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Assessment of haddock in NAFO Division 5Z

by

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ABSTRACT

In 1985 and 1986, the Canadian landings were 3485 t and 3413 t, respectively, accounting for about half of the total catch. USA landings have declined substantially since 1984. The majority of the Canadian and USA catches in 1986 were comprised of 3-yr-old haddock, the 1983 year-class. Both Canadian and USA research surveys indicate that the 1985 year-class is larger than the average recent recruitment. The results of the assessment suggest that fishing mortality has been relatively high, about 0.3 to 0.5, for ages 3 and older. The abundance and biomass of the stock are at about the lowest level since 1963 and few older fish remain in the population.

RESUME

En 1985 et 1986, les débarquements canadiens ont été de 3 485 t et 3 413 t respectivement, représentant environ la moitié des prises totales. Les débarquements américains ont diminué notablement depuis 1984. En 1986, les prises canadiennes et américaines se composaient en majorité d'aiglefin de trois ans, c'est-à-dire de la classe d'âge 1983. Les recherches effectuées séparément par les Canadiens et les Américains permettent d'établir que l'effectif de la classe d'âge 1985 est supérieur au recrutement moyen enregistré récemment. Cela donne à penser que la mortalité due à la pêche a été relativement élevée, de 0,3 à 0,5 environ, parmi les poissons de trois ans et plus. Pour ce qui est de l'abondance et de la biomasse des stocks, les chiffres sont pratiquement à leur niveau le plus bas depuis 1963 et il ne reste que peu de poissons âgés dans la population.

DESCRIPTION OF THE FISHERY

Since the mid-1950's, the annual catches for this stock have ranged from about 4300 t in 1974 to 150,000 t in 1965. Peak catches in the mid-1960's occurred while foreign fleets were present (Table 1). Catches declined rapidly thereafter and since 1977, fishing has been conducted by only Canada and the USA. Over the period 1977-86, landings showed an initial increase followed by a decline. The total catch in 1986 (6751 t) was the lowest since 1976 and represents a 13% decrease from 1985. Statistics on catches were obtained from NAFO (ICNAF) Statistical Bulletins for years prior to and including 1984. Catch statistics for 1985-86 were obtained from the Department of Fisheries and Oceans, Canada and from the National Marine Fisheries Service, USA.

Canadian fishing activity has been concentrated on the northeast peak of Georges Bank and landings have accounted for about 25% of the total since 1963. In 1985 and 1986, the Canadian landings were 3485 t and 3413 t, respectively, representing about half the total catch. The majority of the Canadian catch has been taken during June-September and this pattern persisted in 1986 as well (Table 2). The Canadian catch in 1986 by otter trawlers was about four times the longliner catch (Table 3), similar to previous years (1984 excepted). Most of the otter trawl catch was due to tonnage class 3 stern trawlers in 1985 and 1986 (Table 4).

The USA catch declined by about 50% between 1984 and 1985, and a further 20% between 1985 and 1986. The catches in 1986 show that most of the shortfall occurred in the third quarter (Table 5). Gear composition of the fishery was similar to recent years, primarily tonnage classes 3 and 4 otter trawls (W. Overholtz, pers. comm.).

AGE COMPOSITION OF CATCH

Length frequency and age information were collected for 20 samples from the Canadian commercial fishery in 1986. This level of coverage is similar to that obtained in previous years and has been considered adequate; however, a greater number of samples would be desirable. Table 6 indicates how samples were combined to obtain statistics by age (Tables 7, 8) using the methods described by Gavaris and Gavaris (1983). The length-weight relationship,

$$\text{Weight(kg)} = 0.0000158 \text{ length(cm)}^{2.91612}$$

derived from the Canadian fishery samples (Waiwood and Neilson 1985), was used in these calculations. The USA age statistics provided by the National Marine Fisheries Service were combined with the Canadian statistics to obtain the total values (Table 8). The 1983 year-class was dominant in both countries fisheries and comprised over 70% of the total catch.

Due to computational error, the average length at age reported by Gavaris and Waiwood (1986) for the Canadian fishery were inflated by 0.5 cm. This error also had an impact on the average weight at age. The revised statistics are given in Table 9.

STOCK ABUNDANCE INDICES

Research Vessel Surveys

Groundfish surveys on Georges Bank have been conducted annually by National Marine Fisheries Service, USA since 1968 during the spring and since 1963 during the fall. Summer surveys have also been conducted but only during 1963-65, 1969 and 1977-80. The Department of Fisheries and Oceans, Canada has conducted surveys during the spring of 1986-87. The USA surveys have used a Yankee 36 trawl except for the spring 1973-81 surveys when a Yankee 41 was used. A new type of otter trawl door was introduced in 1985 for both spring and fall surveys; however, the impact of this change on the abundance index has not been quantified. The Canadian surveys have used a Western IIA trawl and the stratification scheme used for 1987 is shown in Fig. 1.

Trends in mean catch per tow from the spring and fall USA surveys (Tables 10, 11) are similar, showing an increase in abundance during the mid to late 1970's and a subsequent decline. Both the USA and Canadian surveys (Table 12) indicate relatively strong 1983 and 1985 year-classes. The abundance of the 1985 year-class in the USA fall survey of 1986, however, is not as high as expected from the previous year's results.

Commercial Fishery

Catch and effort statistics by month for the Canadian fishery, where haddock was designated main species, were derived from Table 5 of NAFO (ICNAF) Statistical Bulletin for 1966-84. Data for 1985 and 1986 were obtained from the Department of Fisheries and Oceans, Canada. Observations where either the catch was less than 10 t or the effort was less than 10 h were excluded; the observation for OTB2-3, March, 1966 was deleted and a weighted multiplicative analysis was applied following Gavaris and Waiwood (1986).

The analysis of variance from the weighted regression (Table 13) indicates that about 63% of the variation was explained by the model. Abundance trends in both the ln scale and the linear scale are presented in Table 14. The high levels in the catch rate index during the late 1970's (Fig. 2) probably reflect recruitment of the strong 1975 and 1978 year-classes.

ESTIMATION OF STOCK SIZE

Two methods were used to assess the status of the stock. The first involved the formulation of structural equations which provided predictions of the observed variables, and applying standard statistical estimation techniques to obtain estimates of population size. This class of models has recently been reviewed by Deriso et al. (1985). The second approach was similar to the method of calibrating a sequential population analysis used by Gavaris and Waiwood (1986).

For the statistical estimation technique, the size of the population at the beginning of the year in 1987 was estimated by minimizing the residual sum of squares, in the ln scale, of the catch at age and the USA fall survey abundance index. This abundance index has been considered the most reliable and is compared to population numbers at the beginning of the succeeding year. The other abundance indices will be discussed later. The survey mean catch per tow was scaled by a factor of 1000 so that these numbers would be of the same order of magnitude as the catch at age.

Specifically, the function being minimized was:

$$(1) \quad \sum_{i=2}^{4+} \sum_{j=1964}^{1986} (\ln c_{ij} - \ln \hat{c}_{ij})^2 + \sum_{i=1}^{4+} \sum_{j=1963}^{1986} (\ln a_{ij} - \ln \hat{a}_{ij})^2$$

where c = observed catch
$\hat{c}$ = predicted catch
a = observed abundance index
$\hat{a}$ = predicted abundance index
i = index for age
j = index for year

There were five occurrences of zero observations (Table 11) of the abundance index. The following interpolated values were used when taking logarithms:

1969	age 3	- 0.02
1971	age 1	- 0.025
1972	age 2	- 0.02
1982	age 1	- 0.2
1986	age 0	- 0.01

The predicted catch and abundance index are functions of the model parameters Θ, cohort size at some designated age group (Fig. 3), ϕ, fishing mortalities and κ, the calibration coefficients. Given Θ and ϕ, the population numbers at age can be calculated by:

$$(2) \quad P_{ij} = P_{i+1,j+1}\exp[\phi_{ij} + M]$$

where P = population numbers
M = natural mortality (assumed to be 0.2)

Note that for convenience the parameters Θ are included in the population matrix P. The predicted catch at age was then obtained using the catch equation:

$$(3) \quad \hat{c}_{ij} = (\phi_{ij}P_{ij}(1 - \exp[-\phi_{ij} + M])) \ / \ (\phi_{ij} + M)$$

The predicted abundance index was obtained from the relationship:

$$(4) \quad \hat{a}_{ij} = \kappa_{1i} + \kappa_{2i}P_{ij}$$

The catch at age 1 (Table 15) was generally small and probably unreliable, reflecting low fishing mortality; therefore, the fishing mortality at age 1 was not estimated. A fixed vector of fishing mortalities at age 1, consistent with small catch, was used in equation 2 and age 1 was not included in minimizing the sum of squares of residuals for the catch in equation 1.

Equation 1 was minimized using a Marquardt algorithm with a penalty function (Bard 1974) constraining parameters as follows:

$$(5) \quad \begin{aligned} 0 < \Theta &< 1000000 \\ 0 < \phi &< 1.5 \\ -9999 < \kappa &< 9999 \end{aligned}$$

For the final iteration, the constraints were removed as recommended. As has been past practice, the calibration to the abundance index was done by age for ages 1 to 3 and a 4+ index was used for older ages. To minimize the number of parameters being estimated, the population numbers were only estimated for similar age groups. The results of the final iteration from this estimation procedure are shown in Table 16. The residuals (Table 17, Fig. 4a-d) demonstrate the tradeoffs between errors in catch and errors in abundance indices.

