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Temporal Variability in Cod Maturity and Spawning Biomass in NAFO Divisions 2J+3KL

by

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Abstract

Maturity ogives for cod in NAFO Divisions 2J and 3K from 1978 to 1990, and in Division 3L from 1981 to 1990, were constructed from research vessel sampling data and combined with results from sequential population analysis to estimate the spawning stock number and biomass each year. There was a spatial trend in length at 50% maturity with northernmost (2J) fish maturing at the smallest size. The spatial trend in the age at 50% maturity is not as clear as length, but the age at 50% maturity in Division 3L was larger than that in 2J and 3K in 7 and 8 of 10 years, respectively.

The age at 50% maturity did not show a temporal trend, but the length at 50% maturity showed a decline trend over time in all three regions.

The likelihood ratio tests show that the age at 50% maturity changed very significantly from year to year in the period of 1981 to 1990, and that the length at 50% maturity changed sometimes very significantly, especially between 1982 and 1986.

Variations in maturity were studied in relation to water temperature and stock abundance. The temperature seems to have a two years lagged effect on cod maturity development, and an optimum temperature for maturity may exist. The cod biomass seems to have one year lagged effects on maturity and high biomass in one year may reduce the proportion mature or increase the age at 50% maturity in the following year. A graphical analysis suggested that the biomass had very little effect on maturity when the temperature is low, and had a positive relationship with the age at 50% maturity when temperature is high.

COD SYMPOSIUM, SEPTEMBER 1991

Introduction

Maturity is so important for a fish stock development that some studies have been done on the NAFO Divisions 2J, 3K and 3L cod to find out the age and length at which 50% of the fish were sexually mature, and compute the maturity ogives using probit analysis for the period of 1947-1950 (Fleming 1960), 1980 (Minet et al. 1980) and 1981-1982 (Baird et al. 1986). In this paper, the maximum likelihood method was used to estimate the maturity ogives annually for female cod in Divisions 2J and 3K from 1978 to 1990, and in Division 3L from 1981 to 1990.

Materials and Methods

The biological data were collected from research vessel surveys conducted during the fall from 1978 to 1990 in Divisions 2J and 3K, and from 1981 to 1990 in Division 3L. The water temperature data were obtained from Station 27 (a frequently sampled location just off St. John's, Newfoundland), and the means of the temperature at 150 m and 175 m for 5 months from April to July, and September were used in the analysis.

To fit the logistic binary data models of maturity, the maximum likelihood estimates were calculated by iteratively reweighted least squares, where the weights are the reciprocals of the estimated variances of the proportion mature. In order to estimate the spawning biomass on January 1 of each year, ages were adjusted by adding 1 to obtain the proportion mature for each age at the beginning of the calendar year. Three nested models were considered and likelihood ratio tests were set up to examine differences between areas and pairs of successive years. The models are:

$$P_x = \frac{1}{1+\exp^{-(\alpha+\beta_1 x+\beta_2 y+\beta_3 xy)}} \qquad (1)$$

$$P_x = \frac{1}{1+\exp^{-(\alpha+\beta_1 x+\beta_2 y)}} \qquad (2)$$

$$P_x = \frac{1}{1+\exp^{-(\alpha+\beta x)}} \qquad (3)$$

where x is the age or length, y is an indicator variable for area or year, and P_x is proportion mature in age or length group x. The difference will be tested in comparison of (2) and (3) for intercepts, (1) and (3) for the coordinated action of slope and intercept.

Results

1. Length at maturity

The coefficients, intercept α and slope β, of the logistic equation of proportion mature versus length for each year and area are shown in Table 1. According to the logistic curves (Fig.1), the proportion mature of 2J is always larger than that in 3L for the same size from 1982 to 1990. The curve in 3K is usually located between 2J and 3L. The three lines intersect each other in 1981. It could therefore be concluded that the proportion mature for the same size generally becomes smaller from the North to the South.

The length at which 50% of the fish are sexually mature (L_{50}) for each year and area were estimated from the logistic equation (Table 2). The L_{50} became larger from the North to the South, except that in 1981 the reverse order was observed.

The likelihood ratio test results for the effects of area are shown in Table 3. The difference between 2J and 3L is very significant ($P<0.01$) except in 1981 and 1988. The differences between 2J and 3K in some years (1978, 1984, 1985, 1987, 1989, 1990) are very significant ($P<0.01$), and in 1986 it is significant at the level of 5%. The differences between 3K and 3L are significant or very significant from 1983 to 1987 and in 1990. It can be found that the logistic maturity curves has changed apparently among regions since 1984, but there is a break in 1988 in which no significant difference between areas was detected.

The likelihood ratio test for comparing successive years shows that, from 1981 to 1990, the relationship between proportion mature and length sometimes changed very significantly (table 4), and the relationship between maturity and length changed especially rapidly between 1982 and 1986.

2. Age at maturity

The intercept α and slope β of the logistic equation of proportion mature versus age for each year and area are shown in Table 5. No clear pattern among regions could be discerned although the curve for 3L tended to be to the right of the others (Fig.2). The age at which 50% of the fish are sexually mature, A_{50} (Table 6) does not show any trend of annual changes for 3 areas, but the age at 50% maturity in Division 3L was larger than that in Division 2J in 7 of 10 years, and larger than that in Division 3K in 8 of 10 years.

