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Sequential Population Analysis of 4VsW cod following the 1984 fishery.

by

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Abstract

The 1984 catch at age was dominated by the 1977 to 1980 year classes which made up over 90% of the catch numbers. A comparison of the projected and observed catch at age indicated fewer young fish (ages 3-5) and more older fish (ages 5-10) than expected. Partial recruitment for 1982-84 was adjusted to account for an observed change in mesh size in the Canadian otter trawl fishery in the area. The age of full recruitment increased from age 6 to age 7, and the age 5 partial recruitment was decreased. There was no change for ages 3 and 4. Sequential population analysis was calibrated using the SURVIVOR method, age 5+ survey numbers versus SPA 5+ mean numbers, and commercial catch rates versus exploitable biomass. The three methods indicated a 1984 fully recruited fishing mortality of .4. This gave a 1983 fully recruited fishing mortality of .35, equivalent to that found in the previous assessment. However, the estimated sizes of the 1979-1981 year classes were substantially lower this year than last. The resulting catch projections indicated a 1986 $F_{0.1}$ catch of 35,000 t if the 1985 TAC of 55,000 t is taken.

Résumé

Les prises par âge en 1984 ont été dominées par les classes d'âge de 1977 à 1980 qui constituaient plus de 90 % des prises. Une comparaison entre les prises par âge prévues et observées a indiqué qu'il y avait moins de jeunes poissons (âges 3-5) et plus de poissons plus vieux (âges 5-10) que prévu. Le recrutement partiel pour 1982-1984 a été ajusté pour tenir compte du fait que la taille des mailles des filets utilisés par les chalutiers canadiens dans cette région avait changé. L'âge de recrutement complet a augmenté de l'âge 6 à l'âge 7 et le recrutement partiel de l'âge 5 a été abaissé. Il n'y a pas eu de changement pour les âges 3 et 4. L'analyse séquentielle de population (ASP) a été calibrée à l'aide de l'analyse des survivants, nombres d'âge 5+ dans le relevé par navire de recherche canadien vs ASP des nombres moyens d'âge 5+, et taux de prises commerciales vs biomasse exploitable. Les 3 méthodes indiquent pour 1984 une mortalité par pêche des poissons pleinement recrutés de 0,4. Ceci donnait une mortalité par pêche des poissons pleinement recrutés de 0,35 pour 1983, ce qui équivaut à la mortalité prévue par l'estimation précédente. Toutefois, cette année, les tailles estimées des classes d'âge 1979-1981 sont considérablement plus faibles que l'année dernière. Une pêche à $F_{0.1}$ en 1986 donne des prévisions de prises de 35 000 t si le TPA de 1985 de 55 000 t est atteint.

Introduction

The 1984 assessment of this stock (Gagné et al. 1984) indicated that the 1983 fully recruited fishing mortality (F) was .35. This was substantially higher than estimates of terminal F (F in the last year) in the previous six assessments, but it was consistent with the levels of F apparent from a retrospective examination of the sequential population analysis (SPA). Also the previous estimates of terminal F were substantially lower than the actual levels (see below).

	Year					
	1977	1978	1979	1980	1981	1982
F in assessment	.15	.18	.30	.225	.225	.25
Mean F from 1984 SPA	.27	.34	.39	.57	.49	.43

Thus the increase in estimated terminal F reflected a new perception of the real situation rather than a real increase in the level of F.

Despite the high recent levels of fishing mortality the stock is currently large in comparison to its size in the mid 1970s. The research vessel survey results indicate that 5+ numbers are currently higher than any previously observed in the series (Figure 1). Similarly, catch-per-unit-effort in the past five years has been higher than any since 1970, and have been 2 to 3 times higher than the lowest levels (Gavaris and Sinclair 1985). Thus it appears that the stock has recovered from low levels in the mid 1970s despite the recent high levels of exploitation.

The projections done in last year's assessment indicated a 1984 $F_{0.1}$ catch of 42,000 t followed by a catch of 54,000 t in 1985 at the same level of F. This large increase from 1984 to 1985 was due to the expected recruitment of very strong 1979 and 1980 year classes. An alternative to the $F_{0.1}$ catch in 1984 was the TAC of 55,000 t. If this was taken in 1984 the 1985 $F_{0.1}$ catch was projected to be 52,000 t. Since the two estimated 1985 $F_{0.1}$ catches were of similar magnitude there was no change in the advice for a 1984 TAC of 55,000 t, and a similar TAC was advised for 1985 (CAFSAC Advisory Doc. 84/14).

The 1984 nominal catch was estimated to be 52,130 t.

Catch-At-Age

In the previous assessment, not all of the length frequency samples were used in the calculation of the 1983 catch-at age. Furthermore, additional fish were aged after the assessment. The age/length keys most affected were otter trawls quarters 2 and 4. The

1983 catch at age was recalculated with these additional data. Table 1a summarizes the data used. The new age compositions by key are shown in Table 2. There were substantial changes in the estimated age compositions for otter trawlers quarters 2 and 4, with more younger fish (age 3 and 4) in quarter 2 and fewer younger fish in quarter 4. These changes balanced each other and the newly calculated catch-at-age for 1983 is very similar to the original (Figure 2).

Sampling in 1984 was good for all gears with the possible exception of seines (Table 1b). As in previous assessments quarterly age/length keys were generated for otter trawlers and half yearly keys for longlines and seines. Portugal again fished a national allocation of cod in 1984 catching 268 t in the fourth quarter. Length frequencies taken by the International Observer Program were similar to commercial samples for otter trawlers in that quarter so the Portuguese catch was added to the Canadian catch for that quarter, and only Canadian length frequencies were used. By-catch in the foreign small mesh fishery was less than 100 t in 1984 and since it was so small a separate age composition was not calculated for this fishery.

Catches-at-age by key for 1984 are shown in Table 2. The keys accounted for 50,558 t of the 52,130 t total catch. The difference consisted of Canadian catch by miscellaneous gears and the catch in the small mesh fishery. In the final calculation the individual keys were combined and the catches at age were increased to reflect the total landings. This assumes that the miscellaneous gear and small mesh catch has the same age composition as the combined otter trawl, longline, and seine catch. The 1984 estimated catch at age, weight at age, and lengths at age are shown in Table 3. The 1977 to 1980 year classes were well represented in the catch, making up over 90% of the total catch in numbers. Coefficients of variation were less than 10% for ages 4-9. The sum of cross products was 52,027 t or 99.8% of the total catch.

A comparison of projected catch-at-age from last year's assessment and the 1984 catch-at-age is given in Figure 3. The projected age composition for a catch of 55,000 t (Gagné et al. 1984, Table 30a) was adjusted to the 1984 nominal catch by the ratio 52,130/55,000. It can be seen that fewer fish aged 3-5 and higher numbers at ages 6-10 were taken than expected.

Partial Recruitment

The input partial recruitment (PR) vector used in the previous assessment (PRAV in Table 4) was calculated as the average PR for the period 1977-1981 from the final F matrix. Age 6 was estimated to be fully recruited. While this method will smooth out spurious results caused by errors in the input data, it is not sensitive to real changes in partial recruitment in recent years. Such changes should be considered if there is supporting evidence.

The offshore trawler fleet has taken more than 70% of the 4VsW cod catch over the past seven years. In 1982 the minimum allowable mesh size was increased from 120 mm to 130 mm. At the same time, and possibly in response to the regulation change, the mean mesh size used by the fleet increased. Data collected by the International Observer Program indicates that the mean mesh size increased from 124 mm in 1980 to 132 mm in 1982, and then to 135 mm in 1983-1985. This change in mesh size should have reduced the partial recruitment to the fishery over this time period.

