NAFO Sci. Coun. Studies, 28: 65–71

Efficiency of Geographical and Depth Stratification in Error Reduction of Groundfish Survey Results: Case Study Atlantic Cod off Greenland

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Introduction

Groundfish bottom trawl surveys carried out by research or commercial vessels have been primarily initiated in order to obtain information on biological parameters of fish stocks such as sexual and age composition, maturity and spawning, growth, feeding etc. In addition to these qualitative characteristics, the quantitative information on age disaggregated fish abundance derived from bottom trawl surveys is a cornerstone in stock assessments since more than two decades ago (Grosslein, MS 1969; Doubleday, 1981). In order to reduce the error of abundance estimates, the idea of stratification has been applied as a standard procedure for groundfish surveys (Cochran, 1953). Regarding the severely depleted status of numerous demersal fish stocks, abundance indices derived from surveys and a minimization of their error have recently gained in significance.

Groundfish survey designs are normally based on geographical and depth stratifications (Saville, 1977). Therefore, the present paper quantifies the precision achieved by such a stratification scheme using the data for Atlantic cod off Greenland as a case study. The results are discussed in order to optimize the survey strategy.

Material and Methods

Since 1982, the demersal fish assemblages off West and East Greenland (NAFO Subarea 1 and ICES Subarea XIV) have been monitored annually by German groundfish surveys which were primarily designed for the assessment of cod. Because of favourable weather and ice conditions and to avoid spawning concentrations, autumn was chosen for the time of the surveys. These were carried out by the research vessel *R/V Walther Herwig II* throughout most of the time period. In 1984 *R/V Anton Dohrn* was used and she was replaced by the new *R/V Walther Herwig III* since 1994.

The fishing gear used was a standardized 140-feet bottom trawl, its net frame rigged with heavy ground gear because of the rough nature of the fishing grounds. A small mesh liner (10 mm) was used inside the cod end. The horizontal distance between wing-ends was 25 m at 300 m depth, the vertical net opening was 4 m. In 1994, smaller Polyvalent doors (4.5 m^2, 1 500 kg) were used for the first time to reduce net damages due to overspread caused by bigger doors (6 m^2, 1 700 kg), which were used earlier. All calculations of abundance and biomass indices are based on the 'swept area' method using 22 m horizontal net opening as trawl parameter, i.e. the constructional width specified by the manufacturer. The towing time was normally 30 min at a speed of 4.5 knots. Trawl parameters are listed in Table 1. Hauls which received net damage or became hung-up after less than 15 min were rejected. Some hauls of the 1987 and 1988 surveys were also included although their towing time had been intentionally reduced to 10 min because of the expected large cod catches as observed from echo sounder traces.

The applied stratification scheme consisted of seven geographical strata. Each stratum was subdivided into two depth strata covering the 0–200 m and 201–400 m zones. Figure 1 and Table 2 indicate the names of the 14 strata, their geographic boundaries, depth ranges and areas in nautical square miles (nm^2). All strata were limited at the 3-mile offshore line.

The applied strategy was to distribute the sampling effort according both to the stratum areas and to cod abundance. Consequently, 50% of the hauls were allocated proportionally to strata by stratum area, while the other 50% were apportioned on the basis of a review of the historical mean cod abundance/nm^2, with all hauls being randomly distributed within trawlable areas of the various strata. Non-trawlable areas were mainly located inshore. During 1982–95, 2 245 successful sets were carried out, the numbers of valid sets by year and stratum are listed in Table 3. Apart from stratum 7.2 (Dohrn Bank), East Greenland strata

TABLE 1. Parameters of the trawl gear used in the survey.

Gear	140-feet bottom trawl
Horizontal net opening	22 m
Standard trawling speed	4.5 kn
Towing time	30 minutes
Coefficient of catchability	1.0