For the calibration approach, sequential population analysis (SPA), assuming a natural mortality of 0.2, was conducted using the catch at age in Table 15. Using a logarithmic transformation to stabilize variances and permitting an additive constant in the relationship, population numbers and the abundance index were compared using:

$$(6) \quad \ln Y_{ij} = \ln(\alpha X_i + \beta X_i \gamma_0 \prod_j \gamma_j X_j) + \varepsilon_{ij}$$

where Y = observed index value or SPA value
i = index for source, i.e. survey index or SPA
j = index for year
α = scaling factor (additive constant)
β = relative source effect (proportionality constant)
X = indicator variables taking values of 0 or 1
γ_0 = reference mean
γ = relative year effect
ε = error.

The minimum sum of squares of residuals for the relationship of ln SPA 4+ numbers and ln 3+ survey index was obtained with a fishing mortality of 0.55 (Table 18; Fig. 5a). The relationships for ages 3, 2 and 1 were examined to establish the strengths of the 1983-85 year-classes (Fig. 5b-d). The residuals were "balanced" with fishing mortalities in 1986 of 0.0002, .05, and .45 for ages 1-3, respectively (Table 18). The 1986 year-class was set at 384 thousand fish, the smallest observed value since 1964, since the observed abundance index for this year-class was zero. The population numbers and fishing mortalities from this SPA are shown in Table 19. These results are similar to those obtained with the estimation method described above.

Though the spring and fall USA surveys show similar trends, there is some concern regarding the fact that the spring index is highest between 1973 and 1981, the period when a different trawl was used. Consequently, this index was not used for estimation of population size. The Canadian survey series is not long enough to be used for estimation of population size; however, the total mortality estimate for the 1983 year-class from these data was 0.71, implying a fishing mortality of about 0.5, a value which is not inconsistent with the results given above.

The catch rate index is suspect due to changes in exploitation patterns of this fishery both in 1977 with the extension of jurisdiction of coastal states and in 1985 with the establishment of the international boundary between Canada and USA. There is also concern about changes in efficiency of the fleet associated with the large number of new vessels introduced during the late 1970's. Furthermore, there would be complications in obtaining a historical partial recruitment pattern for the Canadian fishery only on which the catch rate index is based. Although this index was not used explicitly, the average weight at age (Table 20) was applied to obtain the average annual biomass to which it was compared (Fig. 6).

ASSESSMENT RESULTS

Stock abundance and biomass are amongst the lowest observed since 1963. The population in 1987 is comprised primarily of the 1983 and 1985 year-classes with few older fish remaining. With the addition of information from the fall USA survey, the 1985 year-class was estimated at about 33 million fish at age 1 compared to the previous estimate of about 63 million fish. Estimated size of other year-classes was comparable to previous values. In recent years, this stock has been exploited at about twice the $F_{0.1}$ level (0.26) and recruitment has been variable but generally poor.

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Table 1. Nominal catches (t) of haddock from NAFO Division 5Z. Data were obtained from ICNAF/NAFO for 1956-84 and from NMFS and DFO for 1985-86.

Year	USA	Canada	USSR	Spain	Others	Total
1956	51144	0	0	0	0	51144
1957	48561	0	0	0	0	48561
1958	37322	0	0	0	0	37322
1959	36051	0	0	0	0	36051
1960	40800	77	0	0	0	40877
1961	46384	266	0	0	0	46650
1962	49409	3461	1134	0	0	54004
1963	44150	8379	2317	0	0	54846
1964	46512	11625	5483	2	464	64086
1965	52823	14889	81882	10	758	150362
1966	52918	18292	48409	1111	544	121274
1967	34728	13040	2316	1355	30	51469
1968	25469	9223	1397	3014	1318	40421
1969	16456	3990	66	1201	470	22183
1970	8415	1978	103	782	7	11285
1971	7306	1630	374	1310	242	10862
1972	3869	609	137	1098	20	5733
1973	2777	1563	602	386	3	5331
1974	2396	462	109	764	559	4290*
1975	3989	1358	8	61	4	5420
1976	2904	1361	4	46	9	4324
1977	7934	2909	0	0	0	10843*
1978	12160	10179	0	0	0	22339*
1979	14279	5182	0	0	0	19461
1980	17470	10101	0	0	0	27571*
1981	19245	5659	0	0	3	24907
1982	12622	4931	0	0	0	17553
1983	8680	3212	0	0	0	11892
1984	8806	1463	0	0	0	10269
1985	4272	3485	0	0	0	7757
1986	3338	3413	0	0	0	6751

* Values adjusted for discards are 6190, 20531, 26281, and 51084 for 1974, 1977, 1978, and 1980 respectively.

Table 2. Monthly catch of haddock by Canada in NAFO Division 5Z for 1968-1986.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1968	337	510	990	2337	760	352	693	1240	941	904	120	139	9323
1969	106	73	6	291	587	691	559	607	553	364	119	34	3990
1970	10	105	0	1	576	345	104	456	241	103	25	12	1978
1971	0	9	2	0	400	153	283	279	97	246	140	21	1630
1972	0	118	2	0	4	112	87	116	91	70	9	0	609
1973	4	10	0	0	0	183	198	569	339	233	23	4	1563
1974	19	0	1	0	0	57	64	52	96	60	93	20	462
1975	5	14	0	0	0	167	257	482	104	167	117	45	1358
1976	0	8	61	68	61	595	152	188	186	26	9	7	1361
1977	102	176	6	0	23	519	1098	836	12	58	56	23	2909
1978	103	932	44	21	22	319	407	86	640	5605	2000	0	10179
1979	125	898	398	175	69	1393	905	395	488	261	53	22	5182
1980	39	134	13	33	225	2957	2299	963	1419	1739	103	177	10101
1981	38	482	568	4	254	1354	1242	727	292	82	378	238	5659
1982	131	309	1	12	45	1118	767	684	582	838	400	44	4931
1983	31	67	28	46	60	1288	386	489	527	194	90	6	3212
1984	3	5	80	89	73	433	218	255	212	70	25	0	1463
1985	1	11	33	99	26	354	392	1103	718	594	61	93	3485
1986	11	28	77	99	40	1339	1059	369	233	139	12	8	3413

Table 3. Canadian catch of haddock in NAFO Division 5Z by gear for 1968-1986.

Year	OT	LL	MISC.	Total
1968	9170	111	11	9292
1969	3955	22	13	3990
1970	1900	76	2	1978
1971	1475	154	1	1630
1972	411	198	0	609
1973	1461	102	0	1563
1974	374	87	1	462
1975	1247	111	0	1358
1976	1185	154	15	1354
1977	2814	94	1	2909
1978	9716	171	292	10179
1979	4907	274	1	5182
1980	9510	590	1	10101
1981	4644	1015	0	5659
1982	4222	709	0	4931
1983	2396	813	3	3212
1984	624	838	1	1463
1985	2817	626	42	3485
1986	2786	592	35	3413

Table 4. Canadian otter trawl catch of haddock in NAFO Division 5Z by tonnage class.

	Side				Stern			
Year	2	3	4	5	2	3	4	5
1968	0	176	3463	0	0	0	580	5041 *
1969	1	8	792	0	0	1	225	2928
1970	0	25	553	0	2	0	134	1186
1971	0	0	494	0	0	0	16	965
1972	0	0	0	0	0	0	148	263
1973	0	25	609	0	0	0	61	766
1974	0	0	26	0	0	6	8	334
1975	0	0	223	0	0	1	60	963
1976	0	1	192	23	0	0	61	908
1977	5	47	358	0	91	243	18	2052
1978	69	17	2485	0	238	822	351	5734
1979	12	116	1573	0	135	855	651	1565
1980	9	16	1426	1	354	365	1016	6323
1981	4	87	389	0	448	484	884	2348
1982	1	25	90	0	190	297	250	3359
1983	16	89	0	0	618	432	107	1134
1984	0	5	0	0	181	269	21	148
1985	0	72	0	0	840	1402	155	348
1986	4	48	0	0	829	1378	96	432

* 1165 t shown as stern tonnage class 2 in the Statistical Bulletin was included with tonnage class 5 pers. com. G. Moulton, NAFO

Table 5. Monthly catch of haddock by USA in NAFO Division 5Z for 1968-1986.

Year	NK	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1968	0	1680	1756	3023	2381	2499	2750	2696	2261	2372	1971	1376	704	25469
1969	0	990	909	1617	2422	1688	2329	1357	1466	1392	1119	630	537	16456
1970	0	480	419	409	634	1230	1328	1090	822	747	803	245	208	8415
1971	0	305	476	640	719	1148	1075	670	546	556	543	401	227	7306
1972	0	246	308	273	282	632	561	382	371	236	262	158	158	3869
1973	0	180	165	136	179	338	537	329	269	134	253	129	128	2777
1974	0	190	130	138	212	298	327	349	197	125	155	98	177	2396
1975	20	237	201	142	234	569	849	316	351	359	295	236	180	3989
1976	18	187	226	224	277	534	350	132	167	221	166	238	164	2904
1977	50	237	369	361	382	743	902	1017	829	572	773	955	744	7934
1978	53	535	735	675	977	1313	2061	1249	1287	973	1140	914	248	12160
1979	61	757	637	777	1355	1844	1748	1553	1485	1170	1081	1284	527	14279
1980	84	1006	1393	1130	1705	2319	1583	2060	1554	1769	977	1045	845	17470
1981	68	1190	2373	1436	1528	2650	2586	1976	1635	1273	1006	774	750	19245
1982	25	829	1163	752	772	1416	2416	1624	693	1047	707	725	453	12622
1983	30	869	1075	387	759	864	1674	737	590	511	341	484	359	8680
1984	0	832	1157	583	599	1105	1570	735	747	523	412	271	272	8806
1985	0	262	281	367	534	681	710	443	349	226	170	134	115	4272
1986			1071			1648			391			229		3338

data provided by W. J. Overholtz

Table 6. Length frequencies sampled from the Canadian commercial fishery for haddock in NAFO Division 5Z were applied to the weight indicated. The manner in which statistics were pooled is shown by braces. The numbers in brackets are the numbers of age interpretations for age length keys.

