FiskDir. Skr. Ser. HavUnders., *16*: 315—337

STOCK SIZE FLUCTUATIONS AND RATE OF EXPLOITATION OF THE NORWEGIAN SPRING SPAWNING HERRING, 1950—1974

By
OLAV DRAGESUND
Department of fisheries biology,
University of Bergen
and
ØYVIND ULLTANG
Institute of Marine Research, Bergen

ABSTRACT

DRAGESUND, O. and ULLTANG, Ø. 1978. Stock size fluctuations and rate of exploitation of the Norwegian spring spawning herring, 1950—1974. *FiskDir. Skr. Ser. HavUnders.*, *16*: 315—337.

The collapse of the Norwegian spring spawning herring stock is described, followed by a discussion of the causes. Stock size and fishing mortality were calculated from virtual population analysis for the years 1950—1974. The analysis showed that the young herring fishery had a serious effect on the recruitment to the adult stock during the whole period. The 1961 year class was the last one which survived the small- and fat-herring fisheries in any quantity.

The fishing mortalities on the adult stock were at a low or moderate level until 1964. Thereafter a rapid increase in the fishing mortalities took place, primarily as a result of the escalation in the summer and autumn fisheries off Iceland.

The result of the investigation leaves no doubt that the fishing pressure was the primary factor for the collapse of this herring stock.

INTRODUCTION

Traditionally the main fishery on the adult stock of Norwegian spring spawning herring took place in winter along the Norwegian west coast prior to and during the spawning season (DEVOLD 1963). Another important fishery, the summer and autumn herring fishery, took place on the feeding grounds along the Polar front in the Norwegian Sea. This fishery was for a long period located off northern and northeastern Iceland exploiting mainly the adult stock (JAKOBSSON 1963). During the last two decades there has been a drastic change in the migration pattern of the adult stock, and this has strongly influenced the location of the summer and autumn as well as the winter herring fishery (DEVOLD 1968, JAKOBSSON 1968).

Although the total catch of adult herring (including the summer and

Table 1. Total catch in thousand metric tons of adult Norwegian spring spawning herring 1950—1971.

Year	Iceland	Norway	USSR	Faroes	Fed. Rep. of Germany	Total
1950	30.7	781.4	14.0	—	—	826.1
1951	48.9	902.3	43.0	—	—	994.2
1952	9.2	840.1	69.9	—	—	919.2
1953	31.5	692.2	110.0	16.2	—	849.9
1954	15.2	1 103.6	160.0	27.6	—	1 306.4
1955	18.1	979.3	207.0	13.1	—	1 217.5
1956	41.2	1 160.7	235.0	23.7	—	1 460.6
1957	18.2	813.1	300.0	17.0	—	1 148.3
1958	22.6	356,7	388.0	17.7	—	785.0
1959	34.5	426.9	408.0	13.7	—	883.1
1960	26.7	318.4	465.0	11.0	—	821.1
1961	85.0	111.0	285.0	16.9	—	497.9
1962	176.2	156.2	209.0	9.8	—	551.2
1963	177.5	130.4	350.0	12.9	—	670.8
1964	367.4	366.4	365.8	18.3	—	1 117.9
1965	540.0	259.5	489.2	31.5	5.6	1 325.8
1966	691.4	497.9	447.4	60.7	26.1	1 723.5
1967	359.3	423.7	303.9	34.9	9.7	1 131.5
1968	75.2	55.7	124.3	16.1	1.8	273.1
1969	0.6	15.6	3.2	4.4	0.3	24.1
1970	—	20.3	—	0.6	—	20.9
1971	—	6.9	—	—	—	6.9

autumn fishery) has to a large extent fluctuated in relation to the entrance of strong year classes throughout the history of the fishery (ØSTVEDT 1963), this phenomenon has been especially pronounced during the period 1950—1970 (ANON. 1970). Thus the very rich 1950 year class caused high catches in the adult herring fisheries in the mid 1950s, and the strong year classes of 1959 and 1960 gave high yields in the years 1964—1967 (Table 1). Both periods of high catches were followed by a decline which was most striking in the latter period when the decrease in the adult stock was accelerated by an increase in exploitation rate compared to earlier periods. However, the decline was primarily caused by practically no recruitment to the adult stock after the 1959 and 1960 year classes were fully recruited to the stock in 1966.

From 1965 onwards a rapid decrease in the stock size took place, and in 1969—1971 the catches in both the adult summer and winter herring fisheries were negligible compared with those of earlier years. During the spawning season of 1972 almost no herring were recorded on the traditional spawning grounds, and the spawning stock was reduced to an extraordinari-

Table 2. Catches in thousand metric tons of small and fat herring taken by Norway and USSR 1950—1974. Herring caught south of Stad are excluded except for Norwegian small herring catches in 1950—1959.

Year	Small herring			Fat herring			Grand total
	Norway	USSR	Total	Norway	USSR	Total	
1950	72.9	—	72.9	29.7	4.3–	34.0	106.9
1951	190.1	10.5	200.6	80.5	2.5	83.0	284.2
1952	276.4	2.1	278.5	55.2	1.9	57.1	335.6
1953	147.0	3.8	150.8	84.7	5.2	89.9	240.7
1954	190.1	8.8	198.9	138.0	1.2	139.2	338.1
1955	94.3	3.0	97.3	36.0	9.0	45.0	142.3
1956	86.8	—	86.8	102.0	10.0	112.0	198.8
1957	118.5	3.8	123.3	46.4	1.5	47.9	171.2
1958	133.5	8.1	141.6	55.1	4.6	60.0	201.6
1959	164.5	7.2	171.7	46.8	9.5	56.3	228.0
1960	212.0	5.7	217.7	62.2	0.8	63.0	280.7
1961	222.7	0.9	223.6	108.5	0.1	108.6	332.2
1962	124.5	0.7	125.2	171.3	0.9	172.2	297.4
1963	157.9	—	157.9	143.8	12.0	155.8	313.7
1964	106.8	—	106.8	56.9	0.2	57.1	163.9
1965	116.9	—	116.9	94.3	10.7	105.0	221.9
1966	61.7	—	61.7	147.9	21.9	169.8	231.5
1967	107.1	—	107.1	346.0	92.6	438.6	545.7
1968	26.3	—	26.3	341.1	71.7	412.8	439.1
1969	14.4	—	14.4	21.2	8.1	29.3	43.7
1970	5.2	—	5.2	36.2	—	36.2	41.4
1971	1.1	—	1.1	13.1	—	13.1	14.2
1972	3.3	—	3.3	9.9	—	9.9	13.2
1973	0.3	—	0.3	6.6	—	6.6	6.9
1974	0.6	—	0.6	5.7	—	5.7	6.3

+ Average catch for the period 1941—1950.

ly low level. In 1973—1975 a slight increase in the spawning stock took place due to recruitment from the 1969 year class. (ANON. 1974, 1975 a, 1976.)

In addition to the fishery on adults there was a fishery on young and adolescent herring in the Norwegian fjords, mainly in northern Norway. This fishery is based on the small-herring (småsild), i. e. mainly 0- and I-group fish, and on the fat-herring (feitsild), i. e. I- to IV-group herring (DRAGESUND 1970). The catches of small-herring have declined since the mid 1960s (Table 2). This decline was largely determined by the low abundance of small-herring due to a series of weak to moderate year classes after 1965. Catches of the fat-herring increased considerably in the years 1966–1968 after having fluctuated with no definite trend in the years 1950—1965 (Table 2).

The description of the collapse of the stock of Norwegian spring spawning herring is well documented in several reports (ANON. 1970, 1972, 1975 b). The aim of the present paper is to give an analysis of the effect of the fishery on the stock during the period 1950—1974.

