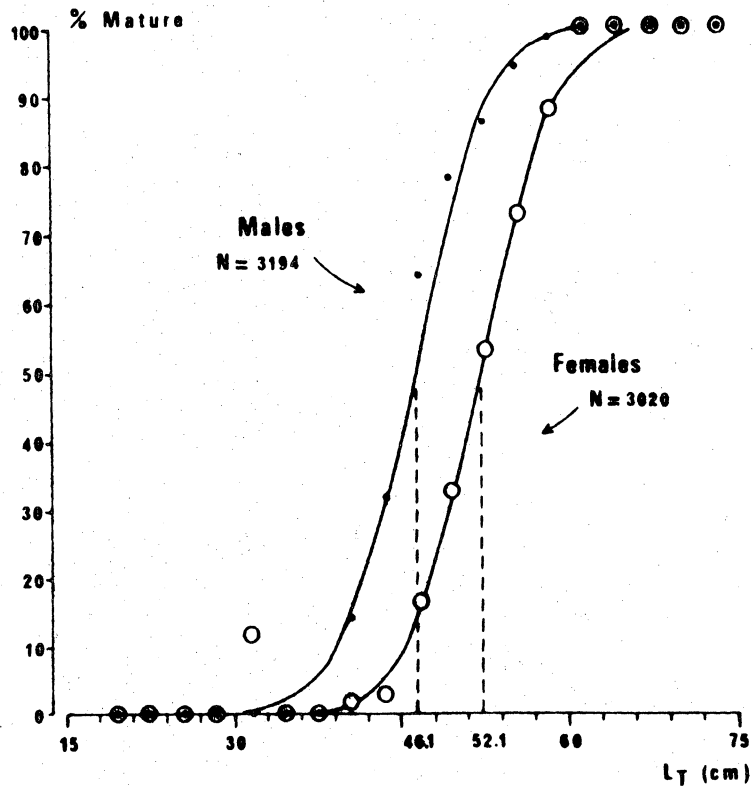

Fig. 6 Fitted sigmoid curves of length at sexual maturity for male and female cod in Div. 2J + 3KL, 1980. (The observed values are represented by open and closed circles).

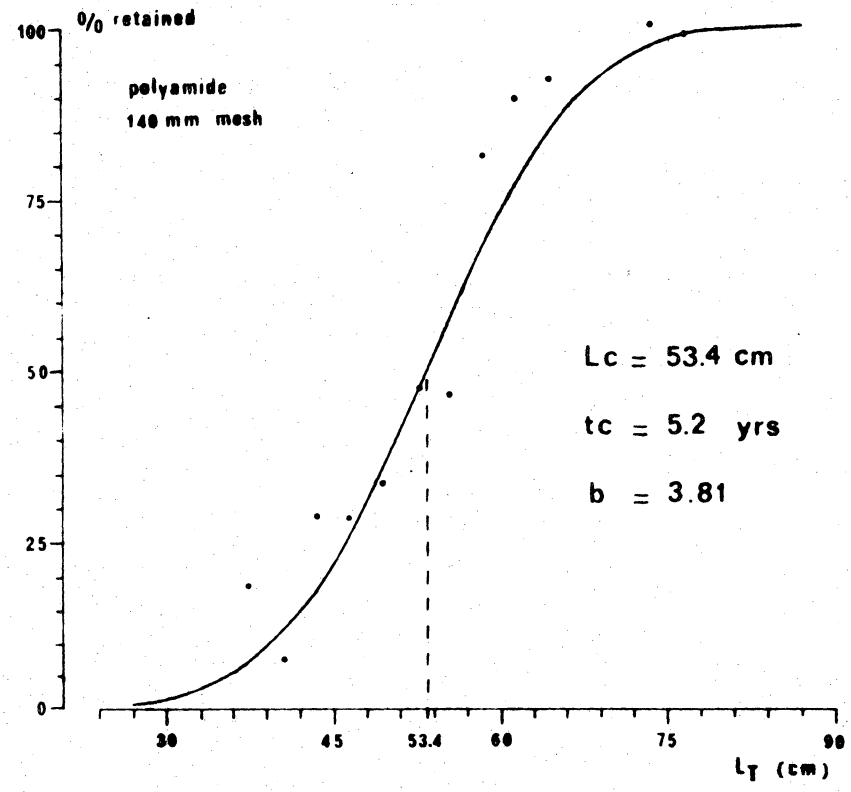

Fig. 7 Fitted selection curve for cod taken by research polyamide trawl with 140 mm codend mesh in Div. 2J, 1980. (Dots represent the observed values).

