THE USE OF ACOUSTIC AND BOTTOM TRAWL SURVEYS IN THE ASSESSMENT OF NORTH-EAST ARCTIC COD AND HADDOCK STOCKS

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ABSTRACT

In recent years survey results constitute the most important part of the material on which the stock assessments of North-east Arctic cod and haddock are based. Both acoustic surveys and bottom trawl surveys have been applied.

The acoustic surveys were carried out in January-April each year, covering the young fish grounds of both species in the Barents Sea and the spawning grounds for cod along the Norwegian coast. The bottom trawl surveys covered the young fish grounds in the Barents Sea during the same period of time as the acoustic surveys. In addition the Svalbard region was surveyed by bottom trawling in September. Both the total and the spawning stocks of cod were assessed on the basis of survey data and estimates of number of fish at age were worked out. These results were further used together with catch data to select input fishing mortalities for virtual population analysis (VPA).

Comparison between survey estimates in previous years and the back calculated figures from the VPA showed rather good agreement for age groups 5-7. The younger age groups were underestimated by the surveys while the older fish appeared to be overestimated. The underestimation of the young (small) fish is explained by lower availability, but the overestimation of the old cod is unexplained.

In general, the surveys tend to give more consistent and reliable results for cod than for haddock.

INTRODUCTION

In recent years fishery dependent data has been less reliable than previously for the stock assessments of North-east Arctic cod and haddock (Anon 1981). This was mainly caused by changes in fishery regimes, introduction of catch quota schemes and changes in fish distribution patterns caused by hydrographical variations. In order to overcome some of the difficulties the survey activity was intensified in 1981-1982 for both acoustic and bottom trawl surveys.

Hylen and Nakken (1982, 1983 , 1984) have evaluated the Norwegian survey results for 1982 - 1984. They have discussed the sources of errors affecting the results, and some of the acoustic estimates arrived at were corrected before they were used in further assessments. Their results have contributed an important part of the material on which the stock assessment of North-east Arctic cod and haddock have been based (Anon 1985).

The present paper gives a brief description of the survey methods, the limitations and errors involved and possible ways of limiting some of the main errors affecting the survey results.

MATERIALS AND METHODS

The basic data originated from a series of surveys in the years 1982 (1981) - 1985. Fig. 1 shows the approximate areas covered by the surveys and Fig. 3-5 give examples of sampling intensity. Details of each survey are given in the respective reports:

1. The Barents Sea acoustic and bottom trawl surveys in January - March (Dalen et al. 1982, 1983, 1984; Hylen et al. 1985)

2. The Lofoten/Vesterålen acoustic survey in February - March (Godø et al. 1982, 1983, 1984a).

3. The Møre acoustic survey in March - April (Godø et al. 1982, 1983, 1984a).

4. The Svalbard bottom trawl survey in September - October (Randa and Smedstad 1982, 1983; Godø et al. 1984b; Godø 1985).

Bottom trawl surveys

The Barents Sea bottom trawl surveys were carried out by two commercial trawlers. In addition R/V "G.O. Sars" worked some stations in the eastern part of the survey area. The Svalbard surveys were carried by one commercial trawler together with R/V "Michael Sars" or R/V "Eldjarn". All vessels used the same gear; an 1800 meshes shrimp trawl with 12-21 inches rubber bobbins and meshsizes decreasing from 80mm in the front part to 35 mm in the codend. The sweep wires used were 40 m in the Barents Sea and 80 m in the Svalbard region. The trawl was towed for 3 nautical miles at a speed of 3 knots. During towing the trawl had a wingspread of 18-24 m and the headline was between 4 and 5 m above the bottom. The distance between the otterboards were 55-60 m.

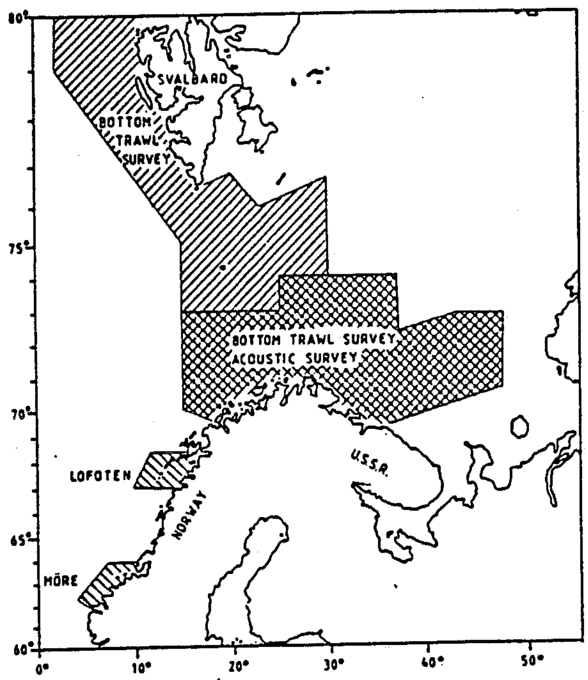

Fig. 1 The areas covered by cod and haddock surveys in the period 1981-1985.

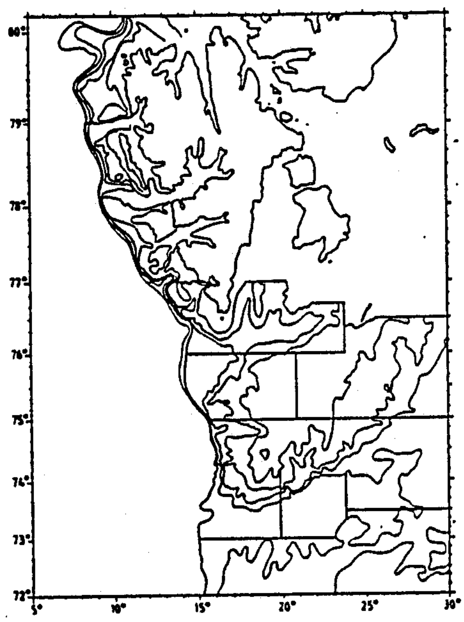

Fig. 2. The stratification used for the bottom trawl survey in the Svalbard region.

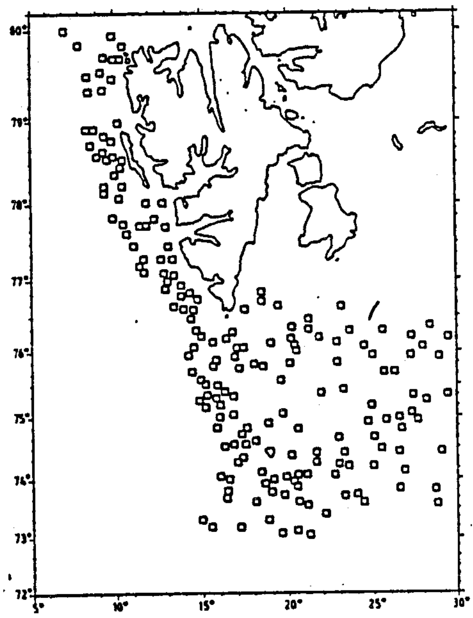

Fig. 3. The trawl stations in 1982 in Svalbard bottom trawl survey.

