DFO Atlantic Fisheries
Research Document 95/28

MPO Pêches de l'Atlantique
Document de recherche 95/28

Assessment of Cod in Division 4X in 1994

by

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ABSTRACT

Landings of cod from Division 4X have fluctuated since 1970 between 33,000t and the low 1994 value of 13,000t. The 1994 fishery was supported to a great extent by the 1990 and 1991 year classes. The survey index for 1994 is the second lowest on record for age 4^+, average for age 2, and slightly below average for age 3.

The adaptive framework was used to calibrate the sequential population analysis with the research survey results. The SPA results indicate that age 3^+ biomass has risen slightly from the record low levels of the previous two years due to the recruitment of the 1990 year-class, which, although only of average size for the time series, is the strongest since the 1987 cohort. The 1988 year-class is the lowest in the time series and the 1989 and 1991 year-classes are below average in size. Early signals from the research survey indicate that the 1992 year-class is about average. Fishing mortality, though down from the 1993 level, still exceeds twice $F_{0.1}$.

Yield projections show that the expected catch of 9,000t in 1995 will result in a fishing mortality of about 0.40. The projected $F_{0.1}$ yield for 1996 is about 6,300t. With preliminary indications of only average recruitment following the 1990 year-class, reducing exploitation rate from those seen in recent years would prolong the contribution of available fish to the fishery and help maintain a higher spawning biomass.

RESUME

Depuis 1970, les débarquements de morue en provenance de la division 4X ont fluctué entre 33 000 t et le seuil de 13 000 t atteint en 1994. La pêche de 1994 a été alimentée dans une large mesure par les classes d'âge de 1990 et 1991. L'indice établi d'après le relevé de recherche de 1994 vient au deuxième rang des plus bas pour les morues d'âge 4+, se situe dans la moyenne pour ce qui est des morues d'âge 2 et est légèrement inférieur à la moyenne en ce qui concerne les morues d'âge 3.

On a étalonné l'analyse séquentielle de population d'après le relevé de recherche, au moyen du modèle ADAPT. Les résultats obtenus révèlent que la biomasse des morues d'âge 3+ a augmenté légèrement par rapport aux seuils records des deux années précédentes, cela à cause du recrutement de la classe d'âge de 1990, qui, quoique de taille moyenne comparativement à la série chronologique, est la plus forte depuis la cohorte de 1987. La classe d'âge de 1988 est la plus faible de la série chronologique tandis que celles de 1989 et de 1991 sont inférieures à la moyenne. Selon les résultats préliminaires du relevé de recherche, la classe d'âge de 1992 équivaut à peu près à la moyenne. La mortalité par pêche, quoique inférieure à celle de 1993, se situe encore à plus du double de $F_{0,1}$.

Les projections de rendement révèlent que les prises de 9 000 t attendues en 1995 correspondront à une mortalité par pêche d'environ 0,40. Le rendement à $F_{0,1}$ projeté pour 1996 est d'environ 6 300 t. Compte tenu du fait que, selon les indications préliminaires, le recrutement après la classe d'âge de 1990 ne sera guère que moyen, un taux d'exploitation inférieur à celui des dernières années prolongerait l'apport du poisson disponible à la pêche et permettrait de maintenir à un niveau plus élevé la biomasse de reproducteurs.

DESCRIPTION OF FISHERY

Landings of cod from Division 4X (including the Canadian portion of Division 5Y; Fig. 1) 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. 2) and declined to a low of 13,000 t in 1994. These landings are a reflection of the total allowable catch, which declined from 26,000t in 1992 to 13,000t in 1994 and has been further reduced to 9,000t for 1995. Reported landings since 1990 are considered to be more accurate due to the introduction of mandatory weigh-outs. There has, however, been some discarding of small fish, although this does not seem to have been widespread in 1994.

The fishery takes place year round, with catches peaking in 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). The proportion of landings from the winter-spring fishery, prosecuted predominantly by the otter trawl fleet, has declined in recent years. The distribution of landings has also shifted west in recent years, with landings from 4Xmno declining to a greater degree than in other areas (Table 3).

Dragger fishermen commented that declines in the winter-spring fishery reflect introduction of individual quota (quota is saved as bycatch to pursue other fisheries through the year) and the Browns Bank spawning closure from February 1-June 15. Traditionally, this was a period of high catch rates for the dragger fishery during which "steak" (large) cod were caught. Longline fishermen commented that fishing was restricted in summer on Browns Bank and some traditional inshore cod areas due to the presence of large amounts of dogfish.

CATCH AND WEIGHT AT AGE

The catch numbers at age for 1994 were based on 78 samples and were aggregated by gear type, quarter and area (Table 4). Samples were aggregated by area to account for growth differences between the Bay of Fundy (4Xqrs5Yb) and southwest Scotian Shelf (4Xmnop) and the inequality in number of samples taken in proportion to landings from the two areas. Landings in 4Xu (uspecified area) were apportioned according to known area landings of the respective gear type and quarter. Catch at age was determined similarly back to 1990. Prior to 1990, catch numbers at age were based on samples aggregated by gear type and quarter, but not area (Gavaris et al, 1994). Differences in catch at age generated by the two methods were most noticeable in 1993 and 1994.

Length-weight parameters were taken from Campana and Hamel (1992). They calculated these parameters as seasonal averages over the years for which seasonal survey information was available. These values have been used since 1985 when seasonal surveys in 4X were discontinued.

In 1994, the 1990 year-class (age 4) and the 1991 year-class (age 3) predominated in both otter trawl and longline catches (Table 5). Landings of cod over age 4 have declined in recent

years (Table 6) and in 1994 the proportions of landings comprised by these ages were all below their long term averages (Fig. 3). The proportions of 3 and 4 year-olds were high in comparison with their long term means. Landings for most ages were well predicted by last year's assessment (Fig. 4); however, landings of the weak 1988 year-class (age 6) were greater than predicted, while age 7+ landings were lower than predicted.

Fishermen from the TC 3 dragger fleet commented that the decline in landings of large cod in recent years is due in part to changes in fishing practices; they are avoiding areas early in the year where catch rates of large fish are generally high for reasons noted above.

In 1995 the minimum hook size for the longline fleet will switch from circle 10 to circle 12. This is intended to reduce the landings of small cod (ages 2 and 3), although it is noteworthy that bait size is a key factor in influencing size of fish caught (Halliday and Kenchington 1993).

Intra-reader ageing comparisons demonstrated a high level of agreement between readings (Appendix 1). Although the level of agreement was acceptable, re-read were skewed to younger ages. Further investigation of patterns in comparative aging results will be conducted in the future.

ABUNDANCE INDICES

Commercial Catch Rates

Catch rate information from the commercial fisheries were used to derive indices of abundance. Total annual landings were divided by the number of trips for the dragger and longline fisheries (tonnage classes 2 and 3). Commercial catch rates for both fisheries were high from 1989-1991, and have since declined, although the longline catch rate in 1994 was slightly higher than in 1993 (Fig. 5). Neither catch rate series was used further in the analysis due to uncertainties regarding interpretation of the trends as a reflection of stock abundance.

There was strong agreement among fishermen that commercial catch rates did not reflect changes in abundance due to several factors which have impacted fishery performance. Key factors identified for the dragger fishery were the change to square mesh and changes in fishing practices associated with the introduction of individual quotas, and, for the longline fishery, trip limits and interannual changes in cod feeding behaviour in relation to the presence of feed in the water. Many dragger captains commented that they no longer targeted for cod and therefore their present catch rates were not comparable to past catch rates. Longline fishermen commented that once the trip limit was reached the remaining hooked fish were discarded. In December, port technicians noted that cod in the Bay of Fundy were being high graded (small fish were discarded at sea), as large cod could fetch a better price than small cod.

Research Surveys

Annual stratified random surveys have been conducted in 4X during summer since 1970. For this assessment, the sequential population analysis (SPA) only used survey information

collected since 1983, when the RV Alfred Needler became the standard survey vessel. The 1994 survey results, like those from 1993, show very low abundance for ages 5 and older (Table 8), however, in 1994, unlike 1993, there were some large catches, primarily at the mouth of the Bay of Fundy. Catch per tow has declined steadily on the Scotian Shelf since 1990, while in the Bay of Fundy the catch per tow remained relatively stable from 1991 to 1993, and increased markedly in 1994. The Bay of Fundy has generally accounted for about 30-40% of the overall index of abundance for 4X, however, in 1994 it made up over 60%, largely due to good catches of ages 3 and 4.

