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Estimating abundance indices from the international 0-group fish survey in the Barents Sea

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Abstract

Annual abundance and distribution of 0-group fish in the Barents Sea have been recorded since 1965. Concern has been raised about the methods presently used to establish the abundance indices and about the catching efficiency of the trawl for the smaller-sized fish. The data have been reviewed for the period 1980–2002 and new abundance indices and length distributions of northeast Arctic cod (*Gadus morhua*), northeast Arctic haddock (*Melanogrammus aeglefinus*), capelin (*Mallotus villosus*), Norwegian spring spawning herring (*Clupea harengus*), and redfish (*Sebastes* spp.) were estimated. The abundance indices were estimated by two different statistical techniques, the method of stratified sample mean and a method based on the lognormal theory. The latter method was concluded to be the preferred one for this particular survey. The poor catching efficiency of smaller cod and haddock was corrected for and the results showed that length dependent selection contributes to a serious bias in the estimates when not corrected for, and it is likely that selection will bias the estimates for the other species as well. It is recommended that the technique based on the lognormal theory and with length corrections becomes the new standard method for estimating abundance indices from the 0-group survey in the Barents Sea.

Keywords: Barents Sea; 0-Group fish; Abundance indices

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1. Introduction

Annually since 1965, the Institute of Marine Research (IMR) in Bergen, Norway, the Polar Research Institute of Marine Fisheries and Oceanography (PINRO) in Murmansk, Russia, and the United Kingdom (participated up to 1976) have conducted a joint international 0-group fish survey in the Barents Sea and adjacent waters (Anonymous, 2002). The purpose of the survey is to give an early indication of the future recruitment to the fishable stocks of the most important commercial fish stocks in the Barents Sea. At present, two different abundance indices are estimated from this survey.

The "area index" (Haug and Nakken, 1977) is estimated for seven species. This method calculates two areas from a distribution map, the area of low density (catch rates) and the area of high density. The limit between low and high densities was established for each

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species separately based on a comparison of catch rates and echo recordings (Haug and Nakken, 1977), e.g. for cod the limit is 85 fish/nm. The abundance index is then estimated as follows:

$$\mathrm{AI} = \mathrm{area\,(low)} + 10 \times \mathrm{area\,(high)} \tag{1}$$

This method has clearly some faults, the indices are smoothed and much of the dynamic in the time series is lost because 1 fish/nm will have the same influence as e.g. 80 fish/nm. Another problem is that there is no knowledge of the precision of the indices.

The second method is a logarithmic index and was developed by Randa (1984). This method is based on the lognormal theory. The catch rates are log transformed, mean densities are calculated for the 18 strata of which the area is divided into, the zero catches are handled separately, and the densities, weighted by stratum area, are summed. This method gives the indices on a logarithmic scale with confidence intervals. There are two problems with this method. The first is that small catch rates will produce negative values when they are log transformed and this may cause bias (Pennington, 1991; Kappenman, 1999). The second is that the indices are logarithmic and may in some cases cause problems in further analysis and interpretation of retransformed means may be difficult.

The aim of this work is to produce a new set of 0-group abundance indices and length distributions for the most important commercial species in the Barents Sea, which are northeast Arctic cod (*Gadus morhua*), northeast Arctic haddock (*Melanogrammus aeglefinus*), capelin (*Mallotus villosus*), Norwegian spring spawning herring (*Clupea harengus*), and redfish (*Sebastes* spp.). A few objectives were desired: the indices should be on an arithmetic scale and there should be some measurements of the precision of the estimates.

There are several more or less successful methods of estimating abundance indices and it seems there is no easy answer as to which method is most appropriate. In this work, two different methods are applied. The method of stratified sample mean, which is used on the bottom trawl survey for older fish in the Barents Sea, and an estimate of the mean based on lognormal theory, which in this paper will be called the Pennington estimator. The latter is an extension of the lognormal based estimator given in Pennington (1983, 1996). Both methods are described in Folmer and Pennington (2000). Godø et al. (1993) and Hylen et al. (1995) showed that the trawl used in the 0-group survey has poor selection properties for the smallest fish and a correction factor is introduced for cod and haddock. Because of poor availability of computerized raw data prior to 1980, new indices and length frequencies are produced for the period 1980–2002.

2. Materials and methods

The data used in this work were extracted from the survey database at the Institute of Marine Research. The data were processed and analyzed using SAS software.

The 0-group survey in the Barents Sea has been carried out in late August–early September each year, using four to six vessels. Since 1980, Norway, and 1981, Russia, the trawling procedure has been standardized. The standard procedure consists of tows at three depths each of 0.5 nm, with the headline at 0, 20, and 40 m. Additional tows are made at 60 and 80 m if the 0-group layer is recorded below these depths with the echo-sounder. Most trawl stations are spaced apart by 30–35 nm sailed distance, but the distance between cruise tracks varies, and the distance between stations is in some cases less than 30 nm. The trawl used is a small-meshed mid-water trawl with 20 m vertical opening and 15 m wing spread (Godø et al., 1993). This sampling trawl has been used regularly since 1979 by Norwegian vessels and 1981 by Russian vessels. All Russian vessels in 1980 and one Russian vessel in 1982–1984 used a smaller sized (6 m × 10 m) trawl. Assuming that the catches are proportional to the area of the trawl mouth, the catches of the smaller sized trawl were multiplied by a factor of 3.33 to even out the difference in vertical opening. In 1994, one Russian vessel used a non standard trawl with 30 m vertical opening and unknown wing spread, two steps were trawled to cover the usual three steps.

Due to the trawling procedure, the effective trawling distance is equal to the total distance towed divided by the number of depth steps (Stensholt and Nakken, 2001). Because of many errors in the datasets, the total distances were recalculated. The duration of a trawl haul was found by the start and stop time, duration was then multiplied by the speed and the total distance was found. If the start time, stop time, or speed was missing, then the total distance from the data was used. Even though there is developed a coding system for the number of depth steps, these codes were often lacking or in some cases erroneous. Thus, the number of depth steps were found by the duration and the following criteria: 1 step when duration <16 min, 2 steps when duration is 16–25 min, 3 steps when duration is 26–35 min, 4 steps when duration is 36–45 min and 5 steps when duration is 46–55 min. If duration could not be calculated, the number of depth steps was found by total distance divided by 0.5 and rounded to the nearest integer. The effective distance, d_s, at station s was then found by

$$d_s = \frac{\text{total distance}}{\text{depth steps}} \tag{2}$$

The common practice in the old indices has been to use the effective distances of 1 nm for 2 steps and 1.5 nm for 3 or more steps (Havforskningsinstituttet, 1994). The reason for making the recalculations above even when values were not missing, is that the fewer links of human touch between input and output, the smaller is the chance of human error in terms of calculation and punching errors.

The area covered by the survey was stratified into four strata (Fig. 1). Earlier in the logarithmic index they have used 18 strata, which is not very practical and usually little is gained in precision having more than six strata (Cochran, 1977). Fewer and larger strata results in larger sample sizes within a stratum, which results in more stable analyses and more varied analytical techniques can be used (Smith, 1988; Pennington, 1996). The new strata system has four strata and extends over a larger area than the previous. The strata are based on the distribution of trawl stations and on the species distribution maps from the survey reports. Strata I and II do normally have higher fish densities than III and IV, but this depends on the species.

