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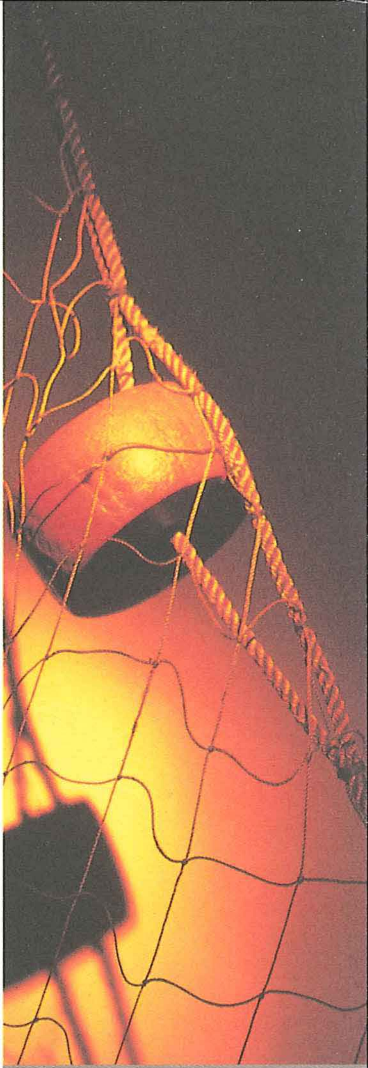

PRECISION AND RELEVANCE OF PRE-RECRUIT STUDIES FOR FISHERY MANAGEMENT RELATED TO FISH STOCKS IN THE BARENTS SEA AND ADJACENT WATERS

Proceedings of the sixth IMR-PINRO Symposium
Bergen, 14-17 June 1994

Edited
by
Arvid Hylen

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1995

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Section VI. Relevance of recruitment on fishery management

PREFACE

The IMR - PINRO symposium is the sixth in a series dealing with important aspect of fish stocks in the North-east Atlantic. Some surveys are at present made jointly or at a national basis, aiming at recruitment measures for stock assessments and management advices. Such surveys are based on the investigations by research vessels and or by hired commersial trawlers. Such activities are costly and it is sometimes necessary to propose an overall analysis of the data with the aim of improving the survey methods. The results might also end up with new recommendations for standardization of recruitment surveys and joint Russian - Norwegian surveys.

Researchers engaged in recruitment studies on cod, haddock, saithe, redfish, Greenland halibut, herring, capelin and polar cod in the Barents Sea and adjacent waters were encouraged to submit papers on the following topics:

Abundance and distribution - trawl and acoustic abundance estimates, statistical aspects, survey design, aspects of sampling gear and operation.

Available food for pre-recruits - feeding, cannibalism, competition, growth.

Unavoidable fishing mortality - sorting grid in shrimp and fishing trawls, closed areas.

Population dynamics and modeling - natural mortality and unavoidable fishing mortality in the pre-recruit stages, relevance of recruitment to fishery management.

As with earlier symposia in the series, the papers have not been subject to pear reviews. However, some changes have been made in order to clarify the content of the papers, greater alterations have always been checked with the authers.

The editor is greatly indebted to Ole-Johan Østvedt, Knut Korsbrekke and other colleques at the Marine Research Institute for valuable help. The editor will also thank Hildegunn Mjanger and Lisbet Solbakken for redrawing some figures and Hildegunn Græsdal for invaluable editorial work with the papers, collected in this proceedings.

Bergen, September 1995

Arvid Hylen

(editor)

FACTORS DETERMINING THE YEAR-CLASS STRENGTH OF NORWEGIAN SPRING SPAWNING HERRING

by

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ABSTRACT

More than 30 years of Russian and Norwegian data on spring-spawning herring larvae along the coast of Norway has been investigated and analyzed together with different environmental parameters and spawning stock size. Quantifiable relations between time series of the yearly abundance of herring larvae, the spawning stock and wind has been found. Together with information on the sea temperature this form the basis for predicting 3 years ahead the strength of the 3 years old herring stock with a preliminary accuracy of about $\pm 3*10^9$ individuals.

INTRODUCTION

In general, recruitment forecasting from larval surveys is not widely employed (Heath 1992). This is partly due to lack of long time series. However, Svendsen *et al.*, (1994) have managed to quantify clear connections between the size of the spawning stock biomass and the environmental conditions during the larval development.

The Institute of Marine Research, Bergen (IMR), has annually since 1948 been sampling fish eggs and larvae at different localities along the Norwegian coast. The sampling during the spring and summer seasons has partly been aimed at the study of single species such as herring and cod. After 1966 a closer sampling grid was introduced from Stad (62°N) to Vestfjorden (68°N), and the sampling in this area in March/April was aimed at the study of the herring larvae only (Fig.1). The objective was to locate spawning grounds and to monitor spawning period, survival and distribution of herring larvae (Bjørke, Fossum and Sætre 1986; Fossum, Bjørke and Sætre 1987 and Sætre, Bjørke and Fossum 1988).

Since 1959, former USSR has annually also been sampling herring larvae outside the Norwegian fishery border at fixed stations along the Norwegian coast (Yudanov 1962; Seliverstov 1974; Krysov, Muchina and Seliverstova 1986 and Krysov and Ergakova 1990).

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A net similar to the modified WP II net has been used (Yudanov 1962). The objective of these investigations was similar to that of the Norwegian investigations. This material presents a rather long time series, and the intention of the present work was to see if this total material can indicate any connection between physical conditions and survival of herring larvae.

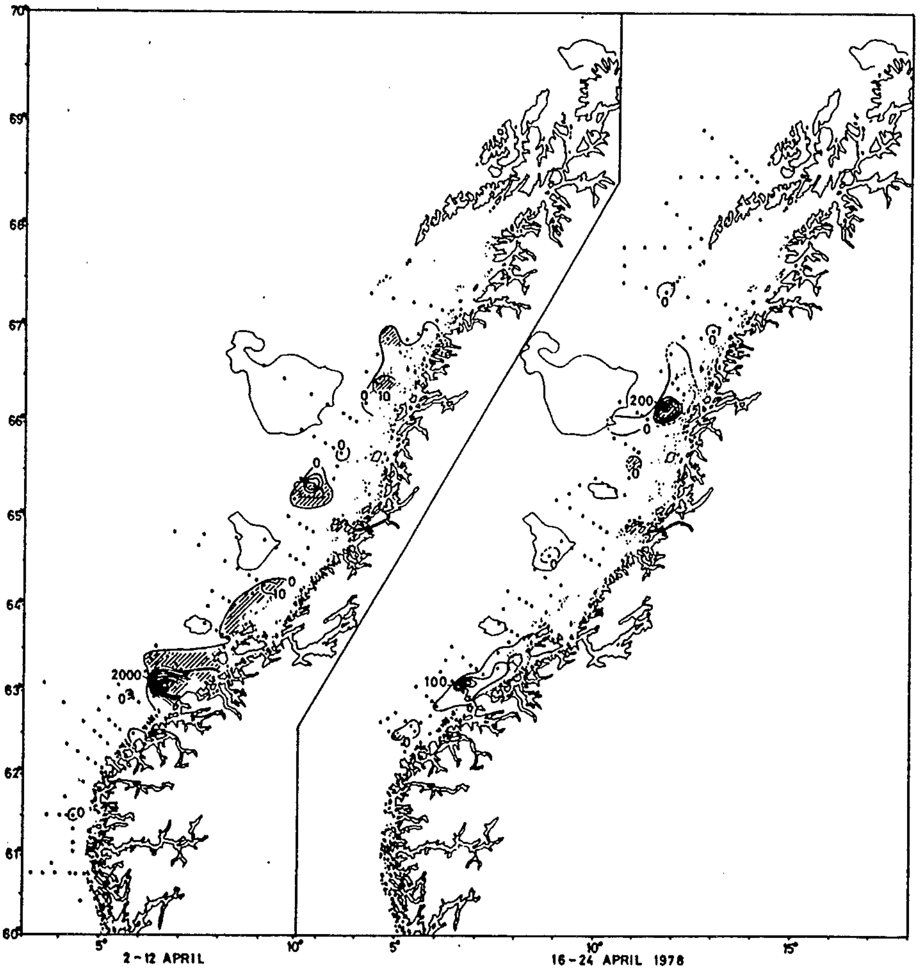

Figure 1. Norwegian stations in 1978. Hatched areas indicate findings of larvae smaller than 9 mm.

BACKGROUND

Hjort (1914) showed that the year-class strength for Atlanto-Scandian herring is established during the early stages of larval life, especially during the transition to mixed feeding. Soleim (1942), conducting investigations under aquarium conditions and at the spawning grounds, found that the survival of larvae depended on the spawning period of zooplankton and the transition of larvae to mixed feeding of copepod eggs and nauplii.

Hjort's hypothesis find some support in recent studies on herring larvae by Moksness and Fossum (1992) and Fossum and Moksness (1993). There seems to be correlations between the temperature in the Atlantic branch of the Norwegian current and the formation of good year-classes of cod, haddock and herring (Sætersdal and Loeng 1987). Ellertsen *et al.* (1990) found that high temperature is a necessity, but not sufficient alone to produce a good year-class of cod. The present authors wanted to study the effect of some physical factors during the period when most of the herring larvae become dependant of external food i. e. in April. These factors were temperature and windstress from different directions.

During the first days of their life, during the yolk-sac stage, the larvae ascend to the surface where sharp fluctuations of temperature and meterological conditions are observed. The hydrographical conditions at the spawning grounds are determined by macroprocesses of atmospheric circulation which affect the heat exchange between the sea and atmosphere and horizontal and vertical transport/mixing of water masses. Abiotic factors have a strong effect both directly and indirectly on the early stages of young fish development. In Atlanto-Scandian herring the effect of abiotic factors is most significant in the embryonic and larval stages, i.e. in the first 2-3 weeks after hatching (Yudanov 1962; Seliverstov and Penin 1969; Seliverstov 1970; Seliverstova 1983 and Krysov and Ergakova 1990).

Marti (1961) noted that, as for cod, abundant year-classes of herring appeared in years with high productive ability of the spawning stock. However, studying the 1959-1992 period, it is clear that among these year-classes only four (1959, 1983, 1991 and 1992) were abundant and only in 1959 the spawning stock was relatively rich (7.5 mill. tonnes).

Marti (1961), Yudanov (1962) and Seliverstov (1971) noted that abundant year-classes did not appear during years of unfavourable physical conditions. Strong year-classes evidently appeared during years with good survival conditions and with a high abundance of breeders.

Krysov and Ergakova (1990) noted that a rise in the heat content of water masses on the spawning grounds and in the routes of herring larval drift and predominance of southwesterly winds determine the appearance of abundant year-classes.

Unfavourable conditions for larval survival is believed to be a short drift into the Norwegian coast where the water temperature is by 1-2°C lower than at the spawning areas over the banks (Seliverstov 1970). The larvae are hence exposed to a limited period of plankton development which could lead to a mismatch between food and larval abundance. By drifting to the north-east the larvae will be brought into conditions of a prolonged spring, which begins in March-April in the southern areas, in April-May in central areas and in June-July in the eastern areas (Pavshtiks 1956). Therefore, it is evident that meterological factors, especially those wind directions transporting the larvae north-eastward should have a positive effect on the development and survival of herring larvae.

Devold (1963) and Røttingen (1992) noted that after 1950 the spawning grounds of herring north of Stad (Figure1) became the most important. According to the data from different scientists mass hatching of herring larvae for the recent 30-35 years was observed in the period from mid-March to mid-April. Therefore the sampling scheme used by the Russians and the Norwegians seems to be suitable for such an investigation.

MATERIAL AND METHODS

Sampling

The Norwegian material has been sampled in March-April with a Gulf III sampler (Zijlstra

1970) and a modified WP II sampler (Anon. 1968) along the Norwegian coast (Figure1). The modification of the WP II consisted of an increase in dimensions of the WP II net to fit a mouth area of 0.5 m^2. Hereafter this net is called the T-80 net. The Gulf III samples were taken in the period 1976-1984 as double oblique hauls from the surface to 60 m depth with a vessel speed of 5 knots and the ship heading towards the next station. Mesh size varied from 500 to 270 micron, most used was nets with 375 micron meshes. The T-80 net was used during the period 1985-1991, and the mesh size was 375 micron. The samples were taken as vertical hauls from 150 m to the surface. In 1976 and 1977 the Norwegian material was preserved in 4% formaldehyde and examined later. During the following years the material was examined fresh. Totally the Norwegian material includes 3704 samples (Appendix I).

The Russian material has been sampled annually in March-April since 1959 at 33-35 fixed stations (Figure 2) along the Norwegian coast with a net similar to the T-80 net (Yudanov 1962). The samples were taken as vertical hauls from 100 m to the surface. During the period 1983-1991 the material was examined fresh. The Russian material includes 1656 samples (Appendix II).

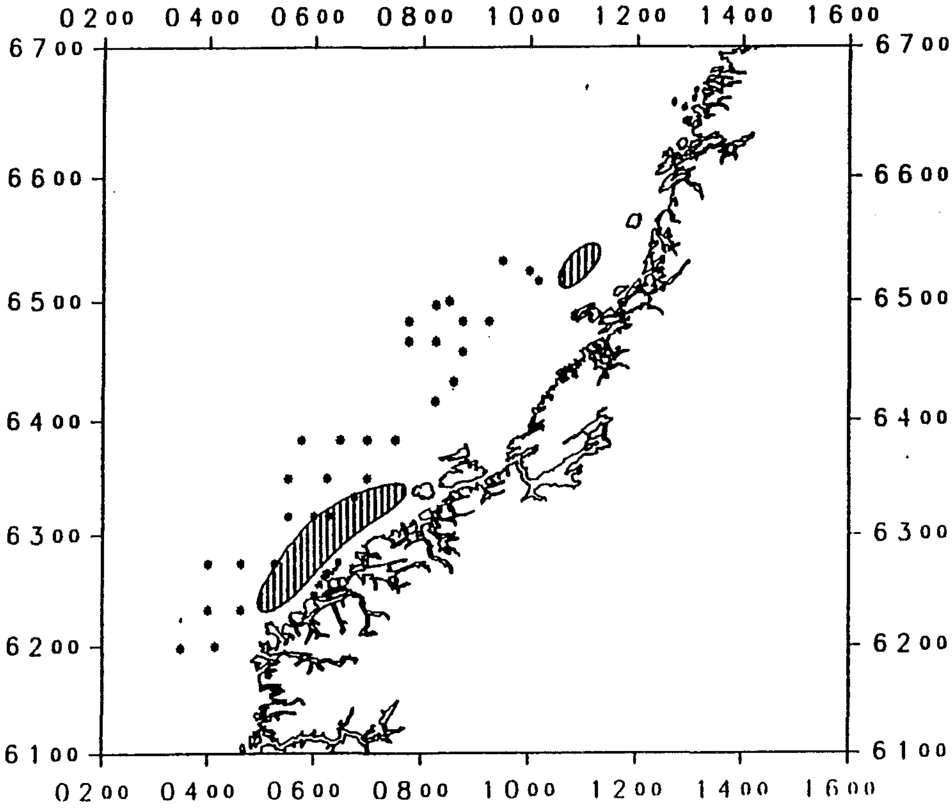

Figure 2. Russian stations in 1973. Hatched areas indicate spawning grounds for herring (Anon. 1993).

Physical variables

Temperature

Daily thermograph data from Hustadvika (Table 1), near Bud (Figure 3), taken from a coastal steamer (Midttun 1975) added with newer data was used in this work. In addition was used temperatures at 20 m depth observed during the Russian larvae surveys and observations from the Kola section. Also average temperature observations from Skrova (Vestfjorden) from 30 to 0 m and 150 to 50 m was used.

Table 1. Mean temperature at Hustadvika and at Russian stations in the Norwegian Sea in April.

Year	Temperature at Hustadvika	Deviation	Russian observations	Deviation
1959	6,8	1,3	6,4	0,2
1960	6,4	0,9		
1961	6	0,5	6,4	0,2
1962	5,4	-0,1	6,4	0,2
1963	5,3	-0,2		
1964	6,1	0,6	7	0,8
1965	5,9	0,4	6,4	0,2
1966	4,1	-1,4	5,2	-1
1967	5,2	-0,3	5,9	-0,3
1968	5,1	-0,4	6	-0,2
1969	4,7	-0,8	6,3	0,1
1970	4,3	-1,2	5,3	-0,9
1971	5,3	-0,2		
1972	5,9	0,4	6,5	0,3
1973	5,9	0,4	6,6	0,4
1974	5,6	0,1	6,1	-0,1
1975	5,9	0,4	6,1	-0,1
1976	5,4	-0,1	6,1	-0,1
1977	5,5	0	6,1	-0,1
1978	5,6	0,1	5,9	-0,3
1979	5	-0,5		
1980	5,1	-0,4	5,8	-0,4
1981	5,3	-0,2		
1982	5,2	-0,3		
1983	6,2	0,7	6,4	0,2
1984	5,3	-0,2	5,8	-0,4
1985	5,1	-0,4	5,8	-0,4
1986	4,6	-0,9	5,8	-0,4
1987	5,3	-0,2	5,9	-0,3
1988	5,4	-0,1	6,2	0
1989	6,1	0,6	6,8	0,6
1990	6	0,5	7	0,8
1991	6	0,5	7,1	0,9
1992	5,9	0,4		
Mean	5,5		6,2	

Wind

These temperature data together with meterological observations from Ona (Figure1), kindly placed to our disposal by The Norwegian Meteorological Institute (DNMI), were used to represent the physical conditions for the herring larvae during their first feeding period. These observations are assumed to represent the shelf area between 62°N and 63°30'N. The directional monthly mean wind stress (Wind (x)) were calculated by using the formula Wind $(x)=f*W^2$, where f is the frequency in percent of observations from a given wind direction $(x^{\pm}15^{\circ})$ and W is the associated mean windspeed in m/sec (Sundby 1982). When the windstress from two directions are used, the sum of the wind stress is applied. However, the winddata for 1963 is missing.

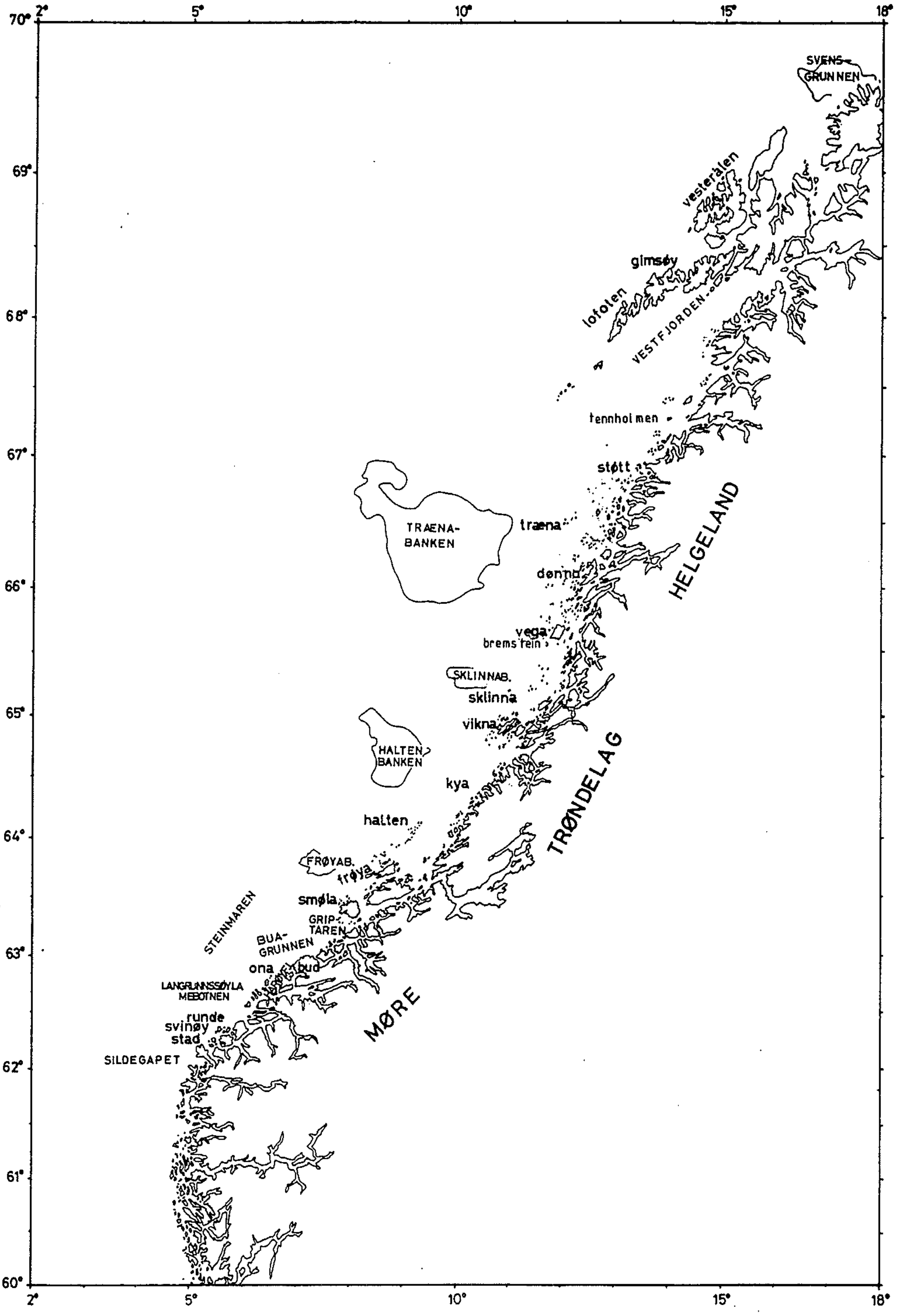

Figure 3. Some of the names used in text.

Biological variables

Larvae index

The herring larvae indices was calculated by a programme by Westgård, Knutsen and Christiansen (1988). The area integrated was between 61°00 and 67°00'N and between 002°00' and 016°00'E. If more than one sample was taken within an area of about one square nautical mile, the average number of larvae per m^2 was calculated. Thus, only one figure represents one year even if the area was sampled more than once (Table 2).

Table 2. Indices and biological and physical variables used in the equations.

Years	Russian index	Norwegian index	Combined index	Temp. Hustad	Wind from 300°	Wind (150-180)°	Age 3 in mill.	Spawning stock in mill. tonnes
1959	2,400	-	2,400	6,8	45	572	21175	6,520
1960	2,900	-	2,900	6,4	899	515	7337	5,310
1961	-	-	-	6,0	205	252	2175	3,930
1962	0,300	-	0,300	5,4	160	190	203	3,130
1963	-	-	-	5,3	-	-	8281	2,450
1964	0,600	-	0,600	6,1	17	421	3832	2,660
1965	0,210	-	0,210	5,9	0	370	107	2,960
1966	0,013	-	0,013	4,1	70	123	230	2,570
1967	0,000	-	0,000	5,2	469	331	21	1,160
1968	0,022	-	0,022	5,1	358	115	10	0,220
1969	0,011	-	0,011	4,7	35	332	513	0,080
1970	0,003	-	0,003	4,3	25	276	7	0,030
1971		-	0,000	5,3	0	217	1	0,009
1972	0,000	-	0,000	5,9	90	123	886	0,002
1973	0,004	-	0,004	5,9	441	374	575	0,100
1974	0,008	-	0,008	5,6	23	51	127	0,120
1975	0,056	-	0,056	5,9	260	356	143	0,120
1976	0,056	0,018	0,056	5,4	101	329	499	0,170
1977	0,029	0,039	0,029	5,5	51	254	324	0,280
1978		0,015	0,015	5,6	70	110	429	0,350
1979		0,077	0,077	5,0	0	315	755	0,380
1980	0,000	0,071	0,000	5,1	276	754	95	0,450
1981		0,007	0,007	5,3	211	312	90	0,470
1982		0,010	0,010	5,2	170	416	232	0,480
1983	0,280	0,074	0,280	6,2	0	352	13478	0,550
1984	0,120	0,190	0,120	5,3	0	354	454	0,580
1985	0,200	0,450	0,200	5,1	0	189	648	0,520
1986	0,072	0,028	0,072	4,6	45	229	96	0,380
1987	0,046	0,230	0,046	5,3	0	163	328	0,730
1988	0,110	0,250	0,110	5,4	114	261	822	2,190
1989	0,340	0,460	0,340	6,1	88	370	8000	2,580
1990	1,000	0,100	1,000	6,0	138	837	8000	2,510
1991	2,600	0,970	2,600	6,0	0	829	10000	2,540
1992		1,700	1,700	5,9	45	570	10000	2,600

Dragesund (1970) suggested that when comparing distribution and abundance of larvae in relation to subsequent year-class strength, those having passed the yolk sac stage (*i.e.* Larvae ≥ 12 mm) should be considered separately. The abundance of these larvae are therefore denoted larvae index, which is believed to reflect the feeding conditions during the early larval stages. The Russian larvae material sampled in 1961 was omitted because the permanent station grid was not sampled and the 1992 material is not worked at present. In 1971 very few larvae were caught during the Norwegian surveys (Dragesund *et al.* 1980) and the index was set at zero.

Spawning stock size and 3-year old herring.

The spawning stock size and number of 3-year old herring is given in Domasnes *et al.* (1993). The recruitment in 1991 and 1992 was estimated as good (Anon. 1993) and the figures as 3 year old is equalled to that of a good year-class (Table 2).

Model

Svendsen *et al.* (1991 and 1994) demonstrated that more than 70% of the year to year recruitment variability of several fish stocks in the North Sea might be explained by an ocean heat parameter and one or two climate/weather parameters representative for the time prior to and/or during the time of larval stages. To find a combination of a few (from many) parameters which could be of main importance for the recruitment success or failure, the authors chose to use a multiple linear regression analysis tool (Wilkinson1989). The physical parameters considered here was the previously mentioned regularly monitored monthly mean sea surface temperature at Hustadvika, ship measured temperatures averaged over different latitudal sectors of the shelf area and monthly mean wind stress from different 30° (or 60°) sectors measured at Ona.

In the present work time series of the following biological variables were taken into consideration (Table 2): Russian larvae index (26 years); Norwegian larvae index (17 years), a combined index (all 31 years), the number of 3-group herring (all years) and the spawning stock size (all years). The statistical analysis gives the coefficients a,b,c.... based on the measured or estimated time series in the equation:

$$\textbf{Biological variable} = \textbf{Const.} + \textbf{a(Spawning stock)} + \textbf{b(physical factor}_1\textbf{)} + \textbf{c(physical factor}_2\textbf{)} + \textbf{d(physical factor}_3\textbf{)}+......$$

It must be mentioned that the statistics do not require that these variables are independent. However, a possible presence of autocorrelation in individual timeseries (especially the spawning stock) will somewhat overestimate the statistical significance of the findings. The requirements set for selecting independent variables are that each selected coefficient has to be significantly different from zero, with a 95% confidence level (preferably better), and that the number of variables must be as few as possible (most of the coefficients equal to zero) to reach a total squared multiple correlation coefficient preferably above 0.7. Another important requirement is that the results should be reasonable explained by common oceanographical and biological knowledge. The use of this type of correlation analysis might be discussed. However, knowing that the variability of certain environmental parameters are in general a combined function of several variables, some kind of multivariate analysis is required to estimate the significance of each variable. It is not claimed that the applied statistical method is the best for this purpose.

RESULTS AND DISCUSSION

The monthly mean surface temperatures at Hustadvika and the mean temperature at 25-30 m depth during the Russian surveys in April (1959-91) showed a considerable variation of the hydrographical situations in 1959-1992 (Table 1). For example, 1959,1960,1961,1964,1965, 1972-1975, 1983, 1989-1992 showed variable positive deviation at Hustadvika. In these years, year- classes of high and mean abundance appeared, except for 1961, 1965, and the period 1972-1975. During the period 1970-1975 the stock was nearly depleted, and no abundant year-classes were to be expected. The 1961 year-class was nearly of average strength, but the 1965 year-class was very poor (Table 2). Thus two of ten observations with temperatures higher than the mean fail to produce year-classes of high and mean abundance. However, based on the analysis of the present data, we think that warm conditions in the atmosphere during the hatching period sometimes have a decisive effect on the development and abundance of herring year-classes.

Larvae index

The different larvae indices were run against spawning stock size and the various physical variables. The best results were found in relation to the combined larvae index, where about 70% of the variability is explained simply by the spawning stock and the wind stress in april from 135° to 195° through the equation:

$$\mathbf{Mod.Comb.ind.= -0.509 + 0.315*Sp.st +0.145*Wind(150°-180°)/100}$$

$$\mathbf{R^2=0.72\ (0.70),\ St.Err.=0.44}$$

where Comb.ind. is the Russian larvae index or the Norwegian index for years when the Russian index is missing. The squared correlation coefficient R^2 is adjusted (in parenthesis) due to statistical properties of the time series, and St.Err is the associated standard error of estimate. 60% of the variability is caused by the spawning stock size, and 10% by the wind.

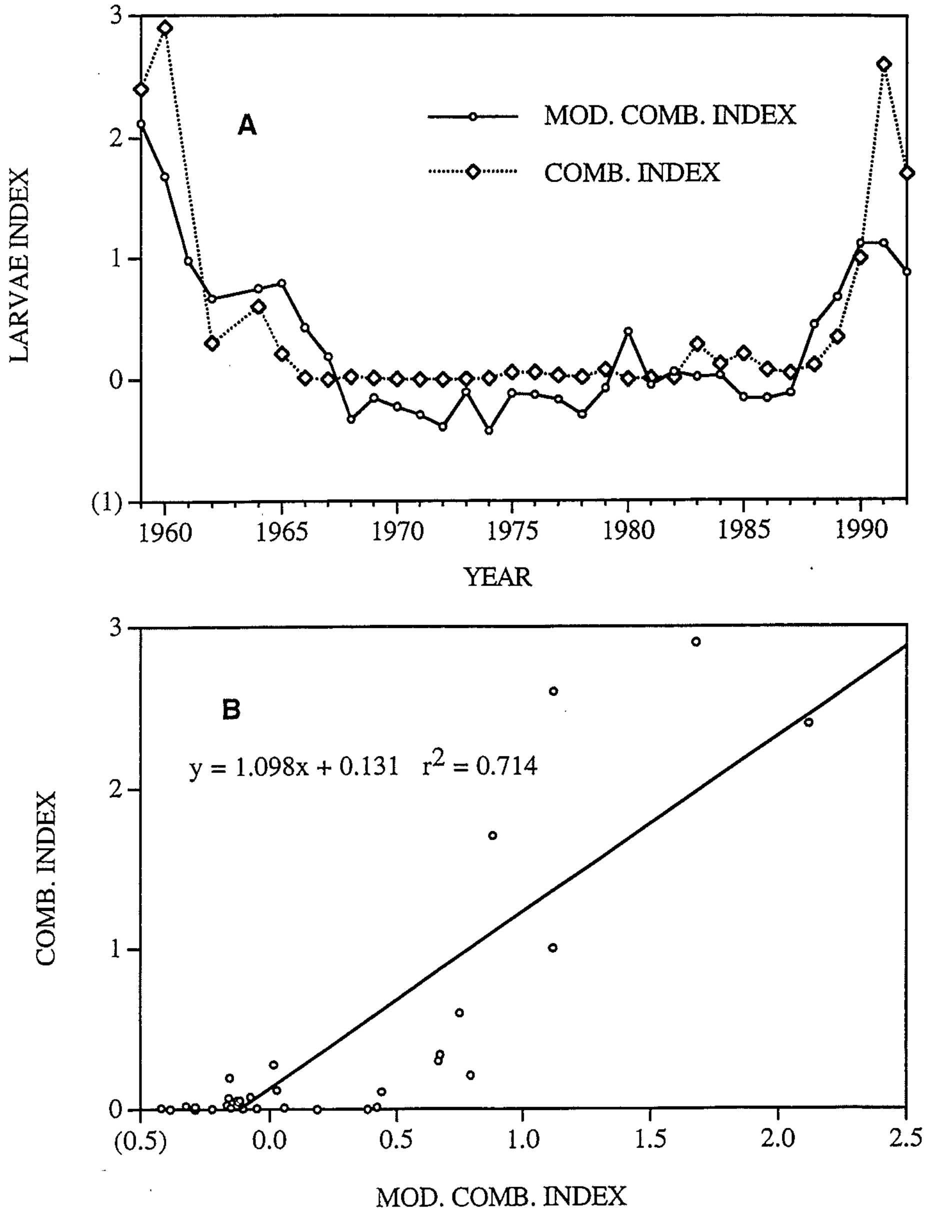

Figure 4. Comparisons (annual time series (A) and sscatter plot (B)) between measurements and empirical model for the abundance of Norwegian spring spawning herring.

This simple empirical model of the combined herring larvae index (Mod.Comb.ind.) and the actual combined index is presented in Figure 4. Clearly some of the variability is picked up, but the high index in 1960 and 1991 is not well simulated. Out of the 32 years with a combined index, only 5 are clearly above the standard error of estimate, and the cluster of all the years with an index close to zero is probably the reason for a relatively higher correlation than expected from just looking at the scatter diagram.

However, the two explainary variables are from a physical and biological point of view very reasonable. Strong and/or persistent winds from south to south-east will indeed favour an effective spread of the larvae northward on the continental shelf in agreement with our hypothesis and earlier postulated by Dragesund (1970). He also found that a widespread distribution of spawning and long duration of the spawning period seemed to give strong year-classes.

Using the same explainary variables for Russian and the Norwegian larvae index separately, gave the following results:

Russian: R^2=0.71 (0.69), St.Err.=0.48

Norwegian: $R^{2=}$0.45 (0.37), St.Err.=0.350

The equations above show that there is little correlation between the Norwegian index and the spawning stock size and wind stress. This is partly due to the fact that the Norwegian index series is much shorter (17 years), during this period the index was only significantly above the standard error of estimate in 1991 and 1992. Since the Russian index time-series is quite similar to the combined time-series, the empirical models for these also come out very similar.

The larvae indices produced above will of course depend on the time of sampling compared to the time of hatching, and for some years the Norwegian index is based only on one ship survey, while the Russian index is in general based on two coverages. In addition Knudsen and Bjørke (in prep.) have shown an avoidance of herring larvae larger than 10mm at daytime when comparing the catch of the T-80 with that of the Gulf sampler. The avoidance increased with larval length. However the sampling has in general been made at the same time of the year during more or less the same light conditions and this fact might have reduced the effect of avoidance. In addition, the sampling with the Gulf III was made from 1976 to 1984 and during this period the size of the spawning stock was rather low. Hence, we prefer to disregard these objections because spawning stock size and wind indices seems to be of major importance in the present material. There is a relatively large difference between the Russian and the Norwegian indices in 1990 and 1991 when the Norwegian estimates are significantly lower than the Russian. In 1990 most of the hatching had taken place in the period just before the survey period, and the samples was dominated by yolksac larvae. In 1991 hatching took place in the middle of March. The survey was carried out 3-4 weeks later, and it is possible that most of the larvae have been advected out of the sampling area (Fossum 1993).

It thus seems that if the larvae indices should be used to predict year-class strength it is important to make two surveys; both perhaps in April. The Russian surveys lasted each 4-5 days (Appendix II) and this sampling strategy seems to be adequate. Most probably indices based on sampling with a Gulf III sampler would fit better than those based on a dip net when the spawning stock is large.

3-group herring

The usefulness of the larvae indices depends on to what degree the amount or survival of larvae has a decisive effect on the year-class strength. This was tested out on the VPA (Virtual Population Analysis) time series for 3-group herring (Dommasnes *et al.* 1993). The resulting empirical model is:

$$\mathbf{Mod.Herr.(3) = -14914.307 + 3854.739{*}Comb.\ ind. {+} 3116.741{*}T_{Hust.-7.49\ Wind\ (300^\circ)}}$$

$$\mathbf{R^{2}{=}0.73\ (0.70),\ St.Err.{=}2710}$$

where $T_{Hust.}$ is the previously mentioned sea surface temperature at Hustadvika, and the number of 3-group herring (Herr.(3)) is given in millions of individuals. 56% of the variability is explained by the larvae index, 8% by the temperature and 6% by the wind. The intercomparison of this empirical model and the VPA timeseries is presented in Figure 5, where the time represents the year of birth. Again it is seen that this simple model describes a good part of the variability, but clearly there is an underestimate of the very important and relatively good 1983 year-class.

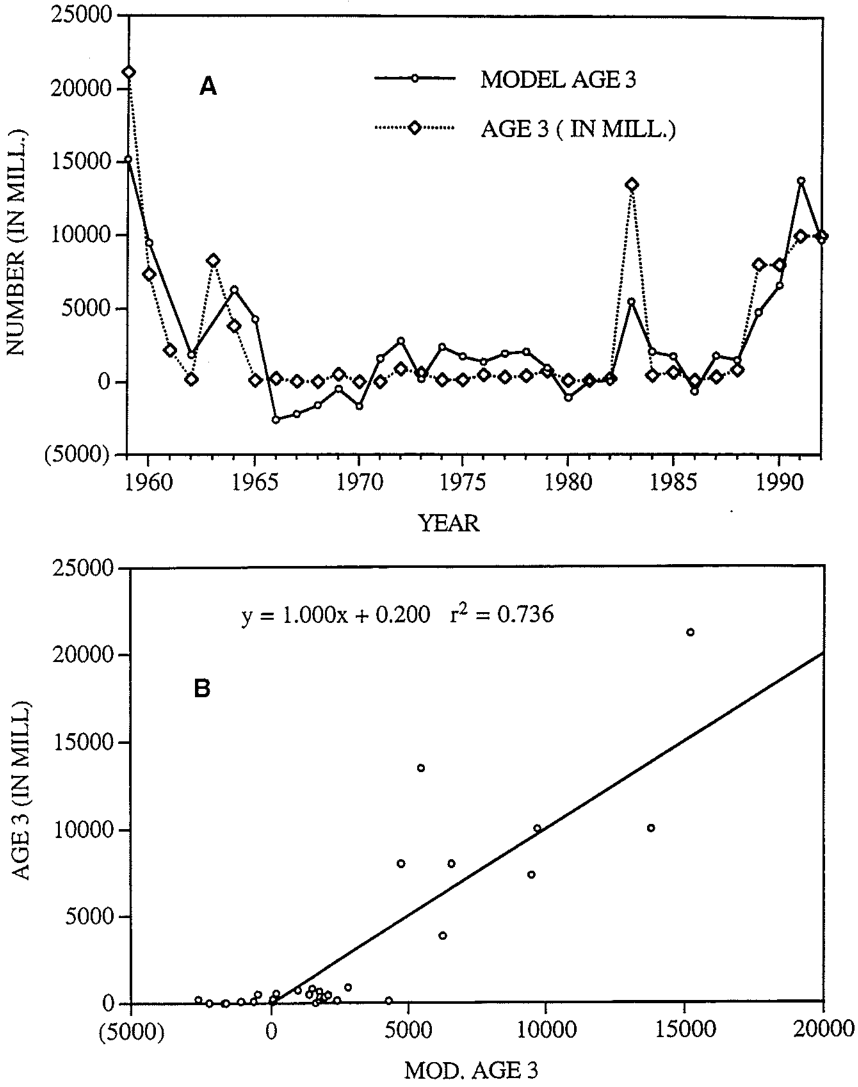

Figure 5. Comparisons (annual time series (A) and scatter plot (B)) between measurements and empirical model for the abundance of 3 year old Norwegian spring spawning herring.

This indicates that probably the measured larvae index for this year is underestimated, probably caused by avoidance of larger larvae. The negative effect of strong and/or persistent winds from northwest is also in agreement with the above hypothesis in the way that it restricts a rapid northeastward spread of larvae. These results indicate a 3 year predictive capability for the year-class strength of 3-group herring through continued monitoring of the larvae index time series, however we feel that more data from years with good recruitment/ strong year-classes is needed to confirm these results.

CONCLUSIONS

This paper clearly demonstrate a quantifiable relation between the abundance of spring spawning herring larvae (above the yolk sack stage) and the combined effect of the spawning stock size and favourable winds from south to southeast. The reason that temperature does not show up as an explainary variable is probably the positive correlation between southerly winds and relatively warm weather leading to relatively high sea temperatures.

The sampling of the larvae should preferably been done twice in April. The Russian surveys lasted each 4-5 days (Appendix 2) and this sampling strategy seems to be adequate. Most probably indices based on sampling with a Gulf III sampler would fit better than those based on a dip net when the spawning stock is increasing.

High abundance of these larvae together with warm ocean climate and reduced northwesterly winds during the early larval stage (April), seems to be the primary factors for producing a good year-class (and vice versa), and these results indicate therefor that the year-class strength (here represented by the number of 3-group herring) can be predicted roughly to within $\pm 3*10^9$ individuals. As in Svendsen *et al.* (1994) this predictive ability should have been tested by hiding some of the data and rerun the statistics. But due to the very few years available with larvae indices significantly above zero, such a test will be postponed until more data are available.

Our preliminary estimate for the numbers of 3 year old herring in 1994 and 1995 is $14*10^9$ and $9*10^9$ respectively, both with an uncertainty of $\pm 3*10^9$ individuals.

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REFERENCES

ANON. 1968. Smaller mesozooplankton. Report of Working Party No. 2. in: Tranter D. J. *Zooplankton sampling. (Monographs on oceanographic methodology 2.).* UNESCO, Paris, 153-159. 174 pp.

ANON. 1993. Report of the Atlanto-Scandian herring and capelin Working Group, Copenhagen 19-23 October 1992. *ICES CM 1993* /Assess:6: 74 pp.

BJØRKE, H., FOSSUM, P. and **SÆTRE, R.** 1986. Distribution, drift and condition of herring larvae off western Norway in 1985.*ICES CM 1986*/ H:39, 15 pp.

DEVOLD, F. 1963. The life history of the Atlanto-Scandian herring. *Rapp. P.-v. Reun. Cons. int. Explor. Mer. 154*:98-108.

DOMMASNES, A., RØTTINGEN, I. and **TANGEN, Ø.** 1993. Norwegian spring spawning herring input data to the virtual population analysis program. *Working paper to the ICES WG on herring and capelin, October 1993,* 5 pp..

DRAGESUND, O. 1970. Factors influencing year-class strength of Norwegian spring spawning herring. *FiskDir. Skr. Ser. HavUnders., 15*: 381-450.

DRAGESUND, O., HAMRE, J. and **ULLTANG, Ø.** 1980. Biology and population dynamics of the Norwegian spring spawning herring. *Rapp. P.-v. Reun. Cons. int. Explor. Mer, 177*: 43-71.

ELLERTSEN, B., SOLEMDAL, P., SUNDBY, S. and **TILSETH, S.** 1990. Environmental influence on recruitment and biomass yilds in the Norwegian Sea ecosystem. Pp. 19-35 in Sherman, K.,Alexander, L. M.,Gold, B. D. (eds.): *Large marine ecosystems: Patterns, processes and yields. Am. Assoc. Adv.Sci.* Washington, D. C., USA.

FOSSUM, P., BJØRKE, H. and **SÆTRE, R.** 1987. Distribution, drift and condition of herring larvae off western Norway in 1986. *ICES CM 1987/* H:34, 33 pp.

FOSSUM, P. 1993. A study of first feeding herring (*Clupea harengus* L.) larvae during the period 1985-1993. *ICES CM 1993/*H:21, 20 pp.

FOSSUM, P. and **MOKSNESS, E.** 1993. A study of spring- and autumn-spawned herring (*Clupea harengus* L.) larvae in the Norwegian Coastal Current during spring 1990. *Fish. Oceanogr., 2*: 73-81.

HEATH, M. R. 1992. Field investigations of the early life stages of marine fish. *Adv. Mar. Biol., 28*:1-174.

HJORT, J. 1914. Fluctuation in the great fisheries in northern Europe viewed in the light of biological research. *Rapp. P.-v.Reun.Cons.int.Explor.Mer, 20*: 1-228.

KRYSOV, A. I., MUKHINA, N. V. and **SELIVERSTOVA, E. I.** 1986. Spawning efficiency of Atlanto-Scandian herring in 1985.*ICES CM 1986/*H:36. 28 pp.

KRYSOV, A. I. and **ERGAKOVA, L. R.** 1990. Distribution and drift of Atlanto-Scandian herring larvae in Norwegian and Lofoten shallows in 1983-1987. Pp. 135-152 in Monstad, T. (ed.):*Biology and fisheries of the Norwegian spring spawning herring,* and blue whiting in the Northeast Atlantic. *Proceedings of the fourth Soviet-Norwegian Symposium, Bergen, 12-16 June 1989.* Institute of Marine Research, Bergen, Norway.

MARTI, Y. Y. 1961. Reasons for decrease of Atlanto-Scandian herring stocks. *Ryb.khoz. 12*: 12-17 (In Russian)

MIDTTUN, L. 1975. Observasjonsserier av overflatetemperatur og saltholdighet i norske kystfarvann 1936-1970. Observations series on surface temperatures and salinity in Norwegian coastal waters. *Fisken Hav. 1975 (Ser. B., 5)*: 1-55.

MOKSNESS, E. and **FOSSUM, P.** 1992. Daily growth rate and hatching-date distribution of Norwegian spring-spawning herring (*Clupea harengus*). *ICES J. mar. Sci. 49*: 217-221.

PAVSHTIKS, E. A. 1956. Seasonal variations in plankton and herring feeding migrations. *Trudy polyar. nauchno.-issled. Inst. morsk. ryb. Khoz. Okeanogr. 9*: 93-123. (In Russian)

RØTTINGEN, I. 1992. Recent migration routes of Norwegian spring spawning herring. *ICES CM 1992/* H:18, 10 pp.

SELIVERSTOV, A. S. and **PENIN, V. V.** 1969. On the velosity of herring larvae drift on spawning grounds in the West Scandia shelf area. *Trudy polyar. nauchno.-issled. Inst. morsk. ryb. Khoz. Okeanogr.* 25: 60-90. (In Russian)

SELIVERSTOV, A. S. 1970. Velosity and direction of drifting of larval herring in the Norwegian shallow area in March-April 1968. *Mater. rybokhoz. issled. sev. Basseina. 16.* (In Russian)

SELIVERSTOV, A. S. 1971. Soviet investigations on the Atlanto-Scandian herring in the Norwegian Sea in 1970. *ICES CM 1979/*H:12, 7 pp.

SELIVERSTOV, A. S. 1974. Vertical migration of larvae of the Atlanto-Scandian herring (*Clupea harengus* L.). Pp. 253-262 in Blaxter, J. H. S. (ed.): *The early life history of fish.* Springer-Verlag, Berlin, Heidelberg, New York. 765 pp.

SELIVERSTOVA, E. I. 1983. Efficiency of Atlanto-Scandian herring in 1973-77, 1980. Pp. 37-51 in: *Biology and fishery of pelagic fishes of Northern basin,* PINRO, Murmansk. (In Russian)

SOLEIM, P. A. 1942. Årsaker til rike og fattige årganger av sild. *FiskDir. Skr. Ser. HavUnders., 7(2)*:1-39.

SUNDBY, S. V. 1. 1982. Investigations in Vestfjorden 1978. 1 Fresh water budget and wind conditions. *Fisken Hav., 1982 (1)*: 1-30.

SVENDSEN, E., AGLEN, A., IVERSEN, S. A., SKAGEN, D. W. and **SMESTAD, O.** 1992. Influence of climate on recruitment and migration of fish stocks in the North Sea. *ICES CM 1992/*H:22, 18 pp.

SVENDSEN, E., AGLEN, A., IVERSEN, S. A., SKAGEN, D. W. and **SMESTAD, O. M.** 1995. Influence of climate on recruitment and migration of fish stocks in the North Sea. *Can. J. Fish. Aquat. Sci.* (in press).

SÆTERSDAL, G. and **LOENG, H.** 1987. Ecological adaption of reproduction in Northeast Arctic cod. *Fish. Res., 5*: 253-270.

SÆTRE, R., BJØRKE, H. and **FOSSUM, P.** 1988. Distribution, drift and condition of herring larvae off western Norway in 1987. *ICES CM 1988*/H:14, 13 pp.

WESTGÅRD, T., CHRISTIANSEN, A. and **KNUTSEN, T.** 1988. FORSKERKART. EDB-presentasjon av marine data. *Havforskningsinstituttets Egg- og Larveprogram (Help) 1988 (17):* 25 pp. (In Norwegian)

WILKINSON, L. 1989. *SYSTAT: The system for Statistics. Evanston. IL:* (SYSTAT. Inc)

YUDANOV, I. G. 1962. Investigation concerning spawning grounds of the Atlanto-Scandian herring. *Trudy polyar. nauchno.-issled. Inst. morsk. ryb. Khoz. Okeanogr*, 14:15-48. (In Russian)

ZIJLSTRA, J. J. 1970. Herring larvae in the central North Sea. *Ber. Dt. Wiss. Komm. Meeresforsch., 21*: 92-115.

APPENDIX I. Sampling period, number of samples, type of sampler used and main heading of sampling of the Norwegian material. A, B and C indicate coverages of the sampling area.

YEAR	SAMPLING PERIOD	NOS. OF SAMPLES	GEAR	HEADING
1976A	0504 - 1004	60	GULF III	S
1976B	2204 - 3004	74	GULF III	N
1977A	1304 - 2204	129	GULF III	N
1977B	2404 - 2504	14	GULF III	S
1978A	0204 - 1204	125	GULF III	N
1978B	1604 - 2404	126	GULF III	N
1979A	2703 - 0704	146	GULF III	S
1979B	1804 - 2904	148	GULF III	N
1980A	2403 - 3103	103	GULF III	S
1980B	1004 - 2004	148	GULF III	N
1980C	2204 - 2904	125	GULF III	N
1981A	0404 - 1304	100	GULF III	S
1981B	2204 - 2904	145	GULF III	N
1982A	0204 - 0604	59	GULF III	S
1982B	1404 - 2404	103	GULF III	N
1983A	0604 - 0604	10	GULF III	N
1983B	1404 - 2104	103	GULF III	S
1984A	1004 - 1704	113	GULF III	S
1984B	2404 - 3004	95	GULF III	N
1985A	1004 - 1604	128	T-80	S
1985B				
1986A	2903 - 0704	130	T-80	N
1986B	0904 - 1804	166	T-80	S
1987A	2803 - 0704	171	T-80	N
1987B	0904 - 2004	94	T-80	N
1988A	2503 - 0404	173	T-80	N
1988B	1904 - 2604	167	T-80	N
1989A	1903 - 2803	203	T-80	N
1989B	0104 - 1604	244	T-80	N
1990A	3003 - 1004	140	T-80	N
1990B				
1991A	0304 - 1404	120	T-80	N
1991B	0704 - 1304	42	T-80	N/S
1992A	1303 - 0904	118	T-80	N
1992B	1304 - 1704	15	T-80	N/S
Total number of samples		3837		

APPENDIX II. Sampling period, number of samples, type of samplers used and main heading of sampling of the Russian material. A and B indicate coverages of the sampling area.

YEAR	SAMPLING PERIOD	NOS. OF SAMPLES	GEAR	HEADING
1959A	0204 - 0404	7	IKS	N
1959B	1704 - 2004	23	IKS	N
1960A	2703 - 3103	40	IKS	N
1960B			IKS	N
1961A	2403 - 0404	40	IKS	N
1961B	0404 - 2504	49	IKS	N
1962A	0404 - 0704	29	IKS	N
1962B	2204 - 2504	23	IKS	N
1963A				
1963B				
1964A	2003 - 2403	25	IKS	N
1964B	1304 - 1804	24	IKS	N
1965A	2703 - 0204	27	IKS	N
1965B	1404 - 1904	27	IKS	N
1966A	1403 - 2003	26	IKS	N
1966B	0804 - 1304	29	IKS	N
1967A	2003 - 2703	32	IKS	N
1967B	0904 - 1604	31	IKS	N
1968A	1803 - 2303	26	IKS	N
1968B	0804 - 1704	41	IKS	N
1969A	2503 - 0204	37	IKS	N
1969B	0304 - 1504	47	IKS	N
1970A	2003 - 2903	32	IKS	N
1970B	0204 - 0704	28	IKS	N
1971A				
1971B				
1972A	0304 - 1004	30	IKS	N
1972B	1404 - 2204	37	IKS	N
1973A	0804 - 1204	31	IKS	N
1973B	1504 - 2004	31	IKS	N
1974A	0804 - 1304	31	IKS	N
1974B	1704 - 2004	25	IKS	N
1975A	1004 - 1504	25	IKS	N
1975B	1804 - 2204	31	IKS	N
1976A	0504 - 0904	31	IKS	N
1976B	1504 - 1904	31	IKS	N
1977A	0404 - 1004	31	IKS	N
1977B	1504 - 1904	31	IKS	N
1978A				
1978B				
1979A				
1979B				
1980A	0404 - 0904	31	IKS	N
1980B	1104 - 1504	31	IKS	N
1981A				
1981B				
1982A				
1982B				
1983A	1904 - 2404	31	IKS	N
1983B	2604 - 3004	30	IKS	N
1984A	0104 - 0604	31	IKS	N
1984B	1204 - 2004	32	IKS	N
1985A	0104 - 0604	33	IKS	N
1985B	1004 - 1504	33	IKS	N
1986A	0504 - 1104	34	IKS	N
1986B	1704 - 2604	34	IKS	N
1987A	1803 - 2503	43	IKS	N
1987B	0204 - 1004	43	IKS	N
1988A	1104 - 1804	28	IKS	N
1988B	1904 - 2604	30	IKS	N
1989A	2103 - 2503	23	IKS	N
1989B	0704 - 1704	51	IKS	N
1990A	1004 - 1504	30	IKS	N
1991A	2803 - 0304	32	IKS	N
1991B	0504 - 1304	48	IKS	N
Total number of samples		1656		

DISTRIBUTION OF CAPELIN DURING THE FIRST YEAR OF LIFE IN THE BARENTS SEA, IN THE PERIOD 1981-1991

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ABSTRACT

This study describes the distribution of larval and 0-group capelin (*Mallotus villosus*) in the Barents Sea during the period from 1981 to 1991, and is based on observations in June and August/September. The distribution of larval and 0-group capelin fluctuated and showed periodical trends; 1981-1985, 1986-1988, and 1989-1991. In 1981-1985 the distribution was characterised by a displacement of the distribution centre towards the central and western part of the Barents Sea. In 1986-1991 the distribution was located in the eastern part of the Barents Sea. In 1986-1988 observations were sparse, but the majority of the capelin seemed to be located east of 26°E. This was probably due to the collapse of the capelin stock. In 1989-1991 the capelin were widely distributed in the Barents Sea, but the main distribution of capelin was centred towards the east during these three years. The distribution of capelin spawning localities may be affected by the distribution of maturing stock during the autumn and the winter as well as climatic conditions, circulatory patterns of the water masses on the bank areas off the coast of northern Norway and area-selective mortality.

INTRODUCTION

Capelin is a circumpolar salmonoid fish, which is distributed in the northern hemisphere (Jangaard 1974). The distribution of capelin changes from year to year and the distribution seem to be related to climatic factors. Adult capelin is mostly distributed in waters with a temperature between -1°C- 2°C (Loeng *et al.* 1983). When the temperatures in the Barents Sea decrease adult capelin seems to move towards the western, warmer waters of the Barents Sea, while it moves towards the eastern, colder parts when temperatures increase (Loeng *et al.* 1983; Luka & Ponomarenko 1983; Dommasnes & Røttingen 1985; Loeng 1989a, b; Gjøsæter 1992b, unpubl.). Capelin make spawning migrations during the winter to the Finnmark and Murman coastlines. It seems obvious that the distribution of the maturing stock of capelin prior to the spawning affect the spawning localities, and therefore the resultant larval distribution. However, previous investigations have indicated no clear-cut relationship between the distribution of the adult stock and the larvae. Other factors than the parental stock

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Hylen, A. editor 1995. Proceedings of the sixth IMR-PINRO symposium, Bergen, 14-17 June 1994.
Institute of Marine Research, Bergen, Norway. ISBN 82-7461-039-3.

distribution may therefore be of importance for the larval and 0-group capelin distribution. Such factors may be the inflow of Atlantic water to the Barents Sea (Ådlandsvik 1989; Loeng *et al.* 1991; Ådlandsvik and Loeng 1991; Skjoldal *et al.* 1992), general hydrographic conditions including the circulatory pattern on the bank areas off Troms and western Finnmark (Bjørke and Sundby 1984, 1987), area selective mortality due to predation from cod, herring and haddock (Antipova *et al.* 1980; Moksness and Øiestad 1987; Mehl 1989; Thorisson 1989; Bogstad and Mehl 1992; Helle 1994), and capelin stock size fluctuations (Sætersdal and Loeng 1987; Mehl 1989; Hamre 1991; Bogstad and Tjelmeland 1992).

Changes in the distribution of capelin may affect the year class strength, according to Gjøsæter (1972). Abundance estimates made at larval and 0-group stages indicate the state of a stock in the following years. Short lived species such as capelin, are difficult to assess. Few capelin spawn more than once, the majority dying after spawning (Friðgeirsson 1976). This might be critical if recruitment fails. Knowledge about the early life stages of short lived species is therefore essential if we are wanting to predict stock development.

The aim of this study was to describe changes in distribution of larval and 0-group capelin during 1981-1991, based on catch observations from annual surveys. The descriptions are based on catch results and abundance indices describing the relative amount of capelin in the western part of the Barents Sea. The results will be discussed in the light of climate, hydrography, interactions with other species, and the overall capelin stock situation.

MATERIALS AND METHODS

Larval capelin have been surveyed each year in June since 1981, by the Institute of Marine Research, Bergen. The aims of this annual survey are to study the distribution and abundance of larval capelin 1-2 months after hatching. Sampling of larval capelin has been conducted with a high speed plankton sampler; Gulf-III (Zijlstra 1971), in the upper 60m of the water column. Standard procedures for sampling capelin larvae in the Barents Sea and how to calculate the abundance based on the number of larval capelin per unit sampled area are described by Alvheim (1985). Larval densities at the sampling station are integrated over the whole distribution area, yielding an abundance estimate. Such estimates for 1981-1991 were published by Fossum (1992).

0-group fish surveys in the Barents Sea have been conducted in August-September since 1965, as joint Russian/Norwegian multiship cruises. The surveys are of 3-5 weeks duration, with five vessels sampling in different, overlapping routes. The aims of the surveys are to observe the distribution of 0-group fish, and to determine year-class strength of the 0-group stage of commercial species in the Barents Sea and adjacent waters (Dragesund, Midthun and Olsen 1970). 0-group fish are sampled using a pelagic trawl, which was originally a commercial trawl for capelin fisheries ('Harstadtrål'). This trawl was described by Godø, Valdemarsen and Engås (1993). The standard procedures for trawling is described by Randa (1981) and Anon. (1983). Sampling has been conducted in the upper 60m of the water column. Supplementary trawling down to 80m is conducted when the echo registrations show layers of 0-group fish deeper than 60m. Data of geographical distribution of 0-group capelin is given by Anon. (1984, 1985, 1986a, 1986b, 1986c, 1986d, 1987, 1988, 1989, 1990, 1991).

Some uncertainty concerning the catch results of 0-group capelin exists. In August/September, capelin, at a length of 50-70mm, is threadlike and appears as a postlarvae. According to Vesin *et al.* (1981), the capelin metamorphorize at a length of 75mm. The capelin tends to stick to the trawl meshes, and in bad weather some of the 0-group capelin may be lost when hauling the trawl. Due to this, abundance estimates for 0-group capelin have not been published. This must be considered when analysing data collected.

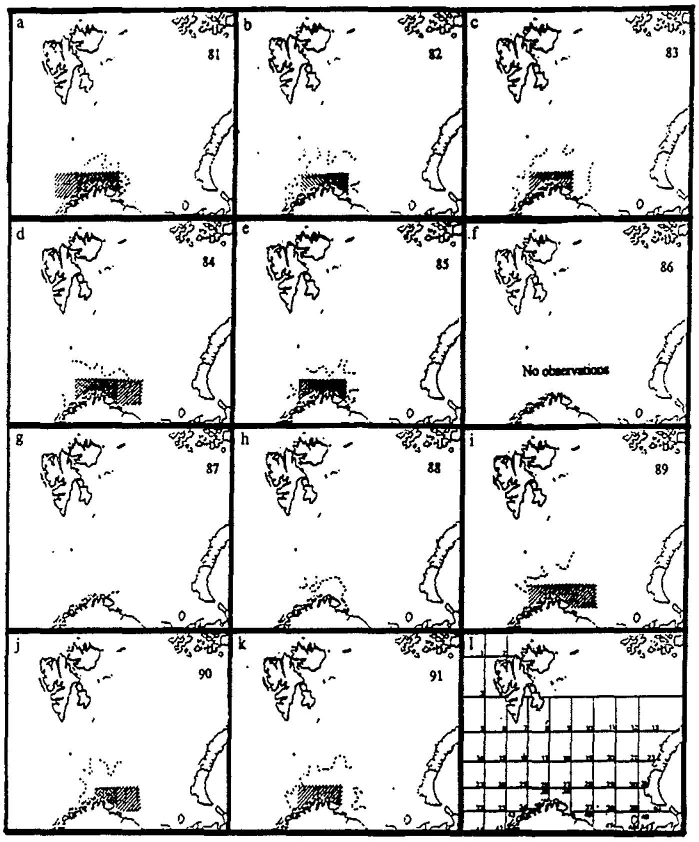

Figure 1. a-k) Distribution of larval capelin during the years 1981-1991. Broken lines indicate the total area of distribution, hatched areas: 10^{12} - $5*10^{12}$ larvae pr unit sampled area. Double hatched areas > $5*10^{12}$ larvae pr unit sampled area. l) The gridline system developed as a basis for distribution analysis.

To describe the distribution of larval and 0-group capelin in a simple, uniform way, a gridline system was devised for the Barents Sea, covering the station registrations of both larval and 0-group capelin (Figure 1 and 2). Local abundance estimates were calculated for each square. These estimates (SI_i) were calculated as the average estimated capelin density (D_i) at the sampling stations,within the square, multiplied with the area of the square (A_i). In cases where the zero-line of the capelin distribution trasected a square, only the area of the part of the square containing capelin was considered when calculating SI_i. The subscript i refers to the square number.

$$SI_i = A_i * D_i$$

The estimates served as a basis for further analyses. To obtain a total abundance index of 0-group capelin, the estimates were summarized each year. A measure for the degree of western distribution was obtained by summarizing the local indices located to the west of a north to south border. This border was located at 26°E for larval capelin. For 0-group capelin, two borders were used; 26°E and 32°E. The purpose for this was to split the potential area of distribution in the middle, and to get an impression of the transport of capelin from the larval to the 0-group stage. The relative density of capelin larvae and 0-group in the western part of the Barents Sea, D_{LW} and D_{0W}, was calculated as the estimated amount in the western part divided by the total amount:

$$D_{LW}= L_W /(L_W + L_E) \quad \text{and} \quad D_{0W} = 0_W /(0_W + 0_E)$$

where L and 0 denotes larvae and 0-group, and W and E denotes the western and eastern area.

The relative amount of capelin served as the following classification of western, central and eastern areas:

$D < 0.40$	eastern distribution
$D \in 0.40<D<0.60$	central distribution
$D > 0.60$	western distribution

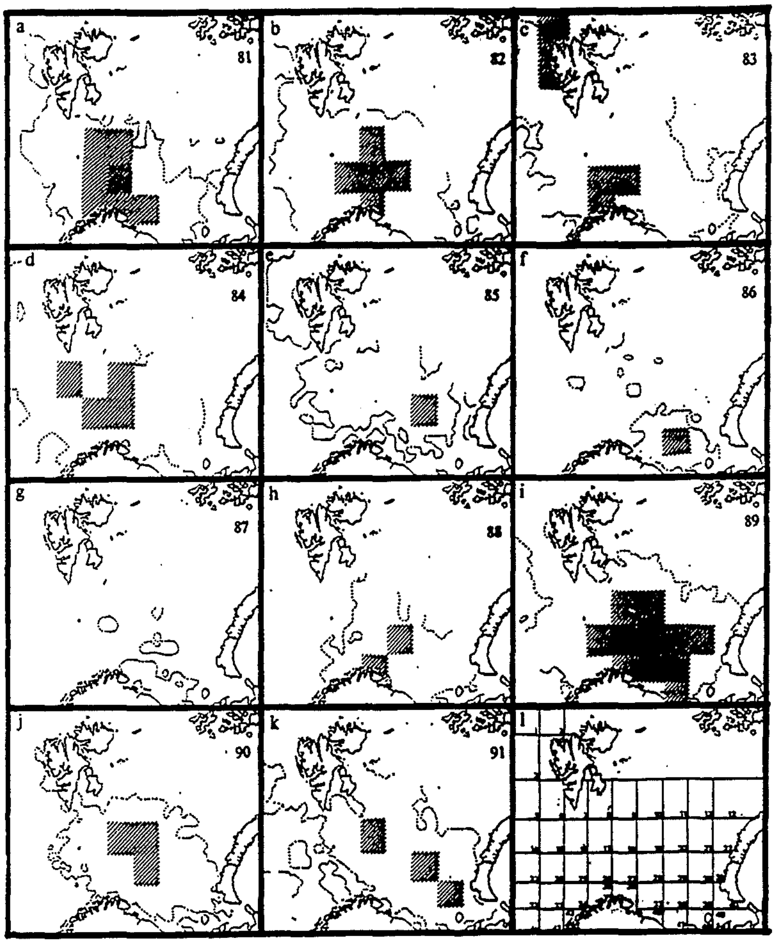

Figure 2. a-k) Distribution of 0-group capelin during the years 1981-1991. Broken lines indicate the total area of distribution, hatched areas: 10^{14} - $5*10^{14}$ caplin caught. Double hatched areas > $5*10^{14}$ caplin caught. l) The gridline system developed as a basis dfr distribution analysis.

RESULTS

The larval and 0-group capelin distribution during the years 1981-1991 indicated periodical trends at both stages (Figures 1, 2 3, Table 1). During 1981-1985 only slight variations in the total area of distribution were observed. Capelin were widely distributed, with only a small degree of varying localization of the main concentrations. Both stages were characterized by considerable amounts of capelin in the western part of the Barents Sea, and west of Svalbard.

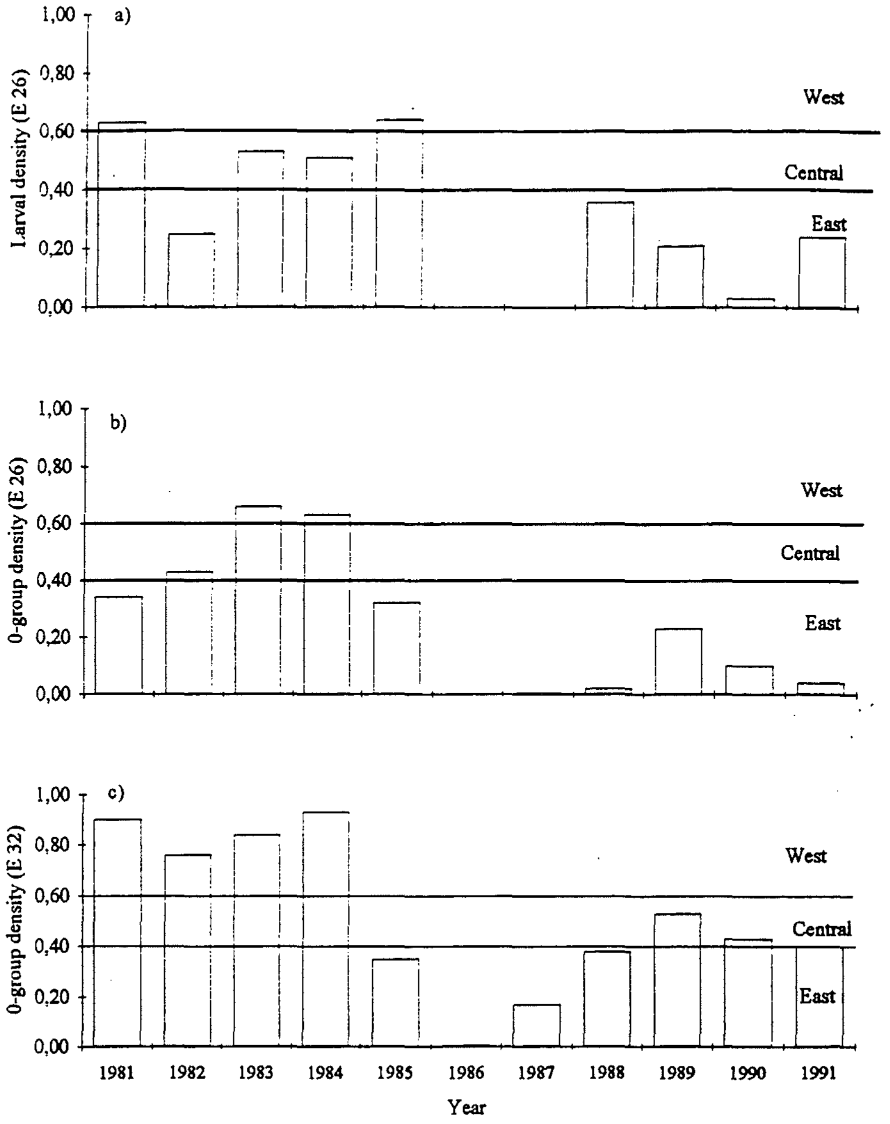

Figure 3. A parameter describing the part of the larval (a) and 0group (b and c) capelin located in the west. The chistogramme show the part of the annual amount of capelin located to the west of the 32°E longitude.

The years 1986-1988 were characterized by small amounts of larval and 0-group capelin. In 1986 no larvae were observed in the larval survey, but scarce observations were made in connection with other survey activities later in the summer, according to Solemdal and Bratland (1987). In both years larval capelin were located in the Varanger Fjord. At the 0-group stage most of the observations were made east of 32°E. In 1988 a change in distribution appeared, the year being characterized as a transitional year. The larval distribution seemed to become wider and more like the situation during the early eighties, while 0-group capelin were still observed mainly in the eastern part of the Barents Sea (Table 1).

Table 1. Relative amount of capelin in the western part of the Barents Sea at the larval and 0-group stage during 1981-1991.

	Larvae	0-group	
Year	26 °E	26°E	32°E
1981	0.63	0.34	0.90
1982	0.25	0.43	0.76
1983	0.53	0.66	0.84
1984	0.51	0.63	0.93
1985	0.64	0.32	0.35
1986	-	0.00	0.004
1987	0.00	0.003	0.17
1988	0.36	0.02	0.38
1989	0.21	0.23	0.53
1990	0.03	0.10	0.43
1991	0.24	0.04	0.40

The total area of distribution during the last three years of the investigated period, 1989-1991, was wide. The situation was quite like the years 1981-1985, but there were larger variations in the localization of high concentrations from one year to another. The larvae were mainly observed east of 26°E (Figures 1 i-k, 3a, Table 1), while 0-group capelin were located in the central to eastern part of the Barents Sea, the centres of distribution having moved towards the east during the three years. During all of the three years 0-group capelin were observed west of Svalbard (Figures 2i-k, 3b,c, Table 1).

Capelin larvae did not occur only in the western part of the coastline. The larval distribution indicated that spawning probably occurred over the greater parts of the Finnmark and Murman coastlines with a displacement towards the west in some years. The relative amount of 0-group capelin in the western part of the Barents Sea (border 32°E) showed the same pattern as the larval parameter, but greater differences between west and east were noted.

Comparison of the relative amount of larval and 0-group capelin in the western part of the Barents Sea (border 26°E) indicated that the transport may vary, being directed westwards in 1982-1985, 1990 and eastwards in 1988, 1989, 1991 in the Barents Sea.

DISCUSSION

Changes of larval and 0-group capelin distribution were observed during 1981-1991. During the years 1981-1985 the capelin were widely distributed at both stages, the main concentrations being gradually displaced towards the western part of the Barents Sea. Temperatures increased during these years (Loeng 1991). It was therefore expected that the mature capelin would spawn further east as the years progressed, and the distribution of overwintering maturing capelin would actually be displaced towards the eastern part of the Barents Sea Dommasnes and Røttingen 1985; Gjøsæter (1992, unpubl.). However, the larval capelin were observed in the western part of the coastlines during all of the years. Similar observations were made by Dragesund *et al.* (1973); a western-central spawning in years having easterly distributed parental stock.

The unexpected results may be explained by several factors. During the years 1981-1985 strong year classes of cod, haddock and herring occurred in the Barents Sea (Sætersdal and

Loeng 1987; Røttingen 1990). Particularly the 1983-year class of all species was strong (Anon. 1986b). This may have led to a considerable area-selective mortality on capelin due to predation (Beltestad *et al.* 1975; Antipova *et al.* 1980; Moksness and Øiestad 1987; Mehl 1989; Bogstad and Mehl 1992 and Helle 1993).

The dispersion of larval capelin in the Barents Sea may have been influenced by the circulatory patterns of the bank areas outside Troms as described for cod larvae (Bjørke and Sundby 1984, 1987). This may explain the considerable amount of capelin west of Svalbard during 1981-1985, having influenced the distribution parameter describing the relative amount of capelin in the western part of the Barents Sea. This may also explain the seemingly westward directed transport in some of the years of the period. For the years having a western distribution at the 0-group stage, capelin was observed west of Svalbard. In 1983, particularly high concentrations of 0-group capelin were observed in this area. This may have contributed to the stock collapsing a few years later, because in years when considerable amounts of capelin west of Svalbard are observed weak year classes of capelin are produced (Gjøsæter 1972).

The apparent eastward displacement of capelin in 1986-1987 was not expected due to the cooling of water masses in the Barents Sea (Loeng 1991). However, the total area of distribution markedly decreased, and the observations may explain the collapse of the capelin stock in 1986 (Hamre 1991).

The main concentrations of larval and 0-group capelin were located in the eastern part of the Barents Sea in 1989-1991. However, the total area of distribution widened considerably in 1988. The results indicate a western dispersion in 1989-1991, when compared to the years 1986-1988. This is probably explained by the rebuilding of the capelin stock after the collapse in 1986 (Hamre 1991). It may also be due to the fact that herring were again abundant in the Barents Sea after some years from 1986 to 1988 when they were scarce (Anon. 1986d, 1987, 1988, 1989, 1990, 1991). In 1985, low abundance of 0-group capelin were observed near the coastlines of Northern Norway and Russia when amounts of herring at the 0-, 1- and 2-group stage were observed (Røttingen 1990). No definite trends in fluctuations of first year capelin distribution related to climate were observed during the period 1981-1988, probably due to interactions with other species causing area-selective mortality in the early 1980's, and the capelin stock collapsing in 1986. In 1989, the temperatures rose considerably and the inflowing activity of the Atlantic water to the Barents Sea was high (Ådlandsvik 1989; Loeng *et al.* 1991; Ådlandsvik and Loeng 1991 Skjoldal *et al.* 1992). During the following years, the main concentrations of 0-group capelin moved towards the east. These results seem to confirm earlier observations that capelin respond to climatic changes and that this response is delayed by one to two years (Ozhigin and Luka 1985).

