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Virtual Population Assessment of ICNAF Division 2J Cod*

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Introduction

Because of increased concern for the state of the cod stocks in Subareas 2 and 3 as a result of increased fishing intensity in recent years, it was recommended at the 1970 ICNAF Annual Meeting that detailed assessments were necessary for these stocks of the type performed by the West Greenland Cod Working Group and presented by Schumacher (1970). As a result of this, assessments have been performed for cod in ICNAF Division 2J and are described in this report. This particular area was chosen first because the sampling data were more complete and it supports one of the most important cod fisheries in the ICNAF area.

Materials and Methods

The "virtual populations" method developed by Fry (1949, 1957) and modified by Gulland (1965) and Jones (1961, 1967) has been used to estimate F. This method requires the total annual number in each age-group taken from a stock for a series of years. The period chosen for this study was 1959-69 and the basic data used were length frequencies, age-composition and age-length keys published in ICNAF Sampling Yearbooks for this period and the nominal catches published in ICNAF Statistical Bulletins for the same period. In addition age-length keys from Canada (Nfld.) research vessel cruises to the area during the period as well as those from the inshore fishery were also used to supplement or replace the Sampling Yearbook data.

Compilation of Length Composition of Otter Trawl Catches

The procedure used to obtain respresentative length compositions of the total catch by otter trawl in each year was identical to that used by Pinhorn and Wells (1970a) for mesh assessment studies and is as follows:

* This is a revised version of a Report to the Mid-term Meeting of Assessments Subcommittee, 25-30 January 1971.

Total catches by country and quarter were obtained by applying appropriate discard rates to the landings of each country in each quarter for each year (Table 1). These discard rates were calculated from information supplied by member countries in Research Reports, Discard Documents and various other documents throughout the period. In years where discard rates were unknown for a country they were estimated from known rates in other years for the same country or from rates for countries with related fishing practices or by using a rate of 5% which is close to the overall average for the period. From a knowledge of average weights of fish caught, total numbers caught could be calculated for each month, quarter and year as needed for each country. Where these average weights were not supplied in the Sampling Yearbooks, they were calculated from average lengths by the length-weight relationship of May (1966a). Per mille length frequencies for each country reporting frequencies for each month were then adjusted to numbers caught by that country in that month. These monthly frequencies were then combined by quarter for each country and the frequencies of all countries reporting then combined for the quarter. This frequency was then adjusted to the numbers caught by all countries in each quarter. Quarterly frequencies were then combined to produce annual catch frequencies by all countries.

Compilation of Numbers Caught at each Age

Two methods were used to estimate numbers of cod caught at each age. The first of these was identical to that used by Wells and Pinhorn (1970) and is as follows: Per mille age compositions of otter trawl catches for each month and country reported in ICNAF Sampling Yearbooks were adjusted to numbers caught in that month by that country. These monthly age compositions were combined by quarters and adjusted to the numbers caught by all countries in each quarter. Quarterly age-compositions were then combined to produce the annual number caught per age-group. This method was used for the 1964-68 period. The second method was used for the entire 1959-69 period and consisted of applying the quarterly age-length keys of each country reported in Sampling Yearbooks to the quarterly length-composition of the otter trawl catches as derived above. In addition Canada (Nfld.) age-length keys from research vessel survey cruises and from samples from the inshore fishery by various gears were used where available. This method produced several estimates of the numbers caught at each age for some quarters and served as a means of validating the age-length keys from various sources. In quarters where no age-length keys were available other keys were used as follows: For the first quarter age-length keys from the second quarter were used if available; otherwise those from one of the adjacent years was used. For the fourth quarter keys from adjacent years were used. For the second and third quarters keys were available for all years except 1959 where 1960 keys had to be used for the third quarter. These quarterly age compositions of otter trawl catches were then compiled into annual compositions by combining minimum, maximum and average estimates of numbers caught at each age producing three sets of estimates of numbers caught at each age in each year. To these were then added the estimates of numbers caught by the Canada (Nfld.) inshore fishery as determined by applying age compositions averaged for all gears to the estimated number caught by this fishery in each year. The "virtual population" technique as modified by Jones (1967) was then applied to each of these estimates of numbers caught at each age to produce three series of estimates of F for the 1959-67 period.

Although no accurate value for M is available at present, age distributions in earlier years when fishing effort was low and calculations based on the change in effort from a low level to a high level (Silliman Method) indicate that M is probably in the vicinity of 0.2 (May, 1966b) and this figure was used in the present analysis. Based on this assumption a value of E of 0.7 and of $E(1-E^{-Z})$ of 0.342 for the oldest age-group was taken from Wells and Pinhorn (1970).

Results

Accuracy of length compositions of the catches

To assess the accuracy of length compositions of the otter trawl catches, Canada (Nfld.) research length frequencies for quarters in which they were available were adjusted to the minimum regulation mesh size in force during the particular year and compared with the length compositions of the commercial catches. In this way compositions could be compared in 9 quarterly periods and in 7 of these the agreement between the two was considered quite satisfactory for assessment purposes (Fig. 1). However, in the 4th quarters of 1966 and 1967, the commercial length compositions contained more of the smaller fish than the research length compositions although the 1967 compositions are still fairly similar. Therefore the commercial length compositions represent what would be expected to be caught by vessels using an otter trawl of minimum regulation mesh size as determined from research vessel surveys in the same area and this indicates that they are probably representative of the actual catch by the otter trawler fishery.