To find the coverage of a stratum, the station positions were loaded into the GIS software; Manifold system 5.50. The boundary stations were traced and

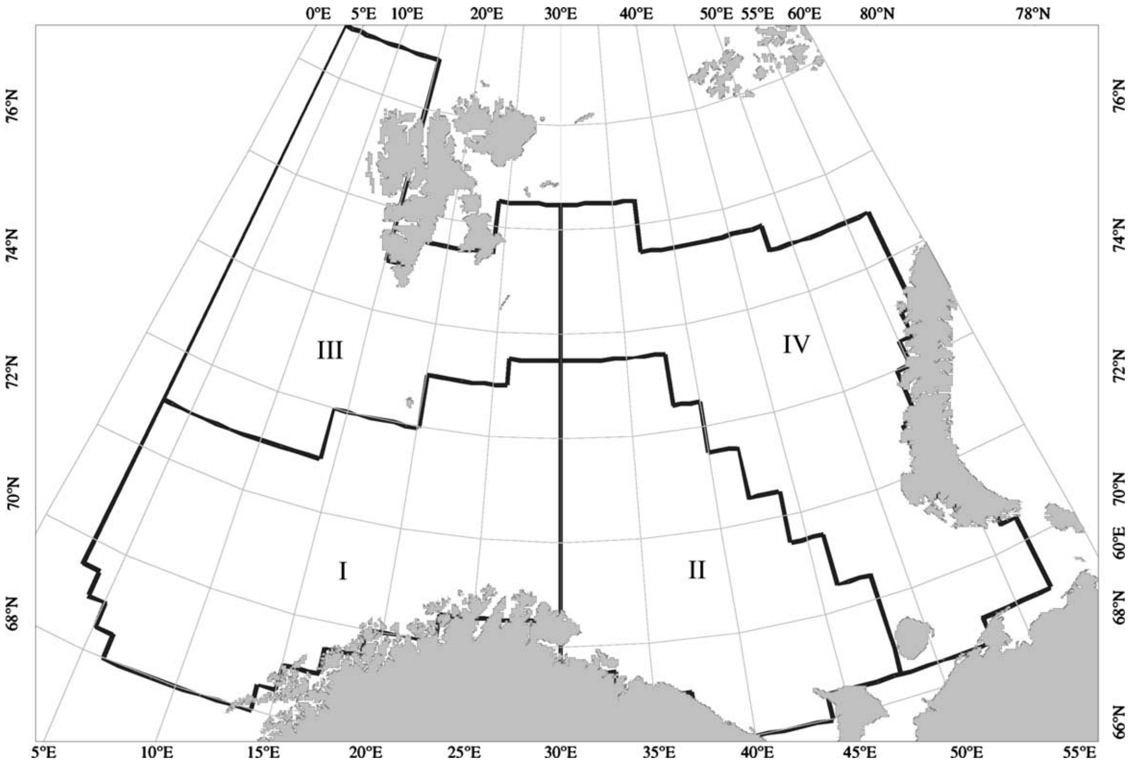
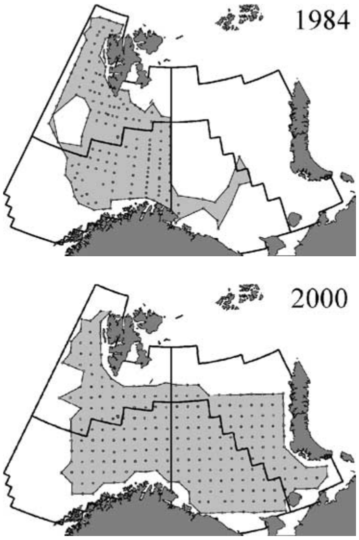


Fig. 1. The Barents Sea divided into four strata. The areas of strata I–IV are 143600, 104314, 111626, and 127747 nm^2, respectively.

Table 1
Coverage of strata and total area in percent

Year	Stratum I	Stratum II	Stratum III	Stratum IV	Total
1980	88	76	63	15	61
1981	56	78	67	25	55
1982[a]	58	57	61	5	45
1983	47	80	68	23	53
1984[a]	50	15	54	1	31
1985	63	81	69	28	59
1986	48	81	57	28	52
1987	52	83	52	23	51
1988	63	78	56	18	53
1989	56	86	60	75	68
1990	55	91	57	46	61
1991	52	91	63	63	66
1992	46	75	65	35	54
1993	43	84	54	37	53
1994	35	82	42	31	46
1995	45	76	41	12	42
1996	45	91	45	47	56
1997	41	86	34	32	47
1998	37	88	41	62	55
1999	38	85	36	51	51
2000	50	85	49	51	58
2001	49	87	57	70	64
2002	48	85	48	49	56



1984 and 2000 are examples of poor and good coverage (inserted figures).

[a] Russian data are missing.

the areas enclosed were calculated. The conic projection Albers equal-area, with center latitude at 74°N, center longitude at 30°E, and standard latitudes at 70° and 78°N, was used in this operation. The coverage varies to a large extent from year to year (Table 1). In 1982 and 1984, the low coverage is due to a lack of Russian data in the IMR database.

To minimize the chance of including older age groups in the analysis, maximum lengths were defined for each year and species. This was done by going through the survey reports and finding the maximum lengths from the length frequency tables. Most length data are also coded with age codes and all data that were coded older than 0-group were excluded from the analysis. Erroneous coding and coding that includes both 0-group and older fish will cause bias when the length distributions of 0- and 1-group overlap. Minimum length was set to one centimeter.

The data were also quality checked. Only ordinary fishing stations with pelagic trawl hauls of satisfactory quality and gear in good condition were included. Longitude and latitude were checked by plots of trawl station positions with survey tracks, compared by eye with maps in the survey reports and corrected by original station forms if large discrepancies were detected.

Godø et al. (1993) showed that the sampling trawl is highly selective for 0-group cod and haddock. Its capture efficiency of fish smaller than 65 mm was much lower than their experimental trawl. Hylen et al. (1995) used data from a similar experiment to estimate the following correction functions, $w(l)$, for cod and haddock

$$w(l)_{\mathrm{cod}} = 1 + \exp(4.158 - 0.422 \times l) \quad (3)$$

$$w(l)_{\mathrm{haddock}} = 1 + \exp(8.031 - 0.838 \times l) \quad (4)$$

where l is the length in cm. These correction functions can be applied directly to the observed length frequencies at each station. But since the functions above give unreasonably high numbers as l decreases, it was decided to set $w(l)_{\mathrm{cod}}$ constant to 10 for $l < 4.6$ cm and

$w(l)_{\mathrm{haddock}}$ constant to 20 for $l < 6.1$ cm. The fact that there were very few fish below these lengths in the datasets used to estimate the correction functions, supports this decision. The correction function, $w(l)$, was set to one for species other than cod and haddock, and in the cases where the non standard Russian trawls were used.

2.1. Stratified sample mean estimator

The number of fish per nm^2, $\rho_{s,l}$, at length, l, at each station, s, were estimated by the following equation:

$$\rho_{s,l} = \frac{f_{s,l}w(l)}{a_s} \tag{5}$$

where $f_{s,l}$ is the calculated frequency of length l at station s, $w(l)$ is the length correction function defined above, and a_{s} is the swept area found by

$$a_{\mathrm{s}} = \frac{d_s \mathrm{ws}}{1852} \tag{6}$$

where d_{s} is the effective trawl distance found by Eq. (2), and ws is the wingspread of the trawl.

