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Assessment of the Southwest Scotian Shelf and Bay of Fundy Cod

by

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ABSTRACT

Landings of cod from Division 4X averaged about 15,000 t between 1947 and 1961. Since then landings have ranged between 16,000 t and 35,500 t. The increased landings during the late 1980s and early 1990s was supported by recruitment of the strong 1985 and 1987 year-classes. Adjacent and subsequent year-classes have been poorer than average. With heavy exploitation of those two strong year-classes, stock biomass has declined rapidly to near historic low levels. Recent exploitation rates imply loss in yield as fish are captured before realizing their full growth potential and catch rates are significantly lower than those which could be attained at $F_{0.1}$. The high exploitation has also resulted in low stock biomass and reliance on incoming recruitment with the consequence of greater fluctuations in landings.

RÉSUMÉ

La moyenne des débarquements de morue de la division 4X s'est chiffrée à environ 15 000 t entre 1947 et 1961. Depuis, les débarquements ont varié entre 16 000 t et 35 500 t. Leur augmentation vers la fin des années quatre-vingt et le début des années quatre-vingt-dix a été soutenue par le recrutement des fortes classes d'âge de 1985 et de 1987. Les classes d'âge adjacentes et subséquentes ont été inférieures à la moyenne. À la suite de l'exploitation intensive de ces deux fortes classes d'âge, la biomasse du stock a diminué rapidement, jusqu'à atteindre des creux presque sans précédent. Ces récents taux d'exploitation entraînent une baisse de rendement puisque le poisson est capturé avant d'avoir réalisé sont plein potentiel de croissance; les taux de prises sont donc beaucoup plus faibles que ceux qui pourraient être atteints à $F_{0,1}$. L'intensité de l'exploitation a aussi entraîné une diminution de la biomasse, de sorte que la pêche dépend du recrutement à venir et que les débarquements fluctuent davantage.

DESCRIPTION OF FISHERY

Landings of cod from Division 4X averaged about 15,000 t between 1947 and 1961. With increased exploitation on the offshore banks, landings increased to a maximum of about 35,500 t in 1968. Since 1969, landings have varied between about 16,000 t and 33,000 t (Fig. 1). Recent landings, TACs and CAFSAC **reference levels are:**

	1987	1988	1989	1990	1991	1992	1993
Nominal Catch	19	19	20	24	28	26	
TAC	17.5	14	12.5	22	26	26	26
Reference Level	13	9	12.5	12	20	20	20

In recent years the fishery has occurred year round with highest catches dring June and July (Table 1) and is prosecuted primarily by otter trawlers less than 65 ft, tonnage classes 2 and 3, and by long liners less than 45 ft, tonnage classes 1 and 2 (Table 2). Much of the increased landings during 1990 to 1992 came from unit area 4Xo (Fig. 2, Table 3). Early reports from the fishery in 1993 indicate that the cod are not being found on the traditional grounds in unit area 4Xo. Reported landings since 1990 are considered to be more accurate due to introduction of mandatory weigh-outs.

DATA

The catch numbers at age for 1992 were based on 87 samples and were aggregated by gear type and quarter as has been done in recent years (Table 4). The 1987 and 1989 year-classes were prominent in both otter trawl and longline catches (Table 5). The catch at age and average weight at age for 1992 were appended to earlier data (Tables 6 and 7). The catch of 3 year olds, the 1989 year-class, was amongst the highest on record. Examination of the catch at length indicated a substantial increase in the catch of 40 to 50 cm cod between 1991 and 1992 (Fig. 3). There were no apparent trends in average weight at age in recent years.

Annual stratified random surveys (Fig. 4) have been conducted during summer since 1970. The relationship between historical population estimates and survey results are poor for ages 1 and 2 (Fig. 5). Recent results for ages 3 and older have identified the 1985 and 1987 year-classes as relatively strong. Early indications for the 1989 year-class suggest that it is below average. From 1991 to 1992 the total biomass declined by about 15% and the abundance for ages 3-10 declined by about 25% (Table 8). The spatial distribution of cod during the 1992 survey was similar to past years (Fig. 6).

ESTIMATION OF STOCK PARAMETERS

The adaptive framework (Gavaris 1988) was used to calibrate the sequential population analysis with the research survey results. Two model formulations were employed, an integrated model and the Laurec-Shepherd model. A third model formulation which used surveys only to estimate annual fully recruited fishing mortality and a partial recruitment gave an F of about 0.7 for 1992 but the time series of annual values was very variable.

Both the integrated and Laurec-Shepherd formulations used the following data:

$C_{a,y}$ = catch	a=1 to 12, y=1970 to 1992
$I_{a,y}$ = Canadian summer survey	a=3 to 10, y=1970 to 1992 excluding 1971 and 1988

The summer survey results were compared to average (mid-year) population abundance. Those for 1971 and 1988 were excluded based on preliminary analyses which showed very large residuals. Natural mortality was assumed constant and equal to 0.2. The fishing mortality rate on age 12 was calculated as the unweighted average for ages 5 to 7 in the same year. Errors in the catch at age were assumed negligible relative to those for the abundance index. The errors for the log transformed abundance index were assumed independent and identically distributed.

Integrated model

A model formulation using ln population abundance at the end of the terminal year (beginning of year y = t+1) as parameters was considered. Natural log population abundance was used because this parameterization displayed a more "close to linear" behaviour improving performance of the search algorithm. Define the model parameters

$\phi_{a,t+1}$ = ln population abundance at age

for a = 4 to 12 and

κ_a = calibration constants for Canadian summer survey

for a = 3 to 10

ADAPT was used to solve for the parameters by minimizing the objective function

$$Q(\phi,\kappa) = \sum_{a,y}(q_{a,y}(\phi,\kappa))^2 = \sum_{a,y}(\ln(I_{a,y}) - \ln(\kappa_a\bar{N}_{a,y}(\phi)))^2$$

To avoid confusion, the average population abundance, $\bar{N}_{a,y}(\phi)$ is abbreviated by $\bar{N}_{a,y}$. It is calculated as:

$$\bar{N}_{a,y} = N_{a,y}\ (1-\exp[-(F_{a,y}+M)])\ /\ (F_{a,y}+M)$$

For year y = t+1, the population abundance are the parameter estimates,

$$N_{a,t+1} = \exp[\phi_{a,t+1}]$$

For all other years, y = 1 to t, the population abundance was computed using the virtual population analysis algorithm which incorporates the exponential decay model

$$N_{a,y} = N_{a+1,y+1}\ \exp[F_{a,y}+M]$$

where the fishing mortality for ages 1 to 11 is obtained by solving the catch equation using a Newton-Raphson algorithm,

$$N_{a,y} = C_{a,y}(F_{a,y} + M)\ /\ F_{a,y}(1 - \exp[-(F_{a,y} + M)])$$

The fishing mortality rate for age 12 was assumed equal to the average for ages 5 to 7,

Analytical approximations of variance and bias for parameters and functions of parameters were derived following Gavaris (1993). A common estimator of the covariance matrix of the parameters which is based on a linear approximation was employed.

$$\mathrm{Cov}(\phi,\kappa) = \sigma^2[\mathbf{J}^T(\phi,\kappa)\mathbf{J}(\phi,\kappa)]^{-1}$$

where σ^2 is the mean square residual and $\mathbf{J}(\phi,\kappa)$ is the Jacobian matrix (first derivatives with respect to parameters) of $\underline{q}(\phi,\kappa)$

$$\mathbf{J}(\phi,\kappa) = \partial\underline{q}(\phi,\kappa)\ /\ \partial(\phi,\kappa)$$

where $\underline{q}(\phi,\kappa)$ is the vector with elements $q_{a,y}(\phi,\kappa)$. The superscript T denotes transpose.

The method of Box (1971), which is also based on a linear approximation and in addition assumes that the errors are normally distributed, was used to estimate the bias of parameters.

$$\mathrm{Bias}(\phi,\kappa) = (-\sigma^2/2)\ (\sum_{a,y}\underline{J}_{a,y}(\phi,\kappa)\underline{J}_{a,y}^T(\phi,\kappa))^{-1}$$

$$\sum_{a,y}\underline{J}_{a,y}(\phi,\kappa)\ \ \mathrm{tr}[(\sum_{a,y}\underline{J}_{a,y}(\phi,\kappa)\underline{J}_{a,y}^T(\phi,\kappa))^{-1}\ \mathbf{H}_{a,y}(\phi,\kappa)]$$

where $\underline{J}_{a,y}(\phi,\kappa)$ are vectors of the first derivatives for each $q_{a,y}(\phi,\kappa)$ (these are rows of the Jacobian matrix defined above) and $\mathbf{H}_{a,y}(\phi,\kappa)$ are the Hessian matrices (second derivatives with respect to parameters) for each $q_{a,y}(\phi,\kappa)$.

$$\mathbf{H}_{a,y}(\phi,\kappa) = \partial^2 q_{a,y}(\phi,\kappa) \;/\; \partial(\phi,\kappa)\;\partial(\phi,\kappa)$$

The expression tr represents the trace (sum of major diagonal) operator.

To derive the projected yield for the target year, y = t+2, the target fishing mortality rate at age and weight at age, as identified above, were used in the following calculations.