MATERIALS AND METHODS

Stock size and fishing mortality were calculated from Virtual Population Analysis (VPA), the main input data being the total catch in number by age in the different years. Catches in weight were converted separately to catch in number by age for the adult fisheries and the young and adolescent herring fisheries (small- and fat-herring).

The catch in number by year class in the adult fisheries from 1962 to 1970, given by the Working Group on Atlanto-Scandian Herring (ANON. 1970, 1972), was extended to cover the period 1950—1971 and all age groups in the adult fisheries (Table 3) by utilizing:

(i) Data on age composition in the winter fishery 1950—1970 and the summer and autumn fishery 1962—1970 given in ANON. (1970, 1972).
(ii) Data on mean weight of herring from the winter fishery 1950—1961 available from the records of Institute of Marine Research, Bergen.
(iii) Icelandic data on age composition in the summer and autumn fishery in 1950—1961 as reported in Annales Biologiques (ANON. 1951—1954, ANON. 1956—1963).
(iv) Icelandic data on mean weight by age during the summer and autumn fishery (JACOBSSON, personal communication).
(v) Data on age composition and mean weight in catches from the Norwegian winter fishery 1971.

The catch in number by year class in the young and adolescent herring fisheries in 1950—1974 (Table 4) were obtained by utilizing:

(i) Data on catch by year class in the small-herring fishery given in DRAGESUND (1970) and data from the records of the Institute of Marine Research, Bergen.
(ii) Data on age composition in the fat-herring fishery given in DRAGESUND (1970) and data from the records of the Institute of Marine Research, Bergen.
(iii) Data on mean weight by month and district for year classes going through the small- and fat-herring fisheries from the 0-group to the adolescent stage given in DRAGESUND (1970).

A constant natural mortality of $M=0.16$, as estimated by the Working Group on Atlanto-Scandian herring (ANON. 1970), was assumed for the whole period 1950—1974 for all age groups. The Working Group arrived at the estimate by utilizing data on catch in number by age for 4 years old and older herring. It is, therefore, uncertain how representative the figure 0.16 is for younger age groups.

Table 3. Catch in numbers (millions) of Norwegian spring spawning herring in the adult fisheries 1950—1971.

Year class	Year							
	1950	1951	1952	1953	1954	1955	1956	1957
1930	3.6							
1931	0.9	0.5						
1932	18.5	8.7	3.8					
1933	42.4	18.4	28.1	22.2				
1934	171.9	158.0	127.7	95.4	63.2			
1935	107.0	119.5	83.2	89.6	80.0	43.0		
1936	66.4	47.4	65.3	73.8	89.2	72.6	45.0	
1937	368.3	348.0	256.3	233.9	247.4	104.6	75.7	31.3
1938	194.5	253.5	186.5	215.5	196.6	141.6	137.5	52.0
1939	86.9	107.6	106.8	98.8	126.8	115.2	122.8	61.8
1940	109.5	103.1	107.7	94.1	133.0	103.6	95.2	60.1
1941	88.6	82.7	85.7	91.2	100.6	84.6	88.9	42.5
1942	79.5	77.1	79.2	61.7	88.4	58.7	63.0	33.7
1943	628.6	602.0	377.9	394.9	460.7	203.2	163.3	131.6
1944	547.0	515.6	380.2	314.1	440.4	295.6	272.8	149.3
1945	185.5	164.4	204.5	110.9	199.8	193.4	198.3	121.2
1946	184.8	172.4	136.3	81.9	128.1	85.5	130.7	88.4
1947	276.2	383.8	602.3	355.6	490.3	274.7	264.2	182.5
1948		6.6	60.5	100.9	236.0	189.6	203.9	127.3
1949			39.3	46.6	142.9	114.3	110.0	72.0
1950				98.2	1 083.9	1 954.3	2 375.4	1 946.4
1951					55.8	262.2	275.8	220.5
1952						62.4	232.7	144.0
1953							27.9	246.1
1954								13.0
1955								
1956								
1957								
1958								
1959								
1960								
1961								
1962								
1963								
1964								
1965								
1966								
1967								
1968								
Total	3 160.1	3 169.3	2 931.1	2 579.3	4 363.1	4 358.8	4 883.1	3 723.7

Table 3 (cont.)

Year class	year						
	1958	1959	1960	1961	1962	1963	1964
1930							
1931							
1932							
1933							
1934							
1935							
1936							
1937							
1938	32.7						
1939	27.7	27.6					
1940	46.6	27.7	15.1				
1941	44.9	31.2	19.9	2.1			
1942	34.3	22.6	19.8	3.4	5.1		
1943	69.4	41.6	27.9	4.5	13.5	1.9	
1944	70.9	85.2	39.0	12.7	16.8	7.7	10.8
1945	77.4	77.4	47.2	15.7	30.3	19.3	14.3
1946	98.7	88.5	56.7	21.7	30.3	25.1	7.2
1947	200.9	198.0	153.5	63.0	79.2	61.8	46.6
1948	123.0	124.3	129.7	45.0	64.1	60.6	43.2
1949	70.7	88.6	85.2	49.7	49.3	79.8	46.1
1950	959.1	1 084.8	1 163.0	727.6	959.3	932.7	771.6
1951	192.9	239.7	203.9	136.1	138.9	174.1	151.9
1952	87.5	113.8	73.2	49.2	59.8	92.5	83.2
1953	100.3	138.0	93.8	61.5	64.1	107.7	96.3
1954	16.1	24.6	21.6	19.4	13.3	9.3	29.3
1955	8.0	22.8	23.3	14.9	20.2	18.3	24.9
1956		7.0	4.0	4.1	6.5	3.5	3.0
1957				1.8	2.0	1.7	1.5
1958					1.4	4.9	13.1
1959					255.7	408.9	1 917.7
1960					49.8	38.2	307.6
1961							90.2
1962							2.2
1963							
1964							
1965							
1966							
1967							
1968							
Total	2 261.1	2 443.4	2 176.8	1 232.4	1 859.6	2 048.0	3 660.7

Table 3 (cont.)

Year class	Year						
	1965	1966	1967	1968	1969	1970	1971
1930							
1931							
1932							
1933							
1934							
1935							
1936							
1937							
1938							
1939							
1940							
1941							
1942							
1943							
1944							
1945	4.3						
1946	8.7	5.5					
1947	21.7	16.5					
1948	52.1	8.8					
1949	70.2	14.9	1.9				
1950	703.0	392.7	64.3	5.4	1.1	0.2	
1951	137.7	96.9	14.3	4.1	0.2	—	
1952	106.9	72.1	14.3	3.6	0.3	0.1	0.02
1953	100.5	69.1	17.5	1.8	0.2	0.1	0.02
1954	40.0	11.0	8.9	2.6	—	0.1	0.02
1955	19.1	26.1	8.5	2.5	0.3	0.1	0.06
1956	7.4	17.4	3.5	0.8	0.2	0.1	—
1957	14.9	14.4	5.7	1.1	0.3	0.1	0.02
1958	19.5	38.0	8.9	2.0	—	0.1	—
1959	2 195.8	2 868.3	1 718.2	345.9	36.3	28.2	5.45
1960	570.4	1 290.6	1 135.0	134.8	33.5	26.7	6.91
1961	245.9	459.1	422.2	93.9	11.6	13.2	4.41
1962	12.1	26.1	27.0	14.3	0.7	1.0	0.36
1963	45.1	80.6	25.7	15.2	2.9	3.3	1.13
1964					—	0.4	1.01
1965					0.2	0.3	0.36
1966						1.3	0.94
1967						0.2	0.62
1968							0.32
Total	4 375.3	5 508.1	3 475.9	628.0	87.8	75.5	21.65

Table 4. Catch in numbers (millions) of Norwegian spawning spring herring in the young herring fisheries (small- and fat- herring) 1950–1974.