The stratified estimator of mean density in the entire area is given by

$$\bar{y}_{\mathrm{st}} = \sum_{i=1}^{L} W_i \bar{y}_i \tag{7}$$

where L is the number of strata, W_i the proportion of the survey area in the ith stratum, $y_{i,s}$ is the sum of the densities found at station s by Eq. (5), and $\bar{y}_i$ is the average density in stratum i. The estimated variance of the stratified mean $\bar{y}_{\mathrm{st}}$ is

$$\mathrm{var}(\bar{y}_{\mathrm{st}}) = \sum_{i=1}^{L} W_i^2 \frac{s_i^2}{n_i} \tag{8}$$

where

$$s_i^2 = \frac{\sum_{s=1}^{n_i}(y_{i,s} - \bar{y}_i)^2}{n_i - 1} \tag{9}$$

The standard error of $\bar{y}_{\mathrm{st}}$ is given by

$$\mathrm{se}(\bar{y}_{\mathrm{st}}) = \sqrt{\mathrm{var}(\bar{y}_{\mathrm{st}})} \tag{10}$$

2.2. Pennington estimator

The patchy distribution of marine organisms causes the sampled densities to have a skewed distribution with many small values and a few very large values. Thus, the sample mean may be an imprecise estimator of the true mean (Pennington and Strømme, 1998). An estimator of the mean based on the lognormal distribution is shown to be more efficient (Pennington, 1983, 1996; Smith, 1988). The 0-group data do usually have a cluster of small values and because values close to zero may severely bias lognormal-based estimators (Myers and Pepin, 1990; Pennington, 1991; Kappenman, 1999) an extension of the estimator in Pennington (1983, 1996), developed by Folmer and Pennington (2000), was used.

The values larger than the cut-level k in each stratum are supposed to be distributed approximately lognormal. The alternative estimator, $\hat{\mu}_i$, of mean density within each stratum is then given by

$$\hat{\mu}_i = \frac{n_i - m_i}{n_i}\bar{y}'_i + \frac{m_i}{n_i}\exp(\bar{x}_i)G_{m_i}\left(\frac{s^2_{x,i}}{2}\right) \tag{11}$$

where m_i is the number of sample values greater than k in stratum i, $\bar{y}'_i$ is the mean of the values smaller or equal to k, $\bar{x}_i$ and $s^2_{x,i}$ are the mean and variance of the logged sample values greater then k, and $G_m(t)$ is an infinite series function of m and t (for example, $m = m_i$ and $t = \frac{1}{2}s^2_{x,i}$) defined by

$$G_m(t) = 1 + \frac{m-1}{m}t + \sum_{j=2}^{\infty} \frac{(m-1)^{2j-1}t^j}{m^j(m+1)(m+3)\cdots(m+2j-3)j!} \tag{12}$$

The variance of $\hat{\mu}_i$ is given by

$$\mathrm{var}(\hat{\mu}_i) = \mathrm{var}(c_i) + \left(\frac{n_i - m_i - 1}{n_i(n_i - 1)}\right)s'^2_i + \left(\frac{m_i(n_i - m_i)}{n_i^2(n_i - 1)}\right)\bar{y}'^2_i - 2\left(\frac{n_i - m_i}{n_i(n_i - 1)}\right)\bar{y}'_i c_i \tag{13}$$

where s'^2_i is the variance of the values less than or equal to k,

$$c_i = \frac{m_i}{n_i}\exp(\bar{x}_i)G_{m_i}\left(\frac{s^2_{x,i}}{2}\right) \tag{14}$$

and

$$\mathrm{var}(c_i) = \frac{m_i}{n_i}\exp(2\bar{x}_i)\left\{\frac{m_i}{n_i}G^2_{m_i}\left(\frac{s^2_{x,i}}{2}\right) - \frac{m_i-1}{n_i-1}G_{m_i}\left(\frac{m_i-2}{m_i-1}s^2_{x,i}\right)\right\} \tag{15}$$

There is no single objective criterion upon which to define a cut-level, k, bigger than zero. For the 0-group data a value of k for a stratum equal to 20% of the average density in that stratum provided a cut-level such that the values larger than k are distributed approximately lognormal. The coefficient of variance (CV) was also used to find the cut-level. The trick was to find a cut level that gave low CVs without violating the assumption of lognormal distributions. The stratified estimate of mean density, $\hat{\mu}_{\mathrm{st}}$, in the entire area is calculated by replacing $\bar{y}_i$ with $\hat{\mu}_i$ for each stratum in Eq. (7). The standard error of $\hat{\mu}_{\mathrm{st}}$ is obtained by substituting $\mathrm{var}(\hat{\mu}_i)$ for s^2_i/n_i in Eq. (8), and then

$$\mathrm{se}(\hat{\mu}_{\mathrm{st}}) = \sqrt{\mathrm{var}(\hat{\mu}_{\mathrm{st}})} \tag{16}$$

2.3. *Length distributions*

Another objective of the 0-group survey is to estimate the length distributions of the juveniles of the year. One way to do this is to use a variation of the ratio estimator, $\hat{R}$, of the mean length given by Cochran (1977)

$$\hat{R} = \frac{\sum_{s=1}^{n} y_s\bar{x}_s}{\sum_{s=1}^{n} y_s} \tag{17}$$

where y_s is the sum of the densities estimated by Eq. (5) at station s, $\bar{x}_s$ is an estimate of the average length of fish at station s, and n is the number of stations where fish of the species in question were caught. An estimate of population variance, σ^2_x, of lengths can be found by modification of the grouped sample variance (Bhattacharyya and Johnson, 1977)

$$\hat{\sigma}^2_x = \frac{\sum_{s=1}^{n}\sum_l \rho_{s,l}(l-\hat{R})^2}{\sum_{s=1}^{n}\sum_l \rho_{s,l}} \tag{18}$$

where $\rho_{s,l}$ is the density of fish of length l at station s.

3. Results

3.1. *Abundance indices*

Abundance indices of 0-group cod, haddock, capelin, herring, and redfish were estimated by the method of stratified sample mean and the Pennington estimator (Table 2). With few exceptions, there were no large differences between the two methods. When large differences occurred between the indices, for example capelin and redfish in 1982, the sample mean, $\bar{y}_{\mathrm{st}}$, was mostly larger than the Pennington estimator, $\hat{\mu}_{\mathrm{st}}$. Generally, the Pennington estimator was more precise than the sample mean, i.e. $\mathrm{se}(\hat{\mu}_{\mathrm{st}})$ was smaller than $\mathrm{se}(\bar{y}_{\mathrm{st}})$.

The length correction had a large influence on the abundance indices of cod and haddock. For both species there was a negative correlation between the index without length correction and the ratio: index with length correction/index without length correction, and for haddock this was significant ($p < 0.05$). This resulted in that the ratio: best year/worst year, got smaller when length correction was applied.

Cod had all the above average year-classes in the 1990s and in year 2000, this applied to the results from both with and without length correction. Without length correction, haddock had most of the good year-classes in the 1990s and 2000s. When length correction was applied, there were three good year-classes in both the 1980s and 1990s, and in year 2000. With the exception of 1983, herring had all the above average year-classes after 1990. With the exception of 1997 and 1999, capelin had the above average year-classes in the 1980s. Redfish had all the above average year-classes prior to 1991.