In 1989, 0-group capelin were observed in large quantities over great parts of the Barents Sea. This was unexpected due to relatively few observations at the larval stage. The year class of 0-group herring was strong, being widely distributed in the Barents Sea and overlapping with the distribution of 0-group capelin (Anon. 1989). However, the inflowing water may have transported high concentrations of zooplankton into the Barents Sea from the Norwegian Sea, as in 1982 according to Skjoldal and Rey (1989). This may have supplied both capelin and herring with sufficient food.

CONCLUSIONS

- The distribution of larval and 0-group capelin fluctuated during the investigated period, showing periodical trends of 1981-1985, 1986-1988 and 1989-1991.

- During the years 1981-1985, capelin were widely distributed at both stages, mainly in the western part of the Barents Sea. In 1986-1987 there was an eastward displacement of capelin distribution at both stges, while the capelin distribution moved towards the west in 1988. The distribution of capelin was more extensive in 1989-1991 with the main concentrations moving in the central to the eastern part of the Barents Sea.

- The dispersion of larval capelin in the Barents Sea may have been influenced by the circulatory patterns on the bank areas outside northern Norway which may explain the considerable amount of capelin west of Svalbard. This may also explain the seemingly westward-directed transport in some years during the period 1981-1991.

- The high amounts of 0-group capelin observed off Svalbard in 1983 may have influenced the stock situation of Barents Sea capelin the following years, as years having considerable amount of capelin west of Svalbard appear never to produce strong year classes of capelin. The stock collapsed in 1986.

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REFERENCES

ALVHEIM, O. 1985. Investigations on capelin off Northern Norway and in the Barents Sea in 1981-1984 Pp. 171-183 in Gjøsæter, H. (ed.): *The Proceedings of the Soviet-Norwegian Symposium on the Barents Sea Capelin. Bergen, 14-17 August 1984.* Institute of Marine Research, Bergen, Norway.

ANON. 1983. Preliminary report of the international 0-group Fish survey in the Barents Sea and adjacent waters in August-September 1980. *Annls. Biol., Copenh. 37*: 259-266.

ANON. 1984. Preliminary report of the international 0-group Fish survey in the Barents Sea and adjacent waters in August-September 1981. *Annls biol., Copenh. 38*: 228-236.

ANON. 1985. Preliminary report of the international 0-group Fish survey in the Barents Sea andadjacent waters in August-September 1985. *ICES CM 1985*/G:75, 27 pp.

ANON. 1986a. Preliminary report of the international 0-group Fish survey in the Barents Sea and adjacent waters in August-September 1982. *Annls biol., Copenh. 41*: 165-172.

ANON. 1986b. Preliminary report of the international 0-group Fish survey in the Barents Sea and adjacent waters in August-September 1983. *Annls biol., Copenh. 41*: 172-180.

ANON. 1986c. Preliminary report of the international 0-group Fish survey in the Barents Sea and adjacent waters in August-September 1984. *Annls biol., Copenh. 41*: 180-188.

ANON. 1986d. Preliminary report of the international 0-group Fish survey in the Barents Sea and adjacent waters in August-September 1986. *ICES CM 1986/ G*: 78, 27 pp.

ANON. 1987. Preliminary report of the international 0-group Fish survey in the Barents Sea and adjacent waters in August-September 1987. *ICES CM 1987*/G: 38, 31 pp.

ANON. 1988. Preliminary report of the international 0-group Fish survey in the Barents Sea and adjacent waters in August-September 1988. *ICES CM 1988*/G:45, 37 pp.

ANON. 1989. Preliminary report of the international 0-group Fish survey in the Barents Sea and adjacent waters in August-September 1989. *ICES CM 1989*/G:40, 40 pp.

ANON. 1990. Preliminary report of the international 0-group Fish survey in the Barents Sea and adjacent waters in August-September 1990. *ICES CM 1990*/G:46, 36 pp.

ANON. 1991. Preliminary report of the international 0-group Fish survey in the Barents Sea and adjacent waters in August-September 1991. *ICES CM 1991*/G:50, 33 pp.

ANTIPOVA, T.P., PONOMARENKO, I.Y. and **YARAGINA, N.A.** 1980. Seasonal and year-to-year dynamics of occurence frequency of the main food objects for haddock and their stomach fullness degree in the Barents Sea. *ICES CM 1980*/H:21, 28 pp.

BELTESTAD, A.K., NAKKEN, O. and **SMEDSTAD, O.M.** 1975. Investigations on dial vertical migration of 0-group fish in the Barents Sea. *FiskDir. Skr. Ser. HavUnders., 16*(7): 229-244.

BJØRKE, H. and **SUNDBY, S.** 1984. Distribution and abundance of post larval northeast Arctic cod and haddock. Pp. 72-99 in Godø, O. R. and Tilseth, S. (eds.): *The Proceedings of the Soviet-Norwegian Symposium on Reproduction and Recruitment of Arctic Cod, Leningrad, 26-30 Sept. 1983.* Institute of Marine Research, Bergen, Norway.

BJØRKE, H. 1987. Distribution and abundance of postlarval and 0-group cod. Pp.127-144 in Loeng, H. (ed.): *On the Effect of Oceanographic Conditions on Distribution and Population Dynamics of Commercial Fish Stocks. Proceedings of the Third Soviet-Norwegian Symposium on the Barents Sea, Murmansk, 26-28 May 1986.* Institute of Marine Research, Bergen, Norway.

BOGSTAD, B. and **MEHL, S.** 1992. The North-East Arctic cod stocks consumption of various prey species 1984-1989, pp. 59-72, in Bogstad, B. and Tjelmeland, S. (eds.): *Interrelations between fish populations in the Barents Sea. Proceedings of the fifth PINRO-IMR Symposium, Murmansk 12-16 August 1991.* Institute of Marine Research, Bergen, Norway.

BOGSTAD, B. and **TJELMELAND, S.** 1992. A method for estimation of predation mortalities on capelin using a cod-capelin model for the Barents Sea. Pp. 111-137 in Bogstad, B. and Tjelmeland, S. (eds.) *Proceedings of the fifth PINRO-IMR Symposium, on Interrelations Between Fish Populations in The Barents Sea, Murmansk 12-16 August 1991.* Institute of Marine Research, Bergen, Norway.

DOMMASNES, A. and **RØTTINGEN, I.** 1985. Acoustic stock measurements of the Barents Sea capelin 1972-1984. Pp. 45-108 in Gjøsæter, H. (ed.): *The Proceedings of the Soviet-Norwegian Symposium on the Barents Sea Capelin, Bergen, Norway, 14-17 August 1984.* Institute of Marine Research, Bergen, Norway.

DRAGESUND, O. and **NAKKEN, O.** 1973. Relationship of parent stock size and year-class strength in Norwegian spring spawning herring. *Rapp P.-v. Réun.Cons.int.Explor.Mer, 164*: 15-29.

DRAGESUND, O., J. GJØSÆTER, J. and **MONSTAD, T.** 1973. Estimates of stock size and reproduction of the Barents Sea capelin in 1970-1972. *FiskDir.Skr.ser.HavUnders., 16*: 105-139.

FOSSUM, P. 1992. The recovery of the Barents Sea Capelin (*Mallotus villosus*) from a larval point of view. *ICES J. Mar.Sci., 49:* 237-243.

FRIÐGEIRSSON, E. 1976. Observations on spawning behaviour and embryonic development of the Icelandic capelin. *Rit Fiskideildar, 5*(5): 1-33.

GODØ, O.R., VALDEMARSEN, J.W. and **ENGÅS, A.** 1993. Comparison of effeciency of standard and wcperimental juvenile gadoid sampling trawls. *ICES Mar.Sci.Symp. 196:* 196-20.

GJØSÆTER, J. 1972. Recruitment of the Barents Sea capelin 1951-1961. *ICES CM 1972*/H:24, 9 pp.

GJØSÆTER, H. 1992a. Pelagic fish and the ecological impact of modern fishing industry. Contribution to the symposium" Man and the Barents Sea Ecosystem", Groningen, The Netherlands, 19-20 November 1992, 28 pp.

GJØSÆTER, H. 1992b. Bestandsestimat og utbreiingskart for lodde 1972-1991. Unpubl., 40 pp. Institute of Marine Research, Bergen, Norway.(In Norwegian)

HAMRE, J. 1988. Some aspects of the interrelation between the herring in the Norwegian Sea and the stocks of capelin and cod in the Barents Sea. *ICES CM 1988*/H:42, 15 pp.

HAMRE, J. 1991. Interrelation between envronmental changes and fluctuating fish populations in the Barents Sea. Pp. 259-270 in Kawasaki, T., Tanaka, S., Toba, Y. and Tanaguchi, A. (eds.): *Long-term Variability of Pelagic Fish Populations and Their Environment. Proceedings of the international symposium, Sendal, Japan, 14-18 November 1989.* Pergamon Press, Oxford, UK.

HELLE, K. 1993. Distribution and abundance of early juvenile Arcto-Norwegian cod (*Gadus morhua* L.) in relation to water mass properties and prey abundance. Cand. Scient thesis in fisheries biology. University of Bergen, Department of Fisheries and Marine Biology, 116 pp.

HELLE, K. 1994. Distribution of early juvenile Arcto-Norwegian cod (*Gadus morhua* L.) in relation to food abundance and watermass properties. *ICES mar.Sci.Symp., 198*: 440-448.

JANGAARD, P.M. 1974. The capelin (*Mallotus villosus*). Biology, distribution, exploitation, utilization and composition. *Bull. Fish. Res. Bd. Can., 186*: 1-68.

LOENG, H. 1989a. Ecological features of the Barents Sea. Pp. 327-365 in Rey, L. and Alexander, V. (eds.): *Proceedings of the Sixth Conference of the Comite Arctique International, 13-15 May 1985.* E. J. Brill, Leiden.

LOENG, H. 1989b. The influence of temperature on some fish population parameters in the Barents Sea. *J. Northw. Atl. Fish., (Ser. 9)*:103-113.

LOENG, H. 1991. Features of the Physical Oceanographic Conditions of the Barents Sea. *Polar Research 10*(1):5-18.

LOENG, H., BLINDHEIM, J., ÅDLANDSVIK, B. and **OTTERSEN, G.** 1991. Climatic variability in the Norwegian and Barents Seas. ICES Variability Symposium, No. 4, Session 1, 19 pp.

LOENG, H., NAKKEN, O. and **RAKNES, A.** 1983. Loddas utbredelse i Barentshavet i forhold til temperaturfeltet i perioden 1974-1982. *Fisken Hav., 1*: 1-17. (In Norwegian, English abstract)

LOENG, H. and **SUNDBY, S.** 1985. Hydrography and climatology of the Barents Sea and the coastal waters of Northern Norway. Pp. 69-88 in Alton, M. (Compiler). *Proceedings of a Workshop on Comparative Biology, Assessment, and Management of Gadoids from the North Pacific and Atlantic Oceans.* U.S. Natl. Mar. Fish. Serv., Northwest and Alaska Fish. Cent., Seattle, WA.

LUKA, G.I. and **PONOMARENKO, V.P.** 1983. Seasonal and daily vertical migrations and structure of capelin concentrations in the Barents Sea. *ICES CM 1983*/H:27, 16 pp.

MEHL, S. 1989. The Northeast Arctic cod stock's consumption of commercially exploited prey species in 1984-1986. *Rapp. P.-v. Réun. Cons. int. Explor. Mer, 188*: 185-205.

MIDTTUN, L. and **LOENG, H.** 1987. Climatic Variationsin the Barents Sea. Pp. 13-27 in Loeng, H. (ed.): *The Effect of Oceanographic Conditions on Distribution and Population Dynamics of Commercial Fish Stocks in the Barents Sea, Proceedings of the Third Soviet-Norwegian Symposium, Murmansk, 26-28 May 1986.* Institute of Marine Research, Bergen, Norway.

OKSNESS, E. and **ØIESTAD, V.** 1987. Interaction of Norwegian spring-spawning herring larvae (*Clupea harengus*) and Barents Sea capelin (*Mallotus villosus*) in a mesocosm study. *J. Cons. int. Explor. Mer, 44*: 32-47.

OZHIGIN, V.K. and **LUKA, G.I.** 1985. Some Peculiarities of Capelin Migration Depending on Thermal Conditions in the Barents Sea. Pp. 135-148 in Gjøsæter, H. (ed.): *The Proceedings of the Soviet-Norwegian Symposium on the Barents Sea Capelin.Bergen-Norway, 14-17 August 1984.* Institute of Marine Research, Bergen, Norway.

RANDA, K. 1981. Rekrutteringsindeksar for Norsk-Arktisk torsk basert på materiale frå dei internasjonale 0-gruppe undersøkingane i Barentshavet. Hovedfagsoppgave i fiskeri-biologi, Institutt for fiskeribiologi, Universitetet i Bergen, hausten 1981. Pp.132. (In Norwegian)

RØTTINGEN, I. 1990. The 1983 year class of Norwegian spring spawning herring as juveniles and recruitment spawners. Pp. 165-203 in Monstad, T. (ed.): *Biology and Fisheries of the Norwegian Spring Spawning Herring and Blue Whiting in the Northeast Atlantic. Proceedings of the fourth Soviet-Norwegian Symposium. Bergen, 12-16 June, 1989.* Institute of Marine Reasearch, Bergen, Norway.

SKJOLDAL, H.R. and **REY, F.** 1989. Pelagic Production and Variability of the Barents Sea Ecosystem. Pp. 241-286 in Sherman, K. and Alexander, L. M. (eds.): *Selected Symposium on Biomass Yields and Geography of Large Marine Ecosystems. AAAS.*

SKJOLDAL, H.R., GJØSÆTER, H. and **LOENG, H.** 1992. The Barents Sea ecosystem in the 1980s: ocean climate, plankton and capelin growth. Pp. 217-238 in Bogstad, B. and Tjelmeland, S. (eds.): *Interrelations Between Fish Populations in The Barents Sea.* Proceedings of the fifth PINRO-IMR Symposium, Murmansk, 12-16 August 1991. Institute of Marine Research, Bergen, Norway.

SOLEMDAL, P. and **BRATLAND, P.** *1987. Klekkeforløpet for lodde i Varangerfjorden* 1986. Havforskningsinstituttets Egg- og Larve Program (HELP), 8 pp. (In Norwegian)

SÆTERSDAL, G. and **LOENG, H.** 1987. Ecological adaptions of reproduction in Northeast Arctic cod. *Fish.Res., 5*: 253-270.

THORISSON, K. 1989. The food of larvae and pelagic juveniles of cod (*Gadus morhua* L.) in the coastal waters west of Iceland. *Rapp. P.-v. Réun.Cons.int.Explor. Mer, 191:* 264-272.

ZIJLSTRA, J.J. 1971. Herring larvae in the central North Sea. *Ber.Dt. Wiss. Komm. Meeresforsch., 21*: 92-115.

VESIN, J-P., LEGGETT, W.C. and **ABLE, K.W.** 1981. Feeding ecology of capelin (*Mallotus villosus*) in the Estuary and Western Gulf of St. Lawrence and its multispecies implications. *Can. J. Fish. Aquat. Sci., 38*: 257-267.

ÅDLANDSVIK, B. 1989. Wind-driven variations in the Atlantic inflow to the Barents Sea. *ICES CM 1989*/C:18, 13 pp.

ÅDLANDSVIK, B. and **LOENG, H.** 1991. A study of the climatic system in the Barents Sea. *Polar Research, 10*(1): 45-49.

THE INABILITY OF THE 0-GROUP SAITHE SURVEY TO FORECAST THE STRENGTH OF THE YEAR-CLASSES ENTERING THE FISHERY

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ABSTRACT

An 0-group saithe trawl survey was conducted annually in the Norwegian Sea and outside the Norwegian coast north of 62°N in April-May 1985-1992. The survey aimed at covering the distribution of 0-group saithe in the open sea before the fish entered inshore waters. The yearclass strength of the saithe measured at this stage did not correspond to the strength of the yearclasses measured later when entering the fishery.

INTRODUCTION

One of the biggest problems in assessing the saithe stocks in the North Atlantic is the lack of good recruitment estimates. The 0-group saithe are very early distributed in the inshore waters and it is almost impossible to measure the abundance when the fish are close to the shore. After the saithe postlarvae have reached the sheltered inshore areas, and until becomming 2-4 years old, oldest in the northern part of Norway, the saithe mostly stay inshore. Above a minimum size the saithe are during this period, however, exposed to a considerable purse seine fishery.

Very little had previously been done on this subject. Damas (1909) described the distribution of fry and alevins of saithe off Møre. Wiborg (e.g., 1960), Dragesund and Hognestad (1966), and Bjørke (1983 and internal survey reports) described the occurrence of fish eggs and larvae in Norwegian coastal and offshore waters, but not at the appropriate time to measure the abundance of 0-group saithe. In 1985 a cruise was undertaken with the aim of measuring the abundance of postlarvae/0-group of the Northeast Arctic saithe before the main concentrations reached the shore (Nedreaas 1986). In 1986 the investigation was expanded to also cover the North Sea south to 58°N (Nedreaas and Smedstad 1987). This paper summarize the experience from the investigations north of 62°N in the time period 1985-1992.

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MATERIALS AND METHODS

Table 1 gives an overview of survey time, research vessel and number of pelagic trawl stations each year. Figure 1 which shows all pelagic trawl stations taken in 1989-1992, illustrates also the regular survey design used every year. Knowledge about spawning grounds of saithe, and a calculated drift of the larvae up to the beginning of the survey were decisive for where and when to start the survey.

Table 1. 0-group saithe survey north of 62°. Time of the survey each year, research vessels and nos. trawl stations.

Year	Survey period	Vessel	Nos. pelagic trawl stations
1985	11.05 - 31.05	R/V "Eldjarn"	148
1986	07.05 - 29.05	R/V "Håkon Mosby"	155
1987	07.05 - 30.05	R/V "Eldjarn"	165
1988	30.04 - 24.05	R/V "Eldjarn"	184
1989	30.04 - 27.05	R/V "Eldjarn"	171
1990	30.04 - 22.05	R/V "Eldjarn"	169
1991	30.04 - 25.05	R/V "G. O. Sars"	171
1992	28.04 - 15.05	R/V "G. O. Sars"	114
		R/V "Michael Sars"	66

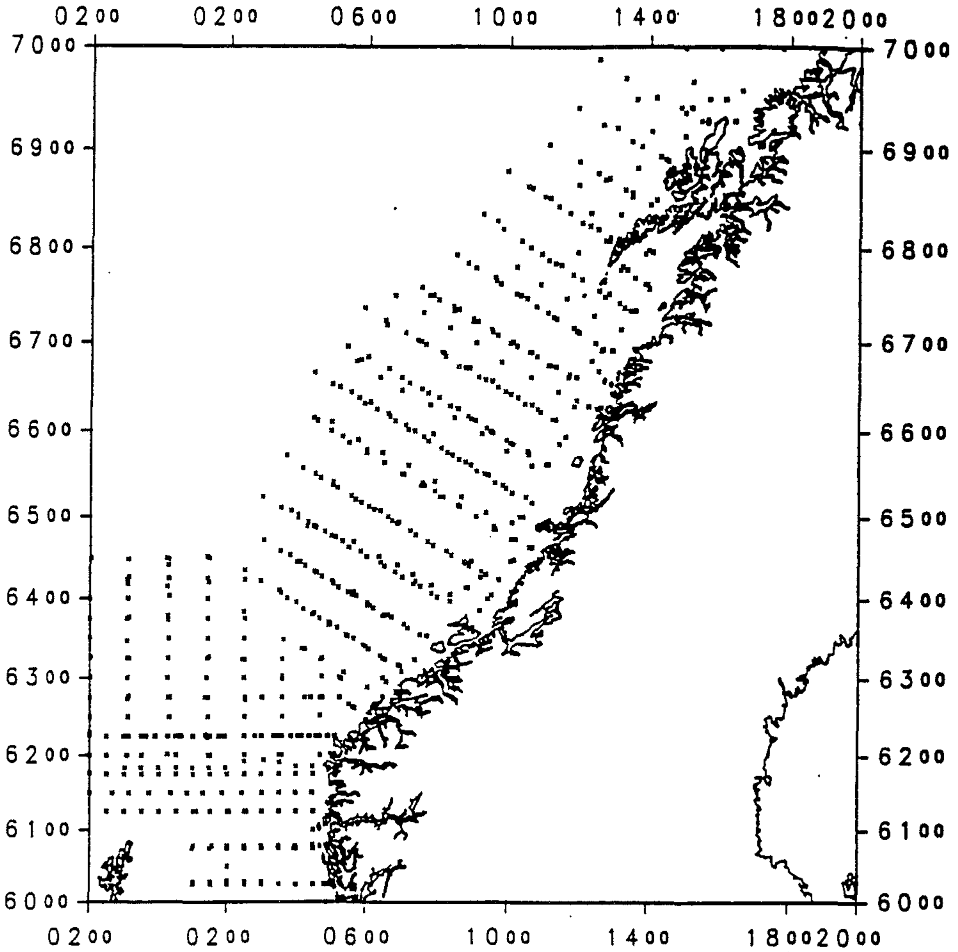

Figure 1. Pelagic trawl stations taken in 1989-1992 between 60°N and 70°N.

Some work was done to find the best sampling gear. The catch efficiency of Isaacs Kidd (9 m^2) and MOCNESS (1 m^2) midwater trawls were compared with the bigger midwater capelin trawl ("Harstad", 16x16 fathoms) possessing a 30 meter fine meshed (8 mm stretched mesh) cod-end.

The capelin trawl was towed with 3 knots for 0.5 n.m. with the headrope at the surface, then 0.5 n.m. at 20 meter, and 0.5 n.m. at 40 meters depth. Six 70" bladders were fastened to the headrope. The total towing distance became 1.5-1.8 n.m. Trawling was conducted both day and night.

The Isaacs Kidd trawl was lowered down to 60 meter, and the MOCNESS was hauled through 1000 m^3 seawater in each of the four depths 10, 20, 30, and 40 meters.

The capelin trawl turned out to be the most suitable gear for catching 2-3 mm saithe postlarvae of those three gears compared, and this trawl was therefore used as the standard gear in the subsequent years.

The catch was shaked or washed down in a tub with water and then filtered out. Afterwards the whole cod-end was thouroughly shaked and the remainder swept up from the deck. The entire catch was sorted, and the length of each fish species or category measured.

Vertical (height) and horizontal (distance between the trawl wings) distances of the trawl opening in front, as well as towing depth, were measured using SCANMAR sensors. Measurements of the trawl geometry were used to calculate the sea volume filtered by a standard trawl haul (V_1=area of the trawl opening times towed distance of 1.5 n.m.). An average trawl geometry for the whole survey was used in the index calculations.

The distance between survey tracks was usually 30 n.m., and between each trawl station it was usually 15 n.m. The trawl was assumed to fish down to approx. 55 meters depth (=0.0297 n.m.). The number of 0-group fish on each trawl station was therefore taken to be proportional to the actual number within a volume of 30x15x0.0297 n.m.^{3} (=V_2). Outside the main regular survey area, especially close to shore, the catches from more than one trawl station were averaged for a given volume differing from place to place. The abundance index (I) was then calculated by the formula:

$$I = \sum V_2/V_1 \times X_i = V_2/V_1 \sum X_i$$, where X_i is the number of 0-group saithe on station i.

RESULTS

The average horizontal distribution of 0-group saithe in 1985-1988 is shown in Figure 2. The figure has been constructed by putting together the catches from all stations taken in these four years, and deviding by the number of survey years. Figure 3 shows a similar figure for the time period 1989-1992.

The distributions seem to coincide with the 7°C isotherm, at least to some extent (Figure 4). Although the saithe spawn in Atlantic waters in February-March, the larvae and 0-group are already in April-May found in the upper 50-60 meters in coastal waters with salinity less than 35% (Figure 5 and 6).

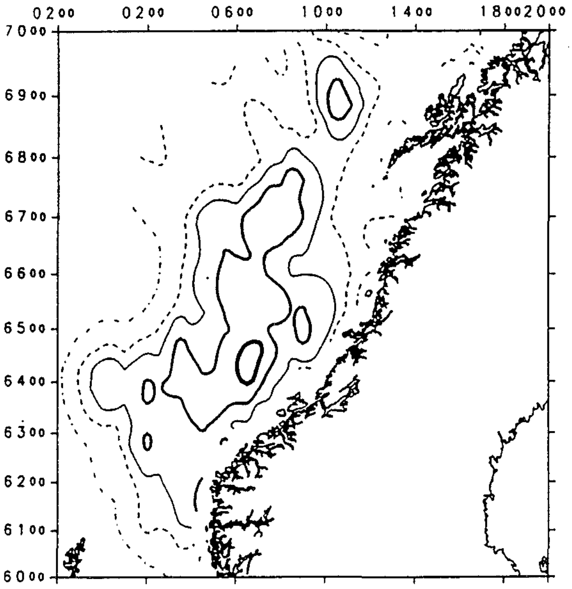

Figure 2. Distribution of 0-group saithe in 1985-1988. Isolines have been drawn for average number of saithe greater than 1 specimen/trawlhour (dotted/stripled line), 10 specimens/trawlhour (stipled line), 30 specimens/trawlhour (single solid line), 100 specimens/trawlhour (thick line), and more than 300 specimens/ trawlhour (extra thick line).

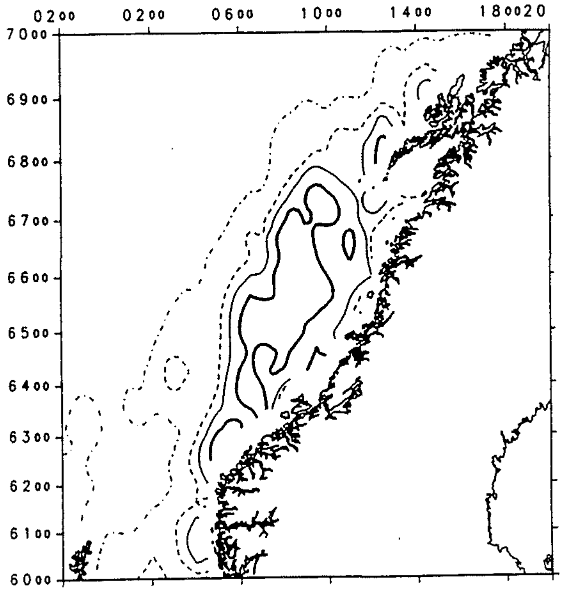

Figure 3. Distribution of 0-group saithe in 1989-1992. Isolines have been drawn for average number of saithe greater than 1 specimen/trawlhour (dotted/stripled line), 10 specimens/trawlhour (stripled line), 30 specimens/trawlhour (single solid line), and greater than 100 specimens/ tawlhour (thick line). In this period the average number per trawlhour did not exceed 300 specimens on any station.

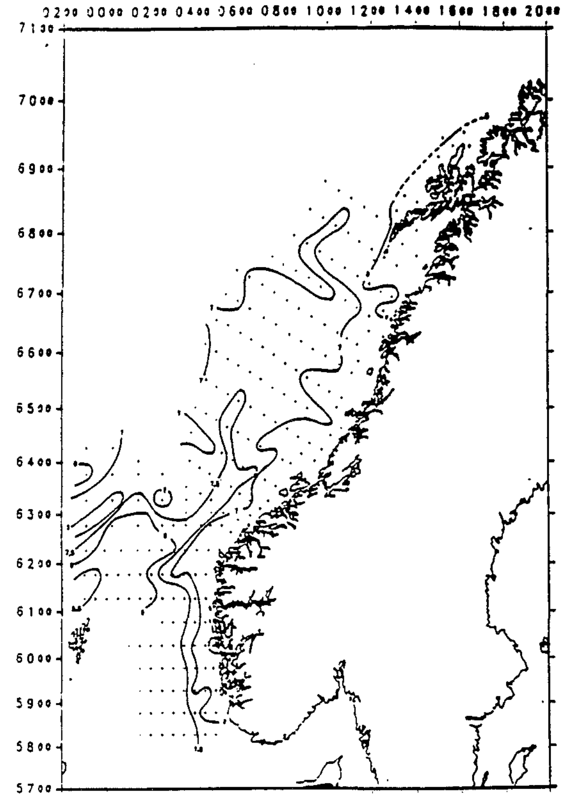

Figure 4. Temperature (C°) at the surface during the survey in May 1992.

The number of 0-group saithe caught each year is shown in the text table below together with the calculated indices.

Year	1985	1986	1987	1988	1989	1990	1991	1992
Nos. 0-group	10424	6669	2569	1334	1459	578	6019	4344
Index x 10^6	828	545	280	165	242	58	637	443

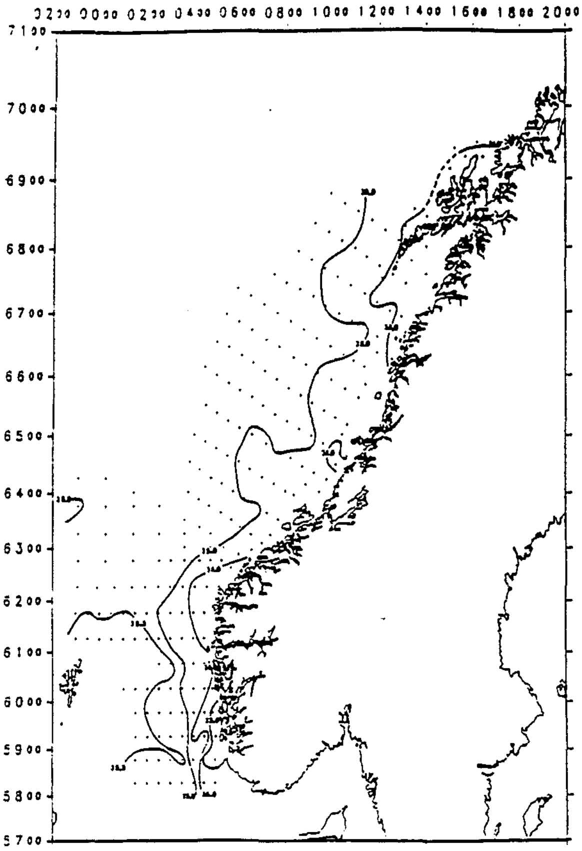

Figure 5. Salinity in 25 meters depth during the survey in May 1992.

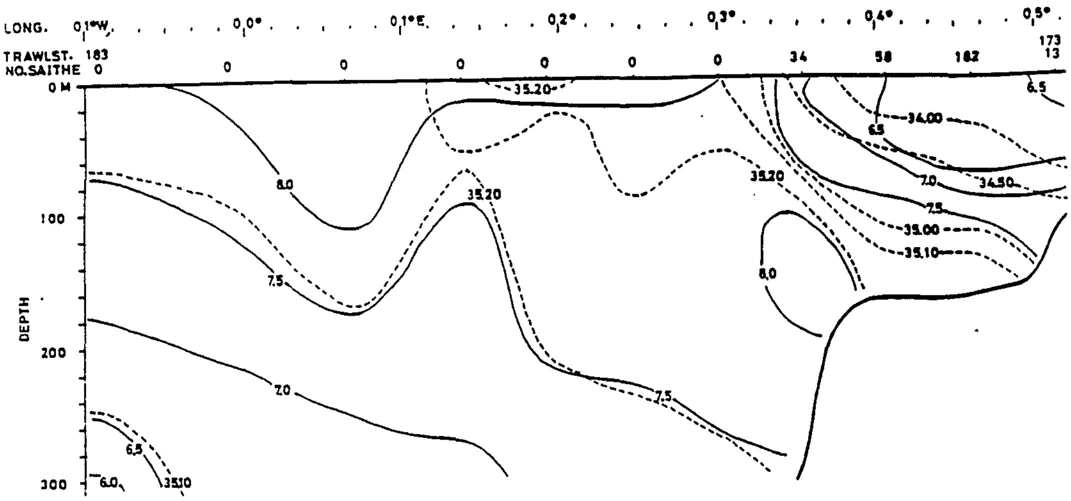

Figure 6. Vertical hydrographical section along 62°15'N during the survey in May 1992. The number of 0-group saithe caught at each trawl station along the section is given at the top of the figure.

In Table 2 and Figure 7 the 0-group indices are compared with the estimates of corresponding yearclasses from the trawl-acoustic survey and the VPA for age 3 (Anon. 1994). Since 1988 the trawl-acoustic survey for saithe has been conducted on the coastal banks from Finnmark to Møre in October each year. The trawl-acoustic survey data on ages 3-5 have been used for tuning the most recent assessments (Anon. 1994). Two year old saithe are in the transition of living inshore and offshore, and it is reasonable to believe that different feeding and hydrographical conditions from year to year will lead to variable recruitment to the offshore coastal banks and thus the acoustic survey results for this age class.

Table 2. Comparable results from the 0-group survey, the trawl-acoustic survey (two and three year olds) and the VPA (three year olds).

Year-class	1985	1986	1987	1988	1989	1990	1991	1992
0-group	828	545	280	165	242	58	637	443
Acoustic survey age 2		40	61	256	220	408		
Acoustic survey age 3	57	70	80	260	659			
VPA age 3	76	66	72	229	330	163		

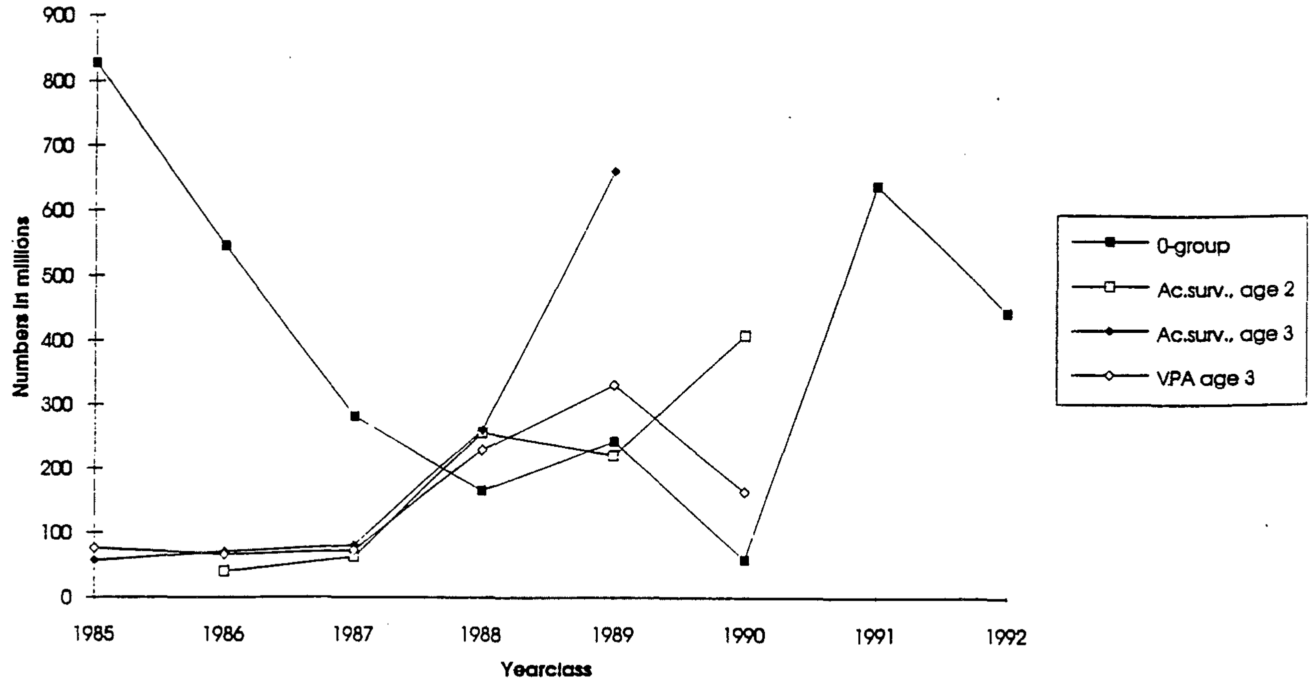

Figure 7. Year-class strength of the North-East Arctic saithe measured at the 0-group survey, the acoustic survey as 2 and 3 year olds, and as age 3 when backcalculated by the VPA.

Although a perfect fit between the 0-group indices and the survey and/or the VPA results was not expected unless suitable scaling, strong and weak yearclasses should have turned out the same way for the same year irrespective of survey or VPA. Figure 7 clearly shows that this is not the case, especially not for the years 1985-1987. For 1988-1990 there is a better fit between the 0-group index and the VPA. However, the 1991-yearclass is the last yearclass entering the VPA as 1-year-olds in 1992, and is therfore considered not reliably estimated by the VPA. The same can most probably also be said about the 1990- and 1989-yearclasses, thus explaining the deviation from the acoustic survey results regarding those yearclasses.

DISCUSSION

Since the time series from the trawl-acoustic survey and the VPA are still too short to compare with the entire 0-group series (1985-1992 yearclasses), the discussion of the results so far is mainly to put forward possible explanations for the big discrepancy between the postlarvae or 0-group index and the results from the acoustic surveys and the VPA regarding the 1985-1987 yearclasses.

Different ways of calculating the 0-group index have been tried, but this had only impact on the scaling, and did not change the relative strength between years.

The big midwater capelin trawl may not be the optimal gear to use for quantitative sampling of these 16-40 mm 0-group saithe postlarvae. Godø and Valdemarsen (1993) used an experimental three level trawl (Hylen *et al.* 1995) and compared the catches with the standard capelin trawl. Although the comparisons were only conducted in two minor areas 180 naut. miles apart, the experimental trawl demonstrated an area difference in vertical distribution of the 0-group saithe. The differences in vertical distribution seemed to be geographic rather than diurnal, and since the efficiency of the capelin trawl is expected to be lower at the surface compared to deeper water (see also Godø, Valdemarsen and Engås 1993), this could affect the reliability of the catch data from the capelin trawl and hence the calculated indices. Godø and Valdemarsen (1993) not find any significant length differences of the 0-group saithe with depth, but differences in mean length between the two areas in the experiment may however explain the observed geographic different vertical distribution. Hence if the 0-group saithe has a different vertical distribution dependent on size, and the mean length of the 0-group differs from year to year as shown in Table 3 thus indicating different vertical distribution, and the trawl efficiency also differs with depth, then this might have had an impact on the index (see Figure 8). Bjørke and Bakkeplass (1991) did also observe similar vertical differences in saithe postlarvae distribution between years in June -August 1977-1981.

Table 3. Length-distribution (%) and mean length (mm) of 0-group saithe north of 62°N in 1985-1992.

Year	Length-group (mm)									Mean length
	<15	15-19	20-24	25-29	30-34	35-39	40-44	45-49	>50	
1985		1	13	37	31	13	3	1	1	29,84
1986	+	18	42	28	10	2	+	+	+	23,99
1987	1	13	43	34	8	2	+			23,98
1988	1	19	40	25	10	4	1			23,91
1989		7	42	33	7	10	1			24,59
1990	8	45	36	10						19,40
1991		1	13	47	32	8	+	+		28,62
1992	+	18	52	26	3	+				22,60

Although no size differences were observed when comparing the length of the postlarvae/0-group saithe caught by the capelin trawl and the Isaacs Kidd and MOCNESS trawls, one should not exclude the possibility that size selective properties of the capelin trawl may underestimate the index when the 0-group are small.

Godø and Valdemarsen (1993) found the catches to be generally lower at night irrespective of gear indicating possible behavioural differences of the postlarvae (more dispersed at night) or day-night differences in trawl efficiency.

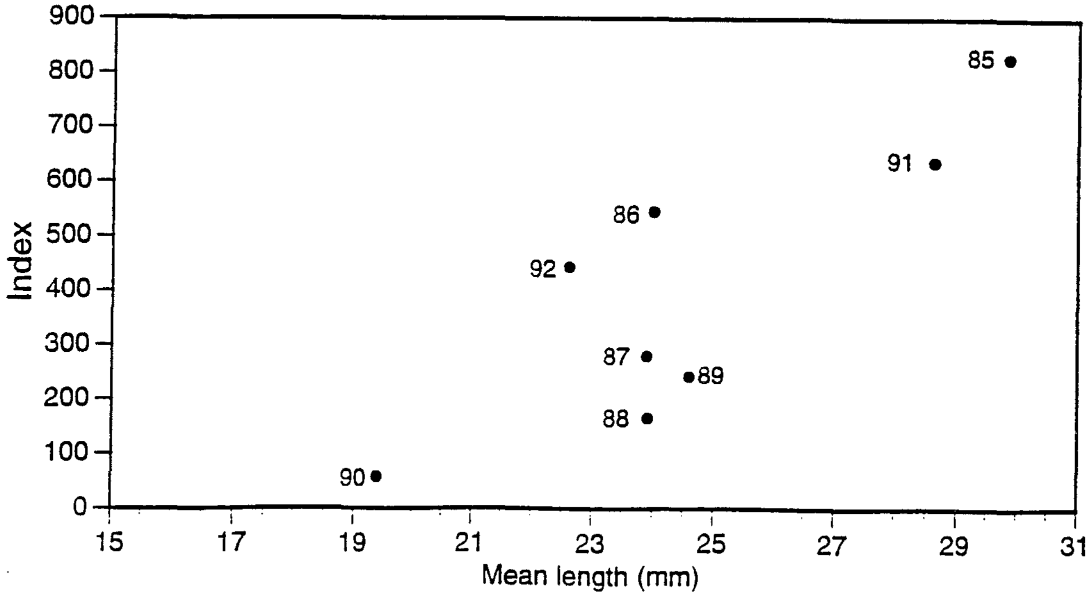

Figure 8. Relationship between calculated 0-group index and mean length of the 0-group saithe 1985-1992 (r^2=0,71).

It is unlikely that very poor yearclasses of saithe would have been recorded in so high abundance as in the 1985-and 1986-surveys relative to the subsequent yearclasses, especially since the yearclasses 1988-1990 are abundant in both the acoustic survey and the fishery. Thus, there is some evidence that the yearclasses 1985 and 1986, possibly also 1987, were considerably reduced from the 0-group stage until they entered the fishery at 2-3 years of age.

In 1987 and 1988 a large number of harp seals (*Phoca groenlandica*) invaded the Norwegian coast, and approximately 80 000 animals were drowned in the gillnet fisheries. Ugland *et al.* (1993) studied the fish consumption by these invading harp seals, and estimated the consumption of saithe of the yearclasses 1985, 1986 and 1987 to be 129, 107, and 24 millions, respectively. Taken this into account, the 1985 and 1986 yearclasses would have been close to the long-term average recruitment of about 300 millions at age 1 (290 and 260 millions, respectively), while the 1987 yearclass would still be a poor one (Ugland *et al.* 1993). There are substantial uncertainties in the different estimates, but it would be a strange coincidence if the discrepancy between the 0-group indices and subsequent abundance on the fishing grounds, and the consumption of harp seals is not to some extent connected.

The 0-group saithe are exposed to predation also by other species. Nothing has been puplished about predation by adult fish on the saithe postlarvae at this time and in this area, but this probably also occurs. However, seabirds are preying on saithe postlarvae. Barrett (1991) showed that 0-group saithe was the most important prey for shags (*Phalacrocorax aristotelis* L.) in the Lofoten area in summer 1985 and 1986. The shags preyed upon both 0- and 1-

group saithe (Figure 9). No quantitative analysis was done, but contrary to the harp seal, the preying upon saithe by shags is likely to take place every year.

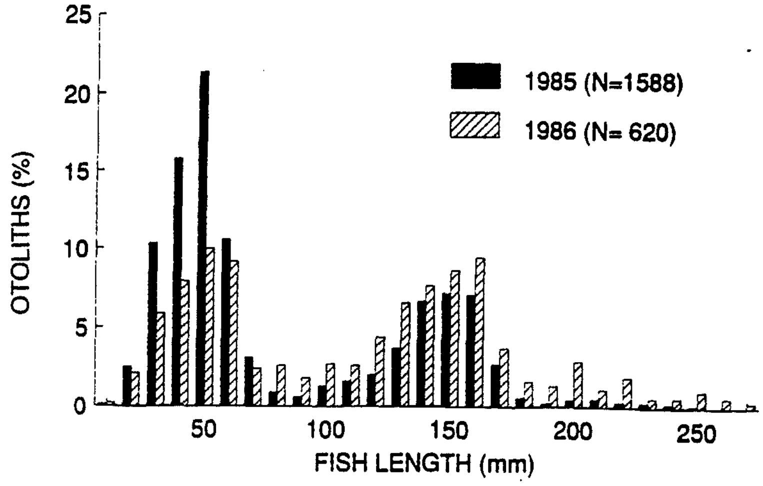

Figure 9. Length frequency distribution (calculated from otolith lengths) of saithe eaten by shags in July 1985 and 1986 (after Barrett 1991).

It has been difficult to find any connection between the different distributions of 0-group saithe in 1985-1987 (1988) and 1989-1992, and the relative high indices measured in the former period. Although we can not see that the 1985-1987 yearclasses later have shown up in the North Sea, one should keep in mind that there may be a different drift of eggs and larvae from the spawning sites (which also may contribute different to the yearclass strength from year to year) to either the stock north of 62°N or the North Sea stock. Jakobsen (1981) showed from tagging experiments that there is a substantial southward migration of 2-3 year old saithe to the North Sea from the nursery area between 62°N and 66°N, but we don't know whether or how this southward migration is linked to a northward drift of the same yearclass as larvae.

Some concluding remarks

It is likely that a trawl survey for 0-group saithe at this time of the year would give a reliable index of the yearclass at this stage, at least if a trawl that can better sample the near surface layer is used. This may be concluded since the survey up to 1992 managed to find the outer distribution limits of 0-group saithe towards west, north and south, and although some postlarvae had entered inshore areas in some years, the areas with highest 0-group concentrations were well defined.

This paper has shown, however, that the estimated yearclass strength of the saithe at this early stage is unreliable to use as an index or prediction of the strength of the same yearclass two or three years later when entering the fishery. It is believed that this is due to variable, and so far unpredictive mortality during the first year(s).

Trough this 0-group saithe survey we have got more knowledge, not only about the saithe at this postlarval stage, but also about other fish species that were caught (e.g., herring, catfish, haddock etc.). However, since the survey failed to fill the main purpose, i.e., to forecast the strength of the saithe yearclass when entering the fishery, these investigations were stopped in 1992. They will probably not be continued until a final evaluation after the latest yearclass, i.e. the 1992 yearclass, has fully recruited to the fishery so that the whole time series of the 0-group survey could be compared with the acoustic survey and the back-calculations by VPA. In meantime the efficiency of the samling gear will be tried improved, and the methodology further developed to take into account differences in the vertical distribution of the saithe postlarvae.

REFERENCES

ANON. 1994. Report of Arctic Fisheries Working Group. Copenhagen, 24 August - 2 September 1993. *ICES CM 1994*/Assess:2, 253 pp.

BARRETT, R.T. 1991. Shags (Phalocrocorax aristotelis L.) as potential samplers of juvenile saithe (Pollachius virens (L.)) stocks in northern Norway. *Sarsia 76*: 153-156.

BJØRKE, H. 1984. Distribution of eggs and larvae of gadoid fishes from Stad to Lofoten during April 1976-1983. Pp. 365-394 in Dahl, E. Danielsen, D.S. Moksness, E. and Solemdal, P. (eds.): *The Propagation of Cod, Gadus morhua L., Flødevigen rapportser., Part 1.* Institute of Marine Research, Biological station Flødevigen, Arendal, Norway.

BJØRKE, H. and **BAKKEPLASS, K.** 1991. Vertikalfordeling av fiskeyngel utenfor Nord-Norge i juni-august. *Havforskningsinstituttet Egg- og Larveprogram (HELP),* No. 40, 24 pp. (In Norwegian)

DAMAS 1909. Contribution a la biologie des gadides. *Rapp. P.-v. Reun. Cons. perm. int. Explor. Mer, 10* (3), 277 pp.

DRAGESUND, O. and **HOGNESTAD, P.T.** 1966. Forekomst av egg og yngel av fisk i vest- og nordnorske kyst- og bankfarvann våren 1965. *Fiskets Gang, 52*: 467-472. (In Norwegian)

GODØ, O.R. and **VALDEMARSEN, J.W.** 1993. A three level pelagic trawl for near surface sampling of juvenile fish. *ICES CM 1993*/B:19, 10 pp.

GODØ, O.R., VALDEMARSEN, J.W. and **ENGÅS, A.** 1993. Coparison of efficiency of standard and experimental juvenile gadoid sampling trawls. *ICES mar.Sci. symp., 196*, 196-201.

HYLEN, A., KORSBREKKE, K., NAKKEN, O. and **ONA, E.** 1995. Comparison of the capture efficiency of 0-group fish in pelagic trawls. Pp. 145-156 in Hylen, A. (ed): *Precision and relevance of pre-recruit studies for fishery management related to fish stocks in the Barents Sea. Proceedings of the sixth IMR-PINRO symposium. Bergen, 14-17 June 1994.* Institute of Marine Research, Bergen, Norway.

JAKOBSEN, T. 1981. Preliminary results of saithe tagging experiments on the Norwegian coast 1975-1977. *ICES CM 1981*/G:35, 25 pp.

NEDREAAS, K. 1986. Abundance and distributon of postlarvae in the 0-group saithe survey in the north-east Arctic in 1985. *NAFO SCR Doc. 86/117*, Ser.no. N1244, 24 pp.

NEDREAAS, K. and **SMEDSTAD, O.M.** 1987. 0-group saithe and herring of Norwegian coast in 1986 and 1987. *Havforskningsinstituttets Egg- og Larveprogram (HELP),(* 9): 27 pp.

UGLAND, K.I., JØDESTØL, K.A., ASPHOLM, P.E., KRØYER, A.B. and **JAKOBSEN, T.** 1993. Fish consumption by invading harp seals off Norwegian coast in 1987 and 1988. *ICES J. mar.Sci., 50*: 27-38.

WIBORG, K.F. 1960. Investigations on eggs and larvae of commercial fishes in Norwegian coastal and offshore waters in 1957-58. *FiskDir. Skr. Ser. Havunders., 12*(7): 1-27.

THE USE OF LARVAL SURVEYS AS A METHOD FOR CALCULATION OF THE SPAWNING STOCK OF DEEPWATER REDFISH FROM THE NORWEGIAN - BARENTS SEA POPULATION

by

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ABSTRACT

Spawning stock biomass of deep-sea redfish (*Sebastes mentella* Travin) from the Norwegian-Barents Sea population was calculated from the abundance and distribution of larval deep-sea redfish in the spawning area in March-May 1993. Catchability coefficient of the IKS-80 net is in the range 0.25-0.60 and the coefficient of larval mortality estimated under natural and experimental conditions were taken into account. The spawning stock biomass estimated by the ichthyoplankton method, the trawl-acoustic survey and the VPA-analysis was found to be of the same order of magnitude.

INTRODUCTION

The most abundant redfish in the Barents and Norwegian Seas is deep-sea redfish (*Sebastes mentella* Travin). In 1975-1992 the catch of this species fluctuated between 269 000 tonnes in 1976 to 10 000 tonnes in 1987. Intensive fishing in the 70's had a serious effect on the stock biomass. In this connection investigations on stock biomass and its variations, caused by fishing became particularly important.

Mass spawning of deep-sea redfish of the Norwegian-Barents Sea population take place in April-May, mainly in the Kopytov area at a depth not more than 300 m. Spawning grounds are located on the warm side of the eastern branch of the Norwegian Current, with a temperature in the 0-500 m layer of 4-5°. Geographic location of the spawning grounds and high velocity of surface currents effect the spatial distribution of larvae (Baranenkova *et al.* 1956; Sorokin 1958, 1960; Borodatov and Travin 1960; Corlett 1961). A large amount of the larvae (more than 50%) are soon after extrusion transported to the open sea with a greater depth than 500 m (Mukhina *et al.* 1992), mainly concentrated in the 0-50 m layer.

One method to study spawning stock biomass is based on quantitative distributions of larvae. A general method was suggested by Hensen and Apstein (1897), and this method has been introduced in several fisheries investigations to assess spawning stock abundance (Sette and

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Ahlstrom 1948; Rass 1953; Simpson 1959; Saville 1956, 1964; Kachina 1967, Lisovenko 1970; Pautov 1973; Crossland 1980; Noskov *et al.* 1985; Mukhina and Smirnov 1993 and others). The present paper gives estimates of spawning stock abundance and biomass of deep-sea redfish of the Norwegian-Barents Sea population, based on obseved number of larvae extruded during the spawning period.

MATERIALS AND METHODS

Data on abundance and distribution of larval redfish obtained during the standard ichthyoplankton survey in March-May 1993 are used in this paper. The number of larvae were counted on 161 stations taken within the spawning area. Ichthyoplankton samples were collected by the IKS-80 net towed with a speed of 2.5 knots during 10 min.

Catchability coefficient (q) of the gear is given as 0.25 - 0.6 (Lisovenko 1970; Shapiro 1971). The numer of larvae (B_a) in the survey is calculated according to Buchanan - Wollaston (1926). The number of larvae extruded in a season (N) is calculated by assuming:

1. the spawning season as 60 days.
2. the larvae are extruded each day in equal numbers.

The daily survival of each extuded group of larvae is taken from investigations on deep-sea redfish in the Irminger Sea (Pavlov, Gorelov and Oganin 1989), giving the survival rate S=0,107 for natural condions, and S=0,012 for experimental conditions.

Total number of larvae extruded during spawning season in the survey area (N_T) is obtained by the following formula

$$N_T = \frac{a \times B_a}{(1+s+\ldots+s^{a-1})\,q},$$

where a is number of spawning days between the first day of extrusion and including the survey day.

Total number of larvae extruded (N_T) will be

$$N_T = \frac{60 \times B_a}{(1+s+s\text{-}+s^{a-1})\,q},$$

According to our data, the mean absolute fecundity of deep-sea redfish females is 33.7 thousand eggs per female (C). However, taking into account that up to 3% of the eggs are not fertilized, the fecundity was reduced by this value (Vaskov 1985). Sex ratio in deep-sea redfish population was in 1993 estimated to be 1.2:1, with the majority as males.

Abundance of females (N_F) which extruded larvae was calculated by the formula:

$$N_F = \frac{N_T}{C-(0.03 \times C)},$$

Abundance of males (N_M) was calculated by the formula:

$$N_M = 1.2 \times N_F.$$

Spawning stock biomass (P) was calculated by the mean weight of mature fish separated by sex, (W_F) for females and (W_M) for males:

$$P = ((N_F \times W_F) + (N_M \times W_M)),$$

RESULTS AND DISCUSSION

In 1993 mass extrusion of larvaE from deep-sea redfish was observed in the south-western Kopytov area and in the north of Andoey and Malangen Bank (Figure1). Larvae 6-7 mm were caught in April in these areas at a depth of 0 - 50 m. Compared to the avarage long-term spawning grounds a more southern spawning area was observed in 1993, caused by a decrease of heat influx TO the eastern branch of the Norwegian Current, with temperatures of 4-5°C. The main concentration of 6-7mm larvae was observed over an area of 43 000 [nautical miles] ^{2}.

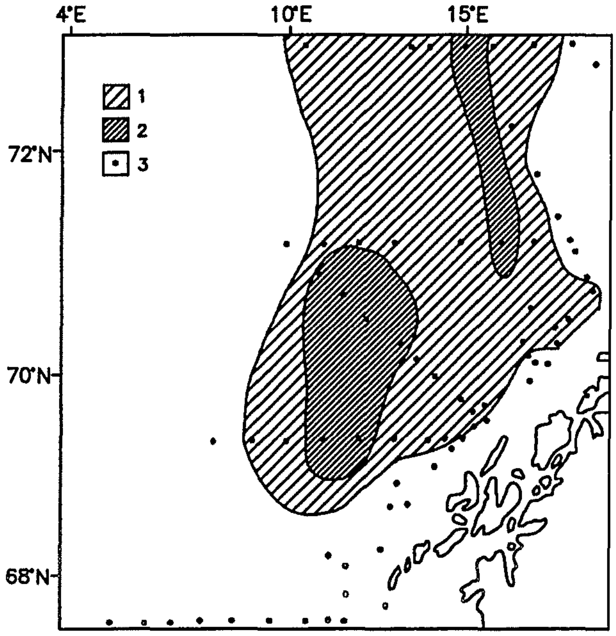

Figure 1. Distribution of deepwater redfish larvae in the 0-50 m layer, observed in the period 19/4-29/5-1993. Number of larvae per haul with a IKS-80 net.
1: 1-10; 2: 11-100; 3: location of station.

The spawning stock biomass obtained by using the data from a larvae survey in 1993 and the survival rates for natural and experimental conditions indicate a low level of spawning stock abundance between 18-43 thousand tonnes and 34-82 thousand tonnes respectively, depending on survival rate and catch coefficient (Table 1). However, the estimates based on the larvae survey data might be too low, caused by dispersal of larvae into open seas. These figures are, however at the same level as estimated by applying the VPA-method on PINRO data (52 thousand tonnes), the ICES data (84 thousand tonnes, Anon. 1994) and the Russian trawl-acoustic survey data (77.5 thousand tonnes).

Table 1. Abundance and biomass of spawning stock of deep-sea redfish from the Norwegian-Barents Sea population in 1993:

A: Daily survival rate S = 0.107. Natural conditions.

Catchability coefficient of IKS-80 net	Abundance of larvae Nos.$\cdot 10^{-10}$	Mature females		Mature males		Biomass of spawning stock, Tonnes$\cdot 10^{-3}$
		Abundance Nos.$\cdot 10^{-7}$	Biomass Tonnes$\cdot 10^{-3}$	Abundance Nos.$\cdot 10^{-7}$	Biomass Tonnes$\cdot 10^{-3}$	
0.6	48.83	1.49	9.3	1.79	8.6	17.9
0.5	8.60	1.79	11.2	2.15	10.3	21.5
0.4	73.25	2.24	14.0	2.69	12.9	26.9
0.3	97.67	2.99	18.7	3.58	17.2	35.9
0.25	117.20	3.58	22.4	4.30	20.7	43.1

B: Daily survival rate S = 0.012. Experimental conditions.

Catchability coefficient of IKS-80 net	Abundance of larvae, Nos.$\cdot 10^{-10}$	Mature females		Mature males		Biomass of spawning stock Tonnes$\cdot 10^{-3}$
		Abundance Nos.$\cdot 10^{-7}$	Biomass Tonnes$\cdot 10^{-3}$	Abundance Nos.$\cdot 10^{-7}$	Biomass Tonnes$\cdot 10^{-3}$	
0.6	93.06	2.84	17.8	3.41	16.4	34.2
0.5	111.67	3.40	21.4	4.10	19.7	41.1
0.4	139.58	4.27	26.7	5.12	24.6	51.3
0.3	186.11	5.69	35.6	6.83	32.8	68.4
0.25	223.34	6.83	42.7	8.19	39.4	82.1

REFERENCES

ANON. 1994. Report of the Arctic Fisheries Working Group. Copenhagen 24 August - 2 September 1993, *ICES CM 1994*/Assess: 2, 253 pp.

BARANENKOVA, A.S., KHOKHLINA, N.S. and **YUDANOV, I.G.** 1956. The distribution of the larvae of the sea-pearch of the genus *Sebastes* in the Norwegian Sea. *The USSR Academy of Science. 111*(2): 489-490.

BORODATOV, V.A. and **TRAVIN, V.I.** 1960. Main stages of Soviet studies of the redfish in the North At lantic. Pp. 277-284 in Mari, Y.,Y. (ed.): *Soviet fisheries investigations in the seas of the European North.* Rybnoe Khozaistvo, Moscow. (In Russian)

BUCHANAN-WOLLASTON H.J. 1926. Place-age production in 1920-1921 treated as a stratified problem with comparison between the data from 1911, 1914 and 1921, *Fish. Invest. Ser.2,9*(2): 36 pp.

CORLETT, I. 1961. *Int.Coun.Northwest.Atl.Fish.Spec,Publ. 3*: 17-23.

CROSSLAND J. 1980. The number of snapper, *Chrysophrus auratus* (Foster), in: The Hauraki Gulf, New Zealand, based on egg surveys in 1974-75 and 1975-76. *Fish.Res.Bull.* (NZ), 1980 (22): 36pp.

HENSEN, V. and **APSTEIN, C.** 1897. Die Nordsee-Expedition 1895 des Deutschen Seefischerei Vereins.Uber die Elmenge der in Winter laichenden Fische. *Wiss.Meeres.unters.* 2(2): 1-97.

KACHINA, T.F. 1967. Method of calculation of the abundance of the fishing stock of herring in the Korff Bay and off Karaginsky Island. *Trudy vses.nauchno.-issled. Inst. morsk. ryb.Khoz. Okeanogr. 62*: 122-128. (In Russian)

LISOVENKO,L.A. 1970. *Reproduction of the Pacific redfish Sebastes alutus Gilb. in the Alaska Bay, synopsis of thesis for candidate of biol. science.* Vses. nauchno-issled. Inst. morsk.ryb.Khoz.Okeanogr., Moscow, pp. 20. (In Russian)

MUKHINA, N.V., DREVETNYAK, K.V. and **DVININA, E.A.** 1992. Spawning areas of redfishes in the Barents Sea and adjacent waters. Pp. 103-123 in Shleinik, V.N. (ed.): *Ecological problems of the Barents Sea. Sbornik nauchnykh Trudov.* Polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., Murmansk. (In Russian)

MUHKINA, N.V. and **SMIRNOV,O.V.** 1993. Assessment of abundance of spawning stock of Arcto-Norwegian cod from data of ichthyoplankton survey in 1992. Pp. 16-27 in: *Materials of PINRO reports on research activity in 1992*. Polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., Murmansk. (Preprint in Russian)

NOSKOV, A.S., PAVLOV, A.I. and **ROMANCHENKO, A.I.** 1985. Abundance of larvae and assessment of spawning stock of deepwater redfish (*Sebastes mentella* Travin) in the Irminger Sea in 1982. Pp. 17-23 in: *Ecology and stocks of some commercial species of the Atlantic Ocean. Sbornik nauchnykh Trudov.* Atl. nauchno-issled. Inst. ryb. Khoz. Okeanogr. Kaliningrad. (In Russian)

PAUTOV, G.P. 1973. Distribution of larvae of the Pacific redfish (*Sebastodes alutus*) and its stock status in the Bering Sea. In: *Trudy vses.nauchno-issled. Inst. morsk. ryb.Khoz. Okeanogr. Vladivostok. 4*: 122-128.

PAVLOV, A.I., GORELOV, A.S. and **OGANIN, I.A.** 1989. Larval distribution, elimination indces and spawning stock assessment for beaked redfish (*Sebastes mentella* Travin) in Irminger Sea in 1984-1988. *ICES CM 1989/ G*: 16, 21pp.

RASS, T.S. 1953. Importance of studying of fish reproduction for assessment of possible catches, *Ryb. Khoz., 1953*(2): 23-27. (In Russian)

RICKER, W. 1948. Methods of estimating vital statistics of fish populations. *Ind.Univ.Publ.Sci.Ser., No.15*, pp.101.

SAVILLE, A. 1956. Egg and larvae of haddock (*Gadus eglefinus L.)* at Faroese. *Mar.Res.Scot., 1956*(4): 27pp.

SAVILLE, A. 1964. Estimation of the abuundance of a fish stock from egg and larvae suurveys. *Rapp.Proc.-Reun., Cons.int.Explor.Mer. 155*:164-170.

SETTE, O.E. and **AHLSTROM, E.H.** 1948. Estimation of abundance of the egg of the Pacifipilchard (*Sardi nops caeruulea*) off southern California during 1940 and 1941. *J.Mar.Res., 7*(3): 511-542.

SIMPSON, A.C. 1959. The spawning of the place (*Pleuronectes platessa*) in the North Sea. *Fish.Invest.,Ser.II, 22*(7): 111 pp.

SHAPIRO, L.S. 1971. On techniquue of ichthyoplankton samples collecting. *Trudy Atl. nauchno-issled. Inst.ryb.Khoz. Okeanogr. 35*: 147-155. (In Russian)

SOROKIN, V.P. 1958. On biology of reproduction of redfish *Sebastes marinus* L., *Sebastes mentella* Travin in the Barents and Norwegian Seas. *Proceedings of the USSR Academy of Science*, *8*: 158-170. (In Russian)

SOROKIN, V.P. 1960. On migrations of the redfish (*Sebastes mentella* Travin) of the Bear Island - Spitsbergen stock. Pp. 285-298 in: *Soviet fisheries investigations in the seas of the European North.* Moscow. (In Russian)

VASKOV, A.A. 1985. On absolute fecuundity of deepwater redfish from the Irminger Sea. Pp. 14 in: *Studying a reasonable exploitation of biological resources of the northern seas and North Atlantic. Abstracts of papers to the scientific conference of young scientists.* Polyar. nauchno-issled. Inst.ryb.Khoz. Okeanogr., Murmansk. (In Russian)

FORMATION OF ABUNDANCE OF 0-GROUP HADDOCK OF THE 1989-1993 YEAR-CLASSES

by

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ABSTRACT

The paper presents analysis of food composition, stomach fulness, condition factor, length of the 0-group haddock at the bottom of the 1989-1993-year-classes as well as feeding and temperature conditions during the first winter.

The 0-group haddock of the 1990-1993-year-classes were found to be characterized by high growth rate. In November-December, their mean length exceeded the long-term mean length and the mean of the 0-group of the 1987-1989-year-classes. Length variation was observed to be greater in the 0-group of rich year-classes compared to poor year-classes.

Euphausiids, hyperiids and gammarides were found to be the most important food for 0-group haddock of the 1989-1993-year-classes. In the diet of the 1990-1992-year-classes, the role of euphausiids were reduced compared to previous years. It resulted in reduced fatness and decrease in condition factor. Variations in stomach fullness, condition factor, and fatness of 0-group haddock of different year-classes depend mainly on the yearly variations of euphausiids. Increasing propotion of euphausiids in 0-group diet give higher fatness.

Decreased fatness and low condition factor of the 0-group of the 1990-1992-year-classes before the first winter ring was formed, caused low survival rates. In the second year of life (1-group), the survival rate of the 1990-and 1991-yaar-classes increased 3 and 2 times respectively and resulted in maintaining a high abundance of those year-classes. The 1992-year-class was reduced from a rich year-class at the 0-group stage to an average level at age 1, caused by a low survival at the 0-group stage.

A realationship between survival rates, temperature conditions and biological parameters of the 0-group is established. A cooling of the southern Barents Sea is expected in 1994 and the 0-group of the 1993-year-class might get low fatness and low condition factor before the first winterring is formed. A low survival rate is expected and the estimated strength of the 1993-year-class at the 1-group stage has probably to be reassessed.

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INTRODUCTION

PINRO has for many years studied feeding and relevant biological parameters of the 0-group haddock in different areas of the Barents Sea with the aim of establish a relationship between feeding conditions and survival of juveniles. These investigations are carried out simultaneously with the abundance estimation of juveniles during autumn - winter.

Measurement of the abundance of juvenile haddock in the Barents Sea has been undertaken since 1946, and these data have been the basis for assessing the year-class strength at age 0, 1 and 2. Previous investigations have shown that the abundance of 0-group give reliable estimates of the year-class strength. However, the most reliable estimates were obtained by assessing the year-class strength at age 2+ (Sonina 1969).

Discrepancies in abundance estimates of haddock year-class strength at age 0, 1, 2 and 3 are caused by variation in mortality during the first two years of life (Ponomarenko 1978, 1984; Kovtsova 1989; Kovtsova, Mukhina and Dvinina 1989), mainly depending on environmental conditions and predation. The annual analysis of the 0-group survival allows to give corrections in assessment of year-class strength before they recruit to the commercial part of the stock. Mortality of 0-group depends to a great extent on their size, condition factor, fatness and distribution. Anomalies of 0-group distribution are caused by hydrological factors or rapid variation in abundance which effect feeding conditions (Kovtsova and Lepesevich 1990).

This paper give informations of feeding and biological parameters of 0-group as well as food and temperature conditions in the distribution area, aiming at determination of the survival rate of juvenile haddock in their first year of life (especially the 1993-year-class) and assess the year-class strength with confidence limits.

MATERIALS AND METHODS

Data from autumn-winter surveys on juvenile haddock in 1987-1993 in the southern Barents Sea serve as a basis for this study. A 25-m bottom trawl with 8 mm mesh (from knot to knot) inserted in the codend was used as standard fishing gear. Samples of 25 0-group haddock were taken from the catches. When the catches had less then 25 specimens, all haddock were collected. Stomach content was analysed by quantitative-weight method. Length of fish, total weight, weight of food bolus, weight of liver and food composition were analysed under laboratory conditions. Prey were identified to species if possible, counted and weighed. The following parameters were calculated:
- Total index of stomach fulness: weight of food in the stomach as percentage of body weight multiplied by 10.000.
- Fatness ; liver weight as per cent of fish weight.
- Fulton's condition factor; whole body weight devided by length cubed and multiplied by 100.
- index of euphausiids; ratio of euphausiids in stomach and fish body weight multiplied by 10.000.

The average fatness, condition factor and other biological parameters in 1987-1993 are given as arithmetical means. The propotion of different preys were estimated as percentage of total weight of the stomach content and by frequency of occurrence. The mean number caught per 1-hour haul was taken as abundance index of age-group 0 and 1.

Survival rate of haddock in the first year of life were estimated as the ratio of the mean catch of of the same year-class. Survival rate calculated in this way, gives relative survival rate of the year-class. However, they can be compared for different year-classes during an equal period of time.

To characterize feeding conditions of 0-group haddock of different year-classes, the assessment of euphausiids were used, based on samples from the same autumn-winter survey (Drobysheva, Nesterova *et al.* 1992).

Heat condition of the southern Barents Sea waters was presented by yearly average water temperature in the Kola section (stations 3-7). The mean water temperature in March-April (the two months of the year with lowest temperature) in the section "Kola meridian" (stations 3-7) and "Kharlovsky" (stations 1-4) in 0-200 m layer was taken as an index of temperature conditions for juvenile haddock in the southern Barents Sea.

RESULTS AND DISCUSSION

Based on data from the the International 0-group fish survey and the autumn-winter survey of haddock juveniles, the 1989-1993-year-classes of haddock were estimated to be abundant (Table 1). Rich haddock year-classes occurred in warm years. For example, the abundance index of the rich 1990-year-class (warm year) at the 0+-group stage exceeded the poor 1987-year-class (cold year) by more than 150 times (Table 1).

Table 1. Abundance indices of the 0- and 1-group haddock and the mean water temperature, characterizing the climate during spawning and the whole year (heat content).

Year-class	0-GROUP SURVEY		AUTUMN - WINTER SURVEY			CLIMATE		
Year	Abundance index[1]	Year-class strength	Mean catch per hour trawling	Year-class strength	Mean catch per hour trawling	Heat content yearly mean temperature Kola-section (t°C)	Characteristics	Mean tempearture March-April Kola-section (t°C)
	(0-group)		(0+-group)		(1+-group)			
1982	90	average	23.0	rich	59.0	3.66	cold	
1983	184	rich	39.9	rich	78.2	4.54	warm	2.96
1984	255	rich	8.7	average	19.1	3.08	normal	2.22
1985	156	average	5.0	average	2.5	3.68	normal	1.73
1986	160	average	0.3	poor	1.5	3.65	cold	1.82
1987	72	poor	0.5	poor	0.4	3.43	cold	1.70
1988	86	poor	2.0	poor	3.1	3.75	normal	2.05
1989	112	average	3.3	average	22.2	4.45	normal	2.35
1990	227	rich	81.0	rich	66.6	4.57	warm	3.02
1991	472	rich	17.0	rich	47.8	4.51	warm	2.70
1992	313	rich	20.0	rich	8.0	4.56	abnormal warm	2.99
1993	240	rich	5.5	average		4.06	warm	2.60
1994								1.75[2]
Long-term mean (1965-1993)	123		17.0					

[1] Anon. 1994 [2] Data from PINRO; Kola section, stations 3-7

Abundance indices of the 0-group based on the bottom trawl survey, fully confirm the year-class strength of the same year-classes estimated by the 0-group survey. Year-classes estimated as rich in their first year of life are later confirmed by the results from surveys on older juveniles. However, it should be noted that the surveys in autumn-winter 1992 and 1993 did not cover the whole area of juveniles (Table 1).

Comparison of the length-distribution of haddock for different year-classes showed that if abundance of the 0-group is high, variability in length is observed to be greater than in case of low abundance (Figurel). Length of 0-group haddock of the 1987- and 1988-year-classes fluctuated from 8 to 21 cm, with the peak at 11 and 13 cm respectively, while length of the rich 1990-1992-year-classes varied from 9 to 25 cm, with the peak at 17 and 15 cm. Percentage of large fish (more than 17 cm) among 0-group of rich year-classes fluctuated between 23 to 44%, and for poor year-classes large fish constituted less than 5% (Figure 1). Fluctuation of mean length of 0-group haddock consided with variation in temperature conditions, stomach fullness, fatness and condition factor and yearly fluctuations in abundance of euphausiids, depending on hydrological conditions (Degtyareva 1986). Thus, mean length of the year-classes consided with temperature and feeding conditions (correlation coefficient R=0.907, n=7).

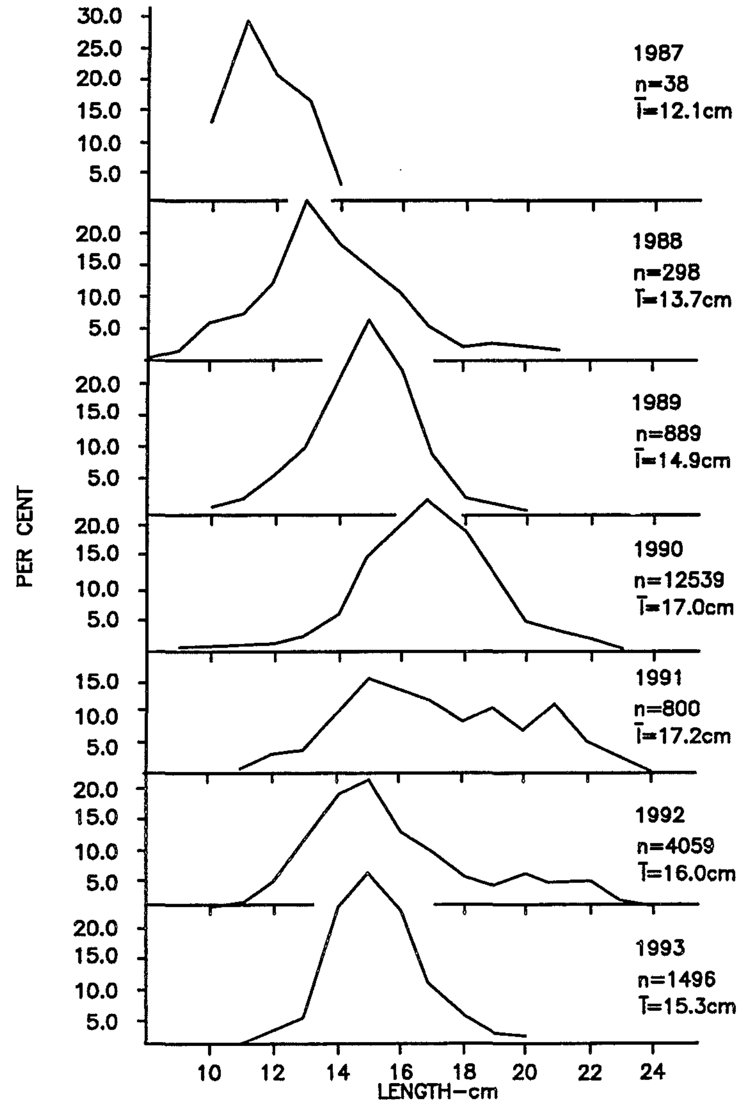

Figure 1. Length distribution of age group 0+(1) of haddock in the authumn - winter bottom trawl survey in the southern Barents Sea 1987-1993.