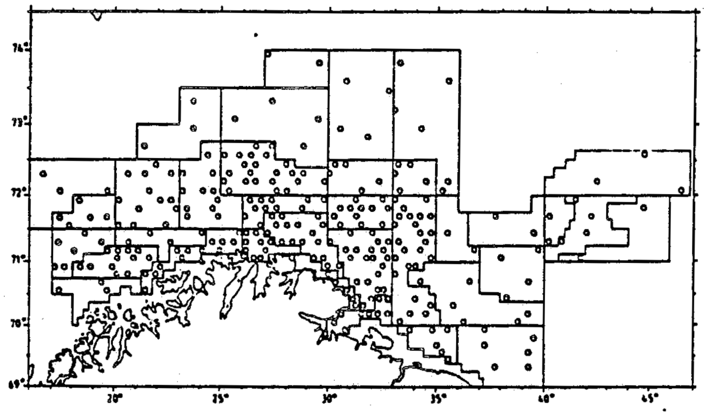

Fig. 4. The stratification used for the bottom trawl survey in the Barents Sea and the stations in the 1984 survey.

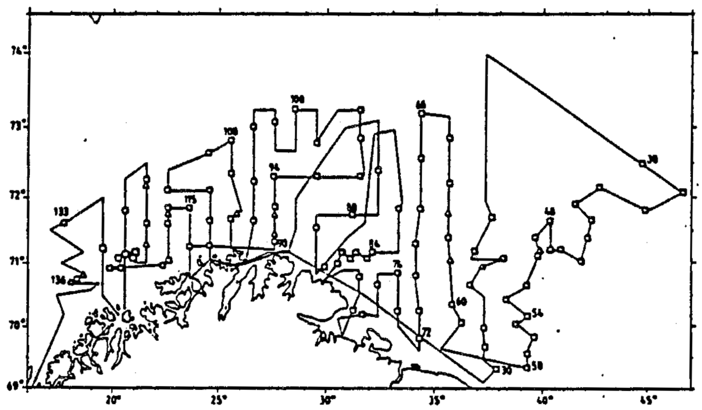

Fig. 5. Survey tracks and trawl stations in the Barents Sea acoustic survey in February 1984. □ Bottom trawl, Δ Pelagic trawl.

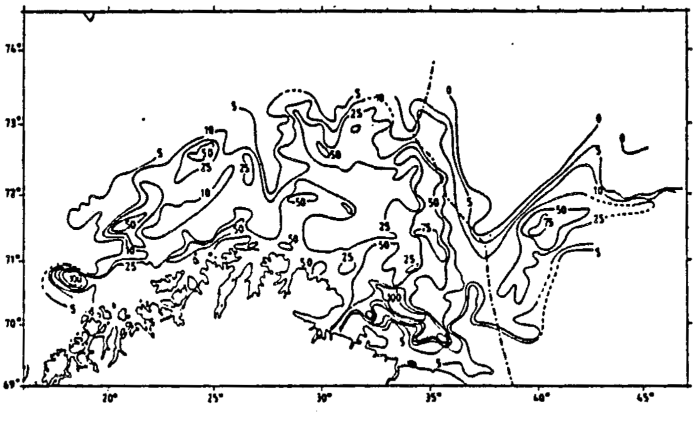

Fig. 6. The distribution of echo abundance (area back scattering, $10m^2$ per nautical mile squared) of cod and haddock in the Barents Sea in February 1984. Concentrations east of the hatched line were mainly 1 year old cod.

Survey design

The trawl stations were distributed throughout the area on the basis of a division of the total area into strata. The stratification (Fig. 2 and 4) was chosen by using information on horisontal fish distribution from acoustic surveys in the period 1977-1980 (Dalen and Smedstad 1983) and knowledge of important fishing grounds. In the Svalbard region the strata were formed on basis of area and depth, using 0, 100, 200,300,400 meters depth as boundaries. The main aim of strata formation was that the density of fish within each strata should be homogenous. According to theory the number of stations to be taken in each strata should then be increased with the expected density of fish in order to minimize the variance.

Given the total number of hauls, N, these were distributed on strata according to the following formula:

$$n_i = (N.V_i.a_i)/A$$

where n_i is the number of hauls in stratum no i

N is the total number of hauls to be taken

A is the total survey area

a_i is the area of stratum no i

V_i is a weight given to stratum no i based on the expected density of fish in the stratum.

Aproximately 280 stations are taken in the Barents Sea and about 200 in the Svalbard region each year. The weightings in the Svalbard strata have been 1.0, giving an area proportional allocation of trawl stations. In the Barents Sea strata weightings ranging from 0.25 to 3.0 have been used to reflect the expected density distribution of fish.

Each stratum was devided into rectangles of 15' longitude and 7.5' latitude in the Barents Sea and rectangles of 7.5' longitude and 3.75' latitude in the Svalbard region. These rectangles were numbered sequentially and chosen at random. Within a chosen rectangle one trawl station could be taken anywhere.

Statistical Computations.

The first step in the calculations have been to calculate the stratified mean catch per haul. The computational formulae for the mean catch per haul and its variance are (Pennington and Grosslein 1978):

$$\overline{X}_{st} = \frac{1}{A} \sum_{i=1}^{k} a_i \, x_i$$

$$\mathrm{Var}(\overline{X}_{st}) = \frac{1}{A^2} \sum_{i=1}^{k} (a_i^2 . s_i^2)/n_i$$

where $\overline{X}_{st}$ - stratified mean
$Var(\overline{X}_{st})$ - variance of stratified mean

x_i - sample mean catch in stratum no i
s_i^2 - sample variance in stratum no i
k - number of strata

An index of abundance have been computed, assumming that the trawl has an effective fishing width of 25 meters:

$$I = \overline{X}_{st}.A.10^{-6}/ SA$$

where SA is the area swept by one standard trawl haul. This index will under certain conditions be proportional to absoulute number of fishes in the area.

The confidence limits to the index are:

$$CI = (\overline{X}_{st} \pm S_{\overline{X}_{st}}.t).A.10^{-6}/ SA$$

where $S_{\overline{X}_{st}}$ is the standard error of the stratified mean catch and t is the 95 percentile of the Student's t-distribution with N-k degrees of freedom.