Likelihood ratio tests of the equality of logistic equations between areas (Tables 7 and 8) show that in all but three comparisons there were differences among the regions, and that A_{50} changed very significantly from year to year in the period studied.

3. Spawning abundance

The spawning stock size for female cod, N_{spawn}, was estimated with the maturity ogive according to the formula:

$$N_{spawn}=\sum_{a=3}^{14} P_a N_a r_a \qquad (4)$$

where P_a is the proportion mature of female cod at age a estimated from the logistic equation, N_a is the stock size at age a (Baird et al. 1991), and r_a is the sex ratio in numbers.
The spawning biomass for female cod, B_{spawn}, was estimated by

$$B_{spawn}=\sum_{a=3}^{14} P_a B_a r_a \qquad (5)$$

where P_a is the same as above, B_a is the biomass at age a (Baird et al. 1991), and r_a is the sex ratio in weight. In the past, the spawning stock (number or biomass) was sometimes approximatedly as the sum of the number or biomass of age 6 and above or age 7 and above. The spawning number and biomass estimated with equation (4) and (5) are located between the values obtained by the approximations (Tables 9 and 10).

4. Relationship between maturity and water temperature

The correlation coefficients, R, are -0.5216 and -0.3956, respectively between L_{50} and temperature and A_{50} and temperature (in the same year), which are not significant at the 5% level. The age at 50% maturity is significantly positively related with the reciprocal of the square of water temperature the current year (R=0.6839, P=0.0292) and significantly negatively related with the reciprocal of the square of temperature of two years earlier (R=-0.7742, P=0.0086).

5. Relationship between maturity and biomass

The correlation between total biomass of cod and the age at 50% maturity the following year is significant. The coefficient R is 0.6704, which is larger than the critical value $R_{0.05}$ (=0.666) for a test at the 5% level. The correlation coefficients between total biomass and proportion mature the following year at age 5 and between total biomass and proportion mature the following year at age 6 are -0.5726 and -0.6928 respectively. The latter is significant at the 0.05 level. Similarly, the correlation between biomass of age 4 and proportion mature at age 5 (1 year lag) is negatively significant at the 0.05 level (R=-0.6732). The correlation between biomass of age 5 and proportion mature at age 6 (1 year lag) is also negative, but not significant (R=-0.3406).
The correlation between the age at 50% maturity and female spawning biomass (not lagged) is significant (R=-0.7422, P=0.014). From Fig. 3, it could be found that annual changes in A_{50} and spawning biomass were in opposite directions in all years except from 1984 to 1985. This suggests that when A_{50} becomes smaller in some year, more fish enter the spawning stock, and spawning biomass increases.

6. Variation in maturity with temperature and biomass

The multiple correlation among A_{50}, biomass and temperature is not significant (R=0.4010, P=0.5411). A smooth surface describing the relationship between the age at 50% maturity and the total biomass and water temperature was derived using SAS Proc G3GRID and G3D (Fig. 4). It appears that A_{50} decreases to the lowest at highest temperature and lowest biomass, and that A_{50} keeps at about the same high level regardless of biomass when the temperature is low.

Because temperature appears to have an opposite effect of biomass on A_{50} over much of the range of the data, and age at 50% of mature may be a dome-shaped function of temperature, we computed the multiple correlation between A_{50} and biomass and the reciprocal of the square of water temperature. The value of R, increased to 0.7510, which was significant at P=0.0547. We further computed the correlation between A_{50}, the reciprocal of the square of temperature two years earlier, and the total biomass one year earlier, the value of R, 0.8320, was significant at P=0.0291. We again plotted the A_{50} against the total biomass one year early and temperature two years early and found that biomass seems to have no effect on A_{50} when water temperature is low (Fig. 5). The temperature around 0.009 C seems to be the optimum temperature for the maturity development, so that A_{50} of two years later decreased to the lowest.

The multiple correlation coefficient, R, among A_{50}, female spawning stock biomass and the reciprocal of the square of water temperature is estimated to be 0.9153. The correlation is very significant (P=0.0017). A significant correlation was also found between A_{50}, the spawning biomass the current year, and reciprocal of the square of temperature two years earlier (R=0.789, P=0.0328).

Discussion

Maturity usually sets in later at higher latitudes than at lower ones (Nikolsky 1963), For 2J3KL cod from 1982 to 1990, the age of 50% maturity in Division 3L is larger than that in 2J and 3K in 7 and 8 of 10 years, respectively (Table 6), and there is a clear trend in length at 50% maturity with fish in Division 2J maturing at the smallest sizes and those in 3L at the largest sizes (Table 2). What causes the spatial variations in maturity for Divisions 2J3KL is not known.