Mesh selection estimates from Hodder (1964), and length frequencies at age from 1984 research vessel surveys were used to estimate partial recruitments for mesh sizes representative of the pre 1982 (127 mm or 5") and post 1982 (140 mm or 5½") fishery. The resulting partial recruitments (PR127 and PR140 respectively in Table 4) show that such a shift in mesh size could theoretically change the age of full recruitment from 6 to 7 and reduce selectivity at age. However PRAV was less than the theoretical PR for the 127 mm mesh (Table 4). This may be due, in part, to the contributions of longliners to the catch-at-age and because of partial recruitment of age 3 to the survey gear. Furthermore, the selection at ages 3 and 4 in PR140 is higher than the average from 1977-1981. If there was a change in selectivity in the fishery caused by an increase in mesh size, then one would expect the selectivities at ages 3 and 4 to be less than in PRAV.

To test for a change in age of full recruitment and partial recruitment a series of trial cohort analyses were begun with an input PR of PR140 and F_t = .35 and .50. Average PR for 1982 and 1983 was calculated from the F matrix and repeatedly input until a stable pattern was found. In each trial the average PR on ages 3 and 4 was greater than in PRAV. This did not seem logical, so the age 3 and 4 PRs were replaced with those in PRAV to give the final PR vector (PR82-84 in Table 4).

Average partial recruitments were used to calculate exploitable biomass. Similar averages as used last year were again used with a period of flat topped recruitment, followed by domed, then again flat topped. The domed period was changed from 1977-1981 to 1979-1981 based on examination of the partial recruitment matrix representing the otter trawl and longline fisheries.

Sequential Population Analysis (SPA)

Since 1977 the catch of ages 1 and 2 fish has been very small. Previous assessments have included these ages in SPA. However, there is little input information to base these calculations on and the numbers are not used in the calibration process. We have more confidence in estimates of year class strengths at age 3 than age 1 for recent year classes because of the available catch-at-age data. Thus the present SPA excludes ages 1 and 2. Furthermore, the age group 16 includes ages 16 and older. Technically, this age group should not be included in SPA. Thus we used only ages 3-15. Also, our version of cohort analysis uses a fixed input for oldest age F rather than an iterative one. The effect was unnoticable on the calibration variables used and it saved substantial computer time. The catch-at-age matrix used is given in Table 5.

Calibration with survey data was carried out by the SURVIVOR method (Rivard, 1982) and using 5+ SPA mean numbers (Ricker 1975, p. 12) vs 5+ survey numbers.

SURVIVOR - Trial analyses showed that the results were not very sensitive to the choice of calibration block. However, the coefficients of variation were greatly reduced by excluding the years 1970-1973. Both the 1970 and 1973 survey estimates have been treated as anomalous in the past (Gray 1979, Maguire 1980). Even after correcting an error in the calculation of mean catch per tow in one of the very large tows from the 1973 survey, that population estimate still remains improbably high for ages 3 and 4 (Gavaris and Sinclair 1985). The preferred survivor analysis included the years 1974-1984, ages 3-9. The calibration block chosen included 1983 and age 8.

The weighted survivors, average calibration coefficient values, estimated survivors, coefficients of variation (C.V.s) and F values for 1984 are shown in Table 6. The average F on ages 7-9 weighted by population numbers was .44. The analysis indicated large 1980 and 1979 year classes. Based on the weighted F the PRs on ages 3-6 would be .01, .12, .30, and .77 respectively. These seem quite low when compared to PR values in Table 4, especially ages 4 and 5, and this may be largely due to high population abundances indicated in the 1984 survey.

5+ Numbers - Calibration was attempted using survey 5+ population numbers and SPA 5+ mean numbers. Preliminary analysis of these data indicated that the 1970 and 1984 points were outliers. The survey estimate for 1970 was much too low when compared to the SPA estimate. Maguire (1980) also noted this problem and elected not to use the point in calibration because 1970 was the first year of the surveys and there was a minor gear adjustment made for the 1971 and subsequent surveys. We too have not used the point in the calibration. The 1984 survey estimate was 60% higher than the 1983 estimate. Much of this increase came from stratum 43, one of the larger strata in the survey area. There was one very large set in the stratum, 20 times larger than the next largest in the stratum. Being the largest survey estimate in the series, the 1984 point was very influential on the calibration regressions. Because of the uncertainties associated with this estimate, the 1984 point was also excluded from the regressions.

Calibration regressions were calculated using the survey estimates as the dependent variable. Usually the survey estimates are used as the independent variable. Several factors support the opposite. Since the survey estimates are thought to be more variable than the SPA estimates it may be preferable to calculate regressions which minimize the variance around the survey estimates. This was done using the survey as the dependent variable. Secondly, with the survey as the independent variable the intercept was high and positive, the correlation coefficient was highest at low terminal fishing mortalities (F_t), and the residual sum on the 1981-1983 points was lowest at high F_t. Thus the criteria used to choose the best F_t were in conflict. However, with the survey as the dependent variable the intercepts were lower, and the correlation coefficient and residual sum indicated similar F_t.

For SPA analyses using F_t ranging from .25 to .45 the correlation coefficients were highest between F_t = .25 and .35 (Table 7). The sum of the residuals around the 1981-1983 points was minimized at F_t = .35. The inverse of the slope of this line was the closest to the fully recruited K value in the survivor analysis. Thus, while there is poor discrimination between runs, the best result seems to be at F_t = .35. The 1970 and 1984 points were not used in the regression but they are included in the plot (Figure 4).

Exploitable Biomass was calculated using mean population numbers, commercial weights-at-age (Table 8) and selectivity-at-age (Table 4). These were calibrated against standardized catch per unit effort. An initial cohort analysis at F_t = .4 was used to investigate the relationship for continuity (Figure 5). The 1965, 1966, 1968, and 1969 points did not follow the general trend shown by the other points. This may be due to errors in the catch-at-age for this time period due to inadequate sampling (Halliday 1975). Whereas the 1967 point was clustered with the other points it may also be subject to the same errors as the other earlier points. The SPA was calibrated using the 1970-1984 data. The SPA esimates were used as the dependent variable and because of the high correlation coefficients and low intercepts, reversal of the dependent and independent variables was not considered to be necessary.

The calibration results show that the correlation coefficients peaked between F_t = .40 and .45 at .94 and the sum of the residuals around the 1981-1984 points was smallest at F_t = .45 (Table 9). Thus this calibration indicates an F_t of .45. The final plot is shown in Figure 6.

To summarize, three methods of calibration were used to estimate F_t. Both the survivor method and the relationship between exploitable biomass and CPUE indicated F_t around .45. Calibration of mean population 5+ numbers and survey 5+ numbers indicated F_t around .35. A F_t of .40 would give a 1983 fully recruited mean F of .35, the same value used last year. Given these results a 1984 fully recruited F of .4 was considered to be the most consistent with the available data. Beginning of the year population numbers, fishing mortality, and mean population biomass with F_t = .4 and PR = PR82-84 are given in Tables 10-12.

Catch Projections

Catches were projected using the input data in Table 13. The 1984 beginning of the year population size was taken from the SPA with F_t = .4 with a modification to the estimate of the 1981 year class size. The catch of this year class at age 3 in 1984 was the smallest age 3 catch observed. The corresponding population estimate, which is highly dependent on the age 3 partial recruitment estimate, was also the smallest on record, approximately half the smallest previously seen. Because the estimation of partial recruitment for this age is not very precise the size of this year class was increased to the size of the smallest previously observed: the 1972 year class which was 64 million fish at age 1 (Gagnê et al. 1984). A natural mortality rate of .2 gives 43 million fish at age 3. Recruitment at age 3 for 1985-86 was set at 71 million, which is arrived at by applying the natural mortality rate to the long-term geometric mean of 107 million at age 1. The weights at age used for the projection were the average over the most recent three years, 1982-84.

