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NORWEGIAN ACOUSTIC SURVEY OF NORTH EAST ARCTIC COD ON THE SPAWNING GROUNDS OFF LOFOTEN

by

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ABSTRACT

An acoustic survey of the spawning stock of North East Arctic Cod off Lofoten has been performed annually in March-April since 1982. The estimates for 1985-1997 have been recalculated and mean length and weight at age are shown together with the abundance indices (both numbers and biomass). The abundance indices for each age are compared with VPA results from a reasonably converged part of the series. It is shown that the VPA tuning assumption of constant log catchability at age should not be used for this survey series. As the survey produces abundance indices for the mature part of the cod stock these indices should be corrected with proportions mature before they are used in traditional assessment methods estimating year class strength.

INTRODUCTION

The main spawning grounds of North East Arctic cod is in the Lofoten area. Echosounder equipment was first used in 1935 to detect concentrations of spawning cod (Sund 1935a, Sund 1935b). The first attempt to map such concentrations was made in 1938 (Sund 1938). Later investigations have provided valuable information on the migratory patterns, the geographical distribution and the age composition and abundance of the stock.

As the Norwegian combined acoustic and bottom trawl in the Barents Sea during the winter covers only the imature part of the population, the survey in Lofoten could introduce valuable information for assessment purposes. See also Jakobsen et al. 1997.

CURRENT OBJECTIVES

The current acoustic survey of cod on the spawning grounds off Lofoten is conducted annually from the middle of march until the beginning of April. The survey aim at achieving the following estimates:

- Estimates of abundance by age
- Estimates of mean length , body weight and liver weight at age
- Estimates of proportions recruit and repeat spawners by age

- Estimates of sex ratios by age

The cod fishery in Lofoten during the spawning season is one of the most traditional fisheries in Norway and information to and contact with local fishermen is a part of the institute (IMR) policy.

HISTORY

An early attempt to measure the distribution of spawning cod off Lofoten by means of echosounder equipment is described by Sætersdal and Hylen 1959. A part of the work by Hylen, Midttun and Sætersdal 1960 describes a second acoustic survey in Lofoten. Monstad, Nakken and Nævdal 1969 describe an acoustic survey on the spawning grounds in 1969. The surveys described in Jakobsen 1974, Smedstad 1974, Jakobsen 1975, Jakobsen 1978a, Jakobsen 1978b and Jakobsen 1979 constitute a short time series of acoustic surveys in the area. In the work listed above there was few attempts to estimate total abundance. Due to the lack of automatic recording of echovalues only single fish counting was used and results obtained was presented as more or less fish compared to last years survey. Included in the reports are estimates of age composition. Total echo values were recorded from 1982. In 1982-1985 the calculations relied to some extent on length distribution samples from commercial catches. In 1982-1984 age sampling from the trawl catches was sparse. (Godø et al. 1982, Godø et al. 1983, Godø et al. 1984, Godø et al. 1985, Hylen et al. 1982, Hylen et al. 1983, Hylen et al. 1984, Hylen et al. 1985, Nakken 1984) Age sampling was introduced as a routine part of the survey in 1985. Until 1990 one of the main objectives of the surveys was the mapping of cod distributions during the migration and the publishing of these results in local newspapers. This would then assist the fishermen in targeting their fishing effort. Later surveys have primarily directed the effort towards abundance estimation.

TECHNICAL DESCRIPTION

Length of the time series

The current time series of survey data starts in 1985. Due to the change in echo sounder equipment in 1990 results obtained earlier are not directly comparable with later results. However by comparing the two series 1985-1989 and 1990-1994 with a converged VPA adjusted for proportions mature there is no significant improvement to the regressions between log VPA numbers and log survey numbers by introducing separate regression lines by age for the periods 1985-1989 and 1990-1994. Although the number of observations is low it seems that the increase in echo values due to the change in echo sounder equipment was compensated with the introduction of a new reduced single fish target strength. See also the sections Assessment calibration and Catchability assumptions.

Design

The survey is designed as equidistant parallell acoustic transects covering 3 strata (North, South and Vestfjorden). These strata and the 1997 courselines are shown in Figure 1. In most surveys previous to 1990 the transects are not parallell, but more as parts of a zig-zag pattern across the spawning grounds aimed at mapping the distribution of cod.

Some of the surveys in the 1980's was designed as a series of "mini surveys" aimed at finding a "peak" in abundance and thus locate the best time for conducting a survey (Nakken 1994).

