NAFO Sci. Coun. Studies, 10: 13–20

Development of a Bottom-trawl Survey for Atlantic Cod (*Gadus morhua*) off East Greenland, 1980–85*

H. P. Cornus
Bundesforschungsanstalt für Fischerei, Institut für Seefischerei
Palmaille 9, D-2000 Hamburg 50, Federal Republic of Germany

Abstract

The development of a bottom-trawl survey over a period of 6 years for cod (*Gadus morhua*) off East Greenland is described in relation to survey design, strategy and evaluation and possible application for fish stock assessments. Several problems are considered in relation to specific characteristics of the East Greenland region, such as timing of the surveys, extent of nontrawlable areas, and method of stratification. The experience gained from conducting successive surveys in the region led to improvements in survey strategy, with concomitant improvements in survey results. Some theoretical considerations on application of survey results to stock assessments are also given.

Introduction

For many years, assessment of fish stocks has involved the application of mathematical models, the most common one being "virtual population analysis" (VPA), when sufficiently long time series of age composition and catch data are available. Because the validity of the results is related to detailed knowledge of the fishery (often complicated by the mixture of two or more species), changes in the pattern of fishing have great influence on the assessment. In the case of the cod stock off East Greenland, additional difficulties involve the area of distribution and such factors as migrations to and from cod stocks in adjacent areas (West Greenland and Iceland). In recent years, the pattern of fishing activity off East Greenland has changed to the extent that vessels which intended to fish cod may take substantial quantities of redfish as bycatch in areas of mixed concentrations. Sometimes there is no directed fishery for cod, but substantial quantities may be taken in the redfish fishery. In such circumstances, the development of a time series of reliable catch-per-unit-effort indices is difficult or impossible.

The difficulties in assessing the East Greenland cod stock by VPA methodology was recognized by the Advisory Committee on Fishery Management of the International Council for the Exploration of the Sea (ICES), which strongly recommended the continuation of research surveys that were initiated in 1980, and concluded that these surveys may be the best method of obtaining estimates of cod abundance and distribution (ICES, 1983). Such surveys for cod were conducted by research vessels of the Federal Republic of Germany during 1980–85, and this paper outlines the development of survey design and strategy, with an evaluation of the data base and its use in stock assessment.

Survey Design and Strategy

Target species

In developing the design and strategy of bottom-trawl surveys, compromises have to be made because different species rarely show the same behavioral pattern. The area of distribution, spawning times and migration patterns do not fit one survey design. This was confirmed from exploratory surveys off East Greenland in different seasons before 1980. Although cod and redfish are the major components of the otter-trawl fishery in this region, experience has shown that bottom-trawl surveys are better suited to monitor the distribution and abundance of cod than redfish, because a substantial part of the redfish stock lives pelagically and cannot be fully represented in bottom-trawl surveys. Hence, cod was chosen as the target species when the standard survey design and strategy was implemented in 1980.

Biological background

Knowledge of the seasonal distribution of cod off East Greenland was derived from the pre-1980 exploratory surveys. Spawning begins in the spring and declines during the summer. No spawning concentrations were found in the autumn, when the cod seemed to be distributed most evenly. Also, the catch rates of commercial trawlers were lower at this time than in any other season. Migrations begin in early winter and continue until the spawning season. During this period, some fish immigrate to the region from West Greenland and other fish emigrate from East Greenland to southern West Greenland and Iceland waters. The intensity of migration during winter and spring is quite variable, whereas the density distribution of cod in the autumn is surprisingly constant, as can be deduced from the results of the 1980–83 surveys (Cornus, MS 1984). Detailed information on cod migrations in

* Contribution to the 75th anniversary of the Institut für Seefischerei in April 1985.

Greenland and Iceland waters and the associated problems have been discussed by an ICES working group (ICES, MS 1981).