Survey results have identified the 1985 and 1987 year-classes as relatively strong and the 1988 year-class as very weak. The 1989 year-class is also below average, while indications from this survey are that the 1990 year class is average and the 1991 year-class slightly below average. Preliminary indications suggest recruitment for the 1992 year class is also average.

ESTIMATION OF STOCK PARAMETERS

The adaptive framework (Gavaris 1988) was used to calibrate the sequential population analysis with the research survey results using the following data :

$C_{a,y}$ = catch	a=1 to 12, y=1983 to 1994
$I_{a,y}$ = Canadian summer survey	a=2 to 10, y=1983 to 1994 excluding 1988 (ages 3 and 4)

where a indexes age and y indexes year. The summer survey results were compared to average (mid-year) population abundance. Data from ages 3 and 4 in 1988 were excluded from the analysis because catchability at these ages appeared to be anomalously high. The 1988 data were influential and their inclusion affected population estimates. Estimates obtained when the 1988 data were excluded were considered more appropriate. All other available data since 1983 were used except when the index was 0 (logarithm not defined). Data prior to 1983 were not used. A comparison of survey indices with results of the sequential population analysis (as in figure 7) for the years 1970-1994 revealed a time trend in the series that corresponded to a change in research vessel in 1983. By using data from a single research vessel (RV Alfred Needler) from 1983-1994, the time trend in the residual pattern was removed, the relative error and bias in population estimates were reduced, and the retrospective pattern was also essentially eliminated. A catch curve analysis of the earlier catch at age data (primarily during the 1970s) revealed that year classes were not being tracked as precisely during this period as in the 1980s. This was likely due to insufficient catch sampling in the 1970s and further supports the exclusion of data from the 1970s.

An age 2 survey index has been developed to estimate population numbers. The age 2 survey index used in the calibration includes sets at depths <50 fathoms, excluding stratum 490 (St. Mary's Bay). Relative error and bias were reduced in population estimates when stratum 490 was removed from the analyses, and the magnitude of the residuals was also decreased.

The weak 1988 year-class (age 7 in 1995) was estimated by use of partial recruitment and

catch data. ADAPT formulations that attempted to estimate this year class failed to find a solution.

Statistical error in the survey data was assumed to be independent and identically distributed after taking logarithms and the error in the catch at age was assumed negligible. Natural mortality, M, was assumed constant and equal to 0.2 and the fishing mortality rate, F, for age 12 was calculated as the average for ages 5, 6 and 8 in the same year. Cod in 4X are fully recruited by age 5.

Following the recommendation by Gavaris (1993), a model formulation using ln population abundances at the end of the terminal year (beginning of year y = 1995) as parameters was employed. Define the model parameters

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

for a = 3 to 12, with ages 1 to 2 fixed at values corresponding to the long-term geometric mean recruitment (1983-91), and

κ_a = calibration constants for Canadian summer survey

for a = 2 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 = 1995, the population abundances are obtained directly from the parameter estimates,

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

For all other years, y = 1983 to 1994, 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, 6 and 8.

Analytical approximations of variance and bias for population abundance estimates and corresponding projected yield were derived following Gavaris (1993).

ASSESSMENT RESULTS

The relative error and bias indicate that there is some uncertainty in the estimates of population abundance (Table 9) reflecting the magnitude of the residuals (Fig. 7). Close correspondence occurred between the survey indices, scaled by the calibration constants and converted to biomass, and the sequential population analysis for ages 4-10 pooled, though for ages 2 and 3 the correspondence was lower (Fig. 8). 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 - 13).

The analysis indicates that the 1985 and 1987 year-classes were the strongest since 1982 (Fig. 9) and the 1990 and 1992 year-classes are about average. The 1988 year-class was very weak and the 1991 year-class below average. The beginning of year population biomass for ages 3 and older is showing a slight increase after declining rapidly from a peak in 1990 to the lowest levels in the time series in 1993 and 1994 (Fig. 10). The peak in 1990 was due almost entirely to the 1985 and 1987 year-classes and was of short duration.

The total fishing mortality rate for ages 4 and older has generally fluctuated about 0.65 (Fig. 11). F increased rapidly after 1989 to about 1.0 in 1992 and declined in the past two years though it remains high. 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.

PROGNOSIS

Yield projections indicated that the point estimates for projected yield 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. The incoming year-classes were assumed to be about equal to the long term geometric mean (Table 14). Average partial recruitment values from the last 3 years were used for younger ages in projections. They are: age 1: 0.0, age 2: 0.06, age 3: 0.48, and age 4: 0.89.

If the TAC of 9,000 t is taken in 1995, the resulting fully recruited fishing mortality would be about 0.40 and the beginning of year 1997 biomass for ages 3 and older would increase to 50,000t. The yield for 1996 at $F_{0.1}$ would be about 6,300t (Fig. 12).

Beginning of year biomass for ages 3 and older has fluctuated between about 30,000t and 70,000t since 1983 and is currently at about its 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 $F_{0.1}$.

ACKNOWLEDGEMENTS

We appreciated the sampling effort by D. Lyon and G. Donaldson and the insight of this fishery which they provided. We thank those members of the industry who took the time to meet with us and discuss their experiences in the fishery. Our thanks to S. Gavaris for his assistance in preparing this document, and his comments on methodology. Thanks also go to L. Van Eeckhaute and J. Neilson, who reviewed an earlier version of this paper, for their constructive comments.

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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
1993	657	903	993	995	1611	2309	2824	2217	1794	1029	562	73	15968
1994	734	972	547	847	824	1771	2246	1503	1267	1154	726	455	13045

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

	Otter Trawl						Gill Net		Long Line and Hand Line				
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	25249
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	-	1968	241	5663	2257	499	439	18958
1988	451	3784	3345	154	382	41	808	424	6026	3145	656	245	19461
1989	409	3933	4184	56	679	12	1267	461	5665	2341	635	205	19847
1990	505	3659	3566	104	113	44	1933	669	8826	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
1993	176	2778	3598	68	238	2	1368	525	5067	1792	310	45	15967
1994	132	2022	2343	138	82	-	993	421	5091	1524	231	67	13045

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	571	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
1993	1339	1639	4842	1418	1949	2419	1396	775	191	15967
1994	828	561	4414	1128	1662	1883	892	1540	137	13045

Table 4. Input data used for the construction of the 1994 catch-at-age matrix.

Gear	Quarter	Area	Length-weight coefficients		Number of samples	Number measured	Number aged	Landings (t)
			a	b				
Otter Trawl	Q1	mnop qrs5Yb	.0000081	3.0503	8 7	1955 1487	252 215	452 1203
	Q2	mnop qrs5Yb	.0000084	3.0410	10 4	2294 700	245 145	540 815
	Q3	mnop qrs5Yb	.0000087	3.0233	2 1	363 260	42 67	176 792
	Q4	mnop qrs5Yb	.0000063	3.1152	3 -	745 759[1]	144 111[1]	325 460
Gill Net	Q2	mnop qrs5Yb	.0000084	3.0410	1 -	201 GNQ2[2]	OTQ2[3] OTQ2[3]	214 156
	Q3	mnop qrs5Yb	.0000087	3.0233	2 -	381 GNQ2[2]	LLQ3[3] OTQ3[3]	502 542
Long Line and Hand Line	Q1	mnop qrs5Yb	.0000081	3.0503	7 -	2127 -	290 -	578 -
	Q2	mnop qrs5Yb	.0000084	3.0410	8 -	2097 LLmnop[2]	319 OTQ2[3]	1480 257
	Q3	mnop qrs5Yb	.0000087	3.0233	14 -	2966 LLmnop[2]	440 OTQ3[3]	2757 498
	Q4	mnop qrs5Yb	.0000063	3.1152	11 -	3357 -	348 -	1102 -

[1] Due to lack of samples from this quarter, 1 OT sample from Sept. was combined with 2 from Jan. 1995.

[2] Due to lack of samples, length frequency samples used for the same gear and quarter, from the other area.

[3] Due to insuficient samples, ALK used for the quarter and gear indicated from the appropriate area.

Table 5. Landed numbers of 4X and 5Y cod at age (000s) by gear type.