Accuracy of age compositions of the catches

To provide some estimate of the accuracy of the age composition of the otter trawl catches, average ages of the actual compositions determined by applying age-length keys as described above were compared with those calculated from the average lengths of the length compositions using growth curves determined in 1959-62 from Canada (Nfld.) research age-length keys and in 1963-68 from commercial age-length keys published in the Sampling Yearbooks. Although the differences between the two average ages are quite variable from year to year, except for 1959 and 1960 the differences are all less than one year and in some cases the agreement is extremely close (Table 2). As a further means of examining the variations in age compositions derived from different age-length keys, the minimum and maximum estimates of the numbers caught at each age are plotted for each year in Figure 2. Again the differences are not large except in 1964 and maybe 1968 and they indicate these age-compositions are probably accurate enough for our purposes. The average estimates of the number caught at each age for 1964-68 from applying age-length keys are practically identical to the estimates obtained by adjusting age distributions as described above (Fig. 3).

Fishing mortality

Table 3 shows average estimates of numbers of cod caught per year and age-group obtained by applying age-length keys to length compositions as described above. Table 4 shows fishing mortality estimates calculated from the figures in Table 3. These estimates differ somewhat from those presented at the Mid-term Meeting of the Assessments Subcommittee, January 1971 for the following reasons:

(a) The assumed values of E and $E(1-e^{-Z})$ for the oldest age-groups in the previous calculations were 0.6 and 0.236, respectively. On further analysis of the data it was obvious that these estimates were too low and resulted in estimates of fishing mortality (F) by the Jones Method which were also too low compared with estimates by the Gulland Method, especially in the later years (Fig. 4). Consequently, values of 0.7 and 0.343 were assumed in the present calculations and these produced estimates of F by the Jones Method which were almost all very close to the Gulland estimates (Fig. 4). Since the Gulland estimates were affected very little by the change from 0.6 to 0.7, the latter value (0.7) is probably closer to the true value.

(b) In the previous calculations no account was taken of the obvious fact that when the oldest age of a year-class is less than the age of full recruitment, an adjustment in the assumed E of the oldest age is necessary since the exploitation rate for the younger age is obviously not as high as for the fully recruited age, where E was assumed to be 0.7.

(c) The 1969 sampling data were included in the present calculations. These changes did not alter the general conclusions from the Mid-term Meeting (ICNAF Comm. Doc. 71/1).

It can be seen that F for ages 4-13 increased from 0.06 in 1959 to 0.36 in 1961 and 0.38 in 1962 and then decreased to a level of 0.28-0.38 during 1963-68 except for 1965 when the level increased to 0.57 for one year only. This was caused by a high proportion of older fish in the catches in 1965. It can also be seen that the cod are fully recruited to the gear in the area at 8 years of age and 50% recruited at about 6 years of age with insignificant numbers of 2- and 3-year-old fish being taken.

Stock size

Numbers present at the beginning of the year were calculated from fishing mortality estimates and numbers caught at each age for each year (Table 5 and Fig. 5). It is obvious that the numbers of older fish in the stock (7+) have declined in recent years. However, indications are that the total stock has not declined accordingly and in fact has increased in 1966-68 as a result of better recruitment in these years from year-classes in the early 1960's. The extent of this increased recruitment may be exaggerated in the stock table (Table 5) especially in relation to estimates of stock size at age 4 since the fishing mortality estimates for this age in Table 4 are 0.02-0.03 and errors in these estimates seem to lead to large errors in the estimate of stock size at this age. Also, there may have been a shift in the fishery from older spawning fish to the younger recruiting ages especially since recruitment was better in this period. This shift may have some effect on the F-values estimated for these ages. However, even disregarding the 4-year-old fish and considering the 5- and 6-year-old fish, where fishing mortality estimates were more reliable, the increase in recruitment is still apparent in 1966-68. The fishery has become increasingly dependent on these younger age-groups recruiting to the fishery and fluctuations in year-class strength, although not as great as in the southern stocks, will probably influence the success of the fishery more in the future.

Yield per recruit

Yield per recruit calculations incorporating the partial recruitment estimates shown in Table 4 produced a curve somewhat similar to that presented by Pinhorn and Wells (1970) (Fig. 6). The level of fishing mortaltiy in 1961-68 has been within 92-98% of the maximum sustained yield per recruit and may have been beyond this point in one year (1965) although the validity of this fishing mortality estimate may be questionable since the fishing effort did not increase accordingly in this year. This may have arisen from some inadequacy in the sampling data in 1965 but re-examination of the data failed to reveal it. These older cod may have been concentrated by hydrographic conditions in 1965 and may have been more susceptible to capture as a result of this. In any case these virtual population assessments have substantiated the conclusion drawn from the previous catch/effort assessment that further increases in fishing mortality will not give a long-term increase in yield, although short-term increases in catch in particular years may result from increased recruitment and/or from pecularities of cod distribution in relation to temperature variations. Increased catches would reduce the abundance of the stock.

Fishing mortality and fishing effort

Fishing mortality values derived from average estimates of numbers caught are plotted against measures of fishing effort as determined by Pinhorn and Wells (1970b) in Figure 7. The correlation coefficient is 0.85 and the Y-intercept is -0.0217 indicating that the value for M used is probably close to the true value.