Acoustic surveys

Acoustic sampling

The acoustic investigations were performed as described by DALEN and SMEDSTAD (1983). Two echo-sounder systems working at 38 kHz were used, one with a hull-mounted transducer and the other within a towed transducer. Both systems were connected to digital echo integrators. Mean values of total back scattering per unit area are produced by an echo integration system at sailed distances of 1 or 5 nautical miles and for selected depth slices, channels, usually 25 or 50 m in depth. One integrator channel was used as a bottom channel, integrating in depth interval between bottom and ten meters off bottom, to have more comparative informations from the depth interval swept by the bottom. Dalen and Nakken (1983) have described in details the method and the data sampling and processing procedures applied onboard the survey vessels. The main steps in the procedure are:

Trawl sampling

Species- and length compositions of the fish which contribute to the total back scattering are obtained from frequent trawl hauls.

Manual preprocessing of data

The echograms, the corresponding values of back scattering and the species- and length composition of the catches form the basis for splitting the total back scattering into species or group categories, "judging". During the cod and haddock surveys the two target species are included in one category called cod + haddock. Hence the result of this process is average values of back scattering per unit area for cod + haddock at distances of 1 or 5 nautical miles in each depth slice.

Computations of fish density

Species and length compositions of cod and haddock in the trawl catches and the established back scattering cross-section/length relationships of individual cod and haddock are used to convert the echo abundances to fish densities. The echo abundance, i.e. integration outputs, were given in relative units up to 1983 and the integrator scaling factors were changed each year according to the observed changes in performance of the integration system. Since 1984 the values of echo abundance have been given in units of back scattering cross section per square nautical mile. The following factor

$$c = \frac{4\pi}{\sigma} = 3.13 \cdot 10^{6} \cdot L^{-2.18}$$

have been multiplied with the echo abundance to give fish density. $\sigma/4\pi$ is the back scattering cross-section of a single fish of length L(cm). This factor has been used for both cod and haddock in 1984 and 1985. Previously a slightly different factor was used for haddock. The two factors were not significantly different in a statistical sense and it was decided to use the cod factor for both species, since that value were based on a much larger set of data (Foote 1979). The main effect of this change was a slight increase of cod relative to haddock.

Final results

The results are given as number of fish by size in 5 cm length group per unit area within statistical rectangles.Finally the length distributions of the two species are converted to age distributions by using age length keys.

RESULTS AND DISCUSSION

Bottom trawl surveys

The most significant trend in Tables 1 and 2 is the increase of the abundance indices in the later years, the indices of the 1982 and 1983 year classes being considerably higher than for the preceeding ones in both areas. Considering a given year class there is also a tendency that the abundance index increased with age. This is clearly seen for the 1977-1981 year classes in the Barents Sea survey (Table 1) for which the highest index occured at an age of 4-5 years. This is less pronounced in the Svalbard area (Table 2), where it might appear as if the index of a given year class reached the maximum value at an age of 2-3 years. Hence it seems that the youngest age groups i.e. the smallest fish, are less available to the trawls than the older fish, a matter which is thoroughly

Table 1. Cod. Stratified swept area trawl indices from the Barents Sea area, winter 1981 - 1985. Numbers in million fish in the area with 95% confidence interval on the total.

Year of invest	1984	1983	1982	1981	1980	Year classes 1979	1978	1977	1976	1975	1974	1973	1972+	TOTAL
1981					0.8	11.0	17.6	16.8	15.1	26.1	4.2	0.8	0.5	92.9± 12.7
1982				0.2	0.8	16.0	20.4	19.5	16.0	15.8	1.4	0.2		90.3± 16.6
1983			44.6	5.9	10.8	28.0	31.9	14.3	4.7	3.0	0.6			143.8± 42.5
1984		355.3	126.6	60.2	19.2	15.6	9.4	3.0	0.4	0.2				589.6±204.9
1985	7.3	169.1	89.6	78.3	15.7	6.5	2.5	0.3						369.3± 59.3

Table 2. Cod. Stratified swept area trawl indices from the Svalbard area, autumn 1981 - 1984. Numbers in million specimens in the area with 95% confidence interval on the total.

Year of invest	1984	1983	1982	1981	1980	Year classes 1979	1978	1977	1976	1975	1974	1973	1972+	TOTAL
1981					0.1	22.2	9.0	5.6	1.3	6.1	3.8	0.7	0.7	49.8±42.4
1982				1.5	4.0	22.2	9.3	2.8	1.9	2.9	0.4	0.1	0.1	45.6±20.4
1983			14.6	5.1	6.2	9.5	3.0	2.5	1.3	1.6	0.4	0.2		44.4±22.5
1984	·	52.2	42.7	5.6	4.2	5.3	2.2	0.5	0.5	0.4	0.2			113.8±26.6

Table 3. Haddock. Stratified swept area trawl indices from the Barents Sea area, winter 1981 - 1985. Numbers in million specimens in the area with 95% confidence interval on the total.

Year of invest	1984	1983	1982	1981	1980	Year classes 1979	1978	1977	1976	1975	1974	1973	1972+	TOTAL
1981					0.3	4.8	3.2	9.4	19.9	6.2	0.4	0.1		44.3± 6.9
1982				0.4	0.8	1.8	2.2	2.2	5.4	2.7	0.3	0.1		16.1± 2.8
1983			314.5	5.7	4.1	3.6	1.9	2.3	3.9	1.6				337.6± 74.1
1984		663.2	355.8	15.2	1.6	0.7	0.2	0.3	0.4					1037.4±286.5
1985	117.2	672.5	368.6	12.9	0.5	0.3	0.3	0.3						1384.0±203.3

Table 4. Haddock. Stratified swept area trawl indices from the Svalbard area, autumn 1981 - 1984. Numbers in million specimens in the area with 95% confidence interval on the total.

Year of invest	1984	1983	1982	1981	1980	Year classes 1979	1978	1977	1976	1975	1974	1973	1972+	TOTAL
1981					+	+	+	+	+	+	+	+	+	0.8
1982				+	+	+	+	+	+	+	+	+		1.0
1983			+	+	+	+	+	+	+	+	+			3.7
1984	+	63.2	3.4	0.1	+	+	+	+	+	+				67.0± 53.0

discussed later in this paper.

Yet it seems that the time (age) variation of the indices for the 1981-1983 year classes might differ considerably from the above mentioned tendency. The figures for the 1981 year class (Table 1) increased considerably more from age 1 to age 4 than the indices for any of the preceeding year classes, a feature which might be explained by the growth of the individuals in the abundant 1982 year class. The individuals in that year class have grown fast and difficulties in the interpretation of the growth pattern and in the establishing of representative age/length keys may have led to a transfer of a significant number of fish from the 1982 year class to the 1981 year class, both in 1984 and 1985 (Dalen et al. 1984). In the Svalbard region the indices of the 1981 and 1982 year classes have developed in line with the expectations.