Gear	Month	Number measured	Weight(t)		
OT	Jan	-	10.2		
	Feb	-	9.5		
	Mar	-	-		
	Apr	-	78.1		
	May	-	25.3		
	Jun	2017	1313.0	1436.2(272)	
	Jul	861	996.7		
	Aug	606	278.8		
	Sep	202	40.2		
	Oct	-	17.2		
	Nov	-	8.7		
	Dec	-	7.7	1349.5(197)	
LL	Jan	-	-		
	Feb	-	16.3		
	Mar	-	68.4		
	Apr	-	13.8		
	May	-	11.7		
	Jun	-	24.4		
	Jul	-	55.7		
	Aug	-	88.6		
	Sep		189.6		
	Oct	586	120.4		
	Nov	-	2.9	591.9(107)	
	Dec	-	-		
Misc				35.4	3412.9

Table 7. Age compositions (000's) for components of the haddock fishery in NAFO Division 5Z during 1986.

Age	a	b	c	d	e	f
1	0	4	2	0	0	0
2	0	4	33	0	7	1
3	101	843	748	215	734	122
4	13	61	10	58	48	19
5	29	25	16	29	53	16
6	20	20	11	38	38	34
7	15	9	3	68	48	13
8	17	8	12	92	108	33
9+	15	1	4	13	9	4

a. Can LL Jan-Dec
b. Can OT Jan-Jun
c. Can OT Jul-Dec
d. USA Jan-Mar
e. USA Apr-Jun
f. USA Jul-Dec

USA data provided by W. J. Overholtz

Table 8. Statistics by age of mean number caught (000's), average length and average weight for the 1986 commercial haddock fishery in NAFO Division 5Z.

Canada

Age	Average Weight	Average Length	Catch Mean	Catch Std Err	Catch CV
1	0.452	33.652	6	0.848	0.148
2	0.981	43.804	38	10.798	0.287
3	1.460	50.134	1710	25.362	0.015
4	2.085	56.096	85	17.756	0.208
5	2.901	63.343	71	11.123	0.158
6	2.889	62.676	51	11.475	0.223
7	3.638	68.605	28	5.778	0.206
8	4.230	72.228	38	6.666	0.175
9	3.442	67.043	3	1.427	0.566
10	3.752	69.002	9	4.078	0.448
11	4.388	73.464	9	4.817	0.539

USA

Age	Average Weight	Average Length	Catch
1			
2	0.832	43.155	8
3	1.242	49.572	1071
4	1.673	54.423	125
5	2.065	58.634	98
6	2.849	65.778	110
7	2.910	66.456	129
8	3.427	70.333	234
9	4.039	74.098	22
10	4.822	78.569	3

Total

Age	Average Weight	Average Length	Catch
1	0.452	33.652	6
2	0.955	43.691	46
3	1.376	49.918	2782
4	1.840	55.102	211
5	2.416	60.610	168
6	2.862	64.789	161
7	3.041	66.841	157
8	3.540	70.598	272
9	3.977	73.362	24
10	4.043	71.605	12
11	4.388	73.464	9

USA data provided by W. J. Overholtz

Table 9. Statistics by age of mean number caught (000's), average length and average weight for the 1985 commercial haddock fishery in NAFO Division 5Z.

Canada

Age	Average Weight	Average Length	Catch Mean	Catch Std Err	Catch CV
1					
2	0.949	43.264	2005	61.266	0.031
3	1.267	47.618	305	57.443	0.188
4	2.074	56.191	115	19.546	0.170
5	2.170	56.803	90	11.712	0.130
6	2.941	63.563	56	7.992	0.143
7	3.279	66.269	88	8.326	0.094
8	3.206	65.556	22	4.671	0.209
9	3.700	68.958	18	3.831	0.211
10	3.952	70.588	17	3.637	0.218
11	3.641	68.441	23	4.651	0.200
12	4.992	76.834	2	0.817	0.511
13	4.235	72.547	2	1.384	0.731
14	5.704	80.500		0.001	0.009
15					
16	5.704	80.500		0.289	1.026

USA

Age	Average Weight	Average Length	Catch
1			
2	1.161	48.129	323
3	1.249	49.384	266
4	1.730	55.642	110
5	2.485	62.862	223
6	2.822	65.734	120
7	2.992	67.270	568
8	3.632	71.845	68
9	3.806	72.989	31
10	4.272	75.546	46
11	3.535	72.114	16
12	5.667	82.990	2
13	3.569	72.500	14
14	4.168	76.500	5

Table 9. continued

Total	Average		
Age	Weight	Length	Catch
1			
2	0.979	43.939	2328
3	1.259	48.440	571
4	1.906	55.922	225
5	2.395	61.120	313
6	2.860	65.045	176
7	3.031	67.135	656
8	3.527	70.294	91
9	3.767	71.516	50
10	4.186	74.221	62
11	3.598	69.916	39
12	5.403	80.587	4
13	3.648	72.506	16
14	4.197	76.577	6
15			
16	5.704	80.500	

USA data provided by W. J. Overholtz

Table 10. Stratified mean catch per tow at age (numbers) for haddock on Georges Bank from the spring USA surveys. From 1973-81 a 41 Yankee trawl was used while a 36 Yankee was used in other years.

Age	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
1	0.27	0.00	0.45	0.00	2.70	20.59	1.43	0.63	54.22	0.41
2	1.90	0.05	0.17	0.78	0.06	3.25	8.92	0.65	0.20	22.42
3	0.31	0.39	0.00	0.17	0.41	0.00	1.92	2.23	0.40	0.28
4	0.47	0.17	0.22	0.00	0.08	0.36	0.00	0.42	0.62	0.82
5	4.51	0.28	0.31	0.08	0.02	0.06	0.16	0.00	0.29	0.40
6	1.13	2.84	0.31	0.08	0.03	0.00	0.00	0.09	0.00	0.30
7	0.17	0.69	1.34	0.06	0.09	0.12	0.01	0.06	0.03	0.00
8	0.30	0.19	0.66	0.55	0.02	0.01	0.07	0.01	0.00	0.03
9+	0.23	0.31	0.57	0.15	0.87	0.86	0.25	0.10	0.07	0.08

Age	1978	1979	1980	1981	1982	1983	1984	1985	1986
1	0.05	24.24	3.49	2.70	0.62	0.29	1.40	0.00	2.49
2	0.65	1.06	31.34	2.69	1.25	0.37	0.79	4.96	0.17
3	10.69	0.76	0.34	15.95	0.77	0.39	0.43	0.76	2.06
4	0.24	3.83	0.70	1.79	3.33	0.15	0.42	0.40	0.24
5	0.63	0.22	3.27	0.62	0.34	1.62	0.39	0.87	0.11
6	0.55	0.11	0.45	1.46	0.23	0.01	0.48	0.34	0.21
7	0.11	0.25	0.25	0.20	0.50	0.03	0.05	1.17	0.12
8	0.04	0.04	0.31	0.09	0.00	0.78	0.03	0.10	0.33
9+	0.07	0.03	0.16	0.04	0.00	0.12	0.20	0.25	0.11

modified from Overholtz et.al. 1983
data for 1983-86 supplied by W. J. Overholtz

Table 11. Stratified mean catch per tow at age (numbers) for haddock on Georges Bank from the fall USA surveys.

Age	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
0	56.33	1.59	0.22	4.12	0.02	0.06	0.26	0.03	1.63	4.53
1	17.04	75.75	6.82	0.64	4.51	0.04	0.02	2.77	0.00	1.69
2	6.19	42.78	51.94	1.94	0.24	0.64	0.00	0.14	0.21	0.00
3	4.57	3.91	6.51	12.34	0.67	0.09	0.19	0.01	0.05	0.35
4	5.60	1.20	0.72	2.25	4.54	0.22	0.09	0.19	0.01	0.06
5	3.99	2.56	0.54	0.35	1.09	2.59	0.11	0.18	0.15	0.00
6	1.37	1.05	0.61	0.33	0.33	0.85	1.02	0.34	0.02	0.06
7	1.13	0.46	0.54	0.22	0.14	0.18	0.34	0.92	0.06	0.04
8	0.79	0.17	0.17	0.08	0.22	0.11	0.06	0.32	0.50	0.02
9+	0.31	0.22	0.18	0.05	0.12	0.26	0.18	0.27	0.19	0.87

Age	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
0	2.17	0.50	15.76	2.90	0.11	10.82	1.08	9.56	0.31	0.89
1	6.04	1.19	0.42	43.07	1.75	0.69	37.29	2.22	5.02	0.00
2	1.08	0.66	0.48	0.35	15.33	0.85	0.03	10.41	1.70	0.74
3	0.00	0.21	3.26	0.36	0.46	7.59	0.74	0.37	3.03	0.32
4	0.13	0.00	0.62	0.55	0.47	0.15	3.12	0.25	0.17	1.27
5	0.03	0.01	0.00	0.20	0.52	0.21	0.21	1.39	0.34	0.13
6	0.00	0.00	0.02	0.00	0.28	0.37	0.23	0.39	0.43	0.07
7	0.05	0.00	0.00	0.03	0.03	0.01	0.04	0.38	0.00	0.19
8	0.01	0.00	0.01	0.07	0.01	0.00	0.01	0.07	0.00	0.01
9+	0.48	0.15	0.20	0.17	0.07	0.01	0.00	0.05	0.01	0.05

Age	1983	1984	1985	1986
0	3.89	0.02	11.35	0.00
1	0.16	2.23	0.65	5.11
2	0.14	0.59	1.53	0.09
3	0.18	0.16	0.22	1.21
4	0.20	0.19	0.05	0.06
5	0.63	0.04	0.10	0.13
6	0.08	0.30	0.01	0.13
7	0.00	0.00	0.17	0.02
8	0.07	0.00	0.00	0.03
9+	0.01	0.08	0.05	0.04

modified from Overholtz et. al. 1983
data for 1983-86 supplied by W. J. Overholtz

Table 12. Stratified mean catch per tow at age(numbers) for haddock in NAFO Division 5Z from the Canadian surveys.