The results of the projections are shown in Table 14. If the 1985 TAC of 55,000 t is taken this would generate a 1985 fully recruited F of .35 and the projected 1986 $F_{0.1}$ catch would be 35,000 t. The projected $F_{0.1}$ catches for 1985 and 1986 are 33,000 t and 39,000 t respectively.

Projected exploitable biomasses in 1985 and 1986 were calculated using average population biomass and PR 82-84. These indicated an increasing trend in exploitable biomass through 1986. The estimated 1984 exploitable biomass using F_t = .4 was 129,000 t (Table 15). If the catch in 1985 is 55,000 t and the $F_{0.1}$ catch is taken in 1986 the projected 1985 and 1986 exploitable biomasses would be 150,000 t and 175,000 t respectively. An increase in exploitable biomass should lead to an increase in CPUE. The standardized CPUE for 1984 was 1.8 t/hr. Using the projected 1985 and 1986 exploitable biomasses and the regression between CPUE and exploitable biomass with F_t = .4 (Table 9) the predicted 1985 and 1986 CPUE would be 2.2 t/hr and 2.4 t/hr respectively (Table 15).

Discussion

The main difference between the results of this assessment and the previous assessment (Gagné et al. 1984) is the estimated sizes of the 1979 to 1981 year classes. Estimates of older year classes were very similar to those of last year. In 1984 both the 1979 and 1980 year classes were estimated to be 111 million at age 3, slightly higher than any previously observed age 3 numbers (106 million for the 1965 year class). This year the age 3 estimates are 81 and 69 million respectively (Table 10).

The current estimates should be more accurate since an additional year of catch-at-age data was used. However, the 1980 year class may be underestimated because of the difficulty in determining the age 4 partial recruitment. When the observed increase in otter trawl mesh size was taken into consideration we concluded that the age 5 and 6 partial recruitments decreased but were unable to reach the same conclusion for age 4. If the 1984 age 4 PR was lower the 1980 year class estimate would be higher. However, the current estimate gives a 1980 year class which is larger than the 1965-83 geometric mean age 3 abundance of 59 million.

The low numbers of age 3 fish in the 1984 catch-at-age indicate that the 1981 year class is small. Using the age 3 partial recruitments this year class was estimated to be less than half the size of the smallest previously observed year class. Because of the uncertainties associated with partial recruitment estimates at this age, we set the 1981 year class equal to the smallest previously observed at age 1 (43 million at age 3). Last year this year class was assumed to be average in size at age 1 (71 million at age 3).

These lower estimates of the 1979 to 1981 year classes were the main reason for the decrease in the projected 1985 $F_{0.1}$ catch level. Last year the 1985 $F_{0.1}$ catch was projected to be 52,000 t if 55,000 t were taken in 1984. This year the 1985 $F_{0.1}$ catch, given a 52,000 t catch in 1984, was projected to be 33,000 t.

This assessment indicates that the 4VsW cod stock is currently large. The trend in exploitable biomass since 1970 shows that between 1970 and 1976 there was a steep decline (Figure 7). This occurred at a time of poor recruitment (Table 10) and high fishing mortality. In 1977 foreign directed effort was eliminated from the fishery and biomass increased rapidly for two years, then more gradually to the present. This increase was largely due to the size of recruiting year classes, beginning with the 1974, and a reduction in the level of fishing mortality. Now it is apparent that the 1977-1980 year classes are all above the average age 3 abundance. Given the succession of good year classes the stock biomass and thus the catch rates are expected to increase through 1986.

The fully recruited fishng mortalities indicate that since 1970 this stock has never been fished below $F_{0.1}$, and only in 1977 was it fished below F_{MAX} (Figure 8). Terminal fishing mortalities had been consistently underestimated in assessments from 1977 to 1982 (Gagné et al. 1984). Consequently, recommended $F_{0.1}$ catches were overestimated. Presumably if a higher reference fishing mortality level, such as F_{MAX}, had been used to recommend catch levels, the levels of exploitation would have been even higher. Despite these high levels of exploitation the stock has continued to increase in size since the low period in the mid 1970s.

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Table 1. Data used to generate 1984 and 1983 age length keys for 4VsW cod.

a. 1983

Key	Gear	Period Covered	Length-Weight Coeff. a	b	No. Measured	No. Aged	Catch
1	Otter-Trawl	Jan. - March	.0103	2.971	10793	1577	8169
2	Otter-Trawl	Apr. - June	.0103	2.971	9206	558	13926
3	Otter-Trawl	July - Sept.	.0096	2.986	3187	318	5833
4	Otter-Trawl	Oct. - Dec.	.0096	2.986	10631	357	10102
5	Longlines	Jan. - June	.0103	2.971	4174	408	4076
6	Longlines	July - Dec.	.0103	2.971	6973	583	4850
7	Seines	Jan. - June	.0105	2.972	1948	178	1116
8	Seines	July - Dec.	.0105	2.972	2797	155	1493
9	USSR & Cuba	Apr. - Sept.	.0105	2.972	3385		226
10	Portugal	Apr. - May	.0096	2.986	11009		961
						TOTAL	50752

b. 1984

Key	Gear	Period Covered	Length-Weight Coeff. a	b	No. Measured	No. Aged	Catch
1	Otter-Trawl	Jan. - March	.0042	3.150	4266	575	7756
2	Otter-Trawl	Apr. - June	.0042	3.150	10676	631	14232
3	Otter-Trawl	July - Aug.	.0123	2.925	1696	252	4994
4	Otter-Trawl	Sept. - Dec.	.0123	2.925	9533	429	13364
5	Longlines	Jan. - June	.0042	3.150	4772	570	2590
6	Longlines	July - Dec.	.0123	2.925	5474	863	4601
7	Seines	Jan. - June	.0042	3.150	2870	201	1356
8	Seines	July - Dec.	.0123	2.925	1628	174	1665
						TOTAL	50558

Table 2. 4VsW cod catch at age by key in 1983 (a) and revised for 1984 (b).

a. 1983

Age	OTB				LL		SDN		USSR & Cuba	Portugal
	Q_1	Q_2	Q_3	Q_4	Q_{1-2}	Q_{3-4}	Q_{1-2}	Q_{3-4}		Q_2
1										
2								4	2	
3	218	1496	127	570	2	16	10	488	43	79
4	1211	3114	958	1745	56	190	215	525	81	156
5	1204	2442	957	1511	158	406	189	262	50	189
6	1377	1858	591	879	499	403	213	29	16	102
7	416	370	243	431	206	195	44	2	2	29
8	291	78	100	107	224	163	28		1	8
9	147	45	46	85	151	95	2	2		4
10	21	7	20	64	51	64				1
11	12	7	8	28	32	53				1
12	4	7	2	5	10	21				1
13	2	1			6	12				
14	1			1	10	4				
15	1				3	2				
16	1				1	8				

b. 1984

Age	OTB				LL		SDN	
	Q_1	Q_2	Q_3	Q_4	Q_{1-2}	Q_{3-4}	Q_{1-2}	Q_{3-4}
1								
2								
3	2	85	39	241		4	2	2
4	478	2255	640	1998	55	82	113	38
5	1012	2826	1232	2928	185	224	339	437
6	1314	1952	555	1196	196	266	254	395
7	977	1289	171	667	200	340	274	231
8	342	300	75	233	105	168	26	83
9	168	109	32	77	70	96	2	13
10	51	31	19	70	38	76		3
11	6	9	7	42	27	53	2	
12	3	4	4	10	11	28		
13	1	4	1		9	19		
14	2	2	1		3	9		
15					1	1		
16					7	5		

Table 3. 1984 4VsW catch at age.