The 1983 year class was found to be a very strong year class already at an age of six months (Anon 1983). Despite the usually low catchability of one year old cod that year class was caught in large numbers in the winter survey 1984. However, the results in 1985 did not fully confirmed the previous years estimate (Table 1).

Haddock

The results for the Barents sea are given in Table 3. For the year classes prior to 1981 the indices are low and variable while the 1982, 1983, 1984 year classes are all abundant. The appearant increase in 1984 and 1985 of the 1981 year class may partly be explained by a transfer of fish from the abundant 1982 year class, as for cod. When comparing the results for cod and haddock in the Barents Sea it is seen that the haddock outnumber cod in all three years1983, 1984 and 1985. The three recent abundant year classes 1982, 1983 and 1984 are all estimated to be considerably more abundant for haddock than for cod.

In the period 1981-1983 a negligible part of the stock was observed in the Svalbard region (Table 4) This component increased in 1984, caused exclusively by the high abundance of the 1983-year class.

Acoustic surveys

The main results of the Barents Sea surveys are given in Tables 5 and 6 for cod and haddock respectively. Figs. 6 and 7 show excamples of fish distribution. In the period 1979 - 1982 the echo-abundance of cod and haddock was characterized by a western distribution in the Barents Sea (Dalen and Smedstad 1982) associated with low temperatures in the eastern areas (Nakken and Raknes 1984). A change in distribution was observed in 1984, which was the first year since 1978 that significant concentrations of either of these species were observed east of 36 - 37 E (Fig.6). The recordings east of the hatched line in Fig. 6 was mainly due to the 1983 year class of cod while further west the various age

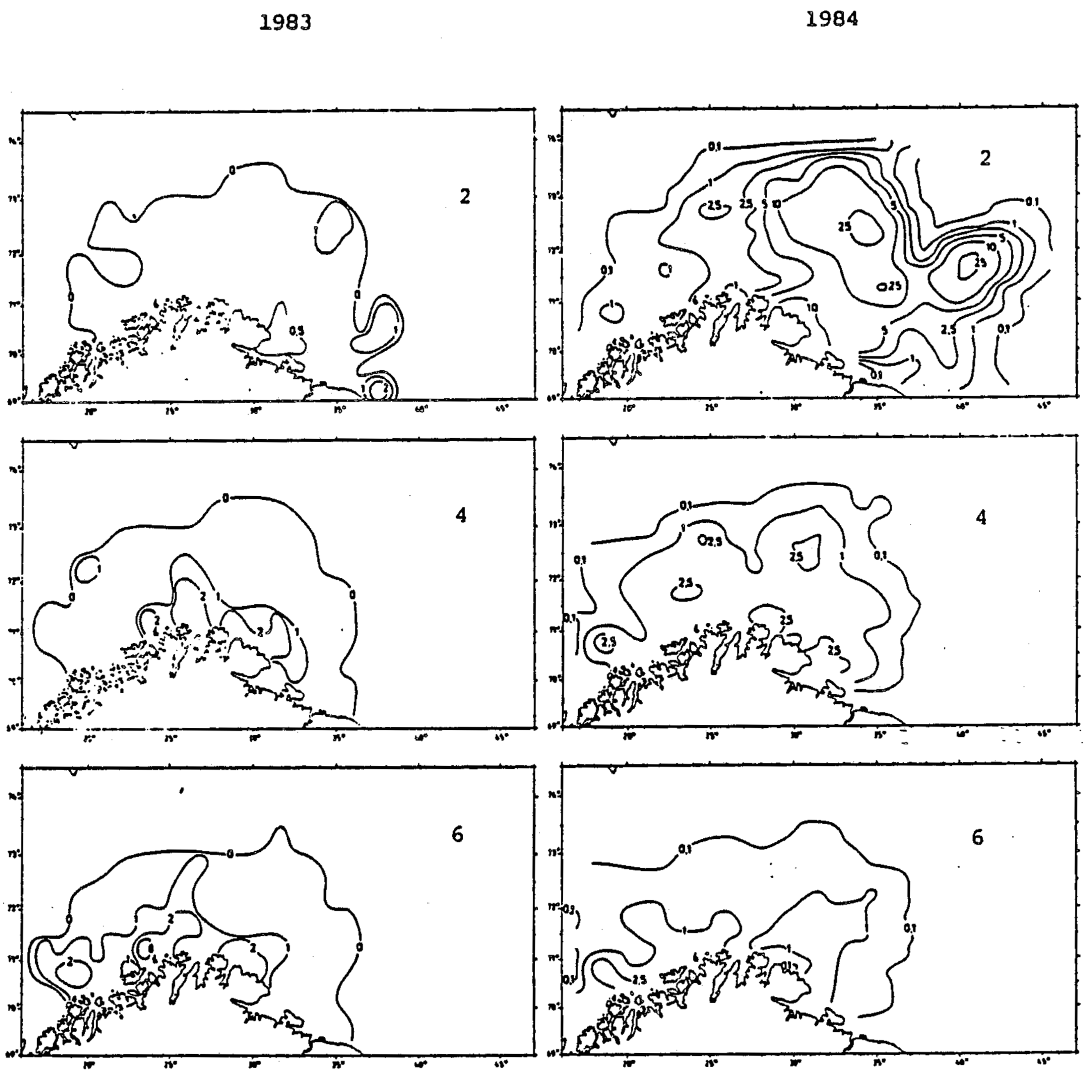

Fig. 7. The distribution of 2, 4, and 6 year old cod in the Barents Sea in February 1983 and 1984 (Number of fish in thousands per square nautical mile).

groups of both species were observed in mixture with increasing proportions of older fish to the west (Midttun et al. 1981).

Cod

The acoustic estimates in Table 5 (above the hatched line) do show a main trend similar to the bottom trawl indices (Table 1). The total numbers in 1984 and 1985 are the highest recorded in the acoustic surveys (Dalen et al 1984 and Table 5 above the hatched line). The year classes 1982 and 1983 make up more than 2/3 of the total number, confirming that these two year classes are much more abundant than the preceeding ones. However, when comparing the series of estimates of the 1983, 1982 and 1981 year classes, large discrepances are seen which will be commented upon later. The indices for 6 year and older fish are reduced year by year (Table 5), because much of the cod reach sexual maturity at these ages and migrate out of the survey area in winter to spawn.

The estimates of abundance for the two main spawning area Lofoten and Møre (Fig. 1), show a decrease in stock abundance year by year in both areas (Table 8). In total, the two components covered by the surveys make up half the total mature stock (Table 8 and 9B). The southern component (Møre) has a higher majority of older fish than Lofoten. In 1984 7 and 8 year old fish dominated in Lofoten and 9, 10 and 11 year olds at Møre.