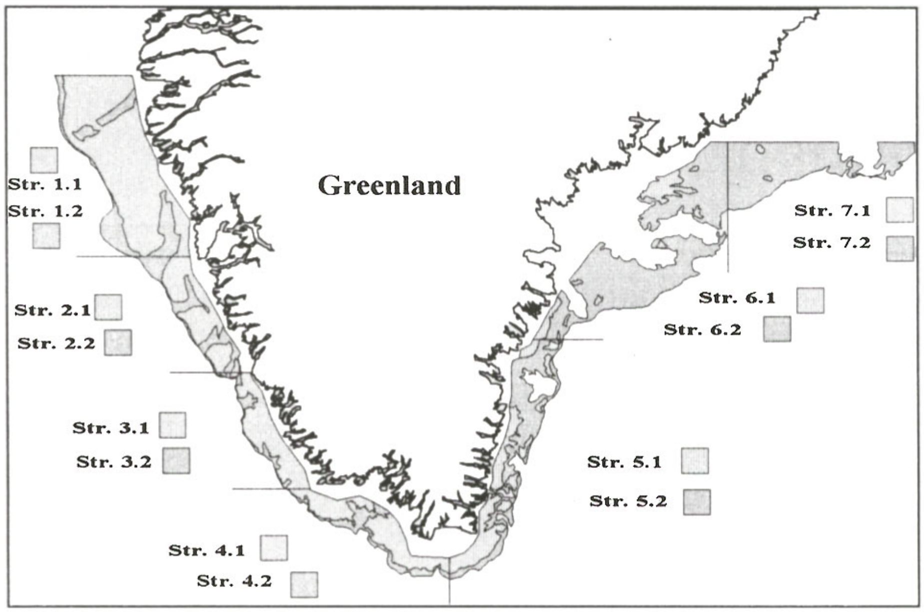

Fig. 1. Survey area and stratification as specified in Table 2.

TABLE 2. Specification of strata.

Stratum	Geographic boundaries South	North	East	West	Depth (m)	Area (nm^2)
1.1	64°15'N	67°00'N	50°00'W	57°00'W	1–200	6 805
1.2	64°15'N	67°00'N	50°00'W	57°00'W	201–400	1 881
2.1	62°30'N	64°15'N	50°00'W	55°00'W	1–200	2 350
2.2	62°30'N	64°15'N	50°00'W	55°00'W	201–400	1 018
3.1	60°45'N	62°30'N	48°00'W	53°00'W	1–200	1 938
3.2	60°45'N	62°30'N	48°00'W	53°00'W	201–400	742
4.1	59°00'N	60°45'N	44°00'W	50°00'W	1–200	2 568
4.2	59°00'N	60°45'N	44°00'W	50°00'W	201–400	971
5.1	59°00'N	63°00'N	40°00'W	44°00'W	1–200	2 468
5.2	59°00'N	63°00'N	40°00'W	44°00'W	201–400	3 126
6.1	63°00'N	66°00'N	35°00'W	41°00'W	1–200	1 120
6.2	63°00'N	66°00'N	35°00'W	41°00'W	201–400	7 795
7.1	64°45'N	67°00'N	29°00'W	35°00'W	1–200	92
7.2	64°45'N	67°00'N	29°00'W	35°00'W	201–400	4 589
TOTAL						37 463

TABLE 3. Numbers of valid hauls by stratum and total, 1982–95.

Year	1.1	1.2	2.1	2.2	3.1	3.2	4.1	4.2	5.1	5.2	6.1	6.2	7.1	7.2	Total
1982	20	11	16	7	9	6	13	2	1	10	3	12	1	25	136
1983	26	11	25	11	17	5	18	4	3	19	10	36	0	18	203
1984	25	13	26	8	18	6	21	4	5	4	2	8	0	5	145
1985	10	8	26	10	17	5	21	4	5	21	14	50	0	28	219
1986	27	9	21	9	16	7	18	3	3	15	14	37	1	34	214
1987	25	11	21	4	18	3	21	3	19	16	13	40	0	18	212
1988	34	21	28	5	18	5	18	2	21	8	13	39	0	26	238
1989	26	14	30	9	8	3	25	3	17	18	12	29	0	11	205
1990	19	7	23	8	16	3	21	6	18	19	6	15	0	13	174
1991	19	11	23	7	12	6	14	5	8	11	10	28	0	16	170
1992	6	6	6	5	6	6	7	5	0	0	0	0	0	6	53
1993	9	6	9	6	10	8	7	0	9	6	6	18	0	14	108
1994	16	13	13	8	10	6	7	5	0	0	0	0	0	6	84
1995	0	0	3	0	10	7	10	5	8	6	6	17	0	12	84

were not covered adequately in 1984, 1992 and 1994 due to technical problems. In 1995, the survey area off West Greenland was incompletely covered for the first time again due to technical problems. The most recent observation covered only 50% of the strata off West Greenland, namely the southern strata 3.1, 3.2, 4.1 and 4.2. Stratum 7.1 has a very low area and therefore has never been covered.