3.2. *Mean lengths*

Mean lengths with corresponding population standard deviations are shown in Fig. 2. There were no significant differences in mean lengths of cod with and

Table 2

Abundance indices based on stratified sample mean estimator ($\bar{y}_{st}$) and Pennington estimator ($\hat{\mu}_{st}$) with corresponding standard errors

Year	Cod without length correction				Cod with length correction				Haddock without length correction				Haddock with length correction			
	$\bar{y}_{st}$	se($\bar{y}_{st}$)	$\hat{\mu}_{st}$	se($\hat{\mu}_{st}$)	$\bar{y}_{st}$	se($\bar{y}_{st}$)	$\hat{\mu}_{st}$	se($\hat{\mu}_{st}$)	$\bar{y}_{st}$	se($\bar{y}_{st}$)	$\hat{\mu}_{st}$	se($\hat{\mu}_{st}$)	$\bar{y}_{st}$	se($\bar{y}_{st}$)	$\hat{\mu}_{st}$	se($\hat{\mu}_{st}$)
1980	0.27	0.05	0.26	0.04	1.60	0.31	1.55	0.27	0.32	0.06	0.31	0.06	3.50	0.68	3.46	0.70
1981	0.23	0.04	0.22	0.04	1.55	0.24	1.54	0.25	0.06	0.02	0.06	0.01	0.81	0.24	0.73	0.17
1982	2.90	0.47	2.81	0.42	17.17	2.67	16.81	2.44	3.05	0.45	3.11	0.51	29.40	4.30	29.64	4.81
1983	19.23	5.52	15.37	2.84	74.91	18.57	62.01	9.88	5.97	1.04	5.65	0.83	33.52	4.61	32.65	4.23
1984	44.27	19.70	30.28	8.21	168.14	65.80	120.23	28.74	8.79	1.66	7.99	1.22	51.84	9.11	49.18	8.09
1985	64.57	16.57	55.92	11.28	266.17	69.73	229.86	43.29	2.81	0.63	2.66	0.65	15.76	2.85	15.80	3.54
1986	7.73	1.33	7.34	1.40	45.65	8.02	42.62	7.85	2.42	0.47	2.25	0.43	19.61	3.94	18.32	3.65
1987	0.68	0.15	0.61	0.10	5.17	1.23	4.53	0.71	0.55	0.12	0.51	0.10	9.62	2.09	8.92	1.76
1988	2.29	0.51	1.97	0.38	13.01	2.94	11.51	2.34	1.67	0.52	1.42	0.33	16.40	5.49	13.89	3.36
1989	2.73	0.69	2.36	0.43	10.27	2.34	9.12	1.52	0.64	0.11	0.62	0.10	4.78	0.81	4.41	0.69
1990	29.31	7.01	26.32	5.46	96.21	21.21	85.62	17.90	4.92	0.68	4.67	0.67	16.49	2.33	15.70	2.29
1991	45.32	6.74	42.75	6.38	160.75	23.45	151.97	21.76	15.74	2.23	15.30	2.07	101.91	13.64	97.87	12.86
1992	220.32	50.53	214.94	50.16	753.36	171.87	742.82	178.30	7.87	1.19	7.27	1.09	26.97	5.08	22.80	3.50
1993	166.01	47.84	157.14	46.30	517.98	136.08	491.78	133.56	5.73	0.92	5.58	0.91	14.10	2.14	13.67	2.01
1994	215.92	62.16	186.01	49.55	583.63	160.56	501.99	124.71	15.05	4.16	13.24	3.30	39.21	8.19	37.98	8.13
1995	426.51	98.22	408.23	80.17	1120.69	272.20	1058.81	207.77	2.61	0.58	2.60	0.60	6.66	1.41	6.37	1.33
1996	317.18	55.00	319.34	56.44	1178.94	205.53	1181.18	204.14	5.07	0.79	5.02	0.85	11.22	1.52	11.53	1.80
1997	389.09	55.48	403.53	64.71	1706.05	236.72	1781.03	286.40	3.38	0.54	3.52	0.67	15.76	2.79	15.60	2.79
1998	32.53	6.17	32.60	6.64	103.24	17.88	105.13	21.01	26.06	4.65	25.84	4.76	65.99	9.96	65.80	10.53
1999	6.57	3.06	6.05	2.96	18.46	7.07	16.79	7.25	5.63	1.97	4.89	1.73	13.94	3.99	12.16	3.13
2000	113.84	29.89	105.07	27.80	467.19	123.23	426.62	106.23	13.04	2.84	12.80	2.96	92.94	21.25	90.04	22.08
2001	3.32	1.41	2.24	0.63	16.51	7.03	11.57	3.45	7.50	1.45	7.26	1.45	24.66	3.76	24.72	4.11
2002	83.93	18.42	76.99	14.76	139.72	26.15	130.09	24.53	7.51	1.21	7.42	1.26	22.08	5.10	22.95	6.91

Year	Caplin				Redfish				Herring			
	$\bar{y}_{st}$	se($\bar{y}_{st}$)	$\hat{\mu}_{st}$	se($\hat{\mu}_{st}$)	$\bar{y}_{st}$	se($\bar{y}_{st}$)	$\hat{\mu}_{st}$	se($\hat{\mu}_{st}$)	$\bar{y}_{st}$	se($\bar{y}_{st}$)	$\hat{\mu}_{st}$	se($\hat{\mu}_{st}$)
1980	1173.64	213.44	1294.47	300.02	779.07	560.15	663.36	433.57	0.02	0.01	0.02	0.01
1981	519.05	126.43	500.98	118.07	697.80	543.96	634.92	448.02	0.01	0.01	0.01	0.01
1982	1177.59	458.83	893.82	281.95	850.53	439.39	583.06	151.83	0.35	0.16	0.21	0.07
1983	419.38	97.58	356.23	66.73	212.20	53.07	188.84	39.97	125.45	40.02	128.30	42.26
1984	417.05	99.89	411.94	104.18	295.54	115.57	258.01	95.01	33.63	12.42	35.83	15.55
1985	99.73	45.93	74.64	30.03	1190.45	404.48	1040.96	399.19	24.65	10.69	31.52	19.61
1986	52.16	25.42	57.07	34.21	375.53	187.63	270.46	93.27	0.03	0.01	0.02	0.01
1987	2.91	1.24	3.13	1.59	88.78	24.31	81.73	21.14	0.01	0.00	0.01	0.00
1988	130.27	50.54	97.82	30.68	300.58	56.87	281.68	55.96	38.35	12.35	54.12	24.81
1989	923.71	95.34	944.57	108.10	62.07	19.25	47.03	9.63	15.98	5.66	11.89	3.40
1990	137.66	24.26	145.39	28.02	365.48	81.02	368.74	88.20	20.69	11.08	19.22	9.28
1991	234.14	69.32	269.23	123.17	111.23	48.44	105.52	49.12	407.91	127.14	340.82	87.33
1992	0.35	0.20	0.40	0.28	45.99	37.74	21.16	10.40	172.29	35.67	176.53	41.97
1993	0.89	0.32	0.71	0.23	24.18	18.26	13.27	6.59	283.60	123.52	243.21	103.73
1994	43.22	21.66	37.38	20.11	188.50	112.51	143.68	72.44	95.04	55.62	93.94	59.93
1995	2.61	1.61	2.67	1.63	65.18	24.96	68.03	27.02	12.77	5.03	10.56	3.30
1996	214.50	53.69	206.94	64.29	0.12	0.04	0.11	0.03	253.18	67.00	250.32	67.26
1997	308.40	86.50	277.73	66.93	0.76	0.43	0.53	0.25	247.32	63.98	249.68	73.45
1998	163.82	31.04	156.45	32.90	3.56	1.77	3.25	1.77	402.72	90.55	378.54	80.26
1999	403.75	104.93	354.68	77.03	0.16	0.05	0.16	0.05	81.74	37.96	73.05	28.37
2000	155.13	79.65	145.68	79.35	33.18	22.06	24.74	16.28	229.12	113.33	208.16	95.64
2001	19.08	8.35	18.71	8.68	0.02	0.01	0.02	0.01	3.24	1.45	2.48	0.87
9009	85.15	19.95	81.05	19.61	0.55	0.25	0.54	0.24	99.87	23.43	107.97	29.48

Estimates are given in thousands per square nautical mile.