Timing of surveys

Mathematical methods of variable complexity are available for evaluating survey data. Often, the timing of surveys helps to simplify procedures and overcome statistical problems. The use of arithmetic means and the "swept-area" method would seem to be very appropriate for analysis of data from surveys which are conducted in the season when the target species is most evenly distributed. This is the case for cod off East Greenland in the autumn, when the low number of fishing vessels and low catch rates are indicative of the absence of commercial concentrations. Therefore, the autumn seems to be the best season to expect minimum variance between hauls. Another advantage is that ice cover throughout the survey area is minimum or non-existent during the autumn.

Stratification

The area of cod distribution off East Greenland involves 36 statistical quadrangles (30′ latitude × 60′ longitude) (Fig. 1), which cover 17,377 nautical square miles (Table 1). The statistical quadrangles serve as basic elements for various types of stratification, such as depth, bottom type, temperature, density, etc.

The first stratification (1980 survey), based on subjective experience and knowledge of the fishery, consisted of 11 strata. The distribution of sets per stratum was weighted only by area. Because the whole survey

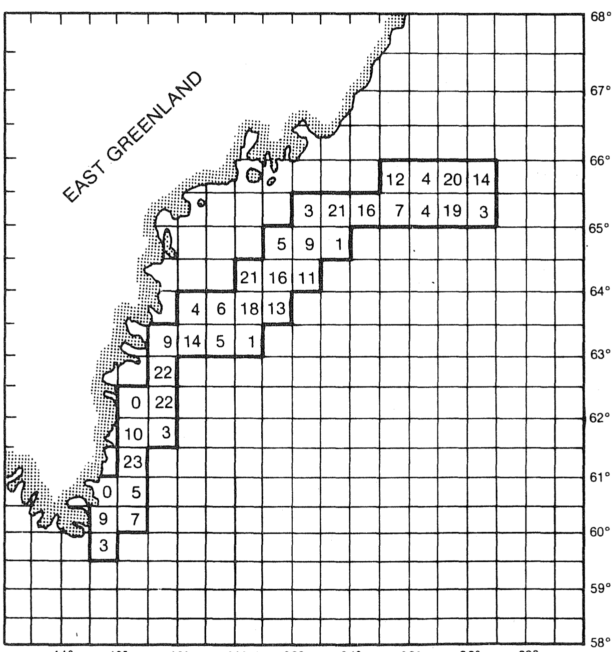

Fig. 1. The survey area off East Greenland and number of hauls by statistical quadrangle in 1980–83.

area was covered evenly by hauls, a restratification of the results could be undertaken without difficulty. The effects of various types of stratification were examined, and it was decided to use a stratification based on depth intervals (0–200, 200–400, 400–600, and 600–800 m). This stratification produced better results in terms of confidence limits than the 11-strata model, and it was applied to the results of the 1980–82 surveys, with the assumption that the distribution of cod by depth coincides approximately with its density distribution.

During the planning for the 1983 survey, the aim was to stratify on density distribution, based on the mean density of cod in the various statistical quadrangles. Mean relative densities (normalized by abundance) for the 36 statistical quadrangles were derived from the 1980–82 surveys, involving a total of 249 sets. Application of an objective method to construct strata boundaries (Dalenius and Hodges, 1959) resulted in five strata with increasing ranges of relative density. Each statistical quadrangle was allocated to the stratum that corresponded to its relative density. The

TABLE 1. Trawlable areas by depth zones for 36 statistical quadrangles off East Greenland.