Temporal variations in A_{50} with year for three areas did not show any significant change trend (Table 6). But A_{50} in 1947-1950 (Fleming 1960) were 5.36 for 2J, 6.13 for 3K and 5.82 (SE Newfoundland) and 6.26 (NE Grand Bank) for 3L. If 1 year is added to Fleming's ages because the data were collected from early summer to early autumn, then these results could be compared to ours. It appears that the age of 50% maturity was generally lower in the period of 1978-1990 compared to the period 1947-1950.

Linear temporal trends in L_{50} with year for 2J and 3K are very significant, and the correlation coefficients, R, are -0.8402 (P=0.0003, d.f.=11) and -0.8500 (P=0.0002, d.f.=11) respectively. There is no significant temporal change for 3L, the correlation coefficient is -0.5236, less than $R_{0.05}$ (=0.632, d.f.=8). The correlation coefficient between L_{50} and year for the total 3 areas is estimated to be -0.8746, which is very significant at the level of P=0.0009. Therefore, the L_{50} appeared to change very significantly and became smaller with year (Fig. 6).

Total cod biomass seems to have no significant correlation with the proportion mature in the current year, but between various measures of biomass in the previous year and proportion mature in the current year some very significant negative relationship were detected. This may suggest that the higher biomass in previous year may reduce the per capita food supply and delay gonad development so that the proportion mature decreased. If maturity is delayed, then one might expect that the spawning biomass would be lowered, assuming the newly maturing fish can potentially form a significant proportion of the spawning biomass. In fact, a significant negative relationship (R=-0.7422, d.f.=8, P=0.014) can been seen in Fig. 3.

The three dimensions graphical analyses suggested that biomass had very little effect on the age at 50% maturity at low temperature and had a postive relationship with the age at 50% maturity at high temperature.

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Table 1 The intercepts α and slopes β of logistic equation of proportion mature versus length

Year	2J		3K		3L		2J3KL	
	α	β	α	β	α	β	α	β
1978	-18.9712	0.3532	-12.1636	0.2006	-	-	-	-
1979	-22.9747	0.4397	-18.0050	0.3377	-	-	-	-
1980	-19.6036	0.3698	-17.6076	0.3198	-	-	-	-
1981	-17.4368	0.3140	-31.7083	0.5787	-25.2804	0.4647	-22.4262	0.4089
1982	-33.3684	0.6151	-32.7807	0.5865	-24.8242	0.4338	-27.5951	0.4930
1983	-23.5253	0.4305	-18.6730	0.3336	-17.1603	0.2919	-18.1495	0.3209
1984	-21.9056	0.4433	-17.9767	0.3399	-24.5151	0.4165	-15.8180	0.3032
1985	-20.3437	0.4210	-18.9284	0.3691	-30.9832	0.5627	-18.8758	0.3733
1986	-26.5192	0.5515	-18.6065	0.3688	-17.0480	0.2964	-15.3428	0.2948
1987	-15.8117	0.3303	-15.9562	0.3092	-22.1706	0.3912	-14.8151	0.2910
1988	-21.3682	0.4416	-27.6852	0.5585	-20.2082	0.4024	-22.8529	0.4640
1989	-32.9271	0.6804	-21.8797	0.4349	-30.5873	0.6012	-24.8852	0.5002
1990	-22.4391	0.4892	-18.6559	0.3750	-20.1440	0.3661	-16.0739	0.3233

Table 2 L_{50} estimated with logisitic equation

Year	Length at 50% maturity (cm)			
	2J	3K	3L	2J3KL
1978	53.71	60.64	-	-
1979	52.25	53.32	-	-
1980	53.01	55.06	-	-
1981	55.53	54.79	54.40	54.85
1982	54.25	55.89	57.23	55.97
1983	54.65	55.97	58.79	56.56
1984	49.41	52.89	58.86	52.17
1985	48.32	51.28	55.06	50.56
1986	48.09	50.45	57.52	52.04
1987	47.87	51.60	56.67	50.91
1988	48.39	49.57	50.22	49.25
1989	48.39	50.31	50.88	49.75
1990	45.87	49.75	55.02	49.72

Table 3 The likelihood ratio test statistics (x^2) for comparing logistic curves of maturity versus length between areas. Freedom for comparing of models (1) and (3) is 2, for models (2) and (3) is 1. * indicates significant at α=0.05, ** indicates significant at α=0.01.

Year	Comparison of models					
	2J-3K		3K-3L		2J-3L	
	(2)&(3)	(1)&(3)	(2)&(3)	(1)&(3)	(2)&(3)	(1)&(3)
1978	25**	33**	-	-	-	-
1979	0.9	2.1	-	-	-	-
1980	3.3	3.8	-	-	-	-
1981	0.4	7.0*	0.2	0.9	0.7	3.9
1982	3.2	3.2	1.7	3.1	7.9**	9.5**
1983	1.6	2.9	6.1*	6.6*	15**	18**
1984	115**	115**	31**	32**	19**	21**
1985	12**	13**	15**	18**	68**	70**
1986	6.1*	9.2*	40**	41**	73**	81**
1987	15**	15**	16**	16**	66**	66**
1988	2.2	3.6	0.6	3.0	3.8	4.0
1989	7.8**	12**	0.4	2.3	9.9**	10**
1990	24**	26**	32**	32**	97**	99**

Table 4 The likelihood ratio test statistics (x^2) for comparing logistic curves of maturity versus length between years. Freedom for comparing of models (1) and (3) is 2, for models (2) and (3) is 1. * indicates significant at α=0.05, ** indicates significant at α=0.01.