Year class	Year												
	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
1950	5 112.6	7 607.7	1 232.9	641.9	351.6	90.8	179.7	38.9	14.4	19.0	—	0.5	
1951		1 635.5	9 149.7	581.3	210.5	14.2	38.4	8.0	1.5	1.0	—	—	
1952			13 721.6	5 055.0	855.4	30.6	18.9	9.8	1.8	1.0	0.1	—	
1953				5 697.2	7 071.1	510.1	88.6	127.2	10.6	8.6	2.4	0.1	
1954					10 676.0	2 871.1	627.1	10.3	1.8	1.3	2.8	—	
1955						5 175.6	2 023.7	219.5	9.5	4.0	4.8	0.1	
1956							5 363.9	3 290.8	666.4	8.1	14.2	—	
1957								5 001.9	2 798.1	325.5	121.7	6.3	0.7
1958									9 667.0	1 985.3	392.5	31.2	6.6
1959										17 896.3	13 580.8	2 884.8	1 641.1
1960											12 884.3	16 075.6	1 006.5
1961												6 207.5	4 049.2
1962													3 687.5
Total	5 112.6	9 243.2	24 104.1	11 975.5	19 164.6	8 692.5	8 340.2	8 706.4	13 171.1	20 250.1	27 003.5	25 206.1	10 391.6

Year class	Year											
	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
1956	0.1											
1957	0.1											
1958	0.4	0.6										
1959	422.8	128.1	4.1	9.6								
1960	722.2	91.4	0.7	17.2								
1961	2 051.7	24.4	10.3	5.9								
1962	2 122.3	218.1	78.0	1.1								
1963	4 811.0	2 728.3	2 806.5	1 957.8	3 241,4	1 367,2	1,8					
1964		3 613.	3 752.0	1 671.0	1 395.5	1 900.6	8.9	2.9	0.1	0.5		
1965			2 303.0	664.0	70.3	98.8	0.6	0.3	—	0.2		
1966				3 893.0	9 911.1	385.4	188.1	17.3	0.3	1.0	0.1	
1967					428.0	435.3	142.2	6.4	0.4	2.2	0.4	
1968						1 782.0	507.9	33.5	1.5	1.6	0.1	
1969							555.9	530.1	85.1	33.6	10.9	5.3
1970								118.9	42.9	8.5	0.8	0.2
1971									30.5	52.3	0.3	0.1
1972										178.5	25.3	10.4
1973											18.0	23.1
1974												37.8
Total	10 130.5	6 803.9	8 954.5	8 219.0	15 046.3	5 969.2	1 405.3	709.4	160.8	278.4	56.0	77.0

Table 5. Spawning stock size in number ($N \times 10^{-9}$) and weight (million metric tons) and fishing mortality 1950—1971. The figures in brackets are uncertain because of the information for the VPA being from only a few years catches.

Year	Spawning stock size		Fishing mortality			
	Number	Weight	4 years old	5 years old	6 years old	7 years old and older
1950	36.9	9.4	0.054	0.047	0.091	0.095
1951	30.3	9.1	0.050	0.062	0.051	0.12
1952	28.8	8.8	0.014	0.098	0.061	0.12
1953	23.5	7.1	0.016	0.028	0.074	0.14
1954	27.0	7.6	0.038	0.059	0.082	0.22
1955	34.1	8.8	0.051	0.067	0.058	0.17
1956	32.3	8.9	0.10	0.072	0.11	0.21
1957	35.8	10.0	0.17	0.079	0.066	0.13
1958	28.7	8.5	0.040	0.065	0.057	0.097
1959	23.3	7.5	0.074	0.072	0.110	0.13
1960	17.3	5.6	0.16	0.10	0.087	0.15
1961	13.1	4.2	0.089	0.048	0.068	0.11
1962	9.9	3.3	0.050	0.037	0.096	0.19
1963	7.5	1.6	0.057	0.041	0.030	0.29
1964	13.6	3.7	0.081	0.18	0.14	0.40
1965	17.8	4.5	0.17	0.15	0.29	0.75
1966	11.2	2.7	0.39	0.51	0.58	0.83
1967	4.8	1.3	1.1	0.80	1.2	1.5
1968	1.0	0.24	4.5	4.4	1.4	1.1
1969	(0.29)	(0.08)	(0.28)	(0.71)	(0.39)	(0.42)
1970	(0.17)	(0.06)	(1.31)	(0.34)	(0.60)	(0.63)
1971	(0.09)	(0.03)	(0.10)	(0.24)	(0.33)	0.3+

+ Assumed value.

RESULTS

ADULT STOCK

Table 5 shows the spawning stock size in number and weight and the fishing mortality on 4, 5, 6, 7 years old and older herring for the years 1950—1971, assuming a fishing mortality of 0.3 on the fully recruited year classes in 1971. A fishing mortality of 0.3 gives a spawning stock size of about 30 000 tonnes in 1971. The results of the calculations given in Table 5 are also plotted in Fig. 1 (stock size in number), Fig. 2 (stock size in weight) and Fig. 3 (fishing mortality on 7 years old and older herring).

The fishing mortalities are those generated by the total catch of an age group and not only the catch in the adult fisheries. It appears from Table 4 that some 4, 5 and 6 years old herring are also taken in the fat-herring

