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Estimates of Mortality for Georges Bank Herring

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Introduction

At the ICNAF Assessment Subcommittee meeting in January, 1970 it was concluded that the catch per effort in the Georges Bank herring fishery was declining for the Polish, German and USSR fishing vessels. The decline in abundance was attributed to the passing of the strong year classes, 1960 and 1961, through the fishery and to the poor recruitment since the entry of these two year classes into the fishery. Estimates of decline in stock abundance from egg studies conducted by the USSR were more severe than the decrease estimated from catch per effort data and it was agreed that other techniques should be investigated to obtain estimates of mortality for assessment purposes. The longest series (1961-1968) of catch per effort data available for Georges Bank herring are those of the USSR, however, in 1965 and 1966 the USSR diverted part of their effort to other species (Table 1). I have tried to resolve this change in effort in 1965 and 1966 to have a complete series of catch and effort data for the estimation of mortality. I have also estimated mortality using the virtual population technique (Gulland, 1965). These estimates are only preliminary because of the limitations of the data and should not be considered as final. Hopefully, the estimates can be improved as better information becomes available.

Analysis of USSR Catch and Effort Statistics

Detailed catch and effort statistics for the USSR fishery in ICNAF Subarea 5Z were taken from the ICNAF Statistical Bulletin. In 1965 and 1966, the herring catch was listed as "mixed" or was incidental to catches of other species. When herring were caught with other species of fish, I estimated the effort expended on herring from the percent of herring in the total catch. The effort data were adjusted in this manner for five years during the period 1961 to 1967. The USSR effort, by vessel tonnage class and gear, for Georges Bank herring is given in Table 2. Apparently, the percentage catch of herring was not related to abundance as the percentages for large trawlers (greater than 1800 tons) from 1963 through 1967 except for 1965 varied only from 21-32 percent even though the abundance of herring changed considerably on Georges Bank during this period. The same situation held for the small trawlers. This provides some assurance that the by-catch of herring in tons was a function of effort and not of abundance and that the percentage by-catch of herring can be used to estimate effort. The true effectiveness of effort on herring is not known when that effort is directed toward another species and it may be quite different than when effort is directed specifically toward herring. The estimated effort for herring should be more realistic, however, than using the total effort expended for all species of fish on Georges Bank. For example, the effort used in determining catch per effort by the USSR presented in the Report of the Interim Meeting of the Assessment Subcommittee (ICNAF Comm. Doc. 70/3) is the total number of hours fished by a given vessel regardless of the composition of catch as long as that catch contained herring. If all the effort in 1965 and 1966 were credited to herring, fishing effort would be overestimated and the catch per effort for herring would be underestimated. For example, in 1966, medium USSR trawlers fished 61,000 hours in a mixed fishery taking 68,626 tons of several species of fish. Herring made up only 10.4% of the catch. Assuming the entire 61,000 hours were fished for herring produces a catch per effort of 0.12. Using 10.4% of the effort produces a more realistic catch per effort of 1.12.

The effort by otter trawling from medium trawlers rose steadily through 1964, declined in 1965 and 1966 and then increased greatly when the fishery concentrated mainly on the two strong year classes of 1960 and 1961. The number of drift nets increased greatly in 1962. This coupled with a slight increase in large trawler (greater than 1800 tons) effort produced a large increase in effort over that of 1961 and this will be reflected in the estimates of mortality. The fishing effort by the large trawlers fluctuated little except in 1965 and 1966. The effort for 1965 is probably an underestimate as it is based on a percentage catch of herring that was much lower than for the other years.

The catch of herring by large trawlers in 1966 was twice the catch in any other year even though effort was directed to other species. The catch of medium trawlers, i.e. 151 to 500 metric tons, was only about 6,000 metric tons in 1965 and 1966 compared with an average of 65,000 metric tons for the other years from 1962 to 1968. The medium trawlers caught more herring than any other tonnage class vessel in every year except 1965 and 1966. Since the 1960 and 1961 year classes were plentiful at this time the low catch for the medium trawlers is further indication that the USSR diverted effort to other species and the catch per effort for herring in 1965 and 1966 for the medium trawlers may underestimate the true abundance (Table 3). The decline in abundance as indicated by the catch per effort data is rapid after 1966.