Age	1	2	3	4	5	6	7	8	9	10	11+
OT	-	146	856	704	128	46	42	10	9	-	1
LL	-	329	1347	1348	683	124	109	25	6	1	1
GN	-	1	77	181	76	25	30	7	4	-	1

OT - otter trawl; LL - long line and hand line; GN - gill net

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

Age	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	4	39	0	0	0	0	10	0	2	0	0	0
2	766	804	888	147	1055	439	519	103	414	640	639	475
3	3896	2381	1594	3129	784	2996	2305	2590	1382	3470	3212	2280
4	2112	3243	1488	2204	2140	1665	3763	2734	5116	2080	1836	2233
5	2376	1845	2458	906	1016	1534	709	2702	1921	3331	665	887
6	1148	923	1159	985	472	686	615	591	1414	858	653	195
7	620	444	491	343	478	211	158	326	226	501	173	181
8	251	159	174	164	230	207	83	77	156	68	88	42
9	136	54	66	82	111	96	54	45	31	43	14	18
10	71	50	44	37	56	59	17	43	18	10	11	1
11	52	31	26	15	31	35	7	14	31	11	3	2
12	9	22	8	15	8	9	6	18	8	4	0	0
1+	11440	9994	8396	8028	6383	7938	8247	9243	10719	11016	7294	6314
2+	11436	9955	8396	8027	6383	7938	8236	9243	10717	11016	7294	6314
3+	10671	9151	7508	7881	5328	7499	7717	9140	10303	10376	6655	5839
4+	6775	6771	5913	4752	4544	4503	5412	6550	8921	6906	3443	3559

Table 7. Average weight (Kg) at age for cod landed in Division 4X.

Age	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1	0.36	0.38	0.37	0.38	0.51	0.51	0.50	0.51	0.50	0.50
2	0.85	0.95	0.83	0.80	0.92	0.96	0.92	0.91	0.89	1.01
3	1.33	1.50	1.41	1.29	1.46	1.35	1.57	1.45	1.39	1.26
4	1.85	2.00	1.97	1.90	2.16	1.88	2.28	2.14	2.08	1.88
5	2.61	2.73	2.52	2.63	3.17	2.71	2.76	2.90	2.81	2.91
6	4.21	3.82	3.53	3.96	3.89	4.01	4.02	3.62	3.88	3.92
7	5.59	5.42	4.96	5.02	5.55	5.25	4.98	5.55	5.55	4.85
8	8.05	7.61	6.89	7.48	7.89	8.07	8.45	7.95	7.43	6.48
9	10.27	9.34	8.09	9.51	9.13	10.12	9.97	10.09	9.84	9.12
10	11.43	11.69	9.87	9.20	11.90	10.99	11.89	11.63	11.95	12.21
11	11.59	13.27	12.41	11.90	12.95	12.17	15.25	13.87	13.81	13.87
12	15.10	14.15	14.52	14.38	15.53	16.25	16.38	14.87	15.69	18.06

	1993	1994
1	0.50	0.50
2	0.76	0.86
3	1.53	1.36
4	1.79	2.27
5	2.57	2.58
6	3.94	3.55
7	5.50	5.47
8	7.16	6.03
9	9.72	10.03
10	10.59	15.98
11	13.51	15.31
12	16.00	16.00

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

Age	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
2	0.95	5.90	4.85	1.10	4.93	2.40	4.57	0.47	1.66	3.72	1.49	3.03
3	2.62	2.25	2.67	1.67	0.37	0.00	2.12	3.47	0.70	1.08	1.52	1.76
4	1.50	1.50	0.95	0.81	0.72	0.00	1.66	1.63	1.95	0.44	0.66	1.03
5	0.93	1.23	0.97	0.23	0.38	1.08	0.28	1.56	0.73	1.07	0.10	0.30
6	0.58	0.45	0.50	0.40	0.17	0.33	0.31	0.20	0.49	0.34	0.19	0.02
7	0.24	0.32	0.34	0.29	0.14	0.13	0.03	0.28	0.09	0.29	0.03	0.13
8	0.00	0.04	0.19	0.14	0.20	0.19	0.02	0.04	0.08	0.07	0.05	0.05
9	0.05	0.04	0.10	0.06	0.05	0.04	0.05	0.03	0.01	0.03	0.00	0.04
10	0.02	0.02	0.01	0.01	0.03	0.00	0.03	0.00	0.01	0.00	0.00	0.00

Table 9. Statistical properties of population abundance and survey calibration constants for cod in Division 4X.

Population abundance

Age	PAR. EST.	STD. ERR.	REL. ERR.	BIAS	REL. BIAS
3	13598	7092	0.52	1898	0.14
4	5157	2434	0.47	490	0.09
5	2854	1481	0.52	301	0.11
6	193	170	0.88	62	0.32
7	115	49	0.43	0	0.00
8	204	123	0.60	30	0.15
9	78	42	0.54	9	0.11
10	108	46	0.42	8	0.07
11	56	37	0.67	8	0.14
12	40	26	0.67	5	0.13

July Survey calibration constants

Age	PAR. EST.	STD. ERR.	REL. ERR.	BIAS	REL. BIAS
2	0.1978	0.0301	0.1522	0.0012	0.0059
3	0.2030	0.0313	0.1545	0.0015	0.0072
4	0.2242	0.0343	0.1529	0.0016	0.0060
5	0.2690	0.0400	0.1485	0.0015	0.0072
6	0.2706	0.0397	0.1468	0.0021	0.0073
7	0.3217	0.0489	0.1521	0.0019	0.0057
8	0.3507	0.0582	0.1661	0.0048	0.0077
9	0.3294	0.0523	0.1587	0.0048	0.0060
10	0.2555	0.0474	0.1853	0.0043	0.0137

Table 10. Estimated bias adjusted population numbers (000s) at the beginning of the year for cod in Division 4X.

Age	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1	13904	18862	9937	27770	18366	26800	9218	12514	16341	13125
2	10812	11380	15408	8136	22735	15037	21942	7538	10245	13377
3	17123	8160	8590	11812	6528	17660	11914	17495	6078	8014
4	8485	10494	4526	5591	6840	4635	11748	7669	11980	3726
5	5643	5036	5658	2360	2583	3663	2289	6214	3805	5179
6	2616	2470	2454	2408	1113	1195	1611	1232	2643	1377
7	1211	1103	1187	960	1081	483	357	763	474	884
8	492	430	502	528	475	452	205	150	329	184
9	336	176	208	253	284	181	182	92	53	129
10	149	152	95	111	133	131	62	100	35	15
11	130	58	79	38	57	58	54	35	43	12
12	19	60	20	41	17	19	16	38	16	7
13	0	7	29	9	20	7	7	8	14	6
1+	60920	58388	48693	60015	60232	70322	59604	53846	52056	46035
2+	47016	39526	38756	32246	41866	43522	50386	41332	35715	32909
3+	36203	28145	23347	24110	19130	28485	28444	33795	25470	19532
4+	19080	19986	14757	12298	12602	10825	16530	16300	19392	11519

	1993	1994	1995
1	18095	16489	16500
2	10746	14815	13500
3	10373	8220	11700
4	3421	5586	4667
5	1168	1140	2553
6	1226	355	131
7	351	413	114
8	271	131	175
9	89	142	69
10	66	60	100
11	3	44	48
12	0	0	34
13	2	0	0
1+	45813	47396	49591
2+	27718	30907	33091
3+	16971	16091	19591
4+	6598	7871	7891

Table 11. Estimated population biomass (000 t) at the beginning of the year for cod in Division 4X.

Age	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1	3076	4865	2504	6800	6873	10283	3377	4868	5751	5309
2	5971	6666	8627	4421	13406	10575	15049	5061	6931	9501
3	18174	9194	9947	12195	7051	19613	14671	20167	6830	8482
4	13317	17133	7782	9131	11437	7675	20573	14067	20818	6022
5	12413	11325	12704	5371	6333	8874	5208	15966	9321	12759
6	8675	7806	7617	7598	3558	4264	5318	3894	8864	4564
7	5870	5267	5168	4039	5065	2186	1597	3600	2123	3833
8	3298	2805	3064	3212	2991	3025	1365	942	2114	1101
9	3053	1523	1635	2048	2343	1617	1635	853	468	1058
10	1617	1662	908	959	1411	1316	676	1077	383	167
11	1501	715	950	409	624	695	697	448	545	158
12	245	769	275	553	236	270	223	565	234	113
13	0	128	452	131	309	130	127	146	212	96
1+	77210	69857	61634	56868	61637	70522	70516	71654	64596	53165
2+	74134	64992	59130	50068	54764	60239	67139	66786	58844	47856
3+	68163	58326	50503	45647	41358	49664	52090	61725	51914	38355
4+	49989	49132	40556	33452	34307	30051	37419	41558	45084	29873

Age	1993	1994	1995
1	6899	6286	6418
2	6642	9715	8928
3	12884	8373	12944
4	5127	10416	7747
5	2567	2446	5793
6	4155	1071	423
7	1628	1919	518
8	1594	753	1027
9	705	1202	567
10	652	748	1107
11	44	565	618
12	2	2	522
13	47	2	2
1+	42945	43498	46615
2+	36046	37211	40196
3+	29404	27496	31268
4+	16520	19124	18324

Table 12. Estimated population biomass (000 t) at mid-year for cod in Division 4X.