Age	1986	1987
1	3.37	0.03
2	0.18	3.07
3	4.93	0.70
4	0.88	2.43
5	0.15	0.64
6	0.25	0.08
7	0.25	0.29
8	0.27	0.10
9+	0.34	0.84
1+	10.62	8.18

Table 13. Results of the multiplicative model regression of ln catch rate for haddock in NAFO Division 5Z using data from 1966-1986.

Multiple R..... 0.793
Multiple R squared..... 0.629

Analysis of Variance

Source of Variation	DF	Sums of Squares	Mean Squares	F-value
Intercept	1	3.401E2	3.401E2	
Regression	35	7.524E1	2.150E0	15.056
Type 1	4	9.569E0	2.392E0	16.755
Type 2	11	1.497E1	1.361E0	9.534
Type 3	20	4.093E1	2.046E0	14.333
Residuals	311	4.440E1	1.428E-1	
Total	347	4.598E2		

Coefficients

Country/Gear	ln Power	Month	ln Power
Can-M OTB2-2	-0.070	Nov	-0.480
Can-M OTB1-4	0.000	Dec	-0.387
Can-M OTB2-4	0.182	Jul	-0.309
Can-M OTB2-3	0.183	Sep	-0.307
Can-M OTB2-5	0.375	Aug	-0.286
		Oct	-0.186
		Jun	-0.158
		May	-0.156
		Jan	0.000
		Feb	0.071
		Mar	0.338
		Apr	0.379

Table 14. Catch rate index for haddock in NAFO Division 5Z, standardized to Can-M OTB2-5 and June. The standardized effort index was derived from the mean catch rate and catch.

	Predicted Catch Rate					
	ln Transform		Retransformed			
Year	Mean	S.E.	Mean	S.E.	Catch	Effort
1966	-0.8437	0.0116	0.459	0.049	121274	263990
1967	-0.9041	0.0071	0.433	0.036	51469	118753
1968	-1.0875	0.0070	0.361	0.030	40421	112029
1969	-1.1976	0.0089	0.323	0.030	22183	68703
1970	-1.1614	0.0125	0.334	0.037	11285	33767
1971	-1.3298	0.0161	0.282	0.036	10862	38532
1972	-1.6893	0.0511	0.193	0.043	5733	29655
1973	-1.2303	0.0187	0.311	0.042	5331	17144
1974	-0.9483	0.2685	0.364	0.177	4290	11795
1975	-1.0535	0.0253	0.370	0.059	5420	14653
1976	-1.1188	0.0181	0.348	0.047	4324	12434
1977	-0.4577	0.0154	0.674	0.083	10843	16077
1978	-0.1372	0.0098	0.932	0.092	22339	23970
1979	-0.4072	0.0076	0.712	0.062	19461	27326
1980	-0.4305	0.0066	0.696	0.057	27571	39607
1981	-0.3246	0.0079	0.773	0.069	24907	32205
1982	-0.8065	0.0142	0.476	0.057	17563	36887
1983	-0.9084	0.0179	0.429	0.057	11892	27706
1984	-0.8846	0.0321	0.436	0.078	10269	23529
1985	-0.6053	0.0148	0.582	0.071	7757	13326
1986	-0.9806	0.0161	0.400	0.051	6751	16891

Table 15. Catch numbers at age(000's) from the commercial fishery for haddock in NAFO Division 5Z.

Age	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
1	10101	9601	114	1150	8	2	46	0	156	2560	46
2	15935	125818	6843	168	2994	11	158	1375	2	2057	4320
3	4554	44496	100810	2891	709	1698	16	223	450	3	657
4	4776	5356	19167	20667	1921	448	570	40	81	386	2
5	8722	4391	2768	10338	14519	654	186	289	32	53	70
6	5794	6690	2591	1209	3499	5954	214	246	120	30	2
7	2082	3772	2332	993	677	1574	2308	285	78	77	2
8	1028	1094	1268	917	453	225	746	1469	66	15	53
9+	1332	1366	867	698	842	570	464	928	1236	447	249

Age	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
1	192	144	0	0	0	8	0	78	0	0	0	6
2	1034	473	19585	761	26	31000	1661	1424	87	94	2328	46
3	1864	550	187	14395	1726	347	9550	1634	748	335	571	2782
4	375	880	680	305	7169	975	754	2895	709	722	225	211
5	4	216	515	567	525	6054	699	335	1923	367	313	168
6	42	1	357	517	410	594	2278	645	267	1532	176	161
7	4	23	4	139	315	546	308	1387	222	199	656	157
8	4	4	39	14	96	153	139	130	875	325	91	272
9+	88	112	111	67	46	81	80	119	96	456	177	45

from Overholtz et.al. 1983
USA data for 1983-86 supplied by W.J. Overholtz

Table 16. Estimated population numbers (000's) at the begining of the year and fishing mortalities for haddock in NAFO Division 5Z.

Population Numbers

Age	1964	1965	1966	1967	1968	1969	1970	1971	1972
1	413293	24319	2008	14091	403	613	3774	395	8077
2	119517	330021	13347	1596	10233	324	501	3059	324
3	25236	84982	180604	6212	1156	4594	255	329	1172
4+	77069	56920	54745	89206	47051	22241	12960	7380	3460

Age	1973	1974	1975	1976	1977	1978	1979	1980	1981
1	20866	6116	2696	111832	8538	940	83824	8799	14133
2	6482	14558	4982	2153	91377	6990	770	68629	7197
3	263	3528	7449	3048	1370	56947	5004	605	26787
4+	2080	982	2722	6464	6207	4597	35241	22951	10850

Age	1982	1983	1984	1985	1986	1987
1	1367	2514	14259	805	33843	341
2	11571	1065	2059	11674	659	27702
3	4546	7758	793	1603	7530	498
4+	15022	7759	7069	2556	1471	4226

Fishing Mortality

Age	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
1	0.02	0.40	0.03	0.12	0.02	0.00	0.01	0.00	0.02	0.16	0.00	0.02
2	0.14	0.40	0.56	0.12	0.60	0.04	0.22	0.76	0.01	0.41	0.47	0.29
3	0.22	0.88	0.76	0.70	1.06	0.50	0.07	1.21	0.53	0.01	0.24	0.27
4+	0.45	0.58	0.80	0.50	0.56	0.53	0.39	0.58	0.63	0.79	0.56	0.22

Age	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
1	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
2	0.25	0.27	0.13	0.04	0.74	0.26	0.20	0.10	0.05	0.24	0.08
3	0.22	0.16	0.35	0.48	0.97	0.75	0.55	0.12	0.63	0.49	0.46
4+	0.23	0.33	0.49	0.35	0.57	0.65	0.78	1.49	0.96	1.14	1.25

Table 17. Residuals for ln catch and ln abundance index from the estimation of population size of haddock in NAFO Division 5Z.

Catch Residuals

Age	1964	1965	1966	1967	1968	1969	1970	1971	1972
2	0.110	0.231	0.262	0.007	-0.346	-0.020	0.562	-0.083	-0.005
3	-0.012	-0.030	0.133	0.010	0.018	0.025	0.000	0.044	0.027
4+	-0.064	-0.017	0.043	0.090	0.166	0.114	0.162	0.090	0.089

Age	1973	1974	1975	1976	1977	1978	1979	1980	1981
2	0.037	-0.144	-0.103	0.081	-0.014	-0.048	-0.070	-0.061	0.104
3	-0.000	-0.056	0.166	0.009	0.007	-0.058	-0.016	0.003	-0.303
4+	-0.039	-0.023	0.049	0.020	0.063	-0.005	-0.092	-0.078	-0.111

Age	1982	1983	1984	1985	1986
2	-0.292	-0.010	0.032	0.032	0.012
3	-0.073	-0.048	-0.009	0.004	0.087
4+	-0.308	-0.312	-0.111	0.019	0.044

Abundance Index Residuals

Age	1963	1964	1965	1966	1967	1968	1969	1970	1971
1	-0.341	-1.064	-0.405	0.442	-0.091	-0.037	-0.944	0.386	0.087
2	-0.831	-0.356	0.460	0.355	0.318	0.245	-1.500	1.093	-0.225
3	0.061	0.776	0.215	0.321	0.026	-0.478	-0.205	1.207	-0.123
4+	0.191	-0.135	-0.130	-0.079	-0.251	-0.061	-0.367	0.197	-0.123

Age	1972	1973	1974	1975	1976	1977	1978	1979	1980
1	0.138	0.663	0.080	-0.306	0.606	-0.127	-0.393	-0.413	1.281
2	-0.194	0.251	-0.270	-0.408	0.365	-0.237	1.356	0.508	-0.029
3	-0.281	0.320	-0.943	-0.338	0.210	0.151	-0.282	-1.261	0.521
4+	0.487	0.072	-0.966	0.906	-0.157	0.334	0.180	-0.077	0.161

Age	1981	1982	1983	1984	1985	1986
1	0.404	0.735	0.373	-1.599	0.567	-0.002
2	0.299	-0.317	-1.323	-0.521	1.526	-0.567
3	0.510	-0.870	-0.065	0.558	-0.113	0.104
4+	0.206	0.071	-0.415	-0.201	-0.116	0.254

Table 18. Residuals for ln abundance index from the SPA calibration using fishing mortalities of 0.0002, 0.05, 0.45 and 0.55 for ages 1 to 4+ respectively.