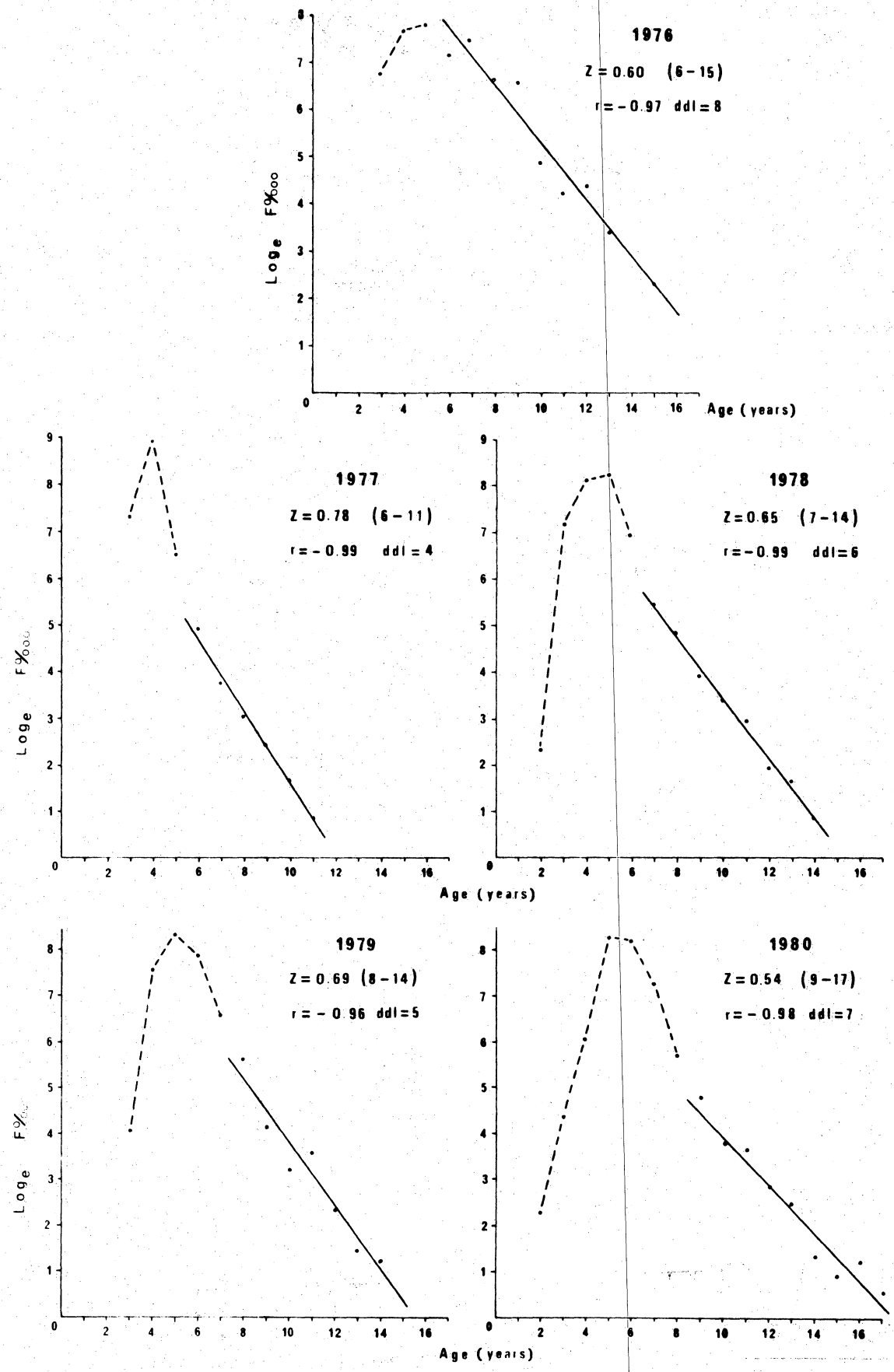

Fig. 8 Catch curves (logarithm of the age compositions) for cod from research trawl catches in Div. 2J + 3KL, 1976-1980.