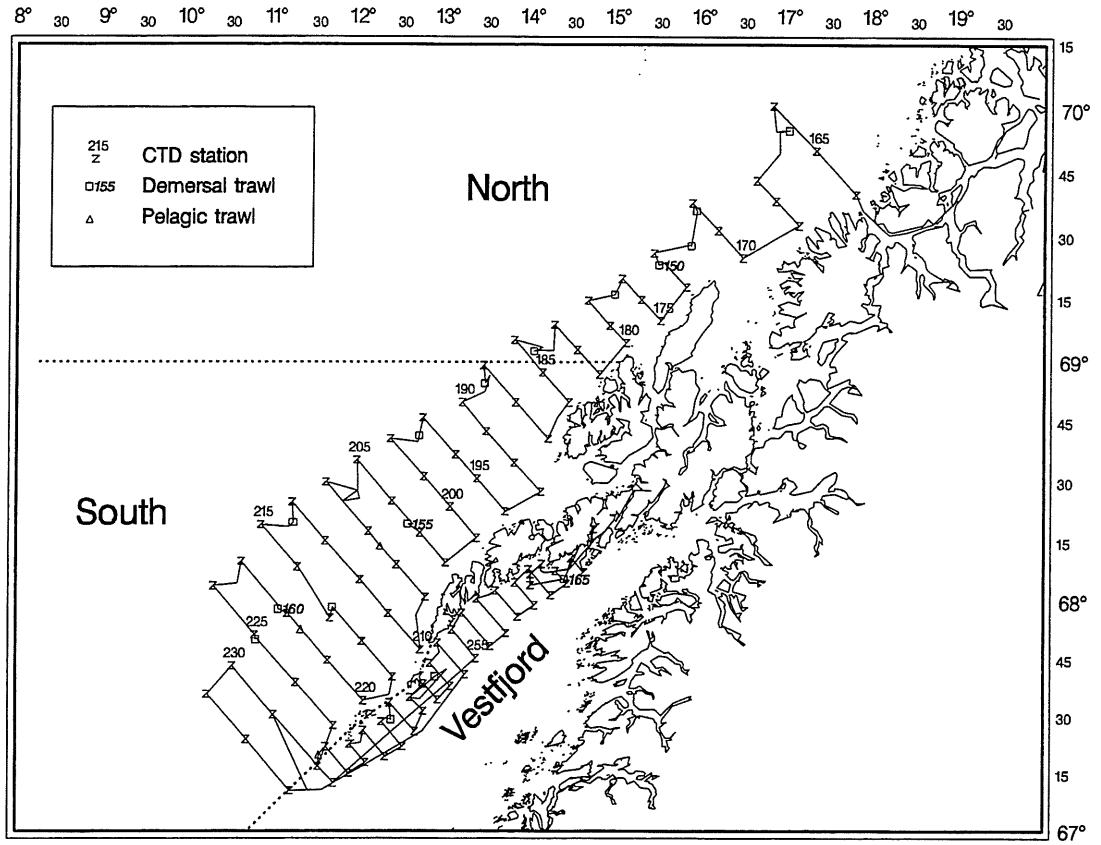

Figure 1 Courselines, hydrographical stations and trawl stations for R/V Johan Hjort in 1997.

Trawl samples are not taken according to a proper survey design. This is due to practical reasons. See also the section Sources of bias in biological sampling (trawl stations) for more details.

Survey effort

Table 1 summarises the effort used in the surveys. Please note that the survey area (or parts of the survey area) was covered several times acoustically in some years.

Table 1 Survey year, vessel, vessel days, person days at sea, number of trawl stations, number of cod lengthmeasured and number of cod age sampled.

Survey year	Vessel[1]	Vessel days	Person days[2]	Trawl stations	No. of cod measured (length)	No. of age samples
1985	GOS	12	84	8	1756	144
1986	MS	18	108	15	794	268

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MS R/V Michael Sars
GOS R/V G.O. Sars
JH R/V Johan Hjort
EJ R/V Eldjarn

[2] Number of scientfific staff multiplied with vessel days

Survey year	Vessel[1]	Vessel days	Person days[2]	Trawl stations	No. of cod measured (length)	No. of age samples
1987	GOS	17	153	20	605	382
1988	GOS	14	84	28[3]	756	424
1989	GOS	18	144	18	696	398
1990	EJ	18	126	37	1379	796
1991	MS	20	120	31	1516	602
1992	MS	22	154	35	2330	732
1993	MS	30	210	41	2362	1241
1994[4]	GOS	29	261	44	2571	1252
1995[5]	MS	17	136	31	2014	994
1996[5]	MS	16	128	41	2129	875
1997	JH	12	84	23	1139	664

Routine analysis and reporting after the survey take usually not more than one month using approximately 30 person days. In the years 1982-1987 the surveys were reported as papers to the ICES statutory meetings. Later reports have been internal cruise reports at IMR.

Information collected

Both acoustic, biological and hydrographical information is collected at this cruise.

The acoustic recording has since 1990 been made with the SIMRAD EK500 scientific echo sounder (Bodholt et al. 1988) connected to a UNIX workstation using Bergen Echo Integrator (BEI) for data storage and postprocessing (Knudsen 1990). After the species allocation process which includes the use of onscreen handling of visual echogramms and the use trawl catch composition data, the echo densities are stored as mean echo density observations for each nautical mile (nm), depth interval and species (cod, haddock, saithe, redfish, herring, Norway pout or others).

Both pelagic and demersal trawl stations are used to collect species, length and age composition. This information is recorded at 5 levels presented in Table 2. Trawl data are punched in ASCII format and transferred to an INGRES database after the survey.

Table 2 Details of the sampling levels used for trawl stations

Sampling level	Data collected
Trawl station data	Gear used, towed distance, depth, time, position, trawl geometry.
Catch composition	Catch by species in kg and numbers, size of length sample (kg and numbers)
Length frequency	Length frequency by species

[3] Includes trawl station taken by R/V Michaels Sars in the same area

[4] The survey included studies of fecundity

[5] The survey was combined with an acoustic survey for herring

Sampling level	Data collected
Individual observations	Age reading, length, weight, maturity, sex, liver weight, age at first spawning. Stratified sampling by 5 cm length intervals.
Stomach samples	Weight of stomach content by species (and unidentified), degree of digestion, length distribution by prey species.

CTD stations are routinely sampled over the survey area (see also Figure 1). Hydrographical sections in the Vestfjorden area are used to evaluate temperature conditions on some important spawning grounds.