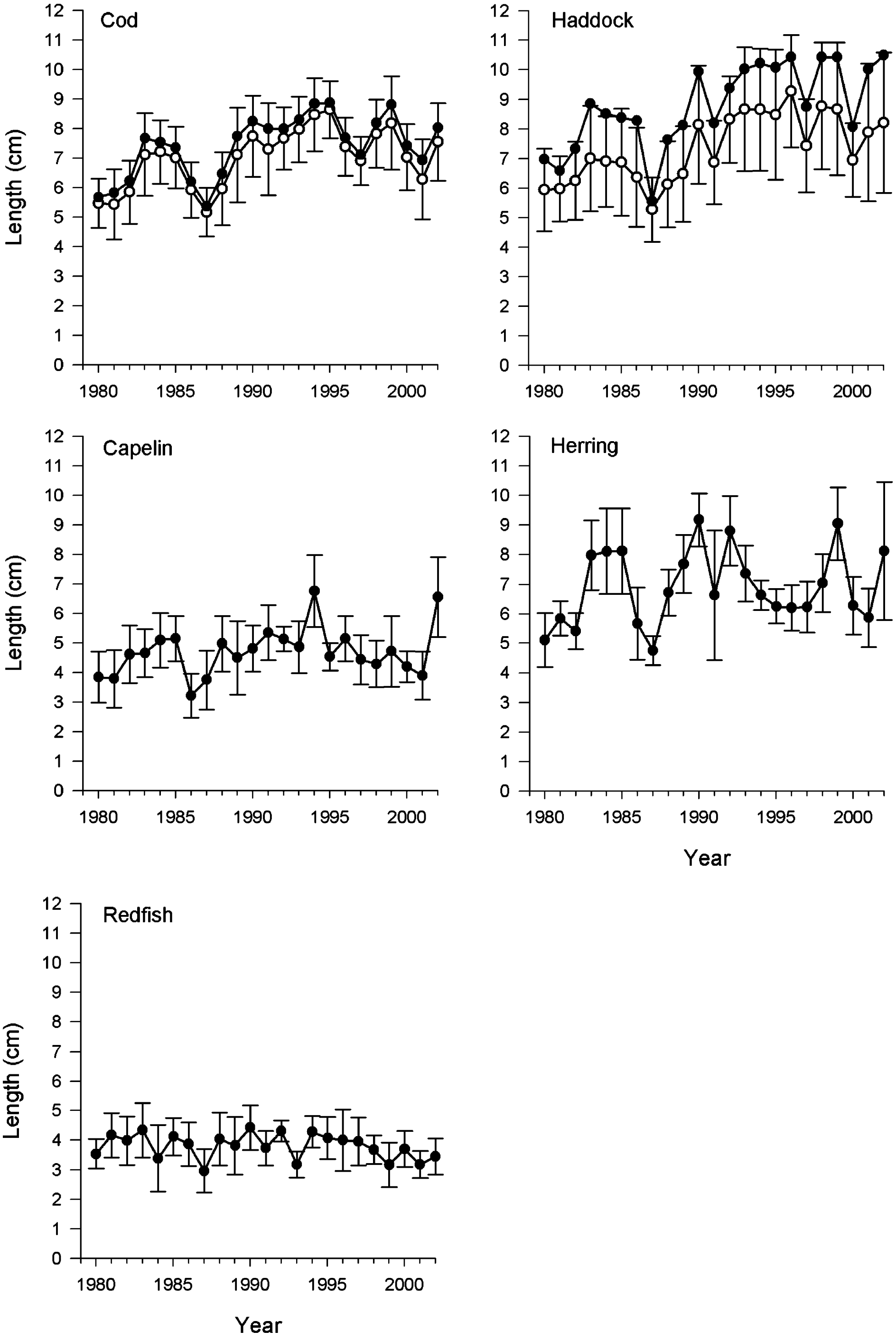


Fig. 2. Estimated mean lengths with population standard deviation. Open circles (cod and haddock) are estimates with length correction and the filled circles are without length correction.

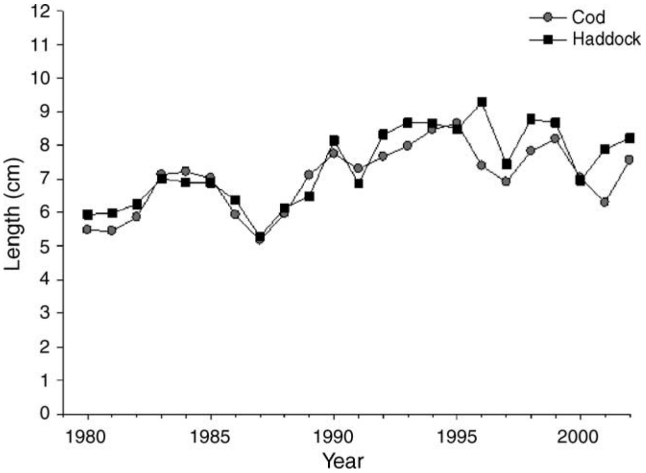


Fig. 3. Estimated mean lengths of cod and haddock after length correction.

without length correction, but the average of the mean lengths was lowered from 7.42 cm, without length correction, to 7.01 cm, with length correction.

Haddock had a significant decrease ($p < 0.01$) in mean lengths after length correction, and the average of mean lengths decreased from 8.81 to 7.37 cm. Mean lengths of cod and haddock became more similar when length correction was applied (Fig. 3), although haddock had larger standard deviations (Fig. 2). Both species had similar trends and were significantly ($p < 0.01$) larger in the 1990s than in the 1980s.

Mean lengths of capelin were smaller ($p < 0.05$) in the 1980s than in the 1990s, but this might be misleading because of the high mean length in 1994, which was caused by an overlap in lengths of 0- and 1-group capelin. This can also be a problem in 2002, but for this year there were no age-determined lengths to verify this. The remaining years, most of the means were close to the average mean length of 4.71 cm.

Herring had no difference in mean lengths between the 1980s and the 1990s, and the average mean length was 6.91 cm. In the 1980s, herring followed a similar pattern to cod, haddock, and capelin, but in the 1990s the pattern was almost the opposite to the pattern of cod and haddock.

Redfish had no trends in the mean lengths. There was little variation between the years and the average mean length was 3.80 cm.

3.3. *Comparing to old indices*

Comparing the Pennington estimator indices to the old area indices (Havforskningsinstituttet, 2003) the trends were similar (Fig. 4), except for capelin in 1980–1983, and for redfish in the 1980s. There was more dynamic in the series of Pennington estimators than in the area indices; the ratios between good and poor years were larger. The length correction of cod and haddock decreased this ratio.

Compared to the logarithmic indices (Havforskningsinstituttet, 2003) the trends were again similar (Fig. 5), but the strong year-class of herring in 1983 was not as evident in the Pennington estimator.

4. Discussion

The abundance indices estimated in this work show the large inter-annual variation in the 0-group abundance. Compared with the area indices, although the trends are similar, it is evident that the new methods retain more of the dynamics in the 0-group recruitment. There is not much difference between the results of the stratified mean estimator and the Pennington estimator for this particular survey. Both length and abundance estimates are influenced by the poor catching efficiency of the trawl for the smaller-sized cod and haddock, as shown by Godø et al. (1993) and Hylen et al. (1995).