No.	Stat. quad.	Trawlable area (nm²) by depth zone (m) 0–200	200–400	400–600	600–800	Total
1	48 A1	217	208	51	39	515
2	49 A1	466	313	76	17	872
3	49 A2	—	28	9	11	48
4	50 A1	343	234	65	—	642
5	50 A2	69	97	39	17	222
6	51 A2	105	225	151	27	508
7	52 A2	208	547	55	7	817
8	52 A3	1	21	13	14	49
9	53 A2	43	444	284	26	797
10	53 A3	31	142	175	50	398
11	54 A3	79	236	93	18	426
12	55 A3	194	456	53	7	710
13	55 B0	—	196	119	15	330
14	55 B1	—	43	22	20	85
15	55 B2	—	5	7	10	22
16	56 B0	57	593	114	33	797
17	56 B1	—	797	—	—	797
18	56 B2	—	666	17	14	697
19	56 B3	—	188	15	11	214
20	57 B2	30	225	378	98	731
21	57 B3	2	572	148	16	738
22	57 B4	—	205	61	30	296
23	58 B3	17	137	569	45	768
24	58 B4	22	323	323	35	703
25	58 B5	—	22	50	89	161
26	59 B4	—	754	—	—	754
27	59 B5	—	728	18	8	754
28	59 B6	25	323	60	79	487
29	59 B7	—	40	33	27	100
30	59 B8	—	13	46	63	122
31	59 B9	—	30	97	47	174
32	59 C0	—	4	9	12	25
33	60 B7	—	709	18	5	732
34	60 B8	—	562	164	15	741
35	60 B9	—	254	487	—	741
36	60 C0	—	388	16	—	404
	Total	1,909	10,728	3,835	905	17,377

procedure was repeated for the 1984 and 1985 surveys on the basis of the results of the 1983 and 1984 surveys respectively.

Number of strata

A critical factor in survey design and strategy is the number of strata. Theoretically, better results in terms of confidence limits are produced with finer stratification (more strata) if the number of hauls per stratum is not too low. To avoid artificially high estimates of the variance that result from a low number of hauls per stratum, about 30 hauls should be made in each stratum (Saville, 1977). Only if it is certain that the variation among hauls in a stratum is reasonably small can the number of hauls be reduced and used to the benefit of other strata. Because the number of hauls during a survey is a limiting factor, the number of strata has to be determined in a way that the above proposition will be realized.

The time schedule of the East Greenland survey allows from 110 to 160 hauls, the actual number being dependent on weather conditions and operational efficiency. Therefore, a 5-strata design, based on the distribution of mean relative density of cod seemed to be a good compromise. The survey in 1983 (Table 2) involved a reasonable number of hauls (122), but the 1984 survey was very restricted, because the research vessel *Walther Herwig* was not operational at the appropriate time and the research vessel *Anton Dohrn* had the task of conducting autumn surveys off both West and East Greenland with a consequent reduction in coverage off East Greenland. Also, the 1982 survey was time-restricted.

Number of hauls per stratum

The distributions of hauls for the 1980–82 surveys were based on weighting by stratum area alone, i.e.

$$N_s = N_t(F_s/F_t)$$

TABLE 2. Statistics relevant to autumn bottom-trawl surveys off East Greenland, stratified by depth in 1980–82 and by density in 1983–85. (CV is coefficient of variation and SD is standard deviation.)

Year	Strat. type	Stratum No.	Area (nm^2)	No. of hauls	No. of fish per nm^2	SD	CV	Area per haul (nm^2)
1980	Depth	1	1,909	20	187	51	0.27	95
		2	10,728	65	34	7	0.21	165
		3	3,035	16	3	1	0.33	190
		4	905	5	0	—	—	181
		Total	17,377	106	42	7	0.17	164
1981	Depth	1	1,909	10	195	72	0.37	191
		2	10.728	38	59	11	0.19	282
		3	3,035	14	14	8	0.57	216
		4	905	1	0	—	—	905
		Total	17,377	63	61	11	0.18	276
1982	Depth	1	1,909	7	56	10	0.18	272
		2	10,728	54	20	8	0.40	199
		3	3,035	17	5	1	0.20	179
		4	905	2	0	—	—	458
		Total	17,377	80	19	5	0.26	217
1983	Density	1	3,237	6	17	11	0.65	540
		2	3,286	41	10	2	0.20	80
		3	7,766	48	19	5	0.26	162
		4	1,931	10	24	10	0.42	193
		5	1,157	17	70	16	0.23	69
		Total	17,377	122	21	3	0.14	143
1984	Density	1	2,570	3	39	5	0.13	857
		2	3,885	9	3	2	0.67	432
		3	8,236	16	18	9	0.50	515
		4	1,527	2	18	18	1.00	763
		5	1,157	6	54	31	0.57	193
		Total	17,377	36	20	5	0.25	483
1985	Density	1	1,551	10	4	1	0.25	155
		2	3,088	25	3	1	0.33	124
		3	7,899	71	14	3	0.21	111
		4	2,885	27	18	5	0.28	107
		5	1,954	25	124	25	0.20	78
		Total	17,377	158	24	3	0.13	110