Age	1984	1985	1986	1987
1	-0.1990	0.5629	-0.3507	
2	0.3984	0.2266	-0.5804	0.1935
3	0.1612	-0.5374	0.0209	0.0222
4+	0.2146	0.1039	-0.0573	-0.1795

Table 19. Results from the calibration of the sequential population analysis for haddock in NAFO Division 5Z.

Population Numbers (000's)

Age	1964	1965	1966	1967	1968	1969	1970	1971
1	467459	32524	4109	11524	435	996	4768	384
2	151662	373583	17941	3261	8395	349	813	3862
3	22627	109752	192019	8497	2518	4164	276	523
4	19918	14405	49596	65995	4341	1420	1873	211
5	27161	11986	6947	23263	35332	1816	757	1017
6	16075	14346	5840	3183	9692	15790	895	452
7	5196	7919	5692	2437	1512	4769	7541	539
8	2859	2370	3070	2550	1097	626	2480	4085
9+	3704	2960	2099	1941	2039	1585	1543	2581
1+	716662	569845	287314	122652	65360	31514	20945	13654
2+	249203	537321	283205	111128	64925	30518	16177	13271
3+	97541	163737	265264	107867	56531	30169	15364	9408
4+	74914	53985	73245	99370	54013	26006	15088	8885

Age	1972	1973	1974	1975	1976	1977	1978	1979
1	8550	19207	10740	8212	103386	13973	5508	78011
2	314	6859	13409	8752	6550	84515	11440	4510
3	1918	255	3755	7070	6230	4935	51474	8678
4	226	1163	206	2480	4101	4603	3871	29118
5	137	112	603	167	1691	2562	3153	2893
6	571	83	44	430	133	1189	1631	2068
7	147	359	41	34	314	108	650	868
8	184	50	224	32	24	237	85	407
9+	3437	1486	1055	695	679	673	406	195
1+	15485	29575	30077	27871	123109	112794	78219	126747
2+	6935	10368	19337	19659	19723	98821	72711	48736
3+	6621	3509	5928	10908	13173	14306	61271	44227
4+	4703	3254	2173	3838	6943	9371	9797	35549

Age	1980	1981	1982	1983	1984	1985	1986	1987
1	9151	6510	2175	2062	15685	1270	33103	384
2	63870	7485	5330	1710	1688	12842	1040	27097
3	3669	24242	4625	3075	1322	1297	8408	810
4	5543	2690	11207	2308	1841	779	545	4389
5	17353	3656	1520	6556	1248	854	434	258
6	1894	8730	2361	941	3627	690	416	205
7	1323	1013	5086	1349	529	1584	406	197
8	425	589	551	2909	904	253	703	192
9+	225	339	504	319	1268	492	116	387
1+	103453	55254	33359	21231	28113	20061	45171	33534
2+	94301	48743	31184	19169	12428	18791	12068	33534
3+	30432	41258	25853	17458	10740	5949	11028	6437
4+	26763	17016	21228	14383	9418	4652	2621	5627

Table 19. continued

Fishing Mortality

Age	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
1	0.02	0.39	0.03	0.12	0.02	0.00	0.01	0.00	0.02	0.16	0.00	0.03	0.00
2	0.12	0.47	0.55	0.06	0.50	0.04	0.24	0.50	0.01	0.40	0.44	0.14	0.08
3	0.25	0.59	0.87	0.47	0.37	0.60	0.07	0.64	0.30	0.01	0.21	0.34	0.10
4	0.31	0.53	0.56	0.42	0.67	0.43	0.41	0.23	0.50	0.46	0.01	0.18	0.27
5	0.44	0.52	0.58	0.68	0.61	0.51	0.32	0.38	0.30	0.74	0.14	0.03	0.15
6	0.51	0.72	0.67	0.54	0.51	0.54	0.31	0.92	0.26	0.51	0.05	0.11	0.01
7	0.58	0.75	0.60	0.60	0.68	0.45	0.41	0.88	0.88	0.27	0.06	0.14	0.08
8	0.50	0.70	0.60	0.50	0.60	0.50	0.40	0.50	0.50	0.40	0.30	0.15	0.20
9+	0.50	0.70	0.60	0.50	0.60	0.50	0.40	0.50	0.50	0.40	0.30	0.15	0.20
4+	0.43	0.63	0.58	0.49	0.60	0.51	0.40	0.52	0.48	0.42	0.22	0.16	0.22

Age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
1	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
2	0.30	0.08	0.01	0.77	0.28	0.35	0.06	0.06	0.22	0.05
3	0.04	0.37	0.25	0.11	0.57	0.49	0.31	0.33	0.67	0.45
4	0.18	0.09	0.32	0.22	0.37	0.34	0.41	0.57	0.38	0.55
5	0.25	0.22	0.22	0.49	0.24	0.28	0.39	0.39	0.52	0.55
6	0.40	0.43	0.25	0.43	0.34	0.36	0.38	0.63	0.33	0.55
7	0.04	0.27	0.51	0.61	0.41	0.36	0.20	0.54	0.61	0.55
8	0.20	0.20	0.30	0.50	0.30	0.30	0.40	0.50	0.50	0.55
9+	0.20	0.20	0.30	0.50	0.30	0.30	0.40	0.50	0.50	0.55
4+	0.23	0.21	0.31	0.43	0.32	0.34	0.38	0.55	0.50	0.55

Table 20. Average weight at age of haddock caught in the commercial fishery in NAFO Division 5Z.

Age	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
1	0.50	0.58	0.58	0.66	0.59	0.52	0.71	0.60	0.62	0.60	0.72	0.62
2	0.83	0.69	0.73	0.70	0.81	0.78	1.27	1.03	1.03	1.03	1.06	0.98
3	1.12	1.03	0.89	0.95	1.05	1.10	1.22	1.31	1.74	1.58	1.82	1.63
4	1.43	1.35	1.26	1.18	1.32	1.69	1.93	1.74	2.04	2.13	2.32	2.21
5	1.64	1.67	1.70	1.42	1.57	1.75	2.19	2.39	2.42	2.41	2.83	2.20
6	2.01	1.99	2.07	2.05	2.10	1.99	2.39	2.81	2.92	3.29	3.76	2.94
7	2.40	2.26	2.28	2.31	2.32	2.52	2.58	2.92	3.06	3.42	4.05	4.00
8	2.64	2.66	2.87	2.66	2.62	2.99	3.23	3.10	3.44	3.86	3.92	4.05
9+	2.97	3.11	3.18	3.10	2.86	3.63	3.75	3.72	3.66	3.94	4.26	4.33

Age	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
1	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
2	0.99	1.07	0.94	1.00	0.72	0.91	0.92	1.00	0.86	0.98	0.95
3	1.39	1.44	1.50	1.28	1.20	1.24	1.41	1.43	1.31	1.26	1.38
4	1.99	2.17	2.04	2.02	1.93	1.80	1.94	1.94	1.74	1.91	1.84
5	2.66	2.73	2.79	2.51	2.30	2.40	2.44	2.31	2.17	2.39	2.42
6	2.63	3.21	3.19	3.14	2.94	2.80	2.83	2.80	2.67	2.86	2.86
7	3.69	4.15	3.37	3.78	3.86	3.73	3.35	3.38	2.98	3.03	3.04
8	4.67	4.00	3.61	3.79	4.13	4.44	4.00	3.59	3.39	3.53	3.54
9+	4.94	4.99	5.11	4.87	4.83	4.04	3.73	3.89	3.62	3.92	4.08