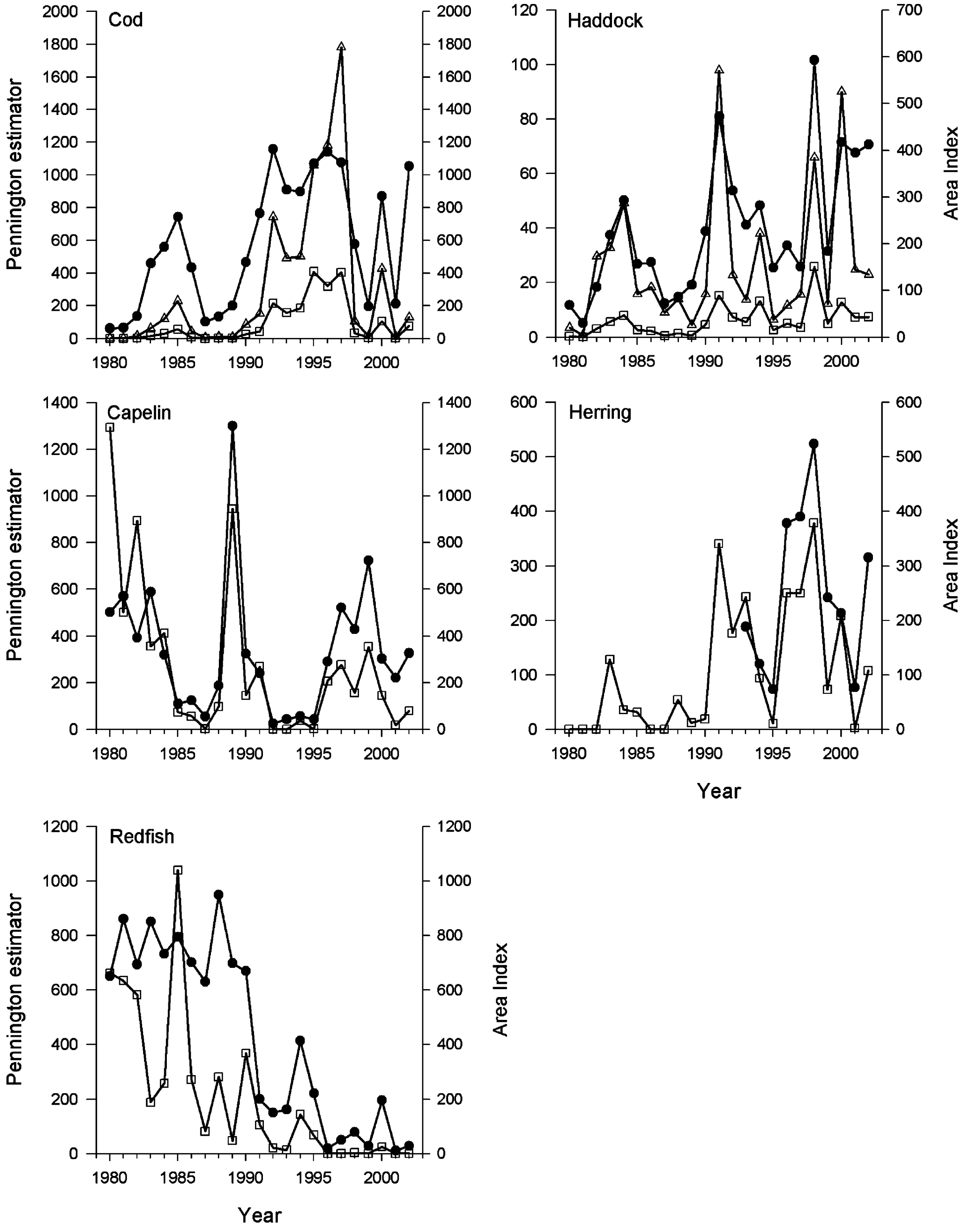


Fig. 4. Pennington mean estimators (open squares: without length correction, open triangles: with length correction) compared with area indices (filled circles).

This is a variable bias that increases with decreasing fish size, and there is reason to assume that this is a problem concerning the other fish species as well.

The data used in this work are gathered from the survey-database at the Institute of Marine Research, Bergen. Until a few years ago, these data were punched manually from the original sampling forms, and even though a lot of effort has been put into quality checking the database, punching errors still occur frequently in the data. In later years, better sampling software that

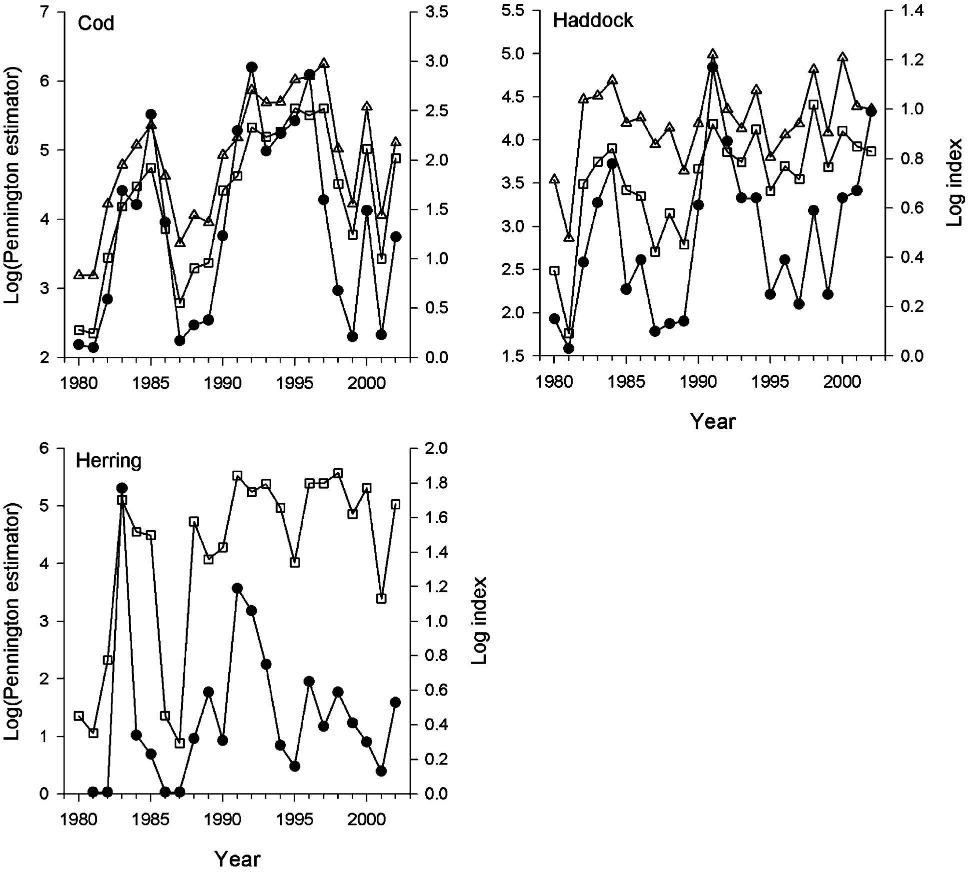


Fig. 5. The log of Pennington mean estimators (open squares: without length correction, open triangles: with length correction) compared with logarithmic indices (filled circles).

test the data for errors as well as the introduction of electronic measurement boards and weights, with direct input to the software, have dramatically reduced the chance of punching errors. Another problem with the IMR database is the lack of data prior to 1980 and Russian 0-group data in 1982 and 1984.