Year	Comparison of models	
	(2) and (3)	(1) and (3)
1981-1982	3.79	5.60
1982-1983	0.57	11.26**
1983-1984	52.31**	52.61**
1984-1985	10.12**	14.48**
1985-1986	7.23**	12.15**
1986-1987	3.23	3.25
1987-1988	11.05**	30.21**
1988-1989	1.11	1.51
1989-1990	0.00	16.66**

Table 5 The intercepts α and slopes β of logistic equation of proportion mature versus age

Year	2J		3K		3L		2J3KL	
	α	β	α	β	α	β	α	β
1978	-13.6802	2.3014	- 9.3915	1.4583	-	-	-	-
1979	-21.2675	3.7809	-10.4456	1.9025	-	-	-	-
1980	- 9.6321	1.7048	-17.0429	2.8271	-	-	-	-
1981	- 7.1553	1.0874	-21.2707	3.5597	-15.2974	2.4286	-14.1816	2.2959
1982	-17.5613	2.8912	-16.7972	2.7075	-16.2927	2.7694	-15.4615	2.5811
1983	-13.7689	2.2317	-14.4780	2.4202	-14.0759	2.2533	-13.6784	2.2265
1984	-17.3750	3.0306	-16.4766	2.8390	-17.3756	2.5337	-13.3867	2.2372
1985	-16.5392	2.7358	-18.7466	3.1662	-14.0054	2.1428	-16.2653	2.6551
1986	-17.2289	2.8459	-17.2877	2.8995	-12.9353	1.8814	-13.9770	2.2197
1987	-15.0031	2.5204	- 9.8345	1.6228	-20.6564	3.1634	-13.7227	2.2181
1988	-12.7011	2.0919	-13.4159	2.3361	-12.1373	2.1251	-11.3974	1.9798
1989	-20.2376	3.4703	-13.4005	2.3033	-13.0518	2.2320	-14.0469	2.4214
1990	-11.7781	2.0560	-11.6220	1.9540	-12.4807	1.9682	-11.4286	1.9148

Table 6 A_{50} estimated with logisitic equation

Year	Age at 50% maturity (yr)			
	2J	3K	3L	2J3KL
1978	5.94	6.44	-	-
1979	5.63	5.49	-	-
1980	5.65	6.03	-	-
1981	6.58	5.98	6.30	6.18
1982	6.07	6.20	5.88	5.99
1983	6.17	5.98	6.25	6.14
1984	5.73	5.80	6.86	5.98
1985	6.05	5.92	6.54	6.13
1986	6.05	5.96	6.88	6.30
1987	5.95	6.06	6.53	6.19
1988	6.07	5.74	5.71	5.76
1989	5.83	5.82	5.85	5.80
1990	5.73	5.95	6.34	5.97

Table 7 The likelihood ratio test statistics (x^2) for comparing logistic curves of maturity versus age between areas. Freedom for comparing of model (1) and (3) is 2, for models (2) and (3) is 1. * indicates significant at α=0.05, ** indicates significant at α=0.01.

Year	Comparison of models					
	2J-3K		3K-3L		2J-3L	
	(2)&(3)	(1)&(3)	(2)&(3)	(1)&(3)	(2)&(3)	(1)&(3)
1978	67**	101**	-	-	-	-
1979	1.6	127**	-	-	-	-
1980	32**	78**	-	-	-	-
1981	260**	547**	32**	50**	24**	118**
1982	7.8**	8.8*	33**	33**	14**	14**
1983	22**	24**	31**	32**	2.9	2.9
1984	5.8*	7.1*	867**	872**	1305**	1316**
1985	12**	18**	220**	259**	218**	250**
1986	21**	21**	682**	758**	662**	742**
1987	37**	105**	173**	310**	402**	419**
1988	72**	73**	50**	53**	0.0	0.0
1989	0.1	81**	0.4	0.8	0.0	61**
1990	49**	52**	179**	179**	279**	280**

Table 8 The likelihood ratio test statistics (x^2) for comparing logistic curves of maturity versus age between years. Freedom for comparing models (1) and (3) is 2, for models (2) and (3) is 1. * indicates significant at α=0.05, ** indicates significant at α=0.01.