The population abundance at the beginning of year y = t+2 is obtained from the exponential decay model,

$$N_{a+1,t+2} = N_{a,t+1} \exp[-(F_{a,t+1} + M)]$$

The catch numbers at age and projected yield in year y = t+2 are derived using the catch equation and then applying the weight at age,

$$C_{a,t+2} = F_{a,t+2}\, N_{a,t+2}(1 - \exp[-(F_{a,t+2} + M)]) \;/\; (F_{a,t+2} + M)$$

$$\psi_{t+2} = \sum_a C_{a,t+2}\, W_a$$

It is seen from these calculations that the projected yield, ψ_y , is a function of the estimated parameters from the model formulation. Let $\psi_y = g(\phi,\kappa)$ denote that transforming function. Estimates of the variance and bias of the projected yield can be derived using the methods described in Ratkowsky (1983).

$$\text{Var}\;(\psi) = \text{tr}\;[(\underline{G}\underline{G}^T)\;\text{cov}\;(\phi,\kappa)]$$

$$\text{Bias}\;(\psi) = \underline{G}^T\;\text{Bias}\;(\phi,\kappa) + 1/2\;\text{tr}\;[\mathbf{W}\;\text{cov}\;(\phi,\kappa)]$$

where $\underline{G}$ is the vector of first derivatives of g with respect to the parameters

$$\underline{G} = \partial g(\phi,\kappa) \;/\; \partial(\phi,\kappa)$$

and **W** is the matrix of second derivatives of g with respect to the parameters

$$\mathbf{W} = \partial^2 g(\phi,\kappa) \;/\; \partial(\phi,\kappa)\;\partial(\phi,\kappa)$$

This same approach for computing statistics of functions of model parameters was used to derive estimates of the precision and bias of terminal (last year and oldest age) population abundance.

Laurec-Shepherd model

Define the model parameters

κ_a = calibration constants for Canadian summer survey

for a = 3 to 10

ADAPT was used to solve for the parameters by minimizing the objective function

$$Q(\kappa) = \sum_{a,y} (q_{a,y}(\kappa))^2 = \sum_{a,y} (\ln\ (I_{a,y}) - \ln(\kappa_a \bar{N}_{a,y}(k)))^2$$

To avoid confusion, $\bar{N}_{a,y}(\kappa)$ is abbreviated by $\bar{N}_{a,y}$. The average population abundance $\bar{N}_{a,y}$ is calculated as:

$$\bar{N}_{a,y} = N_{a,y}\ (1-\exp[-(F_{a,y}+M)])\ /\ (F_{a,y}+M)$$

For year y = t+1, the population abundance is obtained from :

$$N_{a+1,t+1} = (I_{a,y}(F_{a,t}+M)\exp[-(F_{a,t}+M)])\ /\ \kappa_a(1-\exp[-(F_{a,y}+M)])$$

where $F_{a,y} = \kappa_a C_{a,y}\ /\ I_{a,y}$

The remaining computations were done in the same manner as for the integrated model.

The population estimates at the beginning of 1993 for the two model formulations are given in Table 9 and suggest that the results are not different for practical purposes. The relative error and bias derived for the integrated model indicate that there is substantial uncertainty in the estimates. The residual plots for the integrated model do not display any problematic trends or patterns but they corroborate the large variance (Fig. 7).

For each cohort, the terminal population abundance estimates from the integrated model were adjusted for bias and used to construct the history of stock status (Tables 10 and 11). This simple approach, in the absence of unbiased point estimators with well determined statistical properties, was considered more appropriate than using the biased point estimates. It is recommended that the statistical properties of alternative unbiased estimators be studied and compared.

This stock has not exhibited a severe retrospective pattern. Succesive population estimates for older age classes have been both higher and lower than the previous estimates while those for younger age classes have generally been decreased, thought not substantially (Fig. 8).

ASSESSMENT RESULTS

The analysis indicates that the 1985 and 1987 year-classes were among the strongest since 1970 (Fig. 9). Excluding these, recruitment during the 1980s was generally lower than recruitment in the 1970s. The beginning of year population biomass for ages 3 and older has declined rapidly from a peak in 1990 and is approaching historically low levels (Fig. 10). It is noteworthy that the peak during the early 1980s was sustained for a longer period corresponding to the generally better recruitment, while the peak in 1990 which was due almost entirely to the 1985 and 1987 year-classes was of short duration. The total fishing mortality rate for ages 4 and older (Fig. 11), does not show any sustained trends but has fluctuated around 0.5. This exceeds twice $F_{0.1}$ and has likely resulted in lost yield due to capture of fish before their full growth potential has been realized. This also indicates that catch rates have been substantially lower than that which could be achieved at $F_{0.1}$.

The following table shows estimates of population abundance for the dominant age groups in the fishery at the beginning of the year in 1992 for A) last year's assessment (Campana and Hamel 1992) B) last year's assessment redone but excluding the survey estimates for 1971 and 1988 as was done in this assessment, C) this year's assessment (i.e. inclusion of the 1992 catch at age and research survey abundance estimates) and D) this year's results adjusted for bias.

AGE	A	B	C	D
3	12,612	12,000	11,085	9,741
4	3,905	4,213	4,053	3,762
5	9,997	10,551	8,828	8,293
6	3,837	3,917	2,655	2,497
7	2,841	2,052	1,791	1,677
8	250	249	292	273
9	331	285	189	177

The modifications incorporated in the ADAPT formulation did not result in important changes except for the estimate of the 1985 year-class at age 7. The lower estimate from the modified formulation is more consistent with the observed catch in 1992 as the numbers caught of this year-class were about half of what had been forcast with the results from A. Ilcorporating the observed catch at age and survey abundance index for 1992 resulted in lower population estimates for the 1986 and 1987 year-classes. This was because i) greater numbers of the 1987 year-class were caught in 1992 than had been forecast since the TAC was taken while there was a shortfall in the catch of the 1985 and older year-classes, and ii) the survey abundance estimates declined more than expected. The adjustment for bias predominantly affects the estimates for younger ages and has an impact on projections. This adjustment was not applied in last year's assessment. It should be noted that the 1989 year-class in last year's assessment could not be estimated and was assumed equal to the mean following common practice. This year-class is now estimated to be smaller than average. With the reduced estimates of the 1987 and 1989 year-classes, which were to have accounted for almost 50% of the projected catch in 1993, the fishing mortality rate on fully recruited ages in 1993 will have to be substantially higher if the TAC of 26,000t is to be caught.

PROGNOSIS

Yield projections were done using the results from the integrated model. The analysis indicated that the point estimates for projected yield in 1993 and 1994 were biased upward by about 10% and had a standard error of about 25% of the mean. As with population abundance estimates, the simple adjustment for bias was considered more appropriate than using the biased point estimate, especially in view of retrospective results and the declining population biomass. Due to a lack of good abundance indices at younger ages, the incoming year-classes were assumed to be about equal to the long term geometric mean. These year-classes account for about half of the projected yield. If the 1990-93 year-classes continue the trend of lower than average recruitment, the prognosis would be worse than that presented here.

If the TAC of 26,000 t is taken in 1993, the resulting fully recruited fishing mortality would be about 0.8 and the beginning of year 1994 biomass for ages 3 and older will decline further to 47,000 t. The yield for 1994 at $F_{0.1}$ would be about 7,000 t (Fig. 12). A 1993 fishing mortality of 0.5, about the average in recent years, would give a catch of 18,000 t and would result in a beginning of year 1994 biomass for ages 3 and older of 55,000 t. The corresponding yield for 1994 at $F_{0.1}$ would be about 8,500 t. (Fig. 12).

Beginning of year biomass for ages 3 and older has fluctuated between about 50,000 t and 80,000 t since 1970 and it is currently at about the lowest level. Recent fishing mortality rates and those implied by the current management plan imply a loss in yield due to growth overfishing and significantly lower catch rates than would be realized at $F_{0.1}$. With adult biomass declining and no indication of good recruitment to follow, a lower fishing mortality rate would distribute the available yield over more years.

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Table 1. Nominal catch (t) of 4X and 5Y cod by month.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1984	1741	2013	735	788	1773	3453	3659	4522	2734	1656	1203	973	25251
1985	773	1695	941	1264	1982	2595	3200	2612	2720	1810	795	1065	21452
1986	902	1618	1756	1441	1421	1939	2737	1992	2574	1714	771	1107	19971
1987	1209	1825	1236	1050	1866	2771	2661	1821	1673	1394	882	571	18959
1988	2123	1345	521	963	1522	2929	3008	1942	2208	1290	618	992	19461
1989	2148	2346	1360	1705	1292	3535	1830	1772	1535	1278	637	411	19849
1990	2541	2064	712	700	1516	3080	3753	3089	2574	1698	1133	826	23686
1991	2013	2641	993	1663	2312	3113	3945	2880	2967	2208	1650	1241	27626
1992	2075	1746	1297	1497	1677	3565	3324	2752	2595	2318	1460	1474	25780

Table 2. Nominal catch of 4X and 5Y cod by gear type and tonnage class.

	OTB						GN			LL					
Year	0 & 1	2	3	4	5	>6	0	1	2 & 3	0	1	2	>3	Misc.	Total
1984	964	4198	5832	109	1513	-	1248		220	6870	-	2864	980	451	25549
1985	523	3954	5548	57	1185	-	1837		161	5348	-	1764	635	440	21452
1986	573	3662	5094	186	974	-	1453		196	4926	-	1961	576	369	19970
1987	312	2645	3489	516	929	-	1198	770	241	652	5011	2257	499	439	18958
1988	451	3784	3345	154	382	41	478	330	424	1665	4361	3145	656	245	19461
1989	409	3933	4184	56	679	12	656	611	461	1535	4130	2341	635	205	19847
1990	505	3659	3566	104	113	44	992	941	669	2667	6159	3225	849	193	23686
1991	355	4598	5791	253	632	60	-	2225	615	-	8264	3852	853	129	27627
1992	236	4493	5709	128	717	3	-	1815	550	-	7672	3670	670	117	25780

Table 3. Nominal catch (t) of 4X and 5Y cod by unit area.