Estimation of abundance indices

Abundance indices are produced for each of the 3 strata and the total is obtained by summation. The abundance is directly proportional to the echo value. Total echovalue for each of the strata is calculated as the sum of mean $\bar{s}_A$ values along transects weighted with the distance between the transects (1990-1997):

$$Echovalue = \sum_t \sum_n (\bar{s}_A)_{t,n} \cdot k_t \qquad (1)$$

t,n transect number, observation number (on transect)
k_t distance (nautical miles) between parallell transects

Previous to 1990 average $\bar{s}_A$ within rectangles was used to calculate total echo values. The single fish target strength used in calculations previous to 1990 was:

$$TS = 21.8 Log(L) - 74.9 \qquad (2)$$

Since 1990 the following target strength is used in the abundance estimation of cod, haddock and saithe (Ona 1993):

$$TS = 20 Log(L) - 68.0 \qquad (3)$$

This corresponds to the following conversion factor

$$C_F = 5.021 \cdot 10^5 \cdot L^{-2} \qquad (4)$$

Weighted length frequency distribution for each species and stratum together with the estimated echo value is used to estimate the abundance in stratum and lengthgroup.

$$f_i = \sum_s f_{s,i} \cdot \frac{v_s}{v_s^{(L)}} \cdot \frac{1}{d_s} \qquad (5)$$

s,i station number, length group
$v_s, v_s^{(L)}$ weight of catch (by species), weight of length sample
d_s towed distance (nautical miles)

The abundance in numbers at length is estimated as:

$$N_i = Echovalue \cdot 5.021 \cdot 10^5 \cdot \frac{f_i}{\sum_j (f_j \cdot j^2)} \qquad (6)$$

N_i abundance estimate (numbers in lengthgroup i)
j lengthgroup (length in cm)

Age is determined using 5 cm stratified length intervals. The traditional estimation of age-length keys has been changed to produce "keys" that for each 5 cm length group and strata contains estimates of proportions:

$$p^{(l)}_{s,a,m,k} = \frac{\sum_{i}\left(n^{(l)}_{i,s,a,m,k} \cdot f_{i,l}\right)}{\sum_{i,s,a,m,k}\left(n^{(l)}_{i,s,a,m,k} \cdot f_{i,l}\right)} \qquad (7)$$

$p^{(l)}_{s,a,m,k}$ is the weighted proportion of stock s, age a, maturity m and sex k in lengthgroup l

$n^{(l)}_{i,s,a,m,k}$ is the number of samples at station i of stock s, age a, maturity m and sex k in lengthgroup l

$f_{i,l}$ is the raised length frequency density estimate at station i of lengthgroup l

Proportions are used together with the abundance estimates:

$$N^{(l)}_{s,a,m,k} = N_l \cdot p^{(l)}_{s,a,m,k} \qquad (8)$$

Total estimates by summation:

$$N_{s,a,m,k} = \sum_{l} N^{(l)}_{s,a,m,k} \qquad (9)$$

or:

$$N_{s,a} = \sum_{l,m,k} N^{(l)}_{s,a,m,k} \qquad (10)$$

s	Stock: Coastal cod or NEA cod identified from otholith readings
a	Age: 5 to 12+
m	Maturity (spawning history): Immature, recruit spawners or repeat spawners
k	Sex: Female or male

USE OF SURVEY INFORMATION

Survey estimates

A summary of survey estimates is given in APPENDIX I tables A1- A5. Table A4 and A5 give estimates of the population parameters mean length and weight. Some of the estimates are based on very few observations and have a higher standard deviation than other estimates. Some of these can be identified from table A1 which contain the abundance estimates. Estimates representing small proportions of the total have a higher variance. Table A2 presents the biomass estimates while table A3 shows the estimated percentages of males and females. The assessment results presented in APPENDIX II are taken from Anon. 1997.

Assessment calibration

The survey series has since 1996 been used as one of several "tuning" series used by the assessment working group. The time series used for this purpose is given in table A4 in Anon. 1997. Quoting from section 3.4.1 of that report: "... This gave a reference F (age 5-10, unweighted) in 1994 (F_{94}) of 0.52, compared to 0.50 in last year's assessment. Including the

Lofoten survey in the tuning gave F_{94}=0.55, i.e. a slight increase". The Lofoten time series was given relatively low weight in the tuning compared to the Norwegian bottom trawl and acoustic survey series from the Barents Sea.

The Lofoten tuning series was used directly in the 1996 assessment after the numbers was shifted to 31. December the previous year. For younger yearclasses with maybe only small proportions mature the estimates should be corrected by this proportion in future assessments.

Catchability assumptions

Figure 2 and Figure 3 are showing the linear regressions by age groups between the log VPA numbers at the beginning of the year and the log abundance indices from the acoustic survey corrected for proportions mature. The 1988 data are not included because none of the points from that year seemed to fall in line with the other points. All indices from this survey seem to be far to low as compared with other years. The reason for this is not yet clear.