In autumn 1987-1993, euphausiids, hyperiids and gammarids dominated the diet of 0-group haddock at the bottom in the southern Barents Sea, by both weight and frequency of occurence (Table 2). Polychaetes and comb-jellies as well as other benthos organisms were of less importance in the 0-group diet (Table 2). Analysis of food composition show that the importance of euphausiids in 0-group diet increased in the second half of 1980's, especially in 1987-1988 compared to the 1970's which had high abundance of these prey species. Increase in the abundance of euphausiids was observed from 1980 to 1989. However, before 1987 important areas in the southern Barents Sea with high abundance of euphausiids were not covered (typical only for 1987-1989). Since 1991, abundance of these small crustaceans have been reduced (Drobysheva 1989; Drobysheva and Nesterova *et al.* 1992).

Table 2. Food composition and biological parameters of the 0-group haddock and the abundance of auphausids in 1987-1993.

Year	Food components[1]							Number of stocmachs analysed	Empty stomachs (%)	Mean index of stomach fullness (%)	Fulton's condition factor (K)	Fatness (%)	Abundance of euphasids (spec./m^3)
	euphausids	gammarids	hyperids	digested fish	worms	Ophura	others						
1987	71-86	19-1	19-4	5-4	13-4	-	-1	39	28	37.3	0.836	5.16	275
1988	32-28	24-13	33-23	2-12	5-5	-	-19	233	25	29.0	0.860	3.27	553
1989	24-21	11-2	15-7	2-10	7-4	10-13	-43	159	10	24.1	0.825	4.60	668
1990	25-27	7-2	17-10	4-18	12-8	3-1	-34	251	31	25.2	0.734	3.93	270
1991	21-23	3-	12-4	6-20	3-3	-	-31	98	40	25.4	0.867	2.93	195
1992	1-6	7-3	37-37	-	19-40	-	-14	77	35	19.3	0.747	2.72	49
1993	30-14	3-3	27-36	1-9	9-8	1-5	-25	115	9	21.2	0.654	3.02	50

[1] Frequency of occurence - Index of stomach factors

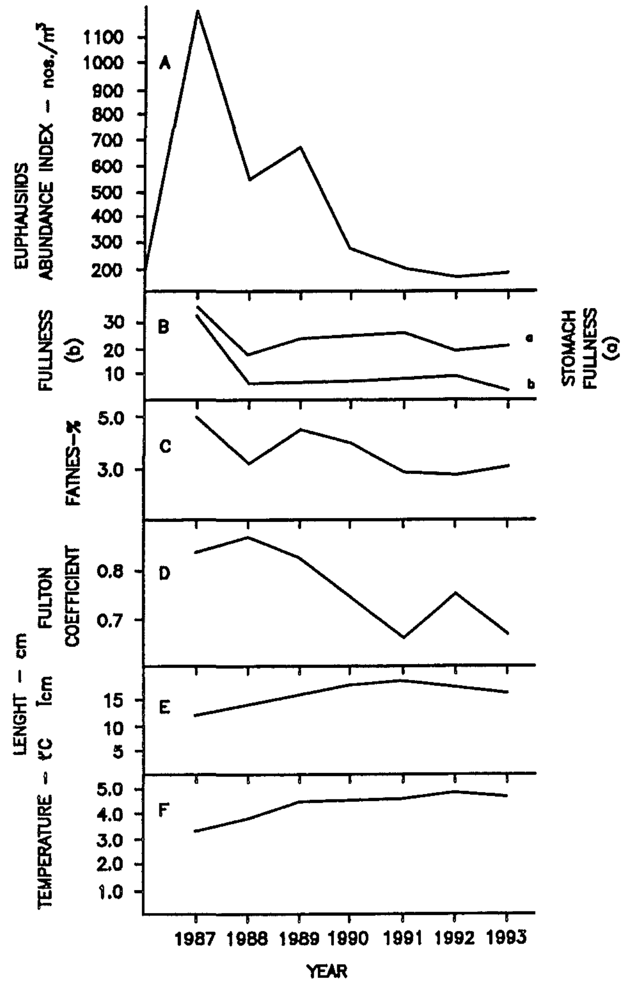

Figure 2. Yearly observations of nutrional parameters related to 0-group haddock and temperature conditions during the authumn - winter survey 1987-1993.
A: Abundance index of euphausiids;
B, C, D: Nutrional parameters;
E: Mean length of 0-group haddock;
F: Heat content: average temperature in Kola section (stations 3-7).

Based on biological parameters of 0-group as well as temperature observations of the water and the mean length, no sharp changes in feeding conditions were observed in 1987-1993 in the southern Barents Sea (Table 2, Figure 2). However, figures for fatness indicated that feeding conditions for 0-group of the 1987-, 1989- and 1990-year-classes were better than for the 1991-1993 year-classes (Figure 2), increasing importance of euphausiids in diet of the 0-group cause higher fatness. Thus, our studies have confirmed the results by Ponomarenko (1964, 1978, 1984) and Kovtsova and Lepesevich (1990) showing that the growth and other biological parameters of 0-group haddock are influenced by temperature and feeding conditions.

It has been shown that survival of 0-group largly depends on feeding conditions before the first winter (Ponomarenko 1984). Data on fatness, condition factor and mean length of the 1989-1993- year-classes measured before the first winter, show a small fluctuation in feeding conditions during the period 1987-1993. The mean length of the 0-group haddock from these year-classes were higher than the long-term mean. Large 0-group haddock are consumed by predators in less amount than the small ones. It has been shown that 0-group haddock become prey for young cod usually when they are below 13 cm (Ponomarenko 1964). Therefore, in the years when 0-group has low linear growth or low condition factor, then might be more easily available for predators, and a decrease in survival would be the consequence.

Data on cod feeding, based on samples taken by bottom trawl in the North-European basin, show higher frequency of occurrence in stomach content (by weight) of 0-group haddock in 1988 is 2,8 compared to 1,0%in 1989. However, in 1990-1992 when rich haddock year-classes appeared, their frequency of occurrence in cod stomachs increased to 2.2%. Thus, good growth of the 0-group haddock of the 1990-1992-year-classes contributed to an increase in abundance of large individuals which should have led to reduced mortality by predation. However, in 1990-1992 a sharp increase in abundance of juveniles not only in haddock but also in cod was recorded, and the food competition for euphausiids apparently increased. This resulted in decreased condition factor and fatness of the 0-group haddock and consequently reduced abundance during the first winter. 0-group haddock of the 1990-1992-year-classes had lower condition factor than the 0-group of the 1987-1989-year-classes and the survival rates of the 0-group of the 1990- and 1992-year-classes were lower than that of the 1989-year-class by a factor of 7.8 and 16.4 respectivily.

Long-series of survival rates of age-group 0 and temperature conditions during the first winter are closely connected (Ponomarenko 1979), which is confirmed by the present analysis of the survival rate (Figure 3, r=0,60, n=7). Temperature conditions during the first winter of the 0-group from the 1989-1992-year-classes were favourable, temperature above 2.5°C (Figure 3). However, in March-April 1990 during the first winter of the 1989-year-class, the mean water temperature was above 3°C, causing high survival rate of this year-class during its first year of life. Because of high survival rate of the 1989-year-class in the first and second year of life, therefore, this year-class was assessed to be above average instead of poor.

Informations about 0-group fatness (X_1), mean length (X_2) and expected mean water temperature during the first winter (X_3) have a joint effect of the survival rate (Y) for age 0. Combining these three factors in the following regression equation (1) would give a prognosis of the survival rate for the 0-group during the first year of life (Y);

$$Y = 0.235 \text{ x } X_1 + 0.146 \text{ x } X_2 + 0.494 \text{ x } X_3 - 2.698 \qquad (1)$$

with a multiple correlations coefficient R=0,798, n=7.

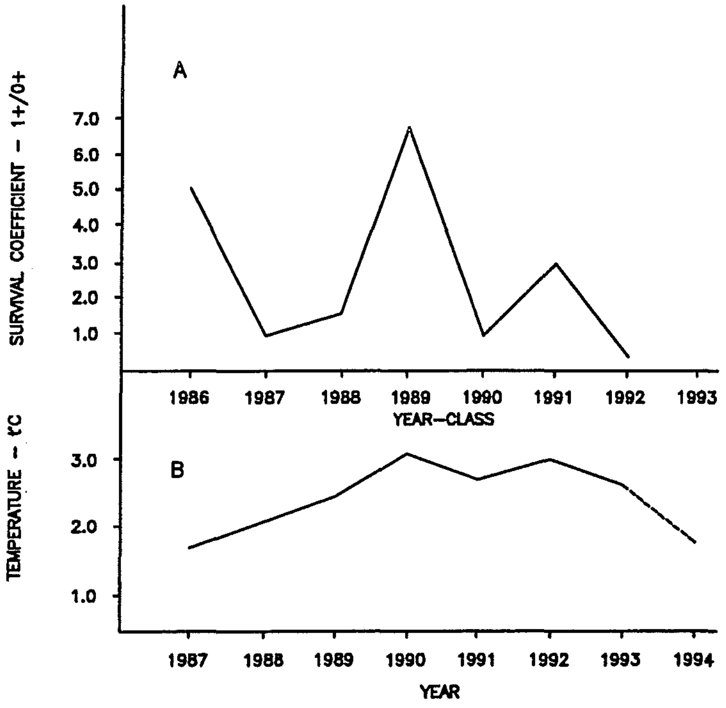

Figure 3. Relative survival coefficient of haddock (A) during the first winter and the mean temperature in the Kola section (station 3-7) in March-April the first winter (B).

Condition factor and fatness of 0-group haddock from the 1993-year-class observed before the first winter, were 0.654 and 3.02 % respectively. These are lower than the long-term mean and they would give higher mortality of the 0-group in March-April 1994 (period of formation of the first winterring), in spite of the rather large size of 0-group. However, expected temperature conditions will be unfavourable for the survival of the 0-group haddock of the 1993-year-class. According to a forecast made by PINRO Laboratory of Oceanography in 1994, based on the mean water temperature on 6 and 8 sections in March-April 1994, cooling of the southern Barents Sea is expected to the 1982 level (cold year). This might give rise to high mortality of the 1993-year-class at the 0-group stage. By substituting corresponding biological parameters for the 0-group haddock from the 1993-year-class and expected mean temperature in March-April 1994 in equation (1) give survival rate equal to 1.11, indicating an increased abundance index of juveniles at age 1. Hence, the 1993-year-class which was estimated as average at the 0-group stage, would remain at the average level at 1-group or a little below.

CONCLUSIONS

1. Length variability was observed to be greater in 0-group haddock of rich year-classes compared to poor year-classes. 0-group haddock from the 1990-1993-year-classes were characterized by high growth rate in November-December and their length exceeded the mean length of the 1987-1989-year-classes and the long-term mean. Observed variations in mean length of 0-group haddock coincided with variations in water temperature.

2. The main prey species observed in the diet of the 0-group haddock of the 1987-1993-year-classes were euphausiids, hyperiids and gammarids. The importance of euphausiids as food for the 0-group of rich year-classes was reduced and the consequences were decreased fatness and condition factor. Fluctuations in stomach fullness, condition factor and fatness of different year-classes were mainly caused by yearly variations in abundance of euphausiids. A higher propotion of euphausiids in the diet of 0-group would result in higher fatness.

3. As a consequence of decrease in fatness and low condition factor of the 0-group haddock of the 1990-1992-year-classes during the first authumn coincided with the reduction in the survival rates of the age 0 during the first winter.

Reduction in fatness and condition factor of the 0-group of the 1993-year-class and expected reduction in temperature in the southern Barents Sea in March-April 1994 (the first winter) would lead to a decrease in relative survival rate of the 0-group (1.11). This indicates that the estimated strength of the 1993-year-class at the 1-group stage would be reduced.

REFERENCES

DEGTYAREVA, A.A. 1986. Long-term dynamics of abundance and biomass of zooplankton in the southern Barents Sea in relation with changes in thermal regime. Pp. 59-60 in: *Ecology and biological productivity of th Barents Sea. Abstracts of papers to the All Union Conference.* Kola Section of the USSR Akademy of Science, Murm. morsk. biol. Inst., Murmansk. (In Russian)

DROBYSHEVA, S.S. and **DOLGOV, A.V.** 1989. Trophic links and ductivity of the Barents Sea. Pp. 21 in: *Abstracts of papers to the III Symposium on trophic links,* Chita. (In Russian)

DROBYSHEVA, S.S., NESTEROVA, A.V. and **TERESHCHENKO, V.V.** 1992. Dynamics of abundance of the Barents Sea euphausiaces in the 80-s; *ICES CM, 1992/*L:40, 11 pp.

KOVTSOVA, M.V. 1989. Population fecundity and year-class strength of Arcto-Norwegian haddock. *ICES CM 1989/*G:14, 11pp.

KOVTSOVA, M.V and **LEPESEVICH, Yu.M.** 1990. Distribution, abundance and survival conditions of haddock fingerlings from the 1982-1989 year-classes in the southern Barents Sea. *ICES CM 1990/*G:7, 15 pp.

KOVTSOVA, M.V., MUKHINA, N.V. and **DVININA, E.A.** 1989. Oceanographic and biological factors effect on survival of Arcto-Norwegian haddock in the early ontogenesis. Pp. 126-138 in: *Problems of fishery oceanography of the northern basin. Sbornik nauchnykh Trudov.* Polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., Murmansk. (In Russian)

PONOMARENKO, I.Ya. 1964. Influence of hydrological regime andfeeding conditions on formation of abundance of cod year-class in the fingerlings period in the bottom layers of the Barents Sea, *Trudy polyar. nauchno.-issled. Inst.morsk.ryb.Khoz. Okeanogr.,* 16: 235-248. (In Russian)

PONOMARENKO, I.Ya. 1978. Influence of temperature conditions of hydrologic winter on survival of juvenile cod and haddock, *Trudy polyar. nauchno.-issled. Inst.morsk.ryb.Khoz. Okeanogr.,* 40: 125-132. (In Russian)

PONOMARENKO, I.Ya. 1984. Survival of bottom-dwelling young cod in the Barents Sea and its determining factors. Pp. 213-229 in Godø, O.R. and Tilseth, S. (eds.): The proceedings of the Soviet-Norwegian symposium on: Reproduction and recruitment of Arctic cod. Leningrad, 26-30 September 1983. Institute of Marine Research, Bergen Norway.

SONINA, M.A. 1969. Migrations of the Barents Sea haddock and factors determining them. *Trudy polyar. nauchno.-issled. Inst. morsk. ryb. Khoz. Okeanogr., 26:* 125 pp. (In Russian)

PREDATION BY JUVENILE HERRING (*Clupea harengus* L.) ON BARENTS SEA CAPELIN (*Mallotus villosus* Müller) LARVAE

by

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ABSTRACT

In years with high abundance of juvenile Norwegian spring spawning herring in the Barents sea, the year-class strength of capelin has frequently been observed to be poor. It has therefore been suggested that predation by herring is an important determinant of year-class strength for capelin. In order to study predation by herring on capelin larvae, stomachs of herring were collected in areas of spatial overlap between herring and capelin larvae in 1992 and 1993. Based on the results of the investigations in these two years, a simple model was used to estimate the impact of predation by herring on capelin larvae through the years 1983-1992. It is concluded that it is likely that predation by herring is the explanation for the poor recruitment of capelin observed in years when rich year-classes of juvenile herring are distributed in the southern Barents Sea.

INTRODUCTION

Two abundant pelagic species of fish occur in the Barents Sea: juvenile Norwegian spring-spawning herring and capelin. The herring spawn in February-April along the west coast of Norway (Dragesund *et al.* 1980). The larvae drift with the Norwegian coastal current and when strong year-classes are produced, large amounts of herring larvae are distributed in the southern part of the Barents Sea during July. The adolescent herring stay there for 2-4 years before they migrate out of the Barents Sea and join the adult stock. The capelin spawn along the coast of northern Norway in March-June (Dragesund *et al.* 1973). Usually during May-July large amounts of capelin larvae are distributed in the southern Barents Sea (Alvheim 1985). As the herring larvae do not enter the Barents Sea until July (Dragesund 1970), there is usually not extensive spatial overlap between the 0-group herring and capelin. However, the youngest herring is distributed in the south and eastern parts of the Barents Sea and the older fish is distributed further to the west. Spatial overlap is therefore most likely to occur between the 1-3 year old herring and capelin larvae. In years when adolescent herring is distributed in the Barents Sea there is a spatial overlap between herring and capelin larvae during summer (Dragesund 1970, Alvheim 1985).

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In the period 1950 to 1980, three strong year-classes of herring were produced (Dragesund *et al.* 1980), in 1950, 1959, and 1960. Following these year-classes, major declines in the abundance of capelin were observed. This apparent inverse relationship between the recruitment of the two species has been pointed out by several authors (Olsen 1968, Hamre 1985, 1988, 1994). In 1983 a very strong year-class of herring was produced, and herring were distributed in the Barents Sea for the first time since the 1960s. The presence of herring seemed to have a dramatic effect on the recruitment of capelin in 1983-86 when very poor year-classes of capelin were produced (Fossum 1992). In early summer of 1986, the herring left the Barents Sea, and the 1986 year-class of capelin had very good survival and it became the basis of the rebuilding of the stock after the collapse in the capelin biomass in 1986-87 (Fossum 1992).

In 1991 and 1992, strong year-classes of herring were produced (Anon. 1992a), and this attracted new attention to the predation theory. Despite the strong indications of predation from the apparent negative influence of abundant herring year-classes on subsequent capelin recruitment, few observations of capelin larvae in the stomachs of herring existed. As a part of the multispecies-model for the Barents Sea, stomachs of herring were sampled in the period 1983-85 (Mehl and Yaragina 1991). From a total of 1505 herring stomachs, only two observations of capelin (1-group) were made (Bjarte Bogstad pers. comm., IMR, Bergen).

Predation by herring (*Clupea harengus* L.) on capelin larvae has been reported from Icelandic waters (Magnusson 1968) and from the Grand Banks (Templeman 1948).

Moksness and Øiestad (1987) studied the interaction between herring- and capelin larvae in a mesocosm experiment. Despite excellent growth, the capelin larvae disappeared in the experiment, and this was suggested to be caused by predation from herring. The capelin larvae disappeared, when the herring had just started schooling.

On the basis of this background knowledge the working hypothesis was made that predation by juvenile herring on capelin larvae has significant impact on capelin recruitment in years with herring in the Barents Sea. To test this hypothesis, stomachs of herring were sampled in the area of spatial overlap of the two species in May-July. This is the period in which predation is most likely to occur as the abundance of capelin larvae has been shown to be dramatically reduced by late August in years with herring present (Fossum 1992).

Hypothesis: Predation by juvenile herring on capelin larvae has significant impact on the recruitment of capelin.

MATERIALS AND METHODS

The surveys

The material was collected during two surveys on the research vessel "G.O.Sars" in the Barents Sea in the period 26 May to 14 June 1992 and in the period 1 June to 24 July 1993. The objectives of these surveys in addition to the present study, were to estimate the abundance of juvenile herring by acoustic methods, and to estimate the abundance of capelin larvae. Sampling of herring and capelin larvae was carried out off the coast of northern Norway between latitude 70°30'N and 72°30'N, and longitude 23°00'E and 33°00'E and in 1993 also off the Murman coast eastwards to 36°00' E and southwards to 69°00'N.

The surveys were carried out by running north-south grid lines one degree longitude apart (about 20 nautical miles (NM)). The abundance of herring was estimated by standard acoustic methods (MacLennan and Simmonds 1992). Fish were recorded using the Simrad EK 500 scientific echo sounder (Bodholt *et al.* 1989) connected to the Bergen Echo Integrator (Knudsen 1990). The estimated capelin larvae abundance was based on Gulf III stations performed every 20 NM within the distribution area of the capelin larvae. The total abundance was calculated based on these samples using the method of calculation outlined by Alvheim (1985).

Sampling equipment

Capelin larvae were collected using Gulf III 375 µm mesh and MIK 2000 µm nets (500 µm in hindmost 1.5 m). The Gulf III was hauled double obliquely to 60 m at a speed of 0.5 m/s with a vessel speed of 5 knots. A flow meter in the opening (19 cm diameter) of the sampler measures the water flow through the sampler (Zijlstra 1971). In July 1993, a circular MIK net (opening 2 m diameter) was applied instead of the Gulf III in order to catch the large capelin larvae (>20 mm) more representatively (Methot 1986; Munk 1988). The MIK was towed in the same way as described for the Gulf III, but with a vessel speed of 3 knots.

Trawling

Pelagic trawling using a midwater trawl ("Fotø" herring trawl in 1992, "Åkra" trawl in 1993) was carried out when echo recordings of fish were done. In areas of high capelin larvae abundance, "blind hauls" were sometimes carried out in order to try to catch herring not observed on the echo sounder or sonar. Trawling depth varied from the surface to 310 m. Trawling time was approximately 30 minutes. The opening height of the trawl was observed by a wireless hydroacoustic sensor attached to the headline of the trawl.

When herring were caught, Gulf III or MIK samples were taken in the same position to obtain an estimate of the local capelin larvae abundance.

Preservation

In 1992 a total of 799 stomachs of herring were collected (18 stations) of which 534 stomachs were preserved, either in formalin or frozen, and 265 were examined fresh. Formalin was injected into the abdominal cavity of the fish to ensure rapid preservation, and the whole fish was thereafter stored in formalin. The herring were frozen whole. The preserved material was examined in a laboratory and the results are presented by Huse and Toresen (1995).

In 1993 a total of 2560 stomachs were collected (48 stations) of which 2140 were examined fresh, and 450 were preserved. At each station, up to 60 herring were collected for stomach content analysis of which 50 stomachs of herring were investigated fresh, and 10 were preserved. The stomachs were preserved individually in 20 ml vials in 96% ethanol. If fewer than 50 herring were caught, all stomachs were investigated fresh.

Stomach content analysis

The stomachs that were investigated fresh, were analysed within one hour after being captured, and the stomachs were kept cool (<8°C) prior to the investigation in order to slow down the digestive process. The sea temperature in the study area was stable and usually below 6°C (Midttun and Loeng 1987). Digestion rate is positively correlated with temperature (Elliott and Persson 1978; Flowerdew and Grove 1979).

For each herring stomach, dominating prey groups and the number of capelin larvae were recorded.

The predation model

The impact of predation on the mortality of capelin larvae was estimated by using a model. The model was based on the method for estimation of predation outlined by Bailey and Houde (1989). The daily amount of capelin larvae consumed by herring was determined by using Bajkov's method (1935) somewhat modified. The following simple multiplicative model was used to estimate the total number of capelin larvae eaten by herring (TP) in each year:

$$TP = X \cdot C \cdot N \cdot D \cdot M \qquad (1)$$

where
X=average number of capelin larvae in herring stomachs
C=proportion of herring containing capelin larvae
N=estimated number of 1-3 year old herring in the Barents Sea
D=number of days that capelin larvae are confined to the predatory field of herring
M=number of meals of herring/day

The distribution area of capelin larvae encompassed the herring distribution in both years studied. All the herring in the Barents Sea were therefore potential predators of capelin larvae, and used in the model.

Statistical analysis

As the assumptions of homogeneity of variance and normality of the data were violated, nonparametric statistics were applied. One way ANOVA was carried out using Kruskal-Wallis (Kruskal and Wallis 1954) or Kolmogorov-Smirnov test (Zar 1984). Correlations were carried out using Spearman rank correlation (Zar 1984). The significance level was set at $p=0.05$.

RESULTS

Horizontal distribution

Herring

In 1992, the herring were distributed between longitudes 21°00'E and 36°00'E, and latitudes 69°20'N and 73°00'N (Figure1). The highest concentrations of herring were detected north-east of the Nordkyn peninsula, east of Vardø, and close to the Murman coast. The herring in the western part of the distribution area were predominantly three year olds, while one and two year old fish dominated in the eastern parts.

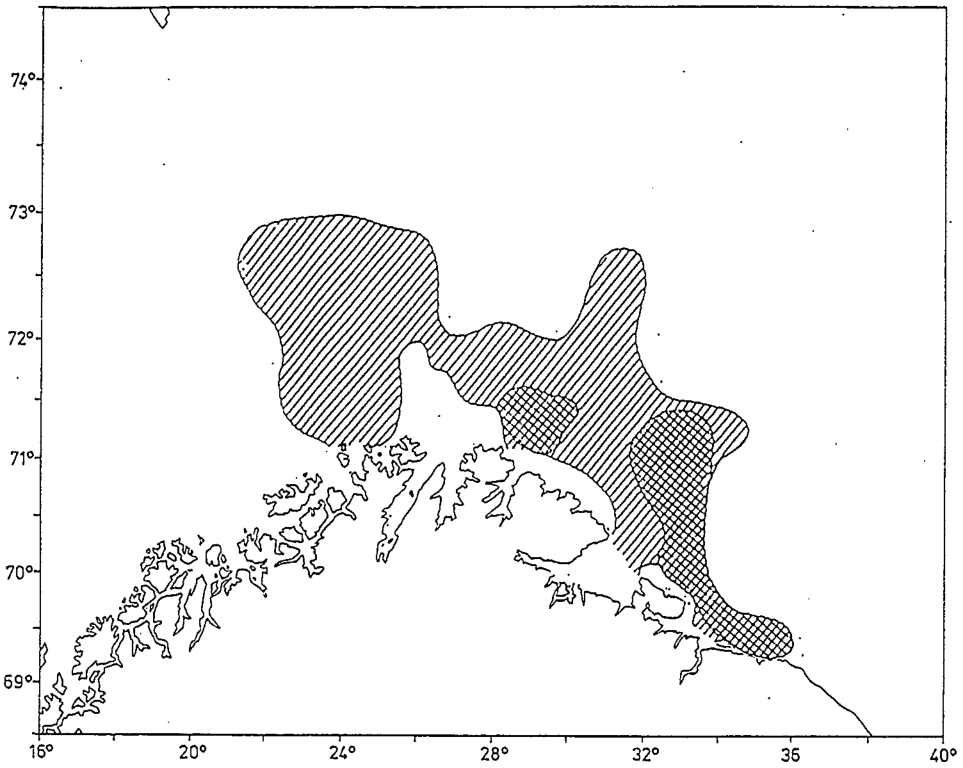

Figure 1. Distribution of adolescent herring June 1992. Double hatched areas indicate highest density. Anon 1992a.

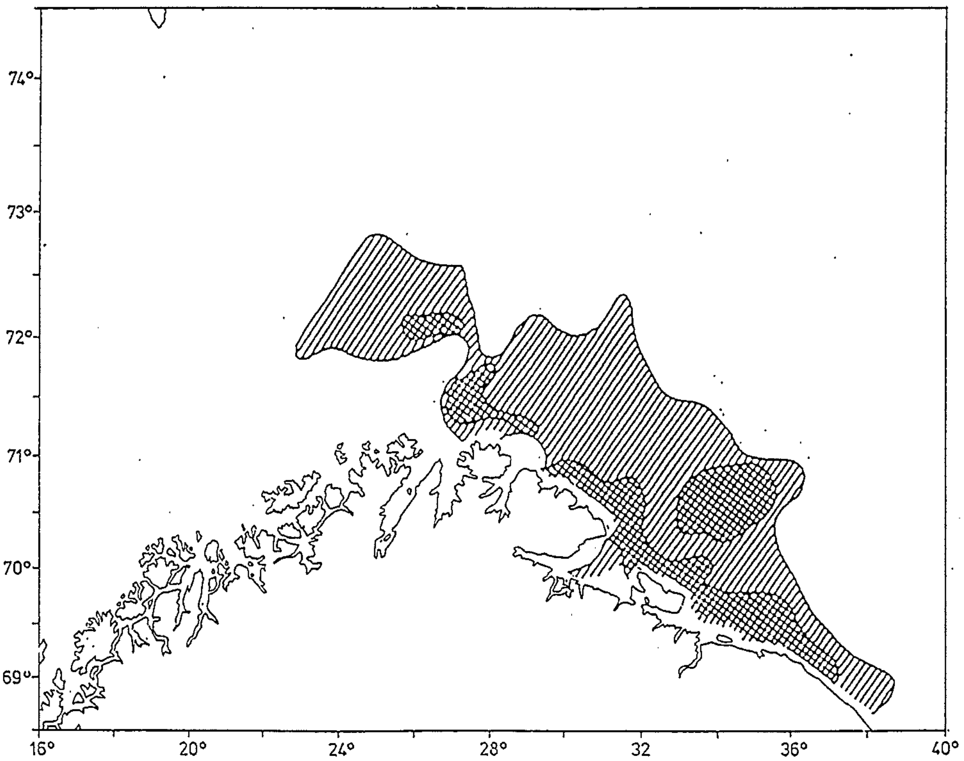

Figure 2. Distribution of adolescent herring June 1993. Double hatched areas indicate highest density. Anon. 1993a.

In 1993 the herring were distributed along the Norwegian and Russian coasts between longitudes 23°00'E and 39°00'E, and extending some 90 NM off the coast (Figure 2). The highest concentrations were recorded in a belt along the coast of Norway (30x180 NM) from about 29°30'E and eastwards along the Russian coast to about 38°30'E. Another high density area was recorded around 70°30'N and 34°00'E extending some 30 NM in each direction. Some very dense schools were also recorded to the east of Vardø and north of Murmansk. The herring in the western part of the survey area (north of Norway) consisted mainly of two year old fish, while the concentrations in the eastern part were dominated by one year old fish. The three year olds seemed to have migrated out of the Barents Sea prior to the survey.

Capelin larvae

Both in 1992 and 1993, the capelin larvae distribution encompassed the entire herring distribution. Some areas of high concentrations of capelin larvae were found, but most of the larvae were distributed evenly within the distribution area, decreasing in abundance towards the edges of the distribution. In 1992, the highest concentrations of capelin larvae were found in the area north-east of North Cape and east of Vardø (Figure 3), where concentrations of up to 1000 larvae per m^2 were found. The highest concentrations of herring and capelin larvae were thus found in the same areas.

In 1993, the highest concentrations of capelin larvae were found in June close to the shore in three separate areas (Figure 4): the area to the west of North Cape (500 larvae/m^2), the area north of the Nordkyn peninsula (100 larvae/m^2) and in the Varanger fjord (100 larvae/m^2). In July, the concentrations were highest in the inner shelf zone (100 m depth) off Syltefjord.

Vertical distribution

Herring

In both years, the herring aggregated in dense schools of varying size with a vertical extension of about 20 m. The schools were mostly recorded in the upper 80 m layer with a dominating distribution closer to surface than 40 m in both years.

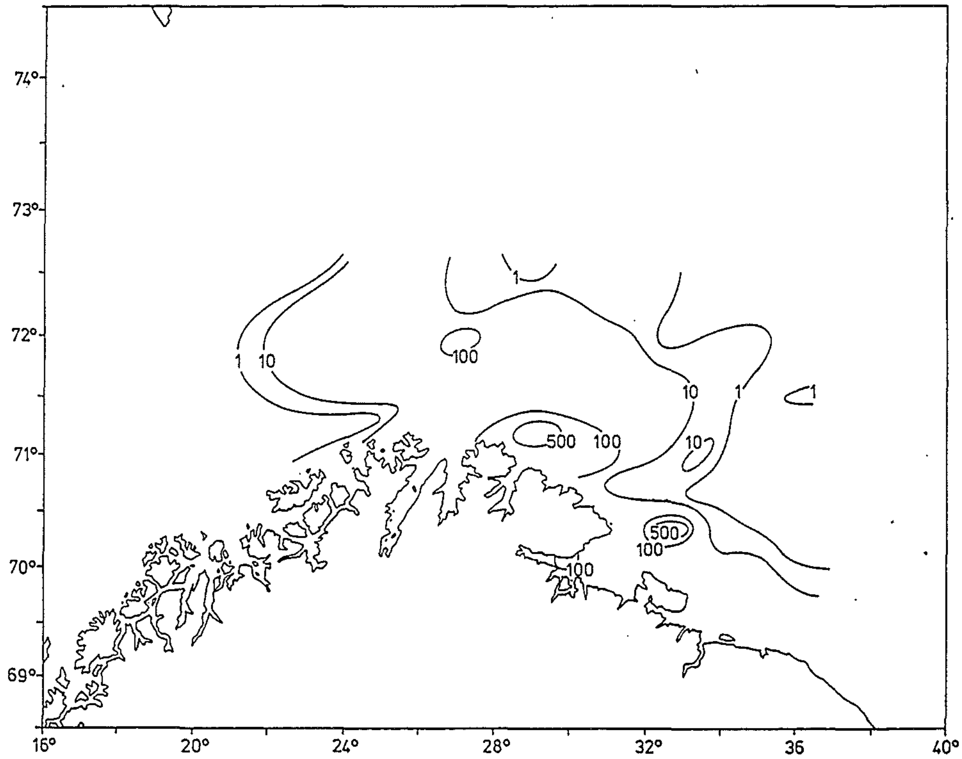

Figure 3. Distribution of capelin larvae in June 1992. Figures in chart indicate number of larvae per m^2. Anon. 1992b. Stippled line indicates 0-line of capelin larvae abundnce.

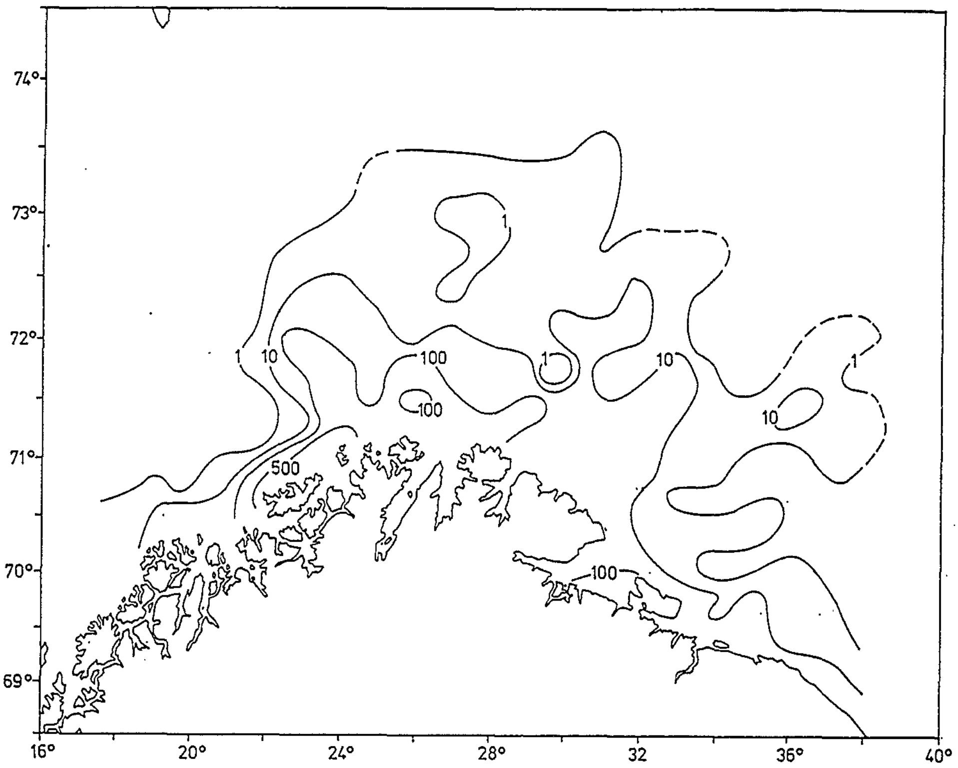

Figure 4. Distribution of capelin larvae in June 1993. Figures indicate number of larvae per m^2. Anon. 1993a.

Capelin larvae

Alvheim (1985) studied the vertical distribution of capelin larvae in three depth intervals 5-25, 30-50 and 55-75 m, and found a decrease in numbers with increasing depth, with only 9% of the total number of capelin larvae in the deepest interval.

Abundance

Herring

The abundance of herring in the Barents Sea in the years 1983 - 1993 is shown in Table 1.

Table 1. Abundance of herring in the Barents Sea. Numbers (N) in billions, (Toresen and Barros 1995).

	Age-groups				
Year	1	2	3	4	Total
1983	0	0	0	0	0
1984	21.4	0	0	0	21.4
1985	0.3	13.9	0	0	14.2
1986	0.5	0.2	3.2	0	3.9
1987	0	0	0	0	0
1988	0	0	0	0	0
1989	2.2	0	0	0	2.2
1990	4.6	0	0	0	4.6
1991	24.3	5.2	0	0	29.5
1992	32.6	14.0	5.7	0	52.3
1993	88.6	25.2	0	0	113.8

Capelin larvae

Table 2. Capelin larvae abundance estimates (nos. x 10^{-12}), average length (mm) of larvae and median date of survey (in June) in the period 1981-1993 (Anon 1992b, Kjell Bakkeplass pers. comm., IMR, Bergen). *Average length of larvae captured on median date of survey.

Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Index	9.7	9.9	9.9	8.2	8.6	0.0	0.3	0.3	7.3	13.0	3.0	7.3	3.3
St.length	11.6	9.2	12.9	11.0	10.3	*8.8	8.9	10.0	12.1	10.3	10.8	10.0	11.0
Date (mid)	8	11	8	2	5	20	25	22	24	19	22	14	15

The capelin larvae abundance estimate (Table 2) was more than two times higher in 1992 than in 1993. The average capelin larvae abundance estimate for the period 1981 to 1993 was 6.2×10^{12}. The abundance of larvae in 1992 was thus above average, while in 1993 it was below average.

Predation

1992

The study was carried out by following predetermined course tracks and trawling on acoustic observations in areas with overlap between herring and capelin larvae. The number of herring stomachs containing capelin larvae was 45, which made up 5.6% of the stomachs investigated. In most of these stomachs, few larvae were found, and usually only single observations were made. At one station (St.no. 362), however, one herring (17.0 cm) contained 40 capelin larvae which comprised more than half of the stomach content. A total of 138 larvae was detected in the herring stomachs, an average of 3.1 larvae per stomach in the herring which were found to have eaten capelin larvae. The larvae eaten by herring ranged from 8 to 15 mm in length.

Predation was observed at six stations (Table 3). There was no correlation (r=0.00, *p*=1.00, n=6) between the number of capelin larvae in the Gulf III samples and the proportion of herring stomachs containing capelin larvae. At one station (St.no. 340), no larvae were caught in the Gulf III while there were several herring containing capelin larvae. Predation occurred in the same areas in both years.

Table 3. Sampling stations at which predation occurred in 1992. The number of larvae in the Gulf III, number of stomachs investigated and the number of stomachs containing larvae.

Date	Time (hrs)	Station	Larvae in Gulf III	Stomachs investigated	Stomachs with larvae
02.06	06.50-07.14	339	0	100	2
02.06	10.08-10.38	340	0	30	28
04.06	08.45-09.05	343	0	60	4
08.06	09.15-09.45	351	2	90	3
11.06	18.51-19.21	360	1	60	4
13.06	20.19-20.49	362	0	4	4
		Sum	3	344	45

1993

The cruise was run following the same procedure as in 1992. Capelin larvae were detected in 77 stomachs of herring, constituting 3.0% of the stomachs examined. Capelin larvae were found in herring stomachs at 19 stations (Table 4). The length of the ingested larvae ranged from 12 to 25 mm. In total, 138 capelin larvae (same as 1992) were found in the herring stomachs, an average of 1.8 larvae per herring containing capelin larvae. There was no correlation (r=0.16, p=0.49, n=19) between the number of capelin larvae in the Gulf III samples and the proportion of herring stomachs containing capelin larvae.

Predation model inputs and results

In order to relate the occurrence of predation to the mortality of capelin larvae, a model was applied. The model was based on the rate of occurrence of larvae in the herring stomachs, on the estimates of herring abundance in the Barents Sea, and a stipulation of the number of "meals" of capelin larvae per day taken by each herring. This stipulation may be based on the observed weight of the stomach content compared to the total amount of expected food intake per day. In the present study, the average observed stomach content was 1.7% of body weight for fish under 9.0 g. This was about 1/3 of the daily ration of 5.0% (at 6.5° C) for comparable sized herring reported by De Silva and Balbontin (1974). Even though the daily ration of food intake is known to decrease with increasing size of the fish (Jobling 1992), the ratio between the observed stomach content and the daily ration should be proportional, independent of fish size (assuming equal daily feeding strategies for all sizes of herring in the study). The relationship between observed stomach content and daily ration from the literature for one year old herring may therefore be adopted to the larger fish. The estimate of the number of meals/day ingested by herring is thus three.

Table 4. Sampling stations at which predation occurred in 1993. The number larvae in the Gulf III, number of stomachs investigated and number of stomachs containing larvae.

Date	Time (hrs)	Station	Larvae in Gulf III	Stomachs investigated	Stomachs with larvae
10.06	04.45-05 05	289	208	80	17
10.06	14.57-15.20	290	8	80	2
19.06	17.12-17.42	304	7	60	1
19.06	21.25-21.55	305	1	60	1
27.06	08.55-09.25	315	3	60	3
27.06	18.20-18.40	317	21	60	3
29.06	17.05-18.05	319	18	60	1
29.06	21.15-21.45	320	16	44	5
01.07	12.12-12.50	325	137	5	3
01.07	17.20-17.50	326	160	60	3
01.07	22.10-22.20	328	142	60	22
02.07	11.54-11.58	331	120	60	1
02.07	20.25-20.45	333	14	60	1
10.07	05.30-06.00	343	1	60	3
10.07	19.00-19.50	345	38	60	5
12.07	20.15-20.45	356	223	60	2
19.07	23.00-24.00	375	92	22	2
20.07	02.20-03.20	376	25	60	1
21.07	01.07-02.17	380	30	50	1
Sum			1264	1061	77

With a daily ration corresponding to three meals/day, and a number of 100 days of exposition to predation, herring would have ingested 37% of the estimated capelin larvae abundance in 1992 and 56% in 1993. In the calculation of mortality in other years than 92 and 93 data of the occurrence of larvae in the stomachs and proportion of herring predators are obtained by calculating the average of the observed 92 and 93 figures. The variables in the model and their input values for all years are shown in Table 5.

Table 5. Variables and their values in the model.

	Input values		
Variables	1992	1993	Other years
X	3.07	1.79	2.43
C	5.6	3.0	4.3
N	52.4×10^9	128.6×10^9	as estimated
M	3	3	3
D	100	100	100

Different scenarios for capelin mortality attributed to predation by herring , dependent on days of availability of capelin larvae to herring predation (80, 100 or 120 days) for the whole time series of herring and capelin larvae estimates since 1984 are shown in Table 6 and in Figure 5.Other scenarios may also be made showing dependence of other paramaters as e.g. meals/day, which the model is quite sensitive to. The results shows that the impact of predation was much higher in the 90'ies than in the mid 80'ties. This is mainly due to a much higher abundance of juvenile herring in the early 90'ies. The occurrence of predation was higher in 1992, but due to higher abundance of herring and lower abundance of capelin larvae in 1993, the impact of predation on the recruitment of capelin was predicted to be higher in 1993.

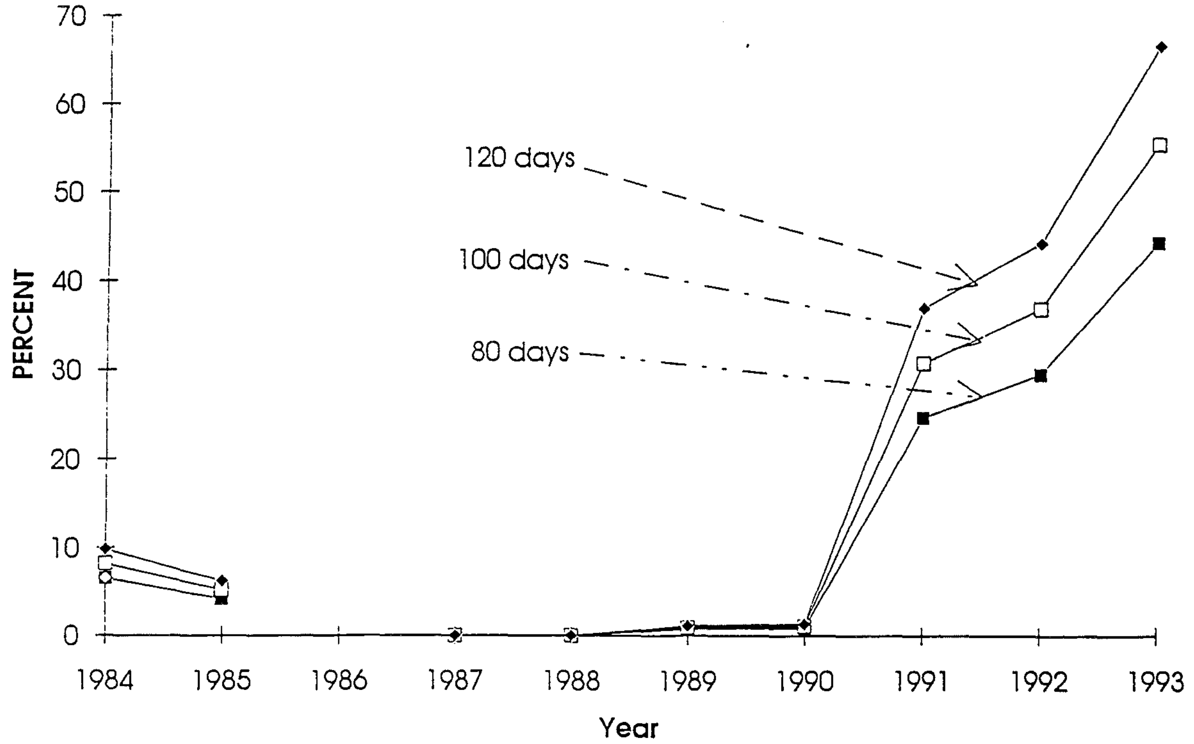

Figure 5. Mortality of capelin larvae in percent of estimated capelin larvae abundance in the years 1984-1993.

Table 6. Estimated number of capelin larvae consumed in the years 1984-1993 in three scenarious of different time-length of predation (80, 100 and 120 days). Proportion of estimated capelin larvae abundance preyed by herring in the same number of days is also given.

Year	TP80	TP100	TP120	TP%80	TP%100	TP%120
1984	0.53	0.67	0.85	7	8	10
1985	0.35	0.45	0.54	4	5	6
1986	0.10	0.12	0.15	-	-	-
1987	-	-	-			
1988	-	-	-			
1989	0.06	0.07	0.08	1	1	1
1990	0.12	0.14	0.17	1	1	1
1991	0.74	0.93	1.11	25	31	37
1992	2.16	2.70	3.24	30	37	44
1993	1.47	1.83	2.20	44	56	67

DISCUSSION

Methodology

Stomach content analysis

In the present study predation by herring on capelin larvae was studied. Ideally, the best way to verify predation in the field is to sample the potential predators and look for prey in their stomachs. Stomach content analysis (SCA) was applied to assess predation by herring on capelin larvae. It has been questioned whether or not this is an appropriate method for investigating predation on fish larvae in the field (Pepin *et al.* 1987; Folkvord 1993). Problems connected with studies of predation on fish larvae using SCA, are those concerned with rapid digestion of larval tissue in fish stomachs, like recognition of larvae and quantification of predation (Bailey and Houde 1989). Several authors have pointed out that fish larvae are digested in less than 30 min. (Hunter and Kimbrell 1980; Christensen 1983). Digestion rate is, however, dependent on the size of the larvae (Folkvord 1993), the temperature (Elliott and Persson 1978; Flowerdew and Grove 1979; Persson 1981) and amount of additional food ingested (dos Santos and Jobling 1991). The studies referred to above were carried out on small larvae (3-6 mm) at higher temperatures than the present study (15°C and 10-11°C for Hunter and Kimbrell 1980 and Christensen 1983 respectively). It is therefore assumed that SCA is applicable under the present conditions.

The surveys

The survey coverage by area was good both in 1992 and in 1993, and the entire distribution area of herring and capelin larvae was covered. In 1992, the area was covered only once, while in 1993, areas of special interest were investigated in more detail. This gave room for a thorough investigation in 1993, and reduced the possibility of missing areas of major importance to predation. However, predation is likely to have continued throughout July and in August in the areas monitored during the survey.

Most of the sampling was carried out in the southern part of the distribution area. As the most abundant locations of herring and capelin larvae were sampled more intensively than other areas, the rates of predation may be slightly overestimated in 1993. In general the concentrations of capelin larvae were relatively uniform within the distribution area of herring, and the estimates of predation are not likely to be systematically overestimated despite the skewed allocation of stations. The total abundance of herring in the Barents Sea was used in the model calculations as potential predators of capelin larvae. This seems reasonable as determined from the spatial overlap in distribution of the predator and the prey.

Abundance estimates

The abundance estimates of herring and capelin larvae used in the model calculations, are likely to be biased. In the survey reports (Anon. 1992a; 1993a), it was concluded that the abundance of the one year old herring may have been underestimated due to avoidance reactions from the vessel. The capelin larvae abundance estimate of 1992 (Anon. 1992b) may have been an overestimate as one station contributed very much to the total estimate. When this station was left out, the capelin larvae abundance estimate was reduced by 25% to 5.6×10^{12}. From this it follows that the predators probably were more abundant and the prey probably were less abundant than the figures applied in the model. If this was the case, the model predictions of the impact of predation are underestimates.

Predation

Horizontal distribution

There was extensive overlap in the distributions of herring in the two years. In 1993 the herring had a more easterly distribution than in 1992. This was probably due to the migration of the three year old herring out of the Barents Sea prior to the survey in 1993, as only few individuals of this age group were caught. In both years studied, the capelin larvae distribution area encompassed the herring distribution, and the predation potential was therefore large. In 1992, the highest concentrations of herring and capelin larvae were in the same areas. This coincided, especially for the area east of Vardø, with high biomass of zooplankton (Anon. 1992d). This is similar to what Helle (1993) found for the larval stages of cod and -capelin in the Barents Sea.

Vertical distribution

Consistent variations of vertical overlap between herring and capelin larvae would influence on the predation model. The capelin larvae abundance estimates are based on the larval abundance in the 0-60 m interval (Gulf III). The larvae found below 60 m would thus have no impact on the predation model, and lack of vertical overlap between the two species is therefore limited to this depth interval. As there seemed to be a high degree of vertical overlap between the species in the 0-60 m interval, the model was not adjusted for this parameter.

The predation model

The number of herring stomachs containing capelin larvae has some value in itself, but it is more interesting if it can be related to the impact of predation on recruitment of capelin. That was the basis for using a predation model.

The time span in which capelin is susceptible to predation by herring is uncertain, but findings in the present study show that herring (13-25 cm) is capable of ingesting relatively large juvenile fish such as 5 cm sand eel. The susceptibility of capelin larvae to predation by herring was here set to be constant for a given number of days while in the predatory field, in order to simplify the model calculations.

The total number of herring in the Barents Sea increased markedly from 1992 to 1993. This was mainly due to a strong herring year-class in 1992 (Anon. 1993a) which was estimated to be 4 times stronger at the one group level than the 1983 year-class, the strongest year-class since the 1960s (Røttingen 1990). The size of the herring did not seem to be important to the predation, as most of the herring stomachs contained few larvae regardless of size of the herring.

It has been shown on several occasions (Fossum 1992) that despite high capelin larvae abundance estimates, the abundance obtained during the 0-group surveys in September have been extremely low. This was the case both in 1992 and in 1993 (Anon. 1992c, 1993b). Predation is therefore probably most important prior to September, and in the model calculations 100 days of predation were applied (May, June, July and early August).

The model predicted that the impact of predation on capelin larvae survival was much higher in the nineties than in the mid eighties. This is probably due to a much higher abundance of herring in recent years combined with a significantly lower abundance of capelin larvae. In addition, the distribution of the 1983 year-class as one year olds was very easterly (Røttingen 1990) and the capelin larvae distribution that particular year therefore did not encompass the distribution of juvenile herring. The impact of predation is therefore overestimated in 1984.

A weakness of the model may be that it does not take into account the reduction in available capelin larvae due to predation. As the capelin larvae are removed by predation, herring will encounter fewer capelin larvae. The model should therefore not be linear, but descending corresponding to the number of larvae left. However, if the predation is assumed to be restricted to a certain size group of larvae, then there would be a steady supply of larvae into the size ranges vulnerable to predation due to differences in hatching time and in growth rate of the larvae. In this case the linear model will be less biased.

The biomass of zooplankton in the Barents Sea was above average for both years studied (Arne Hassel pers. comm., IMR, Bergen). Starvation has thus possibly not been responsible for the extremely high mortality observed for capelin larvae in 1992 and 1993 (according to the 0-group abundances). The presence of herring in the Barents Sea ecosystem seems to be incompatible with normal recruitment of capelin. Fossum (1992) states that there seemes to be two different regimes for recruitment of the Barents Sea capelin, one with herring present and one without herring. Although the number of stomachs containing capelin larvae in the present study were moderate, the model suggests that predation may have severe influence on the survival of capelin larvae. It is therefore likely that predation is the main cause of the high mortality observed for the larvae in years when juvenile herring distribute in the southern Barents Sea. This study thus supports the hypothesis that predation by juvenile herring on capelin larvae has significant impact on capelin recruitment.

CONCLUSIONS

-The capelin larvae abundance encompassed the entire herring distribution area in both years, and there was generally a high degree of vertical overlap.

-In most of the herring stomachs where capelin larvae were found, only a few specimens occurred.

-It is estimated that predation by herring may have strong influence on the survival of capelin larvae when high abundance of herring occur. Predation of capelin larvae was higher in the early nineties than in the mid eighties. This is explained by the much higher abundance of herring and a significant lower abundance of capelin larvae in recent years than in previous years.

REFERENCES

ALVHEIM, O. 1985. Investigations on capelin larvae off Northern Norway and in the Barents Sea in 1981-1984. Pp. 171-184 in Gjøsæter, H. (ed.): *The proceedings of the Soviet-Norwegian Symposium on the Barents Sea capelin. Bergen, 14-17 August 1984.* Institute of Marine Research, Bergen, Norway

ANON. 1992a. Joint survey report. - G.O. Sars, 26 May-14 June. Institute of Marine Research, Bergen, Norway. 9 pp.

ANON. 1992b. Intern toktrapport. - G.O. Sars, 14-21 June. Institute of Marine Research, Bergen, Norway. 4 pp. (In Norwegian).

ANON. 1992c. Preliminary report of the international 0-group survey in the Barents Sea and adjacent waters in August-September 1992. *ICES CM 1992*/G:82, 33 pp.

ANON. 1992d. Datarapport fra planktonundersøkelsene i Barentshavet 1992. Institute of Marine Research, Bergen, Norway. 40 pp. (In Norwegian).

ANON. 1993a. Joint survey report. - G.O. Sars, 1-28 June. Institute of Marine Research, Bergen, Norway. 13pp.

ANON. 1994. Preliminary report of the international 0-group survey in the Barents Sea and adjacent waters in August-September 1993. *ICES CM 1993*/G:3, 38 pp.

BAYLEY, K.M. and **HOUDE, E.D.** 1989. Predation on the eggs and larvae of marine fishes and the recruitment problem. *Adv. Mar. Biol. 25*: 1-83.

BAJKOV, A.D. 1935. How to estimate daily food consumption of fish under natural conditions. *Trans. Am. Fish. Soc.. 65*: 288-289.

BODHOLT, H., NES, H. and **SOLLI, H.** 1989. A new echo-sounder system. *Proceedings of the institute of acoustics (UK). 11* (Pt. 3): 123-130. *Progress Fisheries Acoustics, U.A.G. conf., Lowestoft, UK, 21/22 March 1989.* Institute of Acoustics, Sk. Albans, UK.

CHRISTENSEN, V. 1983. Predation by sand eel on herring larvae. - *ICES CM 1983*/L: 27, 11 pp.

DE SILVA, S.S. and **BALBONTIN, F.** 1974. Laboratory studies on food intake, growth and food conversion of young herring, *Clupea harengus* (L.). *J. Fish.Biol. 6*: 645-658.

DOS SANTOS, J. AND JOBLING, M. 1991. Factors affecting gastric evacuation in cod, *Gadus morhua* L., fed single meals of natural prey. *J. Fish.Biol. 38*: 187-197.

DRAGESUND, O. 1970. Distribution, abundance and mortality of young and adolescent Norwegian spring spawning herring (*Clupea harengus* Linné) in relation to subsequent year-class strength. *FiskDir.Skr.Ser. HavUnders. 15*(4): 451-556.

DRAGESUND, O., GJØSÆTER, J. and **MONSTAD, T.** 1973. Estimates of stock size and reproduction of the Barents Sea capelin in 1970-1972. *FiskDir. Skr. Ser. HavUnders. 16*(4):105-139.

DRAGESUND, O., HAMRE, J. and **ULLTANG, Ø.** 1980. Biology and population dynamics of Norwegian spring-spawning herring. *Rapp. P.-v. Reun. Cons. int. Explor. Mer. 164*: 15-29.

ELLIOTT, J.M. AND PERSSON, L. 1978. The estimation of daily rates of food consumption for fish. *J. Anim. Ecol. 47*: 977-991.

FLOWERDEW, M.W. and **GROVE, D.J.** 1979. Some observations on the effects of body weight, temperature, meal size and quantity on gastric emptying time in turbot using radiography. *J. Fish. Biol. 14*: 229-238.

FOLKVORD, A. 1993. Prey recognition in stomachs of cannibalistic juvenile cod (*Gadus morhua* L.). *Sarsia 78*: 97-100.

FOSSUM, P. 1992. The recovery of the Barents Sea capelin from a larval point of view. *ICES J. mar. Sci. 49*(2): 237-243.

GARROD, C. and **HARDING, D.** 1981. Predation by fish on pelagic eggs and larvae of fishes spawning in the west central North Sea in 1976. *ICES CM 1981*/L: 11, 12 pp.

HAMRE, J. 1985. Assessment and management of Barents Sea capelin. Pp. 5-24 in Gjøsæter, H. (ed.): *The proceedings of the Soviet-Norwegian Symposium on the Barents Sea capelin. Bergen, 14-17 August 1984.* Institute of Marine Research, Bergen, Norway.

HAMRE, J. 1988. Some aspects of the interrelations between the herring in the Barents Sea and the stocks of capelin and cod in the Barents Sea. *ICES CM 1988*/H: 42, 15 pp.

HAMRE, J. 1994. Biodiversity and exploitation of the main fish stocks in the Norwegian-Barents Sea ecosystem. *Biodiv. Conserv. 3*: 272-291.

HELLE, K. 1993. Distribution of early juvenile Arcto-Norwegian cod (*Gadus morhua* L.) in properties. *ICES mar.Sci Symp. 198*: 440-448.

HUNTER, J. and **KIMBRELL, C.** 1980. Egg cannibalism in northern anchovy *Engraulis mordax. Fish. Bull. 78*:811-816.

HUSE, G. AND TORESEN, R. 1995. Feeding habits of juvenile herring and capelin in the Barents Sea. (*In prep.)*

JOBLING, M. 1992. Energiomsetning og vekst. Pp. 258-276 in Døving, K. and Reimers, E. (eds.): *Fiskens Fysiologi.* John Grieg Forlag AS, Bergen, Norway.

KNUDSEN, H.P. 1990. The Bergen Echo Integrator: an introduction. *J. Cons. int. Explor. Mer. 47*:167-174.

KRUSKAL, W.H. and **WALLIS, W.A.** 1952. Use of ranks in one-criterion variance analysis. *J. Am. Stat. Assoc. 47*:583-621.

MACLENNAN, D.N. and **SIMMONDS, J.** 1992. *Fisheries Acoustics.* Chapman and Hall. London. 328 pp.

MAGNUSSON, J. 1968. On the occurrence of capelin larvae in Icelandic waters in relation to temperature. *Rapp. P.-v. Réun. Cons. int. Explor. Mer. 158*:31.

MEHL, S. and **YARAGINA, N.A.** 1991. Methods and results in the joint PINRO-IMR stomach sampling program. Pp. 5-16 in Bogstad, B. and Mehl, S. (eds.): *Interrelations between the fish populations in the Barents Sea. Proceedings of the fifth PINRO-IMR Symposium Murmansk, 12-16 August 1991.* Institute of Marine Research, Bergen, Norway.

METHOT, R.D. 1986. Frame trawl for sampling pelagic juvenile fish. *CalCOFI Rep. 27*: 267-278.

MIDTTUN, L. and **LOENG, H.** 1987. Climatic variations in the Barents Sea. Pp. 13-28 in Loeng, H.(ed.): *The effect of oceanographic conditions on distribution and population dynamics of commercial fish stocks in the Barents Sea. Proceedings of the third Soviet-Norwegian Symposium, Murmansk, 26-28 May 1986.* Institute of Marine Research, Bergen, Norway.

MUNK, P. 1988. Catching large larvae: gear applicability and larval distribution. *J. Cons. int. Explor. Mer. 45*: 97-104.

MOKSNESS, E. and **ØIESTAD, V.** 1987. Interaction of Norwegian spring-spawning herring larvae (*Clupea harengus*) and Barents Sea capelin (*Mallotus villosus*) in a mesocosm study. *J. Cons. int. Explor. Mer. 44*: 32-42.

OLSEN, S. 1968. Some results of the Norwegian capelin investigations 1960-1965. *Rapp. P.-v. Réun. Cons. int. Explor. Mer. 158*: 18-23.

PERSSON, L. 1981. The effects of temperature on the rate of gastric evacuation in perch (*Perca fluviatilis*) fed on fish larvae. - *Freshw. Biol. 11*: 131-138.

PEPIN, P. 1987. Influence of alternative prey abundance on pelagic fish predation of larval fish: a model. *Can. J. Fish. Aquat. Sci. 44*: 222-227.

RØTTINGEN, I. 1990. The 1983 year-class of Norwegian spring spawning herring as juveniles and recruitment spawners. Pp. 165-203 in Monstad, T. (ed.): *Biology and fisheries of the Norwegian spring spawning herring and blue whiting in the Northeast Atlantic. Proceedings of the fourth Soviet-Norwegian symposium, Bergen 12-16 June 1989.* Institute of Marine Research, Bergen, Norway.

TEMPLEMAN, W. 1948. The life history of the capelin (*Mallotus villosus* O. F. Müller) in New Foundland. *Bull. New Foundland. Govt Lab. 17*: 1-151.

TORESEN, R. and **BARROS, P.** 1995. Acoustic estimates of abundance at age of juvenile Norwegian spring-spawning herring (Clupea harengus L.) in the Barents Sea from 1983 to 1993. Pp. 167-178 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, Bergen, 14-17 June 1994.* Institute of Marine Research, Bergen, Norway.

ZAR, J.H. 1984. *Biostatical analysis.* Prentice-Hall, Englewood Cliffs N.J., 718 pp.

ZIJLSTRA, J.J. 1971. Herring larvae in the central North Sea. *Ber. Deutc. Wiss. Komm. Meer. 21*: 92-115.

ØIESTAD, V. 1985. Predation on fish larvae as a regulatory force, illustrated in mesocosm studies with large groups of larvae. NAFO *Sci.Coun.Stud. 8*: 25-32.

THE EFFECT OF DIFFERENT FACTORS UPON THE BARENTS SEA CAPELIN YEAR-CLASSES

by

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ABSTRACT

The analysis of capelin year-class strength is carried out in relation to different factors. Like the majority of species with short life-span, abundance of appearing year-classes of the Barents Sea capelin are subject to considerable fluctuations. Their abundance are positively affected by favourable environmental conditions, especially in the development of early stages. Low abundance of trophic competitors and predators, high level of spawning stock and a wide range of its age composition give higher population fecundity and vatality of juveniles due to favourable feeding and spawning conditions.

An opposite effect of the above factors give rise to a sharp reduction in the abundance of appearing year-classes of capelin. However, under natural conditions, combination of these factors sometimes provides unforeseen results.

INTRODUCTION

The effect of various factors on capelin year-class abundance is analysed. Like most fish species with a short life-span the abundance of new-born year-classes of the Barents Sea capelin show considerable fluctuations. Favourable environmental conditions (especially at early stages of juvenile development), low abundance of trophic competitors and predators, high level of parent stock biomass and wide range of its age composition (which provide a high population fecundity), vitality of juveniles (owing to proper conditions for fattening and wintering of spawners) contribute to an increase in abundance of recruits. The opposite of these factors have negative effects on recruitment and the effect of combination of positive and negative factors under natural conditions are sometimes difficult to forecast. These hypothesis are tested on available data of the Barents Sea capelin.

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MATERIAL AND METHODS

Data from Norwegian, Russian and joint investigations carried out in the Barents Sea were used in this paper. Abundance indices of 0-group capelin of the 1965-1978-year-classes were taken from Anon. 1980. Indices of the 1979-1993-year-classes were calculated by the authers, based on the geographical distribution given in Anon. 1981, 1983, 1984, 1985, 1986a-d, 1987, 1988, 1989, 1990, 1991, 1992, 1994a. The spawning stock biomass and the abundance of capelin at age 1+ were taken from (Dommasnes and Røttingen (1985) and Anon.(1994b).

Results of the assessments on capelin larval abundance in May were taken from national Norwegian investigations (Anon.1994b). Russian estimates of capelin larval abundance are given by Mukhina (1991). Characteristic of the food available (plankton biomass along the Kola section in June-July) is presented by Degtyareva, Nesterova and Panasenko (1990). Information on temperature conditions, population fecundity, age and fatness of capelin are based on materials from PINRO investigations. All factors analysed are shown in Appendix I.

ESTIMATES OF CAPELIN YEAR-CLASS ABUNDANCE

Anomalies of capelin year-class abundance estimated by data from larvae, 0-group and 1-group fish surveys are presented in Figure 1. The data show an overall synchronous variation. However, asynchronous variations are observed for some year-classes. In 1973-1974 and 1982-1984 a rise in abundance of larvae and 0-group fish was noted, whereas the abundance of the same year-classes was reduced at age group 1.

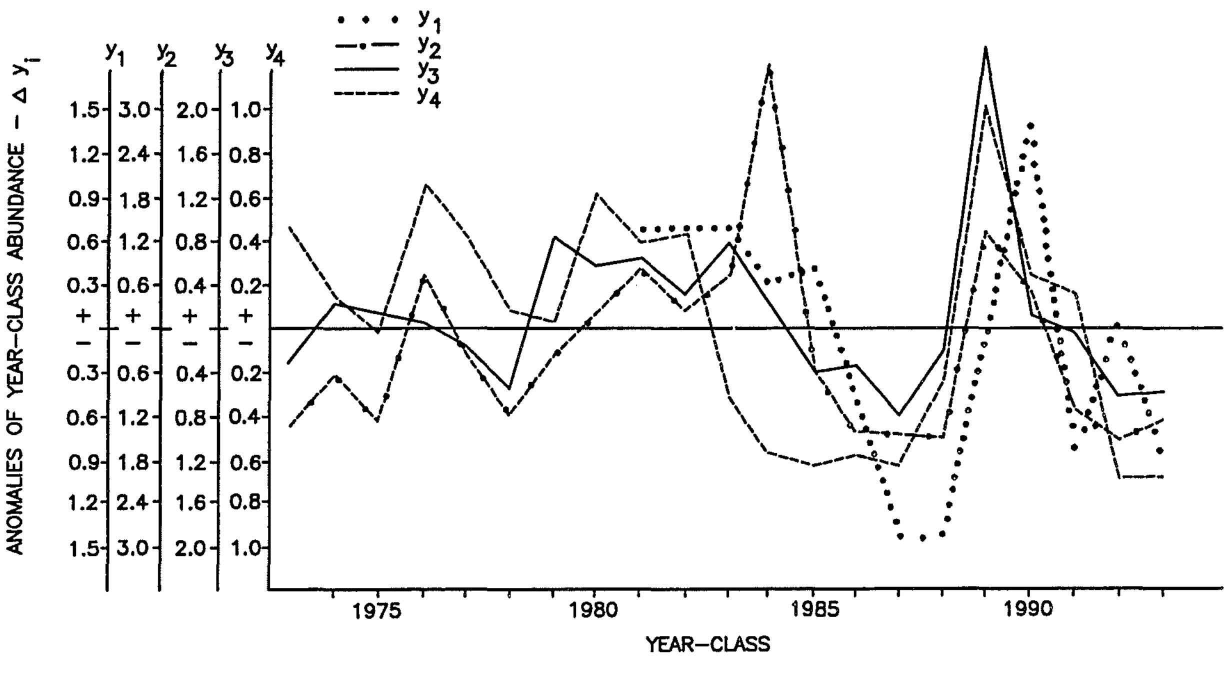

Figure 1. Anomalies of capelin year-class abundance indices for larvae (y_1 and y_2), 0-group fish (y_3) and age-group 1+ in 1973-1993 (y_i corresponds to those in Appendix I).

This reduction in abundance at age 1 was probably due to a marked influence of predators, mainly cod, in those years (Appendix I). Even though, difficulties in obtaining reliable estimates of year-class abundance at the 0-group stage exists (Anon. 1980; Anon. 1981). This estimate is in preference to those obtained at the larval stage. During the 0-group surveys, a complete coverage of the distribution area is obtained, while the larvae survey does not normally cover the whole distribution area.

The analysis of the capelin year-class abundance indices gives significant correlation coefficent (Table 1) between the two larvae abundance measures (r=0,59) and between 0-group and 1-group (r=0,60) compared with r=0,35 and r=0,39 for 0-group and Norwegian larvae index and 0-group and Russian larvae index respectively. However, the 1989-year-class is an outrider and might therefore be excluded in this connections. This cause increased correlation coefficients for Norwegian larvae index and 0-group abundance and 1-group (r=0,59 and r=0,41 respectively). These results indicate that various factors affect the abundance of capelin year-classes between the larvae and the 1-group stage.

Table 1. Relationship between capelin year-class abundance based on Norwegian (y_1) and Russian (y_2) larvae surveys, abundance of 0-group fish (y_3) and fish at age 1 (y_4); Correlation coefficients (r).

:	y_1	y_2	y_3	y_4	y_1*	y_2*	y_3*	y_4*
y_1 :	1,00	0,59	0,35	0,35	1,00	0,60	0,59	0,41
y_2 :	0,59	1,00	0,30	0,39	0,60	1,00	0,30	0,47
y_3 :	0,35	0,30	1,00	0,60	0,59	0,30	1,00	0,46
y_4 :	0,35	0,39	0,60	1,00	0,41	0,47	0,46	1,00

* Excluding data for 1989.

The 0-group capelin indices have been considered unreliable and not included after 1978 in the reports from the joint 0-group survey. Nevertheless, these indices are given in this paper, showing a synchronous dynamics with the abundance estimates of larvae and 1-group capelin. These indices should therefore be carefully considered only in those cases where apparent discrepancy is noted (in 1973, 1983 and 1984). It would be reasonable to rehabilitate the index series for capelin abundance and include it in the report of the joint 0-group survey.

RELATIONSHIP BETWEEN CAPELIN YEAR-CLASS ABUNDANCE AND DIFFERENT FACTORS

The relations between capelin year-class abundance and a wide set of parameters which might influence the abundance of new-born year-classes were analysed (Appendix 1). The production of recruits was assumed by several authors to be determined mainly by the size of the parent stock. A large spawning stock and a wide range of its age groups would provide a higher population fecundity and contribute to the production of abundant progeny (Ushakov and Galkin 1983; Luka *et al.* 1991). Increase in temperature may also contribute to a better survival of fish at the early stages of its development and more abundant year-classes appear (Ushakov and Ozhigin 1987). Fatness of capelin as well as plankton biomass were chosen among factors which might have an effect on abundance of new-born year-class. Low factors mentioned might have a negative influence and give a reduction in abundance of new-born year-classes. Some of these influences are reflected in Figure 2.

The abundance of capelin year-classes is adversely affected by predators, mainly young cod (Mehl 1989; Bogstad and Mehl 1992; Bogstad and Tjelmeland 1992). Summarized logarithmic abundance indices for 0-group cod in the current year and the two previous years were used in this paper as an estimate of the abundance of young cod.

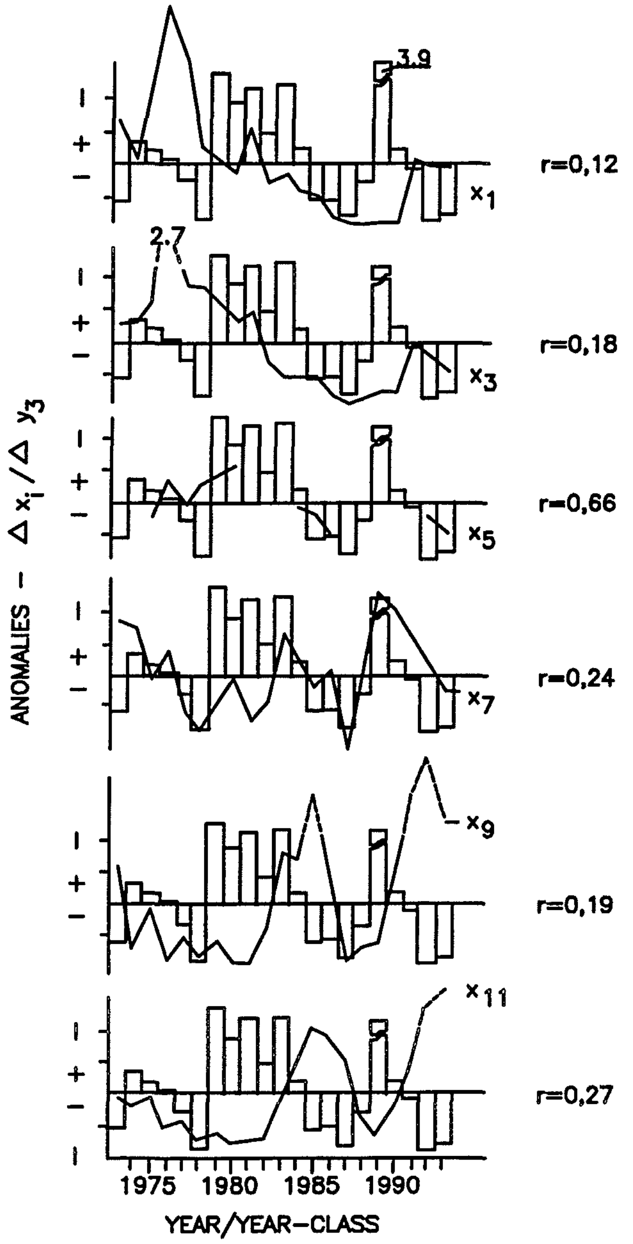

Figure 2. Anomalies of capelin year-class abundance indices at the 0-group-slage (histograms) and some factors (x_i) with potensial effect on the year-class abundance (curves). Basic data given in Appendix I.