Year	comparison of models	
	(2) and (3)	(1) and (3)
1981-1982	40.06**	48.43**
1982-1983	27.62**	43.53**
1983-1984	55.16**	55.16**
1984-1985	71.35**	108.76**
1985-1986	78.51**	126.32**
1986-1987	42.92**	42.92**
1987-1988	364.47**	378.62**
1988-1989	0.10	56.98**
1989-1990	60.74**	178.53**

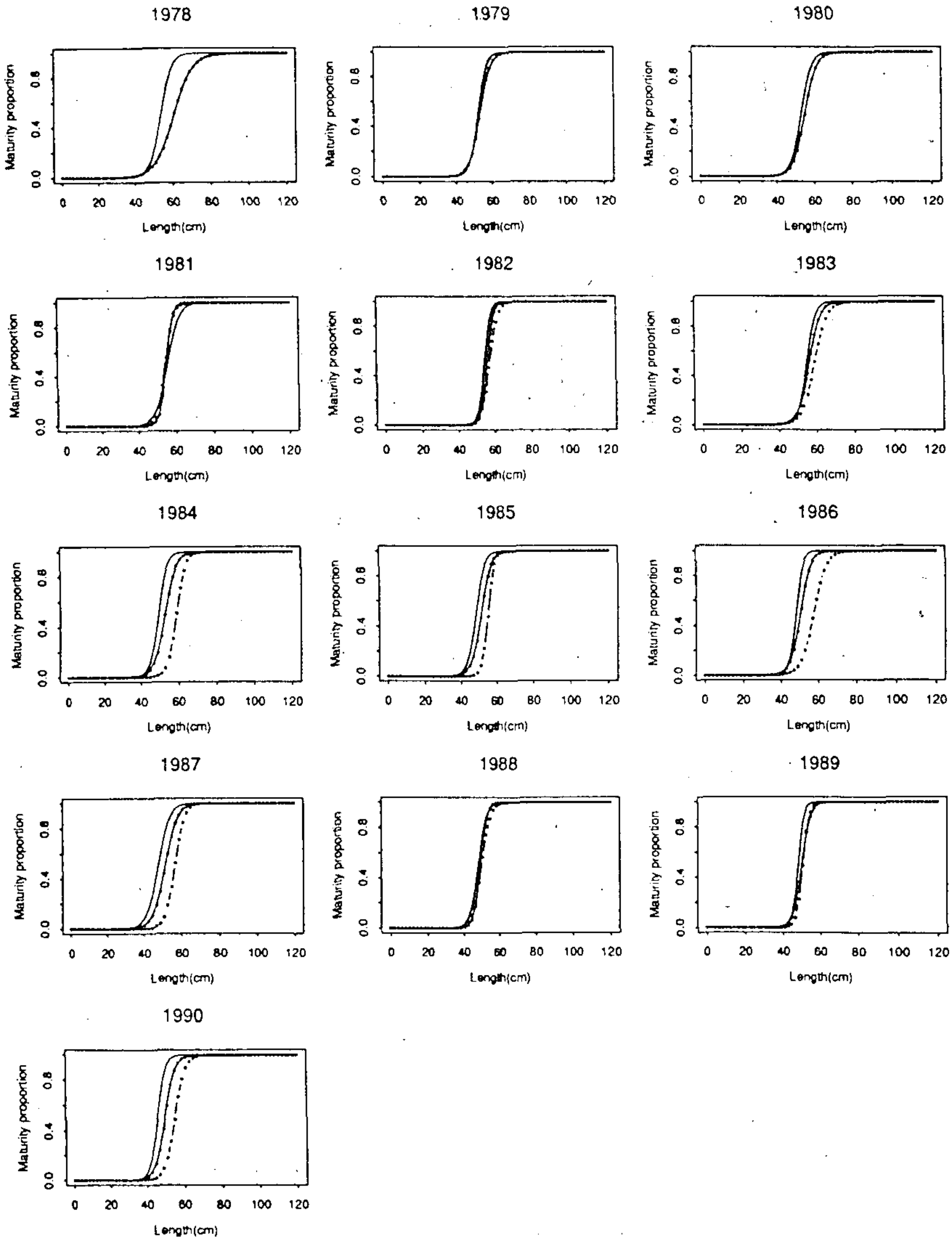
Table 9 Spawning numbers of female cod (x 10^3). Column (2) was obtained by summing the proportion mature (equation 4). A rough estimate of the spawning numbers can be obtained by summing the population numbers of fish aged 6 and above (column 3) or age 7 and above (column 4).

Year	$\sum_{a=3}^{14} P_a N_a r_a$	6+	7+
1981	89790	124237	69949
1982	101442	115427	84002
1983	85288	99610	64570
1984	98558	121994	48810
1985	99497	137599	67608
1986	103547	155465	74471
1987	130738	193122	85518
1988	179232	206817	113701
1989	141476	152202	110345
1990	104973	106637	72429

Table 10 Spawning biomass of female cod (tons). Column (2) was obtained by summing the biomass of proportion mature (equation 5). A rough estimate can be obtained by summing the biomass of age 6 and above (column 3) or age 7 and above (column 4).