Year	4Xm	Xn	Xo	Xp	Xq	Xr	Xs	Xu	5Y	Total
1984	2256	2251	6192	1655	2244	2959	1413	3192	3088	25250
1985	3006	1199	5438	1026	1999	2301	1510	3529	1443	21451
1986	2914	1762	4670	544	1753	1802	1500	4226	801	19972
1987	2675	1609	4777	1130	1240	858	1207	4983	479	18958
1988	1464	1086	5226	1271	1082	746	1109	7475	-	19459
1989	1370	1019	5506	2820	1360	1112	915	5193	555	19850
1990	1846	755	7915	1746	2238	1746	1722	5380	338	23686
1991	2552	1557	8963	2436	2763	4242	2559	2246	307	27625
1992	1509	1776	10296	1437	2770	3295	1489	2937	272	25781

Table 4. Input data used for the construction of the 1992 catch-at-age matrix.

Gear	Period	a	b	No. of samples	Number measured	Number aged	Catch (t)
OTB	Q1	.0000081	3.0503	14	3350	535	3063
	Q2	.0000084	3.0410	13	3369	557	3582
	Q3	.0000087	3.0233	9	2365	482	2411
	Q4	.0000063	3.1152	5	1109	237	2230
LL, LHP	Q1	.0000081	3.0503	5	1484	272	1996
	Q2	.0000084	3.0410	10	2892	391	2684
	Q3	.0000087	3.0233	15	2538	385	4878
	Q4	.0000063	3.1152	7	2053	325	2453
GN	Q1	.0000081	3.0503	-	-	-	28
	Q2	.0000084	3.0410	2	422	80	424
	Q3	.0000087	3.0233	6	267	36	1356
	Q4	.0000063	3.1152	1	90	32	558
Misc.	Q1	.0000081	3.0503	-	-	-	32
	Q2	.0000084	3.0410	-	-	-	48
	Q3	.0000087	3.0233	-	-	-	26
	Q4	.0000063	3.1152	-	-	-	10

Table 5. Numbers at age (000s) by gear type.

Age	1	2	3	4	5	6	7	8	9	10	11+
OT	-	377	1072	840	1460	373	224	18	17	4	5
LL	-	324	2281	1006	1470	423	253	45	30	9	9
GN	-	-	6	89	419	145	35	7	1	-	-

Table 6. Catch at age for cod in Division 4X (includes Canadian catch in Division 5Y).

Age	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	0	0	0	0	0	0	0	2	0	0
2	272	553	358	331	101	766	410	1609	285	326
3	1341	1302	2446	1857	2193	1556	1693	3063	1803	1294
4	1398	1031	3071	2432	2088	2955	2476	1683	2274	3405
5	1565	1324	1903	1952	1814	1022	1401	1606	1991	2632
6	980	1062	953	676	1171	679	467	775	2188	1217
7	435	452	165	295	267	365	190	272	636	703
8	78	388	122	75	209	88	122	257	199	218
9	215	165	141	159	116	58	74	101	55	99
10	52	159	67	68	109	35	18	81	49	79
11	17	32	4	52	98	26	7	36	9	23
12	26	72	2	15	39	14	2	39	16	13
1+	6378	6538	9232	7910	8205	7562	6860	9524	9505	10010
2+	6378	6538	9232	7910	8205	7562	6860	9522	9505	10010
3+	6106	5986	8874	7580	8103	6797	6450	7913	9220	9684
4+	4765	4684	6428	5723	5911	5241	4757	4850	7416	8389

Age	1980	1981	1982	1983	1984	1985	1986	1987	1988
1	0	0	0	4	39	0	0	0	0
2	885	886	982	766	804	888	147	1055	439
3	4773	4063	2549	3896	2381	1594	3129	784	2996
4	1952	4424	4476	2112	3243	1488	2204	2140	1665
5	2476	1684	3332	2376	1845	2458	906	1016	1534
6	1288	1017	873	1148	923	1159	985	472	686
7	426	535	398	620	444	491	343	478	211
8	242	299	301	251	159	174	164	230	207
9	86	165	140	136	54	66	82	111	96
10	51	65	99	71	50	44	37	56	59
11	12	27	52	52	31	26	15	31	35
12	16	18	27	9	22	8	15	8	9
1+	12208	13183	13229	11440	9994	8396	8028	6383	7938
2+	12208	13183	13229	11436	9955	8396	8027	6383	7938
3+	11322	12297	12246	10671	9151	7508	7881	5328	7499
4+	6549	8234	9697	6775	6771	5913	4752	4544	4503

Age	1989	1990	1991	1992
1	10	0	6	0
2	519	101	480	705
3	2305	2195	1679	3380
4	3763	2463	4968	1947
5	709	2633	1878	3317
6	615	586	1417	947
7	158	370	222	515
8	83	76	168	71
9	54	43	30	48
10	17	35	16	13
11	7	12	39	8
12	6	12	15	2
1+	8247	8525	10917	10953
2+	8236	8525	10911	10953
3+	7717	8424	10430	10248
4+	5412	6229	8752	6868

Table 7. Average weight at age for cod caught in Division 4X.

Age	1970	1971	1972	1973	1974	1975	1976	1977
1	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.48
2	0.65	0.61	0.69	0.73	0.60	0.69	0.60	1.04
3	1.37	0.87	1.40	1.26	1.09	1.23	1.19	1.26
4	2.00	1.70	2.02	2.19	1.55	2.14	2.14	1.86
5	3.00	2.73	2.45	3.10	2.62	3.15	3.00	2.34
6	4.85	3.87	4.13	3.62	4.38	6.13	4.42	4.28
7	6.07	6.19	4.96	4.90	5.53	6.63	6.07	5.76
8	6.84	7.05	6.83	7.63	6.56	8.97	8.56	7.75
9	5.14	9.11	6.14	9.54	8.62	9.41	10.83	9.08
10	8.04	10.18	6.36	11.28	8.90	13.52	12.01	9.44
11	12.84	13.44	16.55	10.42	11.27	13.30	16.17	10.75
12	17.38	12.77	15.01	10.55	15.41	13.54	12.47	15.41

Age	1978	1979	1980	1981	1982	1983	1984	1985
1	0.51	0.51	0.51	0.51	0.51	0.36	0.38	0.37
2	0.84	0.83	0.71	0.75	0.81	0.85	0.95	0.82
3	1.57	1.27	1.41	1.25	1.33	1.33	1.50	1.41
4	1.91	2.04	2.17	1.99	1.85	1.85	2.00	1.97
5	2.39	3.11	2.98	2.80	2.84	2.61	2.73	2.52
6	3.54	4.15	4.75	3.60	4.13	4.21	3.82	3.53
7	4.17	5.34	6.71	5.64	5.46	5.58	5.42	4.96
8	6.16	7.26	6.93	7.25	7.08	8.05	7.61	6.89
9	6.18	8.65	9.57	8.38	8.38	10.26	9.34	8.09
10	9.22	11.24	9.81	11.21	9.07	11.42	11.69	9.86
11	6.56	10.65	11.86	12.29	10.63	11.59	13.27	12.41
12	7.23	12.00	14.11	12.41	14.16	15.10	14.15	14.52

Age	1986	1987	1988	1989	1990	1991	1992
1	0.38	0.51	0.51	0.50	0.51	0.50	0.50
2	0.80	0.91	0.96	0.92	0.92	0.88	0.93
3	1.29	1.46	1.35	1.57	1.49	1.36	1.28
4	1.90	2.16	1.88	2.28	2.26	2.03	1.84
5	2.63	3.17	2.71	2.76	3.22	2.74	2.86
6	3.96	3.89	4.01	4.02	3.89	3.86	3.93
7	5.02	5.55	5.25	4.98	5.61	5.47	4.98
8	7.47	7.89	8.07	8.45	7.97	7.58	6.52
9	9.51	9.13	10.12	9.97	10.00	9.77	9.20
10	9.20	11.90	10.99	11.89	12.46	13.25	12.09
11	11.90	12.95	12.17	15.24	14.03	13.63	14.40
12	14.38	15.53	16.25	16.38	16.16	15.66	16.26

Table 8. Research survey mean number per tow for cod in Division 4X.

Age	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
3	1.19	1.99	1.62	0.57	2.29	0.82	1.43	2.16	0.88	0.89	1.43
4	2.09	0.32	1.28	1.13	0.54	1.50	1.18	1.32	1.26	1.01	0.58
5	0.92	0.74	0.36	0.36	0.82	1.27	1.04	0.40	0.68	0.91	0.53
6	1.22	0.34	0.25	0.14	0.48	0.50	0.42	0.65	0.25	0.51	0.72
7	0.53	0.47	0.11	0.08	0.06	0.40	0.21	0.18	0.19	0.23	0.23
8	0.26	0.02	0.27	0.03	0.00	0.08	0.12	0.11	0.05	0.16	0.11
9	0.09	0.00	0.20	0.09	0.02	0.05	0.03	0.02	0.04	0.03	0.06
10	0.05	0.01	0.08	0.02	0.01	0.00	0.03	0.01	0.00	0.03	0.00

Age	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
3	1.16	0.90	2.62	2.25	2.67	1.67	0.37	10.24	2.12	3.47	0.70	1.08
4	1.30	0.94	1.50	1.50	0.95	0.81	0.72	1.77	1.66	1.63	1.95	0.44
5	0.68	0.78	0.93	1.23	0.97	0.23	0.38	1.08	0.28	1.56	0.73	1.07
6	0.44	0.44	0.58	0.45	0.50	0.40	0.17	0.33	0.31	0.20	0.49	0.34
7	0.24	0.12	0.24	0.32	0.34	0.29	0.14	0.13	0.03	0.28	0.09	0.29
8	0.20	0.13	0.00	0.04	0.19	0.14	0.20	0.19	0.02	0.04	0.08	0.07
9	0.05	0.11	0.05	0.04	0.10	0.06	0.05	0.04	0.05	0.03	0.01	0.03
10	0.05	0.03	0.02	0.02	0.01	0.01	0.03	0.00	0.03	0.00	0.01	0.00

Table 9. Results for begining of year estimates in 1993 from calibration of the sequential population analysis with survey results for cod in Div. 4X.