Age	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1	4536	6489	3332	9564	8540	12461	4141	5818	7405	5948
2	7982	9454	11163	5827	18383	12932	18005	6165	8103	11917
3	18007	9242	9826	11758	8082	19551	15157	21103	6676	6777
4	12244	15688	6560	7385	11009	6235	19768	11792	16901	4148
5	10035	9808	9572	4358	5710	6775	4713	12121	6703	7991
6	7373	6693	5616	6554	2938	2786	4557	2871	6226	2938
7	4213	4136	4033	3460	4005	1704	1188	2863	1699	2512
8	2472	2329	2502	2938	2405	2397	1194	740	1585	846
9	2378	1223	1252	1773	1806	1121	1367	596	298	858
10	1104	1301	610	747	1072	955	559	786	259	97
11	1051	472	722	312	445	394	689	335	276	37
12	183	603	196	423	180	193	184	360	157	77
1+	71579	67439	55382	55099	64574	67502	71521	65548	56288	44146
2+	67043	60950	52049	45535	56035	55042	67380	59730	48883	38198
3+	59061	51496	40887	39708	37652	42110	49375	53566	40780	26280
4+	41054	42254	31061	27950	29570	22559	34217	32462	34104	19504

Age	1993	1994
1	8200	7472
2	7202	11349
3	11826	8524
4	3711	8809
5	1752	1200
6	2946	753
7	1226	1515
8	1427	583
9	714	1200
10	578	861
11	13	601
12	2	2
1+	39598	42869
2+	31398	35396
3+	24195	24048
4+	12370	15524

Table 13. Estimated bias adjusted fishing mortality for cod in Division 4X.

Age	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
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	0.08	0.08	0.07	0.02	0.05	0.03	0.03	0.02	0.05	0.05	0.07	0.04
3	0.29	0.39	0.23	0.35	0.14	0.21	0.24	0.18	0.29	0.65	0.42	0.37
4	0.32	0.42	0.45	0.57	0.42	0.51	0.44	0.50	0.64	0.96	0.90	0.58
5	0.63	0.52	0.65	0.55	0.57	0.62	0.42	0.66	0.82	1.24	0.99	1.97
6	0.66	0.53	0.74	0.60	0.63	1.01	0.55	0.76	0.89	1.17	0.89	0.93
7	0.83	0.59	0.61	0.50	0.67	0.66	0.67	0.64	0.75	0.98	0.79	0.66
8	0.83	0.53	0.48	0.42	0.77	0.71	0.60	0.84	0.74	0.53	0.45	0.44
9	0.59	0.42	0.43	0.45	0.57	0.88	0.40	0.77	1.04	0.46	0.19	0.15
10	0.74	0.45	0.72	0.46	0.63	0.69	0.37	0.64	0.84	1.28	0.20	0.02
11	0.58	0.87	0.44	0.58	0.92	1.09	0.16	0.59	1.59	4.41	3.15	0.05
12	0.71	0.53	0.63	0.53	0.66	0.79	0.52	0.75	0.81	0.96	0.00	0.00

Table 14. Projections for cod in Division 4X.

Beginning of year

Age	Population Biomass			Population Numbers			Weight		
	1995	1996	1997	1995	1996	1997	1995	1996	1997
1	6333	6333	6333	16500	16500	16500	0.38	0.38	0.38
2	8708	8714	8714	13500	13509	13509	0.65	0.65	0.65
3	13131	12114	12265	11700	10793	10928	1.12	1.12	1.12
4	7814	13209	13415	4667	7889	8012	1.67	1.67	1.67
5	5628	5943	11939	2553	2696	5417	2.20	2.20	2.20
6	420	4423	5812	131	1407	1807	3.22	3.22	3.22
7	526	331	4343	114	72	943	4.61	4.61	4.61
8	1020	367	282	175	54	48	5.84	5.84	5.84
9	567	790	346	69	96	42	8.21	8.21	8.21
10	1111	423	717	100	38	64	11.12	11.12	11.12
11	617	704	327	48	55	26	12.80	12.80	12.80
12	514	396	550	34	27	37	14.91	14.91	14.91
13	2	355	333	0	19	18	18.68	18.68	18.68
1+	46391	54203	65376	49591	53164	57351			
2+	40058	47870	59043	33091	36664	40851			
3+	31350	39156	50329	19591	23155	27342			
4+	18219	27042	38063	7891	12362	16414			

Mid-Year

Age	Population Biomass		Population Numbers		Weight	
	1995	1996	1995	1996	1995	1996
1	7477	7477	14955	14955	0.50	0.50
2	10616	10684	12096	12173	0.88	0.88
3	13354	12890	9670	9334	1.38	1.38
4	7116	13026	3592	6575	1.98	1.98
5	5164	5967	1923	2222	2.69	2.69
6	374	4408	98	1159	3.80	3.80
7	453	312	86	59	5.27	5.27
8	862	340	132	52	6.55	6.55
9	501	763	52	79	9.62	9.62
10	972	405	75	31	12.92	12.92
11	517	645	36	45	14.23	14.23
12	434	366	26	22	16.69	16.69
1+	47840	57284	42741	46708		
2+	40363	49806	27786	31753		
3+	29746	39122	15690	19580		
4+	16393	26233	6021	10246		

Table 14 (cont.).

Age	Catch Biomass		Catch Numbers		Fishing Mortality	
	1995	1996	1995	1996	1995	1996
1	0	0	0	0	0.00	0.00
2	252	128	288	146	0.02	0.01
3	2592	1263	1877	915	0.19	0.10
4	2481	2293	1252	1157	0.35	0.18
5	2046	1193	762	444	0.40	0.20
6	148	882	39	232	0.40	0.20
7	179	62	34	12	0.40	0.20
8	342	68	52	10	0.40	0.20
9	198	153	21	16	0.40	0.20
10	385	81	30	6	0.40	0.20
11	205	129	14	9	0.40	0.20
12	172	73	10	4	0.40	0.20
1+	9000	6325	4379	2952		
2+	9000	6325	4379	2952		
3+	8748	6197	4091	2806		
4+	6156	4934	2214	1891		