In addition to cod, 0-group herring, has been considered as a potential trophic competitor to capelin. Very low correlation between each of these factors and the year-class abundance measures have been observed, both for the whole series of data, and the series without the anomalous data for 1989 (Table 2). Only the correlations given in Table 3, have a significant correlation coefficient, tested by a t-test. When excluding the anomalous data for 1989, some increase in correlation coefficients was observed. On this basis, fatness of capelin in the previous season (x_5) affected significantly the abundance of capelin larvae in the Norwegian survey (y_1). Capelin abundance at the 0-group stage (y_3) depends on fatness of fish (x_5). However, none of the x_i-factors have any significant affect on the larvae abundance (y_2) recorded in the Russian survey. Apparently, it indicates a low relability of these estimates.

The abundance of capelin at age 1+ (y_4) is affected significantly by nearly all the factors considered with the exception of water temperatures (x_6,x_7) and the available plankton (x_8) biomass. The relation between the abundance of capelin at age 1+ and 0-group cod (x_9), young herring (x_{10}), and young cod (x_{11}) is negative, indicating that these factors have a negative effect on the production of capelin year-class strength.

Table 2. Relationship between capelin year-class abundance and different factors; correlation coefficients.

a) anamalous data for 1989 included

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}
y_1:	0,21	0,17	0,29	0,50	0,95	0,11	0,38	-0,25	0,11	-0,01	-0,32
y_2:	0,01	0,03	0,05	0,14	0,27	0,04	0,32	-0,31	-0,09	-0,10	-0,05
y_3:	-0,12	-0,15	-0,05	-0,21	-0,60	0,08	0,41	0,03	-0,20	0,23	-0,29
y_4:	0,43	0,39	0,52	0,37	0,72	-0,06	0,28	-0,09	-0,58	-0,35	-0,65

b) anamalous data for 1989 excluded

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}
y_1:	0,24	0,20	0,31	0,54	0,95	0,10	0,42	-0,32	0,13	0,01	-0,33
y_2:	0,08	0,12	0,12	0,19	0,27	0,01	0,30	-0,35	-0,08	0,12	-0,03
y_3:	0,10	0,11	0,18	0,05	0,66	-0,12	0,24	-0,19	-0,18	0,18	-0,27
y_4:	0,58	0,48	0,67	0,52	0,72	-0,14	0,18	-0,18	-0,57	-0,42	-0,63

Table 3. Regression equations, correlation and determination coefficients, standard error of method of estimation and possible calculation of year-class abundance indicis in advance. Basic data and legend given in Appendix I.

Regression equations	Coefficients of correlation (r) and determination (R^2)		Standard error	Calculation of year-class abundance in advance (months)
	(r)	(R^2)		
y_1= -2.3+ 1.1X_5	0,95	0,90	0,95	8
y_3= -95.2+27.8X_5	0,66	0,60	156,87	8
y_4=135.9+1.1X_1	0,58	0,34	184,65	24
y_4=127.1+0.1X_2	0,48	0,23	199,25	24
y_4=113.1+0.4X_3	0,67	0,45	168,35	19
y_4=-1185.2+387.1X_4	0,52	0,27	213,43	19
y_4=-276.9+50.6X_5	0,72	0,52	206,09	24
y_4=489.7-160.6X_9	-0,57	0,32	205,32	12
y_4=375.5-206.5X_{10}	-0,42	0,18	225,20	12
y_4=560.3- 78.8X_{11}	-0,63	0,40	194,35	12

The equations obtained, presented separately in Table 3, give opportunity to estimate abundance of capelin new-born year-classes by available parameters 1-2 years in advance.

These measures are very preliminary with wide confidence intervales. However, all the factors (x_i), except (x_5) in the regressions have low coefficient of determination, indicating a low prognostic value of the observed estimators.

Thus, a reduction in capelin year-class abundance in 1975-1978 took place under a high level of spawning stock (x_1), high population fecundity (x_3) and low abundance of predators (x_9, x_{10}, x_{11}). Temperature conditions (x_7), which reached a abnormally low level, had probably a predominant impact in that period. Abnormally high temperatures in 1989 concided, on the other hand, to an abundant capelin year-class under a low level of other parameters in that year. In 1979-1983, abundant capelin year-classes were observed under low levels of all parameters.

On the whole, a pronounced negative relationship is observed between the abundance of 0-group capelin (y_3) and young cod (x_9, x_{11}). However, the abundance of capelin is most probably determined by a combination of many factors instead of one. Therefore, a supplementary analysis using step-by-step multiple regression was done, and the analysis produced the following regression equations:

$$y_1=0.37x_1 - 0.02x_2+1.08x_7+6.44x_9 - 11.24x_{10}-1.84x_{11} \qquad (1)$$

where:
the level of significance by Fisher's criterion : $P=0.0017$;
total determination is $R=96.5\%$ (at - $x_1=58.7\%, x_2=2.3\%,$
$x_7=16.6\%, x_9=0.04\%, x_{10}=8.5\%, x_{11}=10.4\%$);
standard error of estimation is 2.16.

$$y_2=-0.01x_1+0.001x_2+1.3x_7-1.2x_{11} \qquad (2)$$

where:
the significance by Fisher's criterion: $P=0.0103$;
total determination is $R=54.2\%$ (at - $x_1=58.6\%$, $x_2=13.0\%$,
$x_7=17.3\%, x_{11}=11.2\%$);
standard error of estimation is 6.92.

$$y_3=0.7x_1-180.9x_6+135.7x_7+173.2x_{10}-53.0x_{11} \qquad (3)$$

where:
significance by Fisher's criterion: $P=0.0000$;
total determination is $R=86.0\%$ (at - $x_1=45.5\%$, $x_6=15.5\%$,
$x_7=13.6\%, x_{10}=4.1\%, x_{11}=7.2\%$);
standard error of estimation is 140.22.

$$y_4=0.36x_1+0.04x_2+92.1x_4+0.03x_8-14.5x_{10}-65.9x_{11} \qquad (4)$$

where:
significance by Fisher's criterion: $P = 0.0000$;
total determination - $R=92.6\%$ (at $x_1=74.0\%$, $x_2= 3.5\%$,
$x_4=1.7\%$, $x_8=0.9\%$, $x_{10}=4.0\%$, $x_{11}=8.5\%$);
standard error of method of estimation is 113.21.

The equations (1-4) show that the spawning stock abundance (x_1) is the main factor determining the abundance of capelin year-classes (45 to 74% of determination). Therefore, in years with a large spawning stock, but low levels of the other factors (1976, 1979-1981) mainly abundant year-classes were recorded as 0-group (Appendix I). Temperatures (x_6, x_7) mainly influence the abundance of larvae (17%) and the 0-group stage (13%), and the temperature effect was pronounced in 1983 and specially in 1989.

Capelin year-class abundance was adversely affected by the abundance of young cod (x_9, x_{11}) which made up 7-10% of the total determination. Its influence was peculiar in 1979-1983 and in 1989 (low abundance of young cod, and high abundance of capelin year-classes), as well as in 1985-1987 and in 1991-1993 (high abundance of young cod, low abundance of capelin year-classes).

Other factors also affect capelin year-class abundance, but to a lesser extent. Nevertheless, in some periods less important factors might be predominant; for example, in 1989 the spawning stock biomass and the population fecundity (x_3) of capelin were low. The abundance of the cod 1987-1988-year-classes $^{v}(x_2)$ was 0-group were also low. In this period, the temperatures were high and appeared to be the predominant factor contributing to the production of abundant capelin year-classes (Appendix I).

The estimated multiple regressions (equations 1-4) were verified, using independent assessment of capelin year-class abundance in 1994 (Table 4). Due to a wide range of parameters, a verification of the parameters were mainly made for those years in which maximum, minimum and close to long-term mean values of dependent variables (y_i) were observed, as well as for their long-term mean level and the most recent observations (1993). These calculations are given in Table 4, including actual data on capelin abundance for comparison. According to the calculations, the abundance of the capelin 1994-year-class is expected to be low. However, the data obtained indicate that reliable prognostic estimates of capelin year-class abundance occur only in the years where the abundance (y_i) is close to the long-term mean.

Table 4. Verification of relations and calculations year-class abundance of capelin for 1994 (multiple relation)

	y_1			y_2			y_3			y_4*		
	Year	Act.	Calc.	Year	Act.	Calc.	Year	Act.	Calc.	Year	Act.	Calc.
y maximum values	1990	13.0	9.3	1984	27.0	5.6	1989	1300	446.8	1990	700	269.0
	-	-	-	-	-	-	1979	660	480.9	1977	625	577.6
	-	-	-	-	-	-	1983	589	525.5	1981	600	407.5
y minimum values	1987	0.3	0.003	1986	0.6	3.1	1992	26	75.9	1993	2.2	20.6
	1988	0.3	2.8	-	-	-	1985	110	100.8	1986	7.5	63.7
y-close to long-term mean	1989	7.3	3.2	1980	9.0	8.0	1976	281	326.0	1976	270	349.6
	1992	7.3	5.1	1985	4.7	2.9	1991	241	328.1	1980	335	431.8
y long-term means	-	6.7	21.8	-	7.8	6.0	-	265	269.3	-	309.8	289.7
1993	-	3.3	1.1	-	0.9	1.4	-	43	3.1	-	2.2	20.6
1994	-	-	-	-	-	-	-	-	-	-	-	10.5
Standard calcul. error	-	-	2.46	-	-	6.92	-	-	140.22	-	-	113.21

* Estimates of corresponding calendar year; y_i corresponds to those in Table 1.

Probably, considering a spatial distribution of the factors analysed (a locality of young capelin, predators, temperature and other conditions typical of these areas), as it was done by Gundersen (1993), it will be possible to increase the reliability of the relations calculated and to improve their forecasting strength. Besides, to eliminate errors in calculations (in view of a wide range of values of the parameters considered) such analysis should be reasonable to conduct by groups of factors ranged into classes of maximum, average and minimum values. However, it is a subject for further studies.

REFERENCES

ANON. 1980. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1978. *Annls biol., Copenh. 35:*273-280.

ANON. 1981. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1979. *Annls biol., Copenh. 36:*219-226.

ANON. 1983. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1980. *Annls biol., Copenh. 37:*259-266.

ANON. 1984. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1981. *Annls biol., Copenh. 38:*228-236.

ANON. 1985. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1985. *ICES CM 1985*/G: 75, 27 pp.

ANON. 1986a. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1982. *Annls biol., Copenh. 41:*165-172.

ANON. 1986b. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1983. *Annls biol., Copenh. 41:*172-180.

ANON. 1986c. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1984. *Annls biol., Copenh. 41:*180-188.

ANON. 1986d. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1986. *ICES CM 1986/G:* 78,27 pp.

ANON. 1987. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1987. *ICES CM 1987*/G: 38, 31 pp.

ANON. 1988. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1988. *ICES CM 1988*/G: 45, 37 pp.

ANON. 1989. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1989. *ICES CM 1989*/G: 40, 40 pp.;

ANON. 1990. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1990. *ICES CM 1990*/G: 46, 36 pp.

ANON. 1991. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1991. *ICES CM 1991*/G: 50, 33 pp.

ANON. 1992. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1992. *ICES CM 1992*/G: 82, 33 pp.

ANON. 1994a. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1993. *ICES CM 1994*/G: 3, 38 pp.

ANON. 1994b. Report of the Atlanto-Scandian herring and capelin Working Group. *ICES CM 1994*/Assess: 8, 84 pp.

BOGSTAD, B. and **MEHL, S.** 1992. The North East Arctic cod stock consumption of various prey species , 1984-1989. Pp. 59-72 in Bogstad, B. and Tjelmeland, S. (eds.): *Interrelations between fish populations in The Barents Sea. Proceedings of the fifth PINRO - IMR symposium, Murmansk, 12-16 August 1991.* Institute of Marine Research, Bergen, Norway.

BOGSTAD, B. and **TJELMELAND, S.** 1992. A method for estimation mortalities on capelin using a cod-capelin model for the Barents Sea. Pp. 111-137 in Bogstad, B. and Tjelmeland, S. (eds.): *Interrelations between fish populations in The Barents Sea. Proceedings of the fifth PINRO - IMR symposium, Murmansk, 12-16 August 1991.* Institute of Marine Research, Bergen, Norway.

DEGTEREVA, A.A., NESTEROVA, V.N. and **PANASENKO, L.D.** 1990. Peculiarities of forming of food zooplankton in feeding area of the Barents Sea. *Pp. 24-33 in: Food resources and food relations of fish of the north Atlantic. Sbornik nauchnykh Trudov.* Polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., Murmansk. (In Russian)

DOMMASNES, A. and **RØTTINGEN, I.** 1985. Acoustic stock measurements of the Barents Sea capelin 1972-1984. A review. Pp. 45-108 in Gjøsæter, H. (ed.): *The proceeding of the Soviet-Norwegian symposium on The Barents Sea capelin. Bergen, 14-17 August 1984.* Institute of Marine Research, Bergen, Norway.

GUNDERSEN, A.C. 1993. Distribution of larval and 0-group capelin (Mallotus villosus) in the Barents Sea in relation to environmental factors.1981-1991. *ICES CM 1993/*H:15, 20 pp.

LUKA, G.I., USHAKOV, N.G., OZHIGIN, V.K., GALKIN, A.S., TERESHCHENKO, E.S., DVININ, Yu.F. and **BOCHKOV, Yu.A.** 1991. *Recommendations for rational exploitation of the Barents Sea capelin.* Polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., Murmansk, 193 pp. (Internal report in Russian).

MEHL, S. 1989.The Northeast Atctic cod stock's consumption of commercially exploited prey species in 1984-1986. *Rapp.P.-v.Reun.Cons.int.Explor.Mer. 188*: 185-205.

MUKHINA, N.V. 1992. Results from the ichthyoplankton surveys conducted in the Norwegian and Barents Seas in 1959-1990. Pp. 62-102 in*: Ecological problems of the Barents Sea. Sbornik nauchnykh Trudov.* Polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., Murmansk 1983: 100-115. (In Russian)

USHAKOV, N.G. and **GALKIN, A.S.** 1983. Structure and dynamics of abundance of the Barents Sea capelin stocks. Pp. 100-115 in Mitenov, V.K. *et al.* (eds.): *Biology and fishery of pelagic fish of the North Basin.* Polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., Murmansk. (In Russian)

USHAKOV, N.G. and **OZHIGIN, V.K.** 1987.The abundance of year-classes of the Barents Sea capelin and peculiarities of the distribution of the young in relation to hydrographic conditions. Pp. 159-167 in Loeng, H. (ed.): *The effect of oceanographic conditions on distribution and population dynamics of commercial fish stocks in the Barents Sea. Proceedings of the third Soviet-Norwegian symposium. Murmansk, 26-28 May 1986.* Institute of Marine Research, Bergen, Norway.

Appendix I. Parameters included in the analysis. [1)]

	y_1	y_2	y_3	y_4	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}
1965		0.0	37							3.08	5.88	453	0.01		0.01
1966		0.1	119.							1.93	6.12	350	0.02	0.14	0.03
1967		6.4	89							2.98	7.12	247	0.04	0.00	0.07
1968		9.5	99							3.01	5.59	154	0.02	0.00	0.08
1969		13.6	109							2.50	6.10	60	0.25	0.01	0.31
1970		11.1	51							3.41	7.14	185	2.51	0.00	2.78
1971		19.8	151	640.0				4.0	15.3	2.74	6.16	36	0.77	0.00	3.53
1972		38.9	275	410.0				4.2	12.0	3.21	7.88	100	0.52	0.00	3.80
1973		0.9	125	540.0	216.0	2726.7	530.4	4.4		3.84	7.63	199	1.48	0.05	2.77
1974		4.3	359	380.0	138.0	1385.0	548.7	4.3		3.20	7.51	115	0.29	0.01	2.29
1975		1.4	320	270.0	296.0	948.0	667.6	4.1	9.4	3.77	6.74	116	0.90	0.00	2.67
1976		11.8	281	625.0	446.0	2965.0	1551.4	4.1	16.0	3.40	7.22	261	0.13	0.00	1.32
1977		6.0	194	515.0	320.0	2701.0	772.2	4.4	11.3	2.78	6.23	66	0.49	0.01	1.52
1978		1.6	40	360.0	168.0	2762.0	749.2	4.3	15.0	2.17	5.90	61	0.22	0.02	0.84
1979		6.2	660	335.0	136.2	2013.0	641.9	4.0	16.7	1.90	6.34	238	0.40	0.09	1.11
1980		9.0	502	600.0	108.2	1202.0	539.0	3.9	18.1	2.87	6.73	359	0.13		0.75
1981	9.7	12.6	570	496.0	200.1	3867.0	606.3	4.0		2.03	6.07	74	0.10	00.0	0.63
1982	9.9	9.4	393	515.0	84.9	1549.7	277.1	3.9		2.84	6.38	68	0.59	0.00	0.82
1983	9.9	12.0	589	145.0	108.1	1365.0	193.7	3.7		3.73	7.46	46	1.69	1.77	2.38
1984	8.2	27.0	320	35.0	69.9	1327.6	194.6	3.8	10.8	3.28	7.09	54	1.55	0.34	3.83
1985	8.6	4.7	110	7.5	54.5	1141.6	195.5	4.0	9.6	2.95	6.58	306	2.46	0.23	5.70
1986		0.6	125	37.0	17.8	274.7	63.4	3.8	5.7	2.66	6.87	581	1.37	0.00	5.38
1987	0.3	0.01	55	20.0	4.2	62.6	7.6	3.5		2.61	5.60	326	0.17	0.00	4.00
1988	0.3	0.01	187	178.0	1.1	17.0	39.6	3.1		3.11	6.73	30	0.33	0.32	1.87
1989	7.3	14.7	1300	700.0	12.1	203.3	80.9	3.4		3.74	8.01	334	0.38	0.59	0.88
1990	13.0	10.3	324	392.0	10.5	181.3	94.5	3.5		3.92	7.78	44	1.23	0.31	1.94
1991	3.0	1.8	241	351.0	133.4	2620.1	397.5	3.6		3.82	7.45	132	2.30	1.19	3.91
1992	7.3	0.0	26	2.2	121.0	2117.2	339.3	3.6	8.6	3.99	6.99	90	2.94	1.06	6.47
1993	3.3	0.9	43	19.7	120.5	2228.0	225.9	3.8	5.7	3.51	6.50	77	2.09	0.75	7.33
	6.7	7.8	265	309.8	131.7	1601.5	414.6	3.9	14.1	3.09	6.79	201	0.91	0.26	2.78

[1)] - Parameters

y_1 - Norwegian estimate of abundance of larvae in May, 10^{12} spec.;
y_2 - Russian index of abundance of larvae in May, spec./catch;
y_3 - index of 0-group capelin abundance in August;
y_4 - abundance of 1-group capelin in September of subsequent year, bill.spec.;
x_1 - abundance of capelin spawning stock in September of previous year, bill.spec.;
x_2 - biomass of capelin spawning stock in September of previous year, thou.t;
x_3 - population fecundity of capelin, 10^{12} eggs;
x_4 - mean age of capelin in March, years;
x_5 - fatness of capelin in September of previous year, %;
x_6 - water temperature along the Kola section in 0-200 m layer during the second quarter;
x_7 - water temperature along the Kola section in 0-50 m layer in the third quarter;
x_8 - biomass of plankton along the Kola section in March-June, mg/m^3;
x_9 - logarithmic index of 0-group cod abundance in August;
x_{10} - logarithmic index of 0-group herring abundance in August;
x_{11} - summarized logarithmic index of 0-group cod abundance in a the current year and the two previous years;

CHARACTER OF COD EFFECT ON POPULATION OF HERRING IN THE BARENTS SEA

by

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ABSTRACT

The cod effect on the abundance of herring and its importance as food for cod are analysed on the basis of data for consumption of juvenile herring in the Barents Sea in 1984-1994. The effect of cod on poor herring year-classes is negligible caused by their low abundance and small distribution area. Cod experienced a considerable predation pressure on strong year-classes of herring, espesially in periods with decreasing capelin abundance and coincidence of cod and herring distribution. When distribution areas of cod, capelin and herring coincide, small cod feed most intensively on capelin and large cod on herring. 0-group herring from abundant year-classes are less heavily consumed by cod, than herring at age 1+ - 3+ with mean length 13 -19 cm. These length groups become the main prey for cod in some years.

The preliminary results show that the amount of herring consumed by cod when poor yearclasses of herring stay in the Barents Sea varied from 17 to 4 thousand tonnes during a year and increased to 22-76 thousand tonnes when abundant herring year-classes appeared. In 1992 the amount of herring consumed by cod reached more than 600 thousand tonnes.

As a result of strong year-classes the herring abundance in the Barents Sea increased in the beginning of the 1990's, and a delay in growth rate of herring in 1993 will prolong the dwelling in the Barents Sea. In a period with reduced capelin abundance, cod shift to herring as the favorite prey which could be serious.

INTRODUCTION

Two sub-species of *Clupea harengus* are recorded by Russian scientists in the Barents Sea: Norwegian spring spawning herring (*Clupea harengus harengus*) and Arctic herring (*Clupea harengus pallasi natio suworowi*). The Arctic herring has a higher number of vertebrae and a lower growth rate (Pashkova 1983). The two group of herring are to some extent overlapping in distribution. However, the center of the shoals of Arctic herring is recorded further to the east compared with the Norwegian spring spawning herring. The distribution of cod and the two herring groups overlapp each other. Therefore, the Norwegian spring

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spawning herring and the Arctic herring have to be considered as potensial prey for cod. The level of herring consumption by cod depends on their overlapping distribution, density of herring concentrations, as well as availabilty of other prey. The availability of herring is sharply reduced when herring migrate to the surface for feeding on *Calanus* (May-July) and increase after the feeding season when herring discend to the bottom layers (Manteufel and Boldovskij 1938). Seasonal vertical migrations of herring vary, depending on the plankton production, herring density, fullness of the stomach, and herring migration to other areas with higher food abundance (Zelikman and Kamshilov 1960).

In the 1960's, herring as plankton consumer and prey for fish predators, had an important place in the trophic structure of the Barents Sea communities. In the 1930's, herring reached an average of 20% by weight of the cod diet, in some seasons 75-90% annually (Zatsepin and Petrova 1939). In the western and central Barents Sea immature Norwegian spring spawning herring were the main prey for cod. Arctic herring, forming wintering concentrations (adult fish) in the southeastern Barents Sea, were of less importance as prey for cod. In areas of overlapping distribution with Norwegian spring spawning herring both groups were consumed. In the western and central Barents Sea area herring were the most important food item in cod diet from October to April when the herring were living in deeper waters or close to the bottom. From May to September when the herring are feeding on zooplankton in the surface layers their importance in cod diet is small. From the end of September and in November herring occurred in cod stomachs on the slopes of the Goose Bank and adjacent waters (Zatsepin and Petrova 1939).

Studies of predation on herring of the abundant 1983-year-class of cod (Orlova *et al.* 1988, 1989; Orlova 1992a, 1992b) have shown that, provided herring concentrations were available, the main effect on the herring was caused by cod more than 40 cm which selected herring 16-22 cm during their wintering migrations in the western areas. Small cod feed more intensively on prespawning capelin during the migration to the coastal areas as well as juvenile herring of smaller sizes. Therefore, availability of capelin and size composition of cod schools are important factors in considering the effect of cod predation on herring.

The present paper analyses cod predation on herring in the period 1984-1994. The data obtained allow to evaluate the importance of Norwegian spring spawning and Arctic herring jointly as food for cod. This is necessary in relation to reduced capelin abundance and the general dynamic variations in the trophic structure of the Barents Sea.

MATERIALS AND METHODS

In assessing the importance of herring year-classes of different abundance as food for cod several difficulties are met. Available data on cod feeding were not always complete and did not always reflect peculiarities of predators feeding in relation to distribution of capelin, their main prey species. Sometimes, only fragmentary or indirect informations had to be used.

Quantitative weight data on cod feeding available in the Norwegian-Russian data base for the years 1984-1994 as well as data on cod feeding collected by scientists at the Murmansk Marine Biological Institute (MMBI) are used in this paper. Data on cod feeding were collected and processed by generally accepted methods (Anon. 1974). Calculations of predation on herring by cod were made using a modified formula described by dos Santos (Bogstad and Mehl 1992).

This paper gives a Barents Sea map with the fishing areas (Figure 1). Areas with numbers 17, 15, 9, 21-26, 42 are the western areas; 29-36 the northwestern; 37-41 the northern; 3b, 4a, 4b, 4c, 5, 6a, 6b, 8, 10, 10a, 16, 18 the central; 3a, 7, 11-14 the coastal;1a, 1b, 2a, 2b, 19, 20a, 20b the eastern. The maps of herring and cod distribution by quaters of the years show only those areas, where both herring and cod were located.

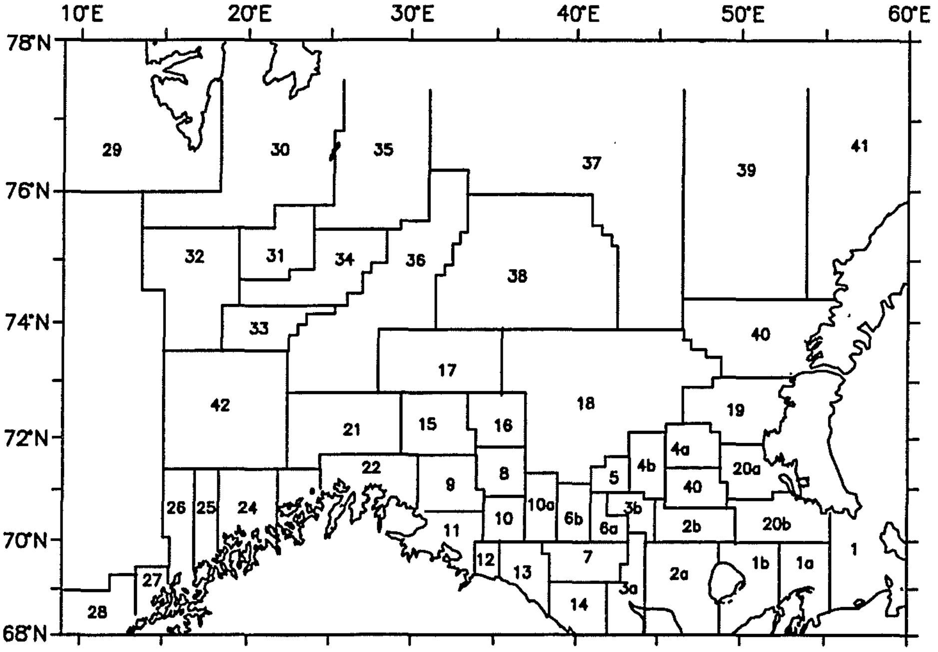

Figure 1. Russian statistical areas in the Barents Sea. Names and area number are used in Tables 4-8.

ABUNDANCE AND DISTRIBUTION OF HERRING IN THE 1980-1990'S

The area of distribution of Norwegian spring spawning herring depends on year-class strength and intensity of the Norwegian Current when herring larvae are drifting from the spawning grounds. Inside the Barents Sea, herring larvae are drifting in warm waters of the North Cape Current and some branches of it (Marti 1941). In cold years when the intensity of the Norwegian Current is low, herring larvae are not carried far to the north but distributed in coastal waters of southern and central Norway. In years characterized by increased water temperature, herring larvae are brought to the northeastern Norwegian Sea and into the Barents Sea (Fedorov 1962). Rich year-classes appear mainly in warm years, and poor year-classes in cold years (Benko and Seliverstov 1969; Judanov 1964).

The level of water heat content of the Barents Sea is described by water temperature in the "Kola meridian" section (Konstantinov 1967; Mukhin and Sarynina 1974) as well as by the temperature in the other hydrographic sections observed at the end of August - beginning of September during the annual international 0-group fish survey (Anon. 1994a). High positive anomalies of water temperature in 0-200 m layer in the main sections in 1983 and 1989-1993 caused high abundance of the corresponding year-classes of Norwegian spring spawning herring (Table 1). Low intensity of the Norwegian Current in 1984-1988 resulted in a decrease in heat content of the Barents Sea, and the water temperature in those years was below or slightly above the long-term mean (Table 1). As a result, only poor year-classes of herring were observed.

Table 1. Anomalies of water temperature (Dt°C) in hydrographic sections and abundance index of 0-group herring in the Barents Sea in 1983-1993. (Anon. 1994a).

Year/	Section							Abundance index of 0-group herring
	"Kola meridian" (70°30'N-72°30'N, 33°30'E)			Cape Kanin (68°45'N-72°05'N, 43°15'E)	Cape Kanin (71°00'N-72°00'N, 43°15'E)	North Cape-Bear Island (71°33'N,25°02'E - 73°35',20°46'E)	Bear Island - West (74°30'N, 06°34'E-15°55'E)	
Depth	0-50	50-200	0-200	0-bottom	0-bottom	0-200	0-200	
1983	+0.8	+1.0	+0.9	+0.9	+1.0	+0.6	+0.5	1.77[1]
1984	+0.4	+0.3	+0.3	+0.3	+0.4	+0.2	+0.4	0.34[1]
1985	-0.2	-0.3	-0.3	-0.8	+0.2	-0.4	+0.0	0.23
1986	+0.2	-0.3	-0.2	-0.3	-0.0	+0.1	-0.2	0.00
1987	-1.1	-0.5	-0.7	-1.5	-0.7	-0.5	-0.7	0.00
1988	-0.3	-0.1	0.2	-0.4	-0.3	-0.2	-0.4	0.32
1989	+1.3	+1.6	+1.1	+2.3	+1.1	+1.2	+0.3	0.59
1990	+0.8	+0.6	+0.6	+0.8	+0.7	+0.6	+1.1	0.31
1991	+0.4	+0.7	+0.6	+0.6	+1.0	+0.3	+0.8	1.19
1992	+0.2	+0.8	+0.6	+0.8	+0.8	+0.4	+0.4	1.06
1993	+0.2	+0.2	+0.2	+0.2	+0.2	+0.1	+0.8	0.75

[1] Toresen 1985

Investigations by Bochkov and Tereshchenko (1992) have shown that large-scale variations of the hydrological regime in the Barents Sea are of particular importance for year-class strength of the main commercial fish species - cod, haddock, capelin, redfish, polar cod and herring. In the warm periods of the Barents Sea, 1930-1964, the frequency of rich herring year-classes increased 2.8 times compared to the cold period 1900-1918. As for cod, a number of strong year-classes exceeded poor year-classes almost 2 times. Decreasing temperature in 1965-1981 and intensified herring fishery at every stage of their life cycle coinsided with poor year-classes of herring. In the next warm period, 1989-1991, strong year-classes of herring, cod and haddock appeared, and in 1989 also a strong capelin year-class (Ushakov and Shamry 1995, Bochkov and Tereshchenko 1992). Changes in the temperature regime had similar consequences for Arctic herring: poor year-classes were observed in the cold period 1984-1987 and rich ones after 1988.

Strong year-classes of Norwegian spring spawning herring are widely distributed in the Barents Sea as shown by the 0-group in 1983 and 1989-1993 (Anon. 1986a, 1989-1992, 1994a). Poor year-classes were distributed in a narrow coastal zone and did not occur east of 28°E. These observations refer both to 0-group and age groups 1 and 2 of the 1984-1987-year-classes (Anon. 1985, 1986b, 1986c, 1987; Pashkova and Seliverstova 1988). 0-group herring of the average 1988-year-class occurred more eastwards, but the area of distribution was considerably smaller than that of the rich year-classes. The area of distribution is somewhat expanded by age. However, the 0-group pattern of distribution remains.

A sharp deterioration of the invironmental conditions in the cold year 1979 might have been responsible for the westward emigration of the Arctic herring to the Kildin Island area (Pashkova 1983). Increasing heat content of the Barents Sea by the end of the 1980's - beginning of the 1990's might have been responsible for the later increase in the distribution area of Arctic herring (Figure 2).

Depending on abiotic conditions, duration of feeding periods as well as growth and maturation rates, Norwegian spring spawning herring remains in the Barents Sea for 2-4 years. Presence or lack of food competition (both intra- and interspecific) have an effect on herring growth (Seliverstova 1990). In the 1980's low abundance of juvenile Norwegian spring spawning herring (compared to 1950-1960's) and low abundance of other plankton-eaters caused high growth rate both of the strong 1983-year-class and the poor 1984-1985-year-classes which involved an early maturation and emigration to the Norwegian Sea at an age of 2-3 years (Seliverstova 1990). Early 1988, increasing heat content of the Barents Sea contributed to good feeding conditions and increased growth rate of the abundant 1989-, 1991-, 1992-year-classes of the Norwegian spring spawning herring and the abundant 1988-year-class of the Arctic herring,

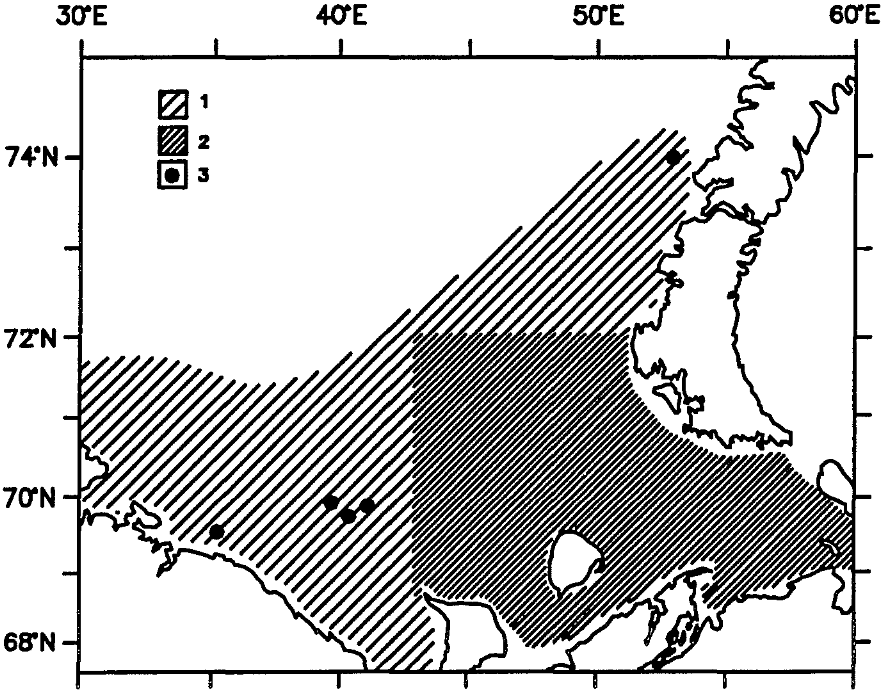

Figure 2. Distribution of Arctic herring in the Barents Sea:
1: Pashkova 1983
2. Data from investigations 1983-1993
3: Pashkova 1983. Data from 1972-1981.

The growth rate of these year-classes is at the same level or even higher than observed of the year-classes of the 70-80's (Table 2). However, in 1993 a decrease in growth rate of the 1991-1992-year-classes at age 2+, 1+, 0+ was observed, which might have been caused by interspecific food competition (Table 2, 3). Acoustic survey for herring in the Barents Sea in May-June 1993 showed that the total estimated abundance of age-group 1+ - 3+ constituted 129930 x 10^6 fish, while in the same period of 1985, when only fish of the 1983-year-class were present in the Barents Sea, the abundance constituted 19900 x 10^6 fish (Anon. 1994b). The observed decrease in growth rate of herring from the 1991-1993 year-classes would prolong their staying in the Barents Sea, and predation by cod will have an increasing effect on herring abundance.

Table 2. Mean length (cm) of herring observed in the Barents Sea.

Year-class	Age				
	0+ 1)	1+ 2)	2+ 2)	3+ 2)	4+ 2)
Norwegian spring spawning herring					
1950	-	-	15.3	17.9	
1959	9.6 3)	-	17.8	17.7	
1983	8.3	13.8	18.9	20.7	
1984	8.4	14.9	18.0	-	
1985	9.0	15.7	-	-	
1988	6.9	-	18.2	19.5	
1989	7.9	14.7	18.4	22.6	
1990	8.9	15.9	18.3	20.2	
1991	7.9	14.3	15.3		
1992	9.0	11.4			
1993	7.5				
Arctic herring			4)	4)	4)
1972				20.3	19.6
1973				18.5	19.5
1974				18.8	19.7
1975				-	17.5
1976				14.8	17.3
1988			18.0	19.7	21.7
1989				19.5	

1) 1983-1994: Anon. (1985, 1986a-1986c, 1987-1992, 1994a)
2) 1950-1985: Pashkova and Seliverstova (1988)
3) 1959: Dragesund (1970)
4) 1972-1976: Pashkova (1983)

COD FEEDING ON HERRING

In 1984, despite lack of data on cod feeding for the whole year and different distribution of the main concentrations of cod and herring in the first half of the year it might be indication that herring of the 1983-year-class might have been a certain part of the cod stomach content (Figure 3).

Table 3. Mean length of herring in the Barents Sea in I and IV quarters in 1983-1994. Length in cm.

Age	1983		1984		1985		1986		1987		1988		1989		1990		1991		1992		1993		1994
	I	IV	I	IV	I	IV	I	IV	I	IV	I	IV	I	IV	I	IV	I	IV	I	IV	I	IV	I
0+	-	9,5	-	10,6	-	10,4	-	-	-	-	-	8,7	-	9,2	-	-	-	-	-	10,9	-	-	-
1+	-	13,0	-	13,9	11,0	15,0	10,0	15,8	-	-	-	-	-	13,8	11,0	17,0	11,0	16,4	-	14,4	10,1	13,8	9,6
2+	-	16,1	14,6	22,0	14,5	19,0	15,0	18,3	15,0	-	-	-	17,8	16,7	16,5	18,7	16,7	19,9	16,8	20,0	14,4	17,0	13,8
3+	-	20,0	19,5	-	18,5	24,7	18,6	21,2	14,6	17,0	16,8	20,6	21,2	21,0	18,0	20,4	19,1	19,7	21,8	23,2	20,0	18,3	18,1
4+	-	-	-	-	-	27,3	23,7	22,3	16,4	16,9	-	20,5	22,5	21,0	25,0	22,8	21,4	21,2	26,4	21,9	25,1	23,6	23,4
5+	-	-	26,0	-	-	-	22,3	27,0	18,1	17,9	25,5	-	-	22,1	27,0	24,2	-	-	26,2	22,5	27,4	26,0	25,8
6+	-	-	-	-	-	-	-	30,0	19,8	19,3	-	-	-	22,4	-	24,2	-	22,5	-	23,7	-	28,0	29,7
7+	-	-	-	-	-	-	24,5	-	21,4	20,7	23,0	19,6	-	22,9	-	-	22,0	-	-	23,5	-	-	-
8+	-	-	-	-	-	-	-	-	22,7	22,1	-	-	-	24,2	-	25,0	23,5	26,0	-	24,5	-	-	-
9+	-	-	-	-	-	-	-	-	26,6	23,6	25,0	-	-	24,3	-	27,0	-	-	-	27,2	32,0	-	-
10+	-	-	-	-	-	-	-	-	-	25,2	22,0	-	-	-	-	-	-	-	-	26,0	-	-	-
11+	-	-	-	-	-	-	-	-	-	25,0	25,5	-	-	27,0	-	-	-	-	-	-	-	-	-
12+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13+	-	-	-	-	-	-	-	-	-	25,0	-	-	-	-	-	-	-	-	-	-	-	-	-
Number of fish		200	8	893	1382	1854	2583	533	274	295	9	10	20	80	83	35	90	149	298	442	813	280	531
Mean length		10,5	17,2	13,8	14,4	18,2	18,6	17,4	17,1	19,2	21,6	14,5	21,5	18,8	16,2	21,7	17,4	17,8	19,2	17,8	15,1	17,0	18,4

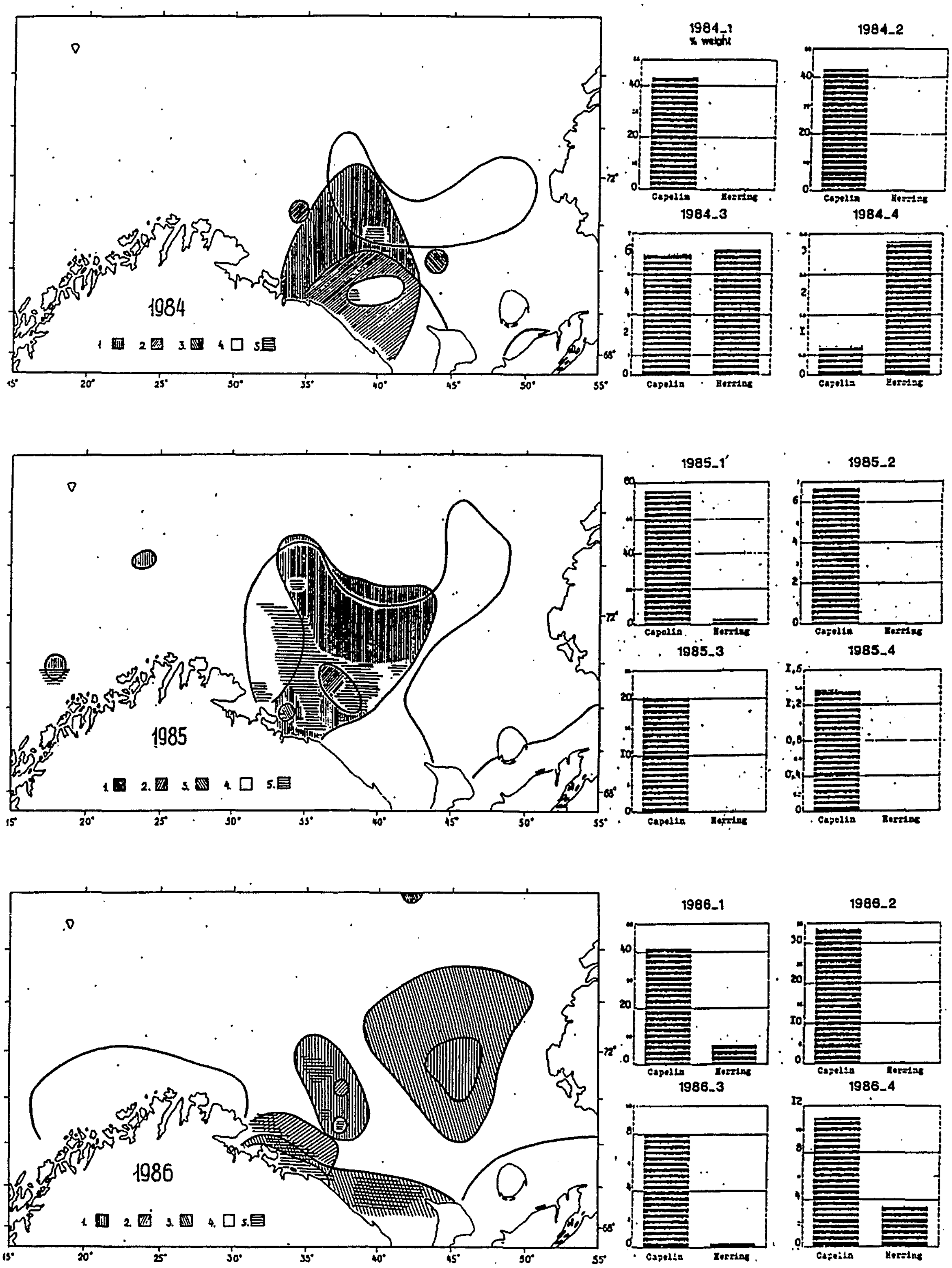

Figure 3. Distribution of herring and cod and per cent of capelin and herring in cod diet (% weight of food bolus) by quarters in 1984-1986.
1-4: distribution of herring by quaters 5: distribution of cod in the same periods.

Table 4. Seasonal variations of herring in cod stomach content by different areas in the Barents Sea in 1984-1985. Area number refer to Figure 1.

Area	Herring in cod stomachs			Mean stomach fullness (%)	Number of empty stomachs (%)	Number of fish examined
	Frequency of occurrence, (%)	Weight (%)	Length (cm)			
		1984 **May**				
The North-Central Area (5)	5,0	24,9	7-10	2,83	5,0	20
		September				
Southern slope of the Bear Island Bank (33)	4,9	9,6	10-14	2,48	9,0	122
Eastern slope of the Bear Island Bank (34)	3,1	44,4	10-14 15-19	3,04	20,0	65
The Murman Tongue (15)	5,9	1,8	10	0,90	0,0	17
		October				
Northern slope of the Murman Shoal (6b)	9,1	16,1	10-14	3,09	40,0	55
The Norwegian Deep (22)	0,8	2,8	15-19	0,78	22,5	120
		November				
North -Central Area (5)	4,4	37,9	no data	1,60	53,3	45
Northeast slope of the Murman Bank (10a)	1,8	3,3	no data	2,32	25,5	55
		December				
Rybachya Bank (11)	2,3	1,0	11	1,00	30,2	43
		1985 **February**				
The Finnmarken Bank (9)	5,6	9,4	10-14 15-19	1,29	50,0	234
The Nordkyn Bank (21)	0,5	1,2	15-19	5,05	18,1	221
Northern slope of the Murman Shoal (6b)	2,9	45,9	no data	1,03	63,8	69
Northwestern slope of the Murman Bank (8)	1,2	1,2	no data	3,30	33,7	36
		March				
Sørøya Bank (23)	2,5	0,5	10-14 15-19	7,14	3,3	122
		November				
Northwestern slope of the Murman Bank (8)	18,6	34,2	7-23	no data	4,3	70

Note. In June-July 1984, herring were not found in cod stomach in the western and coastal areas. In March-July 1985, herring were not found in cod stomach in the western areas or in coastal areas in July-August or in northwestern areas in August.

Small herring 7-10 cm occurred as cod food in the southeastern Barents Sea as early as May, constituting up to 25% in weight of their stomach content (Table 4). In June-July in the western and coastal areas, herring were not observed as cod food, probably because juvenile herring were feeding on *Calanus* in deeper waters. However, in September, rather regularly, herring (as well as capelin) were consumed by cod over an extensive area. On the slopes of the Bear Island Bank (32, 33, 34) herring varied from 10 to 44% of the cod stomach content. In October-November, herring constituted a considerable part of the cod diet in the area east of 35°E. However, a rather high percentage of fish with empty stomach was observed. This might be connected with separate distribution areas in the winter for cod and herring and low availability of other prey species (Table 4, Figure 3). Length of herring, dominating the cod food, did not exceed 10-14 cm, corresponding to fish of the 1983- and 1984-year-classes (Tables 3, 4).

In 1985, more complete data on cod feeding in winter and spring indicated rather low consumption of herring (Table 4). In the extreme western areas, on the Sørøya Bank (23) and the Nordkyn Bank (21), intensive consumption of capelin by cod was observed (Figure 3). The indices of stomach fullness reached maximum values (7.14 and 5.05% respectively) and a relatively small number of fish with empty stomachs occurred (Table 4). In other areas with low concentrations of prey including herring as well as geographical separation of cod and herring in summer, herring did not occur in cod stomachs. One sample in November indicated a relatively intensive feeding on herring by cod, probably explained by overlapping distributions. However, cod were feeding mainly on capelin (Figure 3). Based on the length distribution of herring in the cod stomachs, fish of the 1983- and 1984-year-classes were present (Table 3, 4).

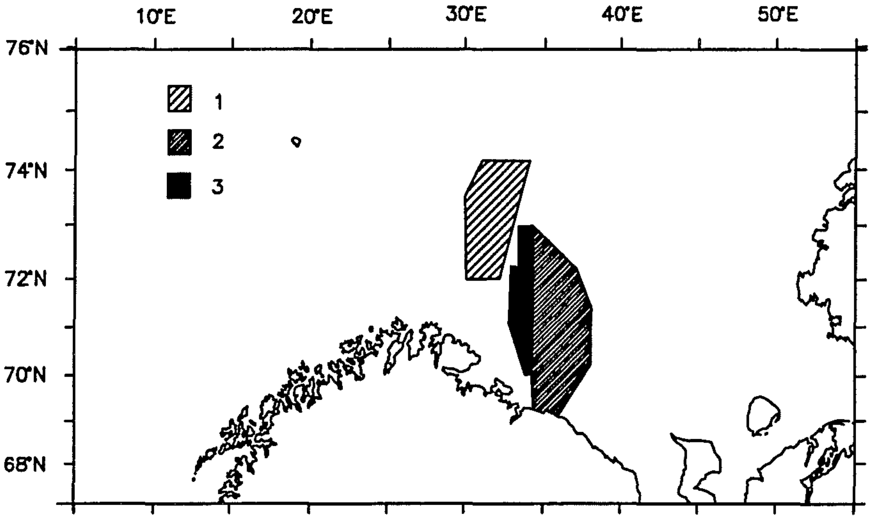

Figure 4. Distribution of commercial concentrations in February 1986 (Orlova and Matishov 1993) of cod (1), capelin (2), herring (3) .

In 1986, despite the almost critical level of capelin stock (Ushakov and Tereshchenko 1992) food supply for cod remained rather stable (Orlova *et al.* 1992). In January-March, capelin migrated from the Demidov Bank (17) to the south-east, a migration typical of cold years. Juvenile herring were concentrated during winter in the same eastern areas (Figure 3). In February, the main concentrations of cod, capelin and herring were distributed on the slopes of the Murman Bank (10, 10a) and adjacent areas (Figure 4). Small cod were feeding mainly on capelin and larger cod on herring. Large herring above 20 cm were observed as cod food in spring in the central and eastern Barents Sea (Table 5). Arctic herring appeared during winter in these areas together with the Norwegian spring spawning herring of the 1983-year-class. Large herring on the Kopytov Bank (42) were Norwegian spring spawning herring. In spite of the small number of cod having consumed relatively large herring (15-19 cm and above), their total amount by weight often reached 30-40% (Table 3, 5). Since herring only served as additional food for cod, the highest indices of stomach fullness were observed when consumption of capelin was predominant (Figure 3). Consumption of herring was observed not to be intensive but regular through the whole year, including the summer months.

Table 5. Seasonal variations of herring consumption by cod in different areas of the Barents Sea in 1986. Area number refer to Figure 1.

Area	Herring in cod stomachs			Mean stomach fullness (%)	Number of empty stomachs (%)	Number of fish examined
	Frequency of occurrence, (%)	Weight (%)	Length (cm)			
		January				
Northwestern slope of the Murman Bank (10) and the Demidov Bank (17)	0,4	0,2	15	no data	17,4	247
		February				
The Demidov Bank (17)	6,1	3,8	15-19	3,28	2,0	49
The Murman Tongue (15)	7,5	28,6	10-14 15-19 20-24	0,87	50,4	268
Northwestern slope of the Murman Bank (8)	19,4	37,7	7-10 10-14 15-19	no data	29,6	98
Southwestern slope of the Murman Bank (10)	2,7	30,4	10-14 20-24	no data	58,7	75
The Finnmarken Bank (9)	0,5	5,2	20-24	0,66	22,8	193
The Kildin Bank (12)	2,9	3,1	15	no data	17,1	35
Kopytov Area (42)	1,1	6,5	25-29	3,87	26,1	92
		March				
The Demidov Bank (17)	9,3	10,2	10-14 15-19	3,41	13,5	237
The Kildin (12) and Rybachya Banks (11)	10,0	1,8	16-19	no data	8,0	50
		April				
The Kildin Bank (12)	1,1	0,6	15-19	4,33	24,1	87
		June				
The Nordkyn Bank (21)	3,2	1,4	18	3,00	15,9	126
		July				
Rybachya Bank (11)	0,5	11,3	10-14 15-19	0,15	19,2	370
		August				
The Kildin Bank (12)	2,9	4,9	7-10	0,32	5,2	174
		October				
The Finnmarken Bank (9)	5,3	33,2	10-14	1,57	14,0	57
The Nordkyn Bank (21)	4,0	5,9	15-19	1,12	15,9	126

Note. In 1986, herring were not found in cod stomachs in the western areas in May, June-August or in the northwestern areas in august.

In 1987-1989 intensive predation on herring was not observed despite analysing a relatively high number of cod stomachs. In some months only single herring was found in the stomach content of cod. These observations correspond to the data available of the poor 1984-1988-year-classes of herring and the migration of the 1983-year-class to the western Barents Sea in summer-autumn 1986, at the beginning of their maturation (Pashkova and Seliverstova 1988). However, in October 1988 and July 1989, high percentage of small herring (1988-year-class) was observed in the cod stomach content (Table 6 and 3, Figure 5) from the Murman coastal areas (11, 12, 13, 14), This is probably connected with reduced feeding in the coastal zone during their south-east migration.

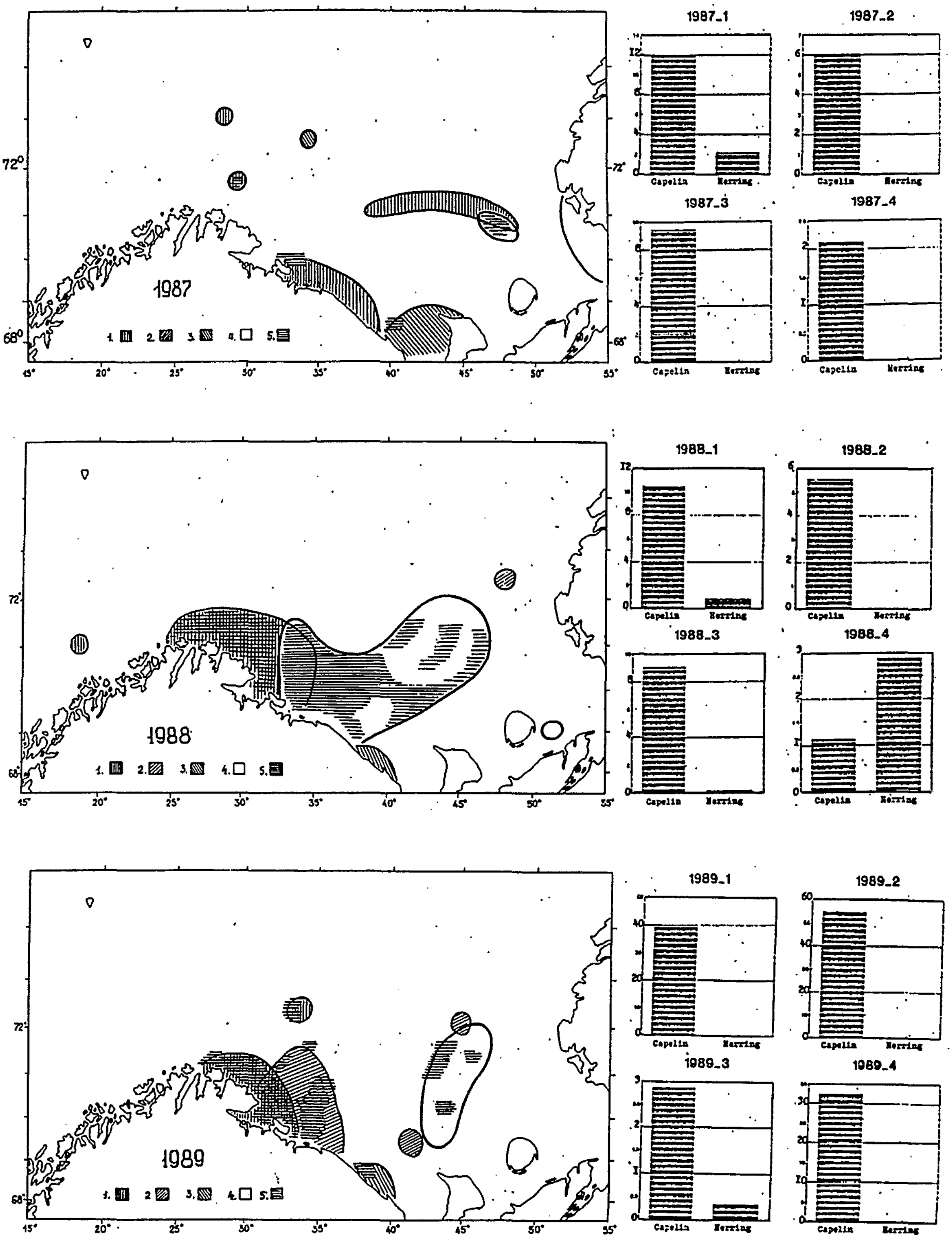

Figure 5. Distribution of herring and cod and per cent of capelin and herring in cod diet (% weight of food bolus) by quarters in 1987-1989. See legend in Figure 3.

Table 6. Seasonal variations of herring consumption by cod in different areas of the Barents Sea in 1987-1989. Area number refer to Figure 1.

Area	Herring in cod stomachs			Mean stomach fullness (%)	Number of empty stomach (%)	Number of fish examined
	Frequency of occurrence, (%)	Weight (%)	Length (cm)			
		1987 **February**				
Kopytov Area (42)	0,6	3,8	15-19	no data	54,6	163
		March				
The Kildin Bank (12)	13,3	11,3	15-19	4,74	0,0	45
		April				
The Demidov Bank (17)	0,4	0,2	16	4,40	2,7	224
		1988 **June**				
The Finnmarken Bank (9)	0,5	0,02	5-6,9	3,18	0,5	192
		September				
Southern slope of the Goose Bank (4c)	2,0	1,4	10-14	4,22	0,0	50
		October				
Kanin-Kolguev Shoal (2a)	0,6	0,3	10-14	1,56	3,2	154
Western Coastal Area (13)	5,7	4,7	5-6,9	0,87	10,7	122
		1989 **July**				
The Coastal areas (11, 12, 13, 14)	17,7	12,1	11,8	1,60	18,8	85
		October				
The Coastal areas (11, 12, 13, 14)	2,7	2,3	15,0	0,40	64,8	37

Note. In 1987, herring were not found in cod stomachs in the western areas; September-December in the northwestern areas in February-May and August-September; in the coastal areas in February, August, September and December; in the central areas in July, September and November; in the eastern areas in October. In January 1988, herring were not found in cod stomachs in the western areas; in the central and coastal areas in August. In July, December 1989, herring were not found in cod stomachs in the western areas; in the northwestern areas in October, November; in the central areas in July; in the coastal areas in February, May.

Cod were in 1990 feeding on spawning capelin, and the available food supply was estimated to 181 thousand tonnes, compared with 14 thousand tonnes in 1988 (Ushakov and Tereshchenko 1992). Dens concentrations of capelin were in February distributed from the Western Coastal area (13) to the Kildin Bank (12) in the west and from Fugløy Bank (24) to Nordkyn (21) and further east along the Finnmark coast (9). The main cod concentrations migrated to these areas. A western distribution of winter-spring concentrations and a wide distribution in summer-autumn were characteristic of the herring distribution in 1990 (Figure 6), represented mainly by fish from the 1988-1989-year-classes (Table 4). Cod were during winter feeding intensively on capelin, and herring were not important as food for cod, although distribution of herring and cod coincided (Figure 6). An increasing consumption of herring was only observed in February on the northwestern slope of the Murman Bank (8). The herring consumed in February-March, were mainly in the length-group 10-19 cm (fish from the 1989-1988-year-classes). Large mature herring were observed in the diet of spawning cod on the Røst Bank (28). However, small amounts of three year old herring was also consumed by cod on the Andøy Bank (26) in April (Table 3, 7).

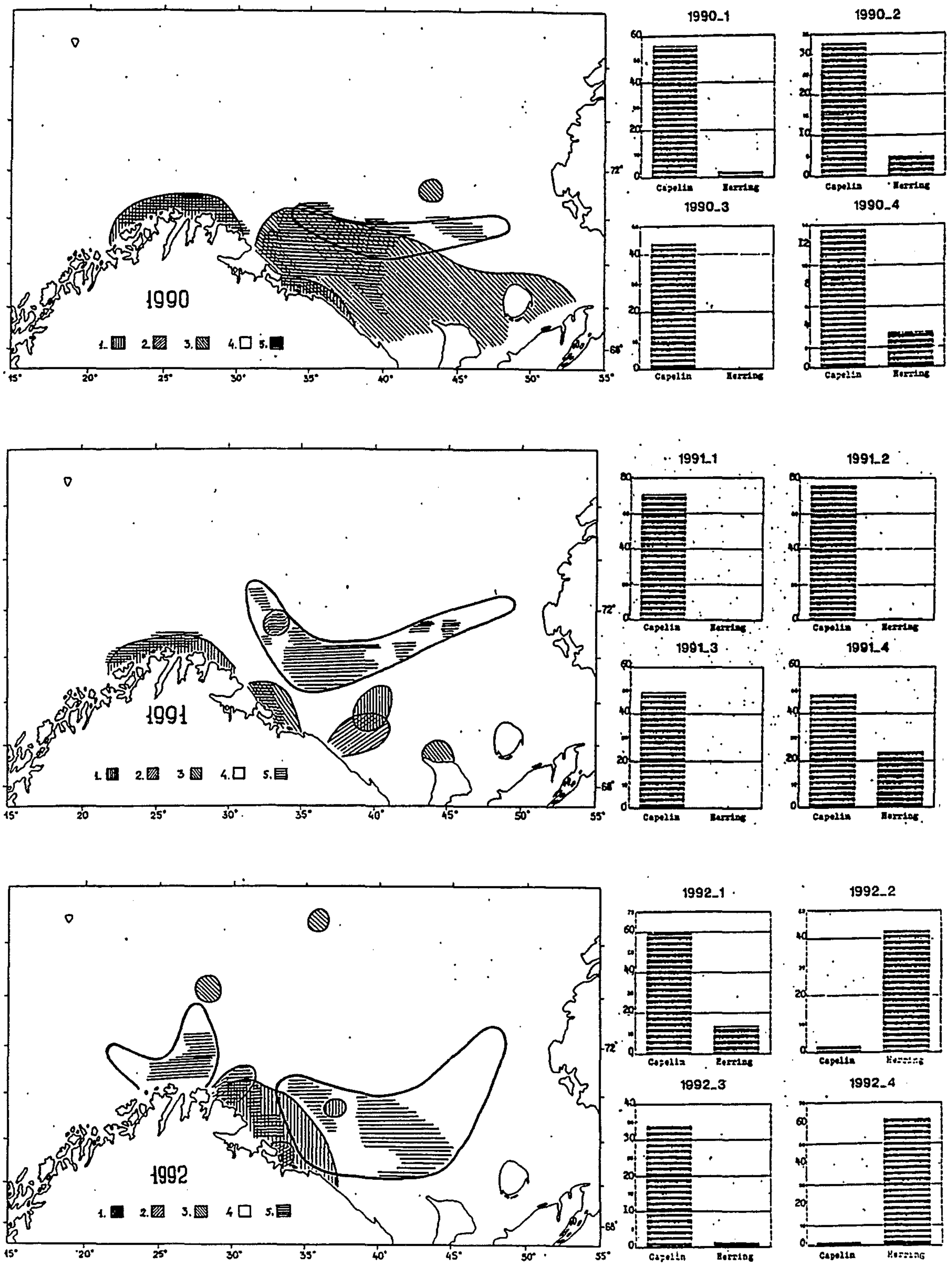

Figure 6. Distribution of herring and cod and per cent of capelin and herring in cod diet (% weight of food bolus) by quarters in 1990-1992. See legend in Figure 3.

In spite of the wide distribution of herring in the second half of 1990, probably caused by the long feeding period in the central and eastern Barents Sea, herring did not occur in the cod diet in summer. In autumn, the main concentrations of cod were west of 37°E, and cod remaining in the east were partly feeding on herring. An exeption was observed on the Goose Bank (4b) in October where cod were scarse and consumed different sizes of herring, corresponding to the general length composition (Table 3, 7).

Table 7. Seasonal variations of herring consumption by cod in different areas of the Barents Sea in 1990. Area number refer to Figure 1.

Area	Herring in cod stomachs			Mean stomach fullness (%)	Number of empty stomachs (%)	Number of fish examined
	Frequency of occurrence (%)	Weight (%)	Length (cm)			
		February				
Northwestern slope of Murman Bank (8)	6,5	12,4	10-14	2,10	15,1	93
Finnmarken Bank (9)	1,0	1,6	15-19	2,70	14,4	202
Murmansk Tongue (15)	0,8	1,2	no data	1,26	10,4	125
		March				
Kildin Bank (12)	0,7	0,3	15-19	3,38	4,7	150
Rost Bank (28)	5,0	43,8	30-39	1,11	63,3	120
		April				
Andoy Bank (26)	3,0	3,3	15-19	1,31	30,3	33
		October				
Western slope of Goose Bank (4b)	20,0	41,2	10-14 15-19	0,69	12,0	25
Central Plateau (16)	3,3	6,7	7-10 10-14 15-19	0,35	16,1	274
Northwestern slope of Murman Bank (8)	5,7	2,7	11,6	0,30	15,3	150

Note. Herring were not found in cod stomachs in coastal areas in May; in western areas in October; in northwestern areas in June-July; in central and eastern areas in July.

In January-March 1991, herring concentrations were distributed in the western areas, in the Norwegian Deep (22), on the Nordkyn (21) and the Sørøya (23) Banks (Figure 6). The 1989- and 1988- year-classes constituted the main part of these concentrations (Table 3, 8). Cod were observed in the same areas, both on spawning grounds and post-spawning feeding areas. The spawning migration of capelin in 1991 was easterly orientated which resulted in separation of the main concentrations of capelin and cod. Only in March, when capelin was distributed from the Rybachya Bank (11) to Nordkyn Bank (21) and Norwegian Deep (22) the distribution areas coincided. Herring were not found in the cod diet when capelin were predominant (Figure 5). In May after capelin spawning, cod became a multispecies predator and herring appeared again in the cod diet. In May on the Nordkyn Bank (21), herring were represented in the stomach content by 1.7% (frequency of occurrence) and 35.3% (by weight of the stomach). However, cod stomach fullness was low in the period and a large number of fish had emty stomachs (78%). In autumn and winter, herring and cod were again distributed in the same area, and herring occurred in stomach contents of cod. With regard to size composition, the wintering herring in the central areas consisted of juvenile Norwegian spring spawning herring of the 1988-1990-year-classes and adult Arctic herring of the 1983-1986-year-classes (Table 3 and 7, Figure 6).

Table 8. Seasonal variations of herring consumption by cod in different areas of the Barents Sea in 1991-1994. Area number refer to Figure 1.

Area	Herring in cod stomachs			Mean stomach fullness (%)	Number of empty stomachs (%)	Number of fish examined
	Frequency of occurrence (%)	Weight (%)	Length (cm)			
		1991 **February**				
Finnmarken Bank (9)	48,5	5,6	10-20	0,52	15,0	101
		May				
Nordkyn Bank (21)	1,7	35,3	no data	0,05	78,3	60
		November				
Finnmarken Bank (9)	100,0	78,6	17-29	1,31	0,0	2
		1992 **December**				
Norwegian Deep (22)	73,7	86,3	17-26	1,47	28,9	38
		1993 **December**				
Finnmarken Bank (9)	6,6	48,6	17-20	0,59	52,5	61
Western Coastal area (13)	3,3	5,6	15	2,42	30,0	30
		1994 **January**				
Demidov Bank (17)	2,4	1,2	10	0,81	54,8	42
Central Plato (16)	2,0	12,5	18	0,66	38,8	49
Northeastern slope of the Murman Bank (10a)	5,3	92,9	18,1	2,65	26,3	38
Eastern Coastal area (14)	41,0	38,5	8,3	2,77	20,5	39
Finnmarken Bank (9)	40,0	79,5	no data	2,63	0,0	10

Note. In 1991, herring were not found in cod stomachs on the Finmarken Bank (9) in May and on the Norwegian Deep (22) in June; on the western slope of the Bear Island Bank (32) in August and on the Nordkyn Bank (21) in March and April. In 1992, herring were not found in cod stomachs in the western areas in March and November; in the northwestern in April, July and in August-October. In 1993, herring were not found in cod stomachs in the western areas in March-April and August; in the northwestern areas in August; on the slopes of the Goose Bank (4c), Murmansk Bank (10a,8) in July-August and in central areas in November. In March 1994, herring were not found in cod stomachs in the western areas and on the Murmansk Tongue (15).

In 1992, cod had a similar distribution as in 1991 but the migration from the spawning grounds were observed to be earlier. Already in April large concentrations appeared on the Nordkyn Bank (21) and in the Norwegian Deep area (22). The spawning migration of capelin was abundant and eastward in the same year and capelin spawning stock biomass increased to 2117 x 10^6 tonnes (Ushakov and Tereshchenko 1992). The main distribution of cod and capelin coincided only in March and April. Analyses of cod stomach content in 1992 showed that cod in March were mainly feeding on capelin in the areas of the Norwegian Deep (22), Nordkyn (21), Rybachya (11) and Kildin Banks (12); in April, mainly on the Rybachya Bank (11). In thise areas capelin constituted 74-89% by frequency of occurrence in stomachs (with the mean degree of stomach fullness 2.0-2.6). In January-March herring were distributed along the Murman coast from the Norwegian Deep (22) to the Western Coastal area (13), and in April-June they formed local concentrations nearby inlets and fjords (Figure 6). In winter and spring the 1990- and 1989-year-classes dominated the herring schools (Table 4). In autumn, herring were distributed over an extensive area in the south-east between 69°-72°N and 33°-48°E. The abundant 1991- and 1990-year-classes were predominant in herring concentrations. In December the cod fed mainly on herring in the Norwegian Deep area (22) (74% by frequency of occurrence and 86% by weight). Length of herring from cod stomachs corresponded to the length structure in the herring concentrations (Table 3). The main predation (53%) was on large herring, 20-25 cm. In spite of lack of avalable data on quantitative weight analysis of cod stomach contents from local areas in winter, spring and autumn, data from cod feeding in June-July (685 stomachs examined) indicated that herring constituted the bulk of the cod diet in local areas. The percentage of herring found in 1-9 year old cod in 1992 over the whole sea are given in Table 9. Data presented in the table show that cod fed on herring practically all the year round. Herring were especially important for the older age groups of cod.

Table 9. Percentage of herring in cod stomachs by quarters and age in 1992. Weight of herring relative to weight of stomach content.

Age of cod (years)	Quarter			
	1	2	3	4
1	-	no data	-	no data
2	-	no data	1.8	-
3	9.3	-	5.0	-
4	6.5	-	1.2	-
5	29.2	72.9	5.6	79.6
6	8.5	-	0.9	65.5
7	10.3	66.1	-	78.0
8	19.2	-	0.1	no data
9	34.2	72.3	3.4	no data

Analysis of the above data as well as data from the field analysis of cod stomachs in December indicated that the period of predation on herring in 1992 was rather long. Herring were in some cases the main prey for cod. Cod were through the year mainly distributed in the same areas as Norwegian spring spawning herring and the Arctic herring (Figure 6).

In 1993, the winter-, spring- and summer-distribution of herring were extensive, and the distribution was to a large degree overlapping with that of cod through all the seasons (Figure 7). Herring was during winter and spring important as food for cod especially when capelin had a patchy distribution with low density (Orlova *et al.* 1993), confirmed by field analysis of cod stomach content in this period. In January-February on the Finnmarken (9), Rybachya (11) and Kildin (12) Banks the frequency of herring occurrence in cod stomach content varied from 50-60% to 43-50% respectively. On the Kildin Bank (12) in March, the intensity of herring consumption by cod decreased to 33% frequency of occurrence for small cod (20-40 cm). In May and July in the coastal and western areas, low feeding rate on herring was observed (frequency of occurrence 0.9-2.0). In April and June, herring were missing in cod stomachs in these areas. However, herring were observed in coastal areas (Figure 7). By the end of the year, cod were distributed in the wintering areas of herring and started to feed on herring (Table 8). Percentage of herring in cod stomachs were especially high (by weight) on the Finnmarken Bank (9), though number of fish with empty stomachs reached 50%. During winter period, the intensity of cod feeding on herring was a little lower in coastal areas. Herring from cod stomachs and wintering concentrations, had similar length and were mainly juvenile herring of the 1991- and 1992-year-classes (Table 3 and 8).

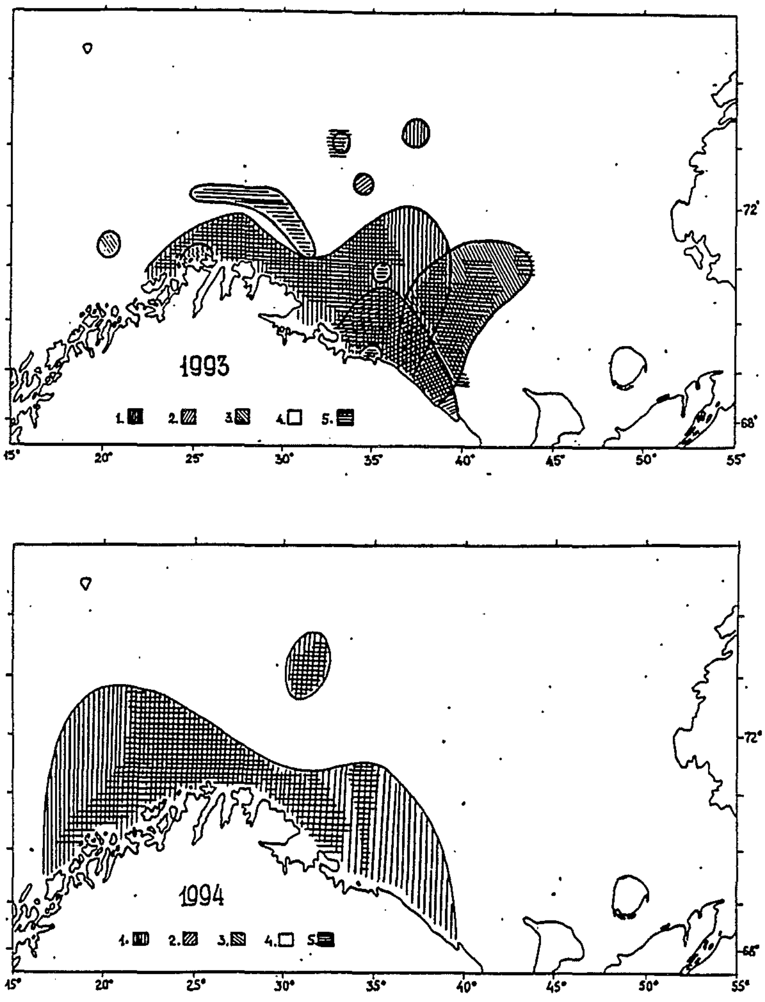

Figure 7. Distribution of herring and cod by quarters in 1993-1994.