Stratified abundance estimates were calculated from catch-per-tow data using the stratum areas as weighting factor. Strata with less than five valid sets were rejected from the calculation. The coefficient of catchability was set arbitrarily at 1.0, implying that estimates were merely indices of abundance. For comparison the unstratified mean abundance indices were determined by random selection without any restrictions of repeated choice. As described earlier, the effort distribution considered not only the stratum area but also the historical cod abundance. In order to ensure an even haul distribution over the survey area, individual hauls were selected from the different strata in a proportional number taking into account the total number of hauls in a given year and the stratum area. In order to minimize the effect of random selections for the calculation of the unstratified abundance indices, comparison with the stratified abundance was based on the means of one hundred iterations each year. Associated stratified and unstratified estimation of errors was given as standard deviation of the means (standard deviation divided by the square root of observations). The method to calculate the stratified values and respective errors is described by Saville (1977) and the equations are given by Cochran (1953):

$$\bar{Y}_{st} = \frac{1}{A} \sum_{i=1}^{k} \bar{Y}_i A_i$$

$$V(\bar{Y}_{st}) = \frac{1}{A^2} \sum_{i=1}^{k} \frac{A_i^2 s_i^2}{n_i}$$

where A = total survey area

A_i = area of the i-th stratum

s_i = standard deviation of the i-th stratum

n_i = number of valid hauls of the i-th stratum

$\bar{Y}_i$ = mean of the i-th stratum

$\bar{Y}_{st}$ = stratified mean abundance

$V(\bar{Y}_{st})$ = variance of the stratified mean

Further, the observed variance of the cod abundance within given strata and years was compared with the respective mean and the number of hauls, in order to illustrate the effects of fish abundance and effort on the precision of survey results.

Results

Comparisons between stratified and unstratified estimations of cod abundance and associated standard deviations based on one hundred iterations are listed in Tables 4 and 5 and illustrated in Fig. 2 and 3, respectively. Figure 2 shows the pronounced year effect in the cod abundance off Greenland. During 1982–84, the estimates decreased from 100 million to 23 million individuals followed by an enormous increase to 840 million in 1987 due to recruitment. Until 1991, the stock collapsed severely and has remained at that low level since then. The differences between stratified and mean unstratified abundance indices are shown in Fig. 2 and found to be negligible not exceeding 5% as specified in Table 4.

The standard deviations of the stratified and unstratified mean abundance indices were found to be also very variable over the time of investigation. As a result of extreme haul by haul variations, the error estimates were very high. In contrast to the abundance indices, the comparison between stratified and unstratified standard deviations revealed significant differences (Table 4, Fig. 3). From 1982 until 1990, the majority (67%) of the stratified standard deviations showed clear error reductions between 8% and 37%. In 1989, both estimates were almost identical and the unstratified standard deviations were found to be around 10% lower in two years only, namely 1985 and 1987. Since 1991, the stratification scheme did not result in any significant error reduction.

TABLE 4. Stratified and unstratified abundance indices (1 000; based on 100 iterations) and percentage differences, 1982–95.

Year	Stratified Indices	Unstratified Indices	Percentage Difference
1982	100364.8	100899.6	0.5
1983	58193.2	57694.9	-0.9
1984	23284.0	23469.3	0.8
1985	71744.4	71007.0	-1.0
1986	160913.5	159506.2	-0.9
1987	828024.2	842542.1	1.7
1988	650078.7	652337.4	0.3
1989	450457.3	445802.7	-1.0
1990	59775.4	59517.9	-0.4
1991	15210.8	15010.2	-1.3
1992	2700.0	2623.3	-2.9
1993	4733.6	4540.4	-4.3
1994	1375.1	1358.7	-1.2
1995	7464.3	7211.2	-3.5

TABLE 5. Stratified and unstratified standard deviations (based on 100 iterations) of abundance indices (1 000) and percentage differences, 1982–95.