	AVERAGE		CATCH		
AGE	WEIGHT	LENGTH	MEAN	STD. ERR.	C. V.
2	0.559	39.135	2	1.69	0.81
3	0.724	43.383	421	54.78	0.13
4	0.999	49.030	6210	234.18	0.04
5	1.422	55.006	9371	305.41	0.03
6	1.911	60.933	6113	249.66	0.04
7	2.488	66.462	4102	180.40	0.04
8	3.437	73.672	1294	82.00	0.06
9	3.776	75.476	569	53.88	0.09
10	4.964	81.933	293	36.07	0.12
11	6.837	91.766	149	15.39	0.10
12	8.098	97.471	61	7.44	0.12
13	8.945	100.589	35	5.46	0.16
14	10.230	105.566	17	3.22	0.19
15	11.849	111.091	2	1.09	0.49
16	13.037	114.259	13	2.39	0.19

Table 4. Partial recruitment estimates for 4VsW cod.

PRAV - average 1977-1981 (Gagné et al., 1984)
PR127 - estimated for 127 mm mesh (pre 1982)
PR140 - estimated for 140 mm mesh (post 1982)
PR82-84 - average PR for 1982-1983
PR79-81 - average 1977-1981 (Gagné et al., 1984)
PR70-78 - average 1968-1976 (Gagné et al., 1984)

Age	PRAV	PR127	PR140	PR82-84	PR79-81	PR70-78
3	.07	.30	.12	.07	.07	.21
4	.34	.65	.42	.34	.34	.54
5	.79	.90	.76	.65	.77	.91
6	1.00	1.00	.85	.85	1.00	1.00
7	1.00	1.00	1.00	1.00	1.00	1.00
8	1.00	1.00	1.00	1.00	.87	1.00
9	1.00	1.00	1.00	1.00	.63	1.00
10	1.00	1.00	1.00	1.00	.45	1.00

TABLE 5: 4VSW COD CATCH AT AGE

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	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
3	18721	17493	6267	17413	7684	8886	12582	14227	14881	12885	9485	3587	386	1004	1629	2034	3742	2500	3048	421
4	12497	13973	7989	17783	13724	14802	9146	13361	7507	9947	4341	3713	1073	3650	6164	5119	9724	7664	8251	6210
5	5345	10577	9456	15633	10248	13673	8809	9661	9755	7130	4549	4818	1559	4621	9145	7112	7276	9953	7368	9371
6	6130	4461	4338	8297	6073	4539	10262	8780	3823	2766	2594	2412	871	2441	4871	6147	4852	3449	5967	6113
7	3135	3256	1467	3482	2144	1942	5160	3432	2996	944	2627	1426	501	768	1162	2929	2991	2408	1938	4102
8	4477	1590	1239	895	510	759	1849	1919	3724	1323	612	611	220	213	371	1066	1455	1273	999	1294
9	2127	856	664	816	237	236	496	358	1166	413	497	184	128	112	76	319	393	674	576	569
10	1583	496	647	361	50	72	114	393	273	369	660	49	35	80	23	88	126	304	229	293
11	172	666	325	152	95	137	131	79	299	15	153	22	44	26	10	47	62	156	140	149
12	91	24	65	211	58	56	72	2	3	5	126	107	55	28	5	26	32	67	50	61
13	96	14	16	33	12	9	98	37	7	0	36	1	11	26	4	4	21	57	22	35
14	88	0	5	17	7	12	12	0	5	0	9	4	3	9	1	1	2	51	16	17
15	163	2	7	1	2	4	51	1	5	0	9	1	2	4	0	4	6	19	6	2
3+	54626	53408	32485	65094	40844	45127	48782	52250	44444	35797	25698	16935	4888	12982	23460	24896	30682	28574	28610	28637
4+	35905	35915	26218	47681	33160	36241	36200	38023	29563	22912	16213	13348	4502	11978	21831	22862	26940	26074	25562	28216
5+	23407	21942	18229	29898	19436	21439	27054	24662	22056	12965	11872	9635	3429	8328	15666	17743	17216	18409	17311	22006
6+	18062	11365	8773	14265	9188	7766	18245	15001	12301	5835	7323	4817	1870	3707	6522	10631	9940	8457	9943	12635

Table 6. Results of survivor analysis of 4VsW cod using 1974-1984 data.

WEIGHTED SURVIVORS

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
3	6	6	0	5	27	0	0	1007	7566	33556	65449
4	0	0	22	8	8	11	0	825	2050	23023	70127
5	0	0	17	33	0	9	43	79	1067	4136	29923
6	0	0	0	29	27	18	17	72	146	2308	6404
7	0	0	0	27	27	80	35	37	150	297	2938
8	0	0	55	13	70	95	157	76	85	340	844
9	157	194	75	256	79	67	248	450	288	319	670

ESTIMATED SURVIVORS FOR 1984 (WEIGHTED)

AGE	SURVIVORS	VARIANCE	STANDARD_ERROR	C.V.(0/0)
3	65449	2400645058	48996	74.86
4	103683	3649943088	60415	58.27
5	60513	1086965966	32969	54.48
6	13596	108621184	10422	76.65
7	7138	34165429	5845	81.88
8	1365	1301191	1141	83.59
9	1313	685357	828	63.05

FINAL ESTIMATION FOR K

AGE	K	LN(K)	VAR(LN(K))	STANDARD_ERROR	D.F
3	1.97	0.5575	0.2414	0.1554	1
4	1.82	0.5009	0.1969	0.1403	1
5	1.80	0.4569	0.2572	0.1604	1
6	1.74	0.4471	0.2159	0.0848	29
7	1.74	0.4471	0.2159	0.0848	29
8	1.74	0.4471	0.2159	0.0848	29
9	1.74	0.4471	0.2159	0.0848	29

Age	Pop	F
3	80404	0.0058
4	133484	0.0526
5	84227	0.1307
6	23313	0.3392
7	13214	0.4158
8	3080	0.6141
9	2228	0.3288

Table 7. Calibration results using research vessel survey numbers (5+) and numbers (5+) from sequential population analysis.

	F_t				
	0.25	0.30	0.35	0.40	0.45
Intercept	4885	2985	1577	626	62
Slope	0.46	0.53	0.59	0.64	0.67
r	0.80	0.80	0.80	0.79	0.78
Residuals					
1981	2664	2774	2925	3099	3281
1982	-4682	-4235	-3610	-2882	-2115
1983	-2175	-620	1162	3020	4842
Sum	-4193	-2081	377	3237	6008

Table 8.