In January-March 1994, wintering concentrations of herring and cod were overlapping in the areas along the Norwegian and Murman coast, between 68°-73°N and 16°-40°E (Figure 7). In January, a Russian acoustic survey in the Kopytov Bank area (42) observed large wintering herring of the 1991- and 1990-year-classes with mean length 18.1 and 23.4 cm respectively (Table 3). The estimated biomass was 124 thousand tonnes. Cod occurred together with the herring in these areas, but herring were not observed in cod stomach content. Cod were mainly feeding on smaller prey, capelin and shrimp.

In the same period small herring were distributed in the central and adjacent western areas as well as at the Murman coast, where cod fed on herring, and the highest occurence was observed in cod less than 40 cm (Figure 7). The percentage of herring was especially high in cod stomachs from the Finnmarken Bank (9) and Eastern Coastal area (14) where the number of fish with empty stomachs were negligible (Table 8). Herring were represented in cod stomach by the 1992- and 1993-year-classes (Table 3).

RESULTS AND DISCUSSIONS

One of the factors influencing the consumption of juvenile Norwegian spring spawning herring by cod is the herring abundance. Effect by cod on the poor herring 1984-1987-year-classes were in some years negligible caused by low abundance and small distribution area. Strong herring year-classes appeared in warm years (1983, 1989, 1991-1993). The development of the strength of these year-classes are influenced by food competition, varying overlapping in distribution areas and predatory effect etc. These factors might have a different effect on the survival of fish from the strong year-classes at different stages of their life. Abundant herring year-classes at the 0-group stage are in some years less consumed by cod due to their pelagic way of life. Investigations showed that herring at age 1+ - 3+ years are the main prey for cod.

Consumption of herring by cod depends also on the total food supply for cod such as the abundance of the capelin stock and the degree of overlapping distribution of cod-capelin, cod-herring and all three species.

Table 10. Abundance of cod 3 years and older and capelin and herring 1 year and older in the Barents Sea in 1983-1993. Number of fish x 10^{-6}.

Year	Cod[1]	Capelin[2]	Herring[2]
1983	503	754000	17900[3]
1984	720	380000	21400
1985	1006	104000	19900
1986	1661	14000	3000
1987	1470	39000	0
1988	1190	49000	0
1989	903	198000	
1990	751	894000	4969
1991	913	1000000	29500
1992	1301	678000	52372
1993	916	75000	129930

[1] Anon. 1994c [2] Anon. 1994b [3] 0+ year and older

During the years of observations a sharp reduction in capelin stock has been observed two times (Table 10). An increase in cod abundance was one of the reasons for the first reduction (Anon. 1994c), and the low abundance of herring could not compensate for the decreased capelin stock. The second reduction of capelin stock (1992-1993) occurred in the same period as an increase in abundance of the herring and the cod stocks were observed. This resulted in an increased predation on herring by cod, strengthened by the eastward migration of the available spawning capelin in typical warm years as 1991-1992. Scattered consentrations of capelin in 1993 resulted in some separation of cod and capelin in eastern areas. At the same time cod and herring were distributted in overlapping areas which increased the cod predation on herring in winter -spring and autumn-winter periods as well as in summer in coastal areas.

When areas of cod, capelin and herring overlapp, small cod feed more intensively on capelin and larger ones on herring. However, in case of lack of capelin, small cod were observed feeding predominantly on small herring. In such cases large cod would feed on juvenile cod (cannibalism) and flatfishes. To a large extent predators have a tendency to feed on prey of optimal size in order to minimize the waste of energy.

Data on cod predation on juvenile herring in the mid-1980's - beginning of 1990's makes it possible to estimate the consumption of herring by year (Table 11). In the period with poor year-classes (1984-1988) in the Barents Sea the amount of herring consumed by year was at a level of 4-17 thousand tonnes. When abundant year-classes (1983, 1989-1991) appeared, the consumption increased to 22-76 thousand tonnes and reached a maximum of 600 thousand tonnes in 1992 when the conditions were favourable for cod predation on herring. There is also a basis to expect high levels of herring predation in 1993-1994, years with strong herring year-classes (1992-1993) and low abundance of capelin. Estimates obtained indicate the same trend in herring consumption as given by Bogstad and Mehl (1992). However, the level of consumption are different for some years as also indicated by Orlova (1992b) and Orlova *et al.* (1994). The discrepancies in the estimated consumption depend on the following factors: first, a little different approaches even with the same methods (time step, selection of areas etc.); second, different choise of initial data (prefer different age groups by seasons, therefore different weight and abundance); third, using different data on cod feeding. The present calculations of the consumption of herring by cod need to be adjusted, but even so, these results together with those by other authers, justify further the dus of the imortance of herring a food for cod and the development of the abundance of herring year-classes by years.

Table 11. Herring consumed by cod in 1984-1992. Tonnes x 10^{-3}.

Quater	1984	1985	1986	1987	1988	1989	1990	1991	1992	Author
1	-	21.8	48.0	17.2	3.8	-	20.7	6.7	120.2	A.V.Dolgov
2	-	-	0.1	-	-	-	22.3	9.8	108.9	(in press)
3	28.1	-	-	-	1.7	3.3	-	-	25.4	
4	40.3	-	24.0	-	18.4	0.7	33.0	7.4	349.0	
Total for year	68.4	21.8	72.1	17.2	23.9	4.0	76.0	23.9	603.5	
Total for year	66	161	131	30	1	4				Bogstad and Mehl 1992
Total for year			709.9	0						Orlova 1992b
Total for year						84				Orlova *et al.* 1994

Thus, the present trend of the recovery of the Norvegian spring-spawning herring population might again be disturbed as a result of both direct or indirect increase of predation pressure, caused by a decrease in food supply for cod (related to reduction in capelin abundance). A reduction in herring growth rate, following an increase in its abundance, usually prolongate its stay in the feeding areas in the Barents Sea. Simultamously, the period of cod predation would be extended. Such analyses should be continnued and quantitative investigations of the dynamics of trophic levels (cod, capelin, herring, euphausiids, calanus) should be increased in the Barents Sea. These investigations should include studies of factors influencing their spacial distribution and factors initiating the migrations. Observations of main biological parameters should also be included in the program.

REFERENCES

ANON. 1974. *Textbook on studying feeding and trophic links of fish under* natural *conditions.* Nauka, Leningrad, 245 pp.

ANON. 1985. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1985. *ICES CM 1985*/G: 75, 27 pp.

ANON. 1986a. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1983. *Annls biol., Copenh. 41:172-180.*

ANON. 1986b. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacentwaters in August-September/ 1984. *Annls biol., Copenh. 41:180-188.*

ANON. 1986c. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1986. *ICES CM 1986/G:* 78,27 pp.

ANON. 1987. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1987. *ICES CM 1987*/G: 38, 31 pp.

ANON. 1988. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1988. *ICES CM 1988*/G: 45, 37 pp.

ANON. 1989. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1989. *ICES CM 1989*/G: 40, 40 pp.;

ANON. 1990. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1990. *ICES CM 1990*/G: 46, 36 pp.

ANON. 1991. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1991. *ICES CM 1991*/G: 50, 33 pp.

ANON. 1992. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1992. *ICES CM 1992*/G: 82, 33 pp.

ANON. 1994a. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September/ 1993. *ICES CM 1994*/G: 3, 38 pp.

ANON. 1994b. Report of the Atlanto-Scandian herring and capelin Working Group. Copenhagen, 18-20 october 1993. *ICES CM 1994*/Assess: 8, 84 pp.

ANON. 1994c. Report of the Arctic Fisheries Working Group.Copenhagen, 24 August - 2 September 1993. *ICES CM 1994/* Assess:2, 239 pp.

BENKO, Yu.,K. and **SELIVERSTOVA, A.S.** 1969. on the influence of some factors upon the abundance of year-classes of the Atlanto-Scandian herring. *Trudy polyar. nauchno - issled. Inst. morsk. ryb. Khoz. Okeanogr. 25*: 5-23. (In Russian)

BOCHKOV, Yu.,A. and **TERESHCHENKO, V.,V.** 1992. Up-to-date long-term variations of hydrometeorological conditions in the Barents Sea and their biological Consequences. Pp. 225-243 in Shleinik, V.N. (ed.*): Ecological problems of the Barents Sea.* Polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr. Murmansk. (In Russian)

BOGSTAD, B. and **MEHL, S.** 1992. The North East Arctic cod stock consumption of various prey species, 1984-1989. Pp. 59-72 in Bogstad, B. and Tjelmeland, S. (eds.): *Interrelations between fish populations in The Barents Sea. Proceedings of the fifth PINRO - IMR symposium, Murmansk, 12-16 August 1991.* Institute of Marine Research, Bergen, Norway.

DOLGOV, A.V. (in prep.) Annual diet and consumption on main prey species by cod in the Barents Sea in 1984-1993. (In Russian)

DRAGESUND, O. 1970. Distribution, abundance and mortality of young and adolescent Norwegian spring spawning herring (*Cupea harengus* Linne) in relation to subsequent year-class strength. *Fisk.Dir.Skr.Ser.HavUnders., 15*(4): 451-556.

FEDOROV,S.S. 1962. The Atlanto-Scandian herring and their distribution. *Ryb.Khoz., 1962*(7): 10-16. (In Russian).

JUDANOV, I.G. 1964. The strength of Atlanto-Scandian herring despending on the sercular changes in climate. *Mater. rybokhoz. issled. sev. Basseina. 4*: 9-13. (In Russian)

KONSTANTINOV, K.G. 1967. Forecasting of the distribution of fish concentrations in the Barents Sea according to the temperature factor. *Trudy polyar. nauchno.- issled. Inst. morsk. ryb. Khoz. Ockeanogr. 20*:167-178. (In Russian)

MANTEUFEL, B.P. and **BOLDOVSKIJ, G.,V.** 1938. The wintering of the Barents Sea herring and the causes of its winter migrations into the fiords of the Murman coast. *Trudy polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr.1*: 88-100. (In Russian)

MARTI, J.,J. 1941. On the life cycle of Murman herring (*Clupea harengus harengus*). *Trudy polyar. nauchno. -issled. Inst. morsk. ryb. Khoz. Okeanogr. 7*: 38-124. (In Russian)

MUKHIN, A.J. and **SARGNINA, R.N.** 1974 "Secular" hydrological sections in the Barents Sea and fishery forecasting. *Trudy polyar. nauchno - issled. Inst. morsk. ryb. Khoz. Okeanogr. 20*: 167-178. (In Russian)

ORLOVA, E.L. 1992a. Predators influence on the population structure and abundance of some commercial fishes in the Barents Sea. *J. Ichthyol. 32*(3): 83-93. (In Russian)

ORLOVA, E.L. 1992b. Prey size preference in cod feeding on capelin and herring in the southern Barents Sea. Interrelations between fish populations in the Barents Sea. Pp. 25-38 in Bogstad, B. and Tjelmeland, S. (eds.): *Interrelations between fish populations in The Barents Sea. Proceedings of the fifth PINRO - IMR symposium, Murmansk, 12-16 August 1991.* Institute of Marine Research, Bergen, Norway.

ORLOVA, E.L., BERESTOVSKY, E.G, ANTONOV, S.G., KARAMUSHKO, L.I., NIZOVTSEV. G.P. and **YARAGINA, N.A.** 1988. *Dynamics of annual cod feeding.* Murm. morsk. biol. Inst., Apatity, 16 pp. (Preprint in Russian)

ORLOVA,. E.L., BERESTOVSKY, E.G, ANTONOV, S.G., KARAMUSHKO, L.I., NIZOVTSEV. G.P. and **YARAGINA, N.A.** 1989. Main trophic interrelations of fish from polar seas. Pp. 182-198 in: *Life and environment of polar seas.* Nauka, Leningrad. (In Russian)

ORLOVA, E.L., PAKHOMOVA. N.A., MATISHOV, G.G., TERESHVHUK, O.V. and **CHUMAKOV, A.K.** 1992. *The peculiarities of feeding behaviour of the cod (Gadus morhua morhua) under the context of anthropogenic impact on its food stocks.* Kola center of the Russian Akademy of Science, Murm. morsk. biol. Inst., Apatity. 66 pp. (In Russian)

ORLOVA, E.L. and **MATISHOV, G.G.** 1993. *Structural and functional role of the cod in the Barents Sea ecosystem.* Kola center of the Russian Academy of Science, Murm. morsk. biol. Inst., Apatity. 163 pp. (In Russian)

ORLOVA, E.L., KARAMUSHKO, O.V. and **KARAMUSHKO, L.I.** 1993. *Conditiion of the fish resources at the murman coast during spring and autumn 1993 (using results of MMBI Research and Fishing expeditions of 1993).* Kola center of the Russian Academy of Science, Murm. morsk. biol. Inst., Apatity. 36 pp. (In Russian)

ORLOVA,. E.L., DOLGOV, A.V and **TERESHCHUK, O.Yu.** 1994. *Quantitative aspects of cod feeding in the Barents Sea. Results from hydrobiological works.* Vses. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., Moscow. (In press in Russian).

PASHKOVA, T.E. 1983. Some features of biology of Arctic herring from the southeastern Barents Sea. Pp. 12-30 in: *Biology and fishery of pelagic fish from the Northern basin. Sbornik nauchnykh Trudov.* Polyar nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., Murmansk. (In Russian)

PASHKOVA, T.E. and **SELIVERSTOVA, E.I.** 1988. Peculiarities of distribution and growth of Atlanto scandian herring in the Barents Sea in 1984-1986. Pp. 112-124 in Shleinik, V.N. (ed.): *Biology of fish in seas of the European North. Ecological problems of the Barents Sea. Sbornik nauchnykh Trudov.* Polyar nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., Murmansk. (In Russian)

SELIVERSTOVA, E.I. 1990. Growth and maturation rate of Atlanto-Scandian herring in the 1950-1980's. *ICES CM 1990/*H: 7, 25 pp.

TORESEN, R. 1985. Recruitment indices of Norwegian spring-spawning herring for the period 1965-1984 based on the international 0-group fish surveys. *ICES CM 1985/*H:54, 9 pp.

USHAKOV, N.G. and **SHAMRY, E.A.** 1995. The effect of different factors upon the Barents Sea capelin year-classes. Pp. 75-84 in Hylen, A. (ed.): *Precixion 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, 14-17 June 1994.* Institute of marine research, Bergen, Norway.

USHAKOV, N.G. and **TERESHCHENKO, E.S.** 1992. On regulation of the Barents sea capelin. *Sb. nauchn. Trudy polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr. 1992*: 137-148. (In Russian)

ZATSEPIN, V.I. and **PETROVA, N.S.** 1939. The feeding of the cod in the southern part of the Barents Sea. *Trudy polyar. nauchno - issled. Inst. morsk.ryb. Khoz. Okeanogr.5*: 170 pp. (In Russian)

ZELIKMAN, E.A. and **KAMSHILOV, M.M.** 1960. Long-term dynamics of plankton biomass in the southern Barents Sea and factors determining it. *Trudy Murm. biol. Inst.* 2(6): 68-113. (In Russian)

RELATIONS BETWEEN RECRUITMENT INDICES AND OCCURENCE IN COD STOMACHS OF PRE-RECRUITS OF COD AND HADDOCK IN THE BARENTS SEA

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ABSTRACT

The predation by North-East Arctic cod on pre-recruits of cod and haddock is reviewed based on data from the joint PINRO-IMR stomach content data base. It is investigated how the abundance indices from surveys of pre-recruits are correlated with the occurrence in cod stomachs of pre-recruits of these species.

Estimates of the consumption of cod and haddock by cod based on a new model for the stomach evacuation rate of cod are also given.

INTRODUCTION

An important part of stock assessment and management advice is to predict the strength of year classes not yet recruited to the fishery. Such predictions are now mainly based on survey indices. However, the natural mortality on pre-recruits is large and variable. This may cause large errors in the predictions, as observed for North-East Arctic cod in the mid-late 80's (Anon. 1986, 1989).

After the post-larvae stage, predation is probably the main cause of natural mortality on pre-recruits. Estimates of the predation mortality on these age groups may thus improve the precision of the prognosis.

In the Barents Sea, North-East Arctic cod is one of the main predators on pre-recruits of a number of commercially important species (cod, haddock, capelin, herring, redfish, shrimp). Since 1984 a rather extensive stomach sampling program has been carried out in this area (Mehl and Yaragina 1992).

Based on these data we will investigate how the abundance indices of pre-recruits are correlated to the occurrence in cod stomachs of pre-recruits of cod and haddock. We then discuss whether cod stomach content data can be used when assessing the recruitment of these

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species. Finally estimates of the consumption of cod and haddock by cod are given based on a new model of the gastric evacuation rate of cod.

MATERIAL AND METHODS

Cod stomach data from the period 1984 to 1992 have been retrieved from the joint IMR-PINRO stomach content data base (Mehl and Yaragina 1992). The data used were collected during main fish abundance surveys in the periods 1 January to 31 March and 15 August to 15 October. Only predators (cod) ≥ 30 cm have been included in the analysis.

The total number of cod and haddock of different 5 cm length groups found in all the stomachs in each period and year were calculated. Prey of unidentified size were omitted. The number of prey in each 5 cm length group was converted to number by age group using age length keys from Norwegian surveys.

The number of prey in each age group found per stomach in the first period are compared to Norwegian acoustic and bottom trawl indices from the same period for the corresponding age groups (Mehl and Nakken 1994). In addition, the VPA-estimates of the year class as 3 year old fish (Anon. 1994a) have been included in the comparison.

For the second period, logarithmic indices from the International 0-group surveys (Anon. 1994b) and Russian acoustic and bottom trawl indices from late autumn surveys (Anon. 1994a) have been used in the comparison.

It was also attempted to include a time series of the number of prey by age in the analysis of recruitment indices performed when assessing the cod and haddock stocks (Anon. 1994a).

The stomach content data can also be used to calculate the amount of pre-recruits of cod and haddock eaten by cod (Mehl 1989, Bogstad and Mehl 1992, Bogstad *et al.* 1994). An updated version of the model for the stomach evacuation rate of cod developed by dos Santos and Jobling (1992) is now available (dos Santos and Jobling 1995). We apply this model to calculate the consumption of cod and haddock by cod using mainly the same approach as in Bogstad and Mehl (1992). The number at age of cod is taken from Anon. 1994a, and it is assumed that the cod spawning stock is outside the Barents Sea for three months during the first half of the year. The new evacuation rate model is given by

$$S_t = S_0 2^{-t/(\alpha_i S_0^{\beta} e^{-\gamma T} B^{-\delta})}$$

where
t: time in hours
S_t: Stomach content at time t (in g)
T: temperature (°C)
B: body weight in g,
S_0: Initial meal size (in g)
The values of the constants are: β=0.52
δ=0.26
γ=0.13
α_i is a prey-specific parameter indicating the half-life of prey i.

Table 1. Number of different age groups of cod found in stomachs of cod ≥ 30 cm in the Barents Sea 1 January - 31 March 1984 - 1992.

	Age group			No. stomachs sampled
	1	2	3	
1984	5	1	0	704
1985	1	1	0	1100
1986	6	11	2	1158
1987	3	1	1	705
1988	0	0	0	1615
1989	9	0	0	2057
1990	33	0	0	1574
1991	4	2	0	2939
1992	9	4	0	1030

Table 2. Number of different age groups of haddock found in stomachs of cod ≥ 30 cm in the Barents Sea 1 January - 31 March 1984 - 1992.

	Age group			No. stomachs sampled
	1	2	3	
1984	11	1	0	704
1985	9	1	0	1100
1986	7	4	2	1158
1987	2	0	0	705
1988	1	3	0	1615
1989	6	1	0	2057
1990	7	2	0	1574
1991	25	1	0	2939
1992	30	4	0	1030

Table 3. Number of different age groups of cod found in stomachs of cod ≥ 30 cm in the Barents Sea and Svalbard area 15 August - 15 October 1984 - 1992.

	Age group				No. stomachs sampled
	0	1	2	3	
1984	0	5	1	0	1114
1985	14	7	0	0	660
1986	5	4	7	1	1225
1987	33	4	2	0	2178
1988	12	3	0	0	1333
1989	63	3	0	0	1233
1990	4	4	2	0	2856
1991	10	9	0	0	818
1992	25	14	2	0	956

Table 4. Number of different age groups of haddock found in stomachs of cod ≥ 30 cm in the Barents Sea and Svalbard area 15 August-15 October 1984 - 1992.

	Age group				No. stomachs sampled
	0	1	2	3	
1984	5	7	0	0	1114
1985	4	17	0	0	660
1986	5	4	1	0	1225
1987	0	0	0	0	2178
1988	0	0	0	0	1333
1989	1	1	0	0	1233
1990	2	5	1	0	2856
1991	1	3	1	0	818
1992	0	4	3	0	956

If one assumes that over a period of days or weeks the fish reaches a steady-state, i.e. the amount ingested equals the amount evacuated, then the consumption of prey i is given by

$$C_i = \ln 2 \exp(\gamma T) B^{\delta} S_i / (\alpha_i S_0^{\beta})$$

The meal size S_0 is normally not known for stomachs sampled in the field, but has in this case been approximated by the total observed stomach content, S_i. The validity of this approximation is discussed by dos Santos and Jobling (1995), found that this approximation overestimates the consumption somewhat. In Bogstad and Mehl (1992) the meal size was set to twice the measured stomach content. Which value of the meal size that should be used and the feeding pattern of cod in general is discussed in Tjelmeland and Alvarez (1994).

The consumption model then becomes:

$$C_i = \ln 2 \exp(\gamma T) B^{\delta} S_i / (\alpha_i S^{\beta})$$

The species-specific constant (half-value) α_i for haddock is 84, and this value is also used for cod as prey. We have used the same age-length keys as mentioned above, and converted the consumption in weight of each length group to consumption in numbers by age group.

RESULTS

Table 1-4 present the number of cod and haddock found in the cod stomachs in the two periods. The total number of stomachs analysed is also given. In the first period the main part of the prey (both cod and haddock) were 1-group, with some occurrence of 2-group and almost none 3-group. In the second period it was on average found three times as many 0-group cod as 1-group in the stomachs and fewer older cod than in the first period. Of haddock it was however found about twice as many 1-group as 0-group, but fewer 2-group and none 3-group.

Figure 1 and 2 show plots of the frequency of occurrence of 1-group of cod and haddock respectively in cod stomachs analysed (multiplied by 100) against the Norwegian bottom trawl and acoustic abundance indices and VPA-estimates (of the year class at age 3) for the first period in 1984-1992. For 1-group cod (Figure 1) the development of the number in the stomachs show the same trend as most of the indices in most of the years. One exception is 1991 when the number in the stomachs is very low while both the bottom trawl index and the VPA-estimate show an increasing trend. The picture for haddock (Figure 2) is similar: decrease and increase in the number of 1-group in the stomachs normally coincide with decrease and increase in the abundance indices. The number of 2-group cod and haddock in the stomachs is very low (in many years zero), and plots of this compared to other indices are not included.

Figures 3-6 show the number of 0 and 1 group of cod and haddock found per cod stomach in the second period, plotted against the Russian bottom trawl (multiplied by 10) and acoustic abundance estimate and the 0-group index (multiplied by 100). The number of 1-group haddock in the stomachs in the autumn (Figure 6) seems to be correlated with the other survey indices in the autumn, while the number of 1-group cod and 0-group cod and haddock in the stomachs does not seem to show the same trend as the survey indices.

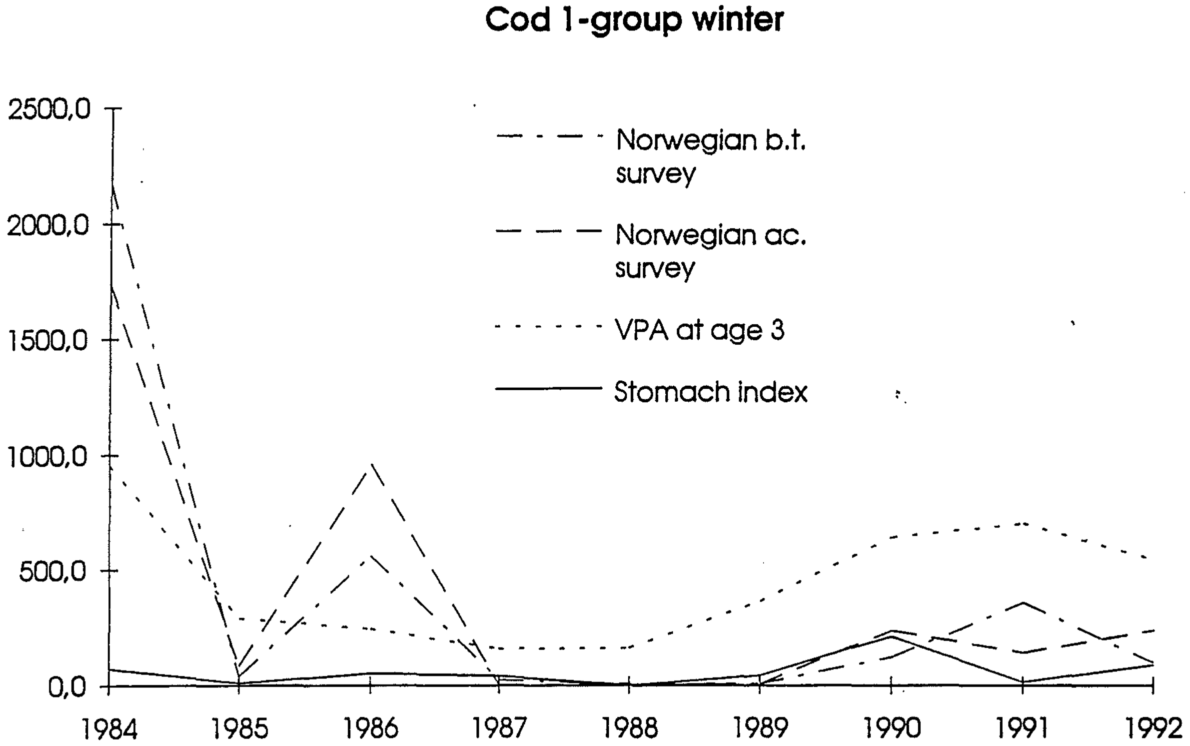

Figure 1. Frequency of occurence of 1-group cod in cod stomachs (scaled) compared to Norwegian survey indices and VPA-estimates of cod in the first period of 1984-1992.

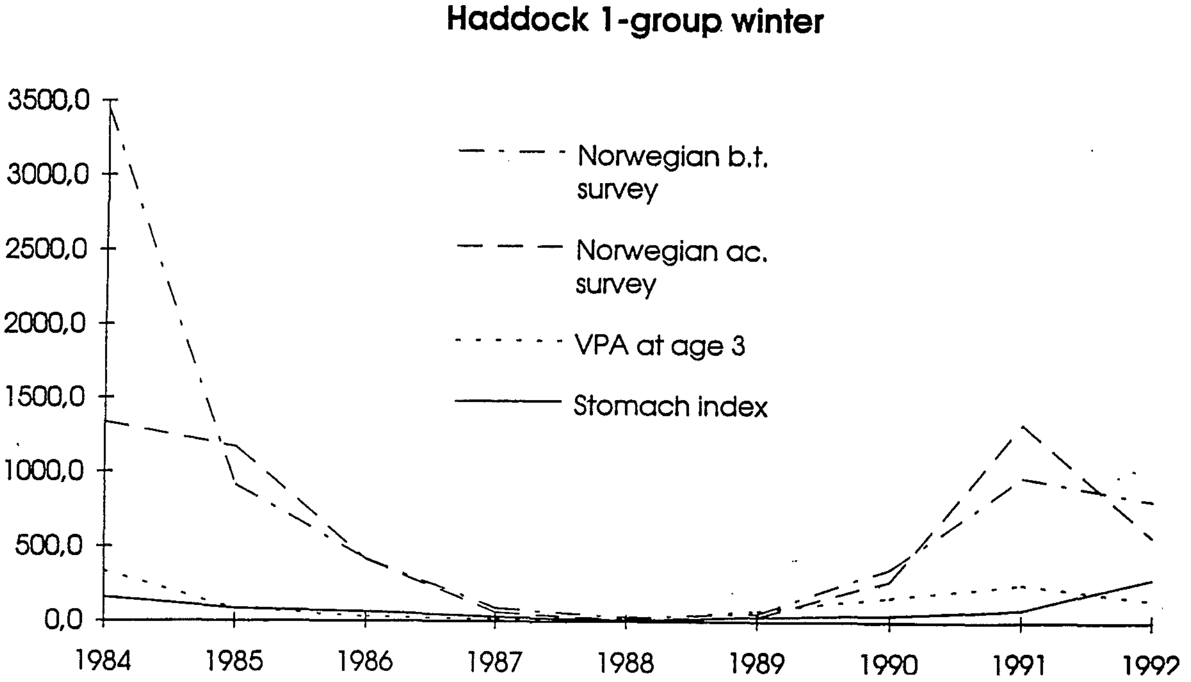

Figure 2. Frequency of occurence of 1-group haddock in cod stomachs (scaled) compared to Norwegian survey indices and VPA-estimates of haddock in the first period of 1984-1992.

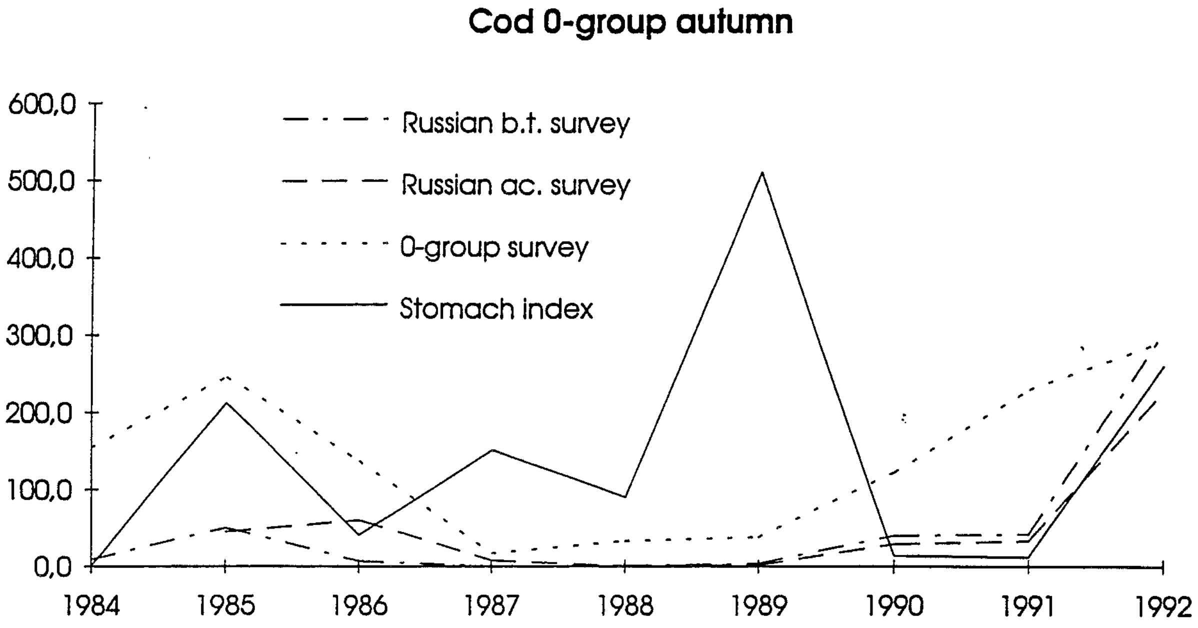

Figure 3. Frequency of occurence of 0-group cod in cod stomachs (scaled) compared to survey indices of cod in the second period of 1984-1992.

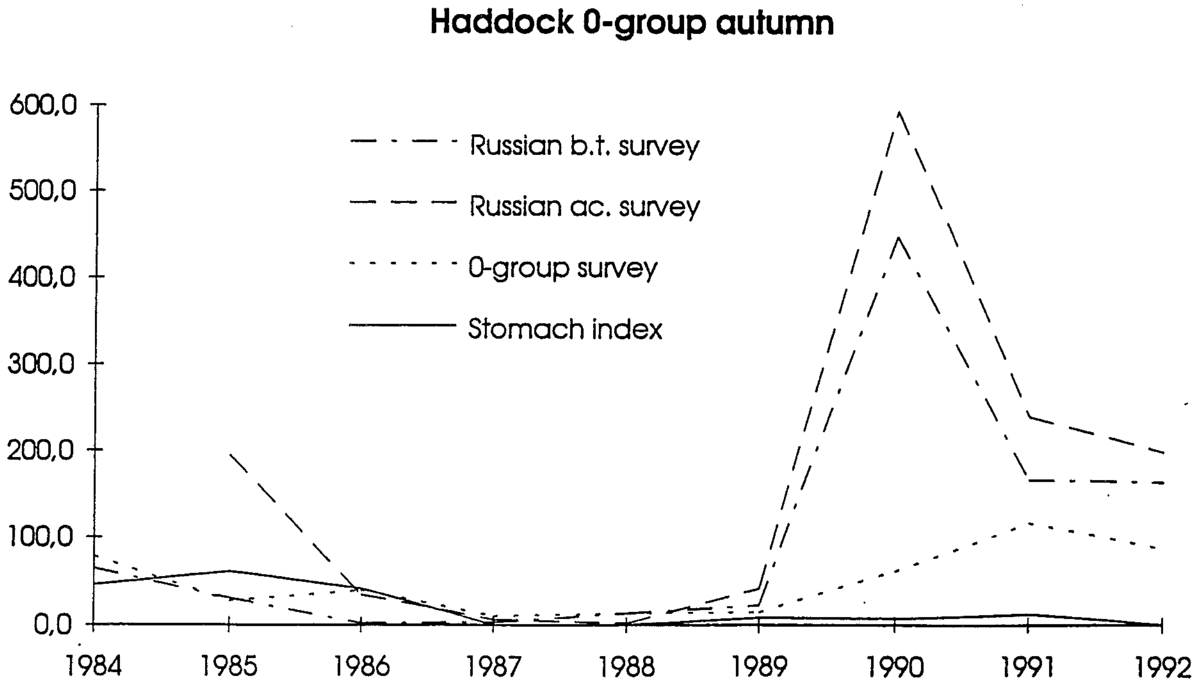

Figure 4. Frequency of occurence of 0-group haddock in cod stomachs (scaled) compared to survey indices of haddock in the second period of 1984-1992.

It was also attempted to include the number of 0, 1- and 2- group cod and haddock in the cod stomachs in the analysis of recruitment indices performed using the ICES computer program RCRTINX2 when assessing these two stocks. The number of 0, 1-and 2-group of each species in winter (not 0-group) and in autumn were included as an extra time series, with zero values set to an arbitrarily low value (1.0) in order to avoid problems when taking logarithms. The input data to the RCRTINX2 analysis are given in Appendix I (cod) and Appendix II (haddock). The analyses were carried out in the same way as done by the Arctic Fisheries Working Group at its last meeting (Anon. 1994a), updated by new survey indices. Some of the survey indices have been recalculated due to changes in gear and acoustic target strength (Mehl and Nakken 1994). The results of the analysis with and without the stomach indices included, are given in Table 5 (cod) and 6 (haddock). The difference in the predicted recruitment is small, as one would expect given the large number of indices already included (16 for cod, 10 for haddock). In general, including the stomach content data as indices lower the estimates of recruiting year classes slightly. However, the correlation coefficients (R^2) for these indices indicate a reasonable correlation (> 0.35 in the last year with data) only for 1-group haddock (both autumn and winter survey) and 1-group cod (winter survey). The number of 2-group found in the stomachs is so low, and zero in many years, that little correlation could be expected.

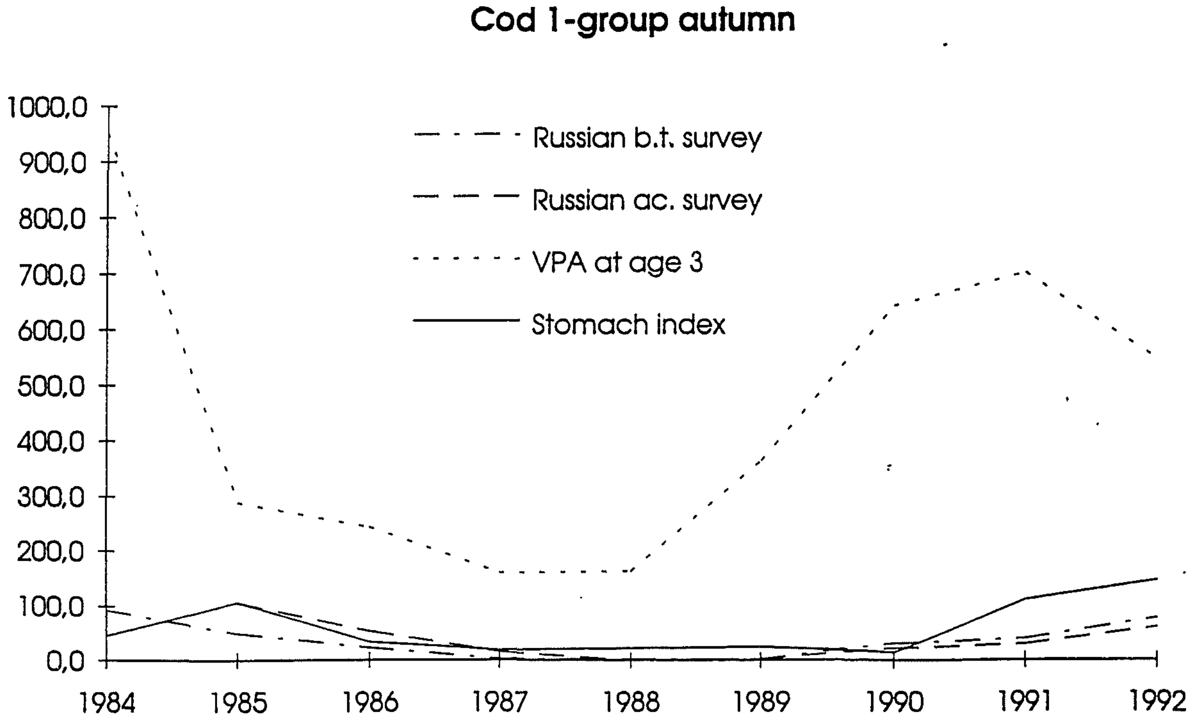

Figure 5. Frequency of occurence of 1-group cod in cod stomachs (scaled) compared to Russian survey indices and VPA-estimates of cod in the second period of 1984-1992.

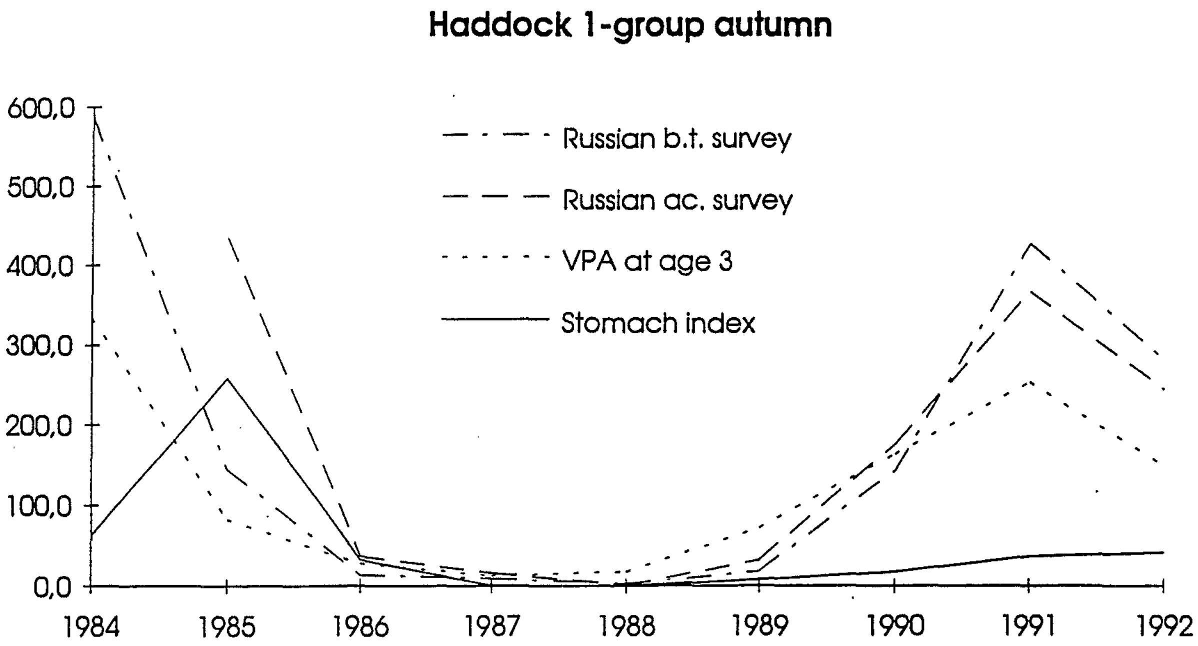

Figure 6. Frequency of occurence of 1-group haddock in cod stomachs (scaled) compared to Russian survey indices and VPA-estimates of haddock in the second period of 1984-1992.

Table 5.

RCRTINX2 analysis of survey data on cod recruitment, with and without abundance in cod stomachs included as indices

Analysis by RCRTINX2 of data from file cod-arctic:rcbb NORTHEAST ARCTIC COD : recruits as 3 year-olds (inc. data for ages 0,1,2 & 3)

Data for 21 surveys over 37 years
REGRESSION TYPE = C TAPERED TIME WEIGHTING APPLIED POWER = 3 OVER 20 YEARS PRIOR WEIGHTING NOT APPLIED FINAL ESTIMATES SHRUNK TOWARDS MEAN ESTIMATES WITH S.E.'S GREATER THAN THAT OF MEAN + INCLUDED MINIMUM S.E. FOR ANY SURVEY TAKEN AS .20
MINIMUM OF 3 POINTS USED FOR REGRESSION

Year-class = 1990

Survey/ Series	Index Value	Slope	Inter- cept	Rsquare	No. Pts	Predicted Value	Sigma	Standard Error	Weight
R-1-1	1.9459	2.306	3.556	.1772	20	8.0436	1.40529	1.60885	.01031
R-2B-1	.6931	2.314	3.072	.1484	20	4.6762	1.56216	1.65244	.00977
R-1-2	1.6094	1.039	4.428	.5856	20	6.1010	.54863	.57677	.08020
R-2B-2	1.6094	1.832	3.625	.2237	20	6.5733	1.21512	1.28766	.01609
R-1-3	3.2958	.686	4.488	.7704	33	6.7485	.35602	.40308	.16421
R-2B-3	4.2905	1.213	3.434	.3156	33	8.6360	.96043	1.25934	.01682
INTOGP	4.8203	2.502	-4.141	.0580	24	7.9211	2.62830	2.81834	.00336
N-BST1	5.8797	.460	4.062	.3262	10	6.7690	.94028	1.03334	.02499
N-BST2	6.1804	.604	3.050	.3831	11	6.7804	.83429	.92165	.03141
N-BST3	5.7519	.672	2.724	.6629	12	6.5884	.46816	.52028	.09856
N-SVT1	4.7622	.629	3.399	.3439	8	6.3917	.96036	1.03814	.02476
N-SVT2	4.8752	.568	3.641	.4700	9	6.4094	.69267	.74940	.04751
N-SVT3									
N-BSA1	4.9488	.362	4.501	.4158	9	6.2918	.80359	.86581	.03559
N-BSA2	6.2285	.528	3.573	.5140	11	6.8624	.63931	.72549	.05069
N-BSA3	5.7137	.575	3.339	.8530	12	6.6229	.27251	.30947	.27858
ST-W-1	2.6810	.685	3.421	.4125	7	5.2566	.87798	.95778	.02908
ST-W-2	3.6839	1.539	2.711	.0939	8	8.3798	2.15994	2.50974	.00424
ST-A-0	2.7081	1.041	1.154	.0704	6	3.9745	2.16168	2.47029	.00437
ST-A-1	4.7095	11.410	-33.326	.0081	7	20.4106	8.13099	10.93833	.00022
ST-A-2	3.0865	-6.238	16.295	.0070	8	-2.9574	8.26752	9.52040	.00029
MEAN						5.6966	.62207	.62207	.06894

Recruitment estimates, stomach content data included in analysis.

Year-class		Weighted Average Prediction	Internal Standard Error	External Standard Error	Virtual Population Analysis		Ext.SE/ Int.SE
1988	5.34	209.26	.14	.09	5.90	364.00	.67
1989	6.02	410.06	.15	.11	6.47	643.00	.73
1990	6.52	676.50	.16	.14			.85
1991	6.41	608.46	.16	.14			.84
1992	6.31	552.21	.29	.38			1.30
1993	6.37	584.90	.44	.34			.76

Recruitment estimates, stomach content data NOT included in analysis.

Year-class		Weighted Average Prediction	Internal Standard Error	External Standard Error	Virtual Population Analysis		Ext.SE/ Int.SE
1988	5.36	212.09	.14	.10	5.90	364.00	.72
1989	6.03	415.47	.15	.09	6.47	643.00	.64
1990	6.56	704.92	.17	.12			.75
1991	6.42	612.54	.17	.13			.79
1992	6.30	547.26	.29	.40			1.37
1993	6.37	584.90	.44	.34			.76

Table 6.

RCRTINX2 analysis of survey data on haddock recruitment, with and without abundance in cod stomachs included as indices.

Analysis by RCRTINX2 of data from file haddock-arctic:rcrt NORTHEAST ARCTIC HADDOCK : recruits as 3 year-olds (inc. data for ages 0,1,2 & 3

Data for 15 surveys over 37 years
REGRESSION TYPE = P TAPERED TIME WEIGHTING APPLIED POWER = 3 OVER 20 YEARS
PRIOR WEIGHTING NOT APPLIED FINAL ESTIMATES NOT SHRUNK TOWARDS MEAN
ESTIMATES WITH S.E.'S GREATER THAN THAT OF MEAN + INCLUDED MINIMUM S.E. FOR ANY SURVEY TAKEN AS .20 MINIMUM OF 3 POINTS USED FOR REGRESSION

Year-class = 1990

Survey/ Series	Index Value	Slope	Inter- cept	Rsquare	No. Pts	Predicted Value	Sigma	Standard Error	Weight
R-T-1	4.4067	.915	2.278	.7206	32	6.3088	.80208	.99970	.05891
R-T-2	4.2195	.812	2.288	.8043	32	5.7154	.67125	.77695	.09753
R-T-3	5.1591	.733	2.163	.7605	31	5.9419	.72081	.86181	.07927
INTOGP	4.0775	.978	.530	.3248	24	4.5181	1.24693	1.36409	.03164
N-BST1	6.8855	.479	1.489	.6557	9	4.7859	.93236	1.02695	.05583
N-BST2	7.0646	.637	1.261	.8244	10	5.7605	.66424	.78900	.09458
N-BST3	6.2683	.753	.995	.8824	11	5.7137	.54633	.64064	.14345
N-BSA1	7.2041	.430	1.763	.4849	8	4.8614	1.10727	1.30581	.03453
N-BSA2	6.4816	.656	1.536	.8078	10	5.7859	.69490	.82940	.08559
N-BSA3	6.4216	.785	1.230	.9133	11	6.2680	.46911	.57819	.17611
ST-W-1	4.4555	.765	1.196	.4165	6	4.6027	1.08499	1.22473	.03925
ST-W-2	3.6839	.395	3.289	.0821	7	4.7442	1.36131	1.66311	.02129
ST-A-0	2.0794	-.171	4.135	.0836	5	3.7802	1.15693	1.28050	.03591
ST-A-1	3.6297	.394	2.937	.3727	6	4.3671	1.12496	1.23818	.03840
ST-A-2	3.4782	.470	3.741	.0491	7	5.3768	1.38556	2.76514	.00770
MEAN						3.6683	1.44021	1.44021	.00000

Recruitment estimates, stomach content data included in analysis

1Year-class		Weighted Average Prediction	Internal Standard Error	External Standard Error	Virtual Population Analysis		Ext.SE/ Int.SE
1988	3.62	37.31	.17	.14	5.11	165.00	.82
1989	4.70	109.53	.22	.16			.73
1990	5.57	261.96	.24	.18			.74
1991	5.21	183.99	.24	.13			.53
1992	4.59	98.29	.34	.14			.42
1993	4.31	74.56	.57	.08			.14

Recruitment estimates, stomach content data NOT included in analysis.

Year-class		Weighted Average Prediction	Internal Standard Error	External Standard Error	Virtual Population Analysis		Ext.SE/ Int.SE
1988	3.63	37.53	.17	.17	5.11	165.00	.98
1989	4.79	120.78	.24	.20			.82
1990	5.76	318.38	.26	.16			.61
1991	5.30	200.30	.26	.10			.39
1992	4.62	101.63	.35	.15			.42
1993	4.31	74.56	.57	.08			.14

The results of the consumption calculations are given in Table 7 (cod) and 8 (haddock). Compared to the old consumption model, the new model gives a higher consumption by smaller fish relative to the consumption by larger fish. In addition, the temperature model used have been changed. Also, the evacuation rate for haddock has now been determined experimentally, while in Bogstad and Mehl (1992) the evacuation rate for haddock and cod was set equal to the evacuation rate of herring, which now is found to be slightly slower (α=88 vs. 84 for haddock). Compared with the calculated consumption of cod by cod using the model by dos Santos and Jobling (1992), which is presented in Bogstad *et al.* (1994), this new model gives somewhat higher consumption estimates. If the meal size had been set to twice the measured stomach content, however, as was done by Bogstad and Mehl (1992) the consumption would have been lower.

The very high consumption calculated of cod 0-group in 1992 should also be noted. Until 1990, the main part of the stomach samples in the period 15 August-15 October were taken during the second half of the survey, while in later years the main part of the samples were collected during the first half of the period. The bottom settling of the 0-group starts in this period. One should keep in mind that the consumption calculations in Tables 7-8 are based on data from throughout the year, while the data in Tables 1-4 are from two short periods (although the main part of the data are collected during these two periods).

Table 7. Consumption of cod by cod (numbers in millions) in the Barents Sea by prey age.

Year	Prey age group				Total consumption	
	0	1	2	3	numbers	tonnes
1984	-	546.2	59.7	1.3	607.2	31873
1985	1180.6	331.5	205.6	8.9	1713.6	49900
1986	66.4	666.2	438.1	273.6	1444.3	128904
1987	902.7	256.8	422.9	22.1	1604.5	36914
1988	43.4	617.7	35.4	+	696.2	13327
1989	1250.8	242.3	0.6	-	1493.7	10832
1990	-	163.5	44.0	-	207.5	28784
1991	139.7	231.3	88.0	55.9	514.9	42627
1992	7095.9	1315.9	204.2	0.1	8616.1	77594

Table 8. Consumption of haddock by cod (numbers in millions) in the Barents Sea by prey age.

Year	Prey age group				Total consumption	
	0	1	2	3	numbers	tonnes
1984	1915.8	1347.6	23.4	0.1	3286.9	59638
1985	1879.6	1557.7	7.6	-	3444.9	57221
1986	142.1	663.9	637.1	150.1	1593.2	160285
1987	-	1064.0	-	-	1064.0	5852
1988	-	21.5	1.0	18.9	41.4	4183
1989	32.6	349.2	3.0	-	384.8	15819
1990	49.2	224.6	67.5	5.3	346.6	24521
1991	-	598.2	22.9	-	621.2	26436
1992	803.3	2086.2	267.6	35.8	3192.9	181218

CONCLUSIONS

The number of 1 group cod and haddock found in cod stomachs may give some indication on the strength of the year class at that stage. The number of prey in cod stomachs is an indication both on the abundance of prey and the number removed. When calculating the consumption by cod of cod and haddock, the predation by cod on pre-recruits of cod and haddock is found to be of the same order of magnitude as the strength of a year-class at age 3. The predation by cod is thus an important factor in regulating the year class strength of cod and haddock, and one should try to model this, as has been attempted for cod cannibalism by Skagen *et al.* (1990), Bogstad *et al.* (1994) and Korzhev and Tretyak (1992).

REFERENCES

ANON. 1986. Report of the Arctic Fisheries Working Group. Copenhagen, 25 September-2 October 1985. *ICES CM 1986l*Assess:4, 53 pp.

ANON. 1989. Report of the Arctic Fisheries Working Group. Copenhagen, 20-29 September 1988. *ICES CM 1989l* Assess:4, 171 pp.

ANON. 1994a. Report of the Arctic Fisheries Working Group. Copenhagen, 24 August-2 September 1993. *ICES CM 1994l* Assess:2, 251 pp.

ANON. 1994b. Preliminary report of the International 0-group Fish Survey in the Barents Sea and adjacent waters in August-September 1993. *ICES CM 1994l*G:3, 37 pp.

BOGSTAD,B., LILLY, G.R., MEHL, S., PÁLSSON, Ó.K. and **STEFÁNSSON, G.** 1994. Cannibalism and year-class strength in cod (*Gadus morhua*) in the Arcto-Boreal ecosystems Barents Sea, Iceland and eastern Newfoundland. *ICES mar.Sci.Symp, 198:* 576-599.

BOGSTAD, B. and **MEHL, S.** 1992. The North-East Arctic cod stock's consumption of various prey species 1984-1989. Pp. 59-72 in Bogstad, B. and Tjelmeland, S. (eds.): *Interrelations between fish populations in the Barents Sea. Proceedings of the fifth PINRO-IMR symposium, Murmansk 12-16 August 1991.* Institute of Marine Research, Bergen, Norway.

DOS SANTOS, J. and **JOBLING, M.** 1992. A model to describe gastric evacuation in cod (*Gadus morhua* L.) fed natural prey. *ICES J.Mar.Sci., 49:* 145-154.

DOS SANTOS, J. and **JOBLING, M.** 1995. Test of a food consumption model for the Atlantic cod. ICES *J.mar.Sci.,52*: 209-219.

KORZHEV, V.A. and **TRETYAK, V.L.** 1992. The effect of cannibalism on recruitment to the North-East Arctic cod stock. Pp. 161-168 in Bogstad, B. and Tjelmeland, S. (eds.): *Interrelations between fish populations in the Barents Sea. Proceedings of the fifth PINRO-IMR symposium, Murmansk, 12-16 August 1991.* Institute of Marine Research, Bergen, Norway.

MEHL, S. 1989. The North-East Arctic cod stock's consumption of commercially exploited prey species in 1984-1986. *Rapp. P.-v. Reun.Cons.int.Explor.Mer, 188:* 185-205.

MEHL, S. and **NAKKEN, O.** 1994. Investigations on demersal fish in the Barents Sea winter 1994. In *Fisken og Hav. 1994*(6): 72 pp. (Norwegian with English summary and legends)

MEHL, S. and **YARAGINA, N.A.** 1992. Methods and results in the joint PINRO-IMR stomach sampling program. Pp. 5-13 in Bogstad, B. and Tjelmeland, S. (eds.): *Interrelations between fish populations in the Barents Sea. Proceedings from the fifth PINRO-IMR Symposium, Murmansk 12-16 August 1991.* Institute of Marine Research, Bergen, Norway.

SKAGEN, D.W., BOGSTAD, B. and **MEHL, S.** 1990. CEC - a VPA for cod with cod-cod cannibalism. Working Document to ICES Multispecies Assessment Working Group 1990, 9 pp. (Unpublished)

TJELMELAND, S. and **ALVAREZ, J.** 1994. Estimating initial stomach content using stochastic simulation. *ICES CM 1994/G:* 16, 19 pp.

Appendix I. Input data to the RCRTINX2 analysis for cod.

NORTHEAST ARCTIC COD: recruits as 3 year-olds (inc. data for ages 0, 1, 2 & 3)

21,37, 2 (No. of surveys, No. of years, VPA Column No.)

1957	800	-11	-11	-11	-11	12	16	-11	-11	-11	-11	-11	-11	-11	-11	-11	11	-11	-11	-11	-11	-11
1958	929	-11	-11	-11	-11	16	24	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1959	736	-11	-11	-11	-11	18	14	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1960	478	-11	-11	-11	-11	9	19	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1961	342	-11	-11	-11	-11	2	2	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1962	776	-11	-11	-11	-11	7	4	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1963	1598	-11	-11	-11	-11	21	120	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1964	1306	-11	-11	-11	-11	49	45	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1965	171	-11	-11	-11	-11	1	1	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1966	113	-11	-11	-11	-11	2	1	002	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1967	199	-11	-11	-11	-11	1	1	004	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1968	409	-11	-11	-11	-11	7	1	002	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1969	1027	-11	-11	-11	-11	11	6	025	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1970	1837	23	64	60	42	70	85	251	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1971	530	7	9	6	3	37	24	077	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1972	629	5	4	34	15	54	17	052	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1973	621	16	5	15	2	70	5	148	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1974	351	1	1	4	1	6	1	029	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1975	646	60	1	44	1	93	4	090	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1976	201	1	1	1	1	4	1	013	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1977	142	1	1	2	1	2	1	049	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1978	160	1	2	1	1	1	3	022	-11	-11	17.2	-11	-11	-11	-11	-11	34	-11	-11	-11	-11	-11
1979	159	1	1	1	1	1	8	040	-11	31.9	30.6	-11	-11	-11	-11	61	40	-11	-11	-11	-11	-11
1980	171	1	1	1	1	1	8	013	3.5	2.7	23.2	-11	-11	10.7	4	4	11	-11	-11	-11	-11	-11
1981	398	1	1	1	1	4	4	010	0.6	17.7	122.0	-11	26.8	7.3	2	14	42	-11	-11	-11	-11	-11
1982	499	1	8	8	13	8	10	059	259.0	366.0	162.0	145.0	113.0	99.1	-11	175	209	-11	14,2	-11	-11	8,9
1983	952	4	9	11	7	45	41	169	2170.0	647.0	679.0	499.0	452.0	297.0	1735	696	602	71.0	9,1	-11	44,9	1,0
1984	288	1	1	2	8	7	15	155	39.0	403.0	233.0	239.0	181.0	141.0	84	503	81	9,1	95,0	1,0	106,1	57,1
1985	243	3	10	2	3	4	6	246	562.0	387.0	180.0	40.9	108.0	33.2	958	53	54	51,8	14,2	2121	32,7	9,2
1986	159	1	2	1	1	2	5	137	25.3	63.5	37.9	41.5	16.6	15.4	2	22	18	42,6	1,0	40,8	18,4	1,0
1987	161	1	1	1	1	1	1	017	3.8	12.7	25.8	3.1	2.7	8.6	1	7	16	1,0	1,0	151.5	22,5	1,0
1988	363	1	1	1	1	7	1	033	7.1	48.9	37.0	3.6	9.4	25.3	5	40	62	43,8	1,0	90,0	24,3	7,0
1989	642	1	1	4	1	7	10	038	122.0	213.0	170.4	70.1	101.0	105.0	235	227	202	209.7	6,8	510,9	14,0	1,0
1990	-11	6	1	4	4	26	72	123	356.7	482.2	313.8	116.0	130.0	-11	140	506	302	13,6	38,8	14,0	110,0	20,9
1991	-11	3	6	3	15	8	24	230	99.7	304.8	293.4	91,8	-11	-11	237	354	349	87,4	-11	12,2	146,4	-11
1992	-11	10	60	1	6	-11	-11	294	423.0	410.0	-11	-11	-11	-11	927	565	-11	-11	-11	261,5	-11	-11
1993	-11	2	5	-11	-11	-11	-11	209	632.4	-11	-11	-11	-11	-11	787	-11	-11	-11	-11	-11	-11	-11

R-1-1 Russian Botom tral survey, area I, age 1
R-2B-1 Russian " " " " IIb, age
R-1-2 Russian " " " " I, age 2
R-2B-2 Russian " " " " IIb, age 2
R-1-3 Russian " " " " I, age 3
R-2B-3 Russian " " " " IIb, age 3
INT0GP International 0-group survey
N-BST1 Norwegian Barents Sea, Bottom trawl survey, age 1
N-BST2 Norwegian " " " " " age 2
N-BST3 Norwegian " " " " " age 3
N-SVT1 Norwegian Svalbardarea " " " age 1
N-SVT2 Norwegian " " " " " age 2
N-SVT3 Norwegian " " " " " age 3
N-BSA1 Norwegian Barents Sea Acoustic survey age 1
N-BSA2 Norwegian " " " " age 2
N-BSA3 Norwegian " " " " age 3
ST-W-1 Number of age 1 cod in cod stomachs , winter
ST-W-2 " 2 , winter
ST-A-0 " 0 , autumn
ST-A-1 " 1 , autumn
ST-A-2 " 2 , autumn

Appendix II. Input data to the RCRTINX2 analysis for haddock

NORTHEAST ARCTIC HADDOCK : recruits as 3 year-olds (inc. data for ages 0,1,2 & 3)
15,37,2 (No. of surveys, No. of years, VPA Column No.)

1957	246	38	9	14	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1958	1092	2	4	5	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1959	44	7	14	33	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1960	277	30	40	72	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1961	323	32	50	34	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1962	101	5	3	4	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1963	242	16	9	12	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1964	293	11	12	15	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1965	20	0,3	0,3	0,3	001	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1966	17	0,3	0,3	0,3	001	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1967	166	3	13	8	008	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1968	97	0,3	0,3	3	000,3	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1969	1028	31	69	120	029	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1970	272	10	33	31	064	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1971	54	3	3	9	026	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1972	49	2	9	3	016	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1973	57	13	8	5	026	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1974	115	15	35	14	051	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1975	172	163	96	59	060	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1976	135	6	13	4	038	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1977	19	1	1	0,3	033	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
1978	6	0,3	0,3	0,3	012	-11	-11	2,6	-11	-11	5	-11	-11	-11	-11	-11
1979	8	036	0,3	0,3	020	-11	7,0	2,0	-11	-11	2	-11	-11	-11	-11	-11
1980	5	036	0,3	-11	015	2,0	1,4	3,1	4	2	2	-11	-11	-11	-11	-11
1981	8	036	0,3	8	003	2,5	5,7	16,9	4	3	7	-11	-11	-11	-11	-11
1982	257	23	59	63	038	1780,0	592,0	436,0	-11	199	284	-11	14,2	-11	-11	1,0
1983	333	40	79	239	062	3450,0	1180,0	385,0	1334	788	474	156,3	9,1	-11	62,8	1,0
1984	82	9	19	18	078	911,0	312,0	187,0	1168	276	60	81,8	34,5	44,9	257,6	8,2
1985	28	5	2	3	027	416,0	78,2	30,3	413	20	7	60,4	1,0	60,6	32,7	1,0
1986	13	1	1	1	039	86,1	15,0	10,1	58	3	6	28,4	18,6	40,8	1,0	1,0
1987	18	1	1	4	010	28,6	6,0	4,8	10	4	4	6,2	4,9	1,0	1,0	1,0
1988	164	2	3	21	013	51,7	49,2	90,4	29	36	61	29,2	12,7	1,0	8,1	3,5
1989	-11	3	25	30	014	356,0	404,7	351,1	273	247	129	44,5	3,4	8,1	17,5	12,2
1990	-11	81	67	173	058	977,0	1168,8	526,6	1344	652	614	85,1	38,8	7,0	36,7	31,4
1991	-11	17	44	69	117	821,9	468,0	316,8	580	537	257	291,3	-11	12,2	41,8	-11
1992	-11	20	8	-11	087	431,9	156,5	-11	832	182	-11	-11	-11	1,0	-11	-11
1993	-11	6	-11	-11	064	369,9	-11	-11	538	-11	-11	-11	-11	-11	-11	-11

R-T-1
R-T-2
R-T-3
INTOGP
N-BST1
N-BST2
N-BST3
N-BSA1
N-BSA2
N-BSA3
ST-W-1
ST-W-2
ST-A-0
ST-A-1
ST-A-2

CANNIBALISM AND ITS IMPORTANCE FOR FORMATION OF RECRUITMENT OF ARCTO-NORWEGIAN COD IN THE BARENTS SEA

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ABSTRACT

Data on predation by cod on own young specimens, age (0+)-3, was obtained by observations of cod feeding under natural conditions in 1984-1992. It was revealed that cod are cannibals from the age of 1 year. However, the maximum age of cod that died from cannibalism is 3 years. The component of natural mortality, caused by cannibalism, was determined for the age groups (0+)-3, calculated by the VPA method for single-species, generalised for the case of cannibalism. The number of young specimens consumed by adult cod is of the same order of magnitude as one average year-class at the age of 3 years and 1.4-3.3 times the number of cod caught during a year. Factors affecting the level of cannibalism are abundance of cod year-classes and possibly also availability of the main food organisms.

INTRODUCTION

The assessment of the Arcto-Norwegian cod stock in the Barents Sea and especially prognoses for changes caused by fishing are impossible without studying the early life history, especially of the pre-recruits, at the age of (0+)-3. However, this problem is connected with some difficulties, one which is the absence of data on abundance of young age groups and on the natural mortality rate. In a number of papers (e.g. Ponomarenko 1968) the problem of survival of young cod in relation to temperature and food conditions were investigated, but such an important factor as the influence of cannibalism on the abundance of cod has only recently been studies (Korzhev and Tretyak 1992). The aim of the present study is to determine the number of young cod consumed by adult cod in 1984-1992 and to calculate a component of natural mortality caused by cannibalism and abundance of age groups (0+)-3.

MATERIAL AND METHOD

The basis of these calculations are data for 1980-1992: mean weight of the specimen, total number of cod in each age group, must be 3 to 15 years, average annual consumption of

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young cod specimens by cod of different age groups. The data were obtained after processing material from numerous research expeditions by PINRO vessels, as well as reports presented by the ICES Arctic Fisheries Working Group (Anon. 1994) and Norwegian colleagues from Bergen.

Predation by adult cod of their own young fish is based on quantitative analysis of stomach contents from cod at different ages (about 50 thousand specimens). The data obtained in Soviet research expeditions in 1986-1992 were combined with Norwegian data for 1984-1992.

The natural mortality of cod and its change by age are discussed. It is supposed that the total natural mortality of young cod is M2 + M1 where M2 is caused by cannibalism and M1 by intra- and interspecific relations and abiotic conditions. Observations on cod in age (0+)-9 years, feeding under natural conditions, show that cod are cannibals already at an age of 1 (Figure 1). The maximum age of cod dying as the result of cannibalism is only 3 years. This means that natural mortality caused by cannibalism for age groups 4-15 is zero (M2=0), whereas M1 is accepted as constant and equal to 0.2. When information of mortality in young age groups (0+)-3 is not available. Mortality is also set equal to 0.2. The method of calculations (modified VPA) is described in detail by Korzhev and Tretyak (1992).

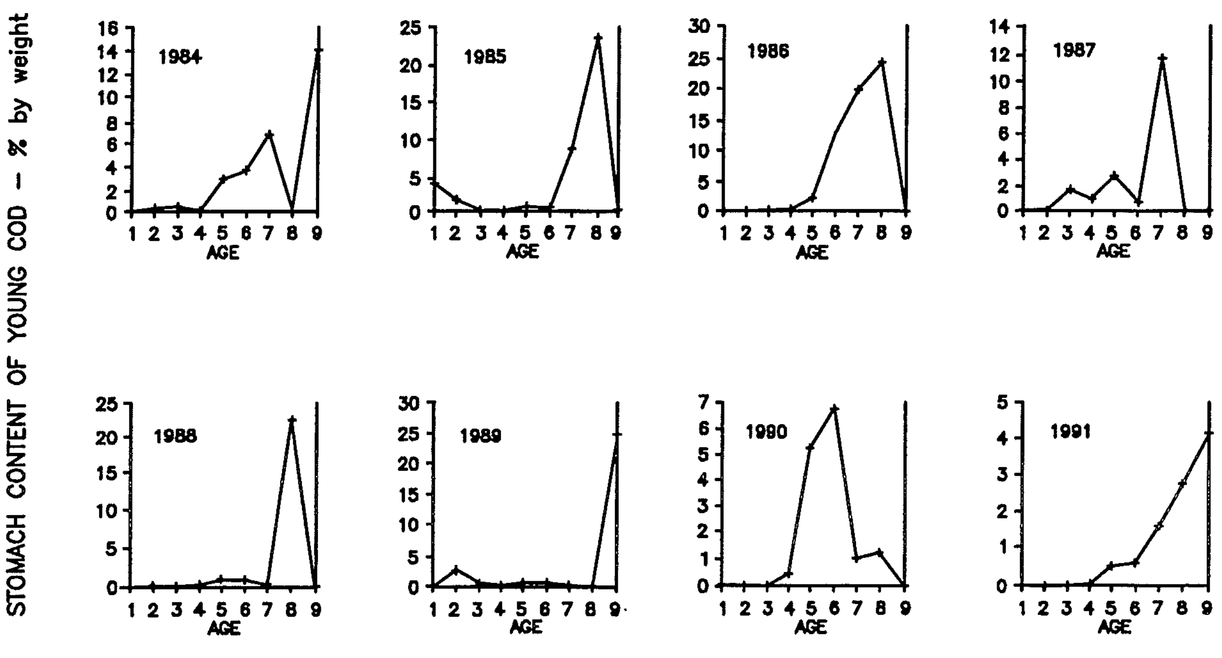

Figure 1. Importance of young cod in stomach content of cod by age group.

To estimate the diet of cod, the materials from Russian-Norwegian data base ("Feeding") were used (Mehl and Yaragina 1992). Data on average quarterly weight of young cod in stomachs of adult cod, separated by ages of predators and prey, were used as input data. Digested food and digested fish were recalculated using identified prey species. Age groups of preys were calculated by applying average Russian age-length keys of cod for 1988-1992 based mainly on data from autumn-winter surveys. In the case of lack of data on feeding of some age groups of cod (usually older than 9-10 years), the mean index of stomach fullness and mean composition of food for younger age groups, starting from 4 years, were used. Daily ratio of cod was calculated by the modified formula of dos Santos (Bogstad and Mehl 1992). For Themisto sp. the rate of evacuation for capelin was accepted, whereas for cod, haddock, polar cod, redfish, long rough dab and other prey - the rate of evacuation for herring was used. Data on mean weights and abundance of different age groups of cod were taken from data, given in the Arctic Fisheries Working Group (Anon. 1994). To calculate mean weights of cod by quarters, it was accepted that cod grow evenly during a year. Cod abundance by quarters were calculated using coefficients of natural and fishing mortalities (Anon. 1994). To characterize the abundance of young cod, the following indices were used: for 0-groups indices of abundance obtained by the 0-group surveys in August-September (Anon. 1994), and for ages (1+)-(3+) -data on mean catch per hour trawling in areas I, IIa and IIb from surveys in October-December.

RESULTS AND DISCUSSION

Cannibalism was observed through the whole period of investigation of feeding of Arcto-Norwegian cod. However, the level of predation varied greatly during different periods (Table 1).

Table 1. Importance of young cod in stomach content of cod (% of weight of food bolus).

Year	Percent young cod	Number investigated
1949	7,60	185
1950	0,22	193
1951	8,18	25
1952	9,41	634
1953	4,38	1123
1954	20,50	51
1955	3,28	188
-		
1958	30,18	451
1959	19,91	1017
1960	2,33	170
-		
1973	55,98	149
1975	0	199
-		
1984	2,79	3731
1985	2,97	3879
1986	6,89	6064
1987	3,88	6944
1988	1,23	5622
1989	0,67	7828
1990	1,66	8443
1991	1,26	6649
1992	1,96	4546

In 1930, young cod and haddock together with herring and capelin had an important place in the food of cod, constituting 20% of the stomach content by weight (Zatsepin and Petrova 1939). In 1940-50's (retrospective data of PINRO), the proportion of young cod in the diet was also quite large and fluctuated from 0.22% in 1950 to 30.2% in 1958.

However, the number of stomachs sampled annually in this period was much lower than in 1984-1992. In the 1980's in comparison with previous years, the level of cannibalism was reduced and did not exceed 2-3%. Only in years with a large reduction of the capelin stock (1986-1987), a sharp increase (1.5-2 times) in predation on cod by cod was revealed. Cannibalism in cod begin at the predator age 1, however, only from the age of 4 the level of cannibalism in cod reaches relatively high values (Figure1).

Daily rations of cod and proportion of young cod consumed show large variability by years and in age groups of cod-predator. Abundances of young age groups (0+)-3 have been assessed both with annual values of diets and with diets averaged for 1984-1992 (Table 2). These calculations have shown that the highest level of mortality (M2) from cannibalism for cod at the age of 0+, is 3-5 times higher than mortality from other sources (M1), accepted as equal to 0.2 (Table 3). However, with increasing cod age, M2 sharply decreases, and the mortality of 2-3-year-old cod caused by cannibalism, is equal to or lower than M1.

Table 2. Stock abundance of young cod by age calculated by VPA with the account of cannibalism. Nos. $\cdot 10^{-3}$.

A: Annual data on feeding.

Age	Year						
	1980	1981	1982	1983	1984	1985	1986
0	2092985	2664548	2118426	2846756	1626701	1996193	1932235
1	510479	526779	742507	869676	1541457	610725	666083
2	308777	331956	367234	562255	673726	1231449	457110
3	180812	195139	211174	250271	425200	521543	982348
Total	3093053	3718424	3439346	4528997	4267090	4359910	4037777

Age	Year					
	1987	1988	1989	1990	1991	1992
0	2428275	4010444	4351254	2470588	1944556	3768151
1	649956	576808	736678	1048073	805871	363796
2	459954	389369	335571	487545	790799	569262
3	338148	327777	259015	183175	388638	637803
Total	3876335	5304398	5682519	4189382	3929665	5339013

B. Average data on feeding for 1984-1993

Age	Year						
	1980	1981	1982	1983	1984	1985	1986
0	2057331	2629403	2380105	2823386	981208	2539622	881455
1	560982	515391	692027	1084188	1549091	755134	597341
2	301977	324589	358512	520244	849191	1225821	616658
3	178314	196803	210303	247565	393978	620872	977143
Total	3048605	3666187	3640948	4675393	3773468	5141449	3072808

Age	Year						
	1987	1988	1989	1990	1991	1992	1993
0	1062781	1181941	2414115	2605563	2457923	2542112	2182513
1	424821	254867	547150	1078948	1278030	618629	1256073
2	366189	203845	200061	447969	811713	919475	390098
3	369426	299810	166468	161355	365558	648941	708142
Total	2223217	1940464	3327795	4293836	4913225	4734158	5042507

Table 3. Mortality coefficient generated by cannibalism on young cod.

A: Annual data on feeding

Age	Year													
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
0	1.191	1.116	.586	.407	.053	1.248	.561	1.240	.570	.609	.514	1.181	.505	1.000
1	.234	.163	.084	.044	.035	.002	.290	.565	.043	.000	.085	.130	.261	.090
2	.225	.233	.170	.077	.114	.027	.313	.000	.003	.015	.003	.024	.062	.220
3	.239	.208	.296	.387	.000	.234	.031	.256	.212	.048	.000	.008	.009	.188

B: Average data on feeding for 1984-1992

Age	Year												
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
0	1.177	1.079	.692	.412	.780	.893	.890	1.233	1.497	1.216	.923	1.476	3.800
1	.230	.160	.076	.055	.024	.090	.169	.315	.341	.213	.081	.148	.270
2	.260	.252	.163	.080	.056	.026	.101	.138	.208	.404	.027	.015	.360
3	.253	.220	.303	.395	.076	.053	.036	.185	.301	.495	.128	.067	.400

Table 4. Annual consumption by cod of young cod, nos. $\cdot 10^{-3}$.