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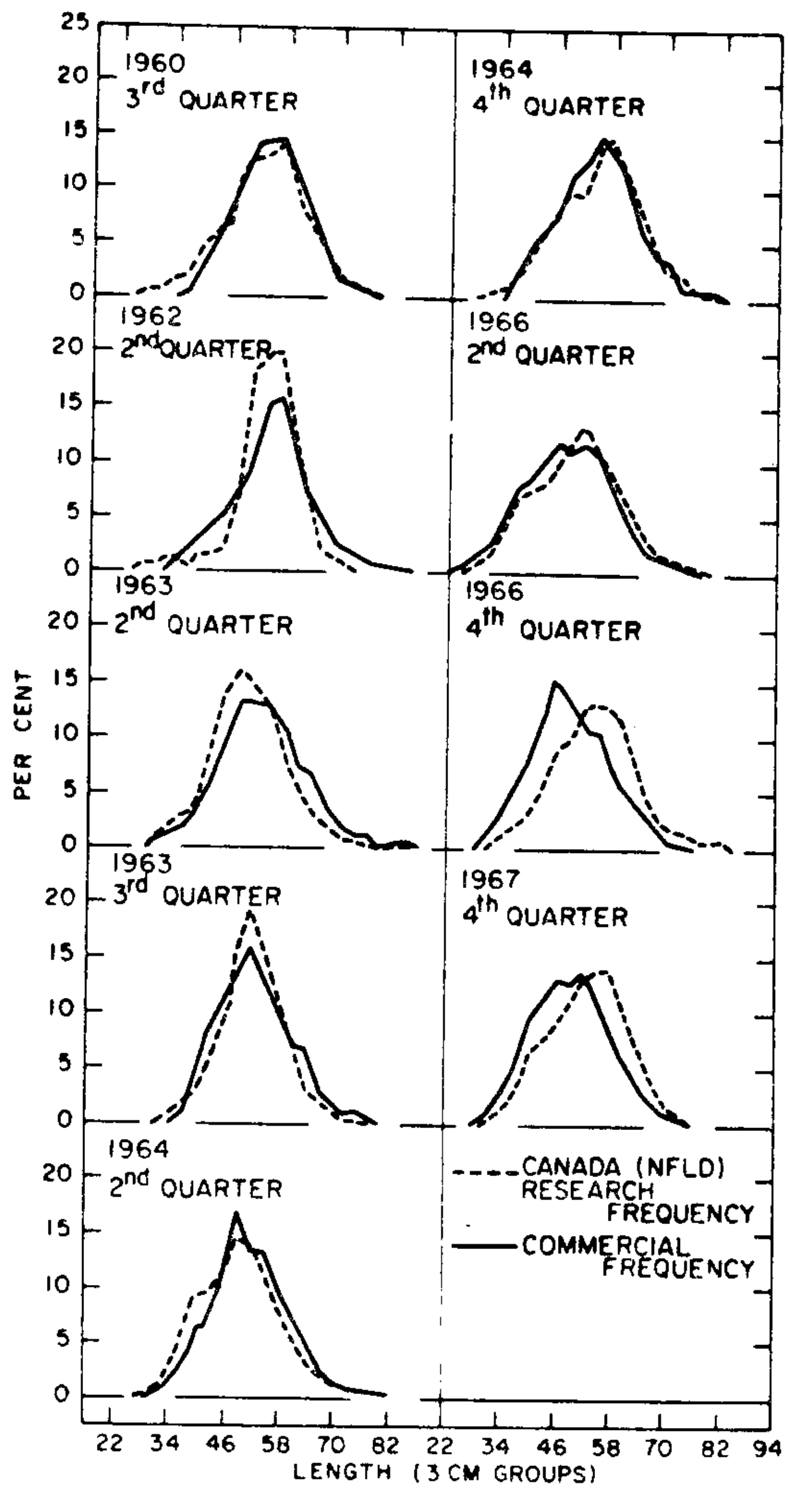

Fig. 1. Comparison of commercial catch frequencies with Canada (Nfld.) research frequencies adjusted to the minimum mesh size in force in each year, Division 2J.