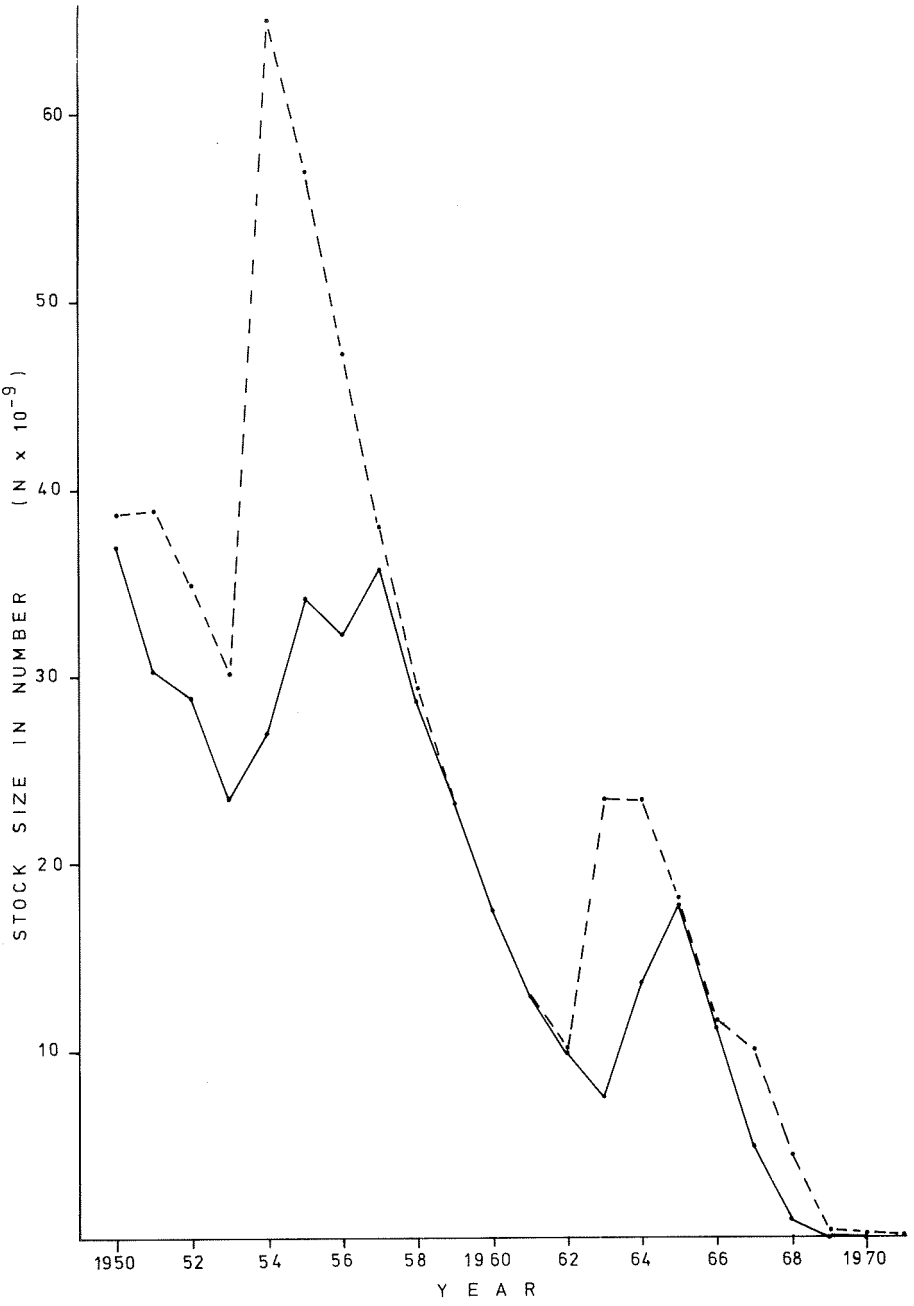

Fig. 1. Spawning stock size in number and total number of 4 years old and older herring (broken line) for the years 1950—1971.

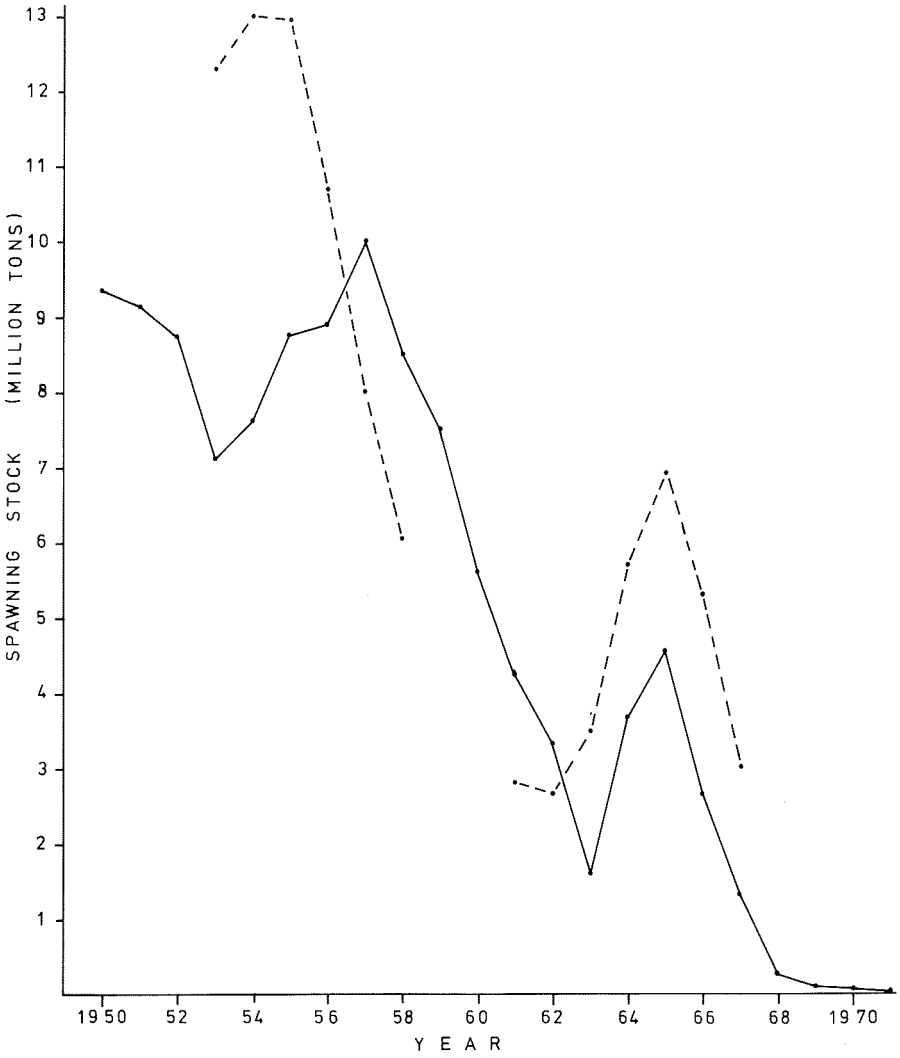

Fig. 2. Spawning stock size in weight for the years 1950—1971. The broken line shows stock size estimates given by the Working Group on Atlanto-Scandian Herring (ANON. 1970, 1972).

fishery. The fishing mortalities on 4–6 years old herring have generally been lower than on 7 years old and older herring. The main reason for this is probably that these age groups show a more oceanic distribution throughout the year than do the older age groups. Thus, they have not been heavily exploited in the fat-herring fishery and have not been fully recruited to the adult stock. The extremely high fishing mortalities on 4 and 5 years old herring in 1968 (Table 5) were generated by the fat-herring fishery.

The spawning stock size was calculated by assuming full recruitment to

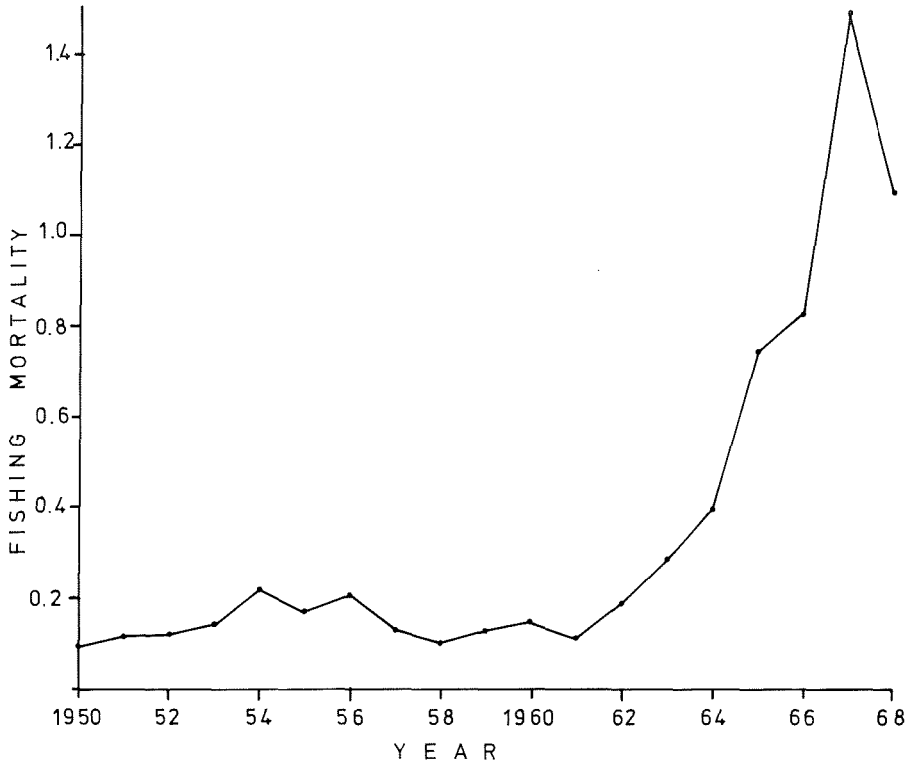

Fig. 3. Fishing mortality on 7 years old and older herring 1950—1968.

the adult stock at an age of 7 years. Portions of the younger year classes were added to the stock size of 7 years old and older herring given by the VPA. The quantity to be added for a year class of age t (t < 7) was calculated by:

$$N_t \text{ adult} = \frac{p_t}{p_{7+}} \cdot N_{7+}$$

where N_{7+} = total number of 7 years old and older herring.
p_t = percentage t years old herring in the winter fishery (Table 6).
p_{7+} = percentage 7 years old and older herring in the winter fishery.