Age	Laurec-Shepherd	Integrated model		
	Pop #	Pop #	Rel. Err.	Rel Bias
4	6009	6017	0.653	0.183
5	1534	1556	0.665	0.153
6	3603	4226	0.546	0.104
7	885	1317	0.534	0.098
8	912	1000	0.507	0.093
9	220	175	0.487	0.089
10	90	112	0.502	0.092
11	35	7	1.870	0.430
12	80	21	0.700	0.123
mean square residual	0.27	0.27		

Table 10. Bias adjusted estimates of population numbers of cod in Division 4X.

Age	1970	1971	1972	1973	1974	1975	1976	1977
1	19383	15249	20597	24390	20329	25493	24609	17245
2	16654	15869	12485	16864	19969	16644	20872	20148
3	9182	13390	12493	9898	13508	16257	12934	16717
4	6603	6303	9785	8015	6424	9075	11903	9058
5	4623	4142	4228	5233	4361	3370	4756	7505
6	2581	2369	2193	1739	2518	1929	1835	2626
7	1726	1227	978	933	813	1002	965	1079
8	736	1020	596	652	497	424	491	618
9	533	532	484	378	466	217	267	292
10	109	242	287	268	165	277	125	152
11	247	43	54	174	158	37	196	87
12	79	186	6	41	96	41	7	154
13	0	41	88	3	20	43	21	4
1+	62456	60613	64273	68587	69323	74810	78980	75684
2+	43073	45364	43676	44197	48994	49317	54371	58439
3+	26419	29494	31191	27333	29025	32673	33499	38291
4+	17237	16105	18698	17436	15518	16416	20565	21574

Age	1978	1979	1980	1981	1982	1983	1984	1985
1	32529	29390	21060	26873	13315	13920	19319	10269
2	14116	26632	24063	17242	22002	10902	11393	15782
3	15040	11300	21510	18900	13316	17125	8233	8601
4	10915	10682	8080	13292	11797	8595	10496	4586
5	5893	6879	5665	4850	6879	5609	5126	5659
6	4691	3023	3251	2398	2447	2617	2442	2528
7	1449	1861	1374	1496	1043	1213	1104	1164
8	638	611	888	740	741	494	432	502
9	274	342	303	508	335	335	177	210
10	147	175	191	170	266	148	151	96
11	51	76	71	109	80	128	57	78
12	38	34	41	47	65	18	58	19
13	90	17	16	19	22	29	7	28
1+	85872	91022	86512	86644	72309	61133	58996	49521
2+	53343	61632	65452	59771	58994	47213	39677	39253
3+	39227	35000	41389	42528	36992	36312	28283	23471
4+	24187	23700	19879	23629	23677	19187	20051	14870

Age	1986	1987	1988	1989	1990	1991	1992	1993
1	30238	20757	32779	9771	15180	18860	19542	20000
2	8407	24757	16995	26837	7990	12429	15436	16000
3	12118	6750	19315	13517	21503	6450	9741	12000
4	5599	7090	4817	13103	8981	15619	3762	4917
5	2409	2590	3868	2437	7323	5124	8293	1318
6	2409	1153	1201	1779	1354	3614	2497	3788
7	1021	1081	516	362	900	578	1677	1187
8	509	525	453	232	154	402	273	907
9	254	268	222	183	114	57	177	159
10	113	133	119	95	100	55	19	101
11	39	58	58	44	62	51	31	4
12	41	18	20	16	29	40	6	18
13	8	20	8	8	8	13	20	3
1+	63164	65201	80370	68383	63699	63292	61473	60403
2+	32925	44444	47591	58612	48519	44432	41930	40403
3+	24518	19687	30596	31775	40529	32003	26494	24403
4+	12401	12937	11281	18258	19026	25553	16753	12403

Table 11. Fishing mortality rate for cod in Division 4X.

Age	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.02	0.04	0.03	0.02	0.01	0.05	0.02	0.09	0.02	0.01	0.04	0.06
3	0.18	0.11	0.24	0.23	0.20	0.11	0.16	0.23	0.14	0.14	0.28	0.27
4	0.27	0.20	0.43	0.41	0.45	0.45	0.26	0.23	0.26	0.43	0.31	0.46
5	0.47	0.44	0.69	0.53	0.62	0.41	0.39	0.27	0.47	0.55	0.66	0.48
6	0.54	0.68	0.65	0.56	0.72	0.49	0.33	0.39	0.72	0.59	0.58	0.63
7	0.33	0.52	0.21	0.43	0.45	0.51	0.25	0.33	0.66	0.54	0.42	0.50
8	0.12	0.55	0.26	0.14	0.63	0.26	0.32	0.61	0.42	0.50	0.36	0.59
9	0.59	0.42	0.39	0.63	0.32	0.35	0.37	0.48	0.25	0.38	0.38	0.45
10	0.74	1.29	0.30	0.33	1.30	0.15	0.17	0.88	0.46	0.70	0.35	0.55
11	0.08	1.79	0.09	0.40	1.15	1.51	0.04	0.63	0.21	0.41	0.21	0.32
12	0.45	0.55	0.52	0.51	0.60	0.48	0.33	0.33	0.62	0.56	0.56	0.54

Age	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.05	0.08	0.08	0.06	0.02	0.05	0.03	0.02	0.01	0.04	0.05
3	0.24	0.29	0.39	0.23	0.34	0.14	0.19	0.21	0.12	0.34	0.48
4	0.54	0.32	0.42	0.44	0.57	0.41	0.48	0.38	0.36	0.43	0.85
5	0.77	0.63	0.51	0.65	0.54	0.57	0.58	0.39	0.51	0.52	0.58
6	0.50	0.66	0.54	0.71	0.60	0.60	1.00	0.48	0.65	0.57	0.54
7	0.55	0.83	0.59	0.63	0.46	0.67	0.60	0.66	0.61	0.55	0.41
8	0.60	0.83	0.52	0.48	0.44	0.66	0.71	0.51	0.80	0.62	0.34
9	0.62	0.60	0.41	0.42	0.45	0.61	0.65	0.40	0.53	0.88	0.36
10	0.53	0.75	0.46	0.70	0.46	0.63	0.80	0.22	0.48	0.37	1.38
11	1.27	0.59	0.90	0.45	0.56	0.89	1.08	0.20	0.23	1.94	0.34
12	0.61	0.72	0.55	0.67	0.54	0.62	0.73	0.51	0.58	0.52	0.46

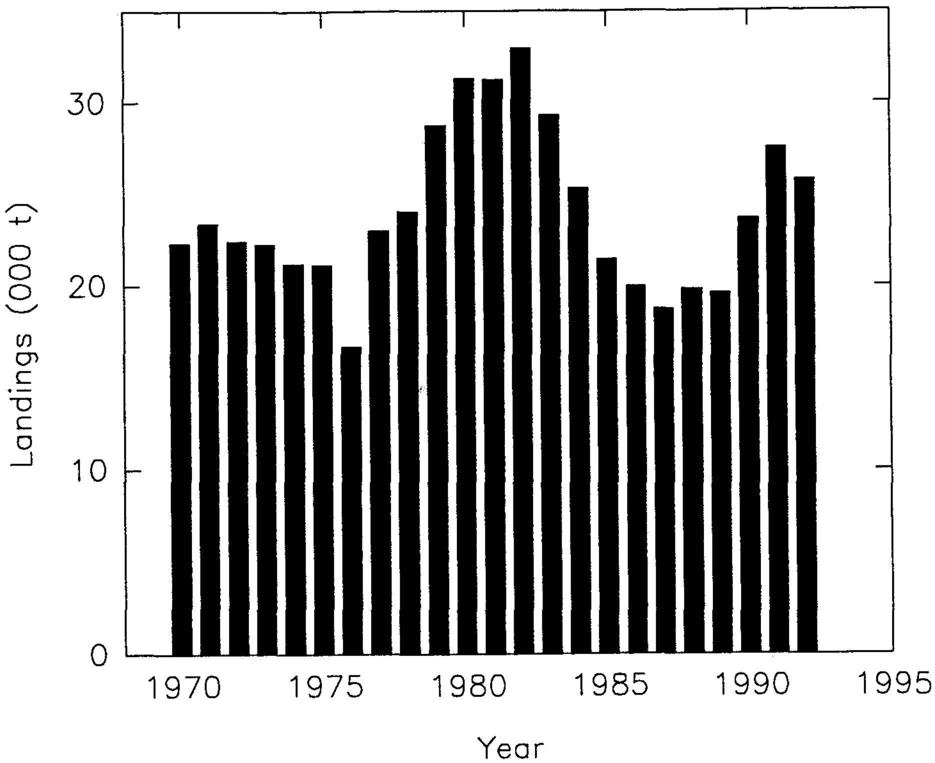


Fig. 1. Landings for cod in Division 4X.