The catch per effort data in Table 3 were used to obtain estimates of fishing power for each tonnage class. The fishing power ratios for each year were weighted by the annual catch to obtain an average value from 1961 through 1967. Using the tonnage class of 151 to 500 tons as a standard, the fishing power factors were: for 1800 metric tons and up, 2.67, for 900 to 1800 metric tons, 0.60, for 501 to 900 tons, 0.83, and for drift nets, 0.09. These values were used to obtain total adjusted fishing effort by the USSR fleet on the Georges Bank herring (Table 4). The total international fishing effort by all countries on Georges Bank herring was estimated by dividing the international catch in tons by the USSR catch per adjusted fishing effort (Table 4). The international effort and the USSR effort were the same until 1965 when nations other than the USSR also began to fish for herring.

Using the mean weights of the dominant year classes in the annual catch, an average number of fish caught per year was obtained from the weight of the total catch. The numbers of herring caught for each year were then divided into year classes using age composition data (Noskov, A.S. and G. P. Zakharow, 1963; Draganik, B., 1966; Bogdanov, A. S., personal communication). The mean lengths and weights of herring from Georges Bank are given in Tables 5 and 6. The mean weights were obtained from the length data and a regression line of weight on length provided by Draganik and Zukowski (ICNAF Doc. 67/53). Two types of curves are presented in that document, for full herring and spent herring. The conversion from length to weight was made using the curve for full herring. Estimates of catch per effort of the USSR fishery are given in Table 7. These were used to estimate total mortalities (Z) for each year class (Table 8). The mortalities are arranged both by age and year to show the increases in Z. If fishing mortality is a function of fishing effort, the mortalities can be expected to vary due to the increase in effort in 1962, the decline of effort in 1965 and the increase after 1966. The mean Z for ages 5 and up decreased from 1962 through 1966 and then increased sharply. These values are average values of year classes of unequal abundance which do not cover the same age span and thus are limited in usefulness. Recruitment before 1966 generally was completed by age 5. After 1966 recruitment was completed much later. This change in age of recruitment can be seen as a steady decline of Z at age 5 with time from the 1958 year class through the 1962 year class. This is also reflected in age 6 and is probably the result of the 2 strong year classes passing through the fishery. The increase in Z with age is very striking especially after age 6 and may explain why Georges Bank herring do not have the long life span found in some other herring stocks.

Virtual Population Techniques

Although the comparative strengths of the strong year classes, 1960 and 1961, are not known, herring populations have shown variation in year class strength of over fivefold. Such variation in year class strength would probably cause the catchability coefficient (q) to be far from constant. Just the presence of a strong year class may reduce the availability of weak year classes which occur during the same year. Because of the possibility of variation in availability and because such a large catch of herring from Georges Bank has come from the two strong year classes, 1960 and 1961, the virtual population technique (Gulland, 1965) was applied to the total international catch of herring from Georges Bank. The virtual population technique is carefully laid out by Gulland and the reader is referred to his work for details. Virtual populations are simply those fish present at the beginning of a year which are caught in that year and in subsequent years. The virtual populations are given in Table 9. The relative strengths of the 1960 and 1961 year classes are obvious even though effort is not considered. Apparent total mortality rates Z' were estimated as ratios of virtual populations at the beginning and end of each year for ages 2 through 8 (Table 10). Recruitment, as also shown by the catch-effort data, occurs at age 5 as indicated by the jump in mean mortality from 0.12 to 0.44. Since the cumulative catch is used to obtain the virtual populations there can be no negative values as were present with the catch-effort data.

The virtual population technique requires that a constant value of natural mortality be known as well as the exploitation ratio (E = F/F+M) for age n+1 of a series of data of n ages. To determine a first estimate of M, the apparent total mortality rates were plotted against the total international fishing effort for each age. Since this technique requires that q be constant, only data after 1964 were used when the 1960 and 1961 year classes provided the bulk of the catch. Using values after 1964 reduced the number of data points but produced reasonably straight regression lines with correlation coefficients of 0.90 to 0.95 for ages 5 through 7. Estimates of M, however, varied from 0.04 to 0.69. A first estimate of M used in the virtual population technique was, therefore, arbitrarily chosen as 0.30 and values of E were determined from the estimates of Z given by the catch per effort ratios. These values were 0.75 age 6, 0.80 age 7, 0.85 age 8, and 0.88 age 9. The corrected estimates of Z as estimated from the virtual population technique (Table 11) were generally greater for ages 5 and 6 than those produced by the catch per effort ratios (Table 8). Values of Z at ages 7 and 8, however, were similar to the values obtained from the catch-effort data. Both sets of total mortality rates (catch-effort and virtual population) show an increase with age. The increase is especially great from age 7 to age 8. Older herring are very difficult to age. Because of this difficulty, age readings usually have been categorized as ages 1 through 7 and "age 8 and up." If some age 9 or age 10 herring have been classified as age 8, the mortality at age 8 could be overestimated. The mortality rates of the older herring therefore are not as reliable as the estimates of mortality for the younger herring.