A. Annual data on feeding

Age	Year						
	1980	1981	1982	1983	1984	1985	1986
0	1331140	1619551	905235	863843	45934	1675087	350791
1	94915	70894	50488	42606	47837	1506	136991
2	55390	61388	51035	34848	82961	29720	150843
3	34070	33308	47889	71981		115772	27149
Total	1515517	1784842	1114649	1013280	176732	1822086	665773

Age	Year						
	1987	1988	1989	1990	1991	1992	1993
0	701662	470188	1010037	957422	1574516	921915	1270961
1	169990	9631		79978	141218	129578	98131
2		500	2714	1199	17454	49770	70078
3	75327	51630	5980	9	2527	5217	108893
Total	946980	531950	1019731	1038610	1735716	1106482	1548064

B. Average data on feeding for 1984-1992.

Age	Year						
	1980	1981	1982	1983	1984	1985	1986
0	1335700	1623581	970459	876645	808445	1082057	1047661
1	95398	70931	50655	42529	33757	47591	94340
2	64306	67342	55700	39016	33483	28829	40016
3	36289	34788	49049	73885	27922	23831	31339
Total	1531696	1796642	1125805	1032078	903608	1182310	1213357

Age	Year					
	1987	1988	1989	1990	1991	1992
0	1588717	2892621	2822374	1370889	1392246	3514179
1	159041	151646	128682	74116	100691	78371
2	53986	66556	101682	11701	10647	156918
3	46430	76965	91659	19632	22617	187738
Total	1848175	3187788	3144394	1476340	1526203	3937207

Comparison of the number of consumed young cod and abundance of age groups (0+)-3 calculated from data on feeding (in spite of the differences in values of consumption), abundances of young cod in both variants are quite similar (Tables 2 and 4). The largest differences, especially in 0-groups, were noted in 1986-1989.

Analysis of cod predation has shown that the annual number of young cod consumed in 1980-1992 by older specimens exceeds the abundance of an average year-class at age 3. The largest number of young fish die from cannibalism at the age of (0+). With increasing age of cod, the number of fish dying from cannibalism sharply decreases (Table 4).

The quantity of young fish consumed depends on a number of factors. The level of cannibalism seem to be correlated with the abundance of the age groups subject to predation (Figure 2) and also with size of the cod stock (Figure 3). An inverse relationship was observed between the abundance of capelin, the main prey species for cod in the 1980's and the consumption of young cod (Figure 4). In this figure, however, the level of cod cannibalism is calculated based on feeding data averaged over the period 1984-1992. If annual data on feeding are used, it can be seen from Figure 2 and Figure 3 that no such inverse relationship exists. Given the shortness of the time-series, one should be very careful in drawing conclusions about the relationship between capelin abundance and cod cannibalism. The feeding data for the years 1993 and later, when the capelin stock collapsed again, will give more information about the existence of such a relationship.

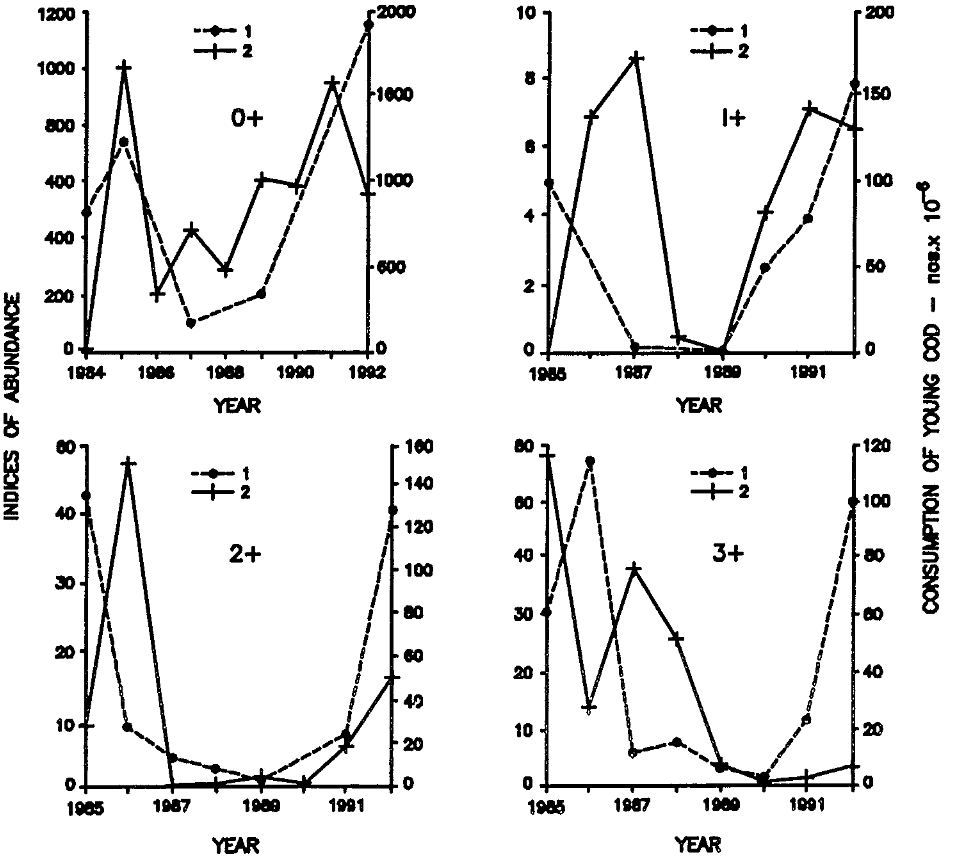

Figure 2. Abundance indices of cod by age (1) and consumption by cod of young cod (2) 1984-1992;

1: Abundance indices of cod by age; area based indices of 0-group cod (Anon. 1994) and the n umber caught per hour trawling of age-group 1+, 2+, 3+.

2: Consumption of young cod by number, based on actual data on feeding.

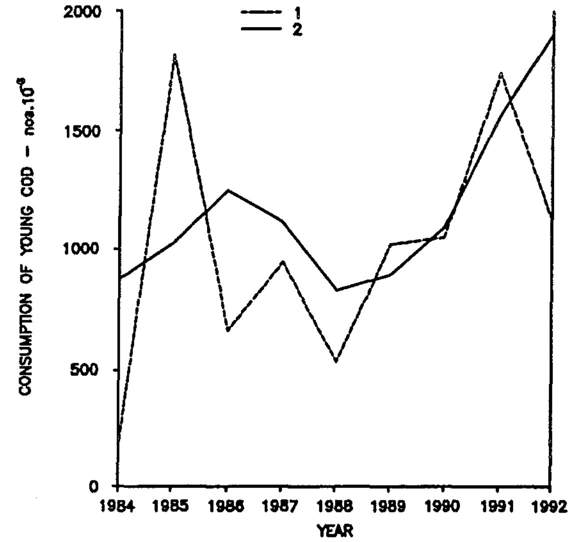

Figure 3. Consumption by cod of young cod (1), based on averaged stomach content and capelin stock abundance (2) in the Barents Sea 1984-1992. Based on actual data for feeding 1984-1992.

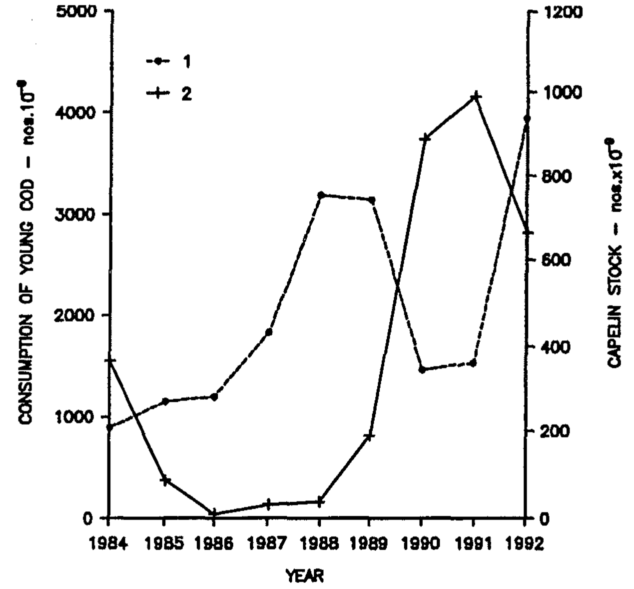

Figure 4. Consmption by cod of young cod (1), based on averaged stomach content and capelin stock abundance (2) in the Barents Sea 1984-1992. Based on actual data for feeding 1984-1992.

REFERENCES

ANON. 1994. Report of the Arctic Fisheries Working Group. Copenhagen, 24 August-2 September 1993. *ICES CM 1994*/Assess:2, 251 pp.

BOGSTAD, B. and **MEHL, S.** 1992. The North-East Arctic cod stock's consumptions of variuos prey species 1984-1989. Pp. 59-72 in Bogstad, B. and Tjelmeland, S. (eds.): *Interrelations between fish populations in the Barents Sea. Proceedings of the fifth PINRO-IMR Symposium. Murmansk 12-16 August 1991.* Institute of Marine Research, Bergen, Norway.

KORZHEV, V.A. and **TRETYAK, V.L.** 1992. The effect of cannibalism on recruitment to the North-East Arctic cod stock. Pp. 161-168 in Bogstad, B. and Tjelmeland, S. (eds.): *Interrelations between fish populations in the Barents Sea. Proceedings of the fifth PINRO-IMR Symposium. Murmansk, 12-16 August 1991.* Institute of Marine Research, Bergen, Norway.

PONOMARENKO, I.Ya. 1968. Feeding, biological characteristics and survival of "demersal" young cod of the Barents Sea. *Trudy polyar. nauchno.-issled. Inst. morsk. ryb. Khoz. Okeanogr.*, *23*: 279-293. (In Russian)

ZATSEPIN, V.I. and **PETROVA, N.S.** 1939. Feeding of commercial schools of cod in the southern part of the Barents Sea (by observations of 1934-1938). *Trudy polyar. nauchno.-issled. Inst. morsk. ryb. Khoz. Okeanogr.*, 5: 171 pp. (In Russian)

FEEDING OF YOUNG *SEBASTES MENTELLA* TRAVIN IN THE BARENTS AND NORWEGIAN SEAS

by

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ABSTRACT

Studies of feeding showed that planktonic crustaceans - (*Calanoida, Hyperiidea* and *Euphausiidae* as well as *Decapoda* including juvenile shrimp, *(Pandalus borealis)* constituted in 1989-1992 the bulk of food of young *Sebastes mentella* at age 0+-3+. It was also shown that the redfish diet changed by age, *i.e.* percentage of small organisms (*Calanoida*) decreased and percentage of larger plankton (*Hyperiidea* and *Euphausiacea*) increased.

INTRODUCTION

One of the most important parts in studies of commercial fish species are investigations of juveniles, in particular growth, survival and abundance. Feeding is an important part of such processes and can be a decisive factor for development of juveniles.

Feeding of deep-sea redfish in the Barents and Norwegian Seas has been rather well studied (Konchina 1970; Antonov *et al.* 1989; Dolgov and Drevetnyak 1993). However, feeding of juveniles remains poorly studied in these areas compared to other Atlantic areas (Konchina 1968; Pavshtiks and Pankova 1967). To be able to carry out further analysis of biological parameters of young age-groups of deep-sea redfish, studies of feeding of juvenile deep-sea redfish were done. The results are presented in this paper.

MATERIAL AND METHODS

Data on feeding by juvenile deep-sea redfish collected during autumn-winter surveys in 1989-1992 are analysed in this paper. Stomach contents were processed under laboratory conditions, using standard methods (Anon. 1974). To characterize feeding, the following parameters were used: mean index of stomach fullness (°/₀₀₀), per cent by weight (m) and per cent frequency of occurrence (f) of stomachs with food, as well as per cent of empty stomachs. A total of 864 juvenile fish stomachs were analysed, including several with evacuated stomachs. All data are given by statistical areas (Figure 1) in Tables 1-4.

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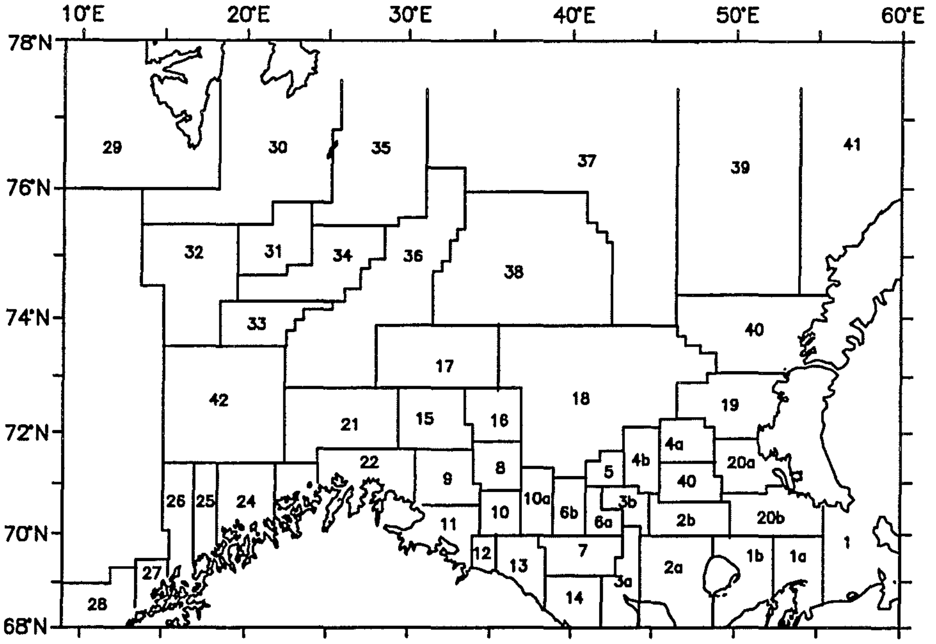

Figure 1. Statistical areas in the Barents Sea. Names and numbers of areas are given in Tables 1-4.

RESULTS AND DISCUSSION

The investigations have shown, that the basis for feeding of young *Sebastes mentella* at the age of 0+-3+ in autumn-winter 1989-1992 was planktonic crustacea - *Calanoida, Hyperiidea, Euphausiidea and Gammaridae* as well as *Decapoda,* including young shrimp *Pandalus borealis.*

During the analysis of the samples, some differences in feeding between age groups were revealed (Figure 2). Such changes were mostly expressed in 1989, when maximum number of stomachs with food were analysed. As young fish grow older, the importance of small plankton organisms (*Calanoida*) decreases and larger plankton (*Hyperiidea* and *Euphausiidea*) begin to play the leading role in the feeding. Besides, various *Decapoda* and fish appear in stomachs. Similar observations of food consumption by young *Sebastes mentella* have been made in the areas of Newfoundland (Konchina 1968).

During autumn-winter, the feeding intensity changed considerably. The mean index of stomach fullness decreased in October-December from 63.1$^{0}/_{000}$ in 1989 to 10.7 $^{0}/_{000}$ in 1992 (Table 1-4). It could be associated with the increase in abundances of capelin and herring, consuming the same prey as redfish.

Local differences in feeding of young *Sebastes mentella* were also revealed (Tables 1-4). *Calanoida* were freguently observed in stomachs, even exclusively in some areas as West Spitsbergen, in some years, also on the Demidov and Nordkyn Banks.

Food composition by young *Sebastes mentella* in the Barents and Norwegian Seas are similar to that in other areas of the Atlantic Ocean with regard to higher taxonomic groups (Order, Family), differring slightly just in species composition within such groups (Konchina 1968; Pavshtiks and Pankova 1967).

Data of stomach content of other commercial fish species, including young fish (Boldovsky 1941; Sysoeva et al., 1976; Ajiad and Pushchaeva, 1992; Ajiad and Gjosaeter, 1990) show that diet of *Sebastes mentella* overlaps the diet of capelin, polar-cod, herring, cod and haddock. Thus, studies of stomach content of young *Sebastes mentella* increase the possebility to give prognoses for growth, survival and recruitment in commercial stocks.

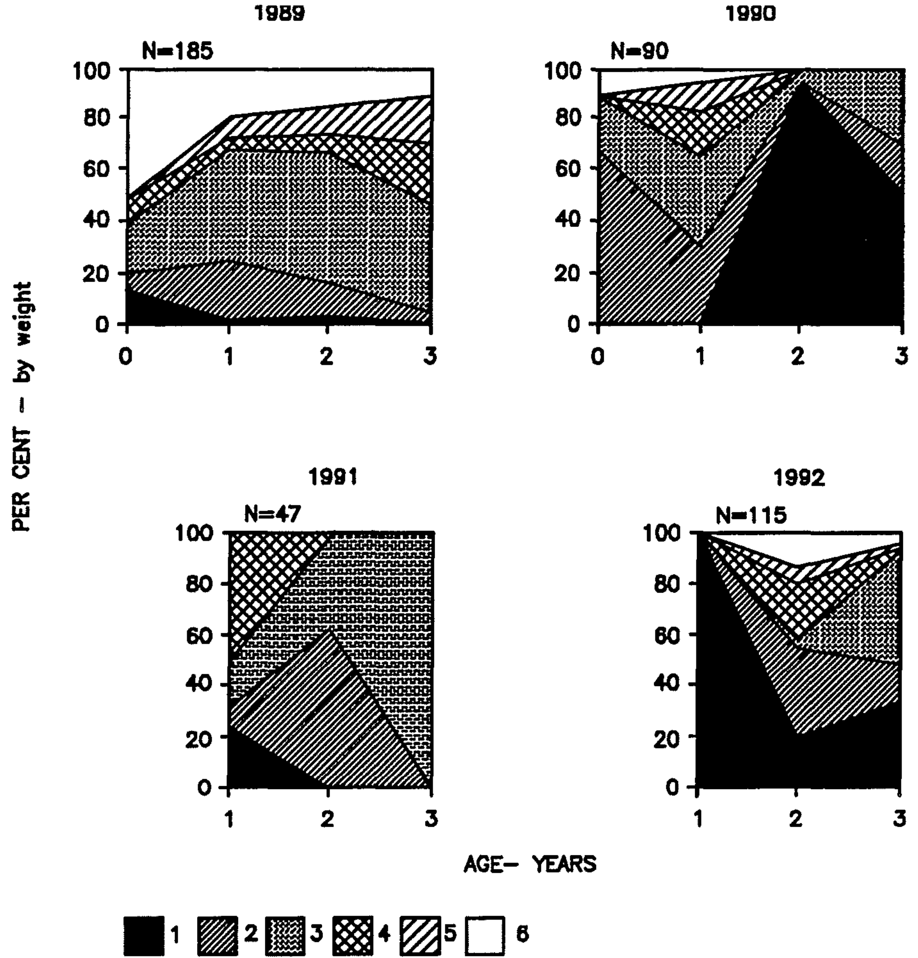

Figure 2. Changes in feeding of young redfish from different age groups in 1989-1992. 1: *Copepoda;* 2: *Hyperiidae;* 3: *Euphausiidae;* 4: *Gammaridea;* 5: *Decapoda;* 6: *Other.*

REFERENCES

AJIAD, A., MEHL, S., KORSBREKKE, K., DOLGOV, A V., KORZHEV, V.A., TRETYAK, V.L. and **YARAGINA, N.A.** 1992. Trophic relationships and feeding-dependent growth in the North-East Arctic cod. Pp. 45-58 in Bogstad B. and Tjelmeland S. (eds.): *Interrelations between fish populations in the Barents Sea. Proceedings of the fifth PINRO-IMR symposium,* Murmansk 12-16 August 1991. Institute of Marine Research, Bergen, Norway.

AJIAD, A. and **PUSHCHAEVA, T.Ya.** 1992. The daily feeding dynamics in various length groups of the Barents Sea capelin. Pp. 181-192 in: Bogstad, B. and Tjelmeland S. (eds.): *Interrelations between fish populations in the Barents Sea. Proceedings of the fifth PINRO-IMR symposium, 12-16 August 1991.* Institute of Marine Research, Bergen, Norway.

AJIAD, A.M. and **GJOSAETER, H.** 1990. Diet of polar cod, *Boreogadus saida,* in the Barents Sea related to fish size and geographical distribution. *ICES CM 1990*/G:48. 9 pp.

ANON. 1974. *Methodical textbook on studying of feeding and nutritive relations of fish under natural conditions.* Nauka, Moscow. 274 pp. (In Russian)

ANTONOV, S.G., BERESTOVSKY, E.G., ORLOVA, E.L. and **SHESTOVA, L.M.** 1989. Studying of feeding of fish from *Sebastes* genus. Pp. 75-88 in: *Daily rythms and rations of feeding of commercial fish species of the World Ocean.* Vses. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr. Moscow. (In Russian)

BOLDOVSKY, G. V. 1941. The food and feeding of the Barents Sea herring. *Trudy polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr. 7*: 219-286. (In Russian)

KONCHINA, Yu. V. 1968. Growth and feeding of young Sebastes mentella of the Newfoundland areas. *Mater. rybokhoz.-issled. sev. Basseira. 12*: 49-61. (In Russian)

KONCHINA, Yu. V. 1970. Feeding of larvae of redfish in the Barents Sea. *Trudy molodykh uchenykh,* 3: 166-181. (In Russian)

PAVSHTIKS, E.A. and **PANKOVA, L.A.** 1967. On feeding of young redfish of the genus of Sebastes in the Davis Strait. Mater. *rybokhoz.-issled. sev. Basseira. 10*: 57-69. (In Russian)

SYSOEVA, T.K., PTITSYNA, L.G. and **GERASIMOVA, L.V.** 1976. Feeding, growth and survival of larvae and fry of the Barents Sea haddock. *Trudy polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr. 37*: 7-18. (In Russian)

Table 1. Stomach content of young redfish from different areas in 1989.

Statistical area	Nordkyn bank (21)		Demidov bank (17)		Sørøya bank (23)		West of Spitsbergen (29)		Kopytov area (42)		Southern slope of Bear Island bank (33)		Western slope of Bear Island bank (32)		Eastern slope of Bear Island bank (34)	
Prey organism	m	f	m	f	m	f	m	f	m	f	m	f	m	f	m	f
Crustacea unident.	1,3	13,3							9,1	25,0	3,4	9,1			50,5	47,4
Calanoida							1,8	7,7	26,5	33,3					2,9	15,8
Calanus spp.	1,7	20,0									2,1	27,3	2,8	22,7		
Calanus finmarchicus	0,7	20,0													0,4	5,3
Metridia longa							1,0	7,7			3,9	18,2	1,4	13,6		
Pareuchaeta norvegica															1,2	5,3
Mysidacea					1,6	20,0			17,1	8,3	0,2	18,2				
Isopoda											0,4	18,2				
Parathemisto spp.	0,5	13,3	0,1	7,1	10,8	30,0	0,1	4,5					0,1	4,5	6,6	21,0
Parathemisto abyssorum					3,3	10,0			12,6	8,3			0,6	4,5	2,8	5,3
Parathemisto libellula	2,4	6,7	24,5	35,7	1,4	20,0	64,4	46,1			8,4	36,4	0,7	4,5	17,0	42,1
Gammaridea	10,1	20,0	38,0	64,3	0,5	10,0	0,9	15,4	18,6	8,3	62,6	81,8	0,2	4,5		
Euphausiidae	48,8	40,0	5,4	21,4	76,9	70,0	3,8	15,4			18,0	18,2	11,4	13,6		
Megaictyphanes norvegica			23,0	21,4									23,6	22,7		
Thysanoessa inermis			3,2	7,1									12,0	9,1	15,2	10,5
Thysonessa longicauda															3,3	5,3
Decapoda	27,1	33,3	4,9	7,1	1,2	10,0							2,0	9,1		
Chaetognatha							0,4	7,7					2,8	18,2		
Oicopleura spp.													2,2	13,6		
Pisces							7,6	7,7								
Unidentified	7,2	13,3	0,9	14,3	4,3	10,0	20,1	23,1	16,1	33,3	0,9	9,1	40,2	22,7		
Number of stomach examined	20		14		16		35		29		28		31		23	
% emty stomachs	25,0		0,0		37,5		34,3		58,6		60,7		29,0		17,4	
Mean index of $^0/000$ fullness$^{3)}$	57,7		65,6		143,4		41,4		6,2		26,3		111,1		45,3	

Note. m: Weight of prey organism in stomachs of *Sebastes mentella* relative to total weight of stomachs (%).
f: Frequency of occurence, number of stomachs with certain prey relative to number of stomachs with food (%).
3: Index of fullness: weight of stomach relative to body weight x 10 000.

Table 2. Stomach content of young redfish from different areas in 1990.

Statistical area	Western Spitsbergen (29)		Central elevation (38)		Central Deep (18)		Eastern slope of Bear Island Bank (34)		Kopytov area (34)		Murman Tangue (15)		Hopen area (35)	
Prey organism	m	f	m	f	m	f	m	f	m	f	m	f	m	f
Crustacea unident.													8,6	50,0
Calanoida														
Calanus finmarchicus	8,5	100,0												
Calanus glacialis	8,5	100,0												
Pareuchaeta norvegica	67,7	100,0												
Mysidacea					8,7	20,0								
Parathemisto abyssorum							95,5	100,0						
Parathemisto libellula	5,0	14,3							27,3	100,0	25,9	50,0		
Gammaridea													91,4	50,0
Euphausiidae	10,4	42,8	64,8	50,0							74,1	100,0		
Thysanoessa inermis					91,3	80,0	4,0	25,0						
Decapoda									72,7	100,0				
Chaetognatha			24,0	25,0										
Unidentified			11,2	25,0										
Number of stomach	9		15		12		22		10		11		14	
examined	22,2		73,3		58,3		63,6		90,0		81,8		85,7	
% emty stomachs	294,0		4,7		60,6		24,8		30,3		13,0		27,7	
Mean fullness														

Note. See note in Table 1.

Table 3. Stomach content of young redfish from different areas in 1991.

Statistical area	South cape Deep. (30)		Eastern slope of Bear Island Bank (34)		Western Spitsbergen (29)	
Prey organism	m	f	m	f	m	f
Crustacea unident.						
Calanus finmarchicus					51,2	12,5
Parathemisto spp.	28,7	50,0	4,5	20,0		
Parathemisto abyssorum			3,8	20,0		
Gammaridea			83,4	40,0		
Euphausiidae			8,3	20,0	48,8	87,5
Thysanoessa inermis	71,3	100,0				
Number of stomach examined	8		19		20	
% emty stomachs	75,0		73,7		60,0	
Mean fullness	12,3		8,0		12,0	

Note. See note in Table 1.

Table 4. Stomach content of young redfish from different areas in 1992.

Statistical area	Nordkyn bank (21)		Demidov bank (17)		Western Deep (36)		West of Spitsbergen (29)		Central elevation (38)		Southern slope of Bear Island bank (33)		North-western slope of Murman Bank (8)	
Prey organism	m	f	m	f	m	f	m	f	m	f	m	f	m	f
Crustacea unident.	9,1	16,7											12,7	20,0
Calanoida	18,8	25,0	2,7	75,0	17,3	40,0								
Microsetella spp.	2,8	33,3												
Metridia longa	25,4	33,3	81,1	50,0										
Parathemisto abyssorum			2,7	25,0	51,7	60,0	86,5	60,0	39,1	71,4	55,9	50,0		
Parathemisto libellula	18,5	41,7											25,5	40,0
Gammaridea	15,1	8,3			30,7	40,0								
Euphausiidae	10,6	16,7	13,5	25,0	0,4	20,0			28,8	28,6			56,0	20,0
Decapoda									15,0	14,3				
Pandatus borealis											44,1	50,0		
Pisces														
Ammodytis spp.									16,6	14,3				
Unidentified							13,5	40,0	0,6	14,3			5,8	40,0
Number of stomach examined	21		8		17		16		22		11		7	
% emty stomachs	42,8		50,0		70,6		68,7		68,2		81,8		18,6	
Mean fullness	21,4		3,8		20,7		1,2		8,6		2,4		14,3	

Note. See note in Table 1.

TRAWL DESIGNS AND TECHNIQUES USED BY NORWEGIAN RESEARCH VESSELS TO SAMPLE FISH IN THE PELAGIC ZONE

by

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ABSTRACT

In resource surveys, representative identification of species and sizes of fish is of vital importance. Various designs and sizes of pelagic trawls and techniques are used in the pelagic zone by Norwegian research vessels for this purpose. This paper describes trawl designs used for 0-group surveys and a larger trawl used for adult fish. The largest trawl, which has a vertical opening of 30 m when towed at 3.5 - 4 knots, can be rigged for close-to-surface trawling as well as for mid- and deep-water trawling with minor adjustment of the rigging. The performance of the various trawls is described, based on geometric measurements using Scanmar instruments and observations with a TV-camera in a towed underwater vehicle. The trawl mouth area of the 0-group trawl is approximately 10 x 10 m, and it can be rigged to catch efficiently in all depths from surface downwards. The large pelagic trawl is rigged with large surface buoys and lenghtened upper bridles when used in the surface layer to sample herring and mackerel.

INTRODUCTION

In the Barents Sea a combination of fishery-dependent and fishery-independent methods is used for assessment of important fish stocks, like cod, haddock, herring, and capelin. Fishery-independent methods are mainly based on echo integration and trawl sampling. Echo intregration depends on representative identification of targets with respect to fish species and sizes, and trawling is at present the only applicable method for this purpose. Trawl sampling may also give information on fish density directly if the sampling area and selection properties of the trawl are known (Dickson 1975).

Small and large fish targets behave differently in the trawling process. Small fish have low swimming capability and can be captured with a small pelagic trawl, whereas a larger trawl opening is needed to capture larger fish effectively. Based on these assumptions, two trawls of different size have been developed in Norway in recent years, one small trawl for sampling of small fish (< 10 cm) and one bigger trawl for larger fish.

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Studies of early recruitment of fish in the Barents Sea (0-group surveys) have been carried out since 1965 in August-September in joint Norwegian-Russian cruises. Relative abundance indices of different 0-group fish is found using a standard pelagic trawl (16x16 fathoms capelin trawl) towed for 30 minutes in three depth intervals, 0-20, 20-40, and 40-60 m, 10 minutes in each depth (Hylen *et al.* 1995). Based on performance studies of the trawl (Godø *et al.* 1993) and special studies of near-surface vertical distribution of 0-group fish (Godø and Valdemarsen 1993), it was recognised that the trawl and technique used were not optimal. This paper describes an alternative trawl design, its rigging and performance data.

When fish are distributed in the pelagic zone, echo integration is widely used for stock assessment. The targets must be identified to species and sizes for converting echo integration values to abundance estimates (Dalen and Nakken 1983). The trawl used for this purpose should ideally have the same efficiency for all species and sizes of fish, or at least its relative efficiency for different species and sizes should be known. A pelagic trawl for research purposes should be relatively easy to handle onboard when shooting and hauling, and it should function well at any depth from the surface downwards. Another factor to have in mind when designing a pelagic trawl for a research vessel which will also operate bottom trawls with combination trawl doors, is that the trawl size must match the doors and therefore also the size of the bottom trawl. The resulting pelagic sampling trawl design therefore must be a compromise among various conflicting considerations. Until 1992 Norwegian research vessels used the 16x16 fathoms capelin trawl for sampling in the pelagic zone in the Barents Sea. On herring cruises in the North Sea and along the Norwegian coast, a pelagic trawl of swedish design (Fotø) have been used with reasonable success, especially when rigged with buoys at the wing tips for sampling near surface (Misund and Aglen 1992). The pelagic trawl now used by all Norwegian research vessels ("Johan Hjort", "G. O. Sars", "Jan Mayen", and "Michael Sars") was designed in 1991 and first introduced on "Johan Hjort" in 1992. This paper describes the trawl design, rigging alternatives, and results from performance tests with this trawl.

0-GROUP TRAWL

Trawl design and rigging

The design of the 0-group trawl is shown in Figure 1. The trawl consists of four identical panels in green coloured nylon material. Mesh size ranges from 200 mm in the front to 10 mm in the codend. These small mesh sizes are intended to reduce the escape losses for smaller fish.

Rigging of the trawl is illustrated in Figure 2. All rigging components were made very light to make it possible to tow the trawl near the surface. The trawl doors were constructed in aluminium, and their design is shown in Figure 3.

Material: Twisted PA				
Norwegian twine number	Rtex (approximate)	Stretched mesh length (mm).	Panel depth (meshes)	Meshes in selvedge
•24	1656	200	34½	4
			23½	4
•18	1242	100	49½	4
•6	414	40	298½	4
•6	414	24	298½	4
•6	414		198½	4
•8	552		99½	4
•6	414	10	849½	4

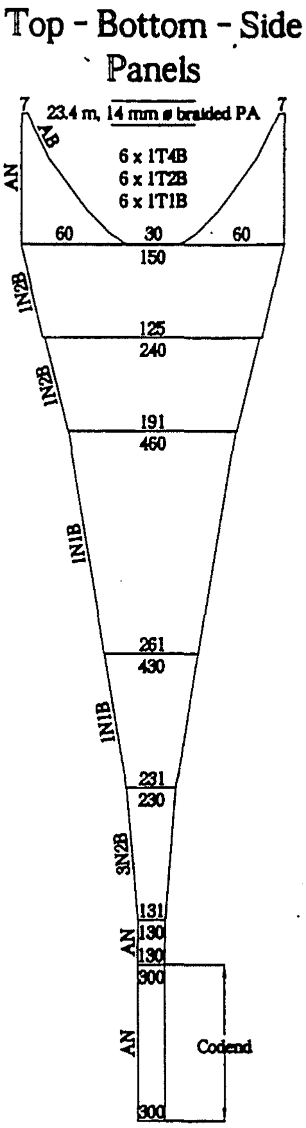

Figure 1. 0-group sampling trawl (113 m net circumference).

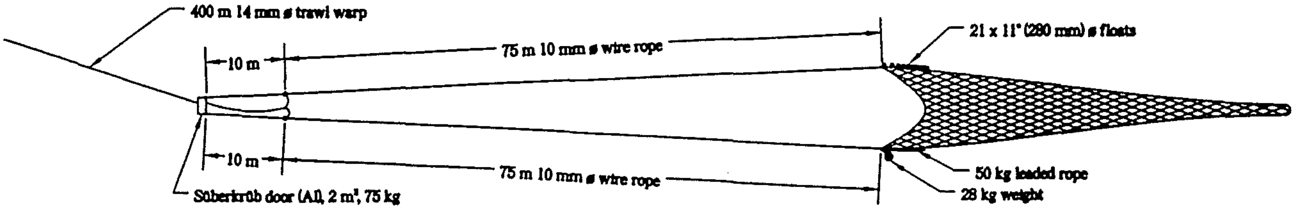

Figure 2. Rigging of the 0-group sampling trawl.

Trawl performance

The geometry of the trawl with different length of warp was measured with Scanmar instruments in a trial with F/F "Michael Sars" in April 1993. Data from this test are given in Table 1.

Table 1. Trawl geometry and vertical position of the 0-group sampling trawl with different warp lengths when towed at 2.3 knots.

Warp length (m)	Trawl depth (m)	Door depth (m)	Trawl height (m)	Door spread (m)	Wing spread (m)
100	0	10	10.5	30	9
150	17	24	10	36	10
200	29	35	10	38	10
250	41	47	10	39	11
300	54	60	10	39	11
350	67	73	10	40	11

A recommended procedure when catching 0-group fish in the upper 60-70 m is to start with 100 m warp for towing in the surface position for 5 minutes, then shoot successively 50 m warp for towing 5 minutes in each depth until the maximum depth for the fish recordings is reached.

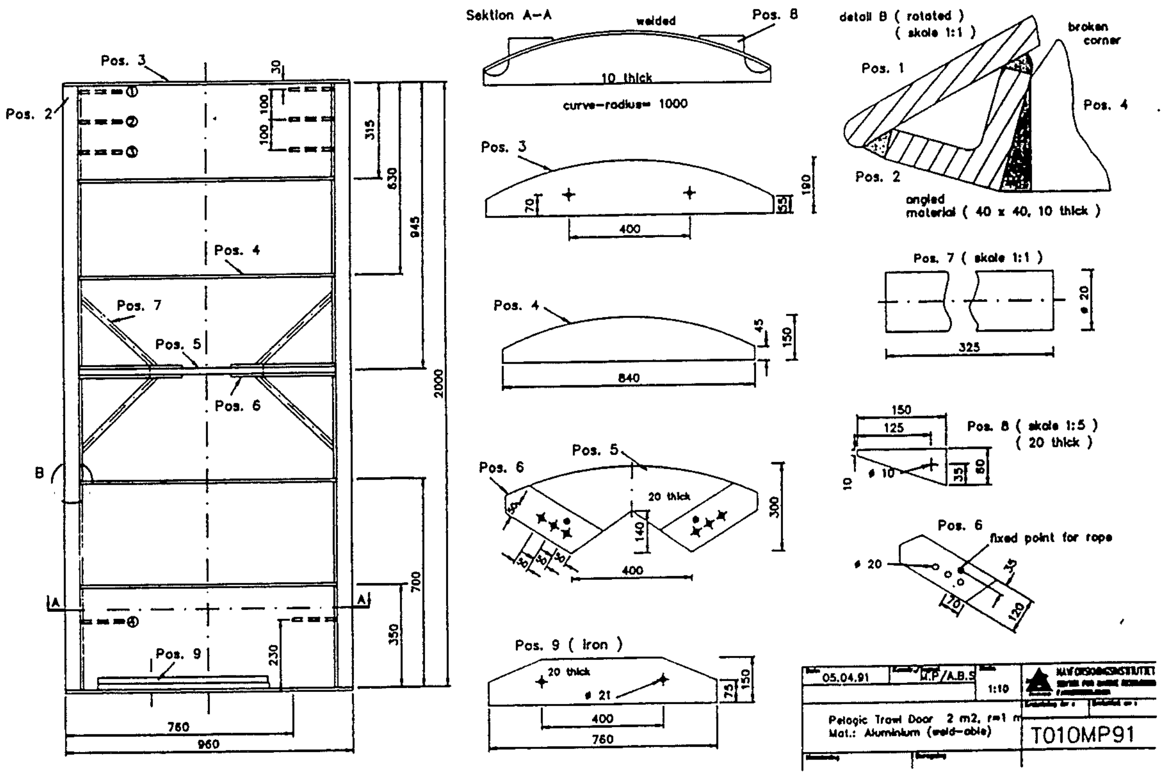

Figure 3. Süberkrüb trawldoor $2m^2$ in aluminium used with the 0-group sampling trawl.

PELAGIC SAMPLING TRAWL (ÅKRA TRAWL)

Trawl design and rigging

The design of the Åkra trawl is illustrated in Figure 4. The trawl is made from four identical panels of black coloured nylon netting. The mesh size ranges from 3200 mm in the front to 20 mm in the codend.

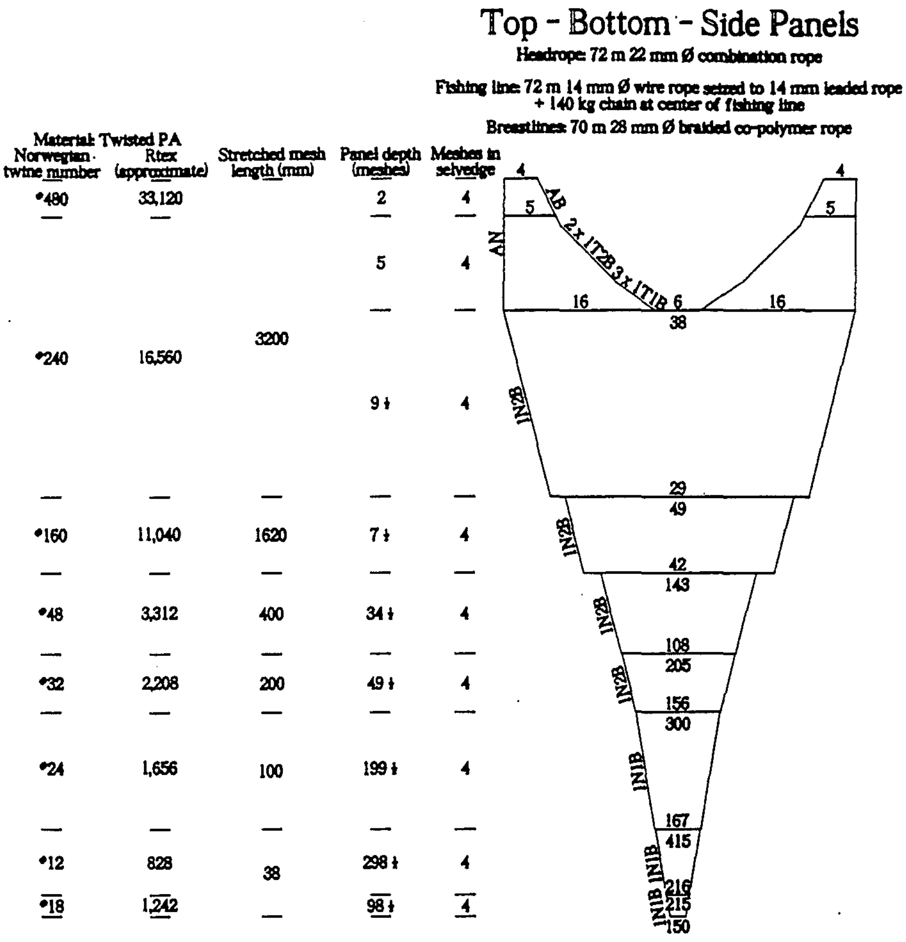

Figure 4. The pelagic sampling trawl (Åkra trawl), 384 m net circumference.

For fishing at greater depth than 50 m, the trawl is rigged as shown in Figure 5 B (standard rigging). Two sizes of trawl doors (Waco type 6 m^2 and 7 m^2) have been tested with this rigging. It should be noted that the lower bridles had an extension of 6 m with this rigging, and 500 kg weights were used on each lower wing tip.

For surface trawling the trawl was rigged as shown in Figure 5a. The difference from the standard rigging is the extra extension of the upper bridles, omission of the weights at the wing tips, and the two large surface buoys (675 kg buoyancy each) attached to each upper wing.

Trawl performance studies

Two series of experiments were conducted to measure trawl performance. The first test was conducted onboard "Johan Hjort" in April 1993, using various Scanmar gear monitoring instruments, Scantrol load cells, Simrad trawl sonar, and a towed vehicle (Ocean Rover). The second set of experiments was carried out onbord "G.O. Sars" during ordinary sampling cruises in January and July 1993.

Test trials

The trawl, rigged as shown in Figure 5 B, was tested with 6 and 7 m^2 Waco doors at towing speeds between 3 and 4 knots and with warp lengths ranging from 150 to 450 m. Doorspread, vertical trawl opening, and trawl depth were recorded when the trawl had stabilized at the fishing depth. Tension was measured with two load cells attached in front of and behind one trawl door. For calculations of drag, it was assumed that the tension was identical on both sides.

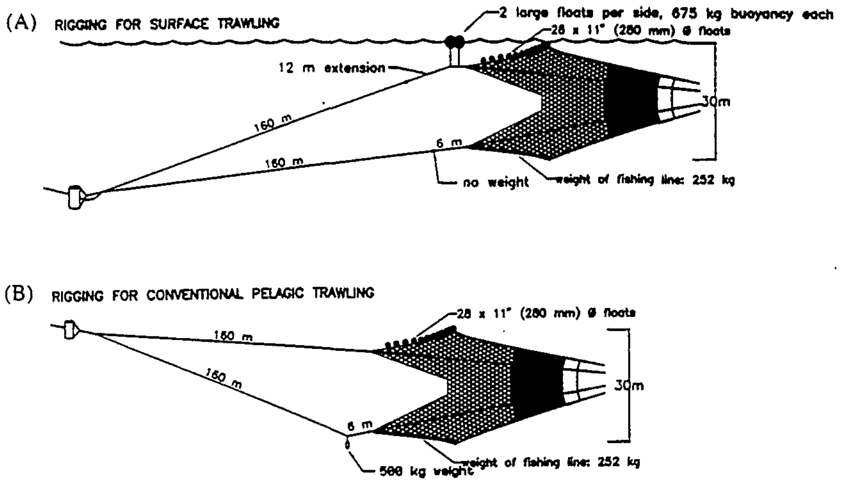

Figure 5. Rigging of the Åkra trawl for surface (A) and midwater (B) trawling.

The door spread for the two door sizes with different warp lengths when towed at 3,4 knots is illustrated in Figure 6. The difference in door spread was approximately 10 m between the two door sizes. The spread reached its maximum with 400 m towing warp.

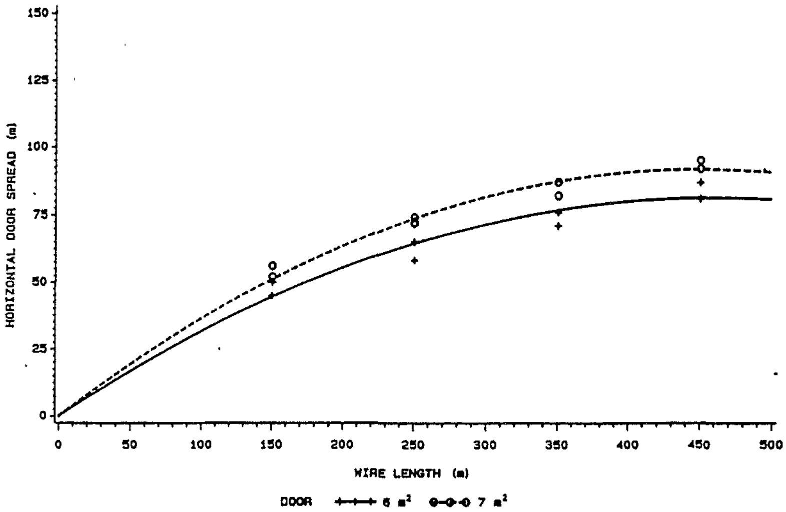

Figure 6. Door spread versus warp length for the two Waco doors (6 and 7 m^2) during test trails with the Åkra trawl onboard F/F "Johan Hjort" in April 1993.

The vertical trawl opening decreased with increased towing speed as shown in Figure 7 for two different warp lengths.

The total drag (trawl doors + trawl net) and drag of the trawl net only as calculated from tension measurements in front of and behind one door are illustrated in Figure 8. The total drag increases from 10 tons at 3 knots to 13 tons at 4 knots. The difference between total drag and trawl net drag is the resistance of the two doors (7 m^2).

Sampling trials

In the January 1993 trial, the trawl was used with conventional rigging to sampling of midwater recordings. The rigging was as shown in Figure 5 B with 6 m^2 Waco doors and 280 kg weight on the wing tips. In the July 1993 trial, the trawl was rigged for midwater sampling as well as for near surface sampling (Figure 5A, B). Larger Waco doors (7 m^2) were used in the July cruise.

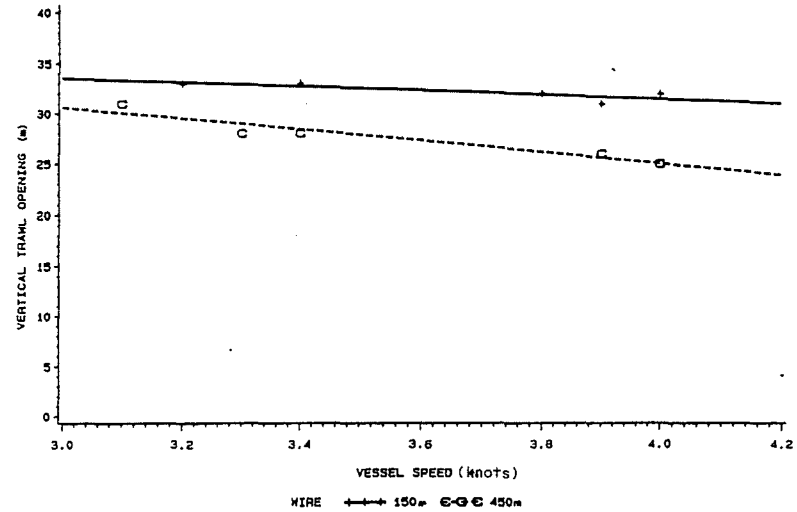

Figure 7. Åkra trawl vertical opening versus towing speed for two different warp lengths (150 and 450 m) during test trails onboard F/F "Johan Hjort" in April 1993.

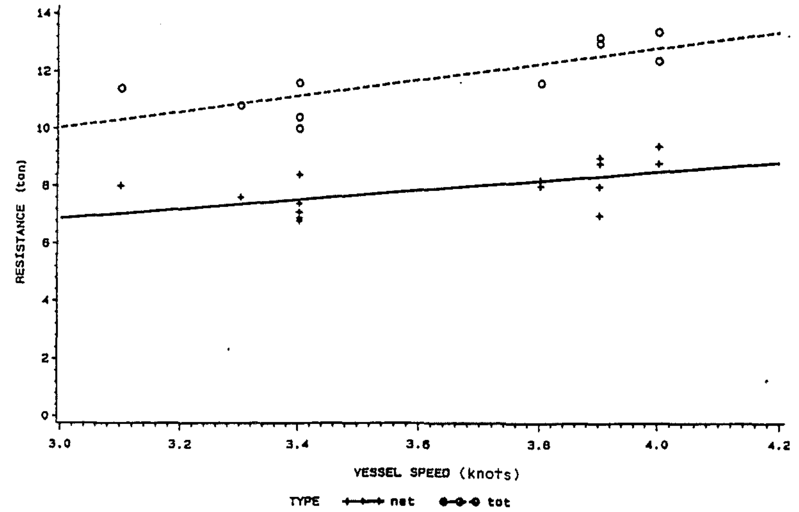

Figure 8. Total and trawl drag versus towing speed calculated from tension measurements in front of and behind one trawl door (7 m^2) during test trials with the Åkra trawl onboard F/F "Johan Hjort" in April 1994.

The depth of the trawl headline versus warp length with 3.5 knots towing speed is illustrated in Figure 9. The trawl depth increased linearly with warp length.

The door spread obtained with the two sizes of Waco doors (6 and 7 m^2) is shown in Figure 10. A difference of 5-10 m in spread was found between the two sizes. The data for the 7 m^2 doors also include hauls when the trawl was towed in surface position.

The vertical opening was 28-32 m with standard rigging and with 300-1200 m of towing warp (Figure 11). Rigged for surface trawling, the vertical opening increased from 24 to 35 m when the warp length increased from 150 to 350 m (Figure 12). The increase in vertical opening is explained by the increase in downward pull of the lower wings as the doors go deeper with increased warp length. Approximately 350 m warp could be shot before the big surface buoys went under. With a towing warp length of 350 m, the trawl's position was 500 m behind the vessel, which was well outside the propeller wake.

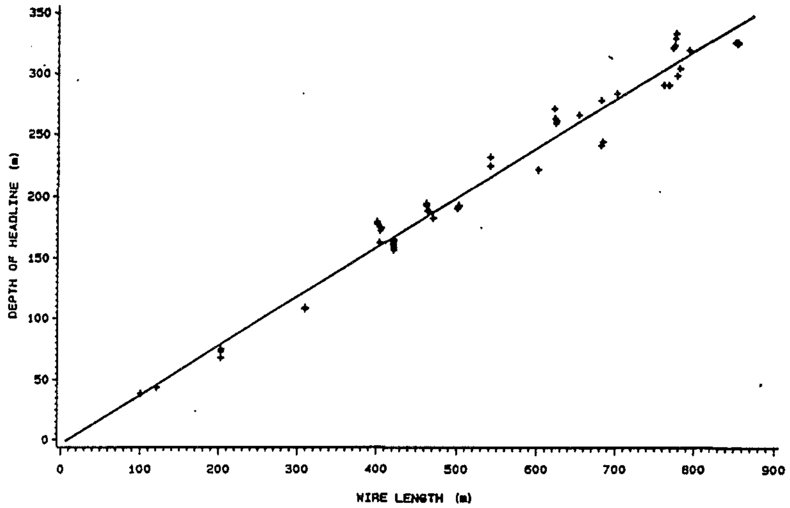

Figure 9. Depth of tawl headline versus warp length when towed at 3,5 knots during sampling trials with the Åkra trawl onboard F/F "G. O. Sars" in January 1993.

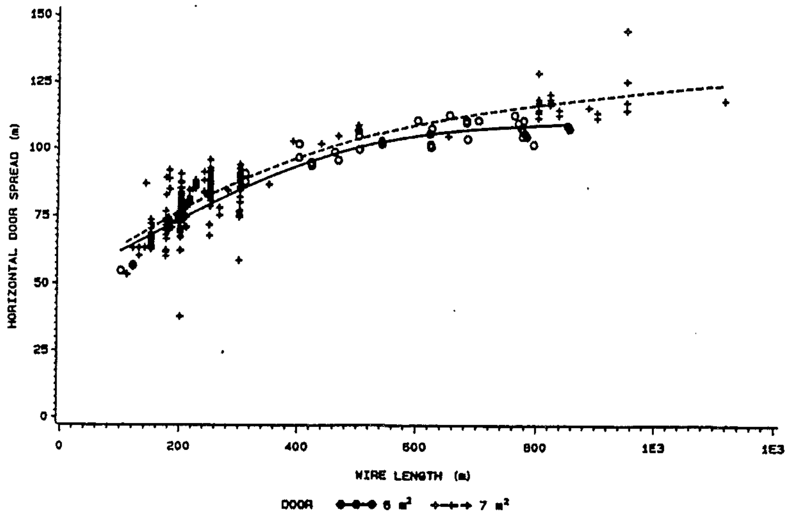

Figure 10. Door spread for 6 and 7 m^2 Waco doors versus warp length during sampling trials with the Åkra trawl in January 1993 (6 m^2) and in July 1993 (7 m^2).

The practical experience with handling of the trawl onboard the research vessels have been satisfactory. Rerigging from standard to surface tows by installing the 12 m extensions in the upper bridles and attaching the buoys at the wing tips were done quite easily.

The catching efficiencies for various species and sizes have not been evaluated. However, the trawl seemed to catch reasonable samples of the important pelagic species. The surface rigging was successfully used to catch scattered concentrations of mackerel and herring in the upper 30 m. Aimed trawling for schools near the surface recorded with sonar has also been successful. The best efficiency for such schools was obtained by towing along a cruved track, so that the trawl passed inside the propeller wake. Nevertheless, occasionally schools avoided the gear. Often these schools seemed to be influenced by the trawl warp and avoided it to pass outside the trawl.

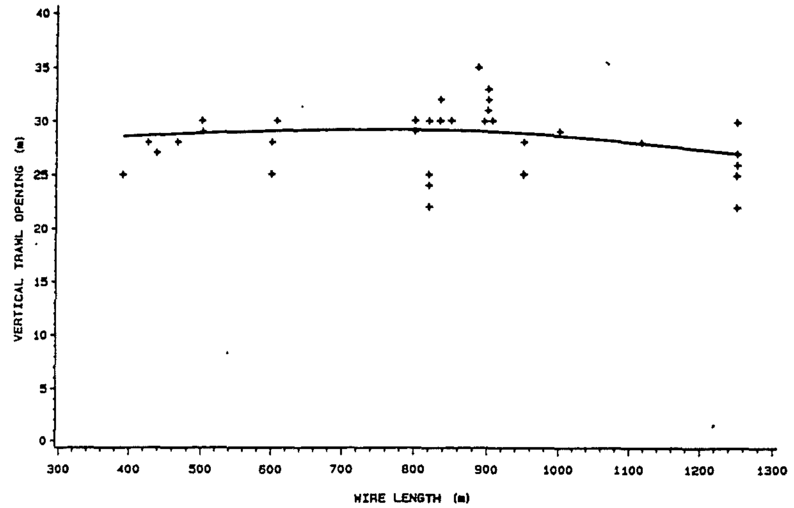

Figure 11. Vertical trawl opening versus warp length with 3,5 knots towing speed during sampling trials with the Åkra trawl onboard F/F "G. O. Sars" in July 1993.

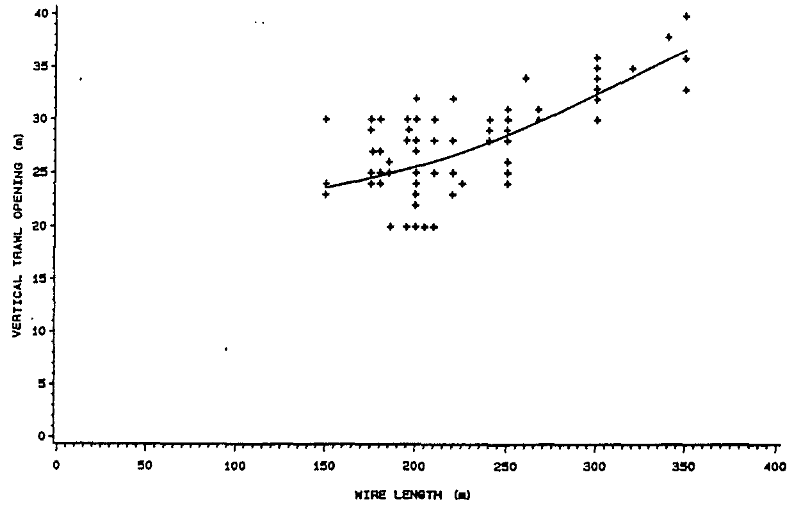

Figure 12. Vertical trawl opening versus warp length when the trawl was rigged for surface towing during sampling trials with the Åkra trawl onboard F/F "G. O. Sars" in July 1993.

DISCUSSION

The advantages of the newly designed 0-group trawl are that it can be towed in any depth from the surface downwards with the same rigging, and that the trawl has nearly the same geometry in all depth intervals. This means that quantitative data can be recorded in any depth independent of the vertical distribution.

Based on a 10 m vertical opening and a 1 m diameter at the entrance of the codend, the belly slope is on average 8°. Such a slope might be too steep to efficiently herd the smallest individuals. A 3 cm fish encountered near the front panel must for example swim at a minimum speed of 5 bodylengths/second for 30 seconds to end up in the codend. Further, the fish must swim away from the netting at right angles, which is unlikely to happen. In the herding process, fish most often avoid an approching object by swimming forward, and therefore the speed and distance the fish must swim to arrive in the codend will exceed the capability of the smallest fish. Some proportions of smaller 0-group fish may be lost, while increasing proportions of larger fish are captured. To evaluate the efficiency for various sizes of fish, small bags covering some areas of the netting outside the trawl could be used to collect the escaping fish. Another method is to observe any escapement through the meshes with a TV- camera either in a towed vehicle or attached to the trawl.

The trawl was tested in three surveys in 1993, for 0-group saithe in the North sea, for herring larvae along the Norwegian coast and in the Norwegian Sea, and for 0-group fish in the Barents Sea. In the first surveys the trawl was considered an improvement compared to the earlier used capelin trawl. The catching performance was, however, not studied in these cruises. In 0-group surveys in the Barents Sea the efficiency of the trawl have been compared with the standard 0-group trawl (Hylen *et al.* 1995).

For sampling schools of larger individuals, which are likely to completely avoid the relatively small fishing area of the 0-group trawl, the Åkra trawl functions well.

The Åkra trawl has been used on several cruises since it was introduced on F/F "Johan Hjort" in 1992. The efficiency of the trawl has not been evaluated in a systematic way. A general experience is, however, that the trawl catches most types of fish recorded with echo sounder and sonar. Compared to catches taken with the former capelin trawl, samples taken with the new trawl consist of larger fish individuals of species like cod and haddock as well as fast swimming pelagic species like herring, mackerel, and horse mackerel.

The rerigging from standard to surface tows is quite simple, and the trawl can therefore be used routinely to sample fish recordings at any depth from the surface downwards. The 6 m^2 Waco doors are, however, not optimal for this trawl, since their spreading force is too low when using short lengths of towing warp. This problem is greatest when fishing on recordings in depths from 30 to 70 m, which is too deep to use the surface rigging. Shallower recordings can be caught with the surface rigging, wheras fish deeper than 70 m are efficiently taken with the standard rigging.

REFERENCES

DALEN, J. and **NAKKEN, O.** 1983. The application of the conventional echo integration method. *ICES CM 1983*/B: 19, 30 pp.

DICKSON, W. 1975. A relationship between capelin density as sampled by echo integration and by pelagic trawl. FTFI-report, Institute of Marine Research, Bergen, Norway. 14 pp.

GODØ, O.R., VALDEMARSEN, J.V. and **ENGÅS, A.** 1993. Comparison of efficiency of standard and experimental juvenile gadoid sampling trawls. *ICES mar.Sci.Symp. 196*: 196-201.

GODØ, O.R. and **VALDEMARSEN, J.W.** 1993. A three level pelagic trawl for near surface sampling of juvenile fish. *ICES CM 1993*/B: 19, 10 pp.

HYLEN, A., KORSBREKKE, K., NAKKEN, O. and **ONA, E.** 1995. *Comparison of capture efficiency of pelagic trawls for 0-group fish.* Pp. 145-156 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. Bergen, 14-17 June 1994.* Institute of Marine Research, Bergen, Norway.

MISUND, O.A. and **AGLEN, A.** 1992. Swimming behaviour of fish schools in the North Sea during acoustic surveying and pelagic trawl sampling. *ICES J.mar.Sci., 49:* 325-334.

COMPARISON OF THE CAPTURE EFFICIENCY OF 0-GROUP FISH IN PELAGIC TRAWLS

by

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ABSTRACT

In 1992 and 1993 experiments were carried out during the international 0-group fish surveys in order to study the capture efficiency of two pelagic trawls. The catches of the standard sampling trawl were compared with those of a special 0-group fish trawl under construction. The results support and strengthen the conclusions arrived at in earlier works; Catches of 0-group cod and haddock in the standard sampling trawl show largely skewed length distributions, the smaller fishes being undersampled relativly to the larger ones, and the new trawl caught 0-group cod in the length range 5-10 cm 3-4 times more efficient than the standard sampling trawl. A significant density dependent catch efficiency is, however apparent for both trawls.

INTRODUCTION

The standard pelagic trawl (ST) used in the annual investigations of 0-group fish in the Barents Sea and adjacent waters is a commercial type trawl designed for small vessels catching spawning capelin in the winter fishery. In recent years the capture efficiency of this trawl for 0-group fish has been investigated and compared with that of various versions of an experimental trawl (ET) particularly designed at the Institute of Marine Research for catching 0-group fish (Godø *et al.* 1993, Godø and Valdemarsen 1993).

During the 0-group surveys in 1992 and 1993 comparative trawlings were conducted with the standard trawl and two versions of the experimental trawl (one version each year) at locations with relatively high density of 0-group fish, mainly cod. Acoustic recordings of the 0-group fish scattering layers were sampled and processed for all comparative trawl hauls. The present paper includes the analyses of the material and a discussion of the results.

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MATERIAL AND METHODS

Field sampling and postprocessing

Locations, dates and vessels as well as the number of trawl hauls carried out appear from Figure 1.

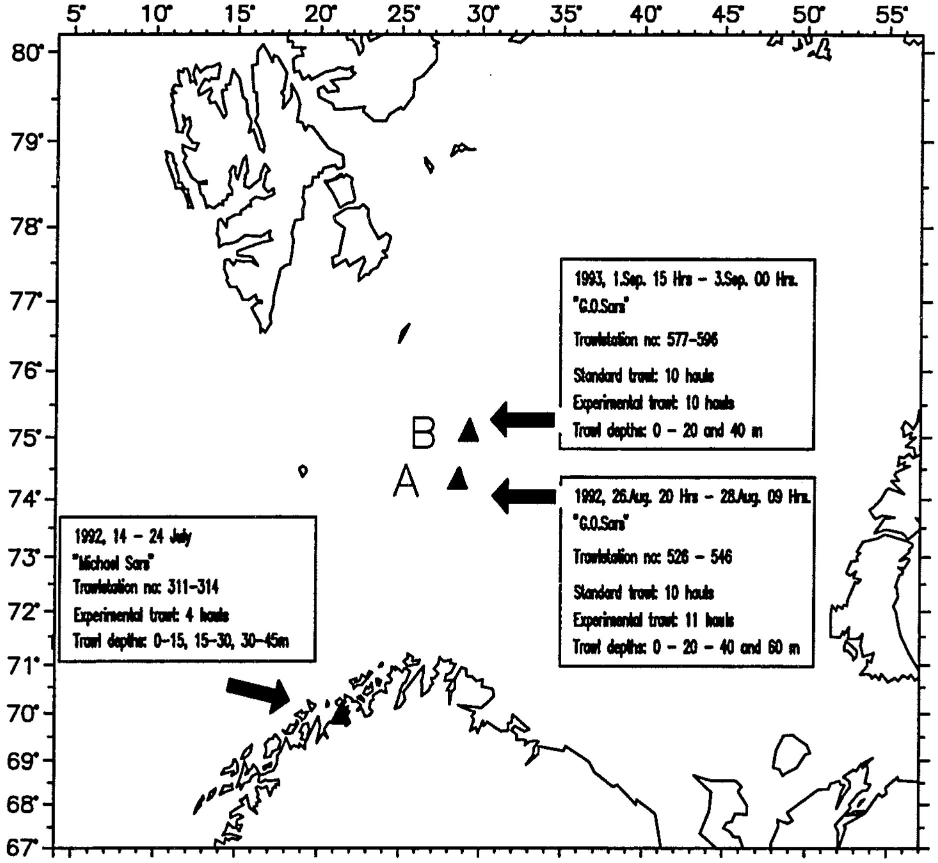


Figure 1. Location and particulars of trawl experiments in 1992 and 1993.

Area back scattering values, s_a, were sampled continously and analyzed with the BEI-system (Knudsen 1990, Foote *et al.* 1991). 0-group herring was separated (Nakken *et al.* 1995) and mean S_A-values of 0-group fish were established within 10 m depth intervals for every trawl haul. Trawl catches were sampled and analyzed according to the standard procedure adopted for the 0-group surveys.

The investigations in 1992 were carried out with the standard 0-group trawl and with an experimental trawl consisting of three equal small trawls on the top of each other (Godø and Valdemarsen 1993). The two trawls were used alternately, all haulings starting in the same position and being in the same direction. Each haul was conducted as a standard 0-group haul; i.e. 10 minutes towing with the headline in each of four depths, 0-20-40 and 60 m, starting at the surface.

In order also to cover low to medium density situations for cod, 28 selected stations worked during the western part of the 1992 international 0-group survey, using the standard sampling trawl are added to the experiments in the analysis of catch efficiency for this trawl. Similarly, 4 stations worked with the experimental trawl from R/V "Michael Sars" in Ullsfjord, 1992, on a low density layer of pure cod 0-group are included in the analysis of catch efficiency.

In 1993 a different version of the experimental trawl, described by Valdemarsen and Misund (1995), was compared with the standard trawl. Trawlings were carried out as standard 0-group hauls with the headline in 50-40-30-20-10 and 0 m, 5 min. towing in each depth. Each trawl was towed two hauls in succession back and forth along the same line.

Computations

In order to obtain comparable figures both the acoustic data and the trawl catches were converted to surface or column densities, ρ_A (number per unit area) as follows:

Acoustics. The density, ρ_A (number per nm^2) was estimated applying the usual equation:

$$\rho_A = \frac{S_A}{<\sigma>} \tag{1}$$

were S_A (m^2/nm^2) is the scattering by 0-group fish during trawling,
$<\sigma>$ is the mean back scattering cross section of the specimens of 0-group fish.

The commonly accepted relationship between the back scattering cross section of cod and fish length

$$10log\frac{\sigma}{4\pi} = 20logL - 68 \tag{2}$$

which gives

$$<\sigma> = 2.0 \cdot 10^{-6} \cdot \overline{L^2} \tag{3}$$

was used to compute $<\sigma>$ from the length distributions in Figure 2.

Trawlcatches. The density, ρ_A (number per nm^2) was estimated by dividing the trawl catch, C (number) with the swept area, A (nm^2):

$$\rho_A = \frac{C}{A} \tag{4}$$

The swept area was defined as the volume filtered by the trawl during the total tow (all depths) divided by the depth extension of the observed water column:

$$A = \frac{D \cdot a}{d} \tag{5}$$

were D: total distance towed (nautical miles)
a: filtering area of trawl mouth (Ona, 1989, Godø and Valdemarsen 1993, Valdemarsen and Misund 1995)
d: depth extension of observed water column (m).

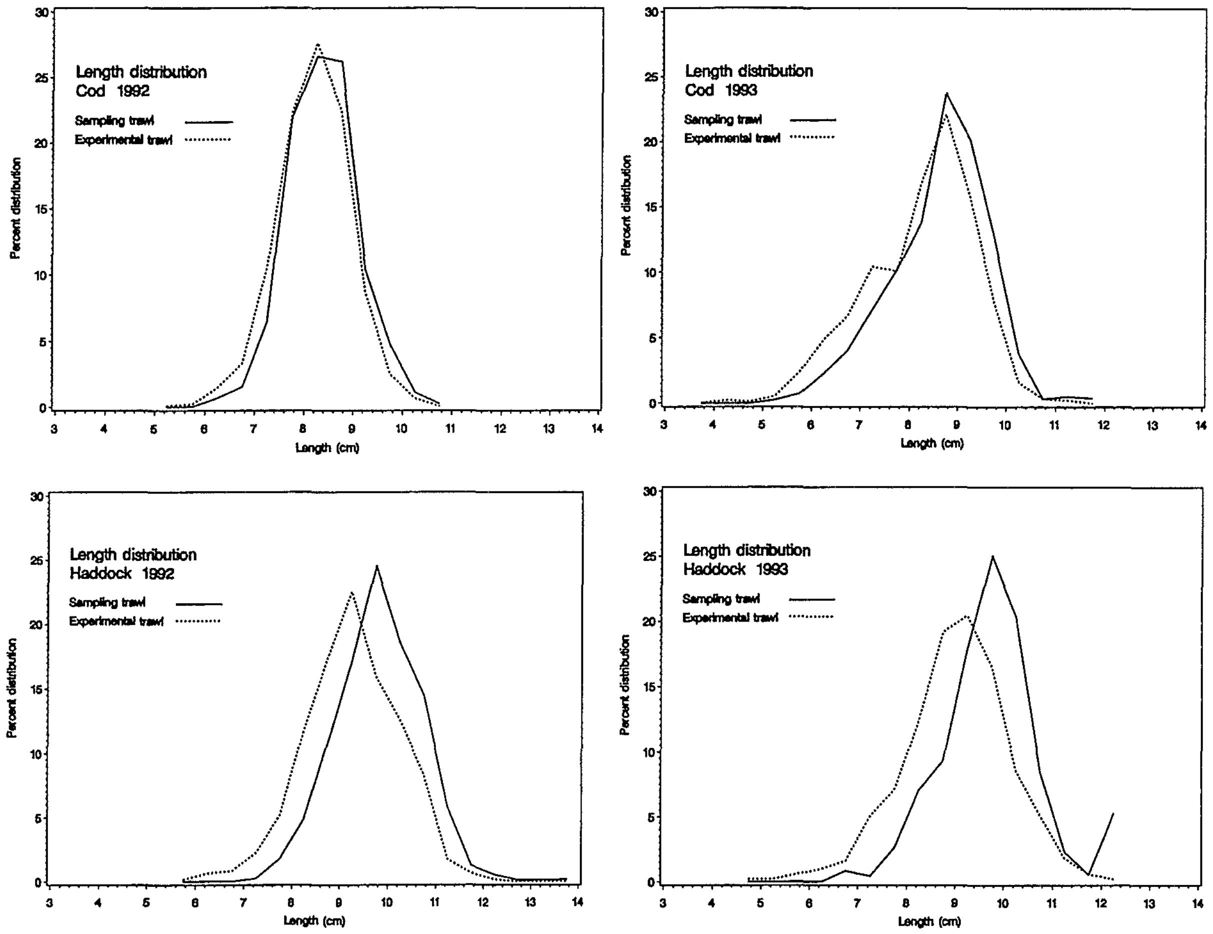


Figure 2. Length distributions of 0-group cod and haddock in the two experiments.

Table 1. Average length (mm) of 0-group cod and haddock at location A, 1992.

	STANDARD TRAWL (10 hauls)	EXPERIMENTAL TRAWL (11 hauls)			
		Total	Upper	Middle	Low
Cod					
All hauls	84	81	82	80	83
Lower value (1 haul)	81	78	78	73	79
Upper value (1 haul)	87	84	85	85	85
Haddock					
All hauls	98	94	93	95	95
Lower value (1 haul)	95	85	79	86	80
Upper value (1 haul)	100	96	100	99	96

Length selection. The length distributions of both 0-group cod and haddock differed between the two types of trawls in both experiments (Figure 2). Mean lengths of catches with the standard trawl were higher than those of the experimental trawl both years (Tables 1 and 2). In order to study and quantify these differences in length selection the following method was used (Millar 1991: The volume density (ρ) of fish in each length group (5mm) was calculated and averaged over 10 hauls for each trawl.

$$\rho = \frac{1}{10}\sum_{j=1}^{10}\frac{C_{j,L}}{D \cdot a} \tag{6}$$

Where $C_{j,L}$ is the catch in number in haul j and length group L.

Table 2. Average length of 0-group cod (mm) at location B, 1993.

	STANDARD TRAWL (10 hauls)		EXPERIMENTAL TRAWL (10 hauls)	
	Cod	Haddock	Cod	Haddock
All hauls	87	95	79	90
Lower value (1 haul)	84	92	63	84
Upper value (1 haul)	89	97	87	95

The probability that any random fish in the sum of catches will occur in the catch of the standard sampling trawl is then

$$P_L^{(st)} = \frac{\rho_L^{(st)}}{\rho_L^{(st)} + \rho_L^{(et)}} \tag{7}$$

We chose the following function as model for this probability

$$P_L^{(st)} = k\,\frac{e^{a+bL}}{1 + e^{a+bL}} \tag{8}$$

and carried out 4 sets of maximum likelihood analyses in order to estimate k, a and b; for cod and haddock in each of the two years (A and B). The estimates of k, a and b are the values that maximize the expression:

$$\sum_L \left[\rho_L^{(st)} \cdot \log P_L^{(st)} + \rho_L^{(et)} \cdot \log (1 - P_L^{(st)}\right] \tag{9}$$

RESULTS AND DISCUSSION

The 1992 experiment

Catch numbers by species are given in Tables 3 and 4. 0-group cod was predominant in the catches of both trawls. 0-group herring was caught in much larger numbers in the standard trawl than in the experimental trawl (Table 3). The back scattering values of 0-group fish appear from Table 4 together with the catches of 0-group cod and haddock. It is seen that the variation in catch numbers of both trawls were much larger than the variation in back scattering values; the range being 2:1 for back scattering values and about 15:1 and 10:1 for the standard- and experimental trawls respectively.

Table 3. Summary of catch per haul (numbers) at location A, 1992. Occ. is the number of hauls with catch.