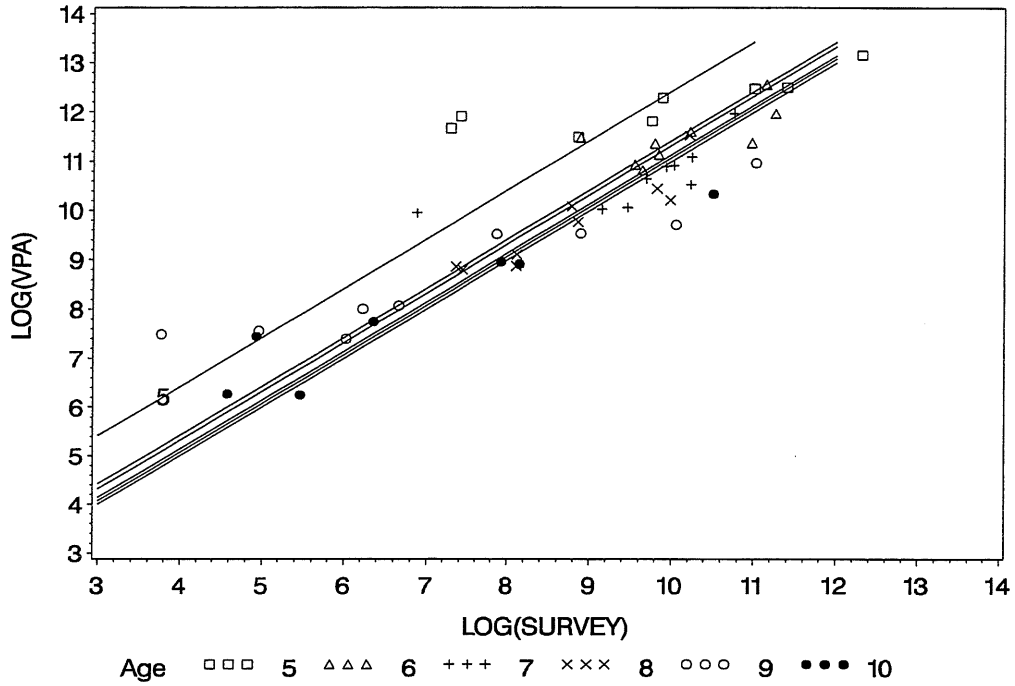

Figure 2 Mean log catchability used as intercept in a regression with slope 1 between log VPA numbers and log survey numbers corrected for proportions mature..

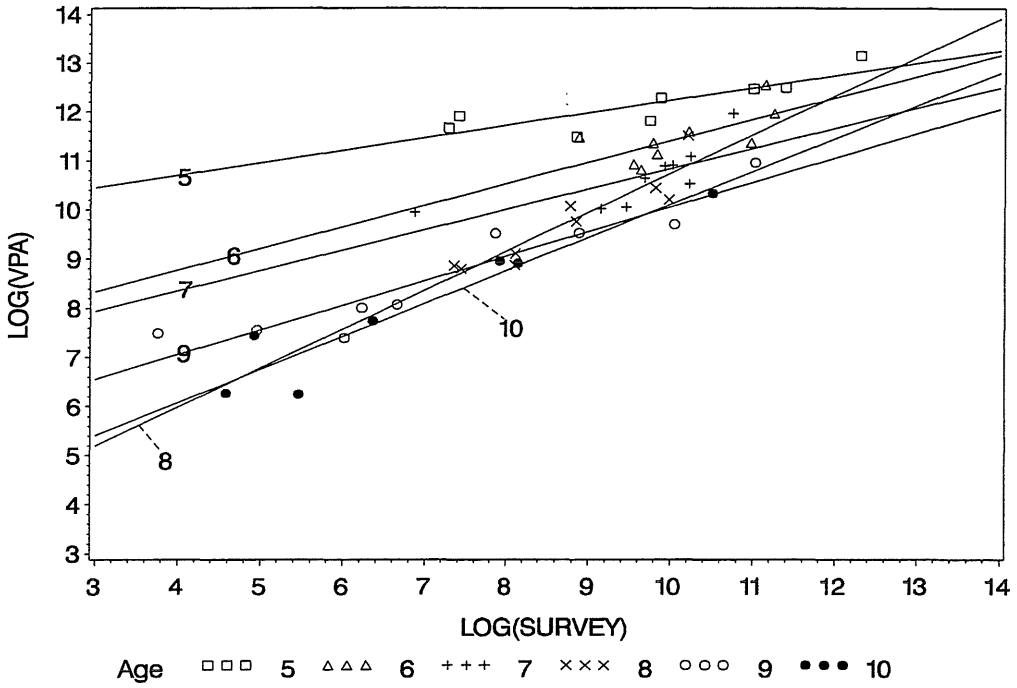

Figure 3 Regression (with intercept) by age between log VPA numbers and log survey numbers corrected for proportions mature.

The "standard" assumption of constant log catchability at age shown on Figure 2 are:

$$\mathrm{Log}\left(N_{VPA}\right)=\mathrm{Log}(q)+\mathrm{Log}\left(N_{Survey}\right) \tag{11}$$

While the regressions shown in Figure 3 are:

$$\mathrm{Log}\left(N_{VPA}\right)=\alpha+\beta\,\mathrm{Log}\left(N_{Survey}\right) \tag{12}$$

Which corresponds to a power law:

$$N_{VPA}=e^{\alpha}\cdot\left(N_{Survey}\right)^{\beta} \tag{13}$$

The emerging pattern with a regression coefficient increasing with age and intercept decreasing is quite distinct. The only age group falling out of the pattern is the 8 year olds.

Figure 4 visualizes the overall effect of choosing either of the regressions. The dotted line is the fitted line corresponding to the traditional assumption of constant log catchability (11) and the solid line is the fitted regression given in (12) backcalculated from log scale (13).