from Clark et al 1982
USA data for 1980-84 supplied by W. J. Overholtz

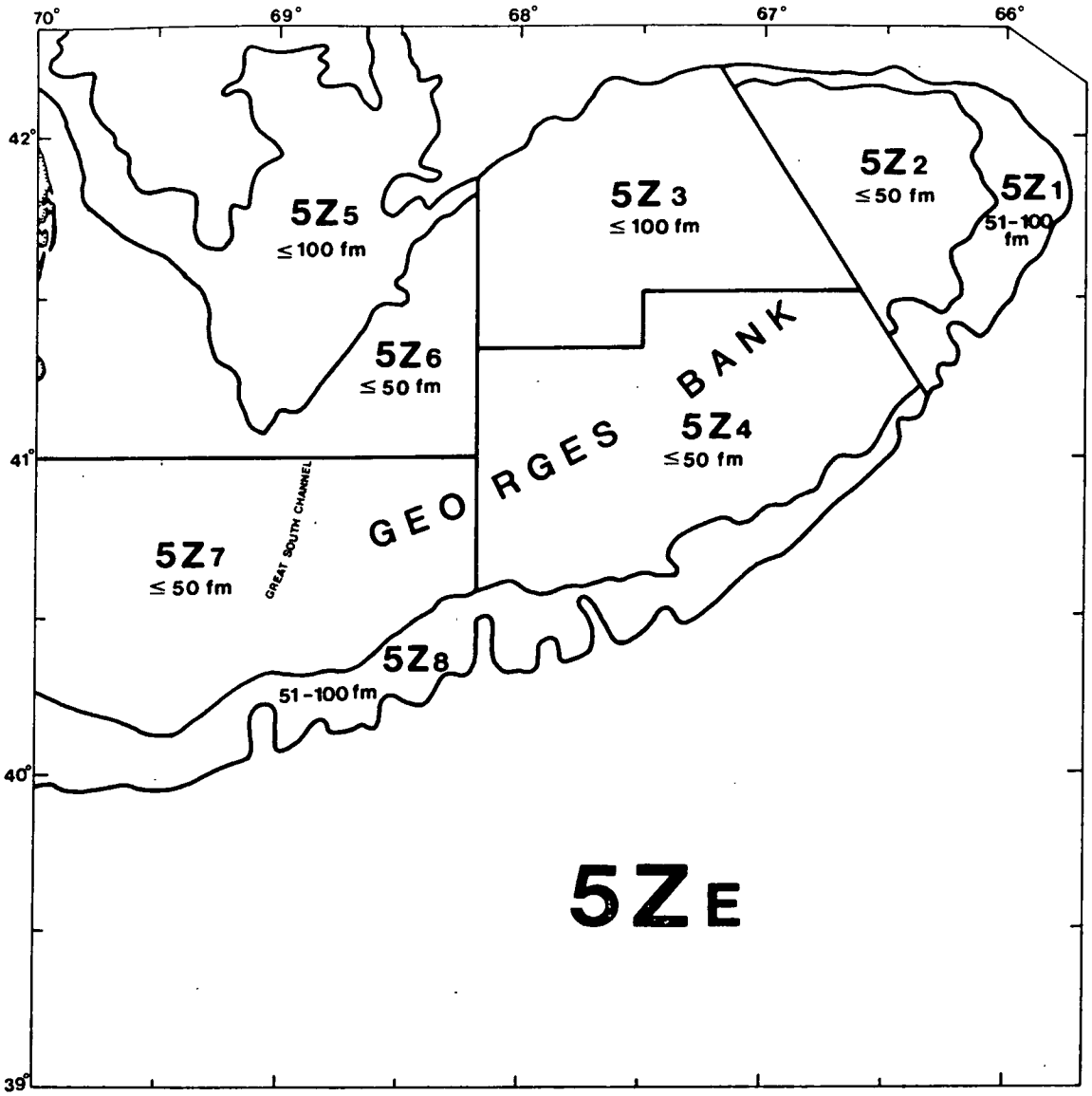


Fig. 1. Stratification scheme used for the Canadian survey of Georges Bank in 1987.

Fig. 2. Catch rate index, with approximate 90% confidence intervals, for haddock in NAFO Division 5Z.

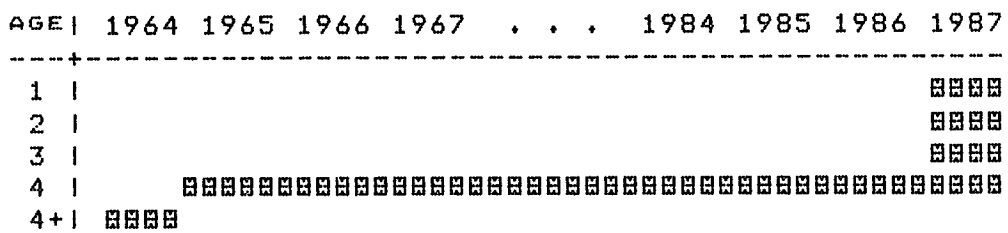


Fig. 3. The shaded area indicates the years and age groups of population numbers used as the parameter vector θ in the statistical estimation technique for haddock in NAFO Division 5Z.

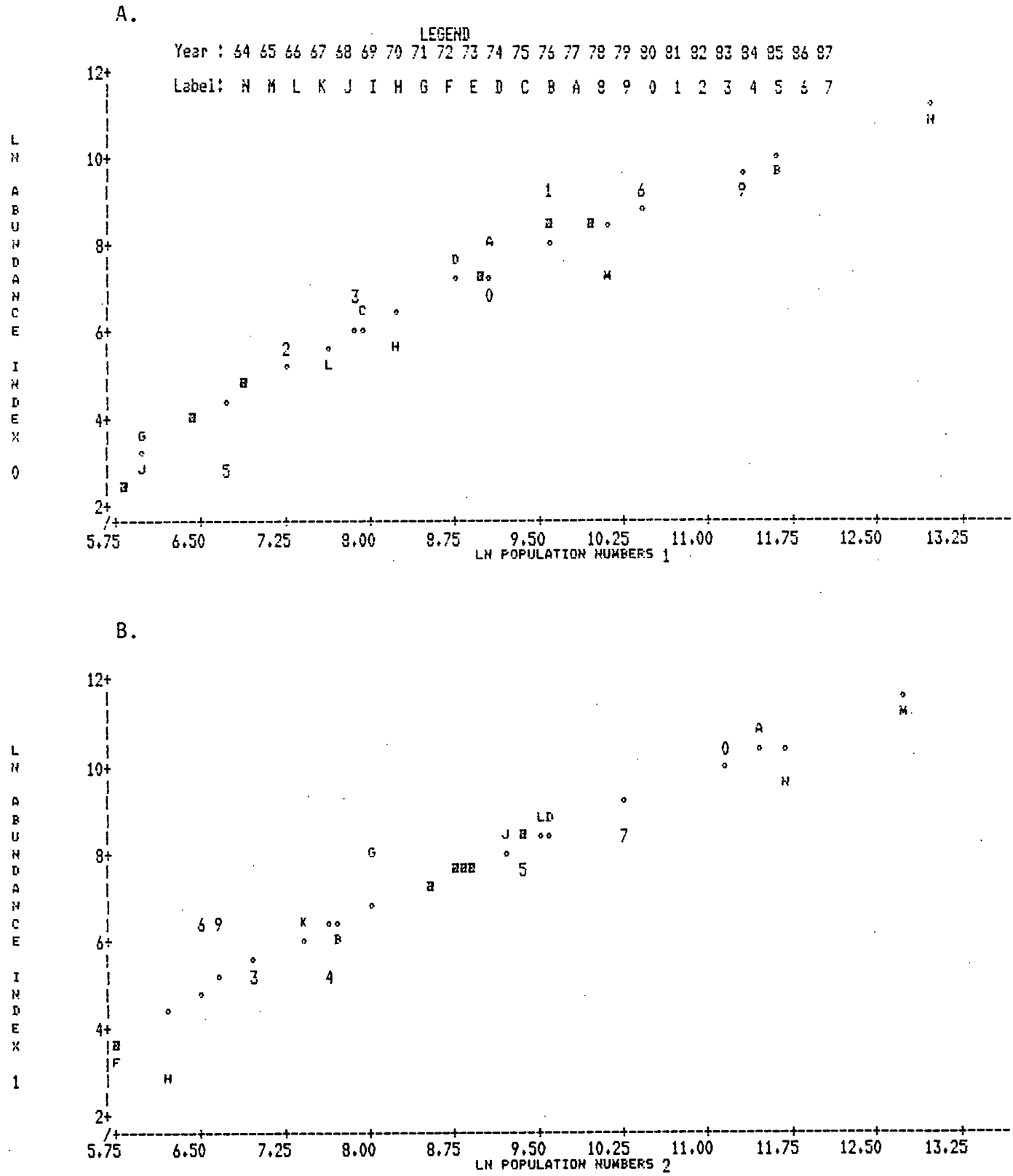
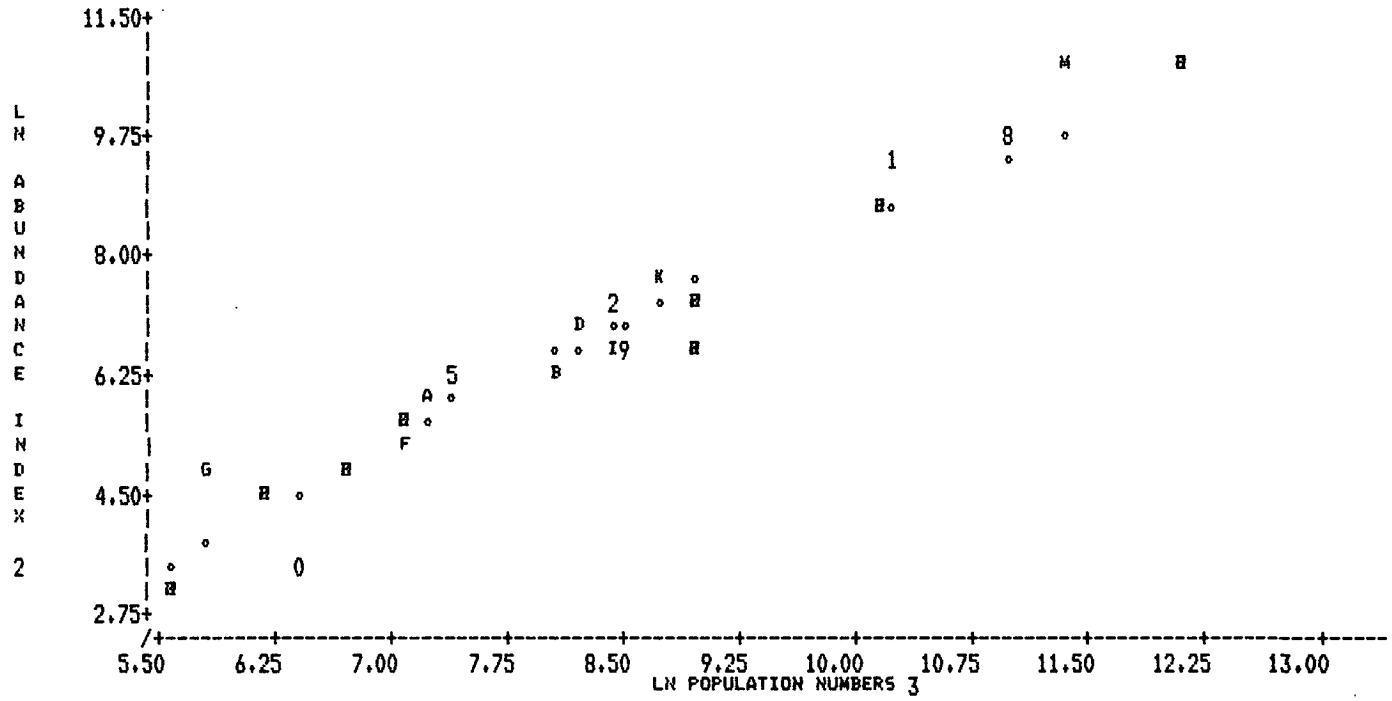