whereas the distributions for the 1983–85 surveys were based on weighting by stratum area and mean relative density of cod per stratum

$$N_S = N_t(F_S D_S / \Sigma F_S D_S)$$

where N_s is number of hauls in stratum s, N_t is total number of hauls, F_s is area of stratum s, D_s is mean relative density in stratum s, and F_t is total survey area.

With the hauls in each stratum distributed at random, weighting only by area has the advantage of covering the total area evenly in a statistical sense. The problems which may arise when restratification is desired are not so evident, but there is the disadvantage of not getting the optimal distribution in relation to the resulting confidence limits. The reverse situation arises when weighting involves both area and density.

Basically, a reasonable improvement of the confidence limits (Yates, 1965) can only be achieved by greatly increasing the number of hauls. In some cases, appropriate stratification and weighting may generate improvements of the same order. However, the total number of hauls must be of reasonable magnitude in relation to the survey area. For example, the high coefficients of variation for most strata during the 1984 survey resulted mainly from the low numbers of hauls (Table 2), and the effect of this factor is clearly evident from comparison of the represented areas per haul for the 1984 survey with those for the other surveys.

Environmental restrictions

Trawling difficulties arise from bottom topography, bottom cover, ice cover and strong currents on the shelf and slope off East Greenland. The trawlable banks and ridges are well-known to fishermen, but a substantial portion of the shelf edge, mainly in the southern part of the region, consists of canyons where trawling is practically impossible. Large areas of the shelf are covered with silicate sponges which fill the net rapidly. Ice may cover the areas which are most suitable for trawling. Strong currents (up to 2 knots) along the edge of the shelf complicate trawling operations.

Survey vessels and gear

The surveys off East Greenland were carried out by the chartered trawler *Karlsburg* in 1980 and the research vessels *Walther Herwig* in 1981–83 and 1985 and *Anton Dohrn* in 1984. The 140-ft (42.5-m) bottom trawl was chosen for the surveys because commercial vessels have used this gear in the area with good results, although larger trawls are in use. The mean horizontal opening of the trawl when towed at a speed of 4.5 knots is 22 m. A detailed description of the trawl and the first results from a special cruise to Rockall Plateau (west of Scotland) were reported by Kroeger and Kock (MS 1982). In additon to mean horizontal opening, use of the "swept-area" method to estimate biomass requires a reliable estimate of the distance trawled. Although the standard duration of haul was 30 min, the times of effective trawling for all hauls are not known precisely.

Evaluation of Survey Data

Data base

The sources of basic information for all surveys are the data from standard hauls, the positions of which were determined randomly within a stratum. Hauls which were discontinued before 10-min duration and all standard hauls with severely-damaged gear were defined as being invalid.

For each valid haul, number and weight of each species were recorded. Length frequencies, sex and maturity determinations, weights of individuals, and otoliths were taken always for the main species and often for other species when time was available. Age-length keys, maturity ogives, mean weight-at-age and mean length-at-age data were subsequently compiled and evaluated.

Number per hour and density

Number of fish per hour of trawling is a function of abundance of the species within the survey area and can serve as an abundance index. It is also a function of trawl velocity, horizontal and vertical net-opening and catchability. Because all parameters are variable from haul to haul, even haul duration, the use of number-per-haul may generate additional variation in computing mean values. Therefore, it is better to normalize the catch (in numbers) in relation to the actual area swept by the trawl, which is also a function of haul duration, trawl velocity and horizontal net-opening. The normalized index (I) is defined as

$$I = C(N/T.V.B)$$

where N is number of fish caught, C is catchability coefficient, T is actual duration of haul, V is towing speed, and B is horizontal net-opening. With C being a dimensionless constant, the calculated index (I) is an estimate of the density (number per unit area).