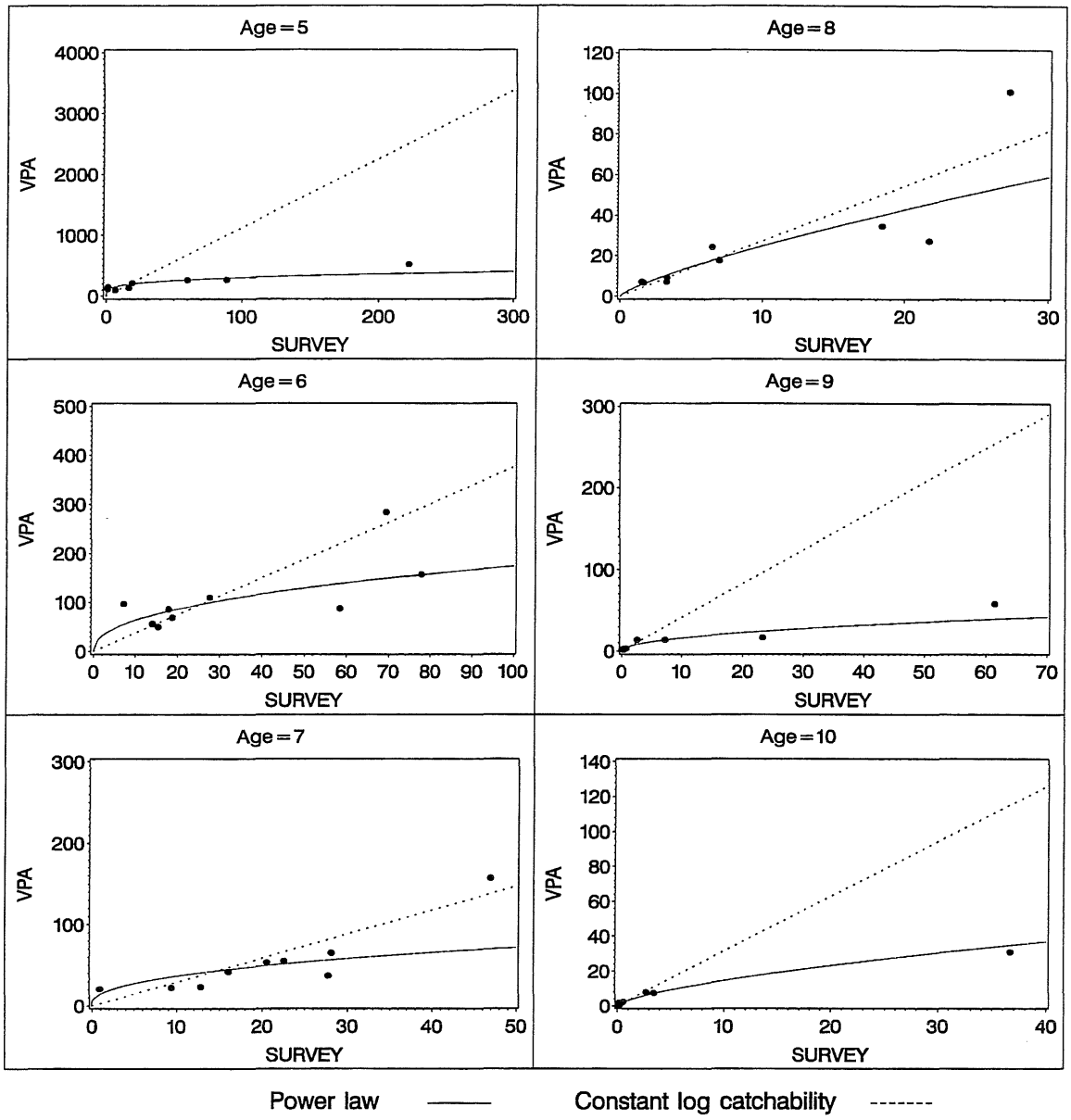

Figure 4 VPA numbers vs survey numbers and the curves backcalculated from the log regressions (numbers in millions).

There is a strong tendency to overestimate the stock by using the traditional assumption on constant log catchability. The exception is the observations of the very large 1983 yearclass in 1989, 1990 and 1991 when even the constant log catchability assumption would tend to lead to underestimates of the stock. This effect could be caused by the proportion mature being underestimated.

Environmental monitoring

Eggvin 1934 proposed that the upper depth limit for spawning cod was the boundary layer between warm Atlantic water and the colder coastal water. But it has been observed later that on some occasions cod has been spawning in lower temperatures than the assumed favourable temperature range of 4-6°C. Some attempts have been made to relate changes in the migrational and distributional patterns to temperature condition. There are indications that such changes are not only related to the absolute conditions, but also to even small changes in temperature.

CRITIQUE

Variance estimation

There has been made no attempts to estimate the variance of the abundance indices or the estimated population parameters. Variance estimation would clearly involve 3 levels of sampling:

- Variance in the echo abundance estimates. Each transect could be treated as a point observation assuming no or negligible error within the transect.
- Variance in trawl sampling for length distributions.
- Variance in age samples including the classification of otholiths into coastal cod or NEA cod.

There has been some attempts to estimate the variance of echo abundance. Due to the design previous to 1990 any variance estimation from that period can not be compared with later years. From Table 1 can it also be seen that the sampling effort was lower in the years previous to 1990.