WEIGHT AT AGE 4VSW COD

3/ 5/85

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
3	0.565	0.450	0.470	0.430	0.420	0.450	0.320	0.440	0.450	0.620	0.530	0.570	0.810	0.950	0.760
4	0.943	0.900	0.960	0.870	0.850	0.910	0.640	0.810	0.790	1.020	0.890	0.960	1.090	1.250	1.060
5	1.465	1.490	1.590	1.440	1.410	1.500	1.070	1.290	1.210	1.530	1.340	1.460	1.670	1.680	1.700
6	2.097	2.180	2.330	2.100	2.070	2.190	1.560	1.850	1.720	2.130	1.870	2.030	2.360	2.470	2.390
7	2.827	2.940	3.130	2.820	2.780	2.940	2.090	2.480	2.280	2.820	2.470	2.660	3.170	3.610	3.130
8	3.671	3.720	3.960	3.570	3.520	3.730	2.650	3.140	2.900	3.580	3.120	3.350	4.580	5.230	3.710
9	4.335	4.500	4.790	4.330	4.260	4.510	3.210	3.830	3.540	4.410	3.810	4.070	4.140	5.590	4.770
10	5.263	5.270	5.610	5.060	4.990	5.280	3.750	4.520	4.220	5.280	4.530	4.800	5.330	6.540	6.840
11	5.956	6.000	6.390	5.770	5.680	6.020	4.280	5.200	4.900	6.190	5.270	5.550	4.650	7.920	7.960
12	6.845	6.690	7.120	6.430	6.340	6.710	4.770	5.870	5.590	7.130	6.010	6.290	4.910	9.210	9.410
13	7.500	7.340	7.810	7.050	6.950	7.360	5.230	6.520	6.280	8.090	6.760	7.020	7.140	10.400	10.630
14	8.000	7.930	8.440	7.620	7.510	7.950	5.650	7.140	6.960	9.050	7.510	7.740	8.590	9.750	10.030
15	9.025	8.470	9.010	8.140	8.020	8.490	6.040	7.730	7.620	10.010	8.240	8.430	10.600	8.680	11.450

	1980	1981	1982	1983	1984
3	0.800	0.833	0.805	0.772	0.724
4	1.150	1.139	1.073	1.052	0.999
5	1.600	1.693	1.580	1.531	1.422
6	2.210	2.133	2.393	2.150	1.911
7	3.080	2.965	2.779	3.086	2.488
8	4.310	3.941	4.074	3.617	3.437
9	5.260	5.698	5.492	4.331	3.776
10	6.920	7.163	7.078	5.798	4.964
11	7.560	7.673	8.743	6.987	6.837
12	10.190	9.261	9.097	9.101	8.098
13	7.920	11.868	11.428	10.585	8.945
14	8.130	8.654	10.589	11.545	10.230
15	14.450	9.836	12.484	13.987	11.849

Table 9. Calibration results using standardized catch rate and exploitable population biomass from sequential population analysis.

	F_t			
	0.35	0.40	0.45	0.50
Intercept	-22681	-14863	-8784	-3924
Slope	87.1	78.7	72.1	66.8
r	.93	.94	.94	.93
Residuals				
1981	-3466	-3051	-2725	-2461
1982	-3251	-4759	-5927	-6856
1983	29017	21006	14782	9811
1984	13751	2610	-6060	-13000
Sum	36051	15803	70	-12506

Table 10.

4VSW COD BEGINING OF THE YEAR POPULATION NUMBERS WITH F=.4. 6/ 5/85

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
3	85082	82139	83088	105977	74814	51891	63903	48688	46253	36582	33839	40367	50052	46131	44113	74150	69027	80981	69033	16815
4	45117	52720	51421	62356	71011	54300	34444	40935	26989	24404	18292	19123	29804	40630	36860	34642	58868	53129	64040	53762
5	17759	25631	30520	34871	34962	45721	31064	19925	21425	15304	10980	11048	12297	23430	29963	24601	23731	39399	36563	44965
6	15848	9703	11414	16432	14405	19352	25061	17462	7572	8715	6079	4874	4686	8657	15002	16257	13706	12846	23251	23269
7	8299	7428	3908	5420	5946	6299	11737	11233	6352	2740	4632	2630	1808	3049	4879	7875	7748	6831	7396	13637
8	7707	3958	3136	1872	1287	2928	3400	4941	6091	2490	1389	1416	863	1027	1801	2943	3798	3637	3415	4302
9	4764	2259	1802	1446	723	592	1710	1110	2309	1618	841	583	606	507	648	1139	1445	1793	1826	1892
10	2885	1976	1075	874	446	377	271	952	585	835	951	239	311	380	314	462	644	828	858	974
11	302	930	1169	295	389	320	244	119	423	232	350	181	151	223	239	237	298	413	402	495
12	135	92	159	663	104	233	138	81	26	76	176	148	128	84	159	187	151	188	197	203
13	150	29	53	71	352	32	140	48	65	18	58	30	24	55	44	126	129	95	93	116
14	108	36	11	29	28	277	18	26	6	47	15	15	24	10	22	32	99	87	26	57
15	690	8	30	4	8	17	216	4	21	0	38	4	8	17	0	17	25	80	25	7
3+	188847	186908	187785	230311	204475	182338	172347	145523	118117	93061	77641	80658	100764	124201	134043	162668	179671	200306	207127	160493
4+	103765	104770	104697	124334	129661	130448	108443	96835	71864	56479	43802	40291	50711	78070	89930	88518	110644	119325	138094	143678
5+	58648	52050	53276	61978	58650	76148	73999	55900	44875	32075	25509	21169	20908	37440	53070	53875	51776	66196	74054	89917
6+	40889	26419	22756	27106	23688	30427	42935	35975	23449	16770	14529	10120	8611	14010	23108	29275	28045	26797	37491	44951

Table 11.

4VSW COD FISHING MORTALITIES WITH F=.4 6/ 5/85

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
3	0.279	0.268	0.087	0.200	0.120	0.210	0.245	0.390	0.439	0.493	0.371	0.103	0.009	0.024	0.042	0.031	0.062	0.035	0.050	0.028
4	0.365	0.347	0.188	0.379	0.240	0.358	0.347	0.447	0.367	0.599	0.304	0.242	0.041	0.105	0.204	0.178	0.202	0.174	0.154	0.136
5	0.404	0.609	0.419	0.684	0.391	0.401	0.376	0.768	0.700	0.723	0.612	0.658	0.151	0.246	0.411	0.385	0.414	0.327	0.252	0.260
6	0.558	0.709	0.545	0.817	0.627	0.300	0.602	0.811	0.816	0.432	0.638	0.792	0.230	0.373	0.444	0.541	0.496	0.352	0.334	0.340
7	0.540	0.662	0.536	1.238	0.508	0.417	0.665	0.412	0.737	0.479	0.986	0.915	0.366	0.326	0.305	0.529	0.556	0.493	0.342	0.400
8	1.027	0.587	0.574	0.752	0.576	0.338	0.919	0.561	1.126	0.885	0.667	0.648	0.331	0.260	0.258	0.511	0.551	0.489	0.391	0.400
9	0.680	0.543	0.523	0.977	0.450	0.581	0.386	0.441	0.817	0.332	1.058	0.429	0.266	0.280	0.138	0.370	0.357	0.537	0.429	0.400
10	0.932	0.325	1.094	0.609	0.132	0.237	0.625	0.610	0.725	0.670	1.458	0.257	0.133	0.264	0.083	0.236	0.244	0.521	0.349	0.400
11	0.993	1.568	0.367	0.844	0.314	0.642	0.901	1.325	1.516	0.074	0.660	0.144	0.387	0.138	0.047	0.248	0.261	0.539	0.485	0.400
12	1.357	0.342	0.602	0.434	0.962	0.309	0.862	0.028	0.137	0.075	1.557	1.606	0.641	0.458	0.035	0.167	0.266	0.502	0.328	0.400
13	1.223	0.781	0.403	0.718	0.038	0.366	1.488	1.953	0.128	0.000	1.165	0.037	0.693	0.732	0.105	0.036	0.198	1.102	0.302	0.400
14	2.342	0.000	0.727	1.035	0.318	0.049	1.271	0.000	6.975	0.000	1.072	0.356	0.149	7.562	0.051	0.035	0.022	1.030	1.156	0.400
15	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.400

Table 12.