The standard parameters for application of the "swept-area" method to data from the East Greenland surveys were: 22 m as horizontal net-opening, 4.5 knots as trawling speed, 30 min as haul duration, 1.0 as catchability coefficient, and strata areas (Table 1).

Estimation of abundance and biomass

The normalized index (density) was calculated for each valid haul. Mean density and standard deviation were computed for each stratum, and abundance was extrapolated to stratum area. By application of methods for evaluating stratified-random sampling (Cochran, 1977), abundance was calculated for the whole survey area and confidence limits were determined at the 95% level of significance.

The same procedure was followed to estimate biomass, with the density indices expressed in terms of weight. However, the evaluation of biomass in terms of confidence limits is not as good as that for abundance, because high abundance may not be correlated with high biomass when catches consist of many small and young fish. The estimated biomass from the above procedure can be compared with that which can be derived from the product of age-composition and mean weight-at-age vectors.

Estimates of abundance and biomass from the 1980–85 surveys off East Greenland are given in Table 3. There may be greater interest from a commercial viewpoint in the biomass estimates, but abundance estimates and age compositions are the basic parameters for stock assessments. The ICES Working Group on Cod Stocks off East Greenland interpreted the 1980–84 survey results in relation to the state of the cod stock (ICES, MS 1981, MS 1982, MS 1983, MS 1984, MS 1985).

No improvement of confidence limits in relation to stock abundance was expected for the 1981 survey because of time restriction, and it was not known whether the distributional pattern of cod changed from 1980 to 1981. The 1982 survey was restricted by poor weather conditions, and, although 80 sets were completed, the coefficient of variation (CV) was considerably higher than in 1980 and 1981 (Table 2). After changing the stratification in 1983, an improvement is noticeable in the coefficient of variation (0.17 in 1980 and 0.14 in 1983), which cannot be explained by the difference of only 16 sets (Table 2). Clearly, the 1984 survey was not a normal one (only 36 sets) and should not be considered here, although the coefficient of variation was similar to that for 1982. Best improvement is seen in the results from the 1985 survey. Although the number of sets (158) was the highest of all surveys, the best results in terms of confidence limits and coefficient of variation are due strictly to stratification on density. Because distribution of density changes only marginally from year to year, the distribution of overall mean relative density is an appropriate basis for stratification.

Note on catchability

Catchability of the gear is a critical parameter in estimating the actual stock size of the species being studied, and its constancy depends basically on two factors: structure and operation of the gear, and behavior of the fish. Poor construction of the trawl and its rigging may cause excessive water turbulence in front of the net and reduce the flow, and variation in towing speed may cause the gear to become more or less stable and result in its collapse unknowingly under certain conditions. On the other hand, variation in the behavior of different species of fish may influence catchability, with some escaping upward, some downward and other sideways by increasing their swimming speed. Also, fish behavior varies from season to season.

In the case of cod, it is known that their escape reaction is movement toward the bottom (Main and Sangster, 1981, 1982), and the vertical opening of the net may not be a significant factor. Although these observations were made in European waters, it is assumed that cod behave in the same way off East Greenland. The "swept-area" method is considered appropriate for estimating abundance of cod from research vessel survey data, and the use of 1.0 as the catchability coefficient prevents the overestimation of abundance and biomass.

Discussion and Conclusions

Restrictions on validity of survey data

The main purpose of stratified-random bottom-trawl surveys is to obtain data which can be used to estimate stock abundance and biomass. Because certain parts of the stock area may not be suitable for trawling, the survey results pertain only to the trawlable area. For example, some adult cod may stay in deep rugged canyons, and young cod (prerecruits) generally live pelagically or in shallow coastal waters. Sometimes, certain age-groups may behave in a way which makes them less available to the gear, with consequent

TABLE 3. Estimates of stock size and biomass of cod from bottom-trawl surveys off East Greenland, 1980–85.