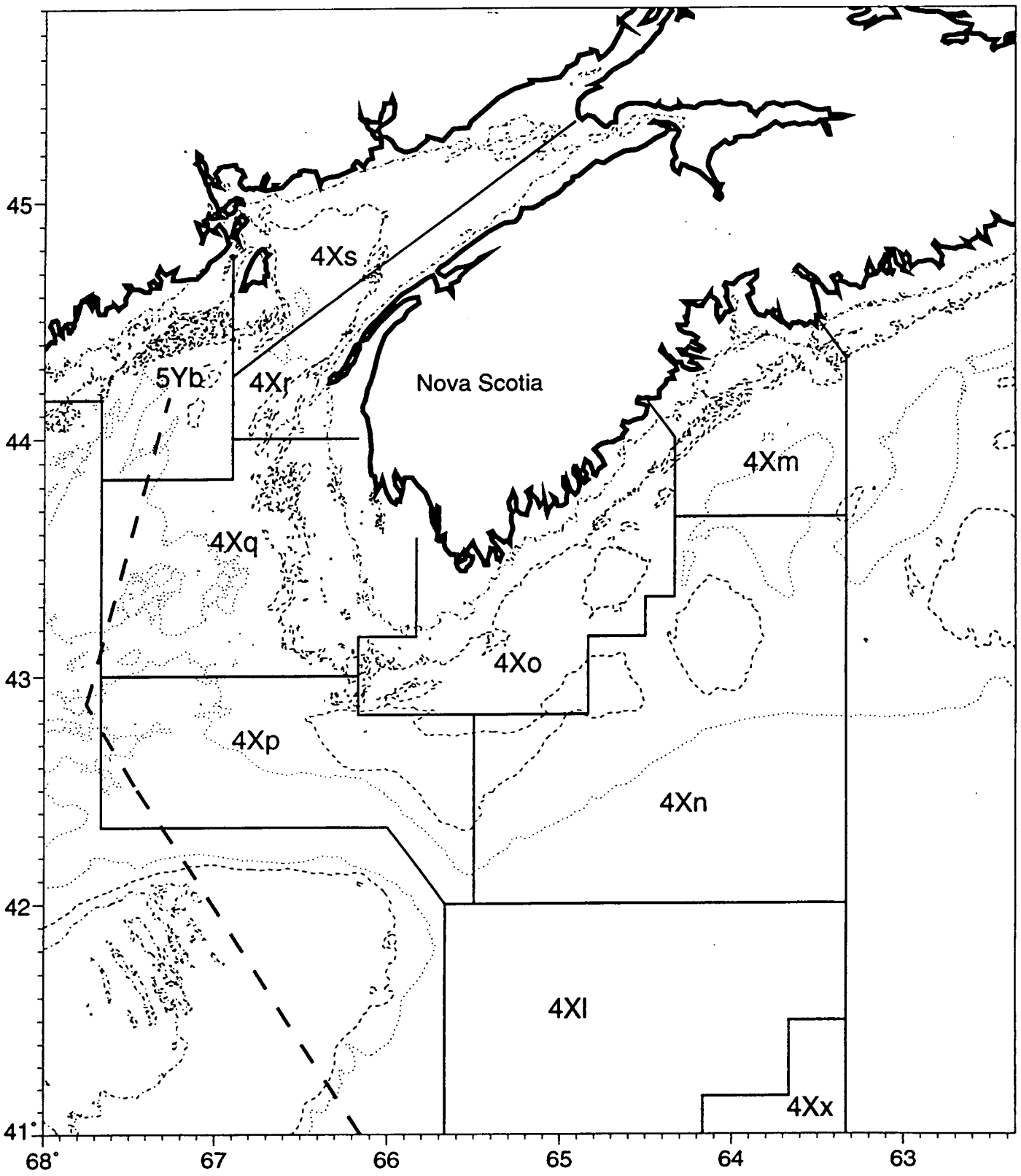

Fig. 1. Canadian fisheries statistical unit areas in NAFO Division 4X.

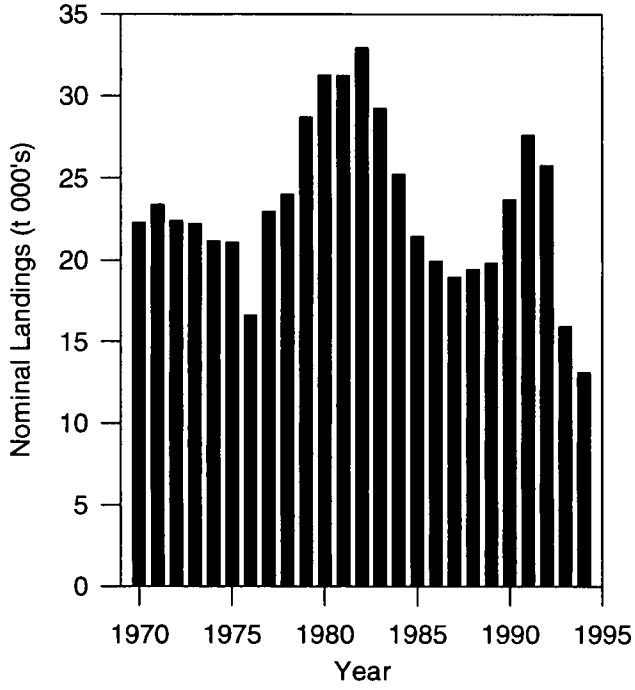

Fig. 2. Nominal landings of cod in Division 4X

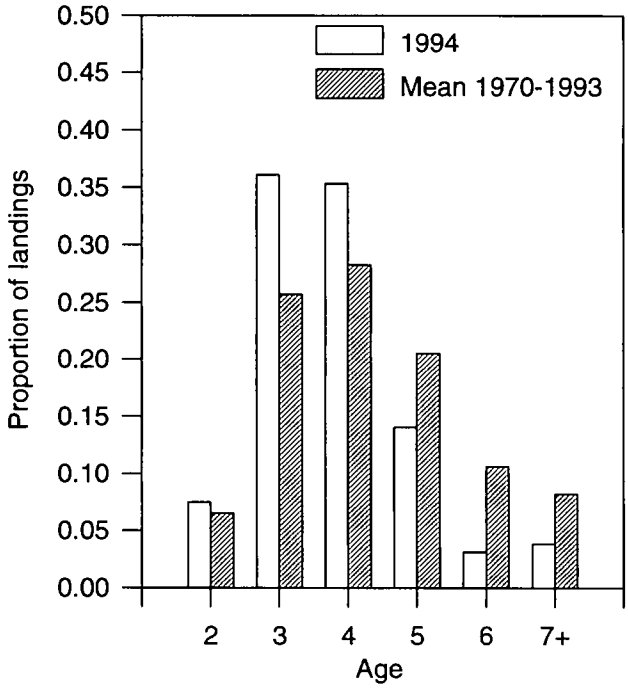

Fig. 3. Division 4X cod catch proportioned by age for 1994 compared to mean for 1983-1993.

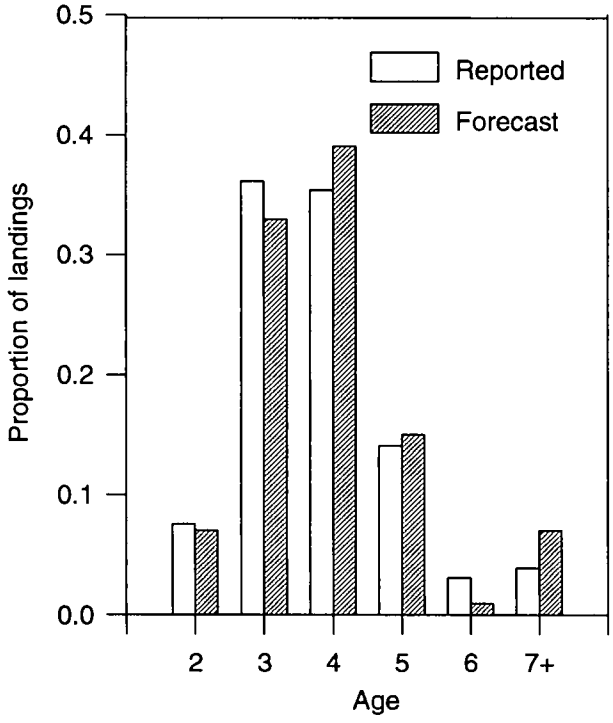

Fig. 4. Reported and forecast landings of cod in Division 4X for 1994 proportioned by age.

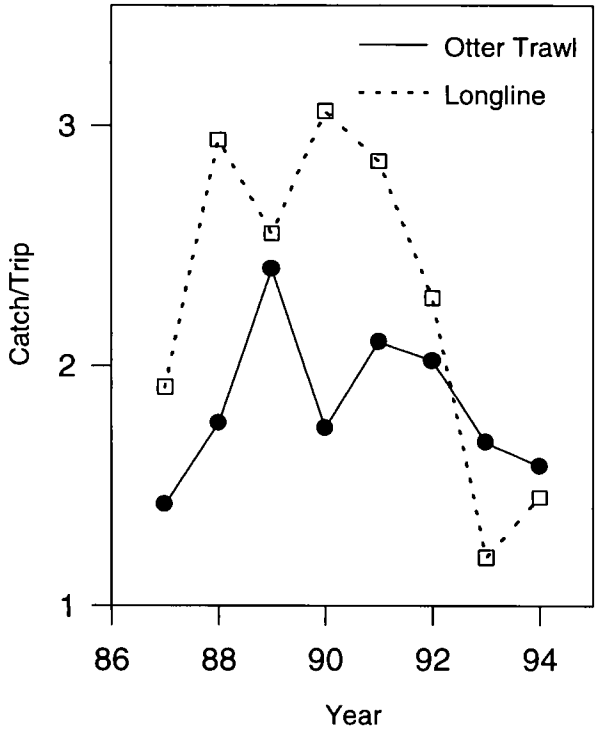

Fig. 5. Catch per unit effort for cod in Division 4X for the longline and otter trawl fisheries.