4VSW COD MEAN POPULATION BIOMASS WITH F=.4

6/ 5/85

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
3	38203	29513	33947	37552	26884	19158	16502	16182	15378	16361	13666	19847	36594	39256	29782	52972	50590	58126	47153	10886
4	32496	36552	40907	41191	48825	37861	16976	24409	16272	17144	12787	14841	28873	43783	32138	33170	55223	47548	56747	45616
5	19525	26186	36178	33335	37213	51543	25266	16470	17097	15287	10074	10830	17319	31759	38107	29801	30025	48374	45037	51252
6	23301	13892	18753	21662	20284	33350	26882	20325	8176	13760	7697	6275	8989	16274	26430	25374	21059	23618	38740	34359
7	16575	14633	8658	8106	11843	13821	16416	20836	9402	5608	6702	4217	4377	8557	11988	17220	16117	13692	17621	25514
8	16297	10193	8645	4312	3150	8448	5422	10862	9785	5440	2898	3197	3066	4303	5360	9078	10526	10709	9327	11119
9	13732	7175	6144	3681	2265	1854	4154	3140	5130	5533	1824	1763	2006	2252	2622	4565	6313	6966	5872	5371
10	9089	8100	3383	3034	1892	1615	693	2948	1611	2945	2102	922	1411	1990	1871	2590	3724	4174	3828	3636
11	1050	2618	5700	1055	1729	1301	633	317	992	1256	1236	850	533	1500	1687	1442	1835	2554	2035	2547
12	470	473	778	3157	389	1224	405	426	123	475	499	431	426	568	1335	1594	1119	1231	1395	1235
13	601	133	312	328	2175	182	353	128	346	135	213	190	115	374	400	888	1268	606	777	783
14	312	260	59	127	167	1950	55	167	5	382	64	88	174	12	193	233	771	530	163	435
15	4904	56	210	27	53	113	1027	26	127	0	247	28	71	116	0	193	197	782	280	59
3+	176556	149785	163674	157567	156869	172421	114784	116236	84443	84326	60011	63479	103953	150745	151911	179119	198768	218909	228976	192812
4+	138353	120272	129727	120015	129985	153263	98282	100054	69065	67964	46345	43633	67359	111489	122129	126147	148178	160783	181823	181926
5+	105857	83720	88820	78824	81160	115402	81305	75645	52793	50820	33558	28792	38486	67706	89991	92977	92955	113235	125076	136310
6+	86332	57534	52642	45489	43947	63859	56039	59175	35696	35533	23484	17961	21167	35947	51885	63176	62930	64861	80039	85058

Table 13. Input data used for catch projections.

Age	Numbers (000's) 1984	Catch (000's) 1984	Weight (kg)	Partial Recruitment
3	43000	421	.767	.07
4	53762	6210	1.041	.34
5	44965	9371	1.511	.66
6	23269	6113	2.151	.85
7	13637	4102	2.784	1.00
8	4302	1294	3.709	1.00
9	1892	569	4.553	1.00
10	974	293	5.947	1.00
11	495	149	7.522	1.00
12	203	61	8.765	1.00
13	116	35	10.319	1.00
14	57	17	10.788	1.00
15	7	2	12.773	1.00

Table 14. Projected catch levels to 1986 given 2 options for 1985, the previous TAC of 55,000 t or $F_{0.1}$ catch.

Option for 1985 Catch	Catch (t) 1985	1986
$F_{0.1}$	33,000	39,000
Previous TAC	55,000	35,000

Table 15. Exploitable biomass and predicted standardized CPUE for 1984-86.

Year	Exploitable Biomass ('000 t)	CPUE
1984	129	1.8
1985	155	2.2
1986	175	2.4

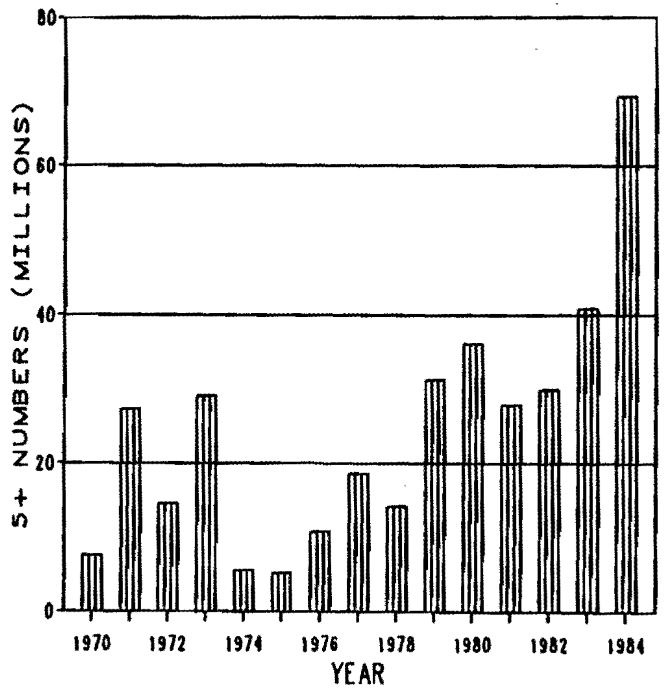


Figure 1. 4VsW cod 5+ population numbers estimates from research surveys.

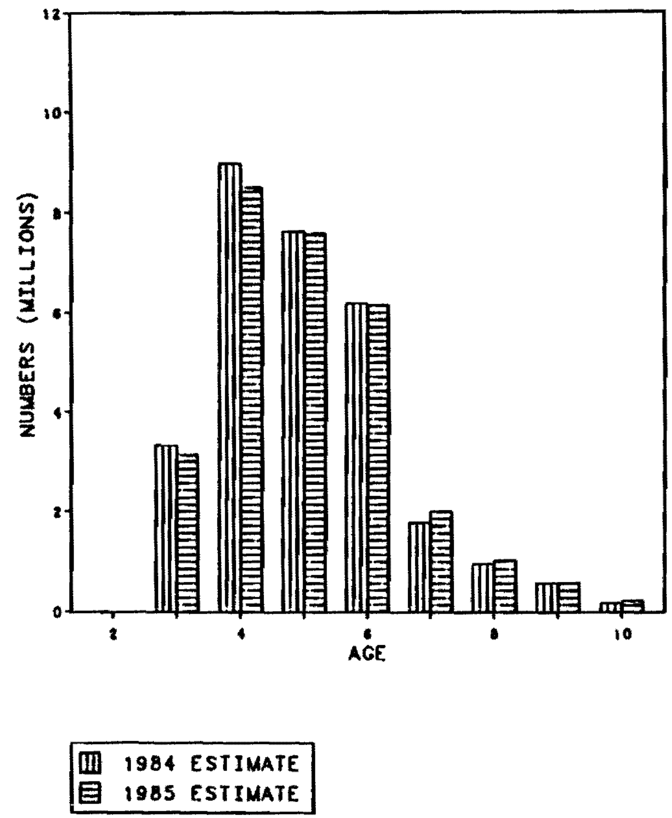


Figure 2. Comparisons of the catch-at-age of 4VsW cod estimated in the last assessment (1984) and in this assessment (1985).