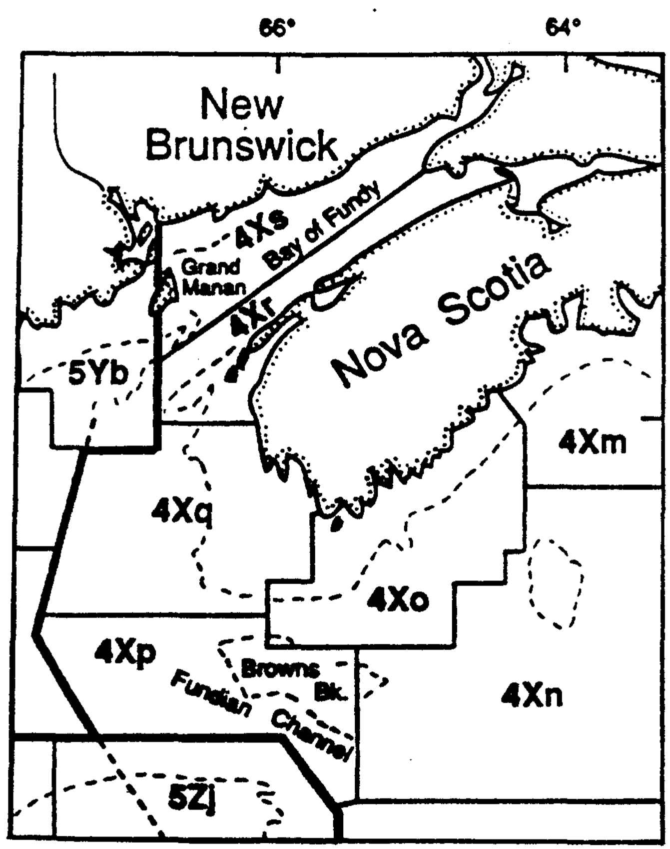


Fig. 2. Map of the southwest Scotian Shelf and the Bay of Fundy showing unit areas.

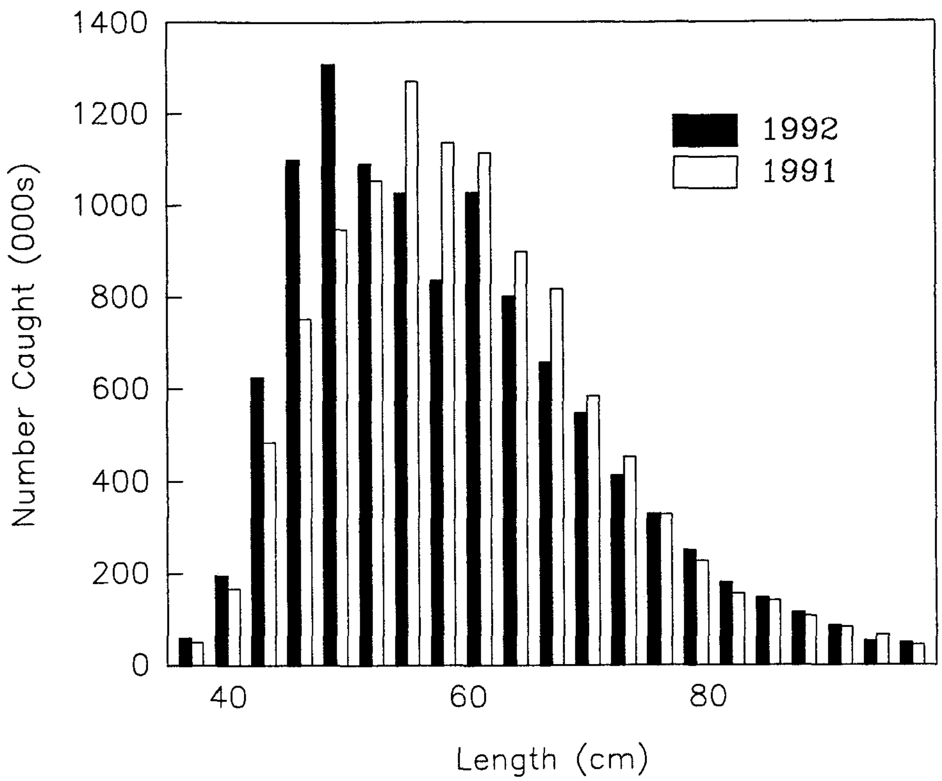


Fig. 3. Commercial catch at length of cod in Division 4X.

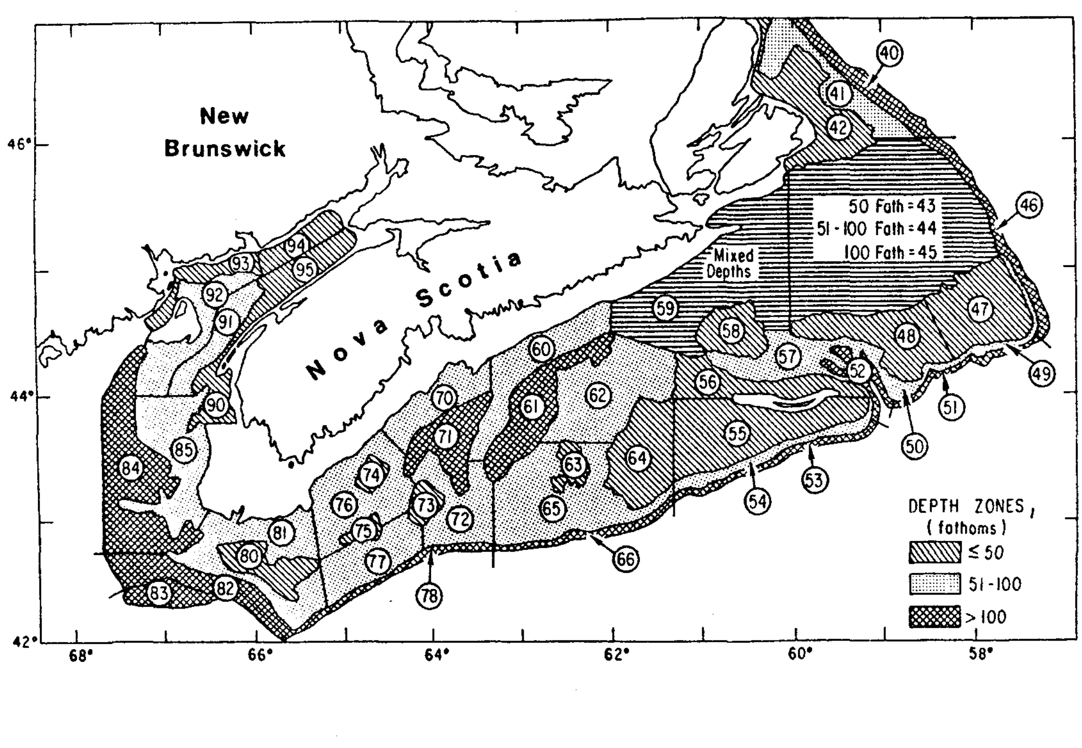


Fig. 4. Depth based stratification scheme used for the summer survey on the Scotian Shelf.

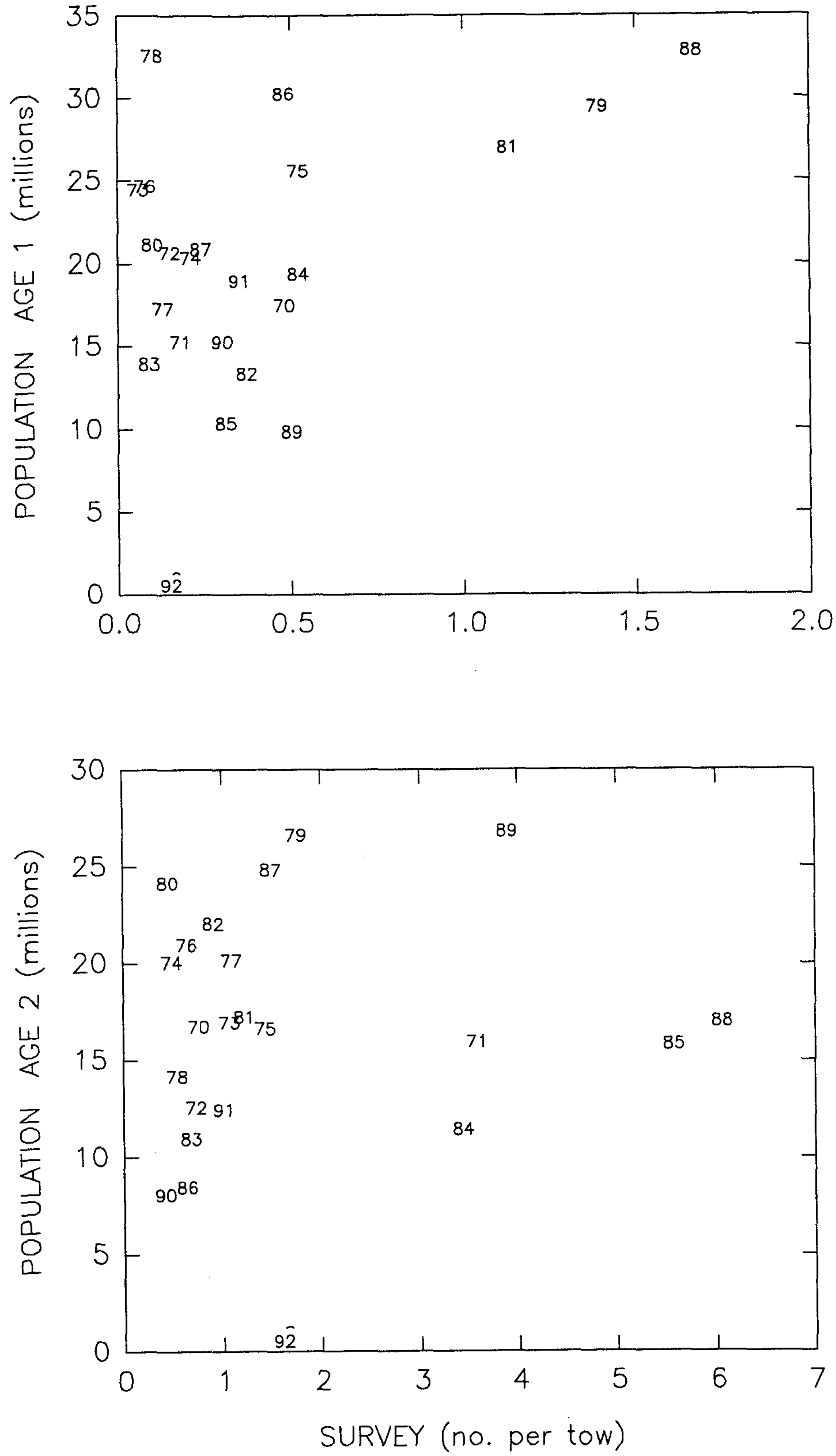


Fig. 5. Scatterplot of population abundance and survey abundance for cod in Division 4X.