0-group	STANDARD TRAWL (10 hauls)			EXPERIMENTAL TRAWL (11 hauls)		
	Average	Range	Occ.	Average	Range	Occ.
Cod	9583	1677-25997	10	5599	973-10236	11
Haddock	221	54-418	10	65	22-138	11
Saithe	12	1-29	10	7	0-29	9
Herring	2368	0-13635	8	24	0-144	8
Others						
1+Herring	77	0-381	5	-	-	10
Jellyfish (liters)	75	11-147	10	62	127-170	11

Table 4. Values of back scattering in 0-100 m, S_A, and catch per haul (number) of 0-group cod and haddock in 1992.

St. No.	Time GMT	D. (n.m)	S_A $\frac{m^2}{nm^2}$	STANDARD TRAWL (a = 480m2)		EXPERIMENTAL TRAWL (a = 71m2)				
				Cod	Haddock	Cod;	Upper	Middle	Lower	Haddock
526	20	2,0	667	1815	112					
527	21	1,3	524			*8410	4789	2930	691	* 138
528	23	2,0	453			2777	533	650	1541	56
529	01	2,0	704	1677	54					
530	03	2,0	505			3780	940	1714	1126	47
531	05	2,0	506	3145	92					
532	08	1,8	442			4812	333	2158	2321	86
533	10	2,0	627	13336	248					
534	11	2,0	753			973	463	232	278	22
535	13	2,0	621	17600	342					
536	14	2,0	450			2733	506	1286	941	33
537	16	2,0	762	11186	160					
538	18	2,0	509			10236	1290	2962	5984	67
539	20	2,0	574	5746	193					
540	22	2,0	393			7057	3216	1874	1967	99
541	00	2,0	389	6057	290					
542	01	2,0	407			6869	1519	3711	1639	46
543	03	2,0	409	9270	299					
544	05	2,0	488			5562	1487	2361	1714	30
545	07	2,0	512	25997	418					
546	09	2,0	445			4642	1156	940	2546	88

* Data excluded from computations. Trawling depth not sufficient due to too small weights.

Figure 3 shows the vertical distribution of the 0-group fish scattering layer during the experiment. A certain tendency of diurnal variation can be observed; the scatterers were concentrated in a very dense layer of limited vertical extension during the afternooen and spread out into larger parts of the water column in the morning. With variations in distribution as shown in Figure 3 large variations in catches are to be expected even though the average density in the water column are fairly constant, particularly when the vertical opening of the trawl is less than the difference between the towing depths.

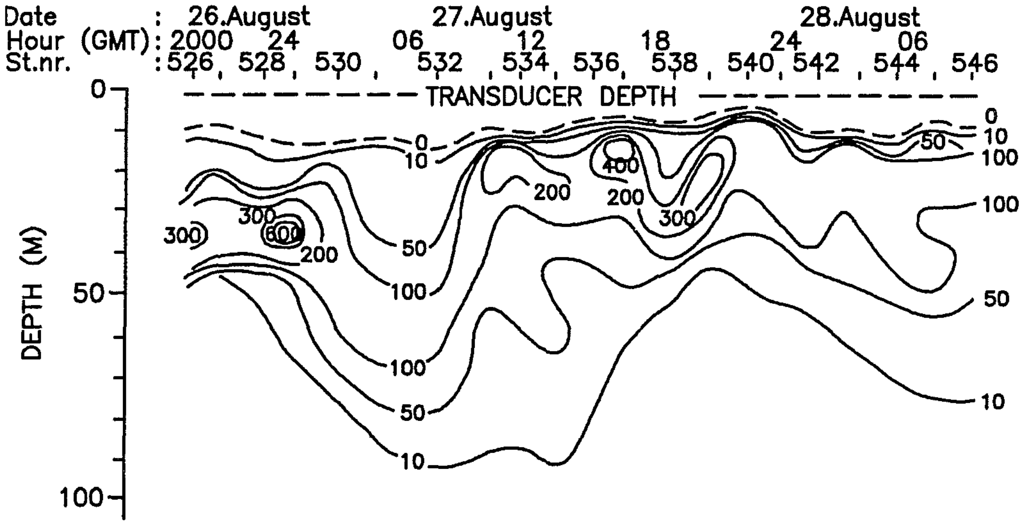


Figure 3. Distribution by depth and time of 0-group fish (mainly cod) back scattering at location A, 1992.

Table 5. Estimated densities (10-6· number per nm^2) of 0-group cod for each trawl haul at location A, 1992.

STANDARD TRAWL				EXPERIMENTAL TRAWL			
		Swept area				Swept area	
St.No.	Acoustics	Cod	Haddock	St.No	Acoustics	Cod	Haddock
526	4,2	0,26	0,02	528	2,9	2,75	0,06
529	4,5	0,25	0,01	530	3,5	3,75	0,05
531	3,2	0,46	0,01	532	3,1	5,30	0,09
533	4,0	1,96	0,04	534	5,2	0,96	0,02
535	3,9	2,58	0,05	536	3,1	2,71	0,03
537	4,8	1,64	0,02	538	3,5	10,14	0,07
539	3,6	0,84	0,03	540	2,7	6,99	0,09
541	2,5	0,89	0,04	542	2,8	6,81	0,05
543	2,6	1,35	0,04	544	3,4	5,51	0,03
545	3,2	3,81	0,06	546	3,1	4,60	0,09
Average (10)	3,7	1,40	0,032	Average (10)	3,4	4,95	0,058
Range (10)	2,5-4,8	0,25 3,81	0,01 0,06	Range (10)	2,7-5,2	0,96 10,14	0,02 0,09
Average (8)	3,7	1,25	0,031	Average (8)	3,2	4,80	0,059
Range (8)	2,6-4,5	0,26 2,58	0,01 0,05	Range (8)	2,8-3,6	2,71 6,99	0,03 0,09

Estimates of fish density (numbers per unit area) are given in Table 5 for each trawl. On an average the densities estimated from the catches of the standard sampling trawl were about 30-40 percent of the "acoustic" density while the average density estimated from the catches of the experimental trawl exceeded the average "acoustic" density by about 50 percent.

When comparing the average densities for the two trawls it seems that the experimental trawl caught 0-group cod 3-4 times more efficient than did the standard sampling trawl.

The 1993 experiment

Catch numbers by species are given in Tables 6 and 7. Also this year 0-group cod dominated in the catches of both trawls. By comparing Tables 3 and 6 it appears as if the version of the experimental trawl used this year caught both haddock and herring more efficient than the version used in 1992 when the catches of the standard trawl are used as reference.

Table 6. Summary of catch per haul (numbers) at location B, 1993. Occ. is the number of hauls.

0-group	STANDARD TRAWL (10 hauls)			EXPERIMENTAL TRAWL (10 hauls)		
	Average	Range	Occ.	Average	Range	Occ.
Cod	1041	293-2180	10	664	49-1988	10
Haddock	66	12-174	10	59	0-122	9
Saithe	3	0-8	8	+	0-2	2
Herring	551	288-3292	4	156	0-901	6
Others						
1+Herring	47	0-260	7	22	0-176	7
Jellyfish (liters)	100	40-180	10	41	20-60	10

Both the acoustic back scattering values and the catches were on an average significantly lower than in 1992 (Tables 4 and 7) and the back scattering showed a much more pronounced variation. The range in back scattering values over the experiment was 50:1 and considerably larger than the range in catches, 7:1 for the standard sampling trawl and about 27:1 for the experimental trawl. The estimates of fish density (Table 8) show results in accordance with those obtained in 1992 (Table 5) when the estimates from the trawl catches are compared. The experimental trawl seem to have caught 0-group cod and haddock 3-4 times more efficient than the standard sampling trawl. However, in 1993 both trawls generated much lower average densities than did the acoustics and using the trawl estimates as reference it appears as if the acoustic method was several times more "efficient" in 1993 than in 1992. A possible reason for this apparent discrepancy might be that high density fish concentrations are herded by otterboards and sweep lines to a much greater extent than low density concentrations. If so, then the actual "mouth area" of the trawls might have been larger than estimated in 1992, when fish densities were much higher than in 1993.

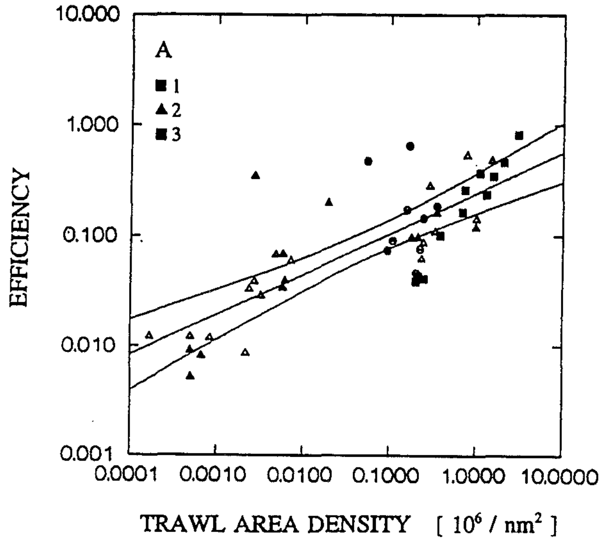
When summarizing the results on trawl efficiency for both trawls (Figures 4a and b) the indicated density dependency, or apparent "increased mouth area for high densities" is significant for both trawls. The experimental trawl has a higher efficiency than the standard trawl for high densities, but at low densities its catch efficiency is low and variable.

Table 7. Towing distance D, back scattering in 0-100 m, S_A and catch per haul (number) of 0-group cod and hadock in location B, 1993.

St.	Time	D.	S_A $\frac{m^2}{nm^2}$	STANDARD TRAWL (a = 480m²)		EXPERIMENTAL TRAWL (a = 100m²)	
No.	GMT	(n.m)		Cod	Haddock	Cod	Haddock
577	15	1,5	813	1457	113		
578	18	1,1	263			1988	120
579	19	1,2	173	309	174		
580	04	1,2	352			23	75
581	06	0,8	266			191	59
582	07	1,2	162	516	39		
583	08	1,2	124	781	12		
584	10	1,0	267			49	24
585	11	1,0	206			103	52
586	12	1,5	229	1464	99		
587	13	1,3	399	1172	56		
588	14	1,1	97			544	51
589	16	0,9	129			579	122
590	17	1,3	16	293	13		
591	18	1,5	35	1005	57		
592	19	1,0	194			1558	51
593	20	1,0	147			652	16
594	21	1,5	255	2180	32		
595	22	1,5	594	1228	63		
596	00	0,8	78			547	21

Table 8. Estimated densities (10^{-5}· number per nm²) of 0-group cod and haddock for each trawl haul at location B, 1993.

STANDARD TRAWL				EXPERIMENTAL TRAWL			
		Swept area				Swept area	
St.No.	Acoustics	Cod	Haddock	St.No	Acoustics	Cod	Haddock
577	60,2	2,2	0,2	578	19,5	20,1	1,2
579	13,4	0,6	0,3	580	27,3	2,1	0,7
582	12,7	1,0	0,1	581	20,8	2,7	0,8
583	12,7	1,5	+	584	27,2	0,5	0,3
586	17,5	2,3	0,2	585	15,7	1,1	0,6
587	28,3	2,1	0,1	588	6,9	5,5	0,5
590	1,1	0,5	+	589	9,1	7,1	1,5
591	2,5	1,5	0,1	592	14,1	1,7	0,5
594	17,0	3,4	0,1	593	9,8	7,2	0,2
595	43,0	1,9	0,1	596	5,7	7,6	0,3
Average (10)	18,8	1,7	0,1	Average (10)	15,6	5,6	0,7
Range (10)	1,0-54,9	0,5-3,4	+-0,3	Range (10)	5,7-27,3	0,5-20,1	0,2-1,5
Average (8)	16,6	1,6	0,1	Average (8)	15,4	4,4	0,5
Range (8)	2,2-39,9	0,6-2,2	0,1-0,2	Range (8)	6,9-27,2	1,1-7,6	0,3-1,2



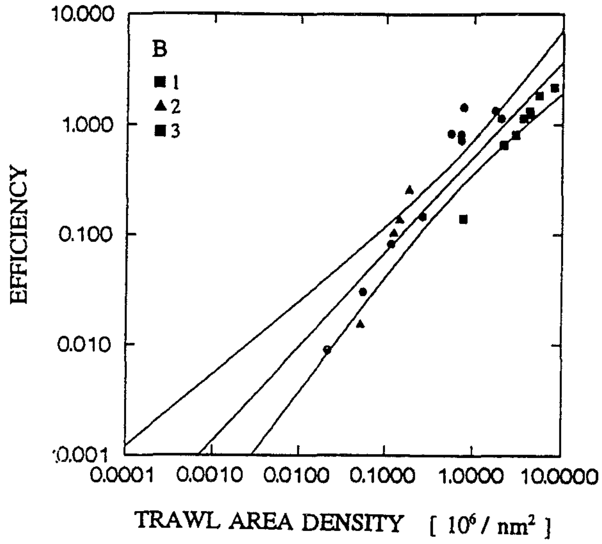


Figure 4a. Standard trawl efficiency (trawl area density/acoustic area density) as a function of trawl area density 1: 1992 experiment, 2: 1993 experiment, 3: stations from 0-group survey 1992.

Figure 4b. Experimental trawl efficiency (trawl area density/acoustic area density) as a function of trawl area density 1: 1992 experiment, 2: 1993 experiment, 3: stations from Ullsfjord.

Accordingly, 0-group abundance will be underestimated with both trawls in years with low abundance, and when the 0-group is well dispersed. In years with high, or spatially aggregated 0-group abundance, however, the experimental trawl is more efficient than the standard trawl, and also seems to be less variable. The results obtained are most likely due to density dependent herding, either in front of the mouth area in the sweeping zone of the trawl, or inside the trawl itself. As differences in efficiency for size and density are undesirable effects in sampling trawls, this should be further studied in order to reduce the effect.

Length and species selection

The results of the selection studies for 0-group cod and haddock are given in Figure 5. The horizontal line at P=0,5 means equal catch efficiency of the two trawls, i.e. that the estimate of fish density for the standard trawl equals that of the experimental trawl. Hence the intercept between the solid curve and this line indicate the fish length for which the two trawls generate equal fish densities. For fish lengths less than that corresponding to the intercept the standard sampling trawl is less efficient than the experimental trawl. It appears that for 0-group cod both versions of the experimental trawl were more efficient than the standard sampling trawl over the whole length range observed. For haddock, however, particularly the 1992 data set indicate that at lengths above 11 cm the standard trawl became more efficient than the sampling trawl, probably because these rather large fishes avoided the small mouth area of the experimental trawl that year. The ratio fish density standard sampling trawl/fish density experimental trawl by length can be read directly from the figures by the dotted curve. It shows that for lengths of 0-group cod and haddock in the range 5-11 cm the catching efficiency of the standard sampling trawl changes significantly, from a few to 10 percent for the lower lengths and 80-100 percent of the larger length of that of the experimental trawl.

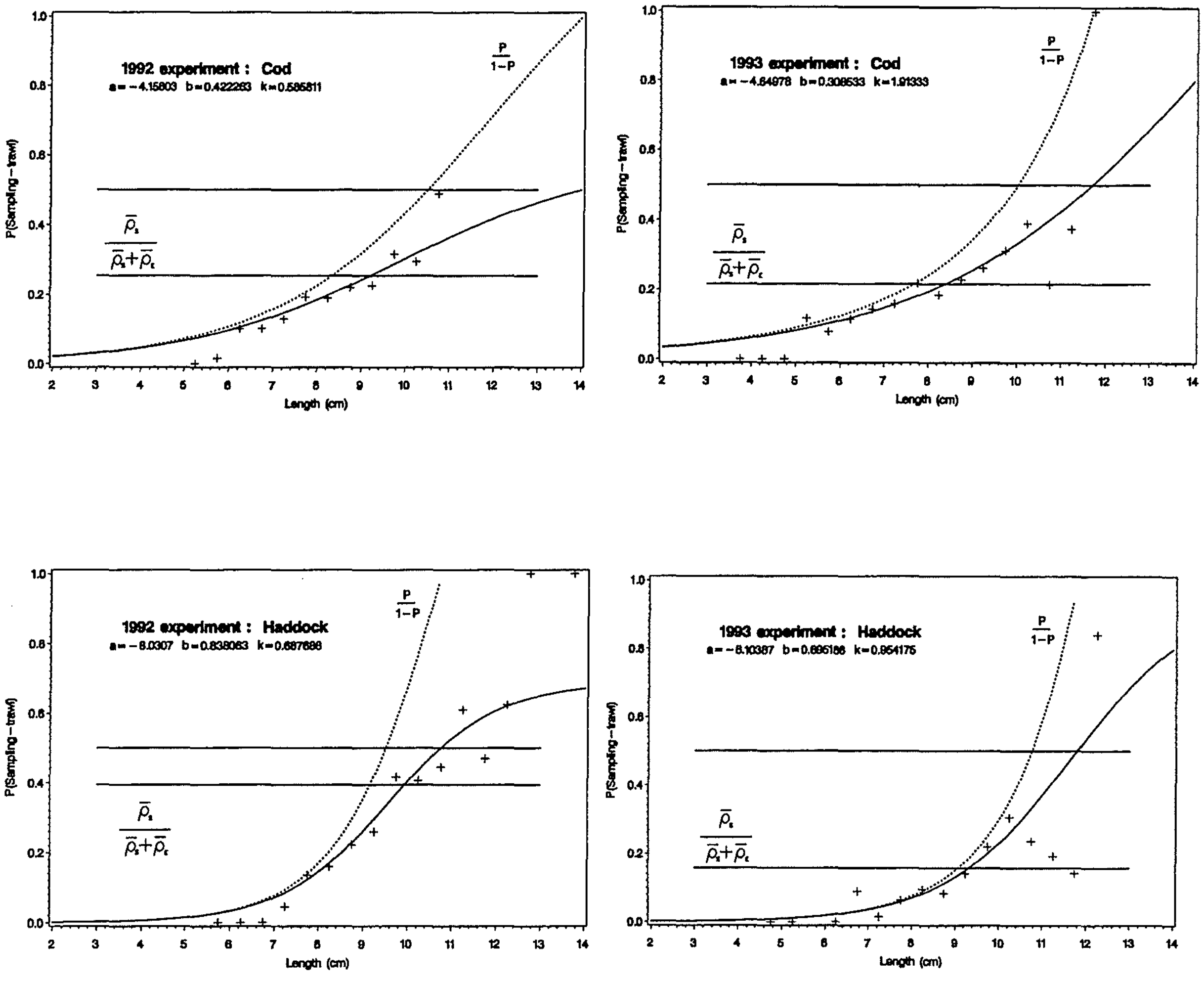


Figure 5. Length selection of standard sampling trawl relative to experimental trawl. Solid curve: Model fitted by maximum likelyhood estimation to observations +. Dotted curve: Fish density in standard sampling trawl relative to that in the experimental trawl, (ρ_{ST}/ρ_{ET}). Upper horisontal line: Probability P=0.5 means equal fish density in the two trawls. Lower horisontal line: Average fish density (all lengths) in standard trawl relative to the sum of average densities in the two trawls.

In Figure 6 is presented the correction factor (multiplier) to be used on the density estimates or catch rates of the standard sampling trawl in order to make them directly comparable with the estimates or catch rates of the experimental trawl (The choice of 9 cm as reference for both species is arbitrary). The curves for the two experiments coincide both for cod and haddock while there seem to be a significant difference in the selection pattern of the two species.

The main results of this study support and strengthen the conclusions of earlier works (Godø *et al.* 1993, Godø and Valdemarsen 1993) that the standard sampling trawl used in the 0-group surveys have a lower catch efficiency of small sized than on larger sized 0-group cod and haddock. The trials with the new experimental trawl were quite promising as they indicate that a trawl which may yield "unbiased" length distributions of 0-group fish can be constructed in near future.

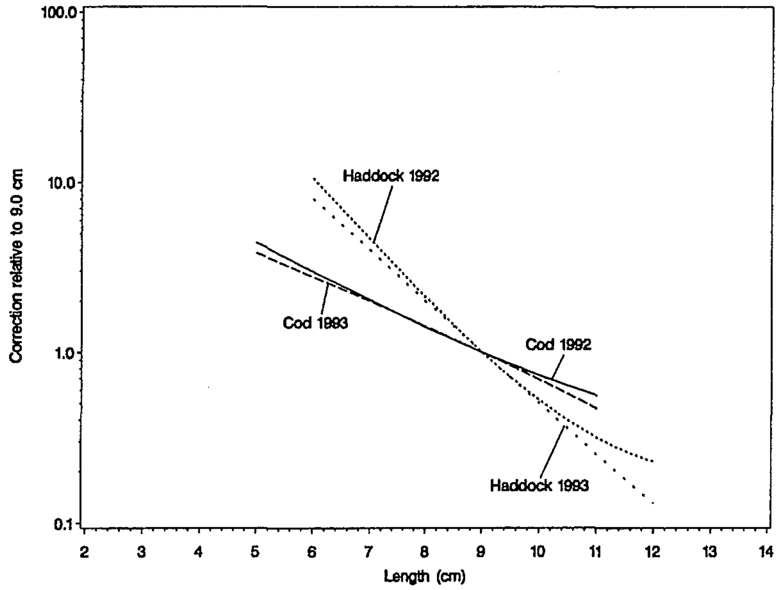


Figure 6. Correction factor (multiplier) to be used for density estimates based on the standard sampling trawl in order to have these comparable to those of the experimental trawl. The choise of 9 cm as a reference point is arbitrarily.

REFERENCES

FOOTE, K.G., KNUDSEN, H.P., KORNELIUSSEN, R.J., NORDBØ, P.E. and **RØANG, K.** 1991. Pastprocessing system for echo sounder data. *J.Acoust.Soc.Am., 90*(1)*:* 37-47.

GODØ, O.R. and **VALDEMARSEN, J.W.** 1993. A three level pelagic trawl for near surface sampling of juvenile fish. *ICES CM 1993/*B:19, 5 pp. 6 Figs. [Mimeo]

GODØ, O.R., VALDEMARSEN, J.W. and **ENGÅS, A.** 1993. Comparison of efficiency of standard and experimental juvenile gadoid sampling trawls. *ICES mar.Sci.Symp.196:* 196-201.

KNUDSEN, H.P. 1990. The Bergen Echo Integrator: an introduction. *J.Cons.int.Explor.Mer. 47:* 167-174.

MILLAR, R.B. 1991. Estimating the size selectivity of fishing gear by conditioning on the total catch: the select (share each length class's catch total) model. *ICES CM 1991* (B:57); 21 pp. [Mimeo]

NAKKEN, O., HYLEN, A. and **ONA, E.** 1995.Acoustic estimates of 0-group fish abundance in the Barents Sea and adjacent waters in 1992 and 1993. Pp. 187-197 in Hylen, A. (ed.): *"Precision and relevance of pre-recruit studies for fishery management related to fish stocks in the Barents Sea area and adjacent waters". Proceedings of the sixth IMR-PINRO symposium, Bergen, 14-17 June 1994.* Institute of Marine Research, Bergen.

ONA, E. 1989. Trawling noise and fish avoidance, related to near-surface trawl sampling. Pp.169-180 in Sundby, S. (ed.): *"Year class variation as determined from pre-recruit investigations". Proceedings from Workshop, Bergen 28-30 September 1988.* Institute of Marine Research, Bergen.

VALDEMARSEN, J.W. and **MISUND, O.A.** 1995. Trawl designs and techniques used by Norwegian research vessels to sample fish in the pelagic zone. Pp. 135-144 in Hylen, A. (ed.): *"Precision and relevance of pre-recruit studies for fishery management related to fish stocks in the Barents Sea area and adjacent waters". Proceedings of the sixth IMR-PINRO symposium, Bergen, 14-17 June 1994.* Institute of Marine Research, Bergen.

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A COMPARISON BETWEEN ABUNDANCE ESTIMATES OF THE BARENTS SEA CAPELIN AT THE LARVAL, 0-GROUP AND 1-GROUP STAGE IN THE PERIOD 1981-1991

by

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ABSTRACT

A larval abundance estimate, obtained during a Norwegian survey in June, an 0-group index, obtained during the International 0-group survey in August, and an acoustic 1-group estimate, obtained during the IMR/PINRO acoustic survey in September, are compared for the year classes of Barents Sea capelin in the period 1981 to 1991.

There was a strong correlation between the 0-group index and the 1-group estimate. This allows for predictions to be made about year class strength at the 1-group stage based on the 0-group estimates.

No correlation was found between the larval abundance estimate and the two other estimates when all the data was included in the analysis. The larval abundance in 1989 was probably grossly underestimated. When this year class was left out, a correlation was found between the larval estimate and the 0-group index.

INTRODUCTION

A reliable estimate of year class strength at an early stage in the life history of the fish, is important for stock assessment purposes. This will, for instance, give an early warning in case of recruitment failure. This particularly applies for short lived species like the capelin, which recruits to the fishery in the second year of life.

There are certain limitations to how early the year class strength can be assessed. In the first few weeks after hatching most species experience a massive mortality. The mechanisms may vary, but most species seem to be particularly vulnerable in the period just after hatching. An estimate of year class strength during this period may, even if it gives a reliable estimate at that particular time, be of little value in forecasting the strength some months later.

Hylen, A. editor 1995. Proceedings of the sixth IMR-PINRO symposium, Bergen, 14-17 June 1994.
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When trying to measure year class strength during the fist year of life, one therefore faces two problems: To obtain a reliable estimate there and then, and to get an estimate that can be related to the year class strength for instance at age 1 or 2.

The capelin larvae are monitored at annual Norwegian surveys in June, and at the international 0-group surveys in the Barents Sea.in August. In June, a high speed plankton sampler (Gulf III), is used to catch the larvae, while in August, a fish trawl with a small meshed net in the cod end is used. The 1-group estimate is obtained during an acoustic survey in September.

The annual surveys result in acoustic estimates of number of individuals and biomass of each year class at age 1 and older. The reliability of the 1-group estimate has been questioned (e.g. Anon. 1993). The main reasons for doubt is the behavior of the capelin at this age. Individuals in this age group, 7-11 cm in length, are often found mixed with various larval fishes and plankton, which often ascends to near surface depths, i.e. near or even above the depth of the hull mounted echo transducers. The validity of the target strength value measured for larger capelin to these small individuals may also be questioned.

Nevertheless, from about 1980 onwards, the acoustic 1-group estimate has shown a relatively strong relationship with that of the two-year-olds, which is normally considered to be reliable. Moreover, much of the variability in the relationship between the 1- and 2-group estimates in this period may be explained by variable natural mortality (Anon. 1993). Previously, the 1-group was most years grossly underestimated (Figure 1). This can, however, at least partly, be explained by an insufficient coverage of the main distribution area of this age group; the southeastern part of the Barents Sea, during the annual autumn surveys prior to 1980.

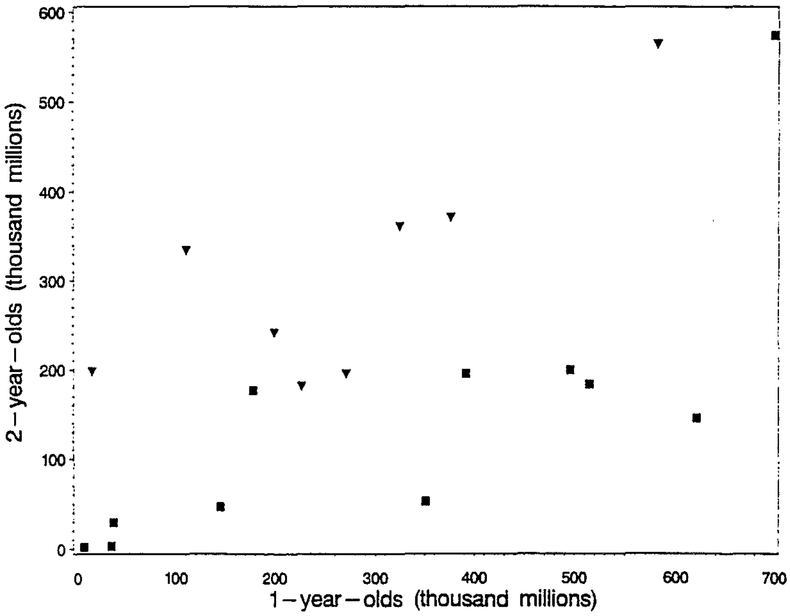

Figure 1. The relationship between abundance estimates of capelin at age 1 and 2 in the perod 1972-1992. The triangles denote the years before 1981, the squares denote the years after. Figures are given in million individuals.

The aim of this paper is to compare the abundance estimates and indices obtained during these annual larval, 0-group, and 1-group surveys. The findings will be discussed in light of the above mentioned problems: When is the right time for a first estimate of the capelin year class strength? How reliable are the estimates obtained so far for the actual amount of larvae at the time of the survey? In the discussion we will look for factors that may explain some of the variability observed, such as distribution, growth and mortality.

MATERIALS AND METHODS

Larval surveys

The larval surveys for capelin, on which the larval abundance estimates (Table 1) are based, have been conducted since 1981. The aim of the surveys are to determine abundance and distribution of larval capelin 1-2 months after hatching. The surveys routes are adjusted to the larval distribution, but in some years the western or the eastern borders are not detected. The stations are located in transects in a north-south direction.

Sampling has been conducted with a high speed planktonic sampler, Gulf III (Zijlstra 1971). Standard procedures for sampling capelin larvae in the Barents Sea are described by Alvheim (1985). The Gulf III is towed in the upper 60m of the water column. A measure of the flow of water through the Gulf III front opening makes it possible to estimate the number of larvae per unit area sampled. Interpolation of these results gives a total annual index of larval capelin abundance in the area of distribution. The method for larval abundance estimation is described by Alvheim (1985). The indices for 1981 to 1991 are published by Fossum (1992).

Table 1. Larval estimate ($N^{\cdot -12}$), 0-group ($N^{\cdot -9}$) index (without units), and acoustic estimate of 1-group capelin ($N^{\cdot -9}$) in the period 1981 to 1991.

Year class	Larval estimate	0-group index	1-group estimate
1981	9.7	2082	496
1982	9.9	1384	575
1983	9.9	1487	145
1984	8.2	1004	35
1985	8.6	508	75
1986	-*	186	37
1987	0.3	11	20
1988	0.3	349	178
1989	7.3	4612	700
1990	13.0	631	392
1991	4.2	1021	351

* No observations were made, the survey was conducted too early compared to main hatching time.

0-group surveys

The 0-group fish surveys in the Barents Sea have been conducted since 1965 (Anon. 1965; Loeng and Gjøsæter 1990). The surveys are made in late August - early September. The aims of the survey are to locate the distribution and determine year class strength of commercial species of the Barents Sea and adjacent waters, including capelin (Beltestad et al. 1975; Loeng and Gjøsæter 1990).

0-group fish are sampled by a pelagic trawl, originally a commercial trawl for capelin fisheries; "Harstadtrawl". The trawl is described by Bjørke *et al.* (1989). Trawl dimensions and the standard procedures are described by Randa (1981). Trawling is conducted in the depths 40-20-0m (Anon. 1980; Loeng and Gjøsæter 1990). Supplementary trawling down to 60m was made when the echo registrations showed layers of 0-group fish deeper than 40m. Abundance estimates of capelin (Table 1) have not been published in connection with the 0-group survey reports due to uncertainty of the catch results as the commercial trawl used for sampling is not fully suitable for catch of 0-group capelin as the capelin is not fully metamorphozed in August-September according to Vesin *et al.* (1981). The capelin tend to stick to the trawl meshes and may be lost during hauling in bad weather, which implements a underestimate of abundance in such occations.

0-group capelin indices (I) were estimated in respect of the total area of distribution based on local abundance indices described by Gundersen (1994).

$I = A * D$

I : indices of capelin abundance.
A : the area covered of capelin.
D : the average density of capelin in the distribution area.

Acoustic surveys

The acoustic surveys which yield the 1-group estimates have been conducted on an annual basis since 1972 (Table 1). The surveys are made during September and the first part of October. Standard published methods for acoustic stock measurements are used (e.g. Nakken and Dommasnes 1977; Foote 1991), where echo abundance data sampled by echosounders and echo integrators are distributed on species and age groups according to information from trawl samples of the fish registrations. Dommasnes and Røttingen (1985) gives a comprehensive account on these capelin investigations.

Statistical analysis

Since the data after 1980 seem to be the most reliable, and since larval estimates are available only from 1981, the period 1981-1991 was chosen for this study. Regression analyses were used to analyze the relationship between the three series of observations. The analysis was performed in three steps;

i) comparing larval estimate and 0-group index.
ii) comparing 0-group index and 1-group estimate.
iii) comparing larval estimate with 1-group estimate.

The statistical analysis and the plotting were made using the SAS software.

One of the assumption underlying regression analysis is that the measurements of each variable should be independent of each other. This assumption may be questioned when the data stem from a time-series, because the factors involved will have a tendency to affect consecutive datapoints in a similar way. The key question is, will the strength of a certain year class in some way imply the strength of the next? Obviously, there is a coupling between year classes in that the strength of one year class partly determines the size of the spawning stock two to three years ahead of time, which again partly determines the year class strength of the offspring. Nevertheless, the strength of a particular year class are also susceptible to a lot of stocastic processes, which may in many cases overshadow the predictable factors. Regression analysis should, in any case, be used with caution when studying time series data.

RESULTS

Larval estimate versus 0-group index

No correlation is found between the two variables (p=0.43). From the plot (Figure 2) it can be seen that there seems to be a positive relationship, but the low correlation coefficient (0.28, p=0.28) is mostly due to one data point; that for the 1989 year class. With a larval estimate close to average for the period, and an 0-group index more than twice as high as any of the other observations, this point represents an outlier in the analysis. If this point is left out of the analysis, the correlation coefficient increases to 0.81, and a correlation significant at the 5% level emerges (p=0.03). Conclusively, no definite judgement can be made about this analysis. Although no correlation is evident when the whole period is analyzed, this lack of correlation is due to one single observation; the 1989 year class.

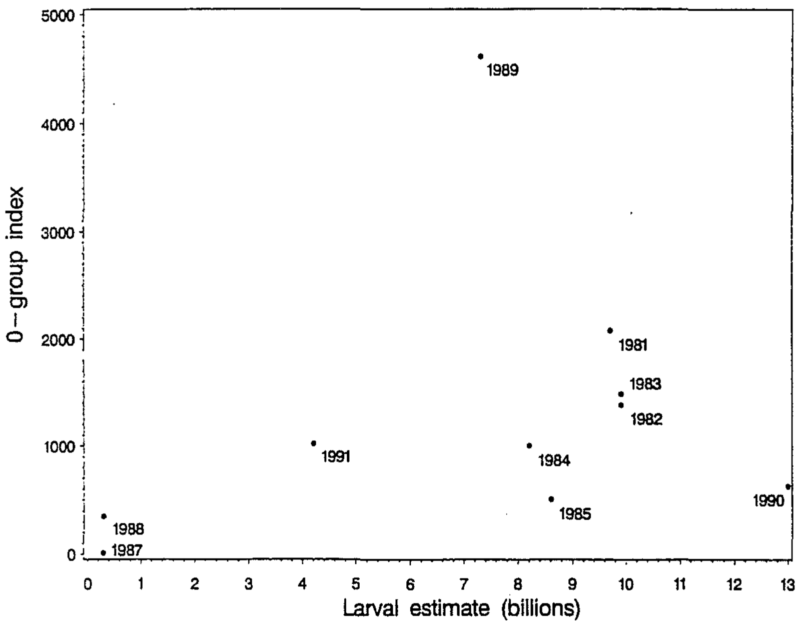

Figure 2. The relationship between larval estimate and 0-group index. The datapoints are labelled with year.

0-group index versus 1-group estimate

A highly significant correlation is found between the variables; p=0.006. About 60% of the total variation can thus be explained by the regression model. Nevertheless, looking at the corresponding scattergram (Figure 3), it is clear that the year class 1989 also in this case represent an extreme value. In this case, however, this point increases the goodness of fit. Abandoning this datapoint lowers the correlation coefficient from 0.77 to 0.73, but the correlation stays significant at the 5% level (p=0.04). It may be concluded that when all available data is taken into consideration, there is a strong correlation between the 0-group index and the 1-group estimate. The relationship is described by the equation:

$$N_{1\text{-gr}} = 98.7 + 0.14 * I_{0\text{-gr}}$$

$N_{1\text{-gr}}$ is the number of 1-year-olds and $I_{0\text{-gr}}$ is the 0-group index for capelin.

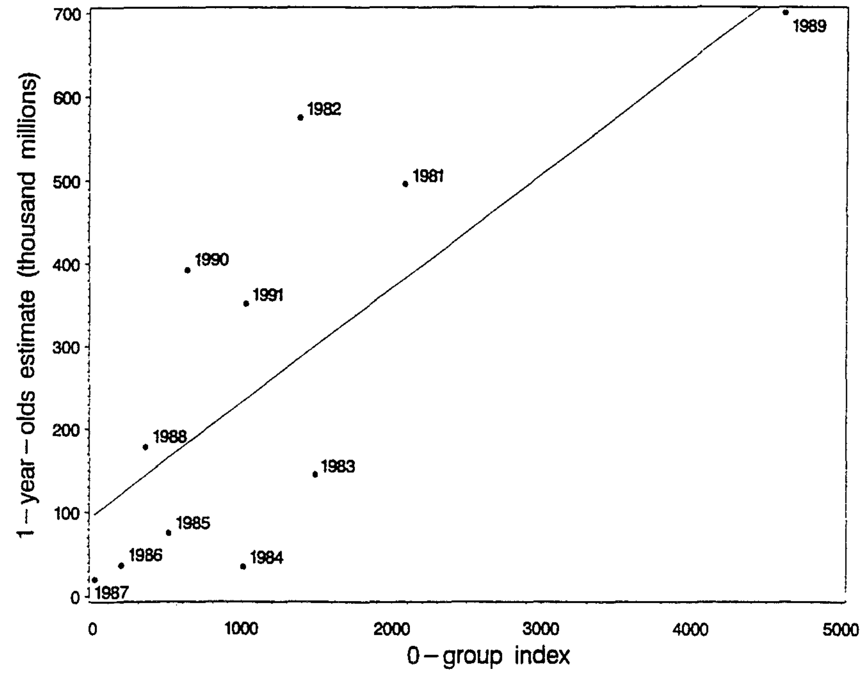

Figure 3. The relationship between 0-group index and 1-group estimate. The datapoints are labelled with year. The regression line is superimposed on the scatterplot.

Larval estimate versus 1-group estimate

No significant correlation is found between the two variables (p=0.29). There is no single outlier explaining the bad fit, the datapoints are scattered all over the graph (Figure 4). It can be concluded that there is no evidence for a relation between larval index and year class strength at the 1-group stage.

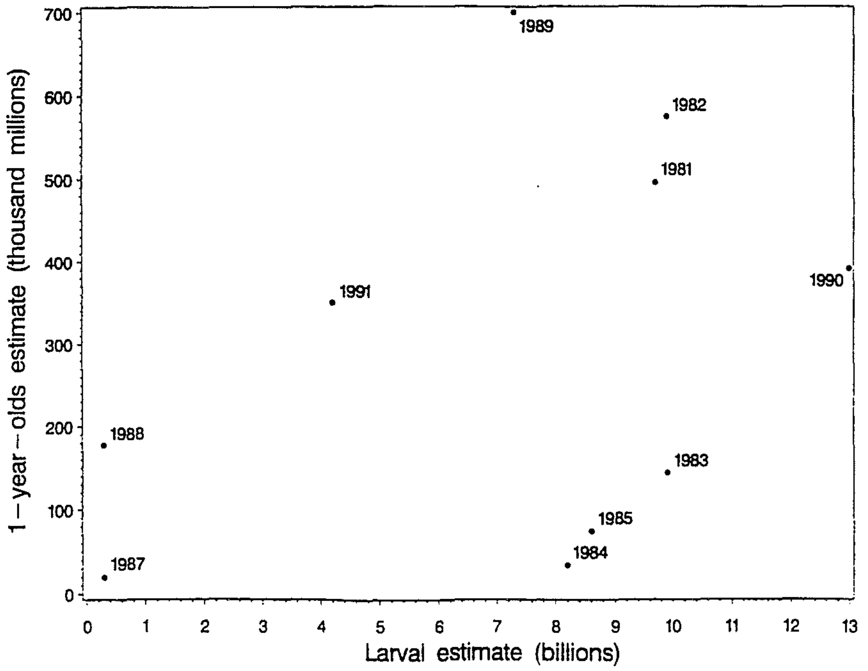

Figure 4. The relationship between larval estimate and 1-group estimate. The datapoints are labelled with year.

DISCUSSION

Larval estimate versus 0-group index

The rather low correlation between these two estimates of year class strength is due to one single year; 1989. This year class, which was classified among the strongest both on the 0-group stage and as one-year-olds, and which strength has been proven in the years after, was seemingly grossly underestimated in the larval estimate. What shows up as an underestimation may, however, be explained by a much lower than usual mortality rate between the measurements in June and August. How could such an unusual low mortality rate in 1989 be explained? This year was characterized by much inflow of Atlantic water, rich in nutrients and zooplankton according to Skjoldal *et al.* (1992). This may, of course, have given the capelin larvae favourable survival conditions. On the other hand, there was much young herring in the Barents Sea this year, which is thought to have a negative influence on the survival of capelin larvae (Hamre 1991, Gjøsæter, *in press*). Methodological errors could possibly cause a real underestimation of capelin larvae in June 1989. There does not seem to be any obvious reason for such an underestimation in the accomplishment of that particular survey. The whole larval distribution area was covered (Gundersen 1993b), and the standard methods applied. However, there is a possibility that a part of the spawning, and consequently the hatching, may have taken place later than usual, and that a part of the larval population had not yet been released from the spawning areas.

If excluding the data point for 1989 from the calculations as an outlier, the regression of 0-group indices on larval estimates becomes quite strong, as 65% of the total variation can be explained by the regression. Even in this case, the variation not accounted for is so large that only very approximate forecasts of year class strength in August may be made based on the larval survey in June. We may hypothize that this is because the survey takes place before or in a period with high and variable mortality. The larval surveys may be more valuable in "hindcasting", i.e. in giving an estimate for the amount of larvae produced, or even, of the spawning stock size. Such use of the larval estimates have not been assessed in this investigation.

0-group index versus 1-group estimate

There is, seemingly, a better correlation between the 0-group index and the 1-group acoustic estimate. The regression of the latter on the former accounts for about 60% of the total variation. There is only about 0.5% probability for such an outcome if the null hypothesis; that there is no correlation between the variables, was true. Admittedly, much of the high correlation can be ascribed to one single datapoint, but also when this point is excluded the correlation is significant at the 5% level. A reasonable interpretation of this fact is that at the time of the August survey, the year class strength is more or less established. The mortality will still vary from year to year, but this will show up as variation around the regression line rather than destroying the correlation altogether. The amount of deviation from the regression line each year, may give clues to quantify this mortality.

It is seen that in the period 1983-1987, and in 1989, the 1-group estimates are lower than expected from the regression line, i.e. the mortality between the two estimates is larger than the mean (Figure 3). In the other years the opposite is true. This is partly, but not totally, in accordance to what we know about mortality in the older parts of the stock. The data points for 1983, 1984 and 1985, which show the largest deviation from the regression line, the natural mortality in the stock, as measured in the one year olds and older part of the stock, was at a maximum for the whole investigation period. In 1986, 1987 and 1989, however, there is a much lower natural mortality among older individuals. There is a possibility that the mortality may be high at the younger stages and low among the older, because the sources of mortality do not have to be the same. Nevertheless, if the year class strength is seen in relation to the (calculated) spawning stock size from these years, we clearly get the impression that there must have been a high survival during the whole life span. This is also in accordance with what we know about possible sources of natural mortality on young capelin: the total amount of 0-group of herring and cod, which is known to predate on the capelin larvae, was low in 1986 and 1987, but high in 1989.

Also among the years with a higher than expected survival from 0-group to one-year-olds there are some years with a low natural mortality and some years with a high one, judged from measurements on older capelin and knowledge about the amount of predators present. The conclusion is, that the variation around the regression line cannot directly be interpreted as a measure of natural mortality. The dispersion due to measurement errors probably make up too much of the variability to make such interpretations feasible.

Larval estimate versus 1-group estimate

There is no correlation between the larval estimate and the 1-group estimate. The explanation is probably that the year class strength, as measured at the 1-group stage, is not yet determined so early in the larval phase, and that measurement errors will add to this variability, hiding week relationship that otherwise might be seen. It should be noted, however, that the same three years of low survival as seen from the 0-group to one-group relationship is evident; 1983, 1984 and 1985. This is probably not a mere coincidence, but lends support to the theory that there was an unusual high mortality on the young stages of capelin during these years.

CONCLUSIONS

Keeping in mind that possible connections between measurements in a time series (autocovariation) may lead us to conclude that there is a correlation when there is not, the results from the regression analyses show that:

1. There is no correlation between the larval estimates and the 0-group indices. The very strong 1989 year class, which was observed both at the 0-group stage and 1-group stage, was grossly underestimated in the larval estimate. If an exclusion of this year can be justified, a quite strong, positive correlation emerges. It's inferential strength is, though, quite low.

2. The strongest relationship is found between the 0-group index and the 1-group estimate. The correlation between these variables is positive and highly significant. This regression can be used to make an early forecast, although not a very accurate one, of the year class strength at the one-group stage.

3. There is no correlation between the larval estimate and the 1-group estimate, even if the 1989 data is left out. It is therefore not possible to make a forecast of year class strength based on this survey.

4. The variation due to measurement errors are too large to allow for any estimation of natural mortality based on the regression analyses. Years with extremely high or low survival rates at the young stages are, though, apparent in the scatterplots.

REFERENCES

ALVHEIM, O. 1985. Investigations on capelin off Northern Norway and in the Barents Sea in 1981-1984. Pp. 171-183 in Gjøsæter, H. (ed.): *The Proceedings of the Soviet-Norwegian Symposium on the Barents Sea Capelin,* Bergen, 14-17 August 1984. Institute of Marine Research, Bergen, Norway.

ANON. 1965. Preliminary report of the international 0-group Fish survey in the Barents Sea and adjacent waters in August-September 1965. *ICES CM 1965*/No. 161, 15 pp.

ANON. 1980. Preliminary report of the international 0-group Fish survey in the Barents Sea and adjacent waters in August-September 1980. *ICES CM 1980*/G:53, 25 pp.

ANON. 1993. Survey report from the joint Norwegian/Russian acoustic survey of pelagic fish in the Barents Sea September-October 1993. Institute of Marine Research, Bergen, Norway.

BELTESTAD, A.K. NAKKEN, O. and **SMEDSTAD, O.M.** 1975. Investigations on dial vertical migration of 0-group fish in the Barents Sea. *FiskDir. Skr. Ser. HavUnders., 16*(7): 229-244.

BJØRKE, H., ELLERTSEN, B., HANSEN, K. and **BAKKEPLASS, K.** 1989. Yngel-undersøkelser i juli-august i 1988 og 1989 utenfor norskekysten. *Havforskningsinstituttets Egg- og LarveProgram (HELP),* 74 pp. (In Norwegian)

DOMMASNES, A. and **RØTTINGEN, I.** 1985. Acoustic stock measurements of the Barents Sea capelin 1972-1984. Pp. 45-108 in Gjøsæter, H. (ed.): *The Proceedings of the Soviet-Norwegian Symposium on the Barents Sea Capelin,* Bergen, 14-17 August 1984. Institute of Marine Research, Bergen, Norway.

FOOTE, K. 1991. Abundance estimation of pelagic fish stocks by acoustic surveying. *ICES CM 1991*/B:33. 8 pp.

FOSSUM, P. 1992. The recovery of the Barents Sea Capelin (*Mallotus villosus)* from a larval point of view. *ICES J. mar. Sci., 49*: 237-243.

GJØSÆTER, H. *(in press).* Pelagic fish and the ecological impact of the modern fishing industry in the Barents Sea. *Journal of the Arctic Institute of North America.*

GUNDERSEN, A.C. 1993a. Distribution of larval and 0-group capelin (*Mallotus villosus)* in the Barents Sea, 1981-1991. *ICES CM 1993*/H:1-20.

GUNDERSEN, A.C. 1993b. *Utbredelsen av lodde (Mallotus villosus) i Barentshavet i det første leveåret, 1981-1991.* Hovedfagsoppgave i fiskeribiologi. Institutt for Fiskeri- og Marinbiologi, Universitetet i Bergen, våren 1993. 106 pp. (In Norwegian)

GUNDERSEN, A.C. 1995. Distribution of capelin during the first year of life in the Barents Sea, in the period 1981-1991. Pp. xx-xx 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, Bergen, 14-17 June 1994.* Institute of Marine Research, Bergen, Norway.

HAMRE, J. 1991. Interrelation between environmental changes and fluctuating fish populations in the Barents Sea. Pp. 259-270 *in* Kawasaki, T., Tanaka, S., Toba, Y. and Tanaguchi, A. (eds.): *Long-term variability of pelagic fish populations and their environment. Proceedings of the international symposium, Sendai, Japan, 14-18 November 1989.* Pergamon Press, Oxford, UK.

LOENG, H. and **GJØSÆTER. H.** 1990. Growth of 0-group fish in relation to temperature conditions in the Barents Sea during the period 1965-1989. *ICES CM 1990*/G:47, 9 pp.

NAKKEN, O. and **DOMMASNES, A.** 1977. Acoustic estimates of the Barents Sea capelin stock 1971-1976. *ICES CM 1977*/H:35. 10 pp.

RANDA, K. 1981. Rekrutteringsstudier for Norsk-Arktisk torsk basert på materiale frå dei internasjonale 0-gruppe undersøkingane i Barentshavet. Hovedfagsoppgave i fiskeri-biologi, Institutt for fiskeribiologi, Universitetet i Bergen, hausten 1981, 1-132. (In Norwegian)

VESIN, J.-P., LEGGETT, W.C. and **ABLE, K.W.** 1981. Feeding Ecology of Capelin (*Mallotus villosus)* in the Estuary and Western Gulf of St. Lawrence and its multispecies implications. *Can. J. Aquat. Sci., 38*: 257-267.

ZIJLSTRA, J.J. 1971. Herring larvae in the central North Sea. *Ber.Dt.Wiss.Komm.Meeresforsch. 21*: 92-115.

ACOUSTIC ESTIMATES OF ABUNDANCE-AT-AGE OF JUVENILE NORWEGIAN SPRING-SPAWNING HERRING (*Clupea harengus* L.) IN THE BARENTS SEA FROM 1983 TO 1993

by

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ABSTRACT

The first year-class of Norwegian spring-spawning herring to enter the Barents Sea in significant numbers since the stock collapse in the late 1960'ies was the 1983-cohort. Regular acoustic surveys have been carried out since then to assess the changes in abundance of recruiting year-classes in the area. In the following 11-year period several more cohorts of herring were distributed in the Barents Sea, and the development of the abundance of each year-class has been followed in the same way. Altogether fifty acoustic estimates of the abundance of the first four age-groups of nine year-classes were obtained during this period. Standardised methods through the young life stages are in this context important to foresee the recruitment to the spawning stock and to make better medium term prognosis of the stock development. It is suggested that the data series presented here may be of use in shedding light on some of the processes determining the variability of year-class strength of Norwegian spring-spawning herring.

INTRODUCTION

Estimating the level of recruitment is necessary for proper assessment of any fish stock. For Norwegian spring-spawning herring various estimates of abundance are at hand from early larval stages to the 0-group stage and further on through the young stages. However, even though each estimate may reflect the abundance at the time it is carried out, it does not necessarily indicate the level of recruitment to the spawning stock which should be expected for the specific year-class (Anon. 1984; Anon. 1993a). To be able to predict recruitment, the various estimates on the recruiting year-classes have to be linked and seen together and the mortality of the year-class has to be estimated.

Hylen, A. editor 1995. Proceedings of the sixth IMR-PINRO symposium, Bergen, 14-17 June 1994. Institute of Marine Research, Bergen, Norway. ISBN 82-7461-039-3.

The nursery areas of Norwegian spring-spawning herring are located along the coast of Norway. Small and adolescent herring are found in variable amounts in most fjords along the coast from about 63°00'N and northwards. In some years, the majority of the juveniles are found in the Barents Sea (Dragesund 1970; Anon. 1994).

The first acoustic surveys of 0-group herring in the coastal and offshore waters of northern Norway were done in the period 1959-1963 by Midttun (1959), Dragesund (1959, 1961, 1962 and 1964), Dragesund and Hognestad (1962), Hognestad (1963) and Olsen (1960). The aim of the surveys was to describe the distribution and abundance of the small herring and to study the relative abundance of the year-classes distributed in the fjords and in the Barents Sea. Dragesund (1970) concluded that most of the 0-group population was distributed in the Barents Sea in the autumn of 1959, 1960, 1963, 1964 and 1965. In 1961 and 1962, however, the proportion of the total 0-group population which was found in this area was somewhat lower, and a correspondingly higher proportion of the 0-group was found inside the fjords.

Systematic surveys of 0-group herring aimed at obtaining a recruitment index started in 1965. These investigations, the International 0-group Fish Surveys in the Barents Sea, have been carried out in August-September every year since then. These surveys cover only the Barents Sea and adjacent waters, and are based on the swept area method by pelagic trawling close to the surface. The acoustic integration system is continuously operated during the surveys, and the acoustic data necessary for computing estimates of abundance of different 0-group fish are stored for later processing.

Acoustic surveys for pelagic fish in the Barents Sea started on a regular basis in 1972 (Nakken and Dommasnes 1977). Capelin (*Mallotus villosus*) was the target species and these investigations have been continued in September-October every year since then (Dommasnes and Røttingen 1984). The results from these surveys are used directly in the assessment of the capelin stock (Anon. 1994).

The Norwegian spring-spawning herring stock collapsed in the 1960's, and has been slowly recovering since the mid-70's (Anon. 1994). To follow the recruitment during the recovery period, an acoustic survey programme for juveniles in the fjords started in 1975. The stock was then at a very low level (Anon. 1983b) and did not produce year-classes large enough to populate the Barents Sea. Every year in November-December, all fjords along the Norwegian coast are surveyed to measure the abundance of small herring. The results are used to forecast the recruitment to the adult stock (Anon. 1983b).

The 1983 year-class represented a turning point in the distribution and abundance of the recruitment to this stock. In the 11-year period since then all but two year-classes have entered the Barents Sea to spend the first few years of life there. The distribution and abundance of the juvenile herring growing up in this area have been frequently estimated by acoustic methods. Particularly, a survey aiming at estimating the abundance of all small herring in the area has been conducted every year in early summer since 1984.

These surveys have already provided a reasonable amount of information on the movements and dynamics of the juvenile population of herring in this area. When the conditions are favourable, the 0-group is spread into the Barents Sea (Figure 1) in late summer, at about the same time as the fish metamorphose. The 0-group is mostly distributed in the upper 50 m of the water column, sometimes in dense schools but are most often found relatively evenly distributed and mixed with other 0-group fish such as cod, haddock or capelin. The herring move to the south-eastern parts of the Barents Sea when they acquire a larger capacity for movement, by the end of the autumn, and stay in this area until they reach a size of approximately 20-25 cm (about 3 years). They then migrate either westwards into the Norwegian Sea or southwards along the Norwegian coast to join the adult stock. A schematic presentation of a typical pattern in the distribution of the different age-groups is presented in Figure 1.

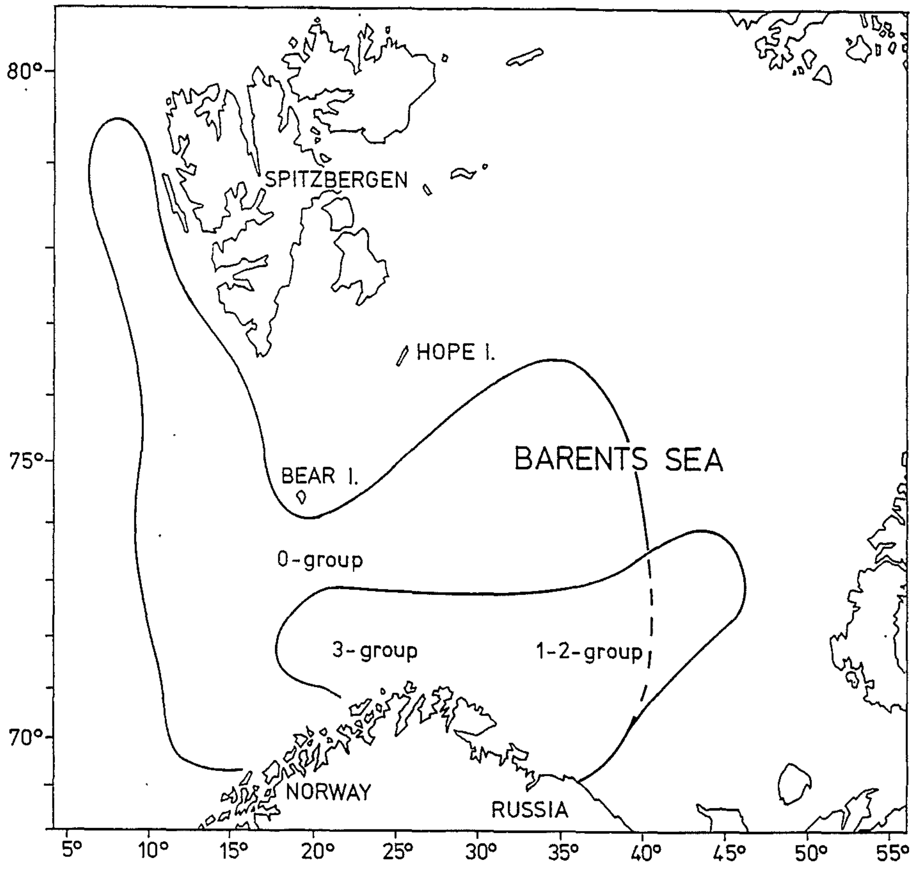

Figure 1. Schematic representation of the distribution areas of the different age-groups of Norwegian spring-spawning herring in the Barents Sea.

This paper gives a description of the herring survey programme as it has been conducted during the last 11 years, and discusses some of the potential uses and limitations of the abundance estimates derived from it have been discussed.

MATERIALS AND METHODS

Survey design

When the surveys on small herring started in 1965, considerable information on herring distribution in the area was already available, especially from earlier scientific surveys (Midttun 1959; Dragesund 1959; 1961; 1962; 1964; Dragesund and Hognestad 1962; Olsen 1960; Hognestad 1963), and this information has been used designing the surveys. The survey grid applied in these investigations has mainly been a systematic parallel grid pattern with north-south transects. This design was chosen to get the most complete coverage within a reasonable time. The distance between the transects has varied according to available time, from about 20 nm in the acoustic surveys to about 30 nm on the 0-group surveys.

Basically the same grid pattern has been used every year. In recent years, with more research vessel time available and with participation of Russian vessels, the distance between the course lines on the acoustic surveys in June has been decreased, especially in the areas with dense concentrations of herring.

Aglen (1982) has analysed the variations between abundance indices for different degrees of survey coverage. He defined the "degree of coverage" for an area as the ratio between sailed distance and the square root of the total area covered. Integrator output was used as the index of abundance. The result indicates that the coverage of the Barents Sea surveys has been adequate, as a further increase of survey effort will not improve the precision significantly.

Acoustic data

Two types of surveys providing data for acoustic abundance estimation of small herring have been carried out; the acoustic surveys, aimed directly at acoustic abundance estimation of pelagic fish, and the International 0-group fish surveys, which are not designed as acoustic surveys but provide data for computing acoustic abundance estimates. The difference between the data from the two types of surveys lies mostly in the level of discrimination of the acoustic information which is done while the survey proceeds.

On the acoustic herring surveys, the total integrator values are split among the different fish categories as the survey proceeds. By the end of the survey there is a record of separate integrator (S_A) values for each category of fish, including herring and capelin.

On the 0-group surveys the S_A-values are not totally separated by fish species. The total integrator values are also separated by different categories of fish, but the values representing the 0-group herring are not separated from the values of other 0-group fish. This was done later using the species composition observed in the trawl data collected during the surveys.

Biological sampling

Acoustic abundance estimation requires the species, size and age composition of the fish recorded by the echo integration system. These compositions are normally provided by samples obtained by trawling.

Two kinds of pelagic trawls have been employed during the acoustic herring surveys. From 1983 to 1991, a "herring trawl" (Fotø-trawl), a description of which is given by Clason (1982), was used. This trawl has been replaced by a specially designed herring trawl (Åkra-trawl) in 1992. A description of the latter trawl and of how it performs is given by Valdemarsen (1991). Trawling was done whenever the echo registrations indicated possible new areas of herring distribution or a potential change in the species- or size-structure of the fish in the area being surveyed. Extra trawl stations were also taken when the echo abundance estimates were high.

A capelin trawl (Harstad-trawl) has been used in the International 0-group Fish Surveys. This trawl, as well as the survey design and the trawling procedure, are described in detail in Anon. 1983c. The essential aspects of the sampling procedure are that trawl stations are taken every 30 nm along the predefined survey tracks; trawling is performed in a stepwise manner in the upper 60 m of the water column, or down to 80 m when the acoustic observations indicate that the distribution of 0-group fish may extend beyond 60 m (Anon. 1993b).

When the trawl catch comes aboard, it is sorted by species, and the different species are counted and weighed separately to estimate the species composition. In the case of large catches, a subsample is taken, and the procedure above is applied to the subsample. The results obtained for the subsample are raised using the ratio catch weight/subsample weight as the raising factor. The length distribution of each species is estimated by measuring the total length of the fish in a sample of at least 100 individuals or the total catch, if it included fewer than 100 specimens. For the main species, another sample is taken according to the same selection criteria, and the total length, weight, maturity, degree of stomach filling and other biological parameters are recorded for each fish in this sample. Scales (for larger herring) or otoliths (for small herring) are collected, and later used for age determination. The radii of the annuli on the scales are measured.

Abundance estimation

The basis of the acoustic estimation method, as well as its limitations, are described by McLennan and Simmonds (1992). Dommasnes and Røttingen (1984) describe in detail the procedure used by IMR for acoustic estimation of the abundance of small pelagic schooling fish in the Barents Sea.

The echo integrator measures the intensity of returned echoes, rather than fish density. To convert the echo measurements into herring density estimates it is therefore necessary to apply the target strength equation appropriate for herring. Since target strength is dependent on fish length, it is also necessary to know the length distribution of the herring whose abundance is being estimated. The density of herring of length-group i can be estimated as

$$\rho_{Ai} = \frac{S_{A_H}}{\bar{\sigma}} p_i ,$$

where

S_{A_H} = average integrator value allocated to herring in the region of interest

p_i = proportion of herring in length group i

The scattering cross section, σ, is calculated from the target-strength equation adopted for herring (Foote 1987):

$$TS = 10 \cdot \log\left(\frac{\sigma}{4\pi}\right) = 20 \log L - 71.9\, dB, \text{ or}$$

$$\bar{\sigma} = 8.13 \cdot 10^{-7} \cdot \overline{L}^2$$

TS is the target strength of the fish and L its total length.

For the surveys where a separate integrator value for herring had not been calculated during the survey, the S_{A_H} value was calculated as

$$S_{A_H} = S_A \cdot \frac{W_H}{W} ,$$

where S_A is the average integrator value allocated to all 0-group fish, and W and W_H represent respectively the total weight of the 0-group fish and the weight of 0-group herring in the trawl samples allocated to the area.

This procedure is not rigorous, and it can be considered that a more precise allocation should take into account the length distribution of all 0-group fish species. Given the uncertainties associated with the target strength function for these small fish, however, and their relatively narrow size-distribution, it was considered that more complex calculation procedures would not necessarily improve the precision of the estimate.

Since the herring are not distributed uniformly over the whole Barents Sea, the area investigated is divided into smaller areas, rectangles usually of 1 degree latitude and 2 degrees longitude. The arithmetic mean of all S_A-values obtained in each rectangle is calculated and used as the average S_A-value for that rectangle. The length distribution of the herring in the rectangle is obtained from the trawl samples. Many of the rectangles have no trawl stations, many have only one, and several have more than one. In order to get representative biological data for the recordings in every rectangle, trawl stations selected from the rectangle in question or from neighbouring rectangles are assigned to each rectangle as the survey proceeds. The main criterion for allocating trawl stations to a rectangle is the similarity of the age and size distribution of the fish in the echo recordings. When trawl stations have been assigned to a rectangle, a length frequency is computed for that rectangle by summing the samples from the assigned trawl stations. The calculations are done by half-centimetre lengthgroups. The total number of herring in each length group in a larger area or in the total area is found by adding the number of fish per length-group in all rectangles included in the area.

RESULTS

The estimates of 0-group herring are taken in the autumn while the estimates of 1-, 2- and 3-group have been made throughout the year, in January, April, May, June, August, September, October and November. However, most of the estimates of 1- and 2-year olds are made during the regular small herring survey in May-June. In 1986 and 1987 no estimate of 0-group herring was made as there were, in practice, no 0-group herring in the Barents Sea in these years. There are therefore no estimates of these year-classes in the series. The year-class which was e stimated most frequently is the 1983 year-class, followed by the 1984 year-class and the 1988 and 1991 year-classes. The age-groups most frequently estimated are the 0- and 1-year-olds followed by the 2 year-olds.

Table 1. Number of estimates per age group of the year-classes which entered the Barents Sea in the period 1983-1993.

	Age-groups				
Year- class	0	1	2	3	Total
1983	2	1	5	2	10
1984	2	5	1	-	8
1985	4	1	-	-	5
1988	3	1	2	-	6
1989	1	2	1	1	5
1990	1	1	1	-	3
1991	1	1	3	1	6
1992	1	3	1	-	5
1993	1	1	-	-	2
TOTAL	16	16	14	4	50

The number of estimates per age group of the year-classes which entered the Barents Sea in the period 1983-1993 is shown in Table 1.The total time series of abundance estimates of herring by cohorts is shown in Table 2. The middle date of the survey and the age-group to which the estimate corresponds is also given.

The estimated numbers of 0-, 1-, and 2-year old herring in the Barents Sea compared to the recruitment at age 3 years, as obtained from VPA (Anon. 1994), are shown in Figures 2 a-c. The correlation between the estimated number of 0-group herring and the abundance of the same cohort at age 3 is rather poor (r_0=0.25), but there is a better correlation between this abundance and the estimated number at 1- and 2- years (r_1=0.98 and r_2=0.70 respectively).

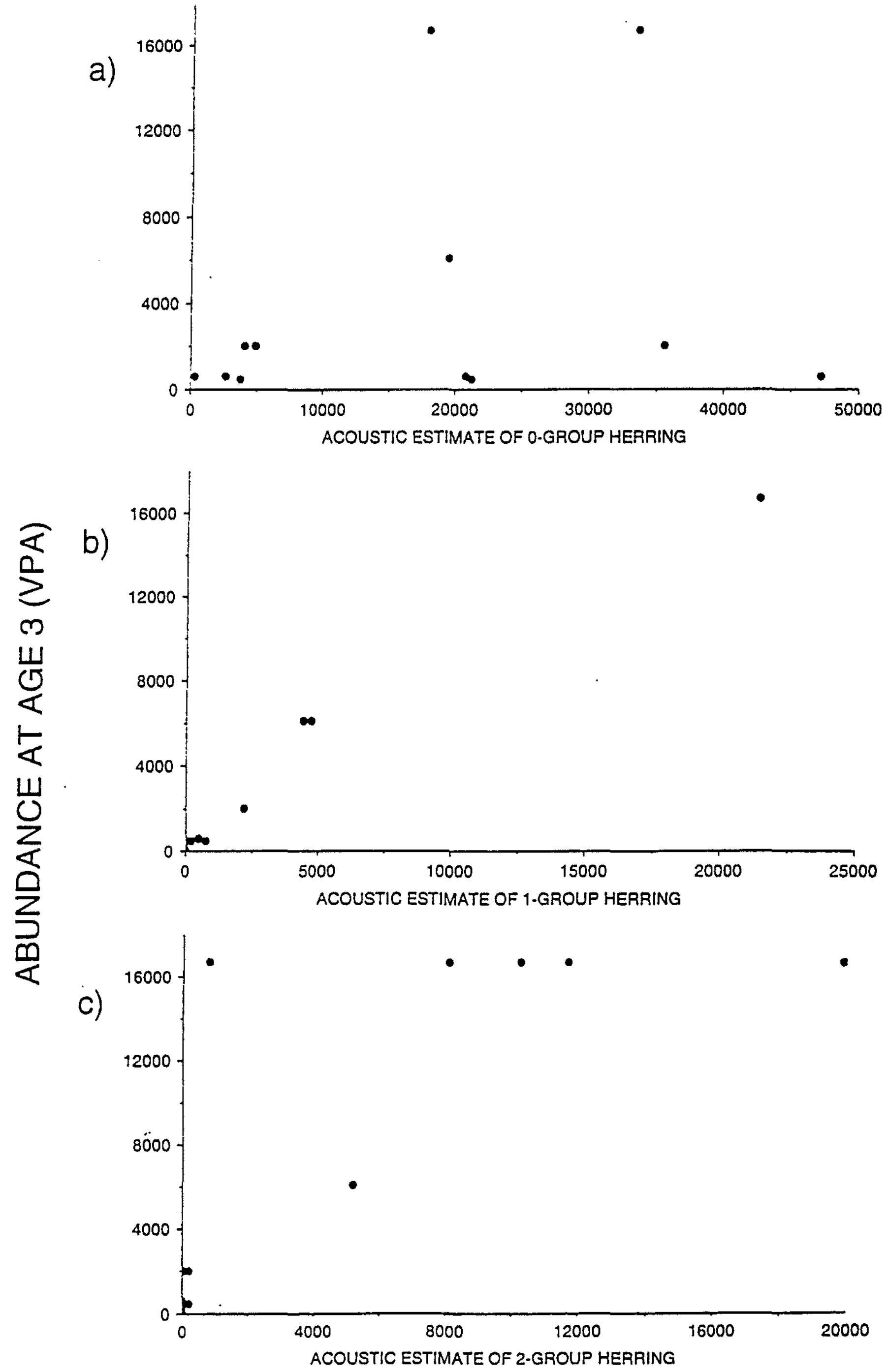

Figure 2a-c. Acoustic estimates of abundance of 0-, 1-, and 2-group herring in the Barents Sea vs. VPA estimates of abundance at age 3 years.

Table 2. Acoustic estimates of the abundance of the different age-groups of juvenile Norwegian spring-spawning herring in the Barents Sea. Data from IMR scientific surveys in the period 1983-1994.

Year-class	Middle date	Age group	Estimate (millions)	Year-class	Middle date	Age group	Estimate (millions)
1983	83/08/29	0	33470	1989	89/08/21	0	19472
	83/11/09	0	17900		90/05/23	1	4436
	84/06/05	1	21400		90/09/7	1	4748
	85/05/06	2	10250		91/05/25	2	5200
	85/06/08	2	19900		92/05/25	3	5700
	85/09/23	2	11699				
	85/11/13	2	817				
	86/01/13	2	8100	1990	90/08/15	0	62215
	86/05/15	3	3000		91/05/25	1	24300
	86/11/04	3	3380		92/05/25	2	14027
1984	84/08/28	0	21238	1991	91/08/9	0	101312
	84/11/26	0	3800		92/05/25	1	32614
	85/05/06	1	56		93/06/01	2	25800
	85/06/08	1	55		93/08/15	2	27000
	85/09/23	1	768		93/09/10	2	22800
	85/11/13	1	94		94/06/03	3	18000
	86/01/13	1	225				
	86/05/15	2	215				
1985	85/08/28	0	47214	1992	92/09/10	0	274800
	85/09/23	0	20800		93/06/01	1	102700
	85/11/13	0	2700		93/08/15	1	74470
	86/01/13	0	387		93/09/10	1	67330
	86/05/15	1	501		94/06/03	2	59200
1988	88/08/31	0	35594	1993	93/09/09	0	100000
	88/09/24	0	4060		94/06/03	1	6600
	88/10/29	0	4900				
	89/05/30	1	2200				
	90/06/03	2	54				
	90/09/22	2	221				

DISCUSSION

Variability is a characteristic feature of estimates of abundance of animal populations (Pielou, 1981), and this is even more true for small pelagic schooling fish, which are often found in dense and highly mobile aggregations separated by large areas of very low densities.

The estimates of abundance of these populations are thus subject to several sources of error, which are discussed in detail by Simmonds *et al.* (1992). The magnitude and direction of these errors will usually not be known for the particular surveys, so they must be considered a part of the random errors in the survey estimates. The experience accumulated on the herring in the

Barents Sea system, however, makes it possible to detect some occasions in which the conditions for effective acoustic abundance estimation are particularly difficult, and therefore to single out estimates of dubious quality.

The major problem is often ensuring that the whole distribution area of the juvenile herring has been covered. The Barents Sea encloses a very large area, and it is normally impossible to cover all potential areas of herring distribution in a single survey. In most cases, however, there is a reasonable certainty that at least all major herring concentrations have been covered.The sea is covered many times during the year and information from all surveys in the area are considered before selecting the actual area to cover. While surveying, several nautical miles are sailed also outside the area of distribution to confirm that the zero-line is adequately recorded. In some occasions, however, it has not been possible to follow exactly this standard procedure. This was especially the case for some surveys in the 80's where the herring was distributed close to the Soviet coast. At that time, Soviet vessels did not regularly take part in the investigations, and Norwegian vessels did not have permission to survey the area within 12 NM of the Soviet coast. Since the area off the Murmansk coast is among the important distribution areas for small herring during some parts of the year, the abundance of young herring may have been appreciably underestimated on a few occasions. In recent years, this factor has been adequately taken care of by the participation of Russian research vessels in the investigations. It is difficult to evaluate how much this factor may have affected the abundance estimates, but it has surely led to significant underestimation of the herring abundance in some years.

The vertical distribution of the herring in the area poses another problem to the acoustic abundance estimation. Young herring is often found in small schools in the upper parts of the water column and especially during summer, when feeding on plankton, it may be distributed in the uppermost 20 m. Much of this herring will not be detected by the echosounder because it either avoids the vessel or it is too close to the surface for detection. This problem has been discussed by several authors (Olsen 1971, Olsen et. al. 1982). The integration of the echo signals starts in general at 10 m distance from the echo sounder, but in practice the system makes it possible to include schools somewhat closer to the sounder (5-8 m). The sounder is hull mounted (at 6 m depth) which means that at least the herring distributed closer to the surface than 10 m cannot be recorded. The sonar system onboard the vessels has allowed to verify that this may be a relevant source of error, but the data from the sonar cannot yet be used in abundance estimation. For herring distributed deeper than 10 m from the surface the problem of avoidance becomes less severe as the vertical distance from the vessel increases. However, even though this problem must be looked upon as a severe one, it only concerns a small part of the estimated population and it seems as if it is not age or size specific in the area.