Year	Stratified Indices	Unstratified Indices	Percentage Difference
1982	14305.4	22579.6	36.6
1983	7445.9	10534.7	29.3
1984	3720.5	5200.8	28.5
1985	11822.4	10943.1	-8.0
1986	25892.1	29027.9	10.8
1987	247509.2	219337.9	-12.8
1988	157362.9	182859.4	13.9
1989	134719.5	131323.5	-2.6
1990	13009.4	14168.0	8.2
1991	2202.2	2186.2	-0.7
1992	674.1	642.3	-5.0
1993	862.6	996.1	13.4
1994	251.0	210.7	-19.1
1995	3490.3	3182.2	-9.7

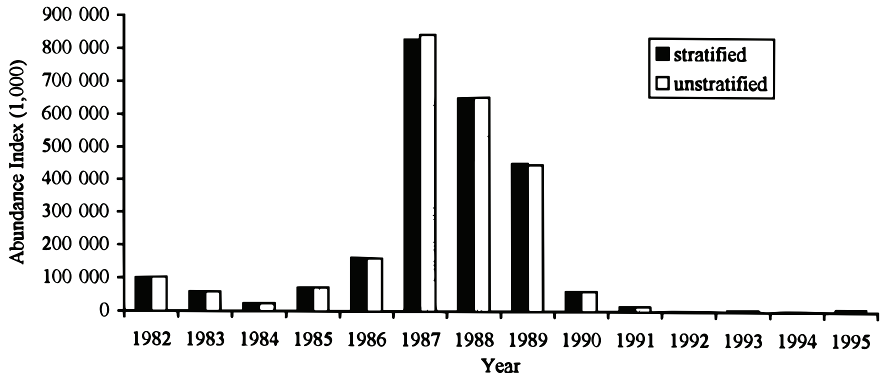

Fig. 2. Comparison between stratified and unstratified abundance indices of Atlantic cod off Greenland (based on 100 iterations).

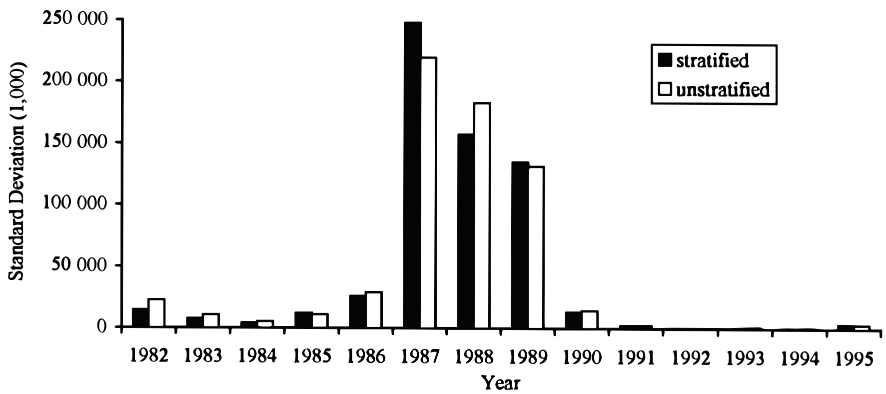

Fig. 3. Comparison between stratified and unstratified deviations of abundance indices of Atlantic cod off Greenland (based on 100 iterations).

Figure 4 shows the scatter plot between log-transformed means and associated log-transformed variances by stratum and year. There was a close linear relation between both variables explaining 96% of the variation, and the slope amounted to a factor of 2.0.

The relationship between the observed coefficients of variation and the number of hauls by stratum and year is plotted in Fig. 5. A significant increase in the coefficient of variation with increasing number of hauls was evident in spite of the high dispersion of the data points ($r^2 = 0.14$).

Discussion

The value of quantitative survey results is dependent on the associated error estimates. In spite of species and stock specific differences, 95% confidence limits are often found to vary around 50% of the stratified mean representing a very low precision. The high variance in the survey catches was derived from the sample method itself (gear behaviour) and fish distribution (Taylor, 1953). The latter effect is dependent of changes in the physical environment such as position, depth, time, light, currents, temperature and salinity as well as various biological circumstances. These are mainly intra- and inter-specific distribution patterns due to prey and predator presence concerning all ontogenic stages and reproduction processes. In order to complete this list of various determining parameters, an impact of simple accidental occurrence must be appended. Because of their different nature and likely interrelations, the difficulty to quantify any of the itemized parameters is obvious.