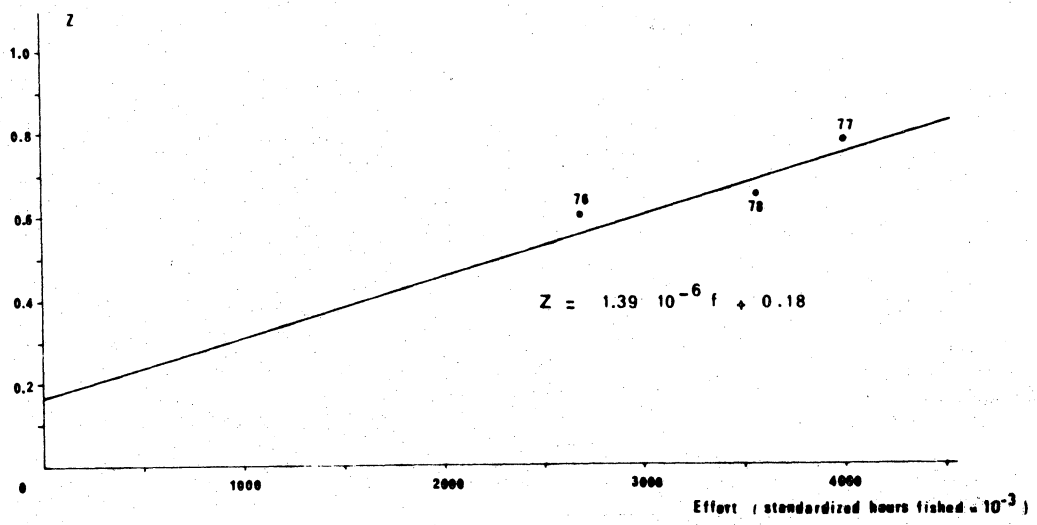

Fig. 9 Fishing effort-total mortality (Z) relationship for the cod stock complex in Div. 2J + 3KL for the 1976-78 period, at M = 0.18.

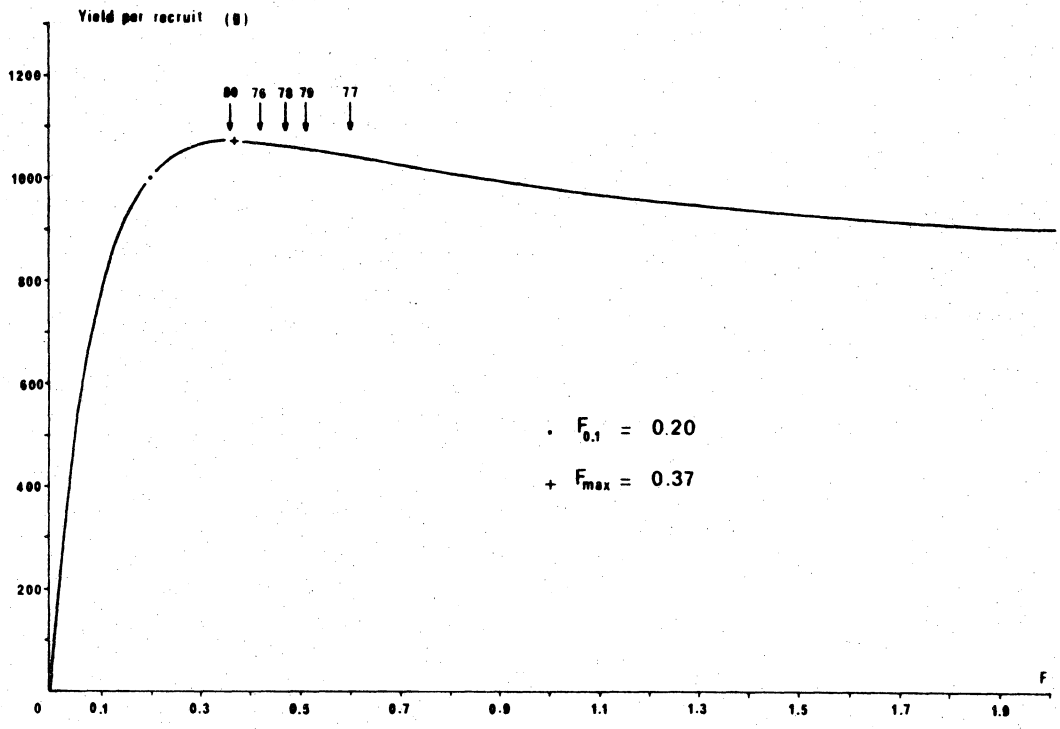

Fig. 10 Yield-per-recruit curve for the cod stock complex in Div. 2J + 3KL at M = 0.18. (Values of F for the 1976-80 period are indicated by arrows).