Year	Time of survey	Vessel	No. of hauls	Stock size (000s)	Biomass tons
1980	Oct–Nov	*Karlsburg*	106	15,425 ± 33.9%	62,944 ± 32.8%
1981	Nov–Dec	*Walther Herwig*	63	19,448 ± 35.3%	88,336 ± 43.4%
1982	Sep–Oct	*Walther Herwig*	80	6,106 ± 52.5%	19,782 ± 35.0%
1983	Sep–Oct	*Walther Herwig*	122	6,730 ± 33.1%	26,980 ± 37.9%
1984	Oct	*Anton Dohrn*	36	6,488 ± 51.2%	21,151 ± 41.7%
1985	Oct	*Walther Herwig*	158	7,815 ± 26.8%	21,842 ± 26.1%

underrepresentation in the data from bottom-trawl surveys. It must be emphasized that such restrictions may have variable effects on survey results and the deduced parameters. This is particularly important when survey results are used for assessment purposes.

Potential for improvement of survey strategy

Deficiencies in bottom-trawl surveys fall into two categories: those of a methodical nature and those which are removable. In the first case, the extrapolation of mean density to derive abundance of fish in an area presupposes that the stock is evenly distributed throughout the area, but this is rarely found in nature. After sufficient knowledge is accumulated from exploratory surveys at different times of the year, proper timing of the survey can reduce the adverse effect of concentrations to a minimum. Also, environmental conditions play an important role in determining whether the survey area can be covered adequately with the desired number of hauls during the allotted time for the survey. Another important presumption is that all fish above the swept area within the vertical opening of the trawl are caught. This may be nearly true for some species but not for others.

The deficiencies which, in principle, are removable relate mainly to technical problems. With the demands on research vessel time, proper timing of the survey may be difficult due to vessel scheduling, or another vessel may be substituted for the regular one, with consequent influence on comparability of results. Application of the "swept area" method requires a fairly precise estimate of the actual distance over which the trawl operated effectively on the bottom during a specified period, but usually the only measurements available are approximate values of the vessel's towing speed and the duration of haul.

Survey results become more valid when experience in survey design and strategy and knowledge of the basic biological parameters increase with the development of a time series of data. Therefore, the important survey parameters should not be changed. One of these is the research vessel which should be the same during the development of the time series, because it is very time-consuming and difficult to undertake the necessary fishing power studies.

Increasing the number of hauls per stratum should make survey results more reliable with respect to biological parameters by decreasing the confidence limits. Survey experience has shown that an average of five hauls per day is realistic. In the case of the East Greenland survey, the number of desired hauls (150) could be achieved in a 7-week period, which includes transfer to and from the survey area and short interruptions for logistic reasons.

The area elements (30′ x 60′ quadrangles), which are used now to generate the strata, could be reduced to a quarter of their present size in order to increase knowledge of density distribution. More refined stratification would produce a higher degree of accuracy, but such a procedure requires information from a large number of hauls (i.e. sum of all surveys).

Increased knowledge of gear behavior could be acquired by conducting additional experiments on gear measurements, similar to those reported by Kroeger and Kock (MS 1982), in combination with research on the behavior of cod in front of the net. A special problem on the shelf off East Greenland is the presence of silicate sponges (*Geodia gigas*) on large areas of the shelf. These areas are trawlable, but the trawl becomes filled with sponges very quickly. Commercial fishermen have found ways to minimize the effect by altering the rigging and design of the gear, but any modification of the research trawl now would negate the basic principle that important survey parameters should not be changed and, additionally, would result in altering the catchability coefficient.

A significant improvement would be the use of a Doppler-log to measure the speed of towing relative to the bottom.

Validity of survey results

Information to validate the results of the East Greenland surveys must come from other independent sources, such as the fishery or other types of surveys. For several years, Iceland has conducted a young-fish survey during the summer off East Greenland and Iceland (Vilhjalmsson and Magnusson, MS 1981, MS 1982, MS 1983), with the aim of estimating the abundance of cod age-groups 0 to 2. These age-groups are not represented in the autumn survey which is aimed at older year-classes. The results from the young-fish surveys maybe useful for comparison with data from the autumn surveys about 1–3 years later when the year-classes become available to the bottom trawl. Meanwhile, the highly variable environmental conditions will have an important effect on the ultimate strength of these year-classes by the time they recruit to the fishery.