Haddock

The estimated total numbers in 1984 and 1985 are virtually the same as for cod and are the highest number recorded in the Barents Sea acoustic surveys (Table 6 above the hatched line). The year classes 1982 and 1983 contributed more than 80%, indicating that both year classes are strong while the very low abundance of older fish is in agreement with earlier observations.

Sources and sizes of errors

Since the final estimates of number of fish at age originate from a variety of data and information it is difficult to do a complete error analyses of the results for each particular survey. However, when different independent assessments methods are applied for the same stock, and/or when the stock is surveyed and assessed several times, for instance in subsequent years, likely sizes of errors or variances can be estimated (Nakken and Ulltang 1983). In the following, the most important type of errors which have occurred in the acoustic abundance estimates of cod and haddock in the Barents Sea are discussed. Some examples of how various errors have been evaluated and corrected for in the processing and further use of the data are given together with further use of the data.

Acoustic sampling errors

Excluding operational errors as wrong gain and treshold settings errors in the total echo abundance values can be of four types:

Table 5. Cod. Acoustic abundance estimates for each yearclass in the Barents Sea survey, winter 1981- 1985. Numbers in millions.

Year of invest	Year classes 1984	1983	1982	1981	1980	1979	1978	1977	1976	1975	1974	1973	1972+	TOTAL
1981					3	73	58	124	243	270	41	8	7	827
1982				1	4	71	86	93	73	74	5	1		408
1983				15	17	45	65	38	17	10	2	1		210
1984		2383	506	121	58	53	38	11	+					3170
1985a	58	959	531	549	101	43	17	2	1	1				2261
1985b	118	3392	667	664	48	14	3	+	+	+				4905

Table 6. Haddock. Acoustic abundance estimates for each yearclass in the Barents Sea survey, winter 1981 - 1985. Numbers in millions.

Year of invest	Year classes 1984	1983	1982	1981	1980	1979	1978	1977	1976	1975	1974	1973	1972+	TOTAL
1981					2	25	14	66	160	50	2	1		320
1982				3	4	7	10	12	29	14	1			80
1983				10	7	9	5	4	10	5				50
1984		2148	1002	53	15	7	2	2	2					3231
1985a	815	2574	1086	45	2	2	1	2						4527
1985b	141	1077	468	15	+	+	+	+						1701

Table 7. Length distribution of cod and haddock in pelagic (PT) and bottom (BT) trawl hauls in the western and eastern part of the Barents Sea in 1985. Bottom trawl hauls are located within 10 nautical miles distance from each pelagic haul. Percentage of numbers caught.

	Western area				Eastern area			
Length	Cod		Haddock		Cod		Haddock	
(cm)	PT	BT	PT	BT	PT	BT	PT	BT
5- 9								
10-14		0.1	1.7	9.7	1.7	1.0	0.9	2.0
15-19		0.5	15.5	46.7	3.8	5.0	6.1	13.5
20-24		1.9	6.9	20.8	38.4	17.7	40.0	16.1
25-29		3.0	6.9	17.8	41.0	21.6	31.3	16.2
30-34	1.2	2.9	10.4	2.9	4.1	9.1	7.5	11.0
35-39	2.8	3.6	15.5	1.9	0.8	7.0	9.7	28.3
40-44	16.5	16.4	36.2	0.5	2.6	12.5	4.0	12.0
45-49	42.2	36.3	5.2	0.1	5.3	12.0	0.5	0.7
50-54	30.4	19.1	1.7		1.8	5.2		0.1
55-59	2.4	5.0			0.1	2.1		
60-64	0.9	4.3			0.1	3.2		
65-69	1.2	3.4			0.1	2.0		
70-74	0.2	1.6				0.6		
75-79		1.0				0.6		
80-84	0.2	0.4			0.1	0.2		
85-89		0.2				0.1		
90+		0.3				0.1		
Numbers caught	1817	4500	425	17125	425	2736	58	5383

Table 8. Cod. Acoustic abundance estimates for each year class in the Norwegian coast survey for spawning cod, winter 1982 - 1984. Numbers in millions.

Area	Year of invest	Year classes 1981	1980	1979	1978	1977	1976	1975	1974	1973	1972+	TOTAL
Lofoten	1982				+	1.0	7.0	44.0	9.0	8.0	11.0	80.0
	1983					2.5	11.2	24.5	7.6	3.0	1.2	50.0
	1984			4.0	8.0	10.0	10.0	6.0	2.0			40.0
Møre	1982			+	0.2	0.3	0.6	7.4	1.8	0.3	0.4	11.0
	1983			0.1	0.1	0.7	1.0	2.0	0.5	0.8	0.8	6.0
	1984		0.1	0.1	0.1	0.3	0.3	0.5	0.5	1.5		3.0

Table 9. Cod. Stock size per 1. January based on survey results and landings between 1. January and completion of surveys. Numbers in millions.

A. Total stock.

Year of invest	Year classes 1983	1982	1981	1980	1979	1978	1977	1976	1975	1974	1973	1972	1971+	TOTAL
1982			1	4	87	94	99	97	153	22	12	6	6	581
1983			27	29	81	99	58	43	50	13	5	2	1	404
1984	2382	506	121	58	59	54	30	19	12	(4)				3246

B. Mature stock.

Year of invest	Year classes 1983	1982	1981	1980	1979	1978	1977	1976	1975	1974	1973	1972	1971+	TOTAL
1982					+	5	10	33	99	18	11	6	6	188
1983				+	6	10	18	31	44	13	5	2	1	129
1984				+	11	19	21	19	12	(4)				87

Table 10.Cod. Total stock estimates from surveys and VPA analysis.

Age	1982 Stock Number (millions) Survey	VPA	1983 Stock Number (millions) Survey	VPA	1984 Stock Number (millions) Survey	VPA	F giving best fit	F from survey and catch 1984
3	87	137	29	67	121	63	.06	.032
4	105	135	81	104	58	52	.25	.230
5	103	99	99	92	59	68	.45	.530
6	95	81	58	64	54	57	.60	.640
7	154	91	43	41	30	37	.70	.920
8	23	15	50	37	19	19	.60	.600
9	12	5	13	5	12	14	.50	.570
10	1	2	5	1	4	2	.50	.200

Table 11.Haddock. Stock estimates from the acoustic Barents Sea survey and the VPA analysis.