Sources of bias in the echo abundance

Measured total echo abundance along transects should be regarded as quite precise estimates of the total echo abundance from about 50 cm above the bottom to the surface. Fish concentrations closer to the bottom than this are not recorded and this "loss" constitutes an obvious source of bias. By comparing estimated echo abundance from trawl catches with observed echo abundance (station by station) it has been found that such "loss" is a large source of bias for haddock. Such loss is negligible for cod and saithe (in this area and time of year).

Another source of bias is the subjective process of allocating echo values between the different species. The allocation is partly based on the size and species compositions from the trawl catches, but relies also quite heavily on visual inspection of echogramms. In the highest densities of cod (spawning) the proportions of other species in the catches are very low. Typically less than 1 percent of the total estimated echo abundance.

A third source of bias is the possible changes in the acoustic performance of the swimbladder due to changes in liver condition, size of the gonads and stomach content (Ona 1990).

Sources of bias in biological sampling (trawl stations)

The trawl stations taken during this survey are due to practical reasons not from a proper design. The fishermen in Lofoten have a high fishing effort during the time of the survey and large areas are blocked from the use of sampling trawl due to the high numbers of fixed gears (gillnets and longlines). This has been a common problem for most years except in 1992, 1993 and 1994 when most fishermen had caught their quota before the survey started. So for most years the there has been few samples from the largest concentrations of cod.

The proportion of coastal cod is largest in low density areas and lowest in high density areas. This is clearly a source of bias, but the estimated proportion of coastal cod is typically less than 10 percent and the bias to the estimate of NEA cod will be quite small. Though the bias in the estimate for coastal cod could be quite large.

Bias could also be introduced if the largest fish in one yearclass or if the oldest fish tended to be more abundant in the high density areas. An analysis of the trawl catches from the surveys in 1992, 1993 and 1994 showed a slight correlation between mean length at age and catch rates at each station, but not more than could be explained from changes between the 3 strata. An analysis of mean age in catches compared with catch rates showed a positive correlation in the data from the 1993 survey. This seems to somehow be related to the distribution of the very large 1983 year class that in this year was quite dominant in the spawning stock.

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APPENDIX I

Table A1: Abundance estimates in mill, percentages recruit and repeat spawners

	Age								Sum	Recruit spawners									Repeat spawners								
										Age								Sum	Age								Sum
	5	6	7	8	9	10	11	12+		5	6	7	8	9	10	11	12+		5	6	7	8	9	10	11	12+	
Year																											
1985	0.70	5.08	7.57	1.33	0.72	0.58	0.27		16.25	100	95	72	10	23				69		5	28	90	77	100	100		31
1986	1.78	2.67	5.27	2.53	0.13		0.36	0.07	12.80	97	82	73	42	4				69	3	18	27	58	96		100	100	31
1987	8.02	6.35	0.26	1.04	0.03		0.03	0.03	15.76	81	50	29	23					64	19	50	71	77	100		100	100	36
1988	0.57	2.98	1.65	0.05	0.01	0.05			5.31	71	61	36	100					54	29	39	64		100	100			46
1989	0.03	10.41	8.81	1.97	0.34	0.10		0.06	21.72	100	93	63	41	63				75		7	37	59	37	100		100	25
1990	0.09	1.44	22.08	4.04	0.41	0.22			28.28	82	93	86	47	6	2			79	18	7	14	53	94	98			21
1991	0.18	4.11	18.57	22.37	2.50	0.14	0.15		48.01	100	100	98	91	47	30	100		92			2	9	53	70			8
1992	1.38	5.81	15.02	16.93	58.41	3.46	1.24	0.18	102.43	100	99	98	87	80	23			82		1	2	13	20	77	100	100	18
1993	4.21	12.27	15.56	19.35	22.12	36.34	3.68	0.62	114.14	97	96	62	66	18	14			41	3	4	38	34	82	86	100	100	59
1994	17.81	23.36	8.86	5.90	6.89	2.70	14.24	2.42	82.17	97	82	30	22	9	4	3	1	50	3	18	70	78	91	96	97	99	50
1995	4.57	29.06	10.02	2.96	2.16	2.36	1.42	6.82	59.38	94	73	45	22	12	4	2		52	6	27	55	78	88	96	98	100	48
1996	1.50	12.21	18.61	3.10	0.53	0.24	0.65	1.04	37.89	100	95	70	23	7				71		5	30	77	93	100	100	100	29
1997	0.38	4.52	24.46	14.65	1.47	0.29		0.72	46.49	100	91	66	35	47	43			57		9	34	65	53	57		100	43

Table A2: Estimated biomass in thousand tonnes, percentages recruit and repeat spawners