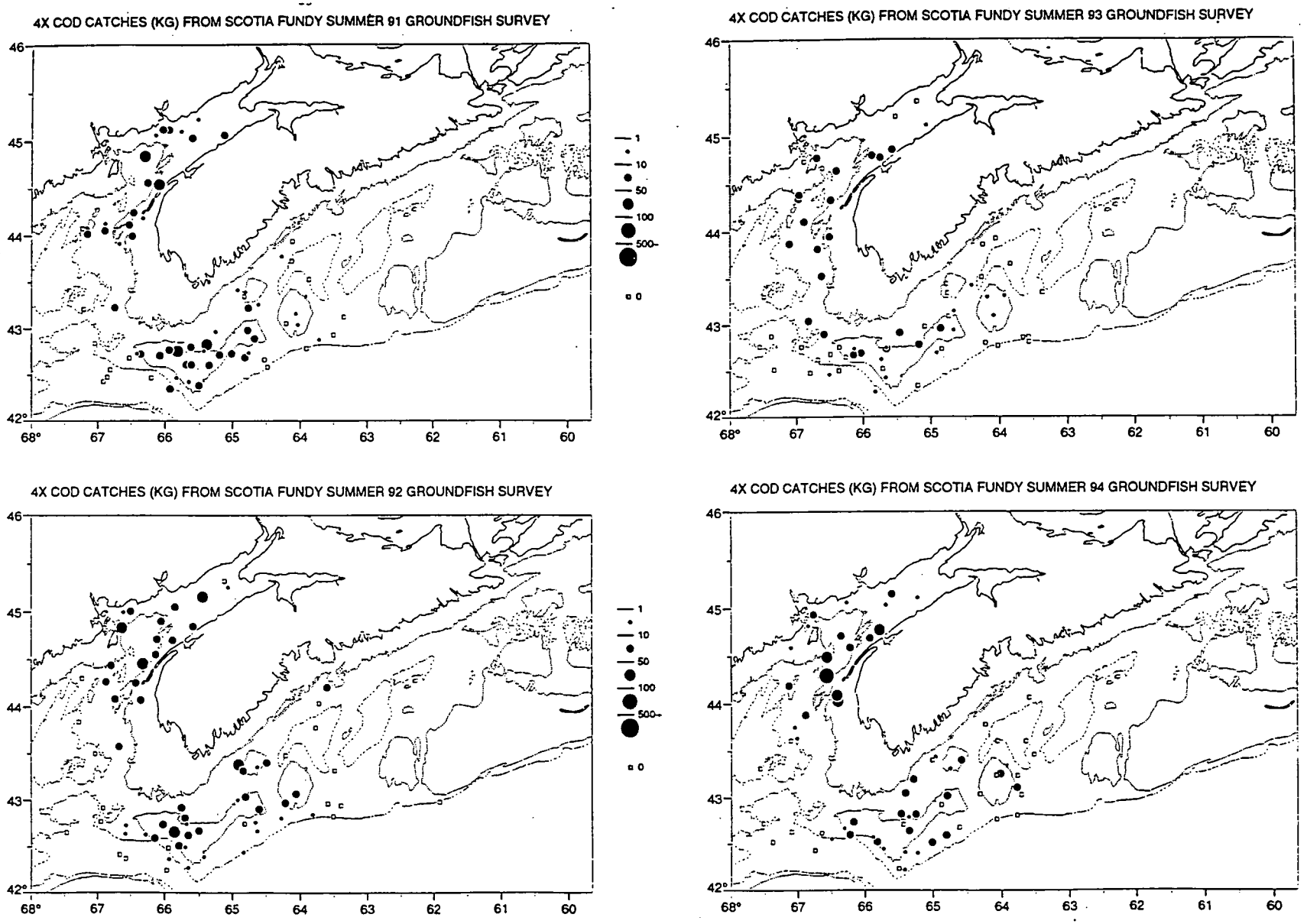

Fig. 6. Abundance plots for 4X cod from summer groundfish survey catches.

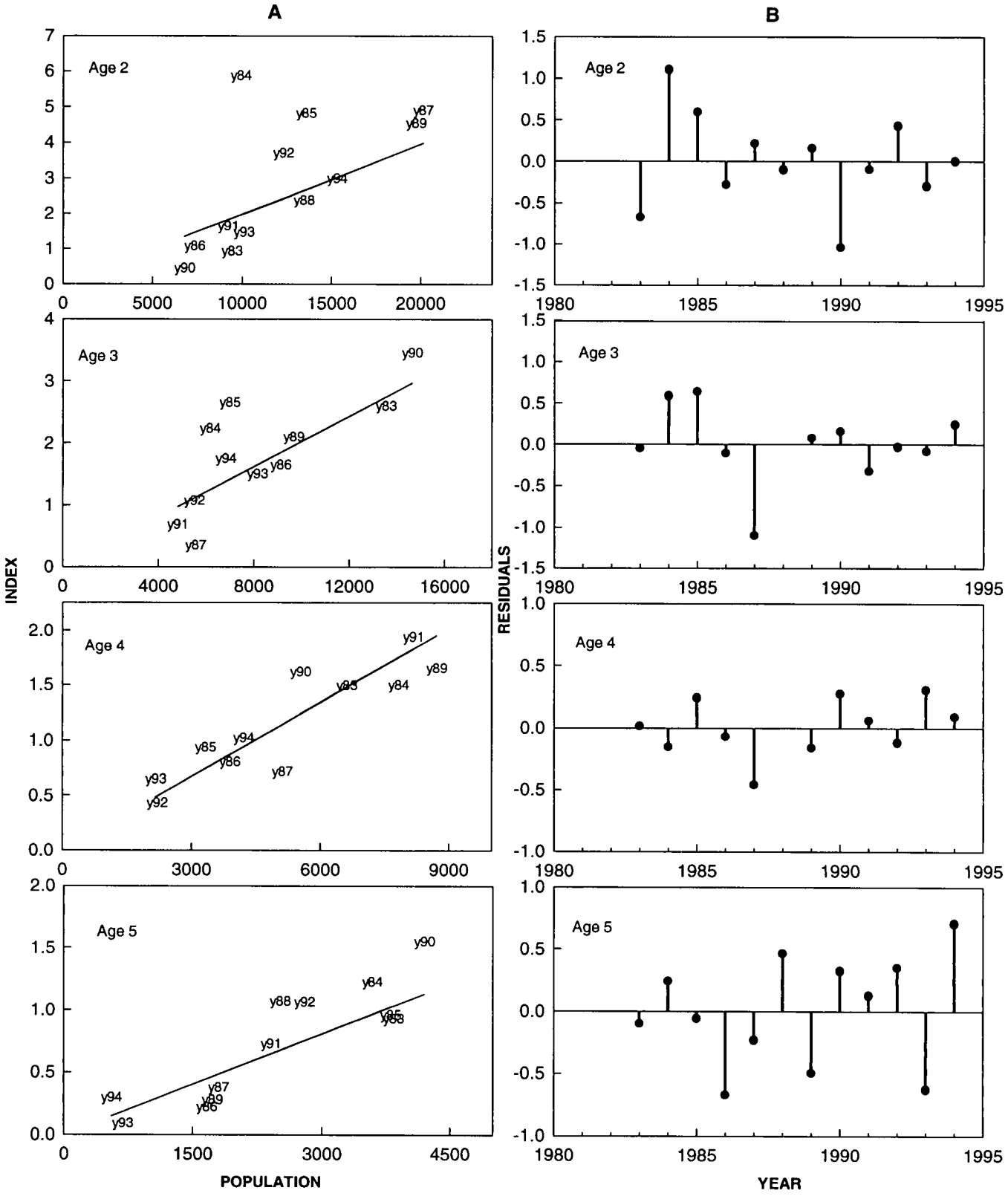

Fig. 7. Age by age plots of A) the observed and predicted abundance index versus population numbers and B) residuals plotted against year for the 1994 Canadian summer survey for cod in divisions 4X and 5Y.