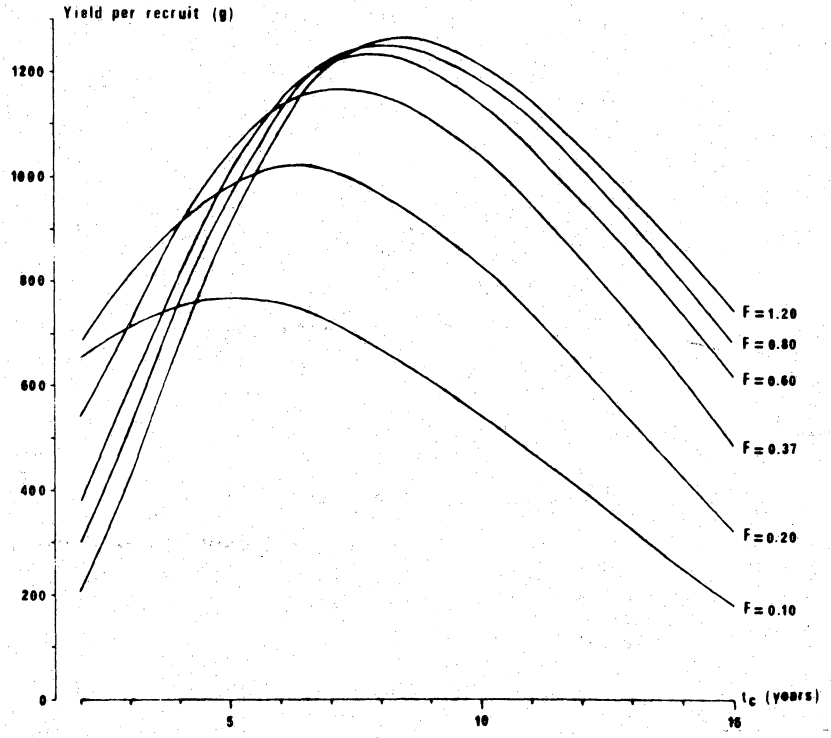

Fig. 11 Yield-per-recruit curves for the cod stock complex in Div. 2J + 3KL in relation to fishing mortality (F) and to age at recruitment to the fishery (t_c).

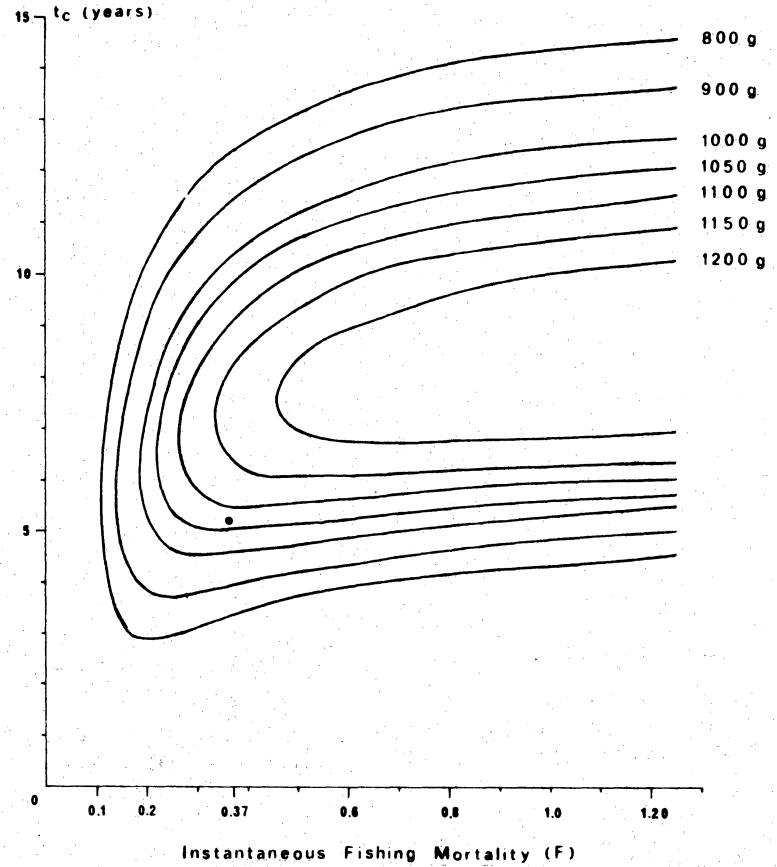

Fig. 12 Yield isopleth diagram for the cod stock complex in Div. 2J + 3KL. (The 1980 position is indicated by a dot).