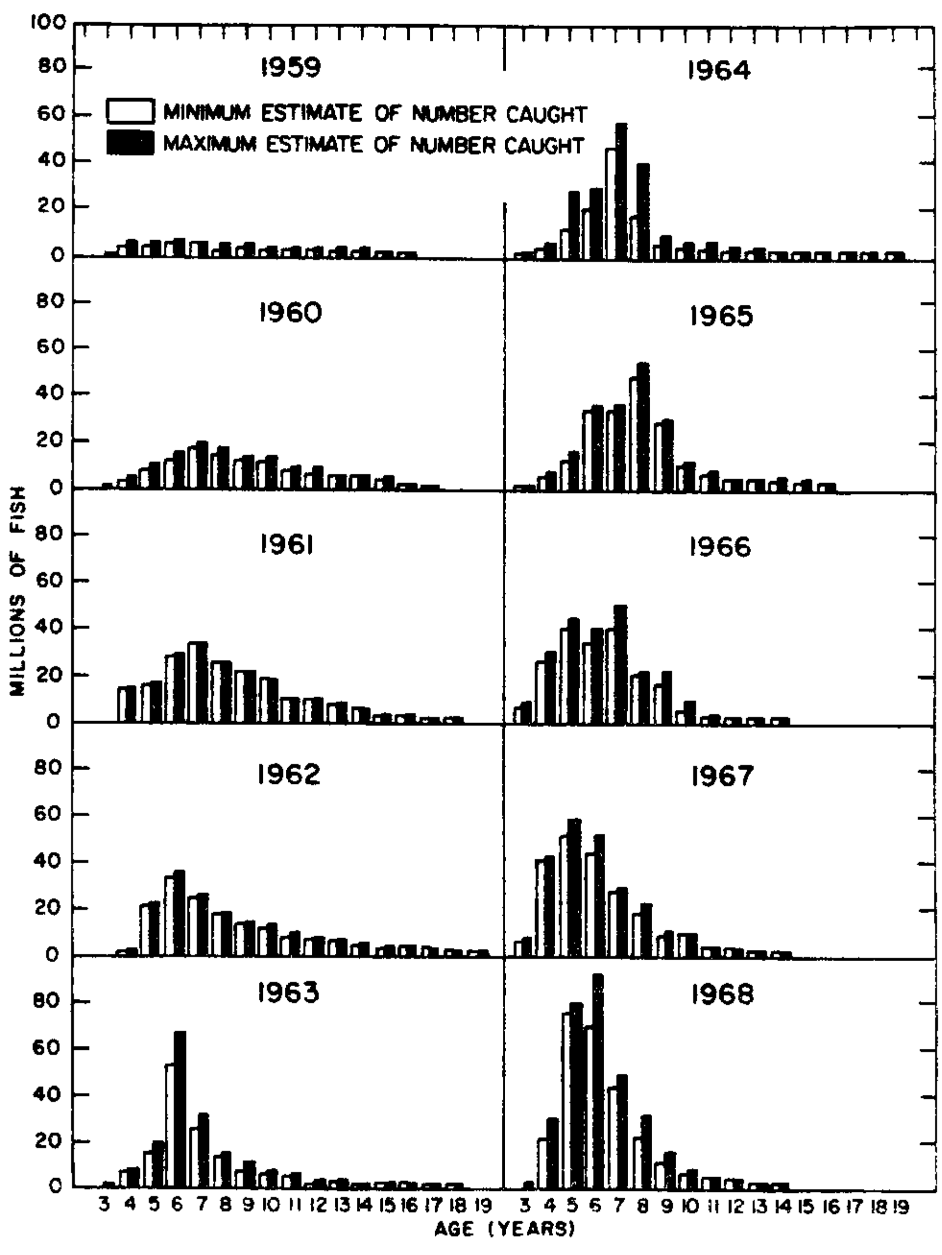

Fig. 2. Comparison of minimum and maximum estimates of numbers caught in each age-group, Division 2J, 1959-68.

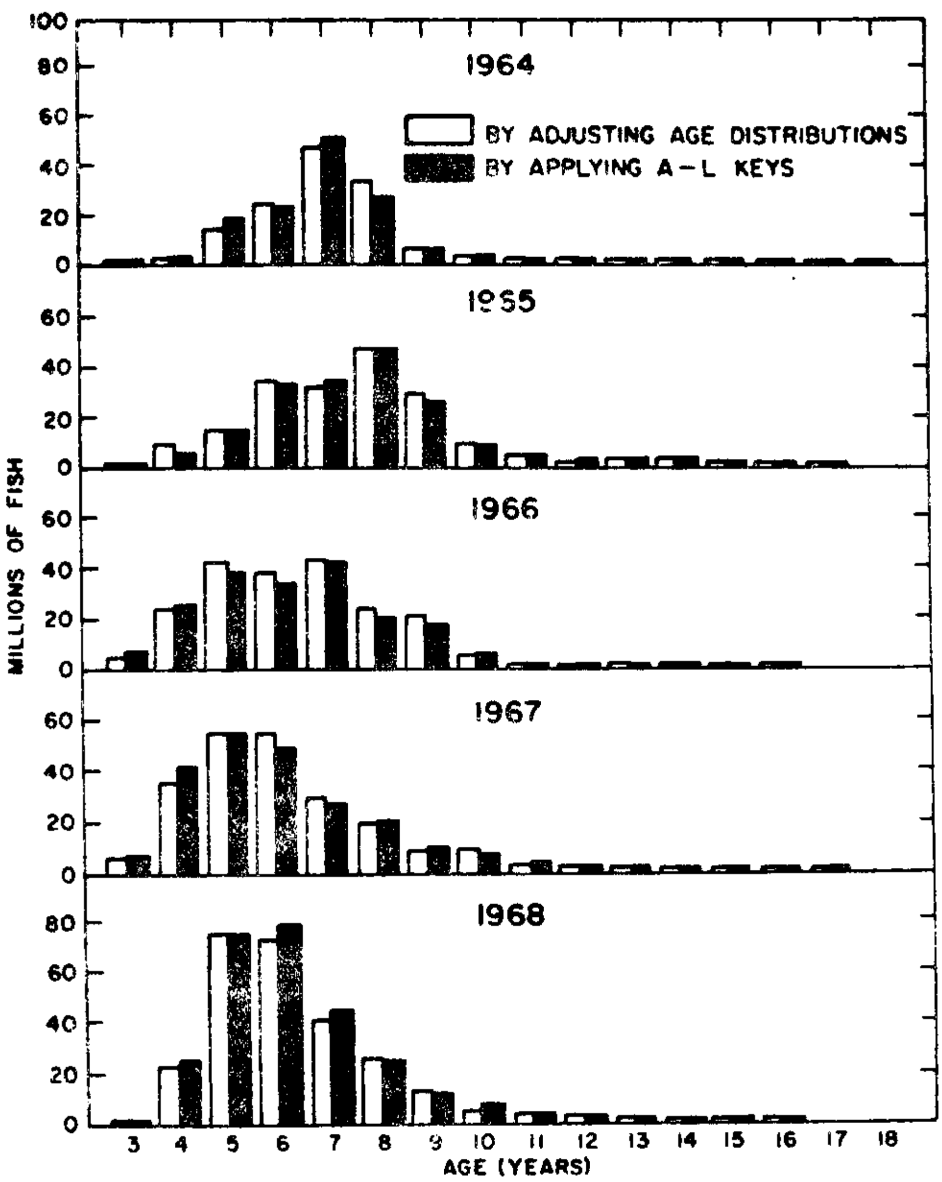

Fig. 3. Comparison of numbers in each age-group derived by applying age-length keys of various countries to the catch frequency and numbers derived by adjusting age compositions to numbers caught by each country, Division 2J, 1964-68.