	Age								Sum	Recruit spawners Age								Sum	Repeat spawners Age								Sum
Year	5	6	7	8	9	10	11	12+		5	6	7	8	9	10	11	12+		5	6	7	8	9	10	11	12+	
1985	1.4	18.0	35.6	9.0	6.4	6.2	3.9		80.6	100	96	73	12	22				59		4	27	88	78	100	100		41
1986	4.0	8.5	23.6	16.3	0.7		3.9	0.9	57.9	99	82	76	46	5				63	1	18	24	54	95		100	100	37
1987	11.5	12.2	0.9	5.1	0.2		0.4	0.3	30.5	83	54	36	19					57	17	46	64	81	100		100	100	43
1988	0.7	7.7	5.4	0.3	0.1	0.6			14.8	72	66	40	100					54	28	34	60		100	100			46
1989	0.0	18.2	25.9	9.3	2.8	1.0		1.5	58.7	100	91	67	42	61				68		9	33	58	39	100		100	32
1990	0.1	3.0	55.0	15.1	2.0	2.0			77.3	77	93	88	50	7	3			77	23	7	12	50	93	97			23
1991	0.4	10.6	65.5	119.3	17.7	1.8	0.8		216.0	100	100	99	89	45	12	100		88			1	11	55	88			12
1992	3.4	16.9	59.1	87.3	369.6	27.7	11.8	3.3	579.1	100	99	99	87	79	27			79		1	1	13	21	73	100	100	21
1993	7.1	30.9	57.4	102.1	139.5	278.5	35.1	9.0	659.7	96	95	66	69	21	15			33	4	5	34	31	79	85	100	100	67
1994	40.8	75.7	44.3	38.9	47.5	21.6	111.2	23.0	402.8	97	82	31	25	9	6	3	3	34	3	18	69	75	91	94	97	97	66
1995	9.9	94.1	48.9	18.6	17.1	23.5	14.2	72.5	298.8	93	73	47	28	10	8	4		37	7	27	53	72	90	92	96	100	63
1996	3.4	33.3	77.0	18.6	4.3	2.6	7.3	11.8	158.3	100	95	73	28	10				61		5	27	72	90	100	100	100	39
1997	0.9	12.9	94.8	84.4	14.6	3.7		9.5	220.7	100	93	67	38	51	37			53		7	33	62	49	63		100	47

Table A3: Percentages females and males

	Recruit spawners																Repeat spawners															
	Females									Males								Females									Males						
	Age									Age								Age									Age						
	5	6	7	8	9	10	11	12+	All	5	6	7	8	9	10	11	All	5	6	7	8	9	10	11	12+	All	5	6	7	8	9	10	11	12+	All
Year																																			
1985	14	39	22	100	100				31	86	61	78					69		100	7	65	100	30			38			93	35		70	100		62
1986	12	14	45	30					29	88	86	55	70	100			71		39	24	44					30	100	61	76	56	100		100	100	70
1987	31	36	52	88					34	69	64	48	12				66	15	11	20	34	39		100	100	17	85	89	80	66	61				83
1988	67	75	76	16					73	33	25	24	84				27	55	72	88		100				76	45	28	12			100			24
1989		16	35	43	36				24	100	84	65	57	64			76		34	31	37	62	100		100	36		66	69	63	38				64
1990		11	15	15	48				15	100	89	85	85	52	100		85			8	13		22			10	100	100	92	87	100	78			90
1991		9	36	19	11				25	100	91	64	81	89	100	100	75				29	1	100			19			100	71	99				81
1992	0	21	28	37	55	70			44	100	79	72	63	45	30		56			12	67	39	38	100		45		100	88	33	61	62		100	55
1993	4	7	13	56	30	63			29	96	93	87	44	70	37		71		38	15	46	42	48	48	61	43	100	62	85	54	58	52	52	39	57
1994	25	23	63	59	87	87	62	100	29	75	77	37	41	13	13	38	71	28	67	60	38	68	57	59	58	58	72	33	40	62	32	43	41	42	42
1995	10	29	29	88	60	100	100		28	90	71	71	12	40			72	22	17	28	31	71	65	61	54	39	78	83	72	69	29	35	39	46	61
1996	43	20	32	68	18				28	57	80	68	32	82			72		48	20	64	44	25	34	61	37		52	80	36	56	75	66	39	63
1997		20	52	59	82	100			48	100	80	48	41	18			52		5	45	47	64	100		74	48		95	55	53	36			26	52

Table A4: Estimated mean length at age

	Recruit spawners								Repeat spawners								All spawners							
	Age								Age								Age							
	5	6	7	8	9	10	11	12+	5	6	7	8	9	10	11	12+	5	6	7	8	9	10	11	12+
Year																								
1985	59.8	72.4	79.9	93.0	96.0					64.0	77.9	88.2	98.1	105.2	114.0		59.8	72.0	79.4	88.7	97.6	105.2	114.0	
1986	62.7	70.3	80.1	92.6	97.0				53.0	70.6	75.6	87.4	85.0		105.8	115.0	62.5	70.4	78.9	89.6	85.4		105.8	115.0
1987	58.5	66.0	80.5	83.1					56.4	62.5	73.0	85.6	88.0		118.5	116.0	58.1	64.3	75.2	85.0	88.0		118.5	116.0
1988	52.4	67.2	75.7	89.4					51.8	64.0	69.4		97.0	119.6			52.2	66.0	71.6	89.4	97.0	119.6		
1989	54.0	58.7	71.4	81.3	97.4					61.7	67.1	80.2	95.7	103.0		125.0	54.0	58.9	69.8	80.6	96.7	103.0		125.0
1990	56.8	63.6	69.2	81.1	93.1	109.0			64.0	63.7	65.7	77.1	85.2	100.6			58.0	63.6	68.8	79.0	85.7	100.8		
1991	59.0	67.4	73.0	81.8	86.6	76.0	85.0				66.0	86.6	91.9	117.0			59.0	67.4	72.9	82.3	89.4	104.5	85.0	
1992	65.3	70.0	78.1	83.6	89.4	100.7				60.0	68.6	80.2	88.7	90.9	102.3	127.0	65.3	69.9	78.0	83.2	89.3	93.2	102.3	127.0
1993	57.6	65.5	75.0	84.6	91.2	95.2			64.2	71.1	71.0	80.5	87.3	92.1	96.4	110.8	57.8	65.7	73.5	83.2	88.0	92.5	96.4	110.8
1994	64.2	70.5	82.6	93.2	94.1	105.6	95.5	126.0	63.6	69.5	81.0	87.0	90.4	95.3	92.6	98.5	64.2	70.3	81.5	88.4	90.7	95.7	92.7	99.0
1995	61.1	70.0	79.9	92.5	89.7	124.3	117.0		64.1	68.4	75.6	82.3	92.0	96.0	97.8	99.2	61.3	69.6	77.5	84.5	91.7	97.0	98.1	99.2
1996	62.5	67.1	77.4	91.2	106.1					66.0	74.1	80.7	92.6	101.7	99.7	102.5	62.5	67.0	76.4	83.1	93.5	101.7	99.7	102.5
1997	63.4	69.2	75.1	87.0	104.0	104.0				61.5	72.8	82.3	97.6	109.0		109.7	63.4	68.5	74.4	84.0	100.6	106.9		109.7