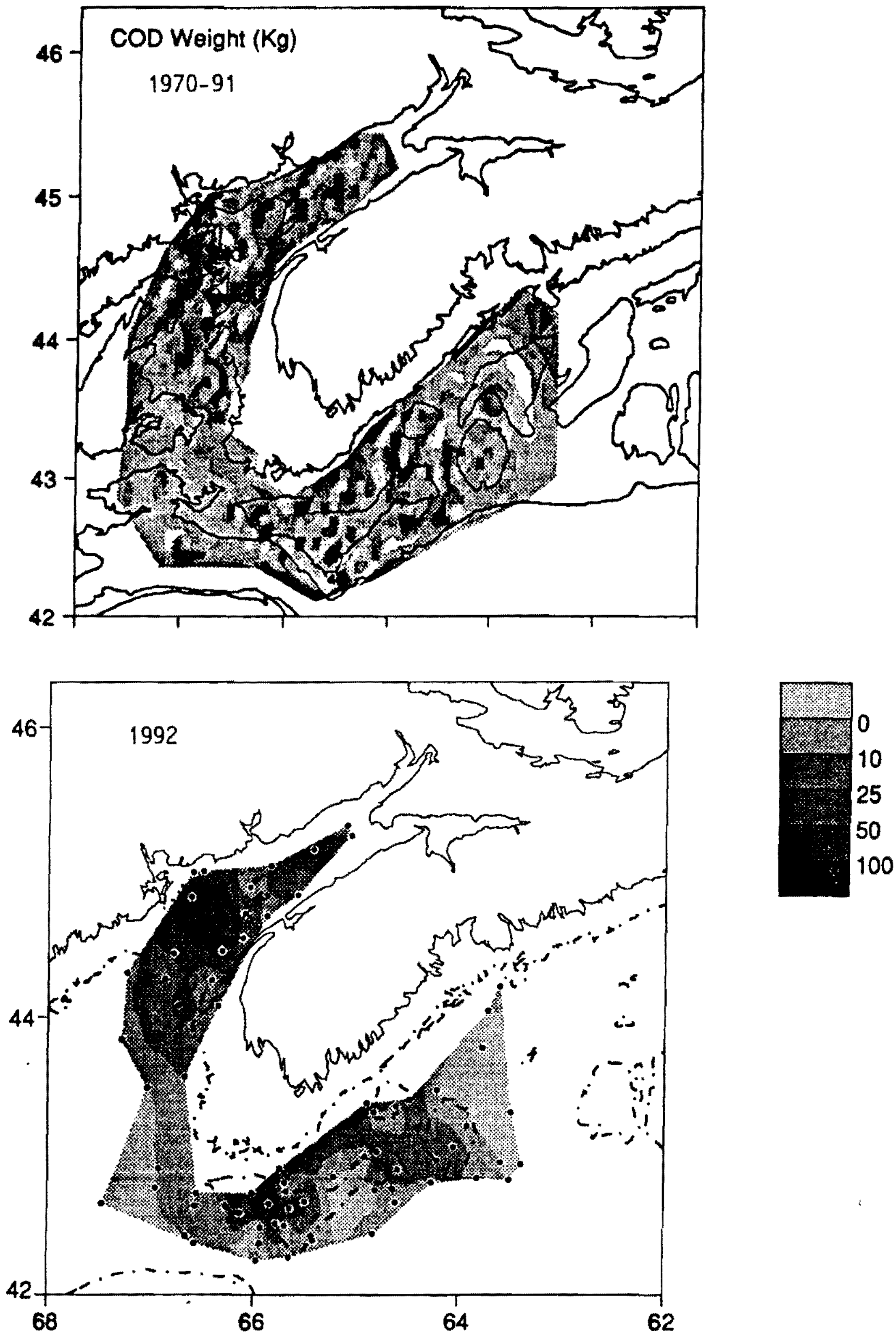


Fig. 6. Distribution of cod in Division 4X from the summer survey on the Scotian Shelf for 1970–91 (from Campana and Hamel 1992) and for 1992

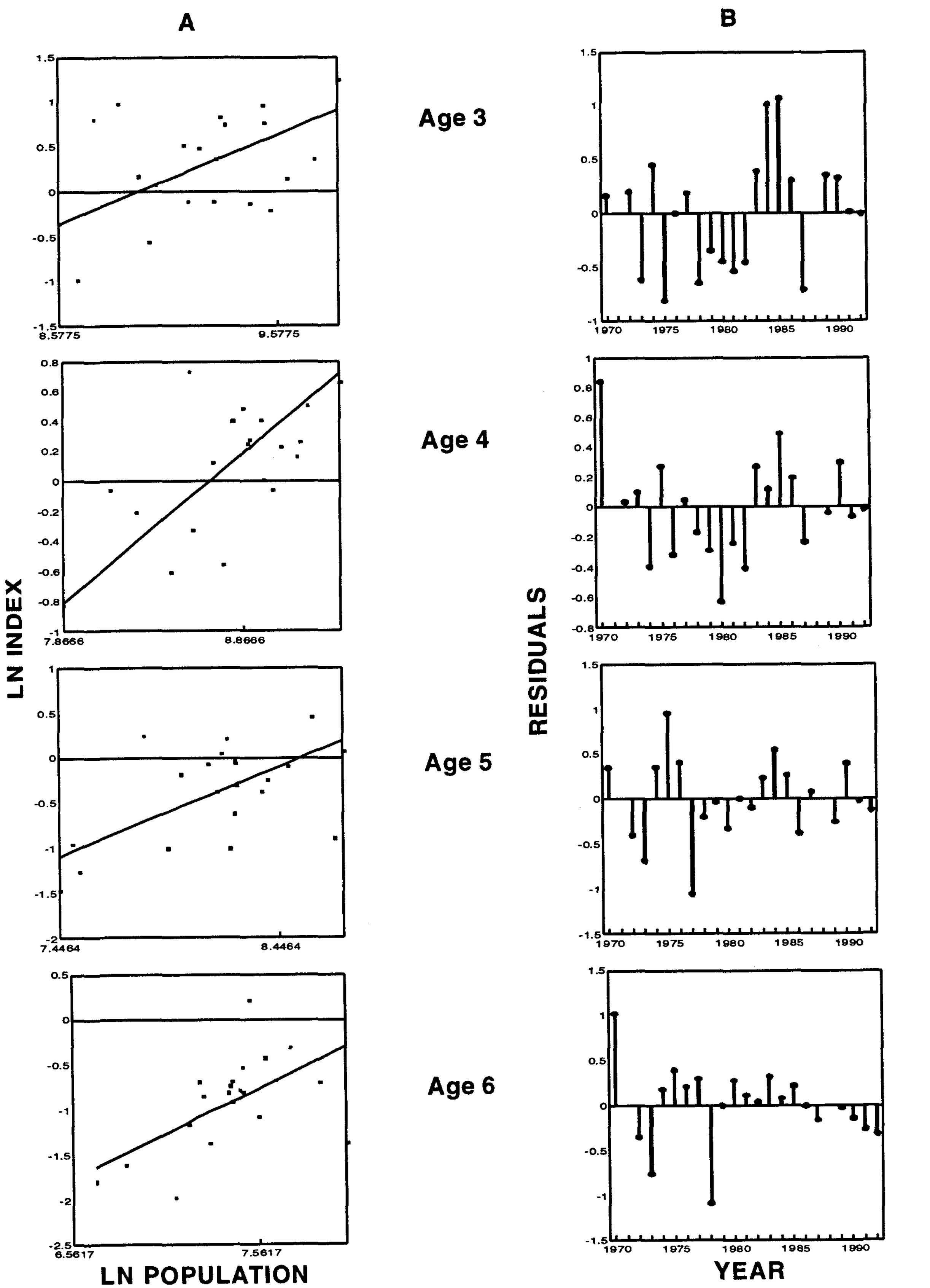


Fig. 7. Age by age plots of A) the observed and predicted ln abundance index versus ln population numbers and B) residuals plotted against year for cod in Division 4X.