Age	1982 Stock Number (millions) Survey	VPA	1983 Stock Number (millions) Survey	VPA	1984 Stock Number (millions) Survey	VPA	F used in VPA
3	7	18	7	21	53	23	.10
4	10	4	9	13	15	16	.20
5	12	10	5	3	7	9	.25
6	29	31	4	5	2	1	.30
7	14	7	10	15	2	3	.25
8	1	1	5	3	2	9	.20

1) <u>Inadequate acoustic sampling in the near surface- and near bottom layers.</u> Since almost all cod and haddock are observed below 50 m depth only the bottom layer (dead zone) effect will be of significance. Fig. 8 illustrates the problem. The dead zone is sampled only by the bottom trawl. Attempts have been made to estimate the number of fish in the dead zone, by comparing the acoustic estimates in the bottom channel (10 m) and the bottom trawl estimates (Hylen and Nakken 1983). The results (Fig. 9) indicated a "deadzone" stock of 50 - 60 million fish in 1983, which were added to the acoustic estimate.

2) <u>Excess attenuation due to air bubbles in the water during bad weather conditions.</u> When using the hullmounted transducer the observed echo abundance values are underestimates even at moderate wind forces. By using the towed transducer at a depth of 30 - 50 m the problem is overcome. The echo abundance values obtained with the hullmounted transducers have been corrected for excess attenuation (Dalen and Løvik 1981), and attempts have been made to see to what extent such corrected figures contributes to the total. The results for 1982 are summarized in the following text table:

Correction factor:	1.0	1.1-1.5	1.6-2.0	2.1
Percent %	46	34	18	2

The table shows the shares (in persent of total number) of fish obtained from echo abundance values which were corrected by the given correction factors. The fish recorded with the towed transducer and by the hullmounted in calm weather amounted to 46 percent (correction factor 1.0) while 2 percent of the fish were recorded under severe conditions with the hullmounted transducer. The results indicated that approximately 80 percent of the total fish number were recorded under conditions when errors due to excess attenuation were of relatively less importance that particular year, while approximately 20 percent of the fish were recorded under circumstances when the relibility of the acoustic data must be questioned.

3) <u>Fish migration.</u> The displacement of concentrations of fish within the survey area during the survey period may give biased results. Depending on the direction and speed of the concentrations relatively to the track of the vessel an aggregation may be recorded over too large or too small areas. Usually the fish will have a significant south-westerly (towards coast) movement during the survey period. The mature individuals are underway to the spawning grounds further south while the largest immatures feed heavily on prespawning capelin which migrates towards the coast of northern Norway and USSR. In 1982 this migration lead to a serious overestimation of the 1975 yearclass (Hylen and Nakken 1983).

4) <u>Calibration of the intergration system.</u> Since 1981 the integration system has been calibrated using a "standard sphere method" (Foot et al. 1983, Dalen and Nakken 1983), A solid (copper) sphere of known back scattering cross-section is placed at the

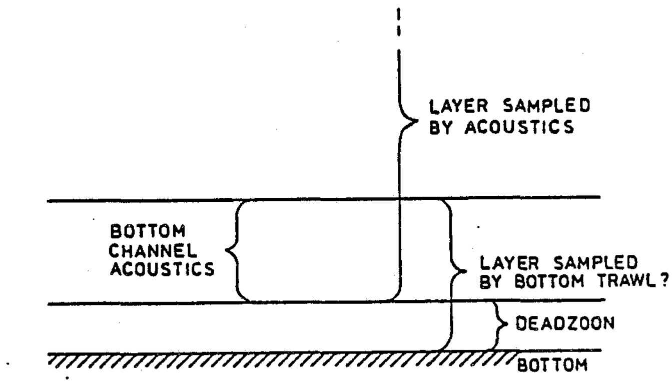

Fig. 8. Schematic illustration of the layers sampled by the two methods: Echo integration and bottom trawl.

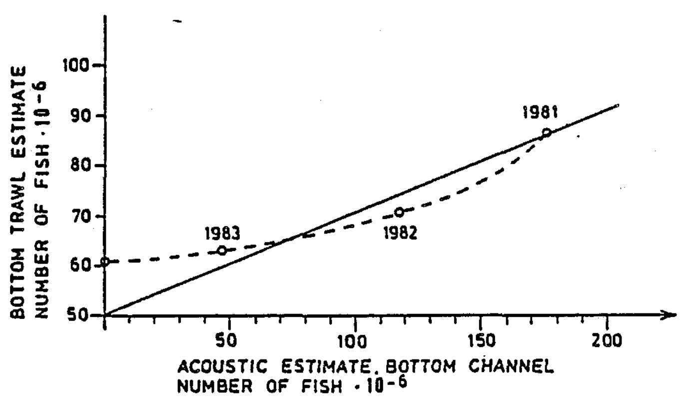

Fig. 9. Acoustic estimates in the bottom channel (the layer between the acoustic bottom and 10m above) plotted against bottom trawl estimates for the offshore areas of the Barents Sea.

acoustic axis of the sounder and the integration system is operated as under usual survey conditions. The result is a calibration factor which scales the outputs of the system to units of back scattering per unit area. The repeatability and consistency of the calibration results were increased considerably by this method as compared to the results obtained prior to 1981 when measuring hydrophones were used for calibration.

Errors in the manual preprocessing of data

The reliability of the separation of echo abundance values into species - or fish group categories depends on three main factors: the extent of mixing of various categories, the intensity of fishing and the experience of the staff. Daily during a cruise, a group of experienced persons (cruiseleader, chief of instrument etc) sqruitinize all the data sampled during the last 24 hours. They compare the recorded echo abundance values with the corresponding traces on the paper record and with catches on trawlstations, decide whether or not trawlstations are giving representative samples of the recordings and allocate echo abundance values to the various species of group of fish. They also instruct the staff what types of recordings which require more trawling effort during the next day.

It is impossible to quantify the errors which are being introduced during this procedure. In general, the errors will be large in areas where the density of cod and haddock is low as compared to other fish and in particular if there is no vertical or horizontal separation of the various species. In areas where cod and haddock predominate the errors are insignificant. Hence, since cod and haddock are spread over wide areas even at low stock levels, the errors introduced in (the manual) preprocessing of data are larger at low stock levels than at high ones.

Trawl sampling errors

During acoustic surveys the primary aim of the fishing is to provide representative samples of the acousticly recorded fish. In addition, the fishing should also provide information on to what extent all the fish are sampled representatively by the acoustic integration system (deadzones). The basic requirements are that each trawlcatch should provide an representative estimate of the density ratios between cod and haddock over the entire length range and that also the length distributions obtained are the "true" ones (Dalen and Nakken 1983). These requirements are met only rarely (Dalen and Smedstad 1983, Dalen et al. 1984 and Hylen and Nakken 1984) and inefficient sampling of the recordings is by far the largest source of error in the cod and haddock survey.