Fig. 4. Age by age plots of observed (numbers or letters) and predicted (0) ln research survey abundance index versus ln population numbers from the statistical estimation technique for haddock in NAFO Division 5Z.

C.



D.

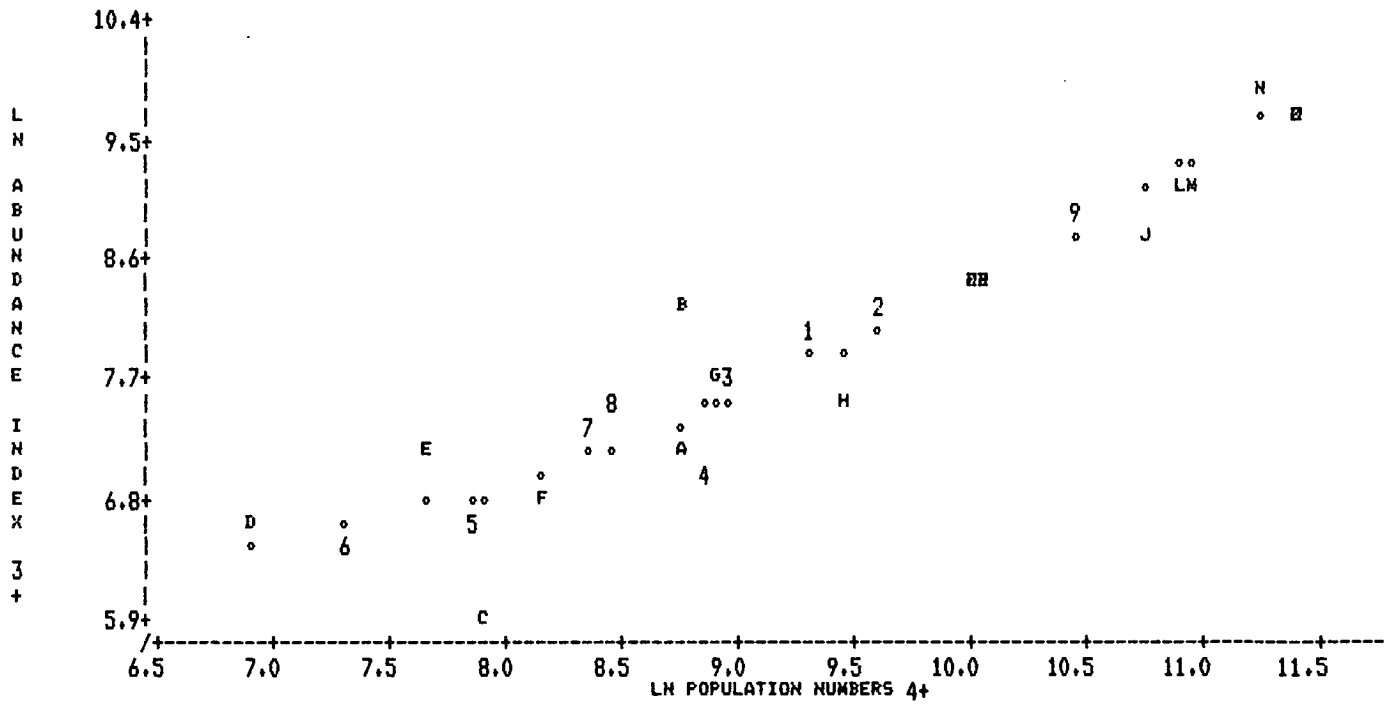


Fig. 4. (Continued)

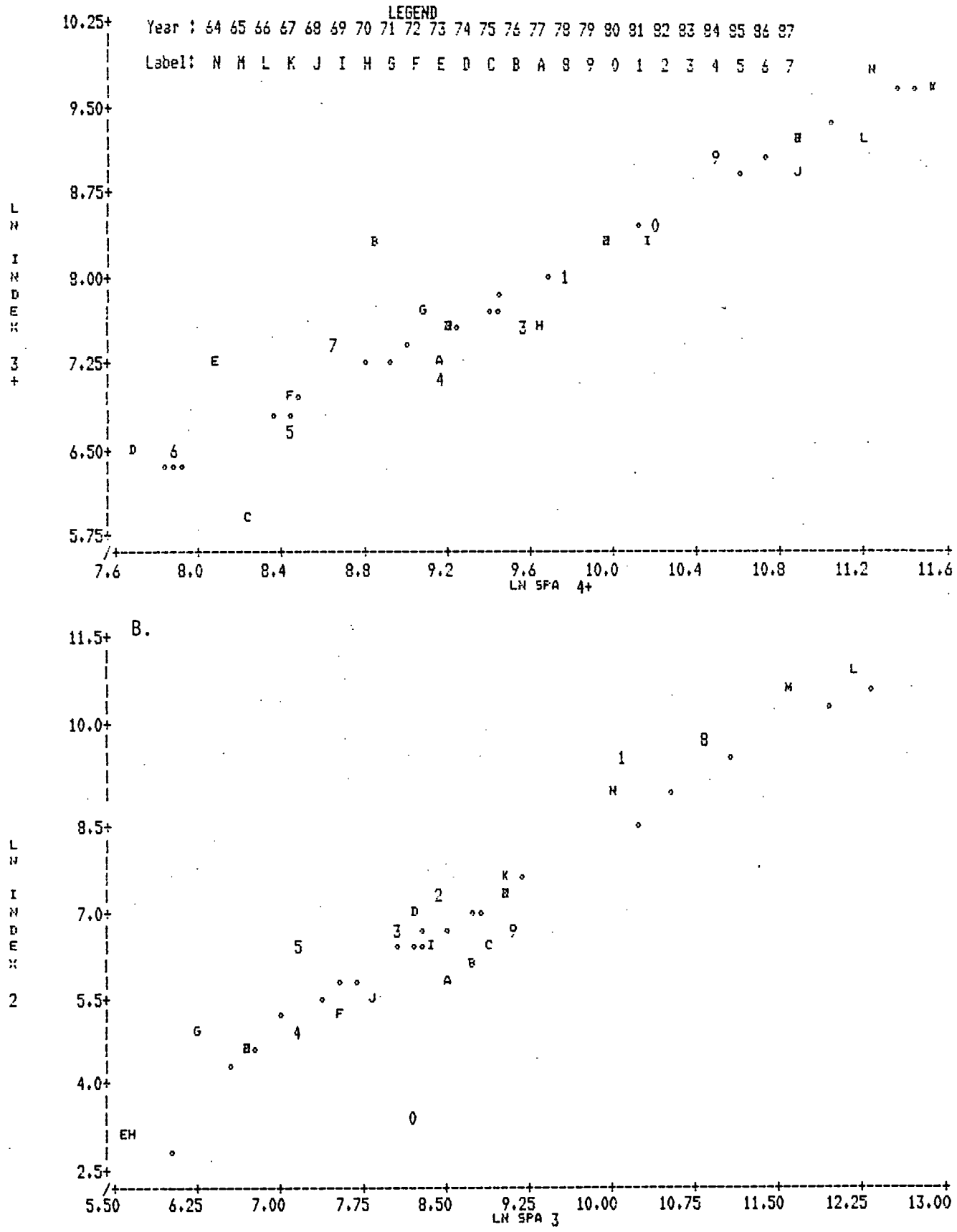
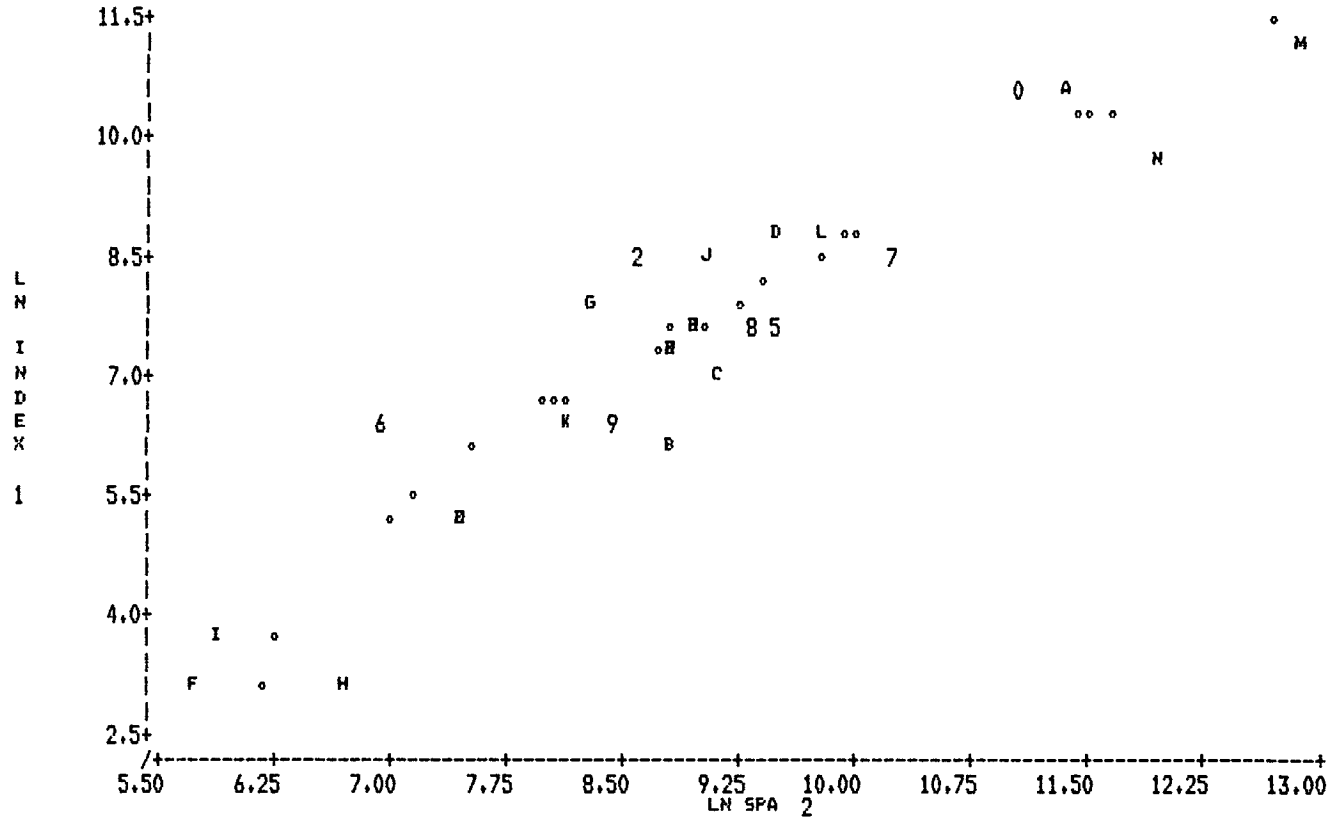