The present paper deals with the effect of the applied geographic and depth stratification on error reduction, compared with simple random distribution of hauls. The good agreement between the stratified

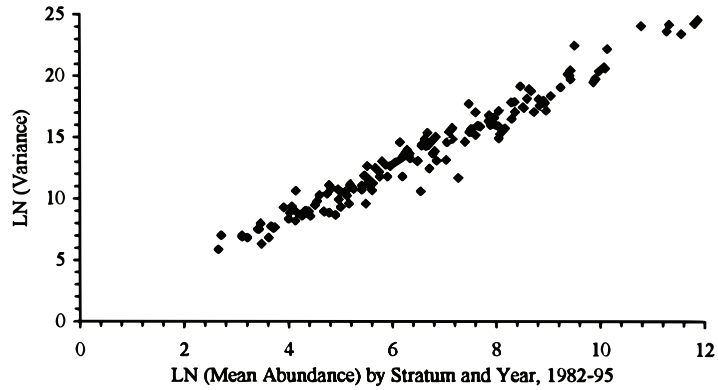

Fig. 4. Scatter plot of log-transformed mean abundance of Atlantic cod off Greenland and associated log-transformed variance by stratum and year, 1982–95. The parameters of correlation were: n = 150, r = 0.98, r^2 = 0.96.

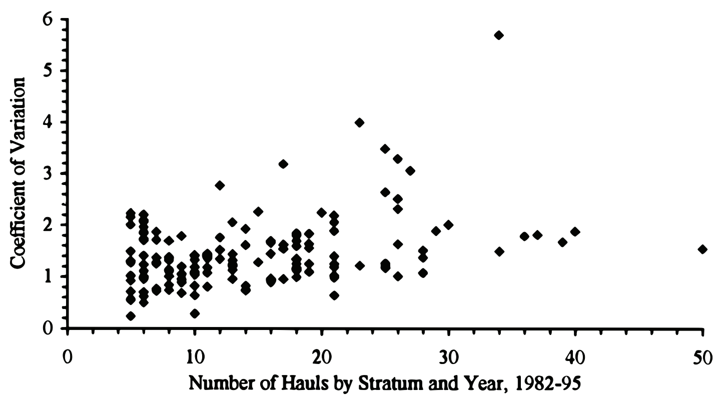

Fig. 5. Scatter plot of calculated coefficients of variation in abundance of Atlantic cod off Greenland and numbers of hauls by stratum and year, 1982–95. The parameters of correlation were: n = 150, r = 0.37, r^2 = 0.14.

and unstratified abundance estimates indicates that 100 iterations are sufficient for reliable comparisons between the different error estimates. During the period 1982–90, the applied geographical and depth stratification as well as the effort strategy contributed to a significant error reduction in the abundance estimates for Atlantic cod off Greenland. The gain in precision is quantified to often exceed 10% in comparison with unstratified estimates. The lack of error reductions during the most recent years is due to the low abundance and more even distribution of the cod since the severe stock collapse in 1991 (Rätz, MS 1996). Apart from deep-sea redfish (*Sebastes mentella* Travin) the applied stratification effort distribution resulted in a more efficient estimator for all groundfish species off East Greenland (Rätz, MS 1990).

In contrast to these findings, the precision of abundance estimates for Atlantic cod on the Scotian Shelf (in Subarea 4) was found to be inferior to what would have been obtained if simple random design had been applied. The lack of any improvement in precision was due to sub-optimal allocation of hauls and the high number of strata (Gavaris and Smith,1987). This is consistent with the 'constrained optimal sampling technique' proposed during the ICES Workshop on the Analysis of Trawl Survey Data (Anon., MS 1992) involving an optimal grouping of homogeneous habitats into a small number of allocation strata (Perry and Smith, 1994). This allows secondary objectives to be met in addition to improve the precision of the abundance estimate of the target species (Ehrich, MS 1988).

A strong linear numerical relationship between log-transformed mean abundance and associated log-transformed variance was found in this study with the slope amounting to 2.0. This indicates that the frequency distribution of the single abundance values are obviously far from normal even when they are logarithmically transformed as described by Pennington and Grosslein (MS 1978) for several fish species caught off Nova Scotia. In order to get more precise error estimates Taylor (1961) used parameters of negative binomial distributions, while Gröger and Ehrich (MS 1992) found better fits using a linear transformation of the original catch data to the very adaptable beta distribution. However, the close relation between the means and associated error estimates has been interpreted as a measurement of aggregation by Almeida *et al*. (MS 1986).

The existence of an increasing trend in resulting coefficients of variations with increasing numbers of survey hauls clearly indicates that the sample sizes are hardly sufficient to ensure representative records in most of the cases. Therefore, the high error in the fish abundance estimates derived from survey catches seems not to be reducible by an increase in effort within a realistic magnitude (Gasjukov and Dorovskikh, 1979). Comparing precision of various groundfish survey results, only the Icelandic survey comprising approximately 700 hauls carried out within the period of three weeks strikes by reduced error estimates (Palsson *et al*., 1989)

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