Using the corrected values of Z in a regression against total international effort produced values of M for age 4 of 0.31 (0.27-0.36 confidence interval); for age 5 of 0.31 (0.19-0.43); for age 6 of 0.44 (0.33-0.54); and for age 7 of 0.88 (0.67-1.09). The correlation coefficients of the regression lines varied between 0.87 and 0.96. The confidence intervals about the values of M i.e., the Y intercept, were quite wide due to the limited number of data points. However, q was reasonably constant from age 5 through age 7 varying from 0.62×10^{-3} to 0.67×10^{-3}. Only 3 points existed for age 8 and these were scattered. Extrapolating the estimates of M for ages 5-7 produced a value of 1.11 for age 8.

Maximum estimates of the rate of exploitation ($\mu = \frac{F}{F+M}(1-e^{-Z})$) and maximum values of fishing mortality (F) were calculated for each year and year class. The maximum rate of exploitation is equal to the catch divided by the virtual population. Fishing mortality equals $-\log_e(1-\mu)$. This, of course, assumes that there is no natural mortality. These data are given in Tables 12 and 13. The fishing mortality does not seem to have been excessive in the 1960's although it increased greatly from 1965-1968. Extrapolating this increase through 1969 gives reason for concern especially since the catch of the 1960 and 1961 year classes is nearly completed and recruitment of subsequent year classes has been poor. If effort continues at its present rate or increases without the appearance of a strong year class, we can anticipate a further decline in the spawning stock of herring on Georges Bank.

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Table 1.
Russian catches of haddock and hake in the ICNAF Area 5
(Metric tons)

Year	Haddock	Silver Hake	Red Hake
1961	------	-------	-------
1962 1/	1,134	41,900	-------
1963	2,361	107,357	3,475
1964	5,483	167,308	3,588
1965	81,882	281,431	-------
1966	48,409	121,373	82,889
1967	2,316	69,984	37,593
Total	141,585	789,353	127,545

1/ Both red and white hake

Table 2.
Fishing effort on Georges Bank herring by the USSR in number of hours or number of nets

	Tonnage class (Metric tons)				
	151 - 500		501-900	901-1800	>1800
Year	Otter trawl	Drift net	Otter trawl	Otter trawl	Otter trawl
1961		216,386*			15,381
1962	13,316	1,105,566*			18,910
1963	32,780	106,079*			13,682
1964	66,753		244		15,864
1965	5,956		303	12	9,469
1966	6,344		360	82	39,462
1967	111,989		208	370	11,622
1968	145,607				12,372
1969	234,634				17,453

*number of nets

Table 3.
Catch per effort on Georges Bank herring by the USSR in metric tons per hour or net

	Tonnage class (Metric tons)				
	151-500		501-900	901-1800	>1800
Year	Drift net	Otter trawl	Otter trawl	Otter trawl	Otter trawl
1961	0.14				2.38
1962	0.08	1.38			2.36
1963	0.07	1.28			3.46[1]
1964		1.23[1]	0.71		3.20
1965		1.03	1.36[1]	1.42	3.12
1966		1.12	1.07	2.85	2.78
1967		0.82	0.83	0.32	2.70
1968		0.64[2]			2.20[2]
1969		0.41[2]			1.93[2]

1 Average of two values weighted by catch.
2 Preliminary data.

Table 4.
Adjusted fishing effort (1000 hours) by the USSR and total international effort on Georges Bank herring in number of hours of fishing by a standard vessel of 151-500 tons