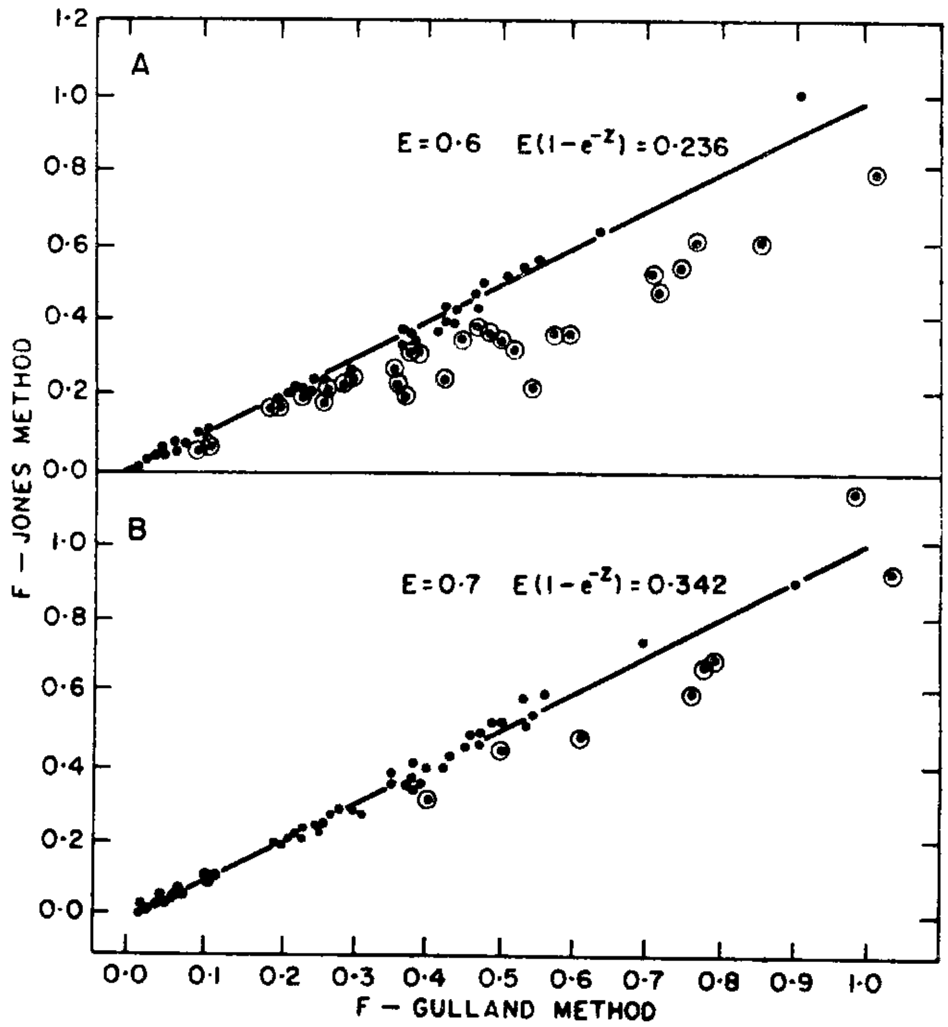

Fig. 4. Comparison of estimates of F for each age group by Gulland and Jones Methods for two different assumed values of E of oldest age-group. Circled points indicate deviations of the Jones estimates from the Gulland estimates by more than 10%.