The sampling problem is a complex one and cannot be discussed in details here. Fig. 10 illustrates a part of the problem. This figure shows the development of the bottom trawl indices for the 1977 - 1980 yearclasses of cod (Dalen et al. 1984) clearly indicating that the young fish has been underestimated as compared to the older one. The LIKELY LINE is drawn through back-calculated values based on 5 year olds,i.e. it represent the approximate expectation of the figures that should have been obtained. The 1 and 2 year olds appear to be underestimated by a factor of 8-10. When age groups are mixed in the sea we must therefore expect that length- or age distributions from bottom trawl catches are heavily biased, the small and young individuals being significantly underestimated as compared to the larger fish. This effects the acoustic estimate in exactly the same manner. The problem become serious in years when abundant young age groups enter an almost depleated stock like that in 1984 and 1985 when strong yearclasses (the 1982 and 1983 yearclasses) entered the stocks of Arctic cod and haddock. The occurrence of large quantities of small fish in the Barents Sea produced much higher echo abundance values than in the preceeding years. However, our inability to have representative length distributions of the fish in areas were these young specimens were mixed with older ones, resulted in gross overestimates of the older age groups and corresponding underestimates of the young ones in these areas. In 1984 Hylen and Nakken (1984) therefore neglected the acoustic estimate of 3 year olds and older fish for the eastern Barents Sea and estimated the abundance of these age groups from the previous years acoustic estimate of the corresponding year classes and the ratio between the bottom trawl indices in 1984 and 1983. A preliminary examination of the 1985-data indicate that errors introduced by biased trawl sampling are even more pronounced this year (Table 5 and 6).

In Tables 5 and 6 are given two alternative sets of estimates for 1985. Alternative a) is based on the length and species compositions in all trawlstations taken in the two types of survey. The underlying assumption was that the bottom trawl catches were representative for the entire water column. The estimates in alternative b) were arrived at by using length and species compositions in pelagic hauls only as representative for the fish concentrations which were more than 10 m above the bottom. In the bottom layer the bottom trawl catches were used. The differences between the two sets of estimates demonstrates the large effect of the two different ways of treating the data. By choosing alternative b instead of a there appears first to be an enourmous transfer of fish from haddock to cod and secondly a shift form older (larger) individuals to younger (smaller) was observed. Yet the absolute smallest fish - the 1 group was reduced in numbers.

The problem of representative sampling includes gear efficiency, vertical distribution and fish behaviour in relation to the fishing system (vessel and gear). Fig. 11 shows a schematic representation of the distribution of the echo abundance of cod and haddock in the Barents Sea in winter 1985. Approximately 14 percent of the echo abundance were recorded in the bottom channel, 40 - 45 percent in the layer between the bottom and 50 m above the bottom while the remaining 40 percent were recorded higher up in the water column. There is also a clear tendency that the pelagic trawl caught cod and haddock were of smaller size than the bottom trawl in the

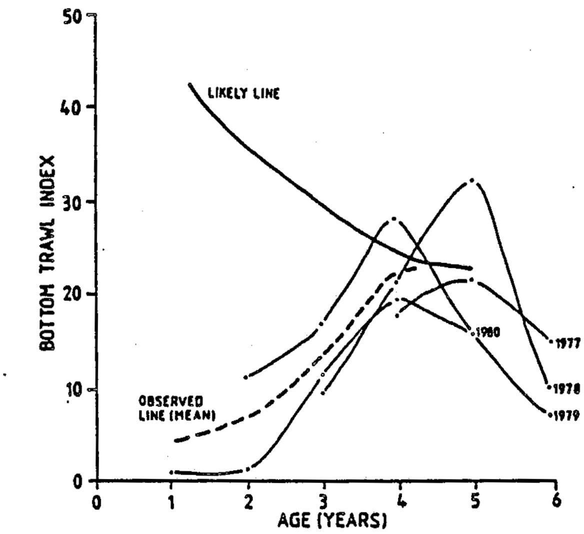

Fig. 10. Bottom trawl indices at age for the 1977-1980 year classes. (See text for explanation).

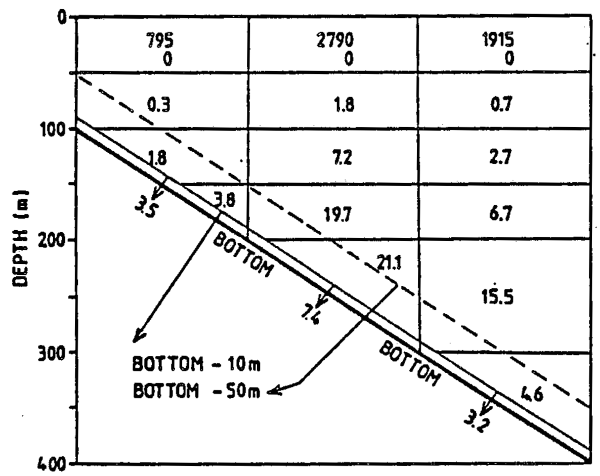

Fig. 11. Schematic presentation of the distribution of echo abundance (in percent of the total within the whole area surveyed) of cod + haddock in the Barents Sea in February 1985. Figures at top show number of nautical miles sampled.

eastern areas (Table 7). In the western parts of the sea the cod has similar length distributions in the two types of gear, while the bottom trawl caught the smallest haddock.

It has been observed many times that cod and haddock tends to descend towards the bottom when towing midwater trawls. Most probably this will also lead to a size selection as the largest fish dive faster than the smaller ones and thereby avoid to be caught. In addition we also suspect that the pelagic trawl undersample the smallest specimens due to mesh selection in the front parts when the mesh size is 20 cm.

In conclusions; We <u>know</u> that the bottom trawl catches provide biased length distributions, - the smallest fish being underrepresented, - and we <u>expect</u> that the midwater trawl catches are biased, the medium sized fish being overrepresented. At present the errors introduced to the acoustic estimates from these sources might be of great significance depending on the extent of mixing between the age groups. In situ measurements of acoustic back scattering strengths of individual fish may in future greatly aid to overcome the problems of representative biological sampling. Yet, it should be remembered that such measurements at least for a period of some years need verification by representative sampling of the fish concentration actually measured acousticly. Effort should, therefore, be put into construction and design of sampling trawls.

Assessment of total and spawning stock size

Cod

In 1982,1983 and 1984 Hylen and Nakken (1982,1983,1984) used the survey results and preliminary commercial landing statictics in the respective areas for the period of the year prior to the surveys in estimating the total stock. The results are shown in Table 9 A. Stock numbers by age at 1 January each year were arrived at, by adding the respective catches and the stock estimates from the surveys.