Year	USSR ADJUSTED FISHING EFFORT						Total USSR effort	Total International effort
	Tonnage class (Metric tons)							
	151 - 500			501-900	901-1800	>1800		
	Otter trawl	Drift nets	Purse seine	Otter trawl	Otter trawl	Otter trawl		
1961		19.5				41.1	60.5	60.5
1962	13.3	99.5				50.5	163.3	163.3
1963	32.8	9.5				36.5	78.9	78.9
1964	66.8			0.2		42.4	109.3	109.3
1965	6.0			0.4		25.3	31.7	34.8
1966	6.3			0.3	0.1	105.4	112.1	130.5
1967	112.0			0.2	0.2	31.0	143.4	253.5
1968	145.6					33.0	178.6	511.0
1969	234.6		*			46.6	281.2	760.9

*purse seine effort not available

Table 5. Mean lengths (cm) of herring from Georges Bank in Aug.-Sept.

Year	YEAR CLASS 1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
1960		27.6[1]	25.6[1]									
1961	30.5[6]	29.3[1]	27.8[1]	24.9[1]								
1962	31.8[6]	30.6[1]	29.3[1]	27.8[1]	25.5[1]							
1963	33.0[6]	31.4[1]	30.4[1]	29.4[1]	27.9[1]	24.3[1]						
1964		33.0[1]	32.1[1]	30.6[1]	29.4[1]	27.3[1]	23.7[1]	20.7[5]				
1965	34.8[5]	34.1[6]	33.3[1]	32.0[1]	30.8[1]	28.9[1]	27.1[1]	25.1[6]				
1966			34.0[2]	33.0[2]	32.0[2]	30.6[2]	29.4[2]	28.0[2]	25.8[2]			
1967				34.2[3]	33.0[3]	31.8[3]	30.4[3]	29.2[3]	27.7[3]	25.3[3]	20.6[5]	
1968					34.1[6]	32.9[4]	31.7[4]	30.3[4]	29.1[4]	27.1[4]	25.5[4]	
1969						34.1[6]	33.0[6]	31.8[6]	30.5[6]	29.3[6]	27.6[6]	25.1[6]

1 From Boyar, H. C. 1968

2 From Boyar, H. C. 1967

3 From Perkins, F. E. 1968

4 From Perkins, F. E. 1969

5 From U.S. Research Cruises

6 Average value for age group

Table 6. Mean weights (grams) of herring from Georges Bank

'ear	YEAR CLASS 1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
.961	265.0	232.5	195.2	133.2								
.962	300.8	268.0	232.5	195.2	144.5							
.963	342.0	290.4	262.0	235.0	197.6	122.4						
.964		342.0	309.6	268.0	235.0	183.2	111.9	78.4				
965	423.0	391.5	355.5	306.0	274.0	222.5	178.4	136.9				
966			387.0	342.0	306.0	268.0	235.0	200.0	150.2			
967				396.0	342.0	300.8	262.0	230.0	192.8	140.7	77.2	
968					391.5	338.4	298.2	259.0	227.5	178.4	144.5	
969						391.5	342.0	300.8	265.0	232.5	190.4	136.9

Table 7. Catch per unit of adjusted effort by the USSR fishery on Georges Bank (millions of herring per 1000 hours of fishing by a standard vessel of 151-500 tons)

r	YEAR CLASS 1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	Total*
1	0.99	2.66	0.70	0.22									3.23
2	0.79	1.68	0.56	0.24									3.42
3	0.09	0.22	1.00	2.15	0.98	2.81							7.24
			0.35	0.99	1.30	2.33	1.52	0.17					6.66
	0.04	0.08	0.26	0.34	0.69	2.81	0.84	0.25					5.31
				0.09	0.47	1.90	1.27	0.24	0.06				4.02
				0.01	0.15	1.30	1.13	0.37	0.11	0.01	0.01		3.09
					0.01	0.43	0.95	0.47	0.49	0.02	0.06		2.43
						0.04	0.32	0.39	0.52	0.50	0.08	0.01	1.85

tal catch of all year classes divided by adjusted effort

Table 8. Estimates of Z from ratios of catches per unit effort by year class, year and age

	YEAR CLASS											
ear	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	Mean*
961	0.23	0.46	0.23	-0.12								0.39
962	2.22	2.05	-0.58	-2.18								1.68
963			1.04	0.78	-0.29	0.19						0.57
964			0.33	1.06	0.63	-0.19	0.59	-0.41				0.75
965				1.39	0.40	0.40	-0.41	0.06				0.51
966				2.65	1.11	0.38	0.12	-0.44	-0.60			0.47
967					3.44	1.12	0.18	-0.26	-1.49	-0.89	-1.86	0.79
968						2.44	1.07	0.21	-0.06	-3.12	-0.30	1.02