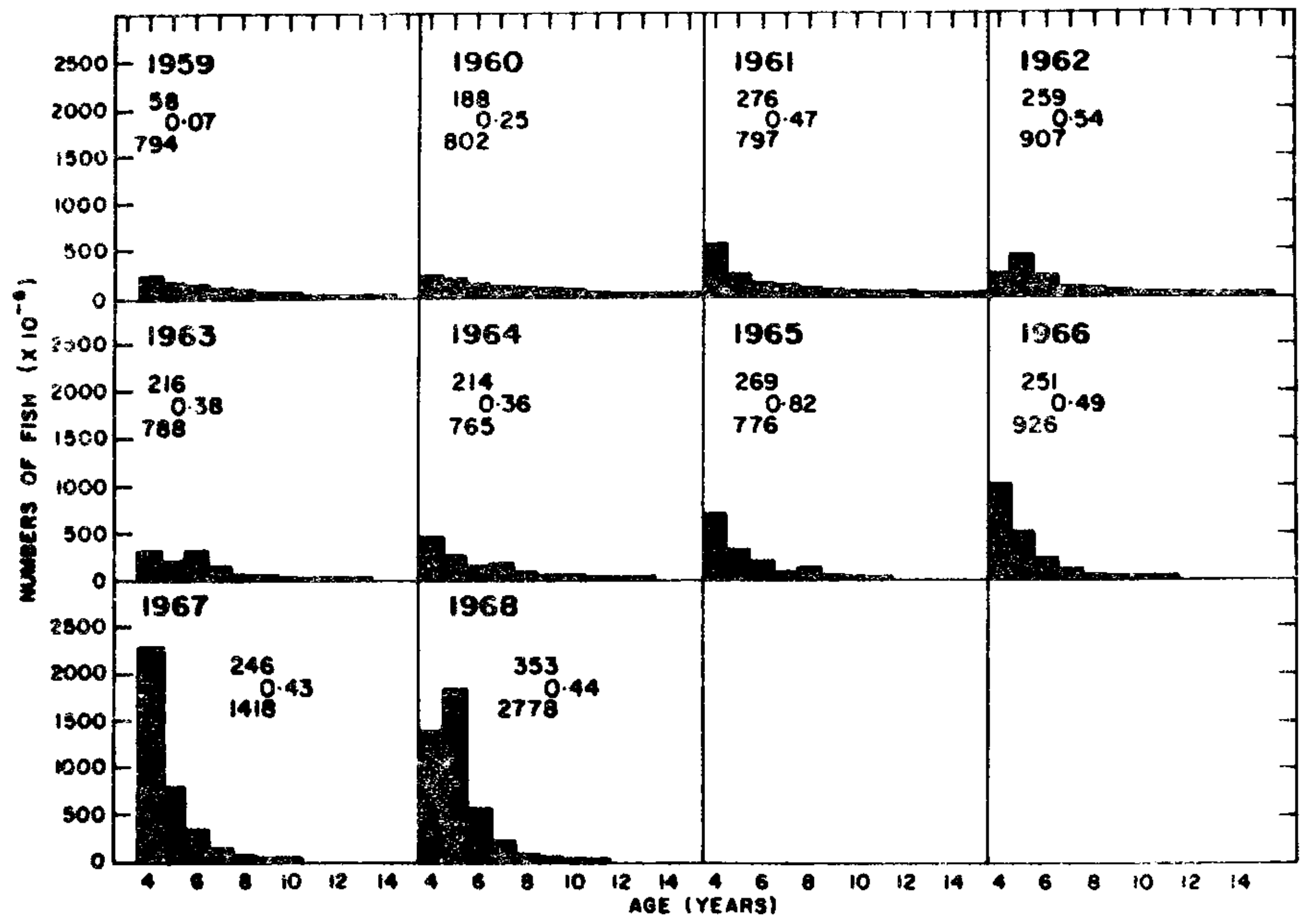

Fig. 5. Numbers of cod per age-group present in the stock at the beginning of the year, ICNAF Division 2J. Values below the date of the year: 1. Catch in 1000 tons; 2. F(8-13). 3. Total number of fish of ages 5-15.

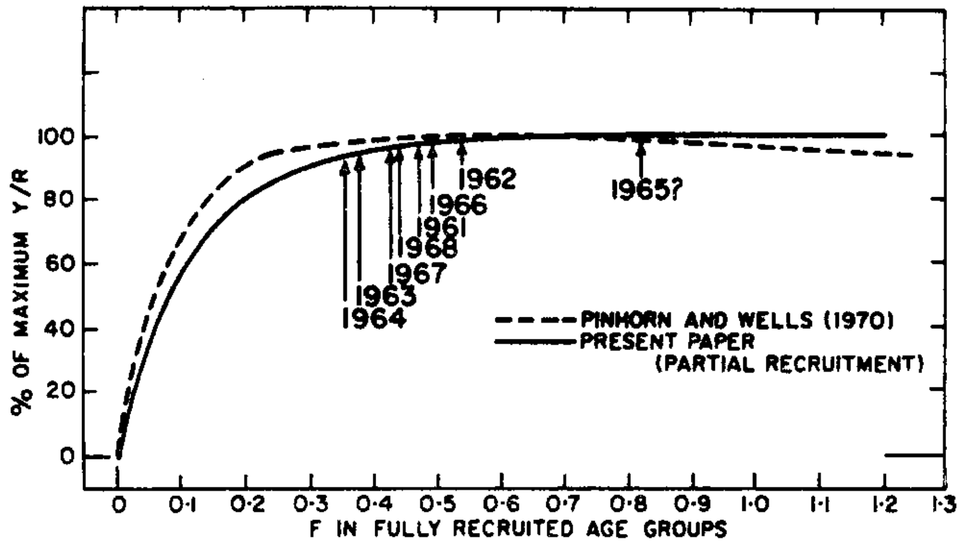

Fig. 6. Yield per recruit curves for ICNAF Division 2J cod incorporating partial recruitment estimates. Curve from previous catch/effort assessment is shown for comparison. Arrows indicate the level of F in various years.

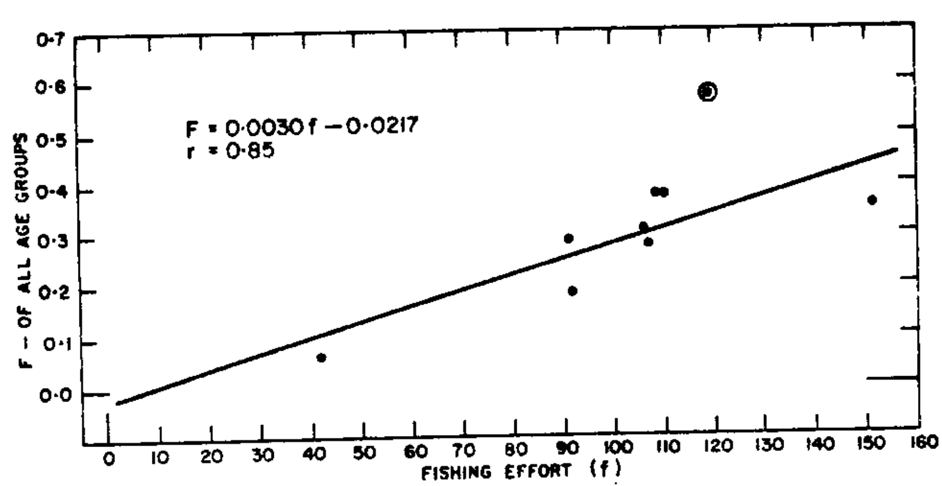

Fig. 7. Regression of estimates of F on fishing effort, ICNAF Division 2J, 1959-67. Circled estimate for 1965 not included in fitting straight line because of doubt as to its validity.

Table 1. Landings and catches by gear and country for ICNAF Division 2J, 1959-69. Discard rates in brackets are assumed values based on best available data or an average of known values. In calculating discard rates it was assumed that Germany and Poland included industrial fish in nominal catches after 1965 but that USSR has not included industrial fish in any year. For other countries it was assumed that no industrial fish was produced in any year.