The spawning stock size was at a level of about 9 million tonnes in 1950 (Table 5, Fig. 2) and decreased to about 7 million tonnes in 1953. From 1954 to 1957 the strong 1950 year class gradually recruited the spawning stock (Table 6), resulting in an increase in stock size which reached a peak of about 10 million tonnes in 1957 when the year class was fully recruited. The stock then decreased again as a result of poor recruitment, reaching a

minimum level of about 1.6 million tonnes in 1963. The fishing mortalities of the whole period 1950—1963 were on a low or moderate level (Table 5, Fig. 3).

The strong 1959 year class started to recruit to the spawning stock only to a small extent in 1963, but in 1964 it contributed about 60% to the spawning stock in number (Table 6).

The stock increased to about 3.7 million tonnes in 1964 and 4.5 million tonnes in 1965 (Fig. 2) when also the relatively strong 1960 year class recruited to the stock. From 1965 onwards there was a rapid decrease in spawning stock size due to an almost complete stop in recruitment to the adult stock and strongly increasing fishing mortalities. The last year class which recruited to the stock to any extent was that of 1961. The increase in fishing mortalities on the adult stock from 1964 onwards was primarily a

Table 6. Percentage age composition of Norwegian spring spawning herring during the Norwegian winter fishery 1950—1970.

Year / Age	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
2	0.1	—	0.1	0.1	0.1	—	—	0.2	—	—	—	—	—
3	8.3	0.2	1.3	4.0	1.3	1.5	0.6	0.4	0.5	0.4	—	—	0.1
4	5.5	11.6	2.0	1.9	25.2	6.3	5.0	7.4	1.0	1.3	0.3	0.4	—
5	5.5	5.2	19.9	4.1	3.3	46.9	5.9	4.3	6.1	1.4	1.6	0.9	0.5
6	16.3	4.8	4.5	14.4	5.4	2.7	50.6	5.6	4.7	7.5	1.2	3.3	0.9
7	18.7	15.2	6.7	3.2	11.0	4.3	2.3	56.5	6.6	5.1	6.5	2.9	2.5
8	2.3	17.7	12.4	4.2	2.8	5.8	3.9	1.8	50.5	7.8	3.5	7.7	1.5
9	2.5	2.0	12.2	12.0	4.2	1.7	4.6	2.6	2.6	47.3	5.0	4.8	8.0
10	3.1	2.2	2.4	14.4	9.2	4.0	2.2	2.4	3.5	2.2	58.1	6.5	4.0
11	2.4	2.6	2.5	2.0	9.5	5.5	3.5	1.6	3.4	3.3	1.6	59.0	6.6
12	5.4	2.7	3.1	2.8	1.7	3.3	4.1	2.2	2.3	4.5	3.8	4.4	63.5
13	10.4	6.7	3.0	2.9	1.9	1.0	1.9	2.7	2.2	1.9	4.1	3.0	2.1
14	1.6	9.1	5.0	3.0	2.5	1.4	0.9	1.5	1.8	2.3	1.5	2.3	3.6
15	2.7	1.5	7.0	6.6	2.2	1.8	1.2	0.5	1.1	2.2	1.0	1.5	3.4
16	4.8	3.0	1.6	7.0	3.4	1.9	1.4	0.6	0.6	0.9	1.3	1.4	0.7
17	1.1	4.0	2.2	2.2	4.3	2.2	1.7	0.8	0.7	0.5	0.9	0.9	1.0
18	0.5	0.4	3.4	2.9	1.7	1.3	1.6	1.0	0.7	0.7	0.5	0.3	1.0
19	—	0.2	0.8	2.9	1.4	1.5	0.6	0.7	0.5	0.4	0.3	0.4	0.3
20	0.1	—	0.1	0.7	1.0	0.7	0.6	0.3	0.3	0.3	0.5	0.1	—
21	—	0.1	—	0.1	0.1	0.2	0.3	0.2	0.2	0.2	0.3	0.1	0.2
22	—	—	—	—	0.1	0.1	0.1	—	—	0.1	0.1	0.1	—
23	—	—	—	—	—	—	—	—	—	0.1	0.1	—	0.1
?	8.6	10.8	9.8	8.6	7.8	5.9	7.0	6.6	10.6	10.0	7.8	—	—
n	3 973	3 841	3 336	2 796	4 839	4 174	4 998	2 779	972	1 116	1 155	452	398

[1]) Age data from samples taken during experimental fishing.

Table 6 (cont.).

Year / Age	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972[1])	1973[1])	1974[1])
2	—	—	—	—	—	—	—	—	—	—	0.2	6.7
3	—	0.2	—	—	—	—	—	0.3	0.6	44.1	5.1	2.0
4	6.9	5.9	5.2	0.1	0.2	—	0.1	1.8	3.3	19.5	83.7	7.3
5	0.4	60.6	13.6	8.8	0.4	0.7	—	0.4	4.4	13.1	2.8	82.0
6	0.4	0.3	66.3	28.9	12.8	1.3	3.3	0.6	1.8	9.1	4.1	0.9
7	0.5	0.1	0.1	54.5	33.7	12.1	0.8	4.4	4.9	2.2	1.7	0.8
8	1.7	0.2	0.2	0.2	48.5	35.0	13.2	1.3	5.1	4.2	0.8	0.2
9	1.0	0.8	0.1	0.1	0.2	47.7	38.2	17.0	1.7	0.9	0.6	—
10	8.6	0.5	0.3	0.1	—	0.1	41.6	35.2	20.9	0.1	0.9	0.1
11	3.6	3.4	0.5	0.2	0.1	—	—	37.9	32.1	2.3	+	—
12	8.2	1.8	1.4	0.2	0.3	0.2	0.3	0.1	25.0	2.3	+	—
13	60.0	2.6	0.8	0.6	0.2	0.2	0.1	0.1	—	2.2	+	—
14	2.0	20.9	1.3	0.6	0.5	0.3	0.3	0.1	+	—	+	—
15	2.7	0.6	9.2	0.4	0.3	0.5	—	0.1	—	—	+	—
16	2.0	0.7	0.3	5.0	0.3	0.4	0.2	0.1	+	—	+	—
17	0.8	1.1	0.3	—	2.5	—	0.3	0.2	+	—	—	—
18	0.5	0.1	0.3	—	—	1.4	0.1	0.2	+	—	—	—
19	0.4	0.1	—	0.3	—	—	1.3	—	+	—	—	—
20	0.2	0.1	—	—	—	—	—	0.3	—	—	—	—
21	—	—	0.2	—	—	—	—	—	+	—	—	—
22	—	—	—	—	—	—	—	—	—	—	—	—
23	0.1	—	—	—	—	—	—	—	—	—	—	—
?	—	—	—	—	—	—	—	—	—	—	—	—
n	399	1 481	1 402	2 531	1 599	2 255	2 207	3 511	2 516	856	1 994	2 178

result of the escalation in the summer and autumn fishery off Iceland where the catch reached a peak about 1 million tonnes in 1966 (ANON. 1972).

The method used for estimating the spawning stock size is liable to errors in the age composition of the winter herring fishery, especially when strong year classes younger than 7 years old are present in the spawning stock. This was the case in the years 1954—1956 and 1963—1965.

After comparing the age composition of the winter herring fishery with the age composition of the total stock calculated by VPA, the estimates show that for the 1950 year class 16% of the 4 years old, 47% of the 5 years old, and 60% of the 6 years old fish spawned. For the 1959 year class the figures are 3%, 63% and 100% respectively.