The 0-group survey has been fairly consistent since 1985 with regards to trawling procedure and the standardized sampling trawl, but the distribution of trawl stations and the coverage of the survey area have varied from year to year. Differences in the distance between trawl stations can influence the standard errors of the estimated mean densities. More important, it can affect the mean estimates if the distances vary within a stratum. For example, if the stations are closer together in an area with high fish-density than in areas with lower fish-densities, the mean density will be overestimated. Through the period 1980–2002 there is a trend of better coverage of stratum IV and poorer coverage of stratum I and III. This change of coverage may have a negative effect on the index of redfish, because dense concentrations of redfish were found in the southwestern part of stratum I and in the western part of stratum III in the 1980s and these areas were not covered as well in the 1990s and in 2000–2002. The increased coverage of stratum IV has resulted in better coverage of the capelin distribution and may have a positive effect on the capelin index. The distribution of cod, haddock, and herring seems to be fairly well covered regardless of the change in area coverage, but the lack of Russian data in 1982 and 1984 affects all estimates for those years.

One possible source of error that is often assumed to be insignificant, but which there is not sufficient knowledge about, is the settlement of northeast Arctic cod and haddock. There is very little information in the literature about when cod and haddock in the Barents Sea change from a pelagic life-stage to a demersal life-stage. It is assumed that this transition occurs from late September to October for cod and gradually throughout the autumn for haddock (Bergstad et al., 1987). Reviewing some of the research performed on settlement of cod and haddock in other areas (Bowman, 1981; Koeller et al., 1986; Mahon and Neilson, 1987; Bolz and Lough, 1988; Lough and Potter, 1993; Salvanes et al., 1994; Tupper and Boutilier, 1995; Hussy et al., 2003), it is apparent that it is not possible to generalize about when or at which length settlement occurs. The timing and size at settlement of cod and haddock seems to be regulated by both biological and environmental factors where time of spawning, growth rate, food abundance, presence of predators and suitable habitats are important factors that may cause variation in settlement both within and between years. The mean lengths of cod and haddock estimated in this work suggest that the majority settle later in the autumn and at longer lengths than more southern stocks, but one cannot disregard that some fish may have settled at time of survey and that this bias may vary annually. This is clearly one problem that needs further investigation.

Drevetnyak (1995) reported that settlement of redfish *Sebastes mentella* takes place when they are 2 and 3 years old, but 0-group redfish may be distributed in the whole water column when strong year-classes occur.

Olsen and Soldal (1989) reported that although the year-classes of northeast Arctic cod were weak in 1987 and 1988, they found dense concentrations in shallow water along the Finnmark coast. Based on these and some earlier observations they argued that coastal 0-group cod recur every year and that its abundance is determined by the "holding capacity" of suitable habitat rather than by year-class strength. They estimated that in a year with a poor year-class of northeast Arctic cod, the coastal portion might be in the order of 10% of the total cohort. This coastal portion is not included in the abundance estimates and will amount to a serious negative bias in years with poor year-classes, but it will not have a large effect in years with strong year-classes.

The pelagic trawl has a fairly low catching efficiency for 0-group fish (30–40%), and the efficiency is positively correlated with fish density (Hylen et al., 1995). More efficient herding by otter-boards and sweep lines when there are high densities of fish can explain the difference in efficiency. This herding will positively bias the abundance indices because of the increased "mouth area", and because larger fish have better swimming capacity, they will be herded more efficiently and mean lengths may be over-estimated. The large-meshed netting herds the smaller fish insignificantly and they are lost through the meshes (Godø et al., 1993). This causes negative bias in the abundance indices and positive bias in the mean lengths. The low catching efficiency for small cod and haddock caused by the insufficient herding by the large-meshed netting is corrected for by Eqs. (3) and (4), but there are no available correction functions for other fish species. Godø et al. (1993) estimated that the fish needed to swim with a speed exceeding 38 cm s^{-1} for as long as 40 s to be herded into the codend, which is far greater than what can be expected of smaller 0-group fish. In addition, small fish are often seen to swim directly towards the meshes at various points along the net walls (Wardle, 1993), and 0-group capelin are often seen entangled in the large meshes of the trawl (own observations). Thus, it is reasonable to assume that there is also a selection of capelin, herring, and redfish and that this causes an annually varying bias in the estimated indices and mean lengths.

As discussed above the swimming capacity of the fish is important in trawl selection. Both fish length and temperature are important factors determining swimming speed and endurance of a fish. Larger fish can swim longer at the same speed or they can swim faster at the same endurance than smaller fish, and a reduction in temperature reduces swimming speed and endurance (He, 1993). Thus, in warmer years the trawl efficiency may be better than in colder years. This and the fact that trawl efficiency is better in high-density fish concentrations will cause the trawl selection to vary from year to year and between areas. Thus, the correction functions used in this work may not be appropriate in all circumstances. However, the gain in precision is likely greater than the bias that may be introduced by using them.

The decrease in the ratio of the best year to the worst year, which was found in the abundance indices of cod and haddock when length correction was applied, indicates that the bias caused by selection is larger when the year-classes are poor. This may partly explain the positive correlation between mean length and year-class strength for cod and haddock (Ottersen and Loeng, 2000). The correlation was also found in my study, but the correlation became weaker after length correction was applied. The more efficient herding of larger fish in high concentrations by the otter-boards and sweep lines may also contribute to this correlation.

The new set of abundance indices show, as expected, more of the dynamic in the 0-group recruitment than the area indices do. Although the results from stratified sample mean are similar to the Pennington estimator, the latter seems to be the preferable method for this particular survey because the estimates are more precise and the occasional large catches do not affect the estimates nearly as much as they do in case of the stratified sample mean (McConnaughey and Conquest, 1993; Pennington, 1996). Occasional large catches occur for all species throughout the time series and when they occur, the lognormal based estimate is normally smaller than the sample mean (Pennington, 1996). This can be seen in Table 2 where $\hat{\mu}_{\mathrm{st}}$ is usually smaller than $\overline{y}_{\mathrm{st}}$.

The lognormal based estimator of abundance has been criticized for not being robust when the model assumptions are violated (Myers and Pepin, 1990). The introduction of the cut-level k makes it possible to reduce the bias introduced by values close to zero and it is possible to adjust k such that the values above better fit a lognormal distribution, thus making the Pennington estimator more stable.

The estimated mean lengths show similarities between the species (Fig. 2) and indicate that there is a common factor that influences the length at this stage. Ottersen and Loeng (2000) showed that the length of 0-group cod, haddock, and herring is closely related to temperature. Cod, haddock, capelin, and herring have in general larger mean lengths in 1983–1984 and 1990–1992 than in 1986–1988 (Fig. 2). This coincides with warm and cold anomalies in the Barents Sea (Furevik, 2001) and supports the conclusion by Ottersen and Loeng (2000). Cod and haddock have very similar mean lengths after length correction (Fig. 3) and this is contradicting the previous hypothesis that haddock is on average larger than cod at this stage and that cod catches up the difference after it has settled. The results indicate that the difference in length previously seen in 0-group cod and haddock is caused by the selection properties of the trawl.

5. Conclusion

The goal of this work has been to improve the Barents Sea 0-group abundance indices of cod, haddock, capelin, herring, and redfish. Different sources of bias have been discussed and it is concluded that length dependent selection by the trawl is the most serious source of bias and it is recommended to apply the length correction functions in the estimates. Concern has been raised about early settlement as a source of bias for cod and haddock estimates. This seems to be negligible, but should be further investigated, although pelagic 1-group cod and haddock have been observed during the winter (Odd Nakken, personal communication). The Pennington estimator is concluded to be the most appropriate method of the two in this work. It is recommended that this method becomes the new standard for estimating 0-group abundance indices in the Barents Sea, and that the new time series are included in the future reports from the 0-group survey in the Barents Sea.