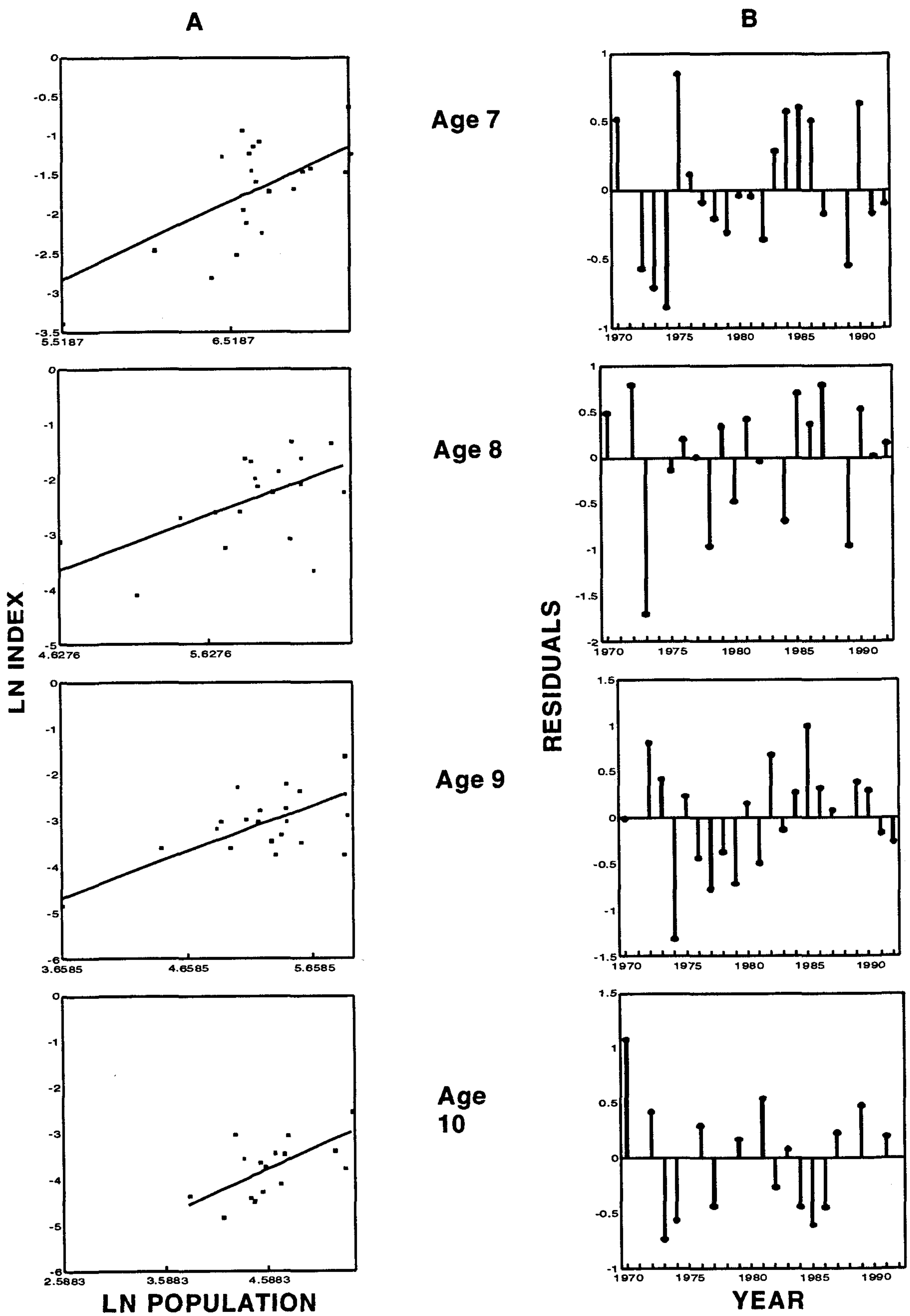


Fig. 7(cont'd). Age by age plots of A) the observed and predicted ln abundance index versus ln population numbers and B) residuals plotted against year for cod in Division 4x.

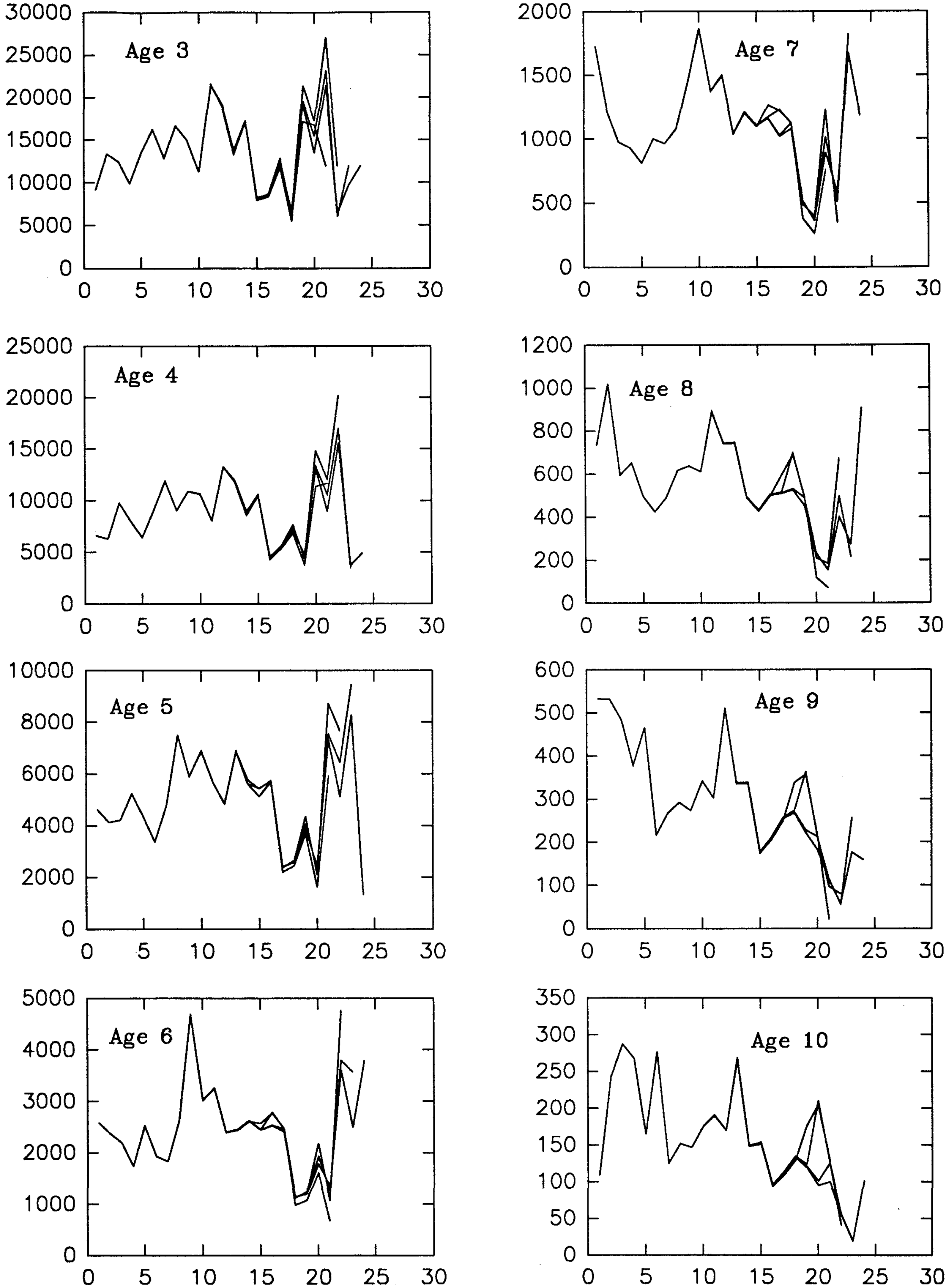


Fig. 8. Retrospective analysis for cod in Division 4X.

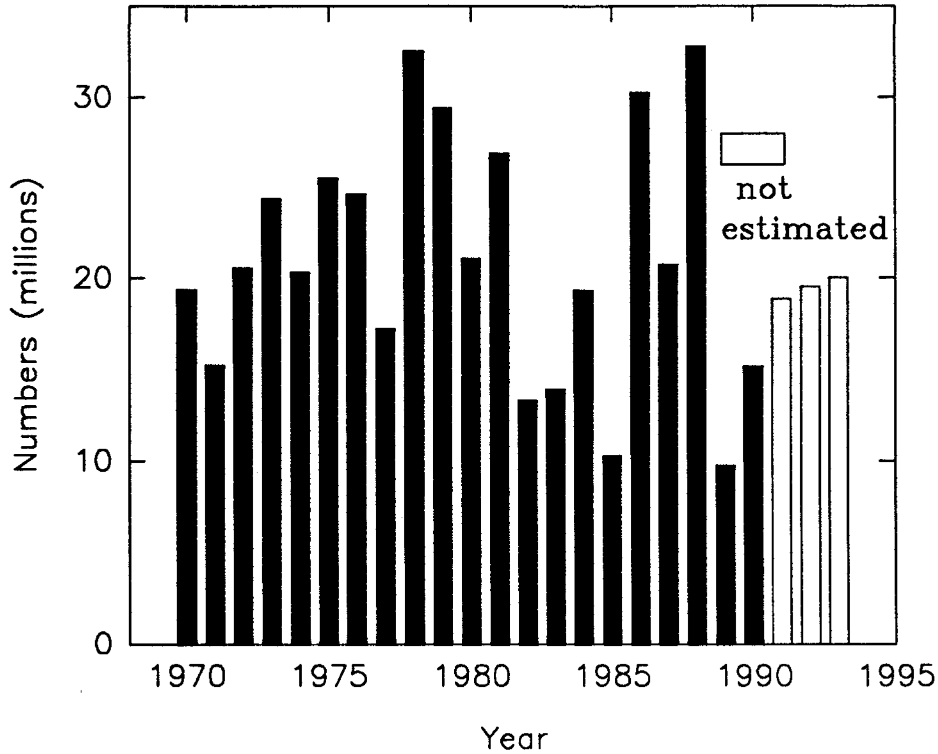


Fig. 9. Recruitment at age 1 for cod in Division 4X.