	YEAR CLASS											
ge	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	Mean**
								-0.41			-1.86	-1.14
				-0.12		0.19	0.59	0.06	-0.60	-0.89	-0.30	-0.15
			0.23	-2.18	-0.29	-0.19	-0.41	-0.44	-1.49	-3.12		-0.99
		0.46	-0.58	0.78	0.63	0.40	0.12	-0.26	-0.06			0.19
	0.23	2.05	1.04	1.06	0.40	0.38	0.18	0.21				0.69
	2.22		0.33	1.39	1.11	1.12	1.07					1.21
				2.65	3.44	2.44						2.84

*weighted by catch in weight of each year class, ages 5 and up only
**unweighted mean

Table 9. Virtual populations of herring from Georges Bank (millions)

At beginning of age	YEAR CLASS 1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
2								683.3			90.9	
3				354.2		1,397.1	1,378.2	665.1	683.1	390.1	88.6	5.6
4			259.5	341.2	345.0	1,175.7	1,211.5	656.6	675.2	387.8	58.8	
5		454.6	217.2	301.5	268.0	921.0	1,182.6	625.5	647.2	376.6		
6	196.7	293.8	126.0	132.0	126.1	824.6	1,016.1	533.6	394.8			
7	136.7	19.8	47.3	24.3	102.5	575.4	731.1	291.2				
8	8.1		8.7	12.7	41.4	246.8	245.0					
9				1.6	2.5	28.0						

Table 10. Apparent Total Mortality Rates (Z′)

	YEAR CLASS											
ge	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	Mean
2								0.03			0.03	0.03
3				0.04		0.17	0.13	0.01	0.01	0.01	0.41	0.11
4			0.18	0.12	0.25	0.25	0.02	0.05	0.04	0.03		0.12
5		0.44	0.55	0.83	0.75	0.11	0.15	0.16	0.49			0.44
6	0.36	2.70	0.98	1.69	0.21	0.36	0.33	0.61				0.91
7	2.83		1.69	0.65	0.91	0.85	1.09					1.34
8				2.07	2.81	2.18						2.36

Table 11. Corrected estimates of Z from virtual populations, assuming M = 0.30.

	YEAR CLASS							
Age	1957	1958	1959	1960	1961	1962	1963	Mean
2						0.31		0.31
3		0.32		0.38	0.35	0.30	0.31	0.33
4	0.40	0.38	0.45	0.43	0.31	0.33	0.33	0.38
5	0.70	0.95	0.78	0.37	0.39	0.40	0.66	0.61
6	1.10	1.61	0.45	0.56	0.54	0.77		0.84
7	1.72	0.83	1.08	1.01	1.22			1.17
8		2.09	2.81	2.20				2.37

Table 12.

Table 12. Maximum rates of exploitation for Georges Bank herring

	YEAR CLASS										
ar	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	Weighted mean*
1	0.31	0.35	0.16	0.04								0.31
2	0.94	0.93	0.42	0.12								0.81
3	0.84	0.86	0.62	0.56	0.22	0.16						0.45
4			0.82	0.82	0.53	0.22	0.12	0.03				0.45
5				0.48	0.19	0.10	0.02	0.01				0.14
6				0.87	0.60	0.30	0.14	0.05	0.01			0.30
7					0.94	0.57	0.28	0.15	0.04	0.01	0.03	0.44
8						0.89	0.66	0.45	0.39	0.03	0.34	0.62

ighted by catch in tons of each year class

Table 13. Maximum values of F for Georges Bank herring

					YEAR CLASS							
ar	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	Weighted mean*
1	0.36	0.44	0.18	0.04								0.38
2	2.83	2.70	0.54	0.12								2.27
3	1.83	1.99	0.98	0.83	0.25	0.17						0.69
4			1.69	1.69	0.75	0.24	0.13	0.03				0.76
5				0.65	0.21	0.11	0.02	0.01				0.16
6				2.07	0.91	0.36	0.15	0.05	0.01			0.41
7					2.81	0.85	0.33	0.16	0.04	0.01	0.03	0.70
8						2.18	1.09	0.61	0.49	0.03	0.41	1.12

ighted by catch in tons of each year class