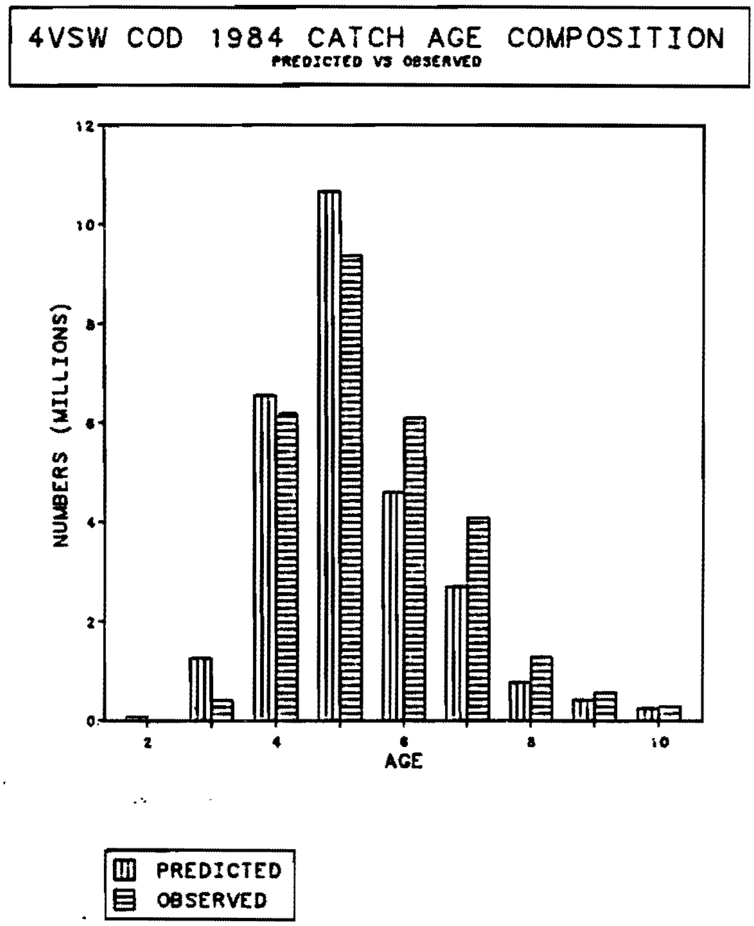
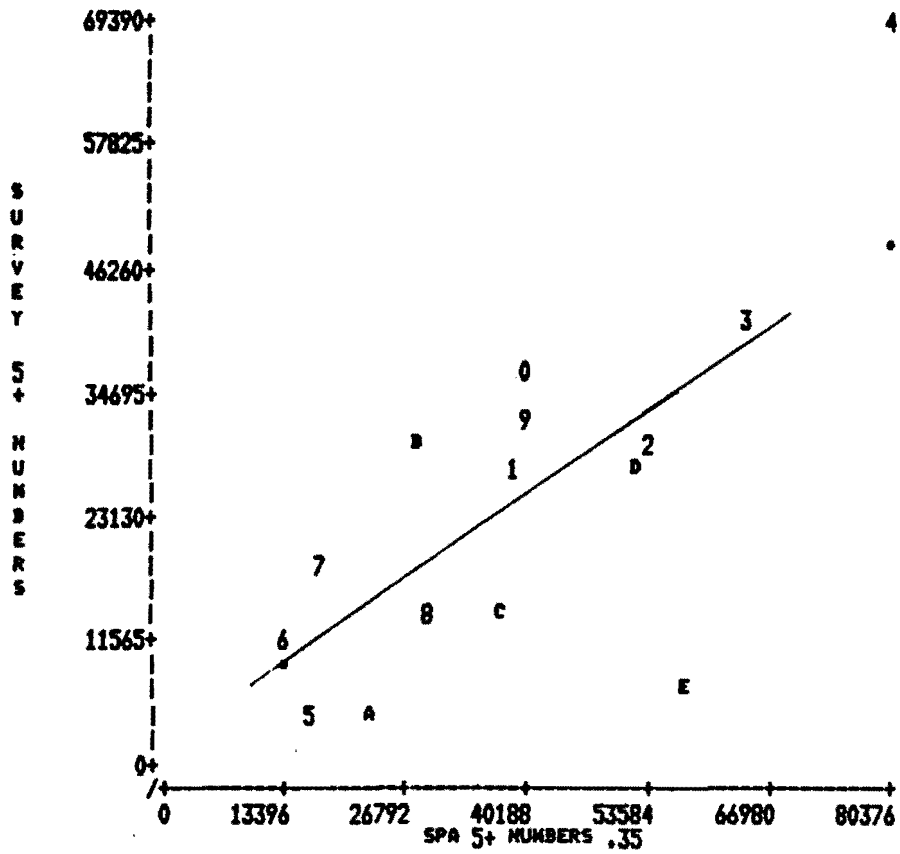


Figure 3. Comparison of the projected and observed 1984 4VsW cod catch-at-age.



S	YEAR	RESIDUALS	IND	DEP
E	1970	1	57955	7631
D	1971	¯5518	52705	27415
C	1972	¯9131	37267	14617
B	1973	10735	28509	29273
A	1974	¯9126	22106	5603
5	1975	¯6222	16649	5260
6	1976	888	14036	10816
7	1977	6749	17389	18672
8	1978	¯5156	30007	14273
9	1979	5690	40525	31377
0	1980	10615	40448	36256
1	1981	2925	39504	28004
2	1982	¯3610	53973	30077
3	1983	1162	64263	40971
4	1984	1	80373	69385

Figure 4. Plot of research survey 5+ numbers and SPA 5+ mean numbers at F_t = .35.