The migrational behaviour of cod in Greenland waters makes fishery statistics difficult or impossible to interpret for use in validating survey results. Trends in catches and catch rates are biased, because the fishery occurs mainly in the spring when the intensity of migration is quite high. The catches at that time may contain a mixture of cod from West Greenland and East Greenland stocks. Information on the proportions of East Greenland cod that are represented in the catches from that region is not yet available, but a joint research program of Greenland and Federal Republic of Germany to study the characteristics of otoliths from West and East Greenland cod may help to resolve some of the problems. In the case of the West Greenland cod stock, the catches seem to be less affected by migrations than those at East Greenland, and consideration of the reliability of survey data from fishery statistics is possible (Cornus *et al.*, MS 1985). Statements on the reliability of survey results for the East Greenland stock will be possible only after the interrelationships of the cod stocks off West and East Greenland and Iceland are better understood.

References

COCHRAN, W. G. 1977. Sampling techniques (3rd ed.). John Wiley and Sons Inc., New York, N. Y., 428 p.

CORNUS, H. P. MS 1984. Stratification of East Greenland trawlable area based on 1980-83 density distribution of cod. *ICES C.M. Doc.*, No. G:59, 16 p.

CORNUS, H. P., H. H. HANSEN, Sv. Aa. HORSTED, J. M. JENSEN, K. M. LEHMANN, J. MESSTORFF, and A. SCHUMACHER. MS 1985. Status of the West Greenland cod stock and management considerations. *NAFO SCR Doc.*, No. 63, Serial No. N1015, 25 p.

DALENIUS, T., and J. HODGES. 1959. Minimum variance stratification. *J. Amer. Stat. Assoc.*, **54**: 84-101.

ICES. MS 1981. Report of the working group on cod stocks off East Greenland. *ICES C.M. Doc.*, No. G:6, 35 p.

MS 1982. Report of the working group on cod stocks off East Greenland. *ICES C.M. Doc.*, No. Assess:4, 27 p.

1983. Report of ICES Advisory Committee on Fishery Management, 1982. *ICES Coop. Res. Rep.*, **119**: 16-18.

MS 1983. Report of the working group on cod stocks off East Greenland. *ICES C.M. Doc.*, No. Assess:8, 26 p.

MS 1984. Report of the working group on cod stocks off East Greenland. *ICES C.M. Doc.*, No. Assess:5, p.

MS 1985. Report of the working group on cod stocks off East Greenland. *ICES C.M. Doc.*, No. Assess:6, 26 p.

KROEGER, M., and K. H. KOCK. MS 1982. First attempts to quantify variations in behaviour of groundfish otter trawls used by the Federal Republic of Germany in North Atlantic surveys. *NAFO SCR Doc.*, No. 51, Serial No. N541, 15 p.

MAIN, J., and G. I. SANGSTER. 1981. A study of the fish capture process in a bottom trawl by direct observations from a towed underwater vehicle. *Scot. Fish. Res. Rep.*, **24**: 10 p.

1982. A study of a multilevel bottom trawl for species separation using direct observation techniques. *Scot. Fish. Rep.*, **26**: 15-16.

SAVILLE, A. 1977. Survey methods of appraising fishery resources. *FAO Fish. Tech. Pap.*, **171**: 76 p.

MESSTORFF, J., and H. P. CORNUS. MS 1984. Subarea 1 cod: results of research vessel surveys conducted off West Greenland in 1982 and 1983. *NAFO SCR Doc.*, No. 93, Serial No. N886, 14 p.

VILHJALMSSON, H., and J. V. MAGNUSSON. MS 1981. Report on the 0-group fish survey in Icelandic and East Greenland waters, August 1981. *ICES C.M. Doc.*, No. H:41, 24 p.

1982. Report on the 0-group fish survey in Icelandic and East Greenland waters, August 1982. *ICES C.M. Doc.*, No. H:63, 26 p.