Table A5: Estimated mean weight at age

	Recruit spawners								Repeat spawners								All spawners							
	Age								Age								Age							
	5	6	7	8	9	10	11	12+	5	6	7	8	9	10	11	12+	5	6	7	8	9	10	11	12+
Year																								
1985	2.04	3.61	4.77	7.75	8.54					2.53	4.49	6.66	9.11	10.75	14.28		2.04	3.55	4.69	6.77	8.98	10.75	14.28	
1986	2.25	3.22	4.70	7.06	8.09				1.25	3.14	3.91	5.98	5.44		10.84	13.48	2.22	3.20	4.49	6.44	5.54		10.84	13.48
1987	1.47	2.10	4.15	4.09					1.28	1.75	3.08	5.12	5.64		13.15	12.55	1.43	1.92	3.40	4.88	5.64		13.15	12.55
1988	1.26	2.78	3.71	5.81					1.22	2.26	3.07		7.27	13.65			1.25	2.58	3.30	5.81	7.27	13.65		
1989	1.30	1.71	3.14	4.95	8.00					2.16	2.61	4.58	8.84	9.98		26.00	1.30	1.75	2.95	4.73	8.31	9.98		26.00
1990	1.48	2.10	2.54	4.01	6.22	11.12			2.05	2.17	2.16	3.52	4.90	8.87			1.58	2.10	2.49	3.75	4.98	8.91		
1991	2.21	2.57	3.54	5.23	6.69	4.84	5.35				2.52	6.37	7.41	16.08			2.21	2.57	3.53	5.33	7.07	12.66	5.35	
1992	2.45	2.93	3.95	5.11	6.29	9.49				2.01	3.09	5.53	6.49	7.57	9.57	17.80	2.45	2.92	3.93	5.16	6.33	8.01	9.57	17.80
1993	1.67	2.49	3.93	5.57	7.34	8.14			2.30	3.23	3.30	4.72	6.09	7.59	9.55	14.42	1.69	2.52	3.69	5.28	6.31	7.67	9.55	14.42
1994	2.29	3.26	5.16	7.45	7.31	10.79	9.08	22.22	2.23	3.16	4.93	6.35	6.86	7.85	7.77	9.30	2.29	3.24	5.00	6.59	6.90	7.98	7.81	9.49
1995	2.15	3.25	5.07	7.99	6.49	20.99	18.48		2.65	3.19	4.72	5.80	8.13	9.54	9.83	10.63	2.18	3.24	4.88	6.27	7.94	9.96	10.00	10.63
1996	2.25	2.74	4.32	7.42	11.49					2.59	3.72	5.58	7.75	10.47	11.17	11.34	2.25	2.73	4.14	6.01	8.02	10.47	11.17	11.34
1997	2.31	2.93	3.97	6.25	10.82	10.90				2.01	3.70	5.50	9.19	14.05		13.10	2.31	2.84	3.88	5.76	9.95	12.70		13.10

APPENDIX II

Table A6: VPA stock numbers at beginning of year, percentage mature (from Anon. 1997)

	Stock numbers by age in mill.						Percentage mature					
Year	5	6	7	8	9	10	5	6	7	8	9	10
1985	99.38	50.56	23.96	7.23	3.28	2.35	10	33	59	85	92	100
1986	219.44	56.74	22.99	7.32	1.96	0.96	9	19	56	76	89	100
1987	270.77	111.36	21.32	6.75	1.84	0.62	9	23	27	61	81	80
1988	509.66	133.63	34.74	5.78	1.96	0.58	3	25	53	79	100	100
1989	150.25	286.79	55.66	9.17	1.65	0.52	2	15	39	59	83	100
1990	117.78	97.56	158.97	24.31	3.03	0.52	6	20	47	62	81	95
1991	102.24	86.82	65.88	101.96	13.87	1.73	1	23	66	82	96	100
1992	136.64	69.62	53.90	35.02	58.68	7.56	8	31	73	92	95	100
1993	265.12	88.54	37.73	27.49	16.73	31.29	7	21	56	89	95	99
1994	523.30	158.81	42.91	17.71	13.98	7.94	8	30	55	84	95	98
1995	702.27	322.98	77.27	13.66	6.34	5.88	4	23	61	75	94	97
1996	427.03	467.02	178.02	34.52	4.35	2.19	1	22	56	82	95	100
1997[6]	239.81	288.47	271.01	88.03	16.45	2.15	4	25	57	80	95	98

[6] Predictions