There is an increasing trend in fishing mortality with age in the adult stock. This is illustrated in Fig. 4 where mean fishing mortalities of the age groups 7—9, 10—12 and 13—15 years are plotted for the period 1950—1965. In the period 1956—1965 the fishing mortality is consistently

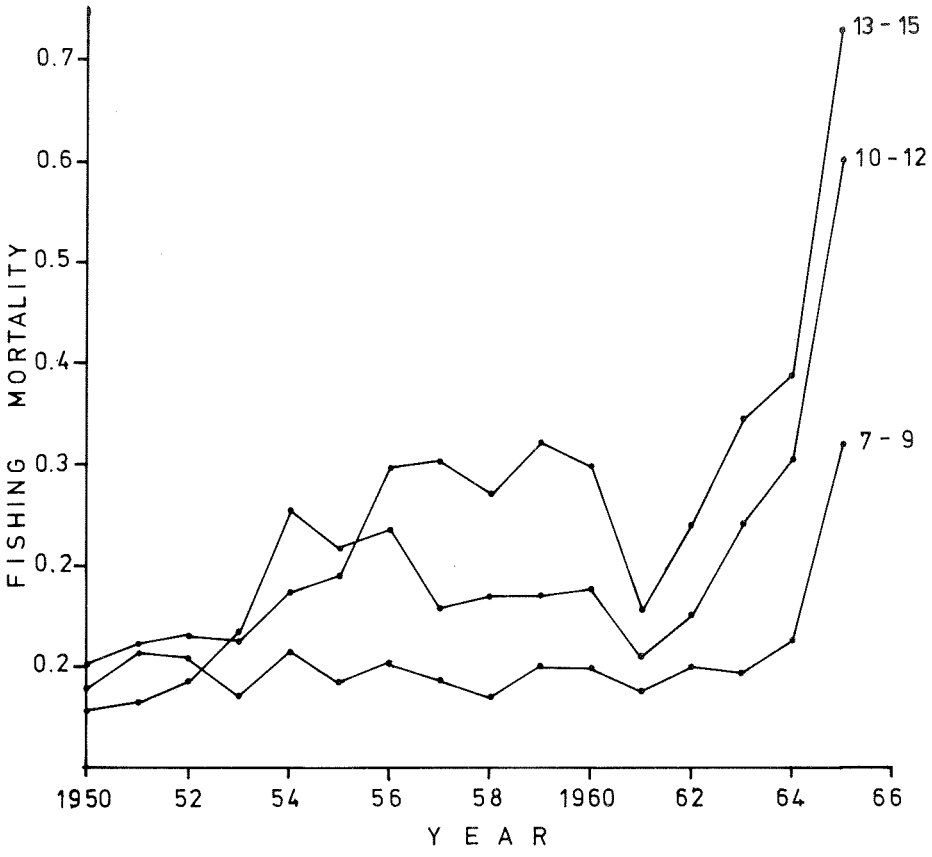

Fig. 4. Mean fishing mortality on 7—9, 10—12 and 13—15 years old herring 1950—1965.

at a minimum for the age groups 7—9 and at a maximum for those of 13—15 years. The oldest age group used in the VPA is the 20 years old herring, and the difference illustrated in Fig. 4 can therefore hardly be explained by the fishing mortalities assumed for the oldest age groups used in the VPA.

There may be several explanations for the observed increase in the fishing mortalities with age.

Two possible explanations are indicated:

1) The exploitation rate on old herring may have been higher than on younger herring in the summer and autumn fishery as indicated by an observed difference in age composition between the winter fishery and the summer and autumn fishery, especially in the 1950s (FRIDRIKSSON 1963, DEVOLD 1963). It is interesting to note that the catches in the summer and autumn fishery show a significant increase around 1955,

Table 7. Fishing mortality by year class and age of young herring 1950—1969. The figures in brackets are uncertain because of the information for the VPA being from only a few years catches.

Age	Year class									
	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
0	0.058	0.07	0.75	0.35	1.12	0.92	0.73	0.80	1.38	0.30
1	0.11	0.64	0.66	0.91	1.06	1.18	1.45	1.59	1.27	0.37
2	0.023	0.07	0.21	0.14	0.67	0.34	1.52	0.78	0.91	0.12
3	0.016	0.04	0.03	0.04	0.04	0.04	0.10	0.73	0.15	0.10
Total	0.21	0.82	1.65	1.43	2.89	2.48	3.80	3.90	3.71	0.89

Table 7 (cont.)

Age	Year class									
	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
0	0.35	0.45	0.79	0.22	0.26	1.17	0.28	0.46	1.32	0.50
1	0.92	0.58	1.62	0.18	0.44	1.38	2.63	1.18	2.36	(1.28)
2	0.12	0.62	0.69	0.28	0.34	0.47	0.93	1.96	(1.41)	(0.68)
3	0.12	0.06	0.65	0.31	0.50	3.26	1.98	(0.41)	(0.22)	(0.60)
Total	1.51	1.71	3.75	0.98	1.53	6.28	5.82	(4.01)	(5.31)	(3.06)

i. e. at the same time as the observed increase in fishing mortalities with age began.

2) Another possibility is that natural mortality increases with age. In the VPA the natural mortality is assumed constant; if, however, it increases with age, it will show up in the calculations as increasing fishing mortalities.

YOUNG HERRING

Table 7 shows the fishing mortality of the age groups 0—3 for the year classes 1950—1969, and Table 8 shows the year class size in number at different ages. The year class size of 0-group and 4 years old herring are plotted in Fig. 5.

The exploitation rate on young herring was high during the whole period of 1950—1969. From Fig. 5 and Table 8 it can be seen that there is clear correlation between year class size and survival during the young herring stages. The survival rate decreases with decreasing year class

Table 8. Stock size in numbers ($N \times 10^{-6}$) of young herring by year class and age and survival (S) from 0-group to 4 years old 1950—1969. The figures in brackets are uncertain because of the information for the VPA being from only a few years catches.

Age	Year class									
	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
0	97 375	26 081	27 910	20 973	16 878	9 188	11 098	9 725	13 723	74 965
1	78 267	20 718	11 254	12 642	4 680	3 114	4 558	3 723	2 937	47 442
2	59 690	9 289	4 969	4 330	1 377	816	906	644	702	27 965
3	49 721	7 380	3 448	3 220	600	494	169	252	241	21 175
4	41 687	6 043	2 852	2 637	490	405	130	103	176	16 297
S	0.428	0.232	0.102	0.126	0.029	0.044	0.012	0.011	0.013	0.217

Table 8 (cont.).

Age	Year class									
	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
0	47 478	18 327	7 242	26 264	17 305	3 560	17 334	1 245	2 587	1 515
1	28 631	9 927	2 807	17 957	11 426	942	11 194	669	589	(782)
2	9 751	4 754	475	12 792	6 297	201	682	175	(47)	(185)
3	7 337	2 175	203	8 281	3 832	107	230	(21)	(10)	(80)
4	5 552	1 747	91	5 185	1 987	4	(27)	(12)	(7)	(38)
S	0.117	0.095	0.013	0.197	0.115	0.001	(0.002)	(0.010)	(0.003)	(0.025)

strength. This is illustrated in Fig. 6 where the logarithm of the number (ln N) is plotted against age for two weak year classes (1955 and 1962) and two strong year classes (1950 and 1959). Year classes, recorded in the 1950s, which traditionally have been called weak, were all, compared to the results presented in Fig. 5, of what could be called an ordinary strength of 10×10^9 – 30×10^9 fish at the 0-group stage. However, year classes of strengths less than 20×10^9 as 0-group survived the fishery only in small quantities to reach the age of 4 years. In addition to the year classes of ordinary strength there were three extraordinarily strong year classes (those of 1950, 1959 and 1960). The 1965 year class (or possibly that of 1962) was the first one in the period studied which really should ble classified as weak.