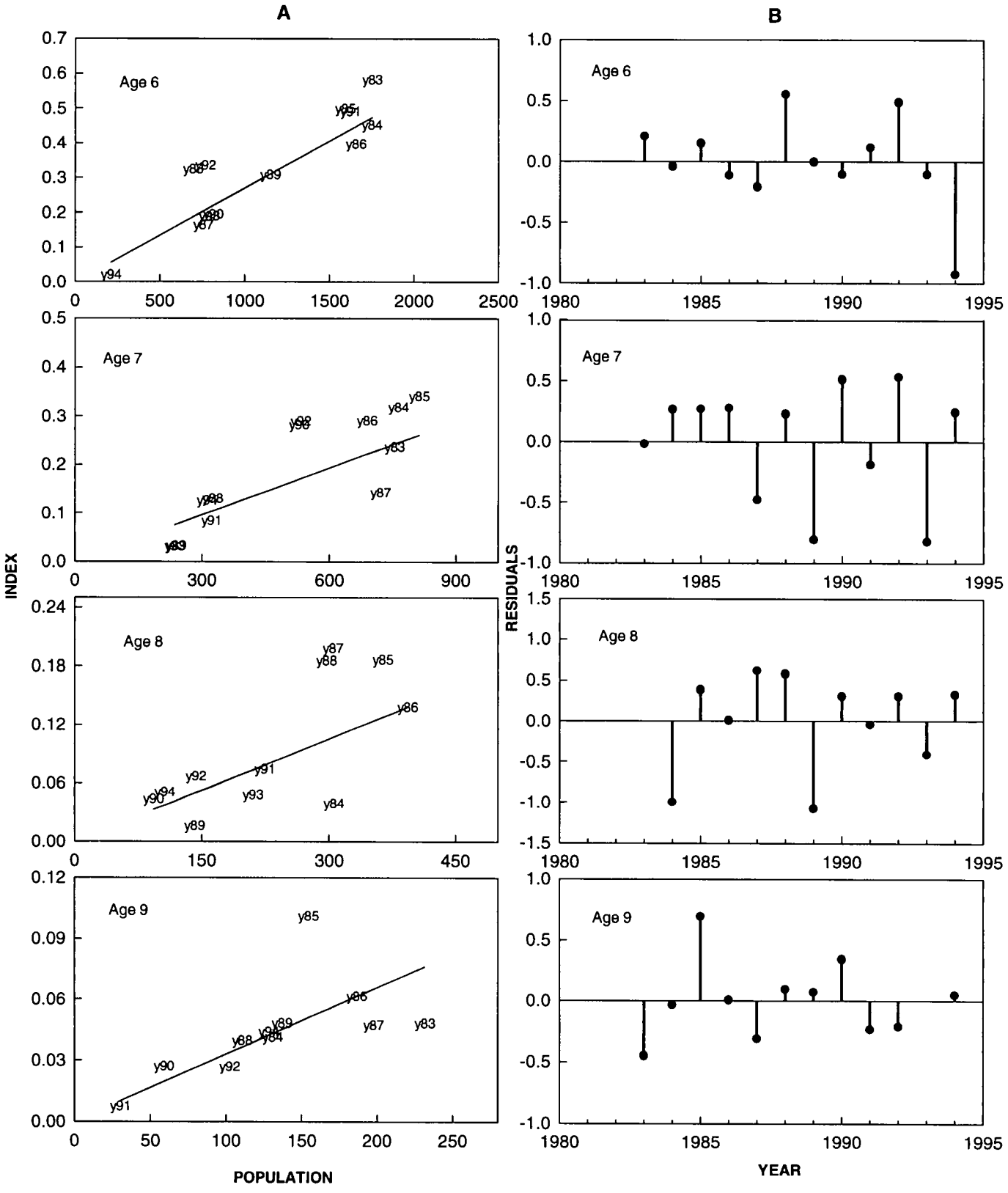

Fig. 7 (cont.). Age by age plots of A) the observed and predicted abundance index versus population numbers and B) residuals plotted against year for the 1994 Canadian summer survey for cod in divisions 4X and 5Y.

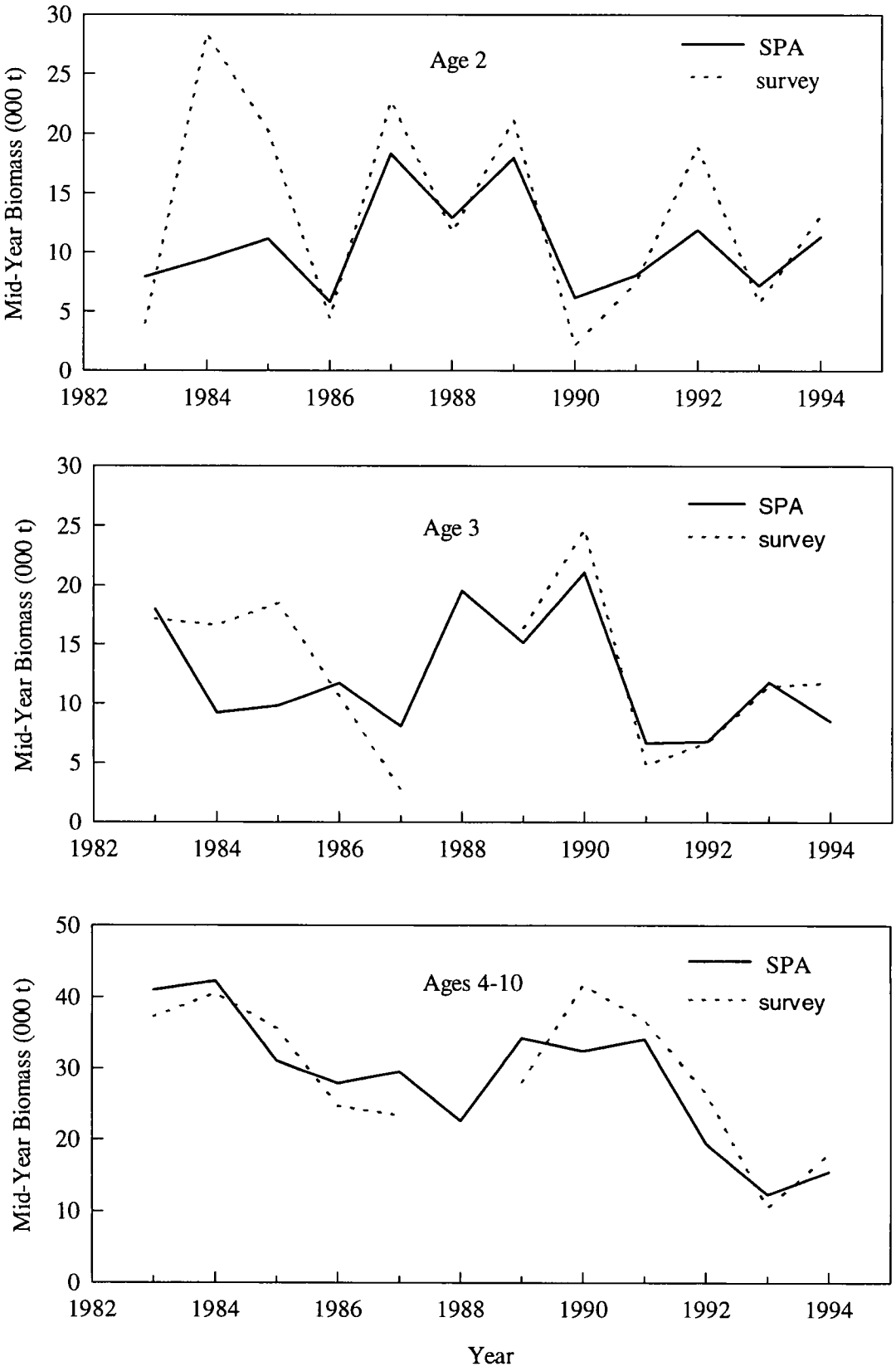

Fig. 8. Mid-year biomass from sequential population analysis (SPA) and research survey index (adjusted by calibration constants) for cod in Division 4X.

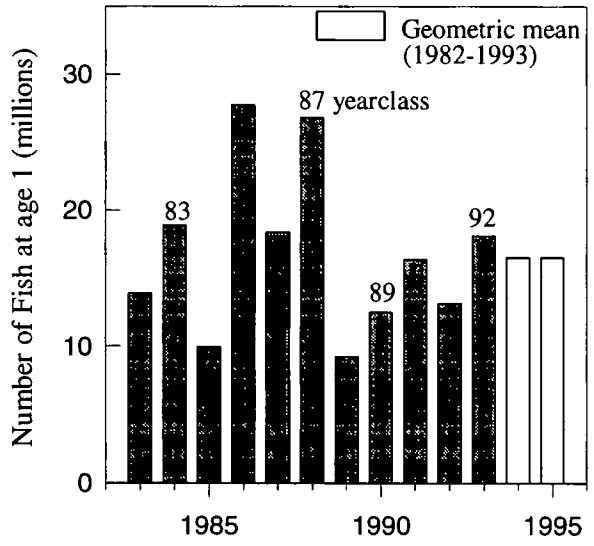

Fig. 9. Recruitment (age 1) for cod in Division 4X.