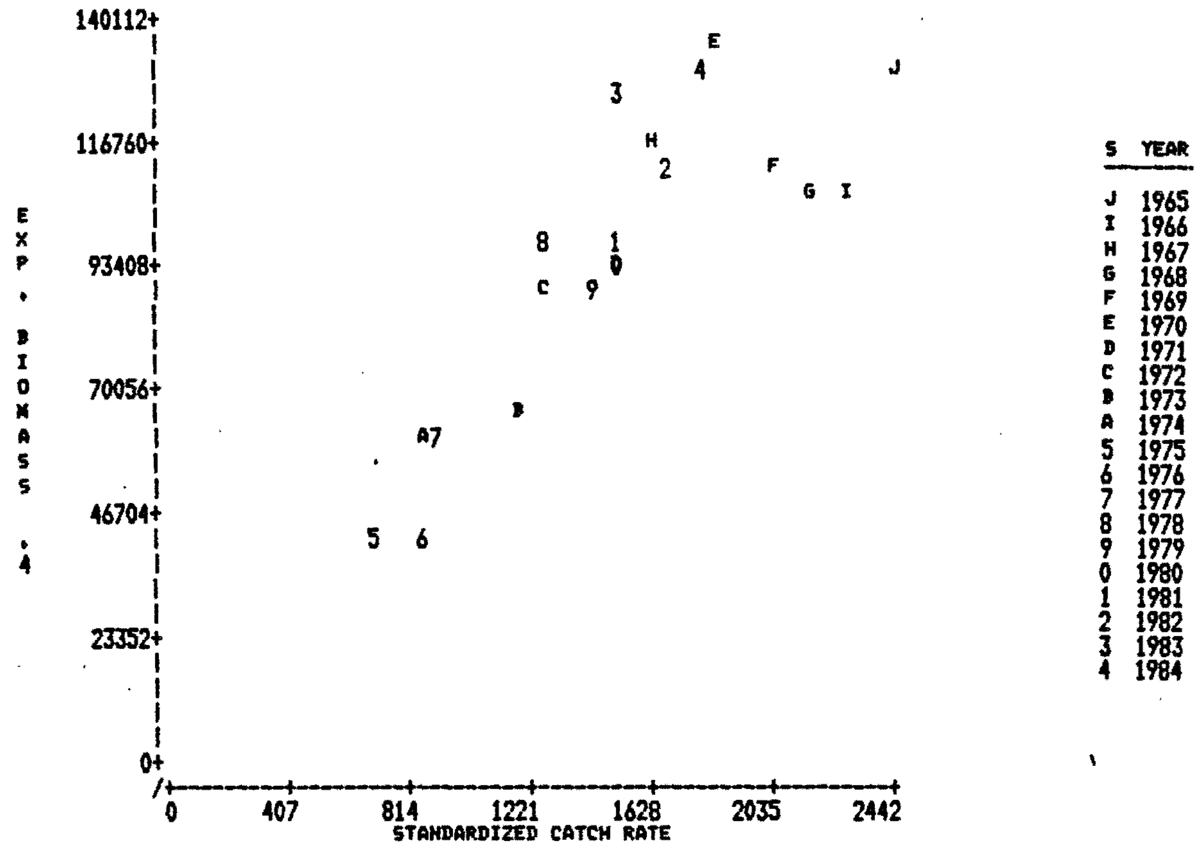
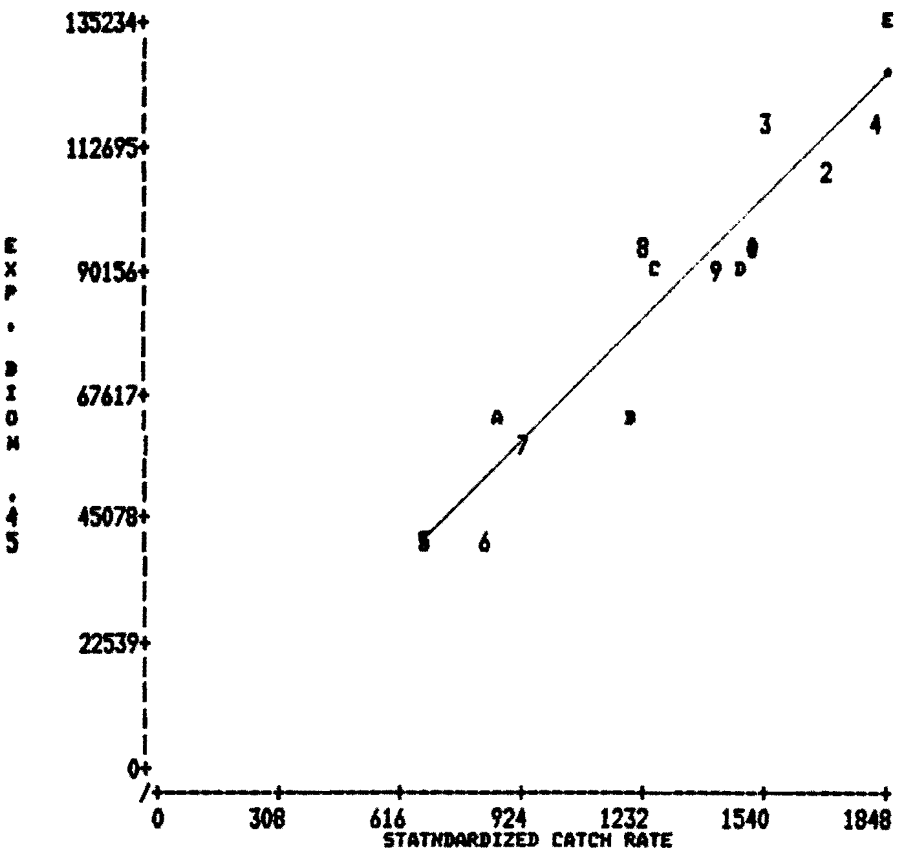


Figure 5. Plot of SPA exploitable biomass vs standardized catch per unit effort showing the 1965, 66, 68, and 69 points as outliers.



S	YEAR	RESIDUALS	IND	DEP
E	1970	10753	1848	135231
D	1971	¯6782	1487	91664
C	1972	7655	1274	90741
B	1973	¯13980	1193	63265
A	1974	8367	867	62103
5	1975	1660	686	42344
6	1976	¯12341	845	39809
7	1977	2947	910	59784
8	1978	14901	1245	95896
9	1979	¯5167	1421	88520
0	1980	¯8084	1518	92598
1	1981	¯2725	1496	96370
2	1982	¯5927	1686	106870
3	1983	14782	1525	115969
4	1984	¯6060	1802	115102

Figure 6. Plot of SPA exploitable biomass vs standardized catch per unit effort at F_t = .45.

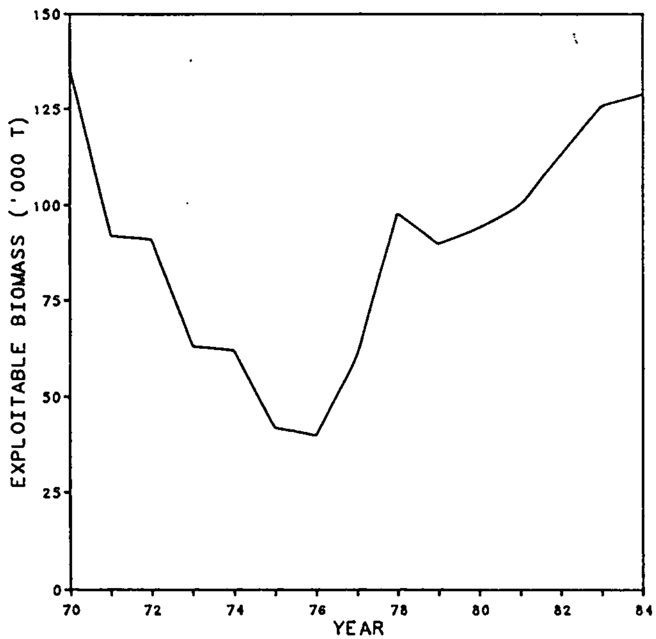


Figure 7. Trend in exploitable biomass for 4VsW cod from 1970 to the present.

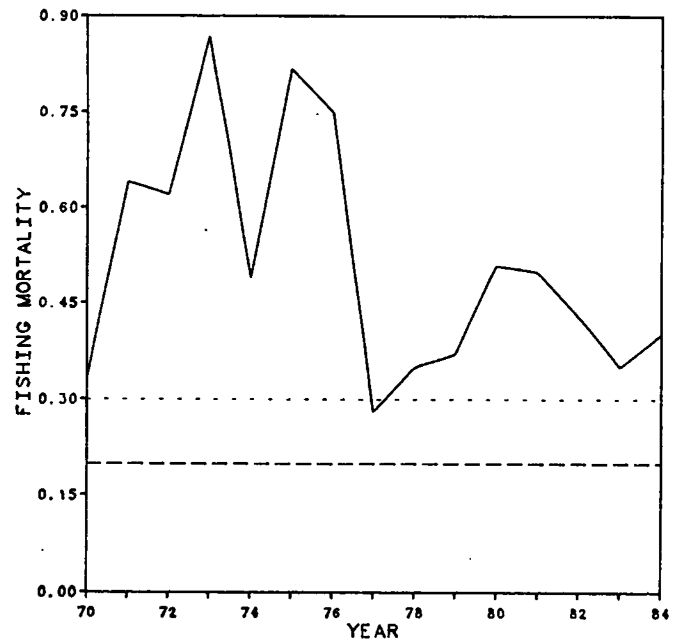


Figure 8. Trend in fully recruited fishing mortality (6+/7+) for 4VsW cod from 1970 to the present. Current estimates of $F_{0.1}$ and F_{MAX} are indicated for reference purposes.