The decreasing survival rate with year class strength indicates that the same fishing effort in a purse seine fishery, such as that for young herring

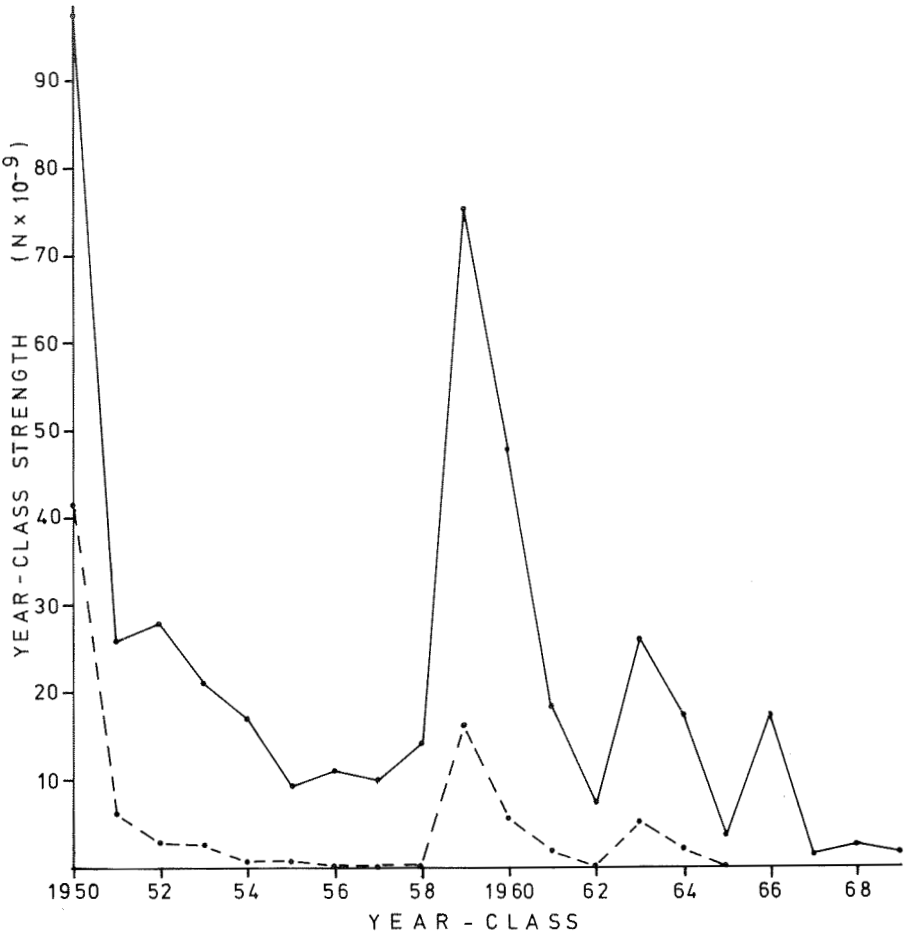

Fig. 5. Year class strength in number as 0-group and 4 years old (broken line) 1950—1969.

going on in coastal waters, may generate a much higher fishing mortality when stock abundance is low than when the abundance is higher. However, it also reflects that strong year classes had a more offshore distribution, and that part of those year classes therefore were outside the traditional fishing areas (DRAGESUND and NAKKEN 1973).

The 1961 year class was the last one which recruited to the spawning stock in any quantity (Table 6). It can be seen from Fig. 5 and Table 8 that some herring of the relatively strong 1963 and 1964 year classes survived to an age of 4 years. The portions of these two year classes which survived the fishery during the first years of life were, however, practically fished out in the fat-herring fishery in 1968 going on off the Finnmark coast. The VPA for that year gives fishing mortality estimates as high as 4.5 (Table 5). The

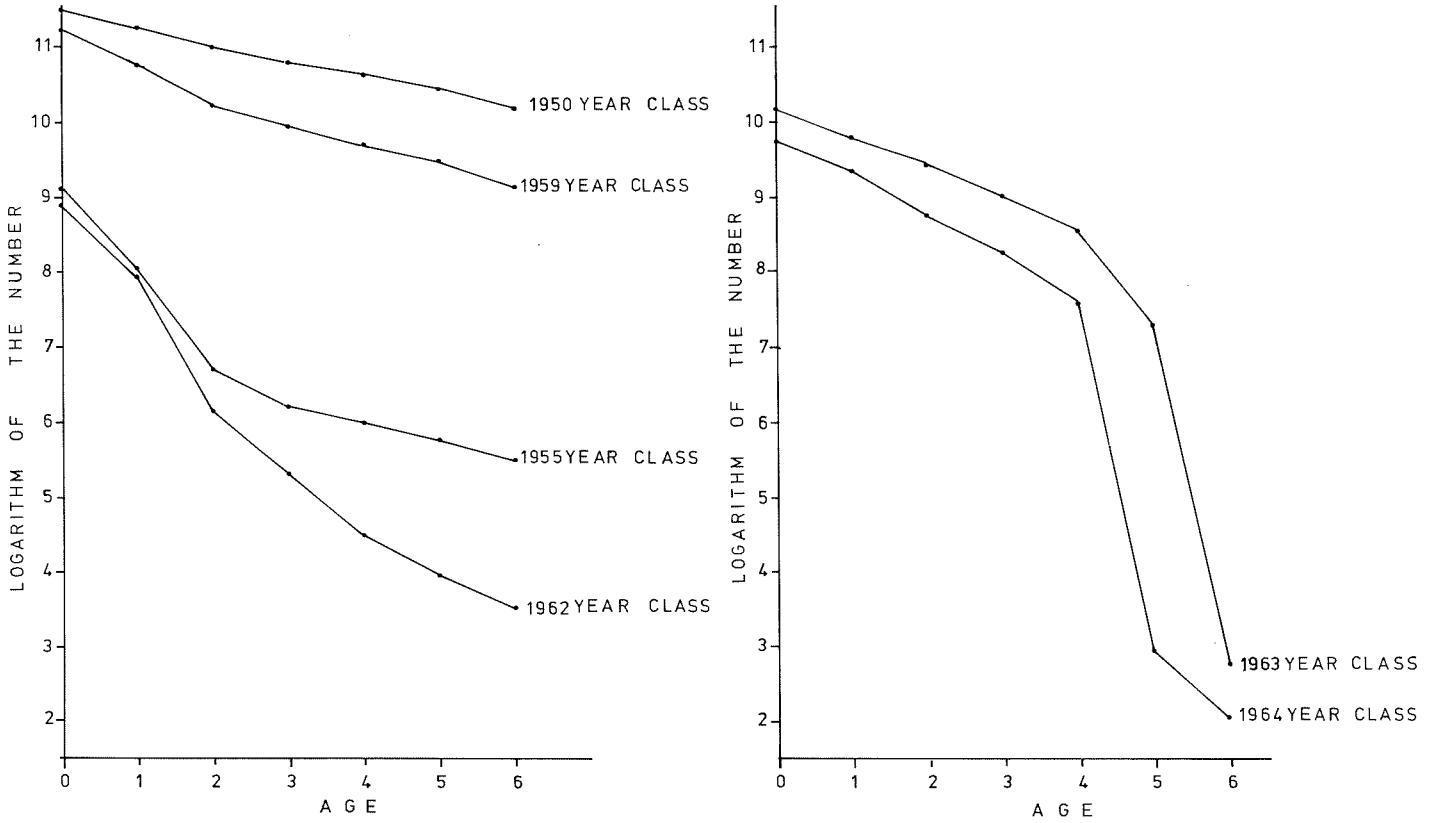

Fig. 6. Logarithm of the number against age for selected year classes.

mortality of these two year classes at different ages is also illustrated in Fig. 6 where ln N is plotted against age.