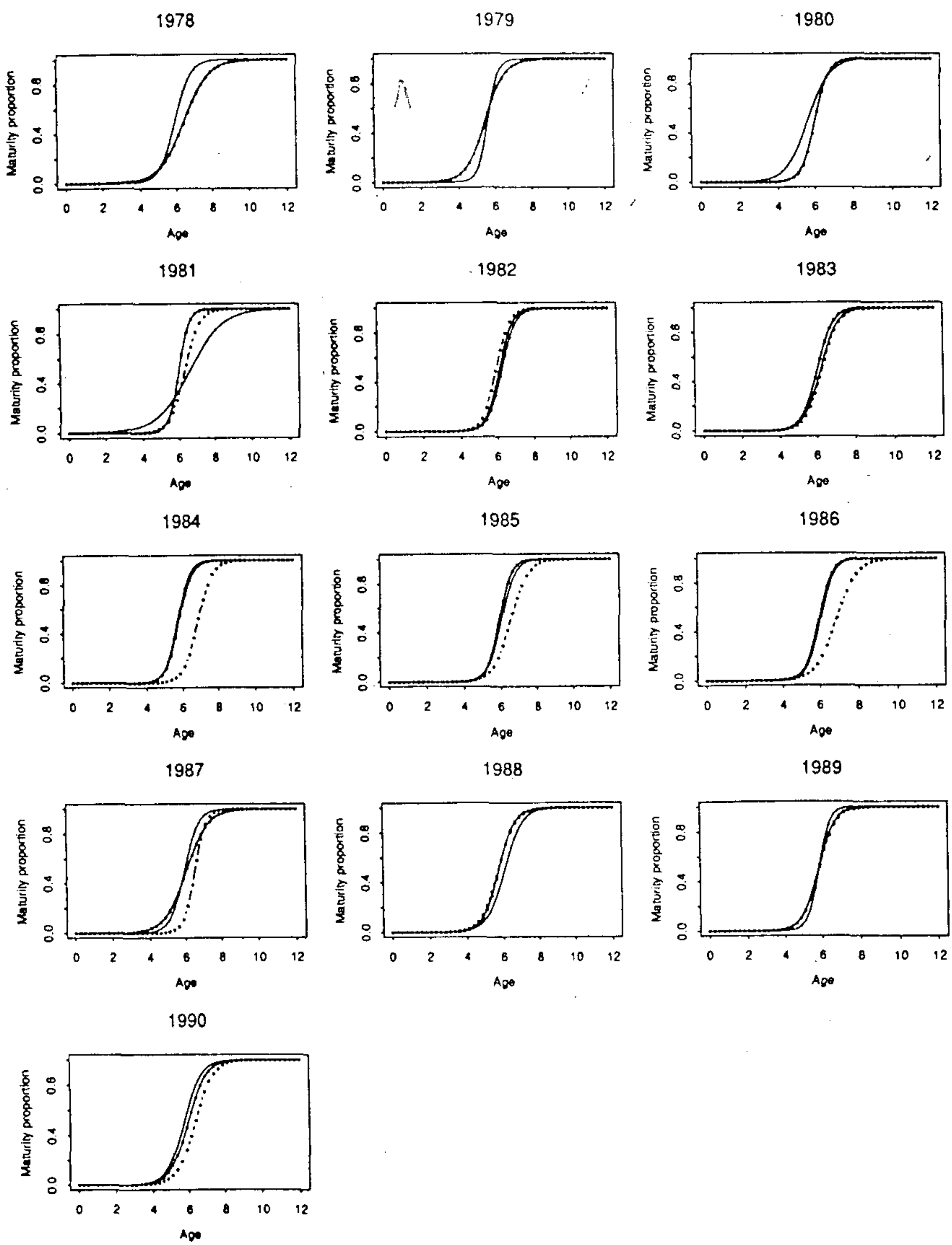
Year	$\sum_{a=3}^{14} P_a B_a r_a$	6+	7+
1981	200655	251110	179984
1982	223873	246253	203572
1983	199805	228656	175257
1984	209185	258654	142048
1985	211579	268255	173836
1986	188931	266179	156918
1987	228936	308023	184489
1988	286362	326374	216943
1989	256738	275160	223307
1990	186028	198779	155152