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References

Anonymous, 2002. Report of the International 0-group fish survey in the Barents Sea and adjacent waters in August–September 2002. IMR/PINRO Joint Report Series, No. 3, 28 pp.

Bergstad, O., Jørgensen, T., Dragesund, O., 1987. Life history and ecology of the gadoid resources of the Barents Sea. Fisheries Res. 5 (2–3), 119–161.

Bhattacharyya, G.K., Johnson, R.A., 1977. Statistical Concepts and Methods. Wiley, New York.

Bolz, G.R., Lough, R.G., 1988. Growth through the 1st 6 months of Atlantic cod, *Gadus morhua*, and haddock, *Melanogrammus aeglefinus*, based on daily otolith increments. Fishery Bull. 86 (2), 223–235.

Bowman, R.E., 1981. Food of 10 species of northwest Atlantic juvenile groundfish. Fishery Bull. 79 (1), 200–206.

Cochran, W.G., 1977. Sampling Techniques, third ed. Wiley, New York.

Drevetnyak, K.V., 1995. Distribution and abundance of young Sebastes mentella in the Barents and Norwegian Seas in 1991 and 1992. In: Hylen, A. (Ed.), Precision and Relevance of Pre-recruit Studies for Fishery Management Related to Fish Stocks in the Barents Sea and Adjacent Waters, Proceedings of the Sixth IMR-PINRO Symposium, Institute of Marine Research, Bergen, Norway, Bergen, 14–17 June 1994, pp. 219–228.

Folmer, O., Pennington, M., 2000. A statistical evaluation of the design and precision of the shrimp trawl survey off West Greenland. Fisheries Res. 49 (2), 165–178.

Furevik, T., 2001. Annual and interannual variability of Atlantic water temperatures in the Norwegian and Barents Seas: 1980–1996. Deep-Sea Research. Part I. Oceanographic Research Papers 48 (2), 383–404.

Godø, O.R., Valdemarsen, J.W., Engås, A., 1993. Comparison of efficiency of standard and experimental juvenile gadoid sampling trawls. ICES Mar. Sci. Symp. 196, 196–201.

Haug, A., Nakken, O., 1977. Echo abundance indices of 0-group fish in the Barents Sea 1965–1972. Rapports et Procés-verbaux des Réunions du Conseil International pour l'Exploration de la Mer, 170, 259–264.

Havforskningsinstituttet, 1994. Manual til bruk ved 0-gruppe tokt i Barentshavet. 10.8.94, Institute of Marine Research, Bergen, 11 pp. (in Norwegian).

Havforskningsinstituttet, 2003. Survey report from the joint Norwegian/Russian ecosystem survey in the Barents Sea: August–October 2003. Toktrapport, 14-2003, Institute of Marine Research, Bergen.

He, P., 1993. Swimming speeds of marine fish in relation to fishing gears. ICES Mar. Sci. Symp. 196, 183–189.

Hussy, K., Mosegaard, H., Hinrichsen, H.H., Bottcher, U., 2003. Using otolith microstructure to analyse growth of juvenile Baltic cod *Gadus morhua*. Mar. Ecol. Prog. Ser. 258, 233–241.

Hylen, A., Korsbrekke, K., Nakken, O., Ona, E., 1995. Comparison of the capture efficiency of 0-group fish in the pelagic trawls. Hylen, A. (Ed.), Precision and Relevance of Pre-recruit Studies for Fishery Management Related to Fish Stocks in the Barents Sea and Adjacent Waters, Proceedings of the Sixth IMR-PINRO Symposium, Bergen, Institute of Marine Research, Bergen, Norway, 14–17 June 1994, pp. 145–156.

Kappenman, R.F., 1999. Trawl survey based abundance estimation using data sets with unusually large catches. ICES J. Mar. Sci. 56 (1), 28–35.

Koeller, P.A., Hurley, P.C.F., Perley, P., Neilson, J.D., 1986. Juvenile fish surveys on the Scotian Shelf—implications for year-class size assessments. Journal du Conseil International pour l'Exploration de la Mer 43 (1), 59–76.

Lough, R.G., Potter, D.C., 1993. Vertical-distribution patterns and diel migrations of larval and juvenile haddock *Melanogrammus aeglefinus* and Atlantic cod *Gadus morhua* on Georges Bank. Fishery Bull. 91 (2), 281–303.

Mahon, R., Neilson, J.D., 1987. Diet changes in Scotian Shelf haddock during the pelagic and demersal phases of the 1st year of life. Mar. Ecol. Prog. Ser. 37 (2–3), 123–130.

McConnaughey, R.A., Conquest, L.L., 1993. Trawl survey estimation using a comparative approach based on lognormal theory. Fishery Bull. 91 (1), 107–118.

Myers, R.A., Pepin, P., 1990. The robustness of lognormal-based estimators of abundance. Biometrics 46 (4), 1185–1192.

Olsen, S., Soldal, A.V., 1989. Observations on inshore distribution and behaviour of 0-group northeast Arctic cod. Rapports et Procés-verbaux des Réunions du Conseil International pour l'Exploration de la Mer 191, 296–302.

Ottersen, G., Loeng, H., 2000. Covariability in early growth and year-class strength of Barents Sea cod, haddock, and herring: the environmental link. ICES J. Mar. Sci. 57 (2), 339–348.

Pennington, M., 1983. Efficient estimators of abundance, for fish and plankton surveys. Biometrics 39 (1), 281–286.

Pennington, M., 1991. On testing the robustness of lognormal-based estimators. Biometrics 47 (4), 1623.

Pennington, M., 1996. Estimating the mean and variance from highly skewed marine data. Fishery Bull. 94 (3), 498–505.

Pennington, M., Strømme, T., 1998. Surveys as a research tool for managing dynamic stocks. Fisheries Res. 37 (1–3), 97–106.

Randa, K., 1984. Abundance and distribution of 0-group Arcto-Norwegian cod and haddock 1965–1982. Godø, O.R., Tilseth, H. (Eds.), Reproduction and Recruitment of Arctic Cod, Proceedings of the First Soviet-Norwegian Symposium, Leningrad, Institute of Marine Research, Bergen, Norway, 26–30 September 1983, pp. 189–209.

Salvanes, A.G.V., Giske, J., Nordeide, J.T., 1994. Life-history approach to habitat shifts for coastal cod, *Gadus morhua* L. Aquaculture Fisheries Manage. 25 (Suppl. 1), 215–228.

Smith, S.J., 1988. Evaluating the efficiency of the delta-distribution mean estimator. Biometrics 44 (2), 485–493.

Stensholt, B.K., Nakken, O., 2001. Environmental factors, spatial density, and size distributions of 0-group fish. In: Kruse, G.H., Bez, N., Booth, A., Dorn, M.W., Hills, S., Lipcius, R.N., Pelletier, D., Roy, C., Smith, S.J., Witherell, D. (Eds.), Spatial Processes and Management of Marine Populations. Alaska Sea Grant College Program, Fairbanks, Alaska, pp. 395–413.

Tupper, M., Boutilier, R.G., 1995. Effects of habitat on settlement, growth, and postsettlement survival of Atlantic cod (*Gadus morhua*). Can. J. Fisheries Aquatic Sci. 52 (9), 1834–1841.

Wardle, C.S., 1993. Fish behaviour and fishing gear. In: Pitcher, T.J. (Ed.), Behaviour of Teleost Fishes. Fish and Fisheries, vol. 7, second ed. Chapman and Hall, London, pp. 609–643.