At the 0-group stage the 1964 and 1966 year classes were of approximately the same strength (Table 8, Fig. 5). However, the 1966 year class was practically fished out in the small-herring fishery in 1967 which generated a fishing mortality of 2.6 in that year (Table 7). When the 1967–1969 year classes were at the 0-group stage, they were of the order of only 10% of the 1963, 1964 and 1966 year classes (Table 8), and the 1969 year class was the only one which was observed in the spawning stock in any quantities the years 1973—1975.

The VPA gives no reliable estimates of the strength of the 1970—1972 year classes, but they were all very weak, tentatively of the order of 10% of the 1967—1969 year classes, i. e. of the order of only 1% of the 1963, 1964 and 1966 year classes.

CONCLUDING REMARKS

The serious effect of the young herring fishery on the recruitment to the adult stock is clearly illustrated in Fig. 5. Even in the 1950s a year class apparently had to be of a size of about 20×10^9 in number as 0-group if a significant quantity was to have a chance to escape the small- and fat-herring fisheries. This means a year class strength of 2–3 times the average strength for the North Sea herring stock which has been estimated to be able to sustain an annual yield of about 800 thousand tonnes if properly managed (ANON. 1973). All year classes in the period 1950—1966, except those of 1962 and 1965, would probably have recruited the adult stock in at least the same quantity as the very strong 1960 year class did if they had not been fished as juveniles.

The 1963 and 1964 year classes were the last ones which survived to an age of 4 years in any quantity, but these two year classes were practically fished out in the fat-herring fishery in 1968 (Table 5, Fig. 6). DRAGESUND and ULLTANG (1972, 1973) discussed the possibility that increased natural mortality from 1968 onwards increased the rate of decline in the adult stock. The authors still regard this as a possibility, and it is also possible that some more fish of the 1963 and 1964 year classes, which never showed up in the spawning stock because of increased natural mortality, were left after 1968. Fishing mortalities of about 4.5, as estimated for these two year classes in 1968, mean that only 1% of the fish present at the beginning of the year survived the fishery, and this seems unlikely as the year classes in question had an offshore distribution in 1968.

The results of the present investigation leave, however, no doubt that the fishing pressure, especially on young and adolescent herring and also on adult herring in the years 1965—1968, was the primary factor for the

collapse of this herring stock. A possible increased natural mortality in later years may have been the result of the already extremely low stock size. In the same way as the fishing fleet was able to generate a much higher fishing mortality on weak than on strong year classes, as demonstrated in Fig. 6 and Table 7 and 8, the predators may have been able to generate a much higher natural mortality when the stock was so strongly depleted by the fishery.

It seems evident from Fig. 3 and 5 that the collapse could have been a reality at a much earlier stage if it had not been for the extraordinarily strong year classes of 1950, 1959 and 1960.

The weak year classes from 1967 onwards were probably the result of the low spawning stock size. If the decline in spawning stock size in 1967 reached the critical level where there is a clear relationship between spawning stock biomass and subsequent recruitment, it means that this critical level for the Norwegian spring spawning herring may be of the order of 1—2 million tonnes. The spawning stock size of 1967 was estimated to 1.3 million tonnes, or 0.8 when catch in the winter fishery is subtracted. The lowest level ever recorded earlier in the period studied, was 1.6 million tonnes in 1963, or 1.5 when catch in the winter fishery is subtracted, and the 1963 year class was relatively strong.

REFERENCES

ANON. 1951. *Annls biol., Copenh., 7* (1950): 122—125.

ANON. 1952. *Annls biol., Copenh., 8* (1951): 136—140.

ANON. 1953. *Annls biol., Copenh., 9* (1952): 164—167.

ANON. 1954. *Annls biol., Copenh., 10* (1953): 143—147.

ANON. 1956. *Annls biol., Copenh., 11* (1954): 114—118.

ANON. 1957. *Annls biol., Copenh., 12* (1955): 158—162.

ANON. 1958. *Annls biol., Copenh., 13* (1956): 173—176.

ANON. 1959. *Annls biol., Copenh., 14* (1957): 149—154.

ANON. 1960. *Annls biol., Copenh., 15* (1958): 126—131.

ANON. 1961. *Annls biol., Copenh., 16* (1959): 163—167.

ANON. 1962. *Annls biol., Copenh., 17* (1960): 161—166.

ANON. 1963 *Annls biol., Copenh., 18* (1961): 142—147.

ANON. 1970. Report of the working group on Atlanto-Scandian herring. *Int.Coun.Explor.Sea Coop.Res.Rep.Ser.A, 17*: 1—43.

ANON. 1973. Report of the North Sea Herring Assessment Working Group. *Coun.Meet.int.Coun.Explor.Sea, 1973* (H:27): 1—33. [Mimeo.]

ANON. 1974. Ressursoversikt for 1974. *Fisken og havet,* 1974 (særnummer): 1—102.

ANON. 1975 a. Ressursoversikt for 1975. *Fisken og havet,* (særnummer): 1—129.

ANON. 1975 b. Report of the working group on Atlanto-Scandian herring. *Coun.Meet.int.Coun.Explor.Sea, 1975* (H:4): 1—16. [Mimeo.]

ANON. 1976. Ressursoversikt for 1976. *Fisken og havet, 1976* (særnummer): 1—107.

BAKKEN, E. and DRAGESUND, O. 1971. Fluctuations of pelagic fish stocks in the northeast Atlantic and their technological and economic effects on the fisheries. *Organisation for Economic Co-operation and Development International Symposium on Fisheries Economics, Paris, 1971* (FI/T 1/6): 1—20, 7 fig. [Mimeo.]

DEVOLD, F. 1963. The life history of the Atlanto-Scandian herring. *Rapp. P.-v. Réun.Cons.perm.int.Explor.Mer, 154*: 98—108.

DEVOLD, F. 1968. The formation and the disappearance of a stock unit of Norwegian herring. *FiskDir.Skr.Ser.HavUnders., 15*: 1—15.

DRAGESUND, O. 1970. Distribution, abundance and mortality of young and adolescent Norwegian spring spawning herring *(Clupea harengus* Linne) in relation to subsequent year-class strength. *FiskDir.Skr.Ser.HavUnders., 15*: 451—556.

DRAGESUND, O. and ULLTANG, Ø. 1972. The collapse of the Norwegian spring spawning herring stock. *Coun.Meet.int.Coun.Explor.Sea, 1972* (H:11): 1—15. [Mimeo.]

DRAGESUND, O. and NAKKEN, O. 1973. Relationship of parent stock size and year-class strength in Norwegian spring spawning herring. *Rapp. P-v. Réun.Cons.perm.int.Explor.Mer, 164*: 15—29.

DRAGESUND, O. and ULLTANG, Ø. 1973. Further studies on stock size fluctuations and rate of exploitation of the Norwegian spring spawning herring, 1950—1971. *Coun.Meet.int.Coun.Explor.Sea, 1973*. (H:19): 1—13. [Mimeo.]

FRIDRIKSSON, A. 1963. Recent trends in the tribal composition of the north coast herring of Iceland. *Rapp. P.-v. Réun.Cons.perm.int.Explor.Mer, 154*: 68—72.

JAKOBSSON, J. 1963. Some remarks on the distribution and availability of the Iceland north coast herring. *Rapp. P.-v. Réun.Cons.perm.int.Explor.Mer, 154*: 73—82.

JAKOBSSON, J. 1968. Appendix. Herring migration east of Iceland during the summer and autumn 1966 and 1967. *FiskDir.Skr.Ser.HavUnders., 15*: 17—22.

ØSTVEDT, O. J. 1963. Catch, effort and composition of the Norwegian winter herring fishery. *Rapp. P.-v. Réun.Cons.perm.int.Explor.Mer, 154*: 109—117.

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