Figure 1. Logistic curves of proportion mature versus length



Solid line -- 2J   Solid line with dot -- 3K   Broken line -- 3L

Figure 2. Logistic curves of proportion mature versus age



Solid line -- 2J Solid line with dot -- 3K Broken line -- 3L

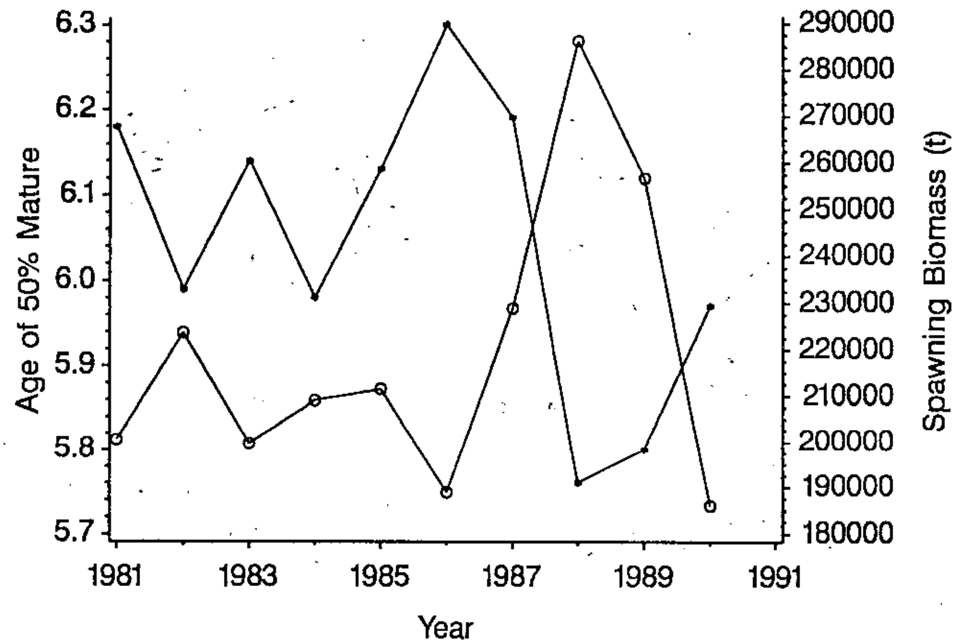


Figure 3. Changes of A50 and spawning biomass with year
– A50 o–o Spawning Biomass