Country	Otter trawl												No. mea-sure-ments	Countries with measure-ments	No. meas. per 1000 tons caught	Inshore gears Can(N)	Long-line
Year	UK	Germ	Icel	USSR	Spain	Fran	Port	Can(N)	Pold	Non(M)	Others	Total					
1959																	
Landing	674	3238	132	158	5671	22963	6415	-	-	154	-	39405		USSR		17533	
% discard	(3)	(20)	(5)	(10)	(1)	(2)	(1)	-	-	(5)	-	3.6	3953	Spain	97		
Catch	695	4048	138	175	5729	23431	6480	-	-	162	-	40858		Germ			
1960																	
Landing	84	12145	-	38589	27441	42407	42721	1	-	80	569	164037		USSR		15418	
% discard	(3)	(20)	-	(10)	1	(2)	(1)	(5)	-	(5)	(5)	5.2	63480	Spain	367		
Catch	87	15182	-	42876	27717	43272	43153	1	-	84	599	172971		Port			
1961																	
Landing	1264	10184	4	108883	40826	35504	46149	-	358	-	1	243173		USSR		17545	
% discard	(3)	14.6	(5)	(10)	1	2.1	1	-	(10)	-	(5)	6.0	24259	Spain	94		
Catch	1303	11925	4	120981	41238	36266	46616	-	398	-	1	258732		Port			
1962																	
Landing	3011	745	-	56617	56853	45992	62702	-	921	-	-	226841		USSR		23424	
% discard	(3)	19.5	-	(10)	(1)	(2)	1.6	-	(10)	-	-	3.9	32503	Spain	138		
Catch	3104	926	-	62908	57427	46931	63721	-	1023	-	-	236040		Pold			
1963																	
Landing	528	828	-	19548	53201	40078	73040	1	702	-	-	187926		USSR		23767	
% discard	(3)	20.2	-	(10)	(1)	(2)	0.5	(5)	(10)	-	-	2.2	82527	Port	430		
Catch	544	1038	-	21719	53737	40896	73407	1	779	-	-	192121		Pold			

(cont'd.)

Table 1 (cont'd.)

Country / Year	Otter trawl UK	Germ	Icel	USSR	Spain	Fran	Port	Can(N)	Pold	Non(M)	Others	Total	No. mea-sure-ments	Countries with measure-ments	No. meas. per 1000 tons caught	Inshore gears Can(N)	Long-line
1964																	
Landing	1609	3207	91	56548	42705	35919	38095	13	2058	8642	300	189187		USSR		14787	
% discard	3	20.1	(5)	(10)	1	3.3	1.2	(5)	(10)	(5)	(5)	4.8	115945	Port, Pold	583		
Catch	1658	4014	96	62831	43136	37144	38558	14	2287	9097	316	199151		Spain			
1965																	
Landing	6258	31274	598	48863	51822	20662	57992	-	9398	-	339	227206		USSR		25117	
% discard	(3)	18.5	(5)	(10)	1	4	3	-	(10)	-	(5)	7.0	168662	Port	691		
Catch	6452	38374	629	54292	52345	21523	59785	-	10443	-	357	244200					
1966																	
Landing	7021	36395	208	26005	43839	25395	36530	39	17866	27745	-	221043		USSR		22645	
% discard	3	0.9	(5)	(10)	1	3	2	(5)	3	(5)	-	3.3	84842	Port	372		
Catch	7238	36725	219	28894	44281	26180	37275	41	18419	29205	-	228477		Fran			
1967																	
Landing	7280	21047	-	14366	36178	23616	46845	1	28592	34403	22	212350		USSR		26359	2367
% discard	(3)	0.6	-	(10)	1	3	1	(5)	0	(5)	(5)	2.5	184031	Port, Spain	844		
Catch	7504	21175	-	15963	36543	24347	47317	1	28592	36213	23	217677		Pold			
1968																	
Landing	9826	47868	-	83478	32852	38587	51485	4466	51301	-	186	320049		USSR		12804	8016
% discard	(3)	1	-	(10)	0	3	2	2	0	-	(5)	3.7	47929	Port, Spain	144		
Catch	10130	48352	-	92753	32852	39780	52536	4557	51301	-	196	332457		Pold			
1969																	
Landing	1449	60391	-	123295	33010	29124	59869	30	46148	-	3257	356573		USSR		4328	
% discard	(3)	1	-	(10)	0	3	2	2	0	-	(10)	4.5	62682	Port, Spain	168		
Catch	1494	61000	-	136995	33010	30025	61091	31	46148	-	3619	373413		Pold, Germ			

Table 2. Comparison of average ages calculated from length frequencies and age distributions, ICNAF Division 2J, 1959-69.

	Average ages			Average ages	
Year quarter	From length frequencies	From age distributions	Year quarter	From length frequencies	From age distributions
1959			1965		
1st	7.9	7.7-8.4	1st	7.8	8.1
2nd	6.7	7.1	2nd	7.6	7.6-8.0
3rd	8.2	8.8-9.8	3rd	6.9	6.6-6.8
4th	6.3	6.7-8.0	4th	7.5	6.8-7.0
1960			1966		
1st	9.0	9.0	1st	6.8	6.9
2nd	7.4	8.8-8.9	2nd	5.8	6.0-6.3
3rd	7.5	8.2-8.9	3rd	6.6	6.2-6.4
4th	8.2	7.8-8.5	4th	5.0	4.7-4.9
1961			1967		
1st	9.2	9.0	1st	5.6	5.8
2nd	6.9	7.7	2nd	6.4	6.4-6.7
3rd	8.4	8.6	3rd	6.0	5.5-6.1
4th	7.8	7.6-8.3	4th	4.9	5.3
1962			1968		
1st	-	-	1st	6.1	6.3-6.5
2nd	8.0	8.8	2nd	5.6	6.2
3rd	7.4	7.0-8.4	3rd	-	-
4th	6.2	7.0	4th	5.4	5.9
1963			1969		
1st	6.4	6.0	1st	6.3	6.9-7.1
2nd	7.4	7.2-7.6	2nd	7.0	6.7
3rd	7.4	6.7-7.6			
4th	6.3	6.4			
1964					
1st	7.3	7.3-7.8			
2nd	6.8	6.9-7.7			
3rd	6.2	6.8-7.7			
4th	6.6	6.6-6.8			

Table 3. Number of cod caught per year and age group, ICNAF Division 2J, 1959-69, using average estimates of numbers caught by applying age-length keys to length compositions (x 10^{-6}).