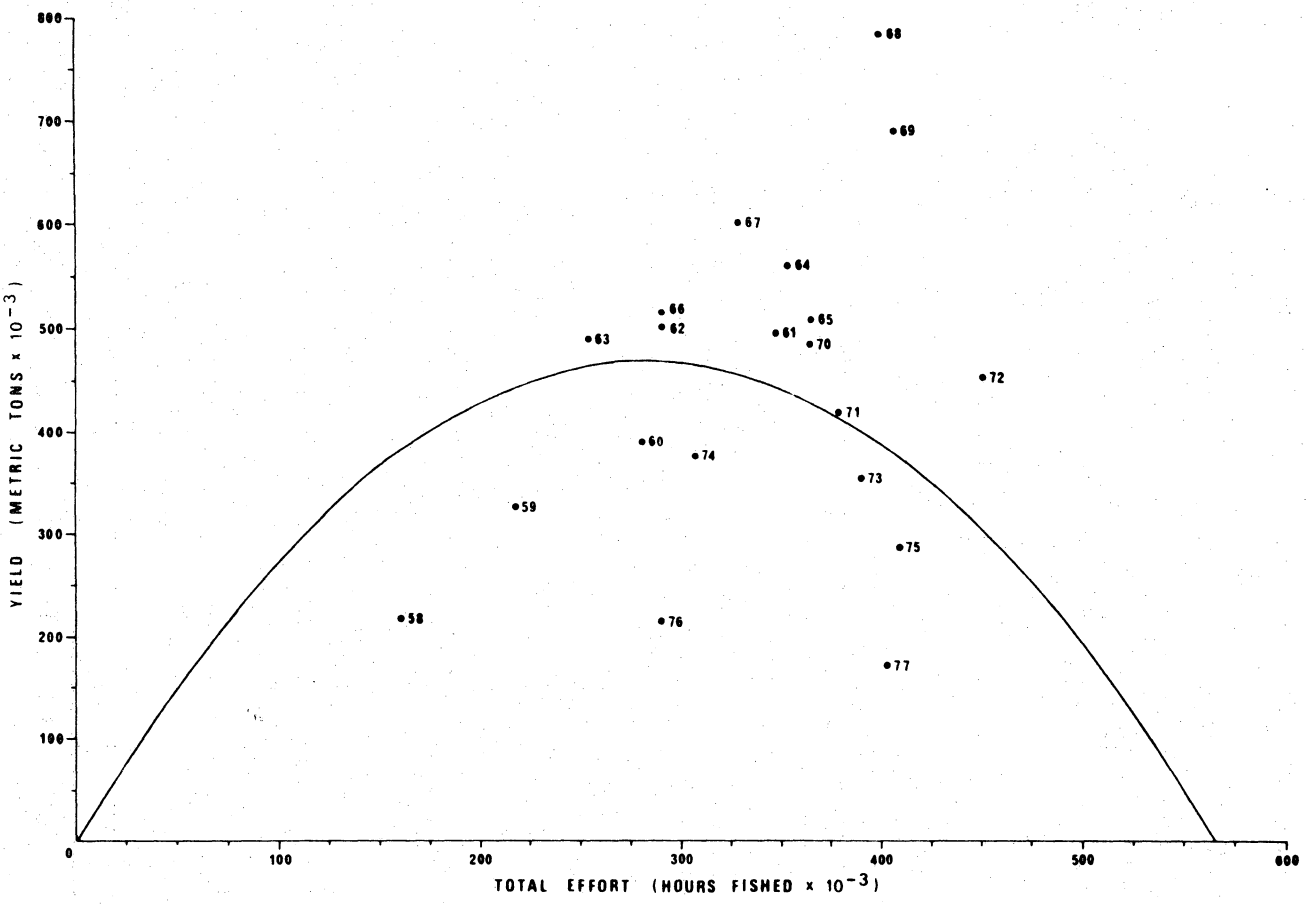

Fig. 13 Equilibrium yield curve from the Schaefer production model for the cod stock complex in Div. 2J + 3KL, 1958-1977.