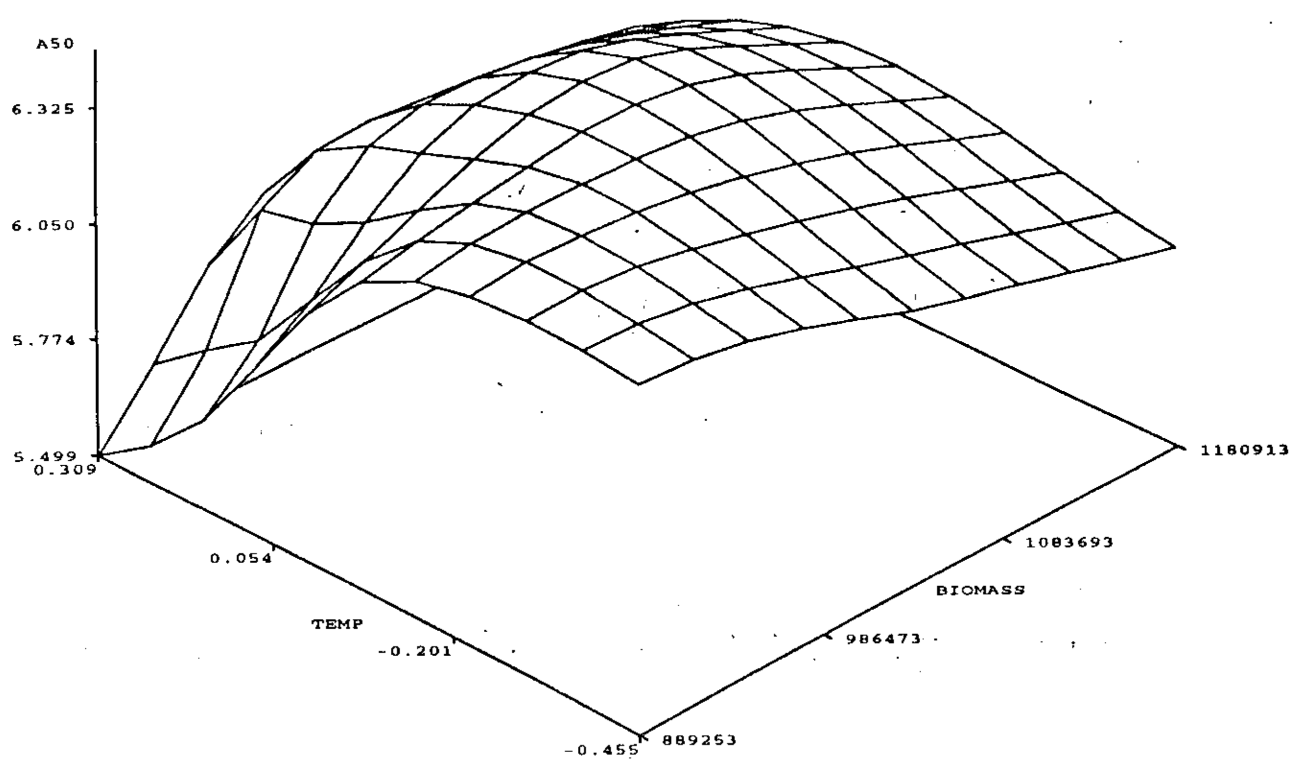


Fig. 4 Relation between A50 and biomass and temperature

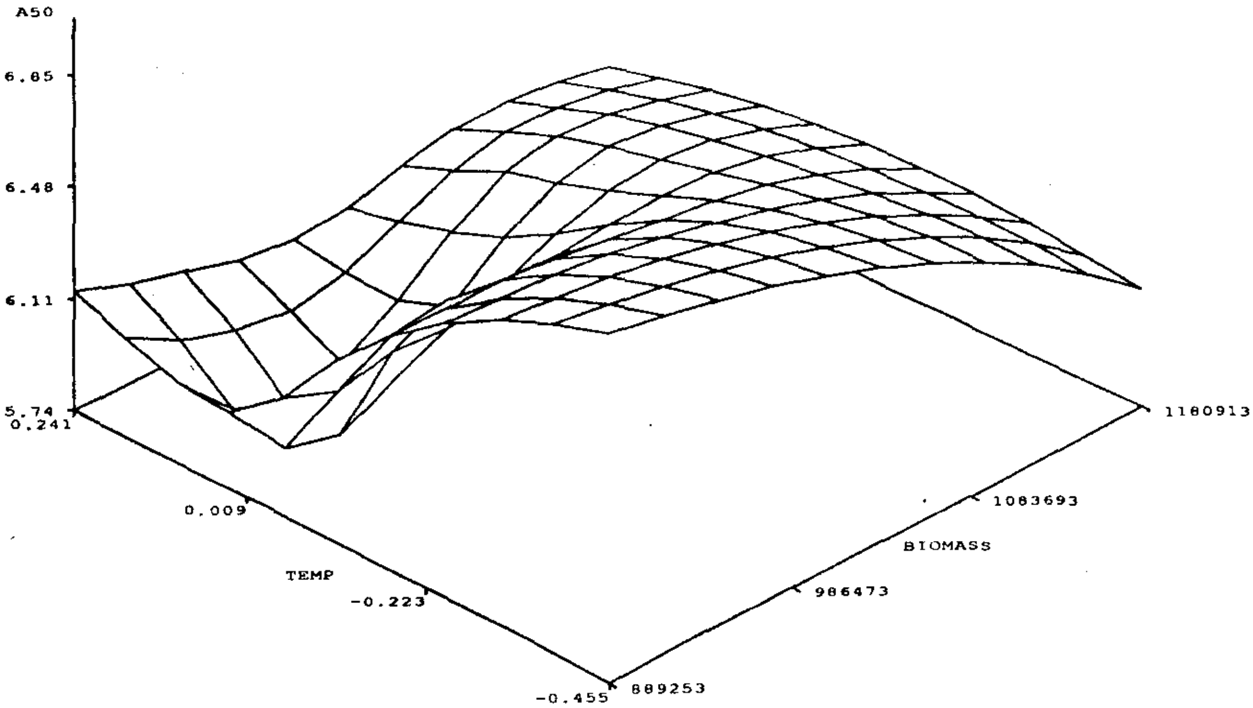


Fig. 5 Relation between A50 and biomass and temperature
temperature 2 year early, biomass 1 year early

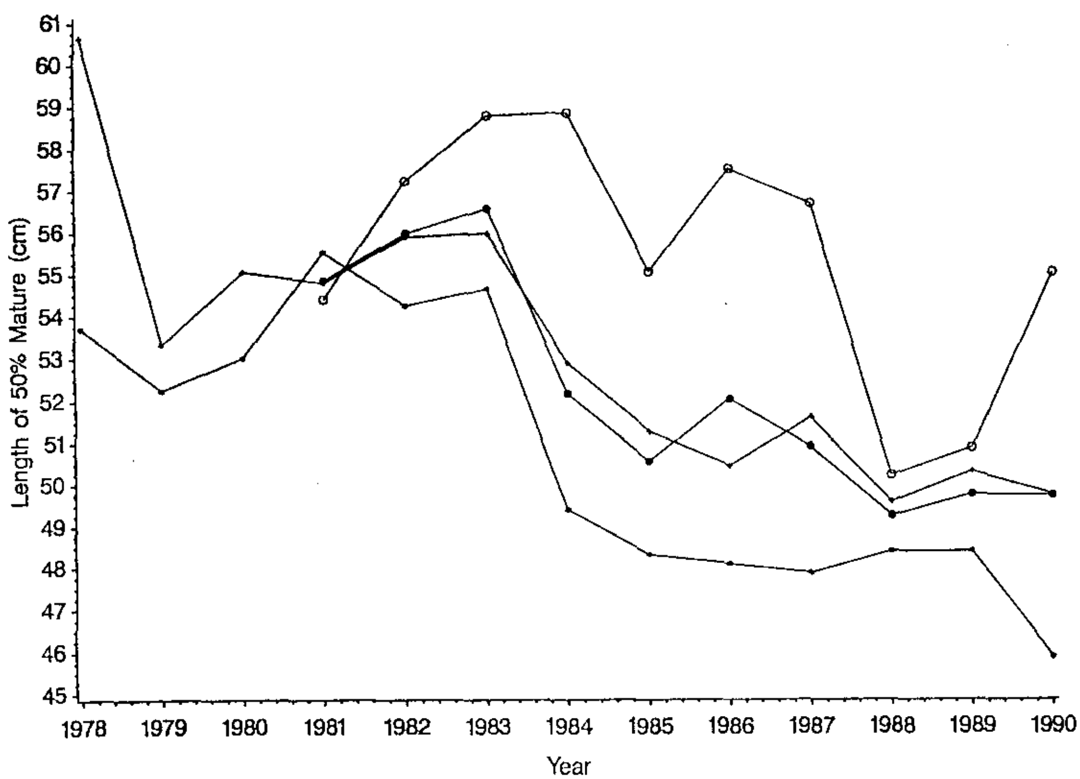


Figure 6. Change in L50 of female cod with years
– 2J +–+ 3K o–o 3L .–. 2J3KL