Age	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
2	-	40	-	-	76	-	-	336	71	-	-
3	132	932	92	326	1541	707	414	7048	6289	1737	699
4	4253	4099	14399	2061	7958	3943	6285	26866	40958	24888	9291
5	4864	9779	15935	22024	17666	20286	13262	40253	54160	76758	29710
6	5260	14052	28604	34910	60262	24133	34267	36332	47873	80238	87890
7	4675	18512	33790	25140	28495	52063	34670	42915	27252	46135	65617
8	3117	16307	24738	17661	13680	27678	49916	20114	18787	26434	32270
9	4380	12730	21728	13559	8808	6524	27488	18169	7872	12828	13537
10	2282	12251	17722	12694	6621	4039	9901	5769	6845	3900	7733
11	2770	7938	9091	8228	5267	3724	5045	2031	2916	3870	4010
12	2720	7042	9060	6907	2129	2158	2591	1147	1014	1440	307[illegible]
13	2193	5028	7317	6562	2588	1984	2413	926	986	601	18[illegible]
14	1567	5439	5197	4536	1637	1241	2779	515	346	596	745
15	505	3691	2390	3398	2055	918	1951	219	129	310	194
15+	554	2049	3657	9549	3692	1855	2230	554	416	339	398
Total	39272	119889	193720	167555	162475	151253	193212	203194	215914	280134	257010

Table . Fishing mortality estimates by year a age-group for cod in ICNAF Division 2J, 59-68, using average estimates of numbe caught.

Age	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968*	1969	$\bar{F}$ 1959-67 Min.	$\bar{F}$ 1959-67 Av.	$\bar{F}$ 1959-67 Max.	Change in F with age as % of F in fully recruited age-groups, 1959-67 Min.	Av.	Max.
3	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01		< 0.01	< 0.01	< 0.01	-	-	-
4	0.021	0.016	0.031	0.009	0.028	0.013	0.013	0.031	0.021	0.021		0.02	0.02	0.02	5	5	5
5	0.029	0.060	0.066	0.065	0.10	0.092	0.053	0.10	0.075	0.050		0.07	0.07	0.07	16	17	18
6	0.041	0.11	0.25	0.20	0.25	0.20	0.22	0.20	0.17	0.16		0.19	0.18	0.18	43	44	47
7	0.044	0.20	0.41	0.37	0.25	0.35	0.49	0.46	0.22	0.25		0.34	0.31	0.29	77	76	76
8	0.039	0.21	0.44	0.39	0.35	0.40	0.68	0.59	0.37	0.34		0.40	0.39	0.37	100	100	100
9	0.071	0.22	0.49	0.47	0.35	0.28	0.91	0.56	0.48	0.46		0.45	0.43	0.43	100	100	100
10	0.049	0.29	0.53	0.59	0.44	0.27	0.89	0.48	0.43	0.44		0.48	0.44	0.40	100	100	100
11	0.076	0.24	0.36	0.50	0.52	0.47	0.63	0.45	0.48	0.49		0.46	0.41	0.37	100	100	100
12	0.094	0.28	0.46	0.52	0.23	0.41	0.71	0.28	0.42	0.50		0.43	0.38	0.33	100	100	100
13	0.096	0.25	0.52	0.74	0.38	0.35	1.13	0.60	0.41	0.40		0.59	0.50	0.39	100	100	100
Min. Ages 4-13	0.05	0.19	0.41	0.47	0.33	0.24	0.68	0.37	0.35								
Max. Ages 4-13	0.06	0.18	0.32	0.33	0.26	0.30	0.50	0.31	0.30								
Av. Ages 4-13	0.06	0.19	0.36	0.38	0.29	0.28	0.57	0.38	0.31	0.31							
Av. Ages 8-13	0.07	0.25	0.47	0.54	0.38	0.36	0.82	0.49	0.43	0.44							
Effort	42	92	151	110	91	107	119	109	106	140	?						
Landing 2J	57	179	261	250	212	204	252	244	241	341	361						

Min. = F-values using minimum estimates of numbers caught.
Av. = F-values using average estimates of numbers caught.
Max. = F-values using maximum estimates of numbers caught.

* Estimated from numbers present at beginning of 1968 and catch in 1968.

Table 5. Number of fish present in the stock at the beginning of the year (x 10^{-6}), ICNAF Division 2J, 1959-68.

Age	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968
4	226	293	522	245	318	340	542	973	2179	(1324)
5	188	183	255	401	198	254	279	452	800	1747
6	145	149	142	212	300	146	191	220	341	628
7	120	113	110	90	142	192	98	127	149	233
8	91	95	75	60	50	92	111	49	67	100
9	71	71	62	40	33	29	50	46	23	38
10	53	54	47	31	20	19	18	17	22	12
11	42	41	33	23	14	11	12	6	9	11
12	33	32	26	19	11	7	6	5	3	4
13	26	25	20	14	9	7	4	2	3	2
14	19	23	15	10	5	5	4	1	1	2
15	6	16	12	7	6	3	3	1	-	1
4+	794	802	797	907	788	765	776	926	1418	2778
5+	606	619	542	506	590	511	497	474	618	1031
5-7	453	445	507	703	640	592	568	799	1290	2722
			2748					5971		
					+117%					
7+	341	357	290	204	148	173	208	127	128	170
			1340					806		
					-40%					