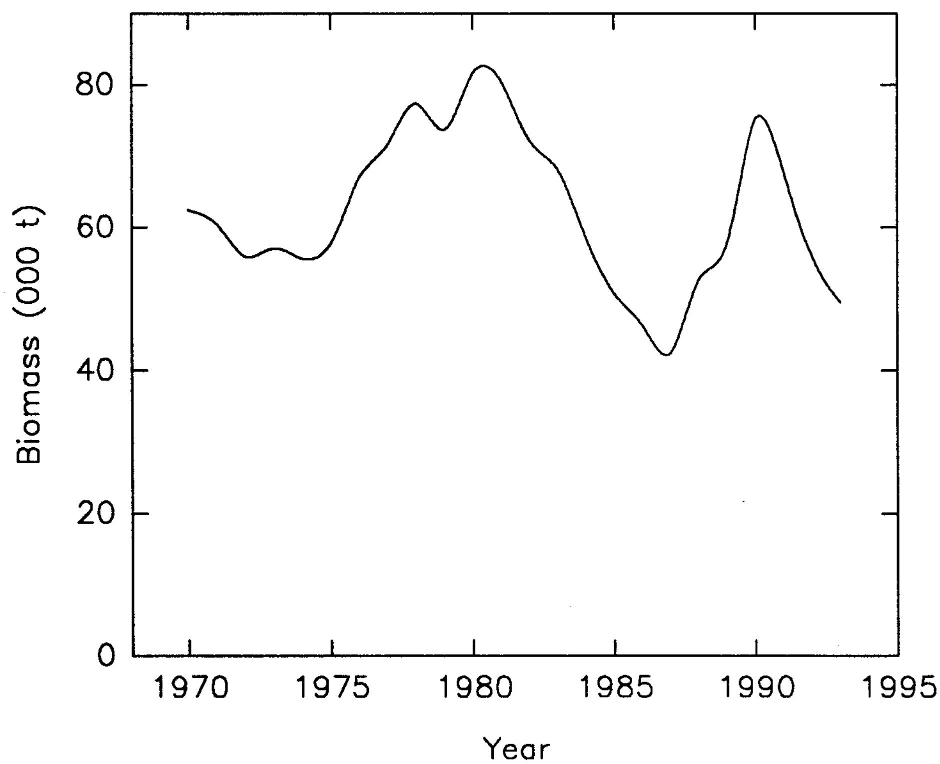


Fig. 10. Begining of year 3+ biomass for cod in Division 4X.

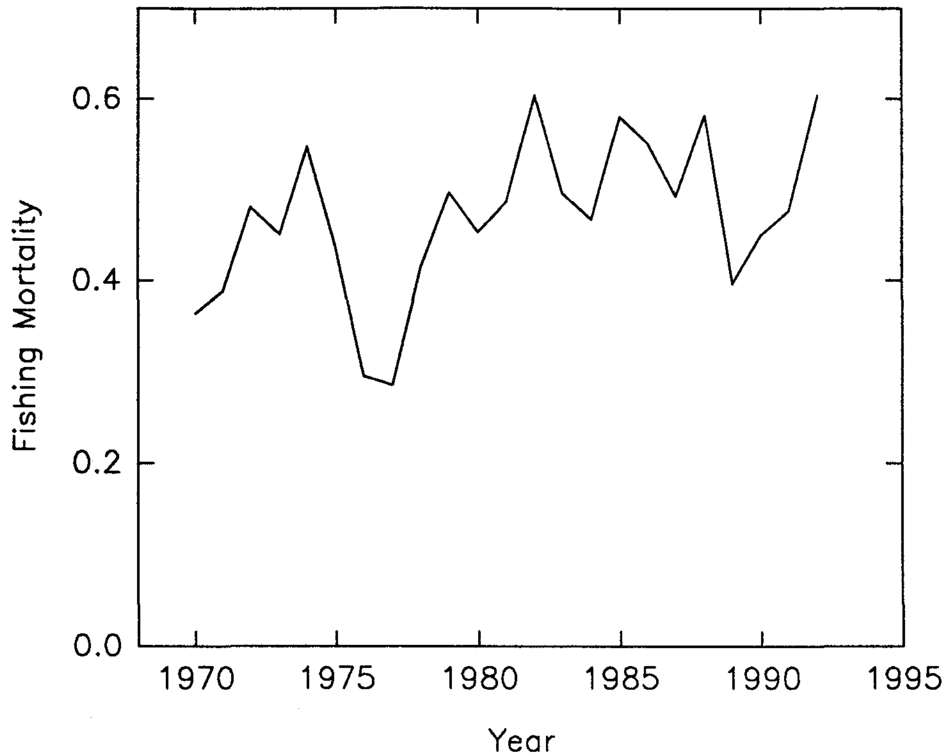
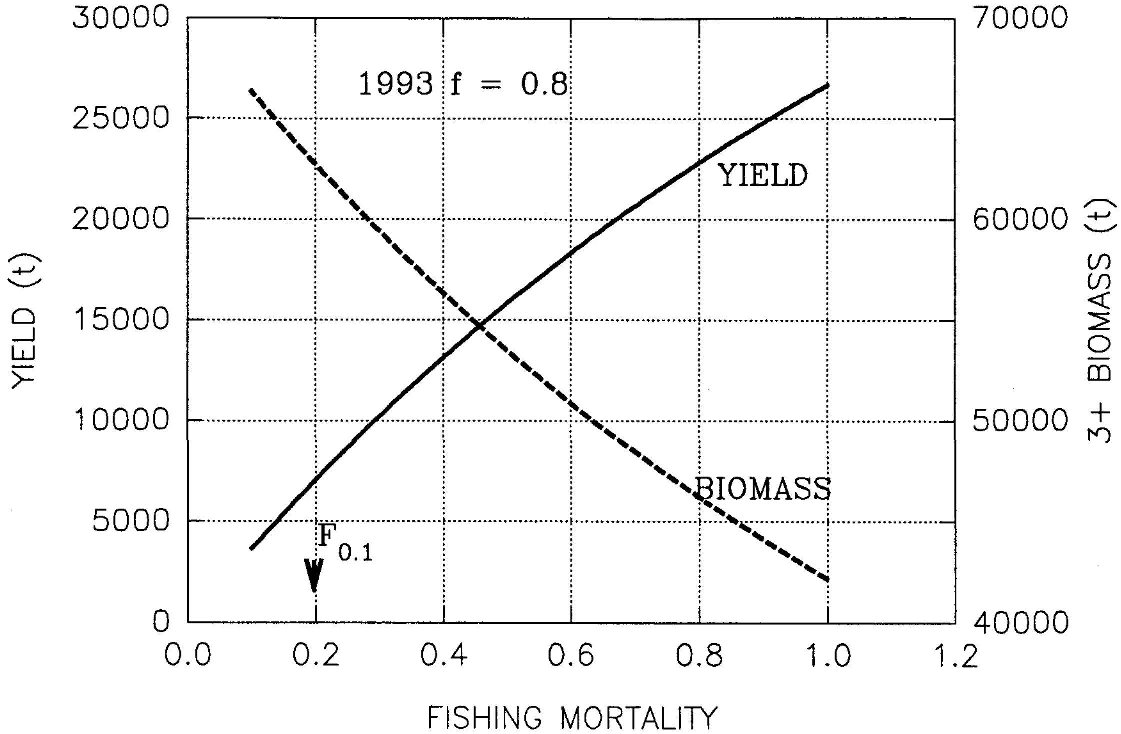


Fig. 11. Fishing mortality rate for cod, ages 4+, in Division 4X.



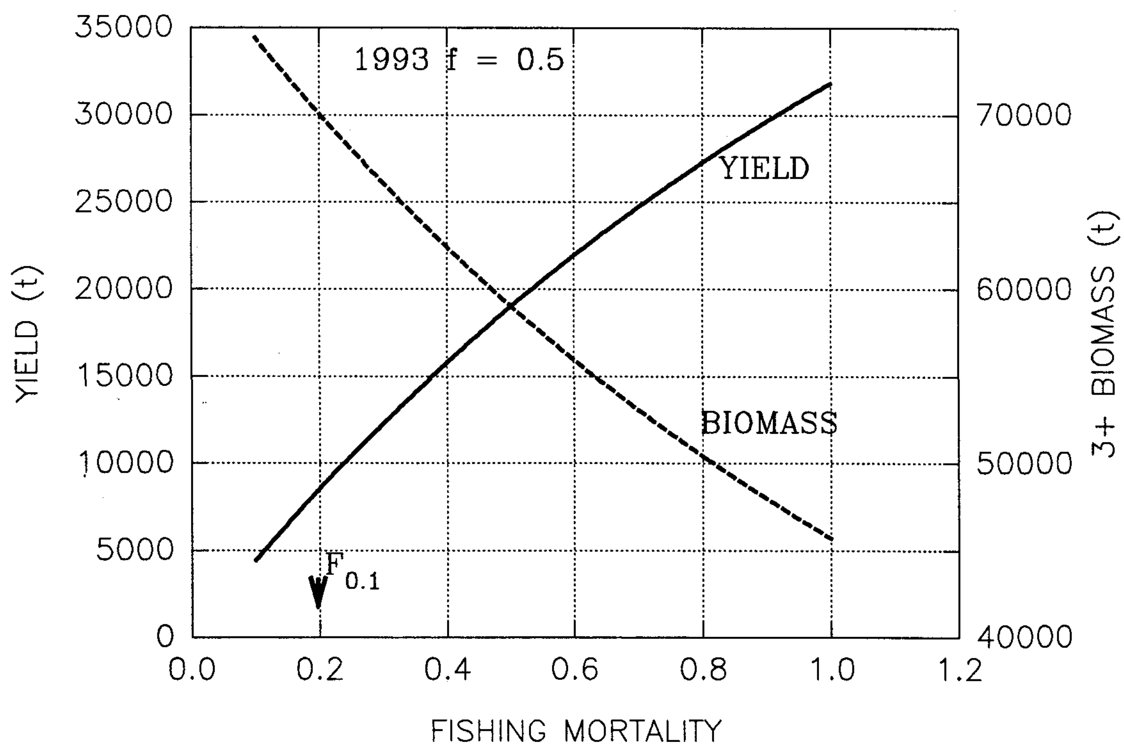


Fig. 12. Yield and biomass projections of cod in Division 4X for 1994.