Fig. 5. Age by age calibration plots of observed (numbers or letters) and predicted (0) ln research survey abundance index versus ln SPA numbers for haddock in NAFO Division 5Z.

C.



D.

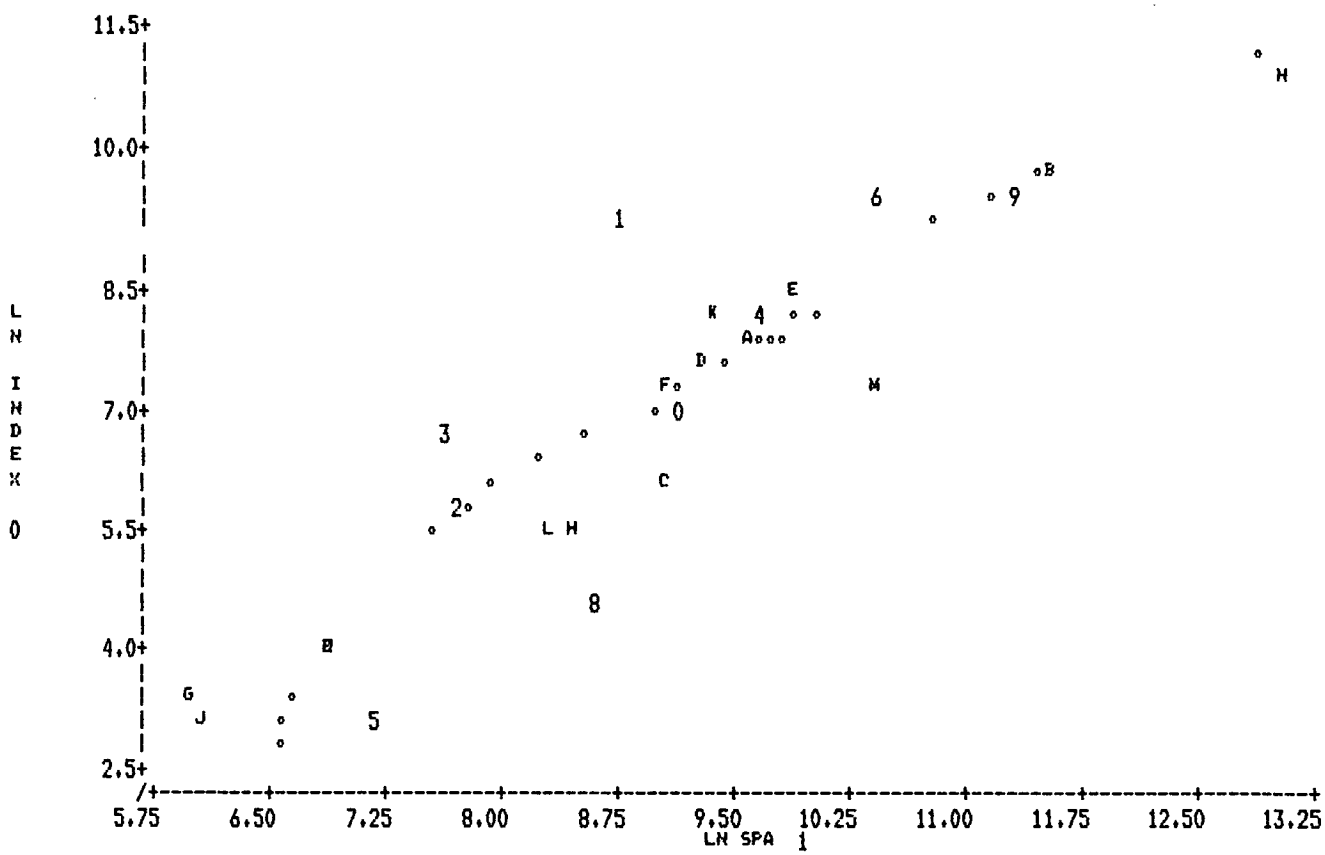


Fig. 5. (Continued)

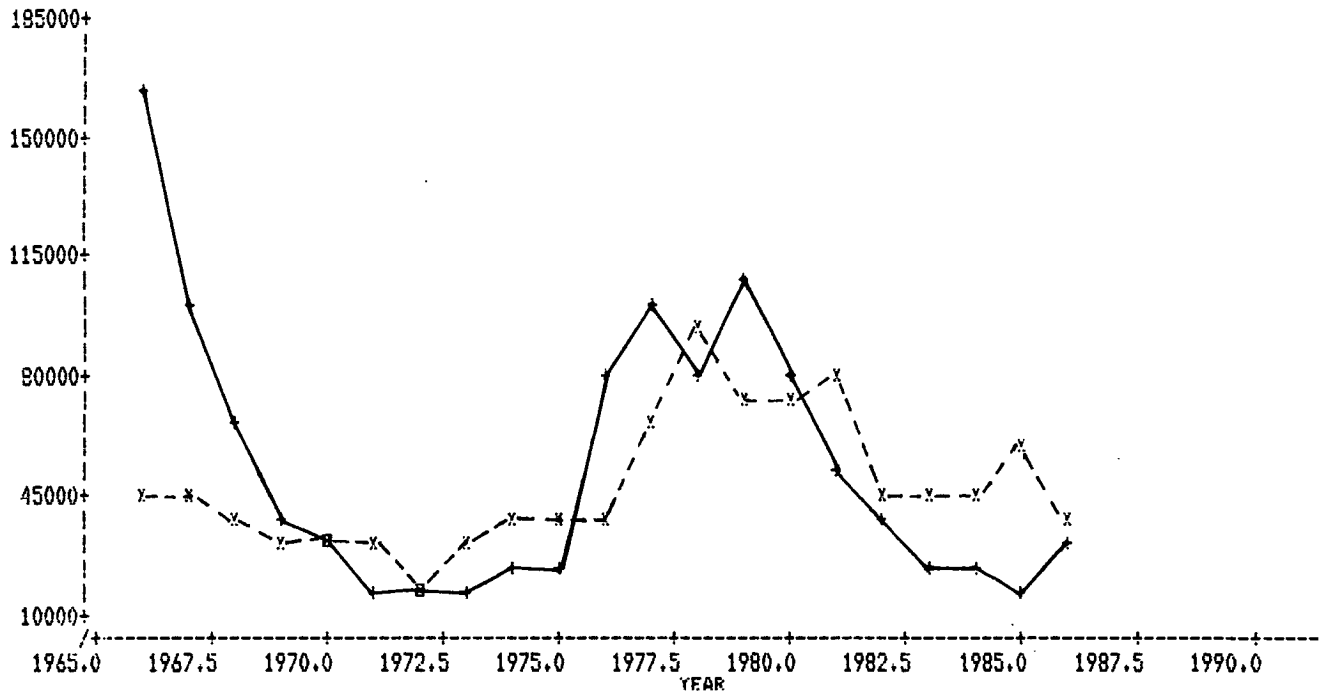


Fig. 6. Biomass (—) and catch rate (---) indices for haddock in NAFO Division 5Z.