MS 1983. Report on the 0-group fish survey in Icelandic and East Greenland waters, August 1983. *ICES C.M. Doc.*, No. H:38, 26 p.

YATES, F. 1965. Sampling methods for censuses and surveys (3rd ed.). Charles Griffen, London, Engl., 440 p.

Appendix. Survey Results and Stock Assessments

Essential information

The basic data for assessment of fish stocks are obtainable from the commercial fishery and biological surveys. Biological sampling of the commercial fishery and the associated nominal catches allow for calculation of the overall age composition of the catch during each year. Data from standard biological surveys allow for calculation of total stock and spawning stock sizes, age compositions, and mean weight and maturity values by age-group.

Theorotical considerations

The population dynamics of the cod stocks off Greenland are complicated by the effects of immigration and emigration in addition to usual effects of recruitment and mortality rates. However, with adequate data from the commercial fishery and consecutive annual surveys, a model can be developed whereby the effects of the various parameters can be examined. With the parameters defined as

S_i =total stock in year i,
S_{i-1} =total stock in year i–1,
C_i =total number caught in year i,
K_i =total number of emigrants, immigrants and recruits in year i,
Z_i =coefficient of total mortality,
F_i =coefficient of fishery mortality,
M_i =coefficient of natural mortality,
and k_i =coefficient of combined effect of emigration, immigration and recruitment,

the following equations are valid:

$$S_i = S_{i-1}e^{-Z_i} \quad (1)$$
$$C_i = S_{i-1}(F_i/Z_i)(1 - e^{-Z_i}) \quad (2)$$
$$K_i = S_{i-1}(k_i/Z_i)(1 - e^{-Z_i}) \quad (3)$$
$$Z_i = F_i + M_i + k_i \quad (4)$$

The known parameters are S_i and S_{i-1} from surveys, C_i from the fishery, and M_i = 0.20 (constant), and the parameters that may be calculated in sequence from the above equations are Z_i, F_i, k_i, whereby

$$Z_i = \ln (S_{i-1}/S_i) \quad (5)$$
$$F_i = C_iZ_i/(S_{i-1}(1 - e^{-Z_i})) \quad (6)$$
$$k_i = Z_i - F_i - M_i \quad (7)$$

and K_i directly from equation (3). The procedure fails only when S_{i-1} or S_i equals zero. All parameters of equation (1) to (7) are also valid with the addition of an age-group index.

If e_i, i_i and r_i are coefficients of emigration, immigration and recruitment respectively, then

$$k_i = e_i - i_i - r_i \quad (8)$$

If some independent means of estimating e_i and i_i are available (e.g. tagging experiments), some crude indication of recruitment could be obtained.

Note on practical application

For convenience in assessing fish stocks and in making projections, stock sizes are usually calculated to correspond with the beginning of the calendar year (1 January). When stock sizes are estimated from biological surveys which do not correspond to that date, adjustments are necessary by applying appropriate fractions of catch, migration and natural mortality for the period between the time of the survey and the beginning or end of the year.

In the East Greenland area, a wide range of age-groups of cod is affected by emigration, immigration and recruitment. Assessment of the state of the stock, as well as catch projections and management advice, are very dependent on those features of the stock which can only be estimated at present from the results of surveys. The practical application of survey results relevant to East Greenland cod had been described in detail by the ICES Working Group on Cod Stocks off East Greenland (ICES, MS 1981, MS 1982, MS 1983, MS 1984, MS 1985).

Future prospects

Consideration of confidence limits in connection with Virtual Population Analysis is very difficult and the problem has generally been ignored in assessments. There is an advantage in having confidence limits with survey results, but a (new) problem relates to the significance of stock size differences in consecutive years.

The reasonable success of the early surveys off East Greenland encouraged the initiation of a similar survey off West Greenland in 1982 (Messtorff and Cornus, MS 1984). Special conditions of that region have to be considered and a stratification on density is in preparation. Combination of the assessments of the East Greenland and West Greenland cod stocks based on survey results may enlighten further the problems of migrations around Greenland.