Three parts of the total area of fish distribution were insufficiently covered by the acoustic survey activity (Fig. 1); north of Lofoten, between Lofoten and Møre, and the Svalbard region. In the two first mentioned areas the number of fish at age were estimated by assuming a stock/catch relationship as for Lofoten and Møre respectively.

The Svalbard stock component which has been investigated by a regular groundfish survey each year in September - October was estimated by the swept area method. During these surveys the fish were mainly recorded at or close to the bottom. It was therefore felt that the swept area indices for this region were less biased than for the Barents Sea and could be used as absolute estimates of fish numbers. The stock estimated at 1 October each year was reduced by total mortality up to the 1 January the following year. In the beginning of the year the mature part of the Svalbard stock component is on the spawning grounds and thus included in the estimates from these areas. The mature fish were therefore excluded from the Svalbard estimates by applying a maturation ogive similar to that estimated for the rest of the stock.

Frequent biological sampling of both survey catches and commercial landings formed the basis for the estimates of spawners from the total figures. The samples from the Møre - Lofoten areas showed that nearly all cod both in commercial landings and research vessel catches was mature and hence the total stock within these areas was assumed to be spawners. For the areas north of Lofoten and in the Barents Sea it was assumed that the percentage of mature fish in the stock was equal to the percentage of mature fish in the commercial landings and in the survey catches respectively. As mentioned previously the mature fish in the Svalbard component was included in the acoustic estimates from the spawning grounds.

The total spawning stock at 1 January was estimated by summing the landings of mature cod and the estimates of the different spawning stock components in the surveys. The figures in Table 9B show a decrease in spawning stock year by year in the period 1982 - 1984, indicating a high exploition rate and poor year classes.

The estimated numbers by age of the total stock and the spawning stock were used to calculate maturation ogive. These differ considerably from those based on samples, taken when the immature and mature fish is mixed in the population (Anon 1983).

Some of the fishes included in both the surveys and landings were coastal cod. Both in Lofoten and off Møre these fishes were found in the younger age groups (Hylen, 1971:Godø et al. 1983). This is not corrected for in the present assessments, and hence the figures for the younger age groups of the spawning stock (Table 9B) are overestimates for the North-East Arctic cod stock. Consequently, also the percentage of mature fish might be somewhat overestimated for the younger age groups.

How consistent and reliable are the total stock estimates in Table 9A? A direct way to investigate this is to compare the estimated numbers at age with the corresponding figures from a virtual population analysis (VPA). A preliminary attempt was made by the Arctic Fisheries Working Group in September 1984 (Anon 1985). Unfortunatly there was no independent information as for instance fishing effort that could be used to indices the input fishing mortalities (F) in 1984. Therefore, the VPA had to be tuned to the survey results by selecting resonable values of F, taking into account also other relevant informations as 0-group estimates and known exploitation patterns. The two sets of stock estimates were compared. By this procedure the consistency in the survey results can be checked , but systematic errors, originating for instance from a wrong integrator scaling factor will not be detected unless the bias is quite large.

The survey stock numbers for 1984 and the expected catches generate a series of F's for 1984 (Table 10). When used as input in the VPA these F's give stock numbers by age which differ from the survey figures and from estimates based on 0-group indices. The F' series were therefore modified, taking into account the underestimation of the younger age groups in the surveys. The 0-group estimates and F-values for the 3 and 4 year olds were modified to get almost equal VPA stock numbers of the 1980 and 1981 year classes as three year olds (Table 10), and the F's for the age groups 5 - 8 were chosen to produce stock numbers close to those estimated in the surveys. For age 9, the survey results indicate that the fishing mortality should be lower than for age 8 (F_8 =0,6) and a value of 0,5 was chosen for the age groups 9 - 10.

The VPA stock numbers by age for 1982 - 1984 generated by the modified F-series are compared with the survey estimates in Table 10 where also the two F's series are given (Anon 1985). The agreement is generally good for the age groups 5-7. The high survey estimate of 7-year-old cod in 1982 is explained by the special behaviour of that year class during the 1982 survey (Hylen and Nakken 1983). Excluding this year class, a linear regression of the survey and the VPA results for age groups 5-7 in 1982 - 1984 gave a correlation coefficient of 0,97, demonstrating that a high correlation between VPA-stock numbers and survey results was obtained with input F values that appeared to be at a reasonable level.

For age group 3 and 4, the acoustic survey produced underestimates in 1982 and 1983, which is in agreement with indications in earlier years, while 1984 for special reasons deviated from this pattern (Dalen et al. 1984). From age 8 or 9 the survey tends to produce overestimates compared to the VPA. The reason for this is not clear.

Haddock

The entire immature part of the haddock stock except the small Svalbard component and an unknown fraction of the mature part are covered by the Barents Sea acoustic survey. The bulk of the spawners were not covered by any of the surveys, Therefore, estimates of total stock numbers cannot be arrived at from the acoustic survey results, and a similar comparison between survey and VPA stock numbers as for cod, can not be made. Yet a comparison of the stock numbers in the Barents Sea acoustic surveys in 1982-1984 and the total VPA stock numbers may be of interest. The Barents Sea survey is felt to cover the bulk of the haddock stock in this period and only small quantities are landed between 1 January and the survey time.

In Table 11 the acoustic estimates in the Barents Sea survey are compared with total VPA stock numbers from the VPA. The input F's for the VPA were chosen on the basis of comparisons between fishing mortalities, catch per unit of effort and biomass of cod and haddock (Anon 1985). In addition, the survey estimates of 3 and 4 year old haddock were considered. Although the variance in the results is large it is seen that the agreement between survey estimates and VPA, indicating that even at low stock sizes as experienced in the past, acoustic surveys might give valuable information on the stock size of haddock.

CONCLUSIONS

1. During the years 1982-1985 large fluctuations in stock size and structure occured in the stocks of North-east Arctic cod and haddock characterized by a rapidly decreasing fishable part of the stock (age 3+) and a high production of recruits in 1982-1984. The stocks were monitored by bottom trawl surveys and acoustic surveys in addition to traditional assessment methods based on catch statistics and biological sampling (VPA).

2. Comparison of the results showed that the information on stock size and structure from the bottom trawl surveys was limited, mainly due to vertical distribution of the fish and length/age/species selection of the fishing sampling gears.

3. The stock estimates produced from the acoustic data were found to be consistent for cod of 5-7 years. However, since representative length and species compostions are needed to convert echo abundances to stock numbers, also the acoustic estimates were heavily biased due to biased trawl sampling, particulary in the 1984 and 1985 surveys when strong year classes recruited to the stocks. Both these years severe difficulties were encountered in arriving at the best estimate of the stocks.

4. Even though acoustic surveys have proved to be a very useful tool in stock assessment of cod and haddock, their performance would be largely increased if reliable in situ target strength measurements and representative length and species compositions of the recordings were available.

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