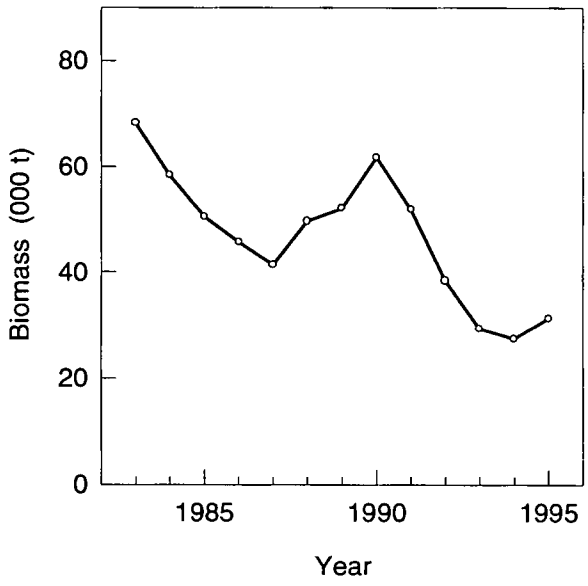

Fig. 10. Beginning of year biomass (3+) for cod in in Division 4X.

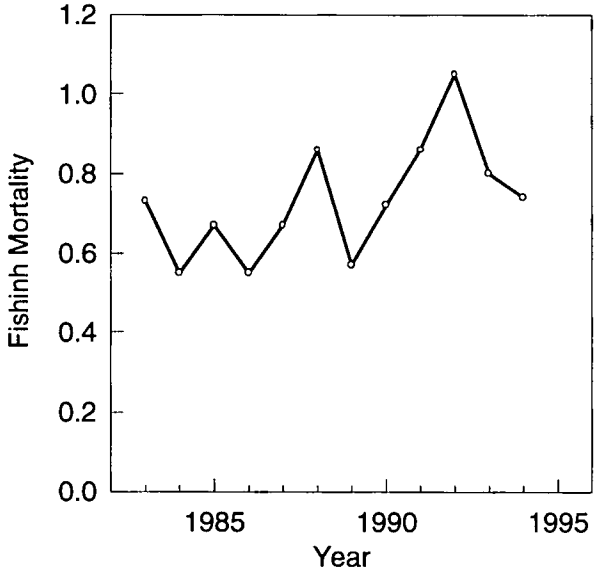

Fig. 11. Fishing mortality (5+) for cod in Division 4X.

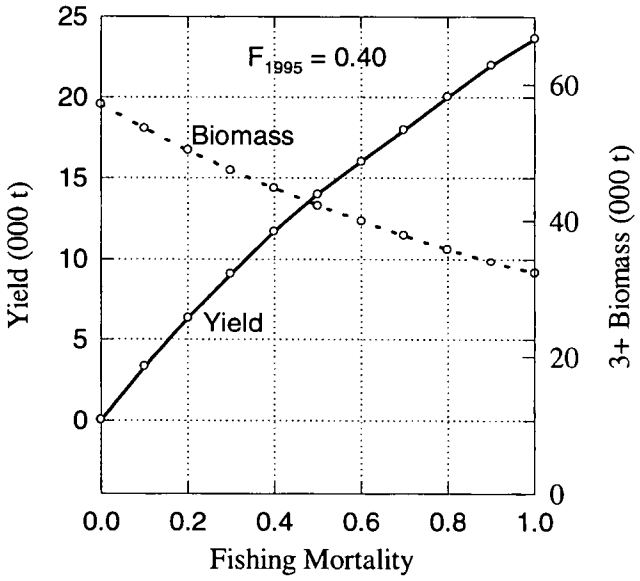

Fig. 12. Projected 4X cod yield for 1996 and beginning of year biomass in 1997.

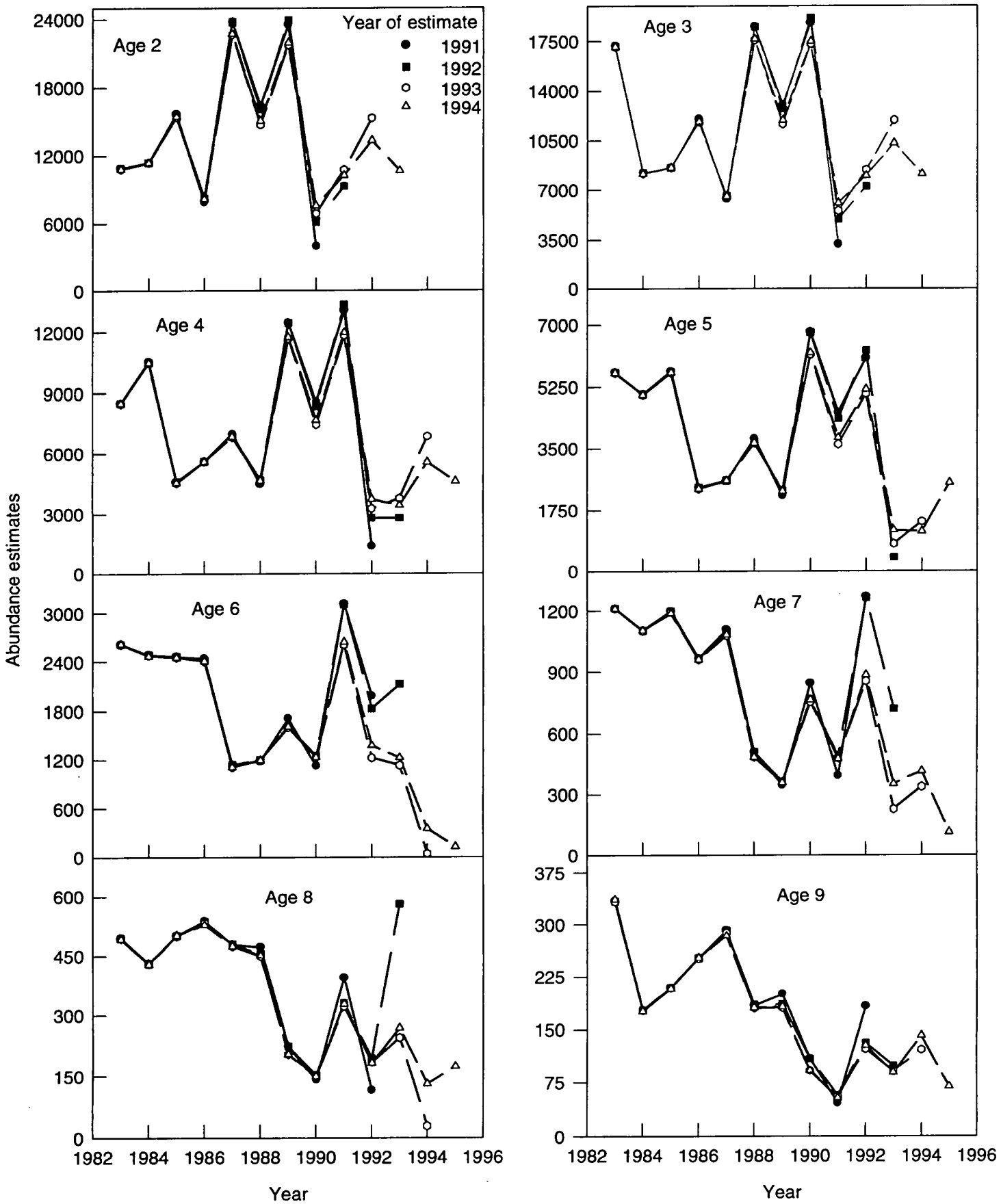

Fig. 13. Retrospective analysis of population abundance of cod in Division 4X.

Table 1. Comparison of ages from 2 independent readings by L. Brown of otoliths from the fourth quarter 4X cod commercial fishery.

First reading

Age	1	2	3	4	5	6	7	8	9	Omit	Tot
1											0
2		22	5								27
3		2	18	3							23
4			2	49	5						56
5				1	22	3				1	27
6						4					4
7						2	22	2			26
8								5			5
9								1	5		6
10									1		1
Omit					1					3	4
Tot	0	24	25	53	28	9	22	8	6	4	179

Agreement between readings = 85%