When estimating the abundance of populations of herring or of other fish with schooling behaviour the shadowing effect must always be considered as a potential source of error. In some cases it may be a severe one (Toresen 1991). When herring schools the S_A-values are no longer proportional to fish density, but they are too low. This problem increases when the schools become larger. This is a preeminent problem when estimating the abundance of adult herring, but might also have been a source of error for small herring, in case they also formed dense schools. The present estimates are not corrected for the shadowing effect, but it is not very likely that this will have seriously affected the abundance estimates, since small herring in the Barents Sea rarely form schools dense or large enough for this to be a major source of error (Dragesund, 1970, Toresen 1991).

A potentially larger source of error in the abundance estimates is the sampling for size- and age-composition of the fish. The assumption behind current practice is that the trawl catches reflect the size- and age-composition of the fish in the sea. However, several studies have shown that different species and size-groups react differently to the trawl and ship noise (Chapman and Hawkins, 1969; Hawkins, 1973; Ona and Toresen, 1988; Ona and Godø, 1990; Misund and Aglen, 1992), and consequently the probability of capture is species- and size-specific. When four age-groups of herring are distributed in the same area, size-dependent avoidance reactions may therefore bias the acoustic estimates of abundance appreciably. The magnitude and direction of this effect is not known, and more research will have to be conducted before it is possible to explicitly account for it.

Differences in the trawling procedure used in the different surveys may also have introduced some extra variability in the estimates. In the ordinary acoustic surveys, trawling is carried out whenever the echo recordings change or indicate high abundance. It is therefore reasonable to accept the assumption that the trawl samples represent the species- and size-distribution of the fish which is recorded by the echo-sounder. During the International 0-group fish surveys, however (which produced the first estimates for most of the cohorts studied) trawling is performed at regular intervals, rather than as dictated by the echo recordings. Nevertheless, the acoustic system is still used to observe the vertical distribution of the 0-group fish, and the trawling depths are defined from the acoustic information, so as to include at least the depths where the acoustic system indicates that the 0-group fish might be distributed (Anon., 1993b). It is thus reasonable to assume that the trawl stations represent the relative distribution of the 0-group fish, at least if the distribution is not too patchy. The patchiness of the distribution of 0-group herring in the Barents Sea in August varies somewhat and depends on the growth prior to the survey. If growth during summer is good and if metamorphosis occurs early, the herring distribution tends to be more patchy than otherwise. Normally, however, the distribution of 0-group herring in August/September is rather dispersed and one finds herring evenly distributed over vast areas (Anon. 1983; Dragesund and Olsen, 1965; Dragesund, 1970).

Overall, the errors which are most likely to be detected are those related to incomplete coverage of the herring distribution. Some of the estimates of the 1983 year-class were particularly affected by this problem. The estimate from the August 1983 survey corresponds only to a part of the total 0-group distribution, since one of the vessels had problems with the acoustic integrator system, and could not provide data for the estimation. During the November 1983 survey, on the other hand, the weather conditions joined to an unfavourable distribution of the young herring (too close to the Soviet coast) to again prevent a full coverage of the stock. Combining an examination of the distribution maps from the trawl stations in the August 1983 survey, and of the density distributions from the November survey with later estimates of abundance of this cohort provides indications that the true abundance of the 1983 cohort at these ages was probably underestimated by as much as 50%. The two estimates taken after May 1986 are also considered to be underestimates, as it is likely that a part of the juvenile herring population had already left the Barents Sea.

Despite the potential uncertainty in the abundance estimates, it can be considered that the data series provides a reasonably good overview of the variations in abundance of the herring year-classes which entered the Barents Sea system as 0-group fish between 1983 and 1993. Even though this is not a very long data series, it opens some new perspectives for the investigations of the dynamics of the juvenile herring in this important nursery area.

The relationships between the abundance estimates of the different age-groups and the abundance at age 3 years as by VPA provide some insight into these dynamics. Hamre (1988) suggested that mortality of juvenile herring in the Barents Sea should be extremely variable, but he did not have the data to actually estimate this mortality or its variations. The very large increase in the correlation with the age-3 abundance as one moves from the 0-group to the 1-group estimates of abundance may be taken as indicating that this mortality is in fact variable, and that most of this variability occurs in the period between the 0-group and the 1-group estimates. Nevertheless, the noise in the data is too large to allow us to extend this reasoning any further. The uncertainty associated with the acoustic estimates is large enough to suggest that such a simple analysis is unlikely to produce very reliable results. Also, the VPA estimates of abundance at age 3 are effected by different kinds of errors. In the later years, the exploitation rate of the Norwegian spring-spawning herring stock has been very low (Anon. 1994), and therefore the estimates of abundance at age 3 derived from VPA are largely dependent on the value adopted for the natural mortality rate of the stock, and cannot be considered as precise estimates of population abundance. More refined methods of analysis, taking into account the variability in the estimates, will probably be required to investigate the patterns in these abundance estimates.

REFERENCES

AGLEN, A. 1982. Random errors of acoustic fish abundance estimates in relation to the survey grid density applied. *FAO Fish.Rep.*, No. 300: 293-298.

ANON. 1983. Preliminary report of the International 0-groups fish survey in the Barents Sea and adjacent waters in August-September 1980. *Annls.biol. Copenhagen. 37*: 259-266.

ANON. 1983b. Report of the Atlanto-Scandian Herring and Capelin Working Group. *ICES CM 1984*/Assess:15, 33 pp

ANON. 1986a. Preliminary report of the International 0-group fish survey in the Barents Sea and adjacent waters in August-September 1983. *Annls.biol., Copenhagen. 41*: 172-180.

ANON. 1986b. Preliminary report of the International 0-group fish survey in the Barents Sea and adjacent waters in August-September 1984. *Annls.biol., Copenhagen. 41*: 180-188.

ANON. 1993. Herring assessment Working Group for the area south of 62°N. Copenhagen 22 March-2 April 1993. *ICES CM 1993*/Assess: 15, 245 pp.

ANON. 1994a. Preliminary report of the International 0-group fish survey in the Barents Sea and adjacent waters in August-September 1993. *ICES CM 1993*/G:3, 38 pp.

ANON. 1994b. Report of the Atlanto-Scandian herring and capelin Working Group. Copenhagen, 18-20 October 1993. *ICES CM 1994*/Assess: 8, 84 pp.

CHAPMAN, C. J. and **HAWKINS, A. A.** 1969. The importance of sound in fish behaviour in relation to capture by trawls. *FAO Fish. Rep. 62*(3): 717-719.

CLASON, P. 1982. Resursbevarande trålredskap. Pp. 113-182 in *Rapport SH.* Chalmers Tekniska Høgskola. Gøteborg. Sverige. (In Swedish).

DOMMASNES, A. and **RØTTINGEN, I.** 1985. Acoustic stock measurements of the Barents Sea capelin 1972 1984. A review. Pp. 45-108 in Gjøsæter, H. (ed.): *The Proceedings of the Soviet-Norwegian Symposium on the Barents Sea capelin, Bergen, 14-19 August 1984.* Institute of Marine Research, Bergen, Norway.

DRAGESUND, O. 1959. Småsild- og feitsildtokt med F/F "G.O. Sars" i tiden 24. september til 29. oktober 1959. *Fiskets Gang, 45*: 694-699. (In Norwegian)

DRAGESUND, O. 1961. Småsild- og feitsildtokt med F/F "G.O. Sars" i tiden 28. september til 29. oktober 1960. *Fiskets Gang, 47*: 59-63. (In Norwegian)

DRAGESUND, O. 1962. Småsild- og feitsildtokt med F/F "G.O. Sars" i tiden 3. september til 4. oktober 1962. *Fiskets Gang, 48*: 611-614. (In Norwegian)

DRAGESUND, O. 1964. Småsild- og feitsildtokt med F/F "G.O. Sars" i tiden 15. september til 10. oktober 1963. *Fiskets Gang, 50*: 48-53. (In Norwegian)

DRAGESUND, O. 1970. Distribution, abundance and mortality of young and adolescent Norwegian spring spawning herring (*Clupea harengus* Linne) in relation to subsequent year-class strength. *FiskDir.Skr.ser.HavUnders. 15*: 451-556.

DRAGESUND, O. and **HOGNESTAD, P.T.** 1962. Småsild- og feitsildtokt med F/F "G.O. Sars" i tiden 30. august til 28. september 1961. *Fiskets Gang, 48*:6-11. (In Norwegian).

DRAGESUND, O. and **OLSEN, S.** 1965. On the possibility of estimating year-class strength by measuring echo-abundance of 0-group fish. *FiskDir. Skr.Ser.HavUnders. 13*: 48-75.

FOGARTY, M. J., SISSENWINE, M.P. and **COHEN, E.B.** 1991. Recruitment variability and the dynamics of exploited marine populations. *Tr.Ecol.Evo., 6*: 241-247.

FOOTE, K. G. 1987. Fish target strengths for use in echo integrator surveys. *J. Acoust. Soc. Am., 82*: 981 -987.

HAMRE, J. 1988. Some aspects of the interrelations between the herring in the Norwegian Sea and the stocks of capelin and cod in the Barents Sea. *ICES CM 1988*/H:42, 15 pp.

HAWKINS, A. D. 1973. The sensitivity of fish to sounds. *Oceanogr.Mar.Biol. Annu. Rev., 11*: 291-340.

HOGNESTAD, P. T. 1963. Småsild- og feitsildtokt med F/F "G. O. Sars" i tiden 18. oktober til 7. november 1962. *Fiskets Gang, 49*: 31-33. (In Norwegian)

MACLENNAN, D. N. and **SIMMONDS, J.** 1992. *Fisheries Acoustics*. Chapman and Hall. London. 328 pp.

MIDTTUN, L. 1959. Rapport om tokt med "Johan Hjort" til Barentshavet 19. september til 24. oktober 1959. *Fiskets Gang, 45*: 639-640. (In Norwegian)

MISUND, O. A. and **AGLEN, A.** 1992. Swimming behaviour of fish schools in the North Sea during acoustic surveying and pelagic trawl sampling. *ICES J. Mar. Sci., 49*: 325-334.

NAKKEN, O. and **DOMMASNES, A.** 1977. Acoustic estimates of the Barents Sea capelin stock 1971-1976. *ICES C.M. 1977*/H:35.

OLSEN, S. 1960. Rapport om tokt med "G.O. Sars" til Barentshavet i september 1960. Fiskets Gang, 46: 690-692. (In Norwegian)

OLSEN, K. 1971. Influence of vessel noise on behaviour of herring. Pp. 291-294 in Kristjonson, H. (ed.): *Modern fishing gear of the world, No.3.* FAO-Fishing News Books Ltd., Rome, Italy.

OLSEN, K., ANGELL, J., PETTERSEN, F. and **LØVIK, A.** 1982. Observed fish reaction to a surveying vessel with special reference to herring, cod, capelin and polar cod. *FAO Fish. Rep., 300*: 131-138.

ONA, E. and **GODØ, O. R.** 1990. Fish reaction to trawling noise: the significance for trawl sampling. *Rapp. P.v. Réun. Cons. int. Explor. Mer., 189*: 159-166.

ONA, E. and **TORESEN, R.** 1988. Reactions of herring to trawling noise. *ICES CM 1988*/B:36.

PIELOU, E. C. 1981. The usefulness of ecological models: a stocktaking. *Quart.Rev.Biol., 56*: 17-31.

SIMMONDS, E. J., WILLIAMSON, N. J., GERLOTTO, F. and **AGLEN, A.** 1992. Acoustic survey design and analysis procedures: a comprehensive review of current practice. *ICES Coop.Res. Rep.*, No. 187, 131 pp.

SISSENWINE, M. P. 1984. Why do fish populations vary?. *Pp. 59-94 in May, R.M. (ed.): Report of the Dalhem workshop on Exploitation of Marine Communities. Berlin, 1-6 April, 1984.*

TORESEN, R. 1991. Absorption of acoustic energy in dense herring schools studied by the attenuation in the bottom echo signal. *Fish.Res., 10*: 317-327.

VALDEMARSEN, J. W. 1991. Redskapstekniske målinger av ny flytetrål ("boretårn"-trål) og harstadtrål ombord i "Johan Hjort" i januar 1991. *Intern rapport.,* 15 pp. Havforskningsinstituttet, Bergen, Norway. (In Norwegian)

SURVEYING THE YOUNGER AGE GROUPS OF SAITHE - EXPERIENCES FROM A SMALL SCALE ACOUSTIC SURVEY AT THE COAST OF WESTERN FINNMARK

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ABSTRACT

The small saithe (1- and 2- group) is mainly distributed in fairly shallow areas close to the Norwegian coast from Rogaland to eastern Finnmark. It is known to occur quite regularily at certain localities. It is usually schooling, at least in daylight. Thus, by using a small vessel equipped with an echo sounder it is usually easy to detect. This paper discuss the possibilities of acoustic surveying a fixed number of known "saithe localities" to obtain a yearclass index. Hypothesis regarding the distribution pattern and fish behaviour are presented, and the cosequences for the reliability of a survey index are discussed. Absolute estimates seem unrealistic, because a large proportion of the most important areas can not be surveyed even with a small vessel. Results from a survey in western Finnmark during early August 1993 are presented and discussed. The results indicate that in these areas the 1- group tended to stay rather close to the shore, while the 2- group showed a more favourable distribution. At the lower limit of its vertical distribution range it showed some overlap with the 3- group.

METHODS

A 49 feet research vessel ("Fjordfangst") equipped with a Simrad EY 200 (38 kHz) echo sounder was used for echo surveying in the period from 6 to 16 August 1993. The first 5 days were aimed at 0-group cod in the fjords on the north western part of Sørøya, while the rest of the survey were aimed at small saithe in the area around Rolvsøy and the areas west and south west of Havøysund. All observations were made during daytime.

A PC-based echo integrator (Floen *et al.* 1991) was connected to the echo sounder, and the system was calibrated by use of a standard copper sphere (TS= -33.6 dB), lowered to 9 meter range in Hammerfest harbour. Integrator outputs were given in absolute terms (S_A - values), and the distance interval (Elementary Sampling Distance Unit (ESDU)) was set to 0.3 nautical miles. Recordings were mainly identified by use of handline. To catch 0-group fish a small meshed Danish seine was used. After removing contributions from plankton and bottom, the

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Hylen, A. editor 1995. Proceedings of the sixth IMR-PINRO symposium, Bergen, 14-17 June 1994.
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s_A -values were allocated to the categories: small saithe (less than about 33 cm), larger saithe, 0-group cod, 0-group herring, larger herring and large demersal fish (cod and haddock).

Small saithe was the target for the last part of the survey. Narrow grounds where the bottom raised steeply from the surroundings to a minimum depth between 10 and 40 meters were considered as typical localities for small saithe and were selected for surveying. Figure 1 shows the survey tracks and the selected saithe localities. At most localities only one transect was worked "diametrically" across the ground. The vessel usually returned to the detected schools immidiately after finishing the transect to catch a few fish for identification. Mean S_A -value for saithe was calculated for each locality and converted to mean density by applying a target strength (TS) = 20 log L -68 (Foote 1987). An abundance estimate for the locality was obtained by assuming the area of the locality to be circular with diameter equal to the distance sailed across the locality (diameter = number of S_A -values times 0.3 nautical miles)

RESULTS

Echo recordings

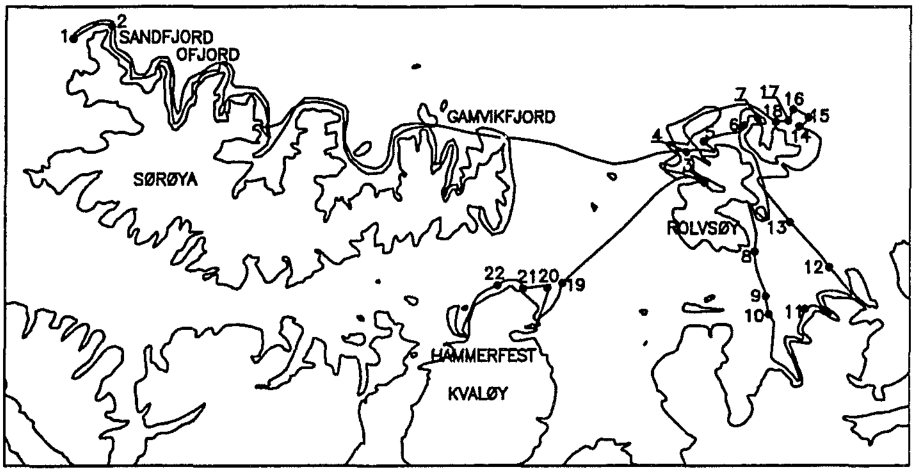


Figure 1. Survey tracks and saithe localities (filled circles 1-22). The localities 4-22 were preselected.

On the echogramme the small saithe formed rather dense schools, with irregularities along the edges indicating single fish traces. It was mainly restricted to the "typical" saithe localities described above. The larger saithe tended to occur deeper and the schools appeared looser; Single fish traces were evident throughout large parts of the school. Location 1 (Figure 1) showed an exception from this rule. Here, at 20 meter bottom depth, the schools appaered identical to schools of smaller saithe, but fishing showed fish in the size range 43-48 cm. Most schools of larger saithe were found along sloping bottom at bottom depths between 60 and 120 meters, while a few were recorded at rather flat bottom. The few traces identified as 0-group cod appeared as quite small schools of moderate acoustic density close to the bottom at bottom depths less than 25 meters. At common survey speed those traces were difficult to distinguish from traces of larger individual fish close to bottom. 0-group herring were recorded as fairly dense, irregular schools in the upper 20 meters, while the larger herring seemed to form more regular, nearly symmetrical, dense schools with rather wide vertical extension. Compared to the schools of small saithe they tended to have sharper edges and they did usually not occur at the typical saithe localities. Larger fish (cod and haddock) were widespread, particulary at depths below 30 meters. They tended to be resolved as single fishes. One exception was close to Melkøy (outside Hammerfest) where dense schools seemed to be pure cod.

Saithe

Length distributions of all saithe and cod taken with handline are shown in Figure 2. Figure 3 indicates an increasing size of the saithe with increasing bottom depth. (Locality 1 and 2 are rather far from the other localities and are not included in Figures 2 and 3). Figure 4 shows the S_A -values allocated to small and larger saithe averaged within bottom depth intervals. Here also the observations outside saithe localities are included, except those around Sørøya. Table 2 shows within depth intervals the number of S_A -observations and the frequency of occurence of saithe for the same set of data. Both Figures 3 and 4 show that small saithe dominates where the bottom depth is 60 meters or less, while no small saithe were observed at larger bottom depths.

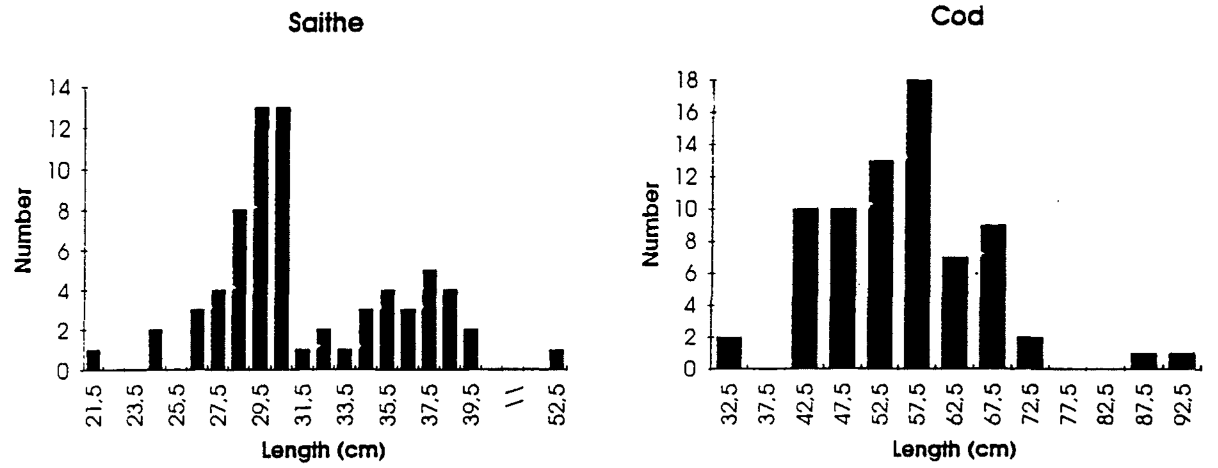


Figure 2. Length distribution of saithe and cod for all handline stations (except for locality 1 and 2) merged.

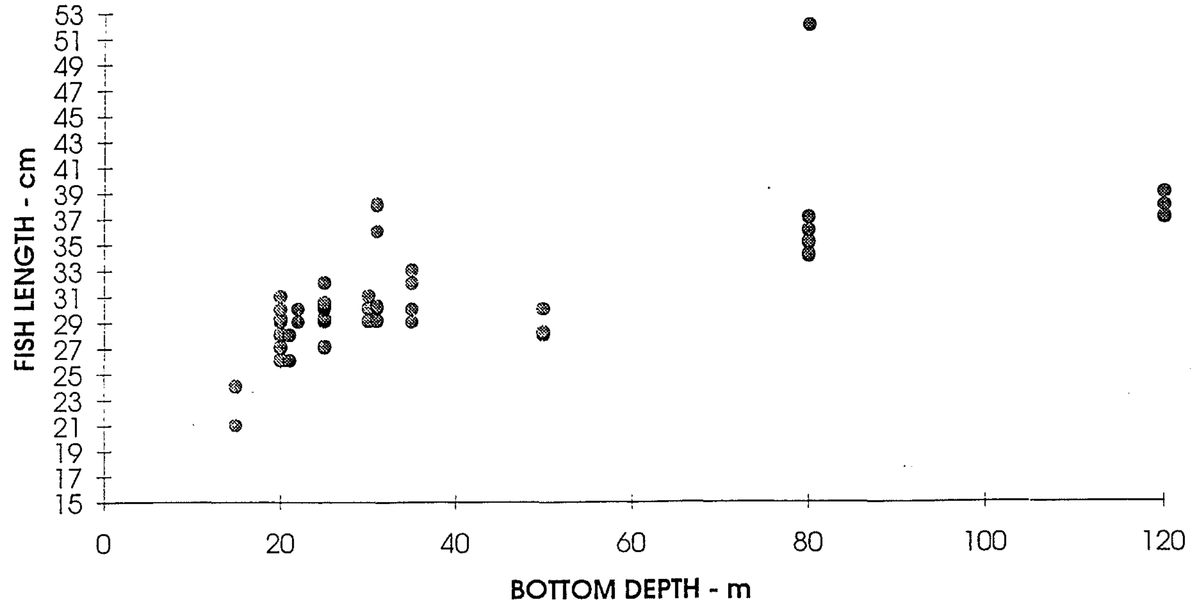


Figure 3. Length of saithe sampled at different bottom depths. Localities 1 and 2 are not included.

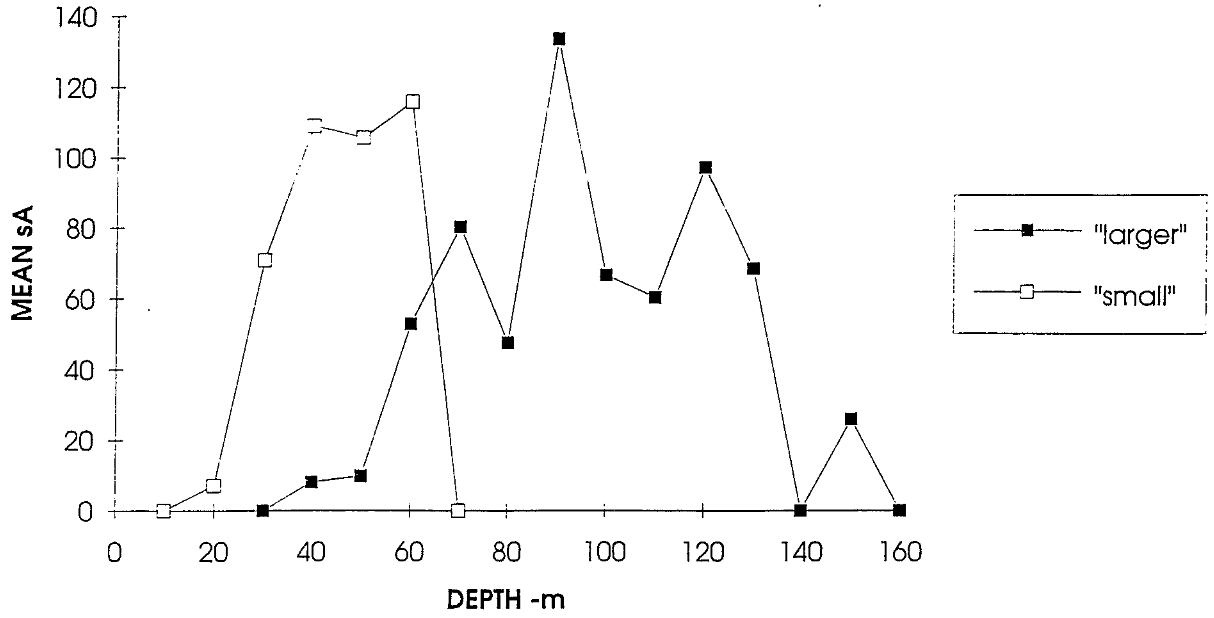


Figure 4. Mean S_A within intervals of bottom depth for "small" (<33 cm) and "larger" saithe. Observations along the transects between the selected localities are included. The observations along Sørøya are not included.

Table 1. Estimated mean density and abundance of saithe by locality. Localities marked with * were not pre-selected.

Locality	#samples á 0,3 nm	mean S_A	Area (sq. nm)	Density (#/sq.nm)	Abundance (#)	Age group
1* Darupskjær 1	2	237	0,28	58948	16659	3+
1* Darupskjær 2	2	123	0,28	30653	8663	3+
2* Skinnbrokskjær	2	151	0,28	56452	15953	3+
3* i Valfjord	3	135	0,64	85025	54063	2
4 Tunæringen	2	179	0,28	110556	31243	2
5 Kvalskjær 1	1	228	0,07	140853	9951	2
5 Kvalskjær 2	1	215	0,07	132880	9388	2
6 Vesterskjæra	1	129	0,07	73714	5208	2
7 Terningskallen	3	574	0,64	354086	225146	2
8 Gorgeboen	3	99	0,64	61049	38818	2
9 Lysgrunnen	1	258	0,07	159259	11252	2
10 Latøy	2	963	0,28	594568	168025	2
11 Rundgrunnen	3	527	0,64	304728	193762	2
12 Kjerkegrunnen	4	142	1,13	73600	83197	2
13 Saramannsgrunnen	5	65	1,77	42222	74575	2
14 Langeskjærgrunnen	2	73	0,28	46859	13242	2
15 Beskallen	3	748	0,64	479615	304963	2
16 Englan	5	1147	1,77	535593	945991	45% 2; 55% 3
17 Knausen	2	47	0,28	22082	6240	45% 2; 55% 3
18 Sandholmen	4	347	1,13	161802	182901	45% 2; 55% 3
19 Forsølgrunnen	1	155	0,07	54278	3835	3
20 Laibagrunnen	4	318	1,13	111571	126120	3
21 Mylingsbukta	2	194	0,28	67847	19174	3
22 Fluengrunnen	3	316	0,64	297194	188971	1
				TOTAL	0,19 mill. (21 t)	1-gr
					1,73 mill. (380 t)	2-gr
					0,81 mill. (370 t)	3+-gr

Table 1 shows estimated density and abundance of saithe for each locality. A tentative split on age groups was based on the observed fish lengths by applying age/ length keys from samples taken in neighbouring areas during october. Locality 19, 20 and 21 were the deepest ones with minimum bottom depths of 60-90 meters, while locality 22 was the most shallow (11 meters). All the remaining localities have minimum bottom depth in the range 15-45 meters, and except for the localities 16, 17 and 18 (and 1 and 2, beeing considerably further to the west) they seemed dominated by the 2-group.

Table 2. Total number of S_A observation and number where S_A for saithe is >0, within bottom dept intervals. Observations outside the saithe localities are included.

Mean bottom depth (m)	Total obs.	Obs. >0	Frequency of obs. >0
10	30	0	0,00
20	48	3	0,06
30	80	30	0,38
40	81	33	0,41
50	58	18	0,31
60	35	12	0,34
70	26	5	0,19
80	13	6	0,46
90	19	8	0,42
100	13	7	0,54
110	21	6	0,29
120	12	5	0,42
130	8	2	0,25
140	13	0	0,00
150	5	2	0,40
>150	45	0	0,00

Other species

When planning the survey one of the purposes was to make acoustic measurements of 0-group cod in the the north western fjords on Sørøya, to compare with those reported by Olsen and Soldal (1989). During this survey in 1993 recordings of 0-group cod were quite scarce in these areas. Five fishing stations were made with a small meshed Danish seine. Only one of the stations (in Sandfjord) gave a reasonable catch of 0-group cod. The length distribution is shown in Figure 5. This distribution, with modal length slightly below 5 cm , is similar to those observed in these areas in August 1987. Echo recordings resembling those giving this catch occured at a few locations in Sandfjord, Ofjord and Gamvikfjord. The total abundance of 0-group cod along Sørøya seemed to be considerably lower than reported by Olsen and Soldal (1989) for the years 1987 and 1988.

By using buoys on the headline the Danish seine was also used to identify recordings of 0-group herring close to surface. Besides herring around 5 cm (Figure 5) the catch showed a small admixture of sandeel (size range 5.5-7.5 cm). Such recordings were widespread both along Sørøya, outside Hammerfest and around Rolvsøy. The highest densities were observed in the inner parts of the fjords at Sørøya. 0-group herring were frequently observed in the stomack of saithe and cod. Schools classified as larger herring were observed along the eastern side of Sørøya, outside Forsøl, and a number of schools were recorded in Bakfjord. The cod caught in Bakfjord had herring (15-20 cm) in their stomacks.

DISCUSSION

Survey design

The survey reported here did not follow the usual design of an acoustic survey. The topography and the typical distribution of saithe would mean that a systematic survey grid with equally spaced transects over the entire large-scale distribution area would be a waste of effort. Instead the survey was aimed at the type of localities which the saithe seem to prefer.

The observed distribution of saithe confirms that the smaller saithe are assossiated with certain localities; Only at 4 or 5 occasions schools of small saithe were observed outside such localities. The results also indicate that, at least in this area during the present survey, the possibility of findig saithe at a typical locality is quite high; Saithe recordings were absent only at one of the 20 preselected localities. Bearing in mind that only one transect were worked through each locality, this is a rather high rate of "success". The repeatability of such one-transect coverages was not systematically investigated. Locality 1 was covered during the afternoon one day and covered again the next morning, while at locality 5 the same transect was repeated within half an hour. The results (Table 1) indicate large variation at locality 1 and small variation at locality 5. Due to variations in currents, weather, light conditions and diurnal rythms in the activity of the fish, it is quite likely to have temporal variations of the distribution within a locality. On schooling fish the likely sampling variation (at a fixed fish distribution) also tends to be large, and the result from locality 5 should not be taken as typical.

From Table 1 it is seen that the range between the lowest and highest estimate of the area of the localities is 1 to 25, which is approximately the same as the ratio between the lowest and the highest density estimate. It is also seen that the decision whether the locality extends over 1 or 2 ESDUs changes the area by a factor of 4. It is evident that for this purpose an ESDU of 0.3 nautical miles is too large, and the abundance estimates are strongly influenced by area estimation errors. This could have been improved by adjusting the S_A -value and area estimate according to the proportion of each ESDU falling within the locality. This would require some criteria based on the topography (like bottom depth and bottom slope) to determine the extent of the location. Preferably the area should be worked out from a map with detailed depth contours.

One could argue that mean S_A -values could be used as an abundance index without taking the area of the localities into account. If mean values are wanted by locality, the problem of deciding the averaging distance still remains. A better alternative is to use the sum of S_A -values for each locality as a basis for an index. An underlaying assumption would then be that all localities have the same extension across the transect. The basis for estimating total S_A, mean S_A and area would be considerably improved by working an additional transect perpendicular to the first one at ech locality.

The survey reported here is a pilot study on the possibility of designing a survey for estimating the year class strength of the younger age groups of saithe. The results indicate that it is easy to design an "aimed" survey that covers a large number of saithe schools. Therefore, one possibility could be to select a number of typical localities in all regions along the coast where young saithe tend to be distributed, to get a direct index for the covered localities. A refined index could be obtained by taking account of the number of uncovered saithe localities within each region. The reliability of such an index will both depend on sampling errors at the covered localities and on the between year variability in the proportion of a year class inhabiting the selected localities. The sampling errors could be studied by repeated coverages of a number of localities.

Regarding the between year variability one could speculate that in the case of large year classes the "best" localities become saturated and a large proportion of the fish is forced to stay at less typical areas. It is also conceivable that different age groups might compete for the same localities, thereby influencing the between year variability of the distribution of a given age group.

By including some less typical locations in the coverage, the index would become more robust against such effects. This could be done by stratifying the whole survey area according to how suitable the environment is for saithe. (Bottom depth, bottom slope and exposure to waves and currents would be important parameters for stratification). Then the effort could be allocated to strata according to the expected distribution of saithe. Precise maps are required for defining and calculating the area of such strata. One remaining problem is that along the Norwegian coast there are large areas containing typical saithe localities which, for safety reasons, are not surveyable even for a small vessel.

Which age groups?

0-group saithe is known to have a predominantly littoral distribution during most of the year and is thus not available for acoustic surveying. At the present survey 0-group were only observed in the harbour areas visited. The information obtained on 1-group was also quite scarce. It was recorded acoustically only at one of the selected localities. In addition some amounts of 1-group were observed visiually in harbours. It seems to be a tendency for the 1-group to stay in more shallow waters and closer to the shore than the 2-group, thus making it less surveyable. The lack of 1-group at most selected localities might as well be caused by a low abundance of that year class in this region. In other regions of the coast 1-group is commonly occuring at the type of localities investigated here.

Anyhow, judging from this small survey, the 2-group seem to show the most favourable distribution for such an aimed acoustic survey.

Fish sampling

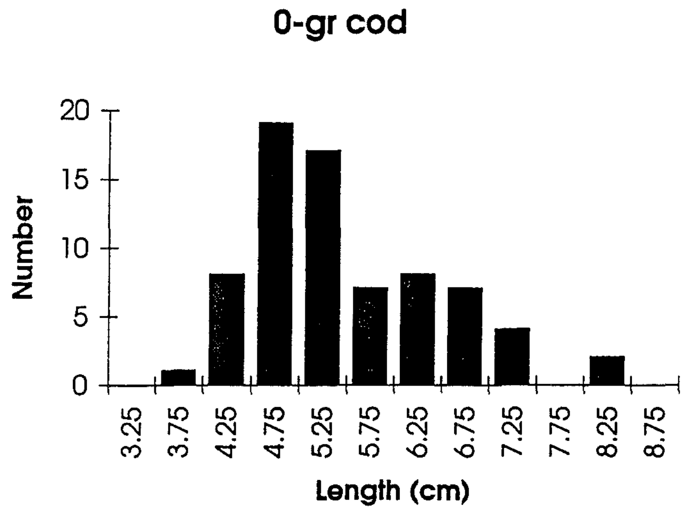
Sampling with handline (jigging and trolling) might be regarded as both ineffective and biased. At the present survey conditions it showed to be a surprisingly effective way of identifying echo records. With such a small, easily manoeuvrable vessel it was possible to fish on any fish recordings of interest. We could take a look at the echo sunder at the particular moment when the fish was biting and get an "answer" when the fish were taken onboard. Both saithe, cod and haddock seemed to be in the right mood for biting all day, and some catch was obtained at every trial when large fish were seen on the echogramme. Herring and other small fish did of course not take the hooks, but they could usually be distinguished from larger fish on the echogramme. Their presence were often verified by inspecting the stomack contents of larger fish caught. The conclusion is that for this kind of studies jigging is a quick way of identifying records, while when aiming for large samples it tends to be time consuming.

The selectivity of a handline is difficult to evaluate. We got the impression that when jigging in saithe schools occuring inbetween recordings of cod, the cod tended to be overrepresented in the catch. It might be that cod is more effective in competing for the hooks. In a few cases trolling was applied. Then the tendency appeared opposite.

One could expect that the saithe, at least to some extent, is schooling by size, thereby reducing the bias caused by size selectivity of the gear. This could be studied by sampling on the same schools both with handline and purse seine.

CONCLUSIONS

In spite of the variable topography and the patchy distribution of young saithe along the Norwegian coast, one should not rule out the possibility of obtaining a useful acoustic index of year class strength. One should not expect a high precision, but it might be worth the relatively small effort required for running a small vessel fishing with handline. Such a survey will also provide valuable additional information, for instance regarding predation on 0-group herring in coastal areas.



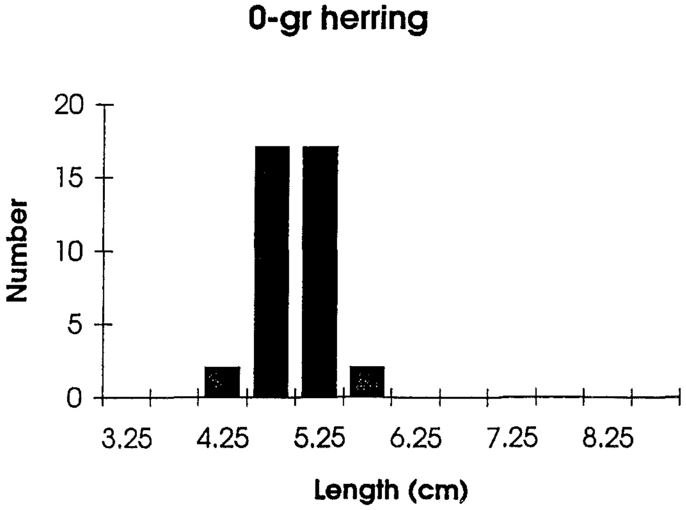


Figure 5. Length distribution of 0-group cod at Sandfjord, Sørøya, and of 0-group herring at Ofjord, Sørøya.

REFERENCES

FLOEN, S., TOTLAND, B., ØVREDAL, J.T. and **MISUND, O.A.** 1991. A PC-based echo integrator applicable for school structure analysis. *ICES CM 1991*/B:43, 10 pp.

FOOTE, K.G. 1987. Fish target strengths for use in echo integrator surveys. *J.Acoust. Soc.Am.* (82)3: 981-987.

OLSEN, S. and **SOLDAL, A.V.** 1989. Observations on inshore distribution and behaviour of 0-group northeast Arctic cod. *Rapp.P.-v.Rèun.Cons.int.Explor.Mer, 191*: 296-302.

ACOUSTIC ESTIMATES OF 0-GROUP FISH ABUNDANCE IN THE BARENTS SEA AND ADJACENT WATERS IN 1992 AND 1993

by

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ABSTRACT

Acoustic and biological data collected during the international 0-group surveys in 1992 and 1993 were used to estimate the abundance of 0-group fish of 4 species; cod, haddock, redfish and polar cod.

The abundances of 0-group cod amounted to $107 \cdot 10^9$ and $84 \cdot 10^9$ specimens in 1992 and 1993 respectively. These estimates are considerably higher than those arrived at by the swept volume/area method when resonable values for trawl catch efficiencies were applied. Instantaneous mortality rates of 8-9 were calculated from the acoustic estimates of 0-group in August and 1-group in February for cod of the 1992 and 1993 year classes.

The acoustic estimates of 0-group haddock abundance amounted to $12 \cdot 10^9$ and $8 \cdot 10^9$ specimens and the ratio between cod and haddock abundances were significantly higher for the acoustic estimates than for the traditional indices of 0-group abundance. For the two year classes under observation instantaneous mortality rates of 4-5 were arrived at from the acoustic estimates of 0- and 1-group haddock.

For 0-group redfish the acoustic estimates of abundance amounted to $38 \cdot 10^9$ and $48 \cdot 10^9$ specimens in 1992 and 1993 respectively.

The estimates arrived at for 0-group polar cod, $100 \cdot 10^9$ and $62 \cdot 10^9$ specimens, were underestimates due to insufficient acoustic coverage of the 0-group polar cod distribution area in both years.

INTRODUCTION

The annual 0-group surveys in August-September in the Barents Sea and adjacent waters provide information on distribution, abundance and biological parameters (length, weight, stomach content e.t.c) of several important species. Indices of abundance are regularly

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computed using two different methods and the time series of both types of indices are presented in the report (Anon 1994).

The area index, AI was introduced by Haug and Nakken (1977). They compared trawl catch rates and acoustic recordings, and for each species they estimated a limit above which catch rates ought to be given 10 times the weight of catch rates below that limit in the calculation of the index of abundance. The index is arrived at simply by adding up areas where the species occur in the catches; areas with catch rates above the estimated limit are multiplied by 10.

The logarithmic index, LI introduced by Randa (1984), is based exclusively on trawlcatches. Catch rates are normalized by using their natural logarithms. Mean values and variances are calculated for geographical areas (strata) as well as proportions of nonzero hauls and the variances of these proportions. The procedure enables both computations of a stratified logaritmic abundance index and confidence limits at the approximate 90-95 percent levels.

Acoustic data have been collected regularly during the annual surveys, but little use has so far been made of these observations when the abundance indices have been computed apart from the estimates of abundance given by Dorchenkov (1993) for a limited area in the Barents Sea in 1992. The only estimates of the total number of 0-group fish (cod) that have been given are those made by Sundby *et al.* (1989). Assuming catching efficiencies (of q=0,1 and 0,25) for the trawl used they arrived at estimates of 0-group cod in the range 0,4-10 billion specimens for the year classes 1979-1988 (Sundby *et al.* 1989).

In order to improve our understanding of energy transfer processes in the ecosystem and our ability to predict recruitment to the fisheries, estimates of absolute abundance at various stages during the prerecruit phase are a neccessity. The present paper is an attemt to estimate the number of 0-group specimens of cod, haddock, redfish and polarcod in 1992 and 1993 based on the acoustic data during the 0-group surveys.

MATERIAL AND METHODS

Field sampling and postprocessing

The material included mean column- or area back scattering coefficients, s_A, sampled with Bergen Echo Integrator, BEI, (Foote *et al.* 1991) and species - and length distributions of the scattering organisms collected with pelagic trawls (Anon, 1992 and 1994). Figures 1 shows the trawl stations and the courselines at which acoustic data were sampled. The geographical distributions of area back scattering coefficients of 0-group fish are presented in Figure2. Trawling and biological sampling of the catches was carried out in accordance with the standards adopted for the 0-group survey (Anon, 1992 and 1994). During the daily postprocessing of acoustic data onboard the vessels (Foote *et al.* 1991) mean values of s_A were partitioned to various groups of scatterers by each 5 nautical miles sailing distance on the basis of

- the appearance of scatterers on the echogram (Figure3)
- the catch composition at the trawlstations
- the frequency distributions of target strength of individual scatterers

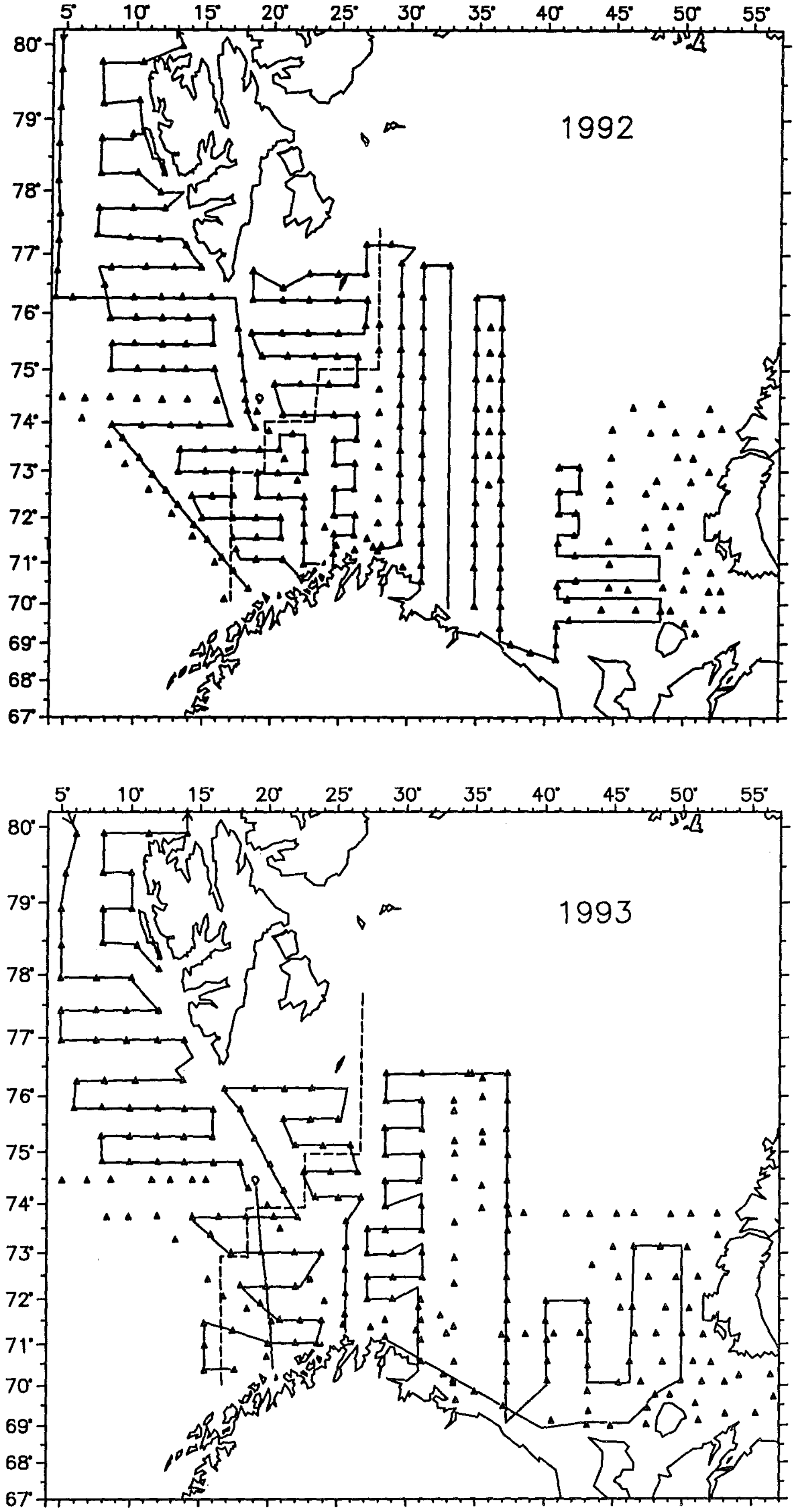

Figure 1. Survey tracks along which acoustic data were available and trawlstations in August-September 1992 and 1993. The thin line is the borderline between the two areas for which estimates of abundance are worked out (Table 1).

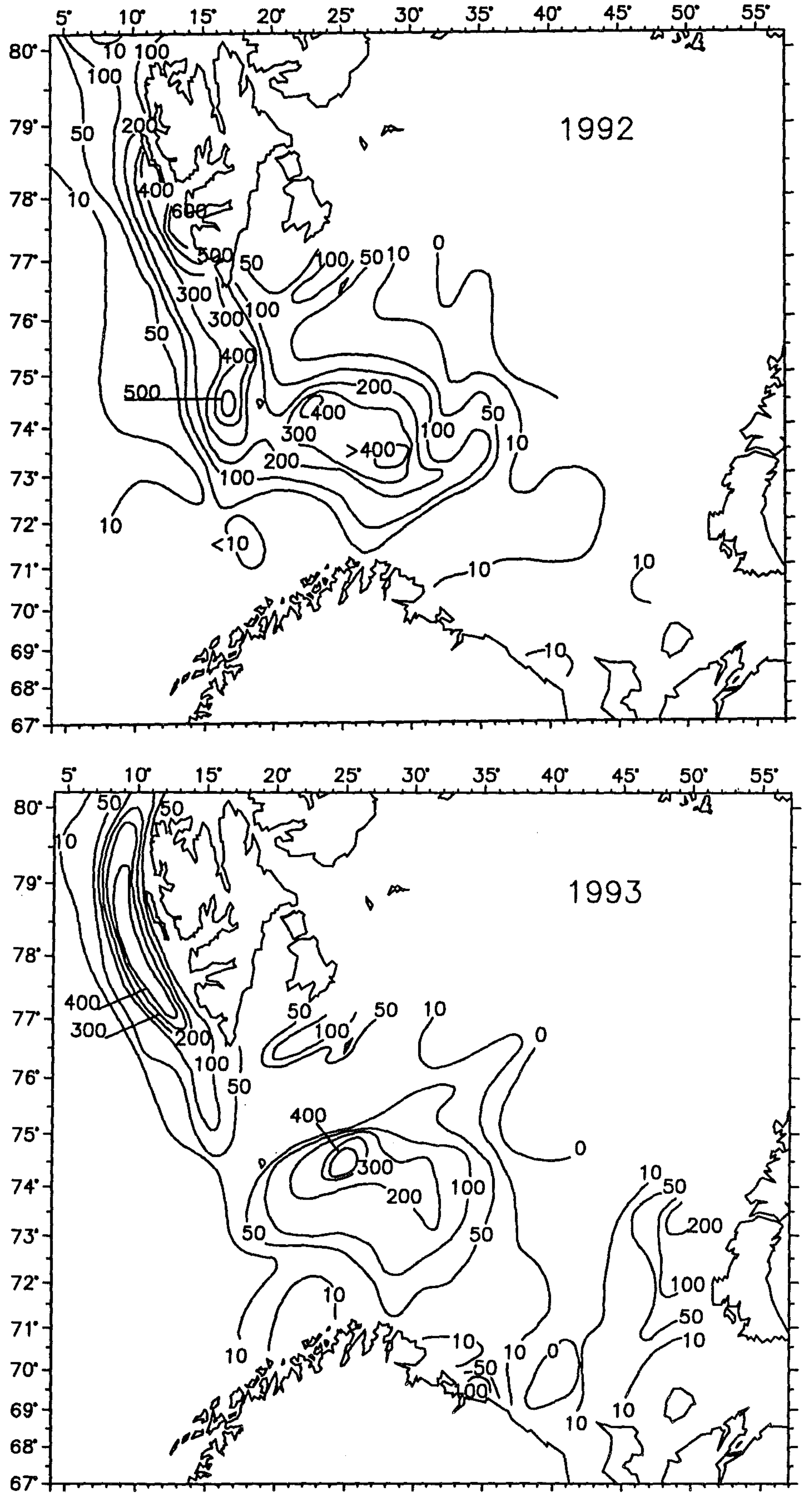

Figure 2. Distribution of the area back scattering coefficient, S_A (m^2/nm^2 of 0-group fish (0-group herring excluded) in August-september 1992 (upper) and 1993 (lower).

s_A-values in the upper 100 m of the water column mainly fell into 3 groups:

- 0-group fish, mainly including cod, haddock, redfish and polarcod. The contribution from other 0-group fish (capelin, long rough dab, Greenland halibut and *Lumpenus spp.*) was insignificant according to the trawl catches (Anon 1992 and 1994).
- 0-group herring; which was frequently observed in dense schools at somewhat shallover depths than the 0-group gadoids and redfish so that its contribution to the total S_A- value could readily be established.
- Plankton; consisting of jellyfish, 0-group squid (*Gonatus fabricii*) and euphausiids, which at times were almost impossible to separate from the 0-group fish layers on the echograms. In these particular areas the separation of plankton back scattering had to be done according to the composition of trawlcatches, and comparison of integrator outputs at different threshold levels on the postprocessing system.

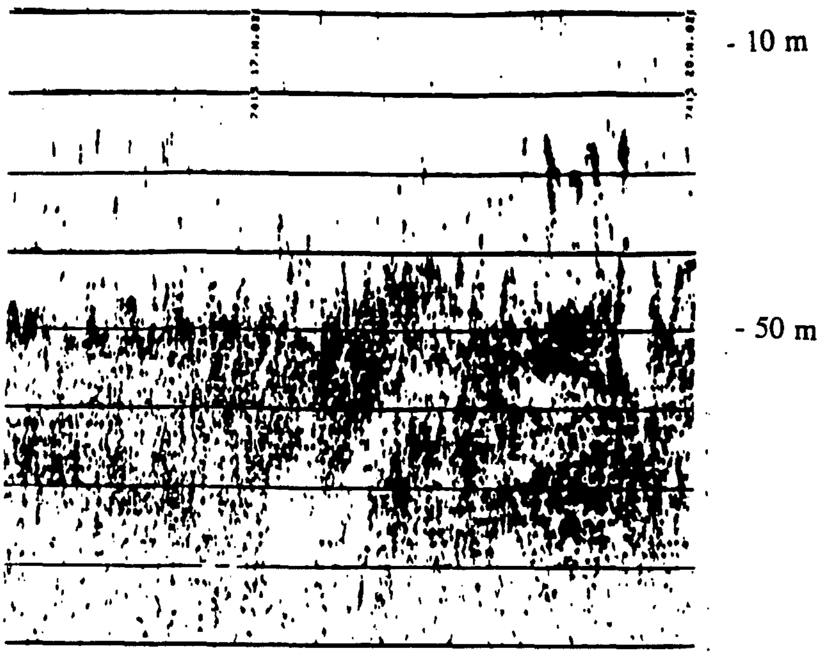

Figure 3. Echogram of 0-group cod in the Barents Sea in August 1992. Horizontal lines mark 10 m depth intervals.

Computations

The mean values of S_A of 0-group fish for each 5 nautical miles sailing distance were plotted in maps and averaged over standard areas of 1 degree latitude by 2 degrees longitude (Figure 4). In each standard area the total catch per unit effort of cod, haddock, redfish and polarcod was assumed to constitute a representative sample of the species- and length composition of the 0-group fish scatterers.

Mean densities of 0-group fish for each standard area were computed in accordance with the usual method (McLennan and Simmonds, 1991) applying the formula

$$\rho_A = \frac{s_A}{<\sigma>} \tag{1}$$

Where ρ_A is fish density (number per nautical mile^2)
s_A is the observed mean area back scattering coefficient of 0-group fish in the

standard area (m^2/nm^2).

$<\sigma>$ is the mean scattering cross-section of one individual 0-group fish (m^2) $<\sigma>$ was computed using the length frequency distribution of all four target species pooled, and the target strength (TS)-length (L) relationship:

$$TS = 10\log \frac{\sigma}{4\pi} = 20\log L - 68 \qquad (2)$$

which gives

$$< \sigma > = 2.0 \cdot 10^{-6} \cdot \overline{L^2} \qquad (3)$$

Where the fish length L is in cm.

Within each standard area the densities of each target species were assumed to be proportional to the species compositions in the trawl catches. Fish abundances in terms of numbers of specimens were calculated by multiplying the densities with the appropriate area and then accumulated for two separate areas, the Svalbard area and the Barents Sea area (Figure1). The borderline between the two subareas is nearly identical to the one used by Randa (1984).

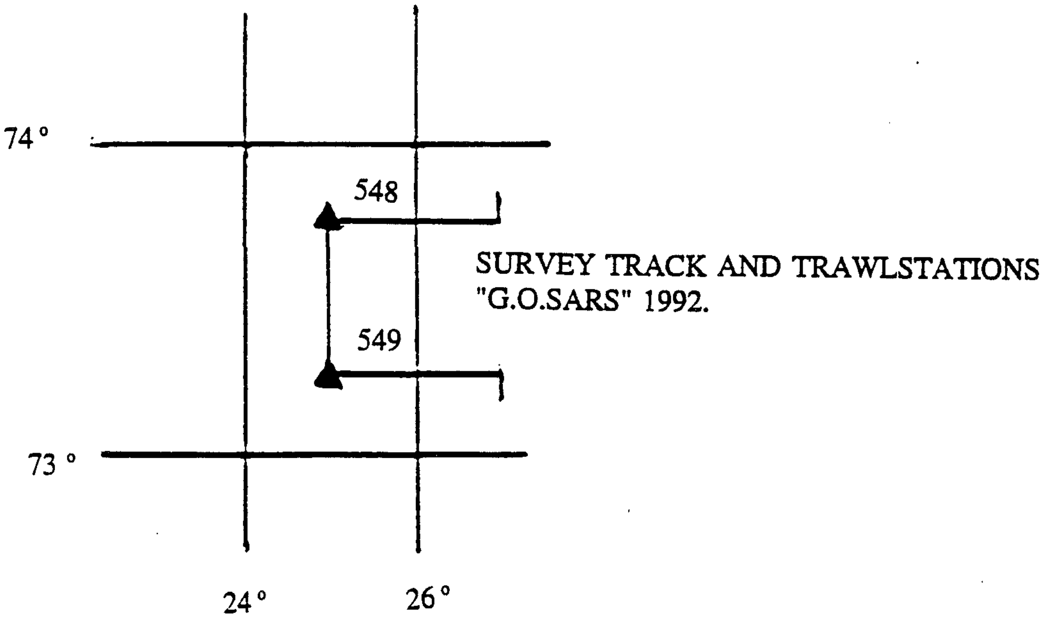

Figure 4. Example of standard area for computation of density (number per unit area) of 0-group fish in 1992 and 1993.

In situ target strength measurements of 0-group cod

Two pure populations of 0-group cod have been measured using the EK-500 split beam echosounder. A comprehensive description of the measuring techniques is given by Ona (1994). The first data set was collected in Parisvatnet, a closed salt water basin used by the Institute of Marine Research for production of cod fry for later release. The transducer was mounted at a fixed raft in the deepest part (7 m) of the basin and TS data were sampled as fish passed the acoustic beam. A total of 566 fish tracks (3396 TS measurements) were analyzed. Length and weight measurements of the fish were obtained from a dipnet catch three days after the acoustic measurements.

The second data set was collected in a fjord in northern Norway (Ullsfjord) with R/V "Michael Sars" in July 1992 where a total of 12 separate trawl hauls were taken of the scatterers along with the acoustic measurements. Ten series containing a total of 8697 target strength measurements were collected in the depth layer 5-45 meters during the trawl hauls. Fish standard lengths were measured to the nearest mm below and the equation.

$$\text{Total length} = \frac{\text{standard length} + 1{,}26}{0{,}941}$$

established during the same survey, was used to obtain comparable length data for the target strength measurement.

RESULTS AND DISCUSSION

The estimates and their reliability

The acoustic estimates of abundance are given in Table 1 for the Svalbard- and Barents Sea area separately. Various sources may have generated errors in these estimates:

Table 1. Acoustic estimates of 0-group abundance in the Svalbard and Barents Sea areas in 1992 and 1993 (Number$\cdot 10^{-9}$)

	1992			1993		
	Svalbard	**Barents S.**	**Total**	**Svalbard**	**Barents S.**	**Total**
Cod	56	51	107	24	50	84
Haddock	4	8	12	2	6	8
Redfish	38	0.1	38	48	0.1	48
Polar cod	100	0.2	100	31	31	62

Insufficient area coverage has particularly affected the estimates of polar cod in both years. It is evident from a comparison of the acoustic coverage (Figs. 1 and 2) with the distribution maps in the annual survey reports (Anon 1992 and 1994) that the distributions of 0-group polar cod were not satisfactionly covered in any of the two years. In 1992 only a fraction of the polar cod distribution area in the south-eastern Barents Sea was sampled by the recording vessels and in 1993 significant areas were left out also to the south-east of Svalbard. For 1992 Dorchenkov (1993) reported acoustic estimates of $170 \cdot 10^9$ 0-group polar cod and $6 \cdot 10^9$ 0-group cod in the southeastern area (east of 45° east) based on data from the 0-group survey. The target strength-length relationship he used, (TS=21.8 log L-72.7) generates about twice the density estimates as does equation III for fish lengths 4-10 cm. Dorchenkov's findings indicate therefore that the amount of 0-group polar cod in the southeastern area in 1992 was at the same level as our estimate for the Svalbard area. Hence the estimates of polar cod in Table 1 are much too low in both years.

The acoustic sampling of the distribution areas of cod, haddock and redfish appears adequate in 1992 but in 1993 the lack of acoustic "coverage" in the area between 31°E and 37°E increases the uncertainty of the Barents Sea estimate of cod. In 1993 the values of back scattering used in that area were interpolated from those observed along 31°13'E and 37°20'E.

Species- and length selection in trawlcatches have biased both species- and length distributions; the smaller specimens being less effectively caught than the larger individuals (Hylen *et al.* 1995). Hence the abundances of polar cod and redfish, specimens which had only about half the mean length of cod (and haddock), were underestimated in all standard areas where the two species occurred in mixture with cod (and/or haddock). The abundances of cod in the same standard areas were overestimated accordingly. However, it should be noted that the removal of 1 specimen of cod from the acoustic estimate will generate an increase of 4 specimens in the acoustic estimates of redfish or polar cod because of the differences in mean lengths and target strengths (equation III and I).

The application of the target strength-length relationship commonly accepted for larger fish may not be valid for 0-group. The main results of the *in situ* target strength measurements are shown in Figure5 together with the target strength-length relationship used in the computations (equation II). It appears that the *in situ* experiments resulted in lower values than those estimated from equation II. Although the material is to small to estimate a length dependency, the constant in equation II under the assumed 20 log L dependancy may be estimated at 69.8 rather than 68 as used. This may indicate that the estimates of abundance arrived at (Table 1)for fish of lengths 2-6 cm more likely are underestimates. If so, the estimates of redfish and polar cod (mean lengths of about 4 cm) will be most affected.. However, more results on both the species - as well as the length specific target strength of 0-group fish are needed in order to be conclusive on this point.

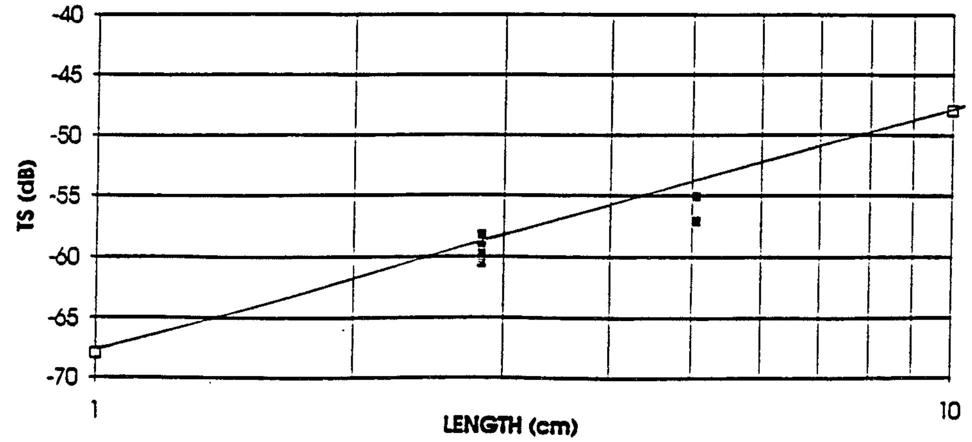

Figure 5. Results of *in situ* target strength measurements of 0-group cod. The line shows the relationship, TS = 20 log L-68 (dB), used in the istimation of abundance of 0-group cod, haddock, redfish and polar cod.

Inaccurate separation of the 0-group fish scattering (s_A-values) from the scattering of other organisms in the upper 100 m layer may have introduced errors to the estimates. As already mentioned it was at times impossible to distinguish between planktonic scatterers and 0-group fish on the echograms and the separation of the total scattering into scattering groups were made rather subjectively on the basis of the composition of the trawl catches. Korsbrekke and

Misund (1993) investigated the subjectivity in the judging of acoustic records by analyzing the homogeneity in allocation of scattering values to various species by different teams of scientists. They found that although the allocation showed variances on a one-to-one value scale a resonable degree of similarity in judgement by the different teams was maintained, and in general the average scattering allocated to a species was rather similar. The analyses was made on data from the winter surveys of young cod and haddock, but it is anticipated that Korsbrekke and Misund's (1993) main conclusions also are valid for the separation of scattering values during the 0-group surveys.

Comparision with the "traditional" abundance indicies

Table 2 shows the acoustic estimates of abundance together with the two types of indices, the logarithmic indies and the area indices as well as the total number of specimens caught during the survey for the two years of observation (Anon, 1992 and 1994). For cod and haddock separately the year to year ratios between the acoustic estimates compare well with the ratios between the two types of abundance indices. However, in both years the acoustic estimates indicate that 0-group cod was 9 to 10 times as abundant as haddock whereas the abundance indices (LI and AI) show a cod/haddock ratio of 3-4. Further, the area indices (AI) indicate abundances of redfish and polar cod of about the same level as for haddock while the acoustic estimates of redfish are 3 and 6 times higher than for haddock and those for polar cod 8 times higher. It thus appears as if the species compositions of the acoustic estimates are more similar to the pattern shown by the total numbers caught (N) than to the indices.

Table 2 Estimates and indices of 0-group abundance. AE = Acoustic estimates (Number$\cdot 10^{-9}$), LI = Logarithmic index (Randa, 1984, Anon, 1993-1994) AI=Area index (Haug and Nakken, 1977) N = Total numbers caught $\cdot 10^{-3}$ (Anon, 1993-1994).

	1992				1993			
	AE	LI	AI	N	AE	LI	AI	N
Cod	107	2.94	1159	179	84	2.09	910	134
Haddock	12	0.87	313	4	8	0.64	240	6
Redfish	38	-	150	80	48	-	162	34
Polar cod	100	-	313	69	62	-	327	326

Sundby *et al.* (1989) used the logaritmic index, LI to compute total numbers of 0-group cod of several yearclasses. They assumed catching efficiencies, q, of the trawl of 0,25 and 0,1 and used the results in their estimation of mortality rates of the year classes both prior to and after the 0-group stage. Assuming similar catching efficiencies and using the same formula as Sundby *et al.* (1989) for the computation of total numbers of 0-group cod in 1992 and 1993, estimates of $19\cdot 10^9$ and $8\cdot 10^9$ in 1992, and $8\cdot 10^9$ and $3\cdot 10^9$ specimens in 1993 were arrived at. These estimates are considerably below those obtained by the acoustic method.

Apart from the uncertainty of which value of catching efficiency to apply there are reasons to belive that the total numbers were underestimated by the procedure used by Sundby *et al.* (1989). Firstly, the distance towed at each particular depth step, 0,5 nautical mile (10 minutes) should be considered the effort, not the total haul (mainly 1,5 n.m.) which is used now. This would increase the catch rates by a factor 3 and the logarithmic index accordingly.

Secondly, the effect of determining the index as an average of the logarithm of catch rates (Randa, 1984), will, when the antilogarithm of that average is taken, give a total number well below the average of catch rates. Hence it is to be expected that the total numbers estimated by the procedure used by Sundby *et al.* (1989) are underestimates.

Mortality of cod and haddock during the first autumn and winter

The acoustic estimates of 0-group cod and haddock of the 1992 and 1993 year classes and the acoustic estimates of the same yearclasses as 1-group in February 1993 and 1994 (Mehl and Nakken, 1994) were used to calculate mortality rates (Table 3). A substantial reduction in abundance appeared to have taken place during the period August-February and the mortality of cod seems considerably larger than that of haddock for both year classes. Length selection in the trawl used in February have to some extent biased downwards the 1-group figures presented in Table 3 (Dickson 1993, Aglen and Nakken, 1994). Yet, even if the 1-group figures in Table 3 are raised by a factor of 2, the mortalities will come out very high, particularly for cod.

Table 3 Acoustic estimates of abundance of 0- and 1-group cod and haddock of the year-classes 1992 and 1993 (Number$\cdot 10^{-9}$) in the Barents Sea area and the corresponding mortality rate, M (year^{-1}).

Year-class	1992			1993		
	O-GR	**I-GR**	**M**	**O-GR**	**I-GR**	**M**
Cod	51	0,9	8,1	60	0,8	8,6
Haddock	8	0,8	4,6	06	0,5	5,0

Assuming that these mortality rates are real, what would have caused them, starvation or predation? Ponomarenko (1984) reported that the abundance of euphausiids, suitable food for 0- and 1-group cod, were of importance for the survival of fingerlings during the first winter. She also pointed out that the winter temperatures in the Barents Sea had an influence on the survival. Regarding predation, the published estimates of the amounts of 0- and 1-group cod removed by cannibalism (Bogstad *et al.* 1993) for several yearclasses in the 1980's will account for only 1-3 percent of the removals from the 1992 and 1993 yearclasses. However, Ponomarenko (1961) reported that significant amounts of 0-group cod were eaten by young cod, 1-3 years of age, during autums in the 1950s. Yet, whatever cause there is for the enormous reduction in numbers during autumn and early winter, acoustic estimates of abundance of 0-group fish might become a tool for the understanding of the energy transfer in the ecosystem. The presence of about 1-2 million tonnes of 0-group fish (plankton feeders) in August in addition to the stocks of capelin and herring may at least in some years add significantly to the food resources for creatures at higher trophic levels.

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REFERENCES

ANON. 1992. Preliminary report of the International 0-group fish surveys in the Barents Sea and adjacent waters in August/September 1992. *ICES CM 1992*/G: 82, 33 pp.

ANON. 1994. Preliminary report of the International 0-group fish surveys in the Barents Sea and adjacent waters in August/September 1993. *ICES CM 1994*/G: 3, 38 pp.

AGLEN, A. and **NAKKEN, O.** 1994. Length dependant corrections of survey estimates of cod and haddock in the Barents Sea. *ICES CM 1994/G: 27*, 14 pp.

BOGSTAD, B., LILLY, G., MEHL, S., PÅLSSON, O.K. and **STEFANSON, G.** 1993. Cannibalism and year class strength in Atlantic cod (*Gadus morhua L*) in Arcto-boreal ecosystems (Barents Sea, Iceland and eastern Newfoundland). *ICES mar.Sci.Symp., 198:* 576-599.

DICKSON, W. 1993. Estimation of the capture efficiency of trawl gear. II: Testing a theoretical model. *Fish.Res., 16:* 255-272.

DORCHENKOV, A.E. 1993. Experimentaal acoustic estimates of abundance and biomass of 0-group capelin, polar cod and cod in the eastern part of the Barents Sea in August-September 1992. (Unpublished manuscript)

FOOTE, K.G., KNUDSEN, H.P., KORNELIUSSEN, T.J., NORDBØ, P.E. and **RØANG, K.** 1991. Postprocessing system for echo sounder data. *J.Acoust.Soc.Am.,90 (1):* 37-47.

HAUG, A. and **NAKKEN, O.** 1977. Echo abundance indecies of 0-group fish in the Barents Sea 1965-1972. *Rapp.P.-V.Réun.Cons.int.Explor.Mer,170: 259-264.*

HYLEN, A., KORSBREKKE, K., NAKKEN, O. and **ONA, E.** 1995. Comparision of the capture efficiency of 0-group fish in pelagic trawls. Pp. xx-xx in Hylen, A. (ed.): *Precition and relevance of pre-recruit studies for fishery management related to fish stocks in the Baretns Sea and adjacent waters. Proceedings of the sixth IMR-PINRO symposium, Bergen 14-17 June 1994.* Institute of Marie Research, Bergen, Norway.

KNUDSEN, H.P. 1990. The Bergen Echo Integrator: an introduction. *J.Cons.int.Explor.Mer, 47:* 167-174.

KORSBREKKE, K. and **MISUND, O.A.** 1993. On subjectivity in the judging of acoustic records: Comparison of degree of homogenity in allocation of echo values by different teams. *ICES CM 1993/*B: 21, 13 pp.

MEHL, S. and **NAKKEN, O.** 1994. Investigations of demersal fish in the Barents Sea winter 1994. *Fisken Hav., 1994(6): 1-72.*

MCLENNAN, D.N. and **SIMMONDS,E.J.** 1991. *Fisheries Acoustics.* Chapman and Hall, London, UK, 336 pp.

ONA, E. 1994. Detailed in situ target strength measurements of 0-group cod. *ICES C.M. 1994/B:* 30, 9 pp.

PONOMARENKO, I.Y. 1984. Survival of bottom-dwelling young cod in the Barents Sea and its determining factors. Pp. 213-229 in Godø, O.R. and Tilseth, S. (eds.): *The proceedings of the first Sovjet-Norwegian Symposium. On Reproduction and recruitment of Arctic cod.* Leningrad, 26-30 September 1983. Institute of Marine Research, Bergen, Norway.

PONOMARENKO, I.Y. 1961. On the possible influence of feeding of- and predation on cod fry on cod abundance. *Trudy Sovjeshch.ikhtiol.Kom. 13:* 301-306.

RANDA, K. 1984. Abundance and distribution of 0-group Arcto-Norwegian cod and haddock 1965-1982. Pp. 192-212 in Godø,O.R. and Tilseth,S. (eds.): *The proceedings of the first Sovjet-Norwegian symposium. On reproduction and recruitment of Arctic cod.* Leningrad, 26-30 September 1983. Institute of Marine Research, Bergen, Norway.

SUNDBY, S., BJØRKE, H., SOLDAL, A.V. and **OLSEN, S.** 1989. Mortality rates during the early life stages and yearclass strength of northeast Arctic cod (*Gadus morhua L.*) *Rapp. P.-v.Réun.Cons.int.Explor.Mer, 191:* 351-358.

RELATIONSHIP BETWEEN SURVEY INDICES OF RECRUITMENT AND VPA ABUNDANCE ESTIMATES FOR NORTH-EAST ARCTIC COD

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ABSTRACT

Survey estimates of abundance of recruiting and partially recruited age groups are important elements for tuning the VPA of north-east Arctic cod, both for estimating the present state of the stock and for future exploitation. The reliability of the assessment and prognosis is therefore dependent on the validity of the survey indices. In this paper, year-class abundances based on surveys are compared to estimated year-class abundances from a VPA.

The variability of the survey estimates, both within and between year-classes, is discussed in relation to observed changes in cod density and vertical distribution. It appeared that the catchability of recruiting age groups is density dependent. Specifically, catchability increases with increasing stock abundance. Furthermore, cod appear to be distributed more pelagically at high densities as compared with at low densities. The increase in catchability with density is found to override the expected negative effect on catchability of low availability at high density. As a consequence, a positive relation between catchability and reduced availability was found. Alternatives to a simple linear relation between survey and VPA abundance estimates are proposed.

INTRODUCTION

The validity and importance of commercial CPUE as a measure of stock densities for use in the assessment of commercially important demersal stocks in the Barents Sea have been reduced over the last few decades. For the main part, this is a result of increasing exploitation, changing fishing strategies and the fundamental shift in regulation regime following the extension to a 200 n. mile economic zones. Abundance indices from scientific surveys have gradually replaced the commercial CPUE data in assessments. Presently, the abundance of recruiting and partially recruited year-classes of north-east Arctic cod are mainly determined by survey data (ANON. 1994a).

The most important Norwegian surveys for assessments are the International 0-group survey (ANON. 1994b) and the Norwegian combined bottom trawl and acoustic survey in the Barents Sea. In this paper, the data from these surveys are analysed and compared with VPA abundance

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at age estimates. The validity of comparing survey and VPA abundance estimates for recent years can be highly questionable since the survey data are used to tune the current VPA (ANON. 1994a). The comparison becomes increasingly valid for VPA estimates further back in time.

MATERIAL AND METHODS

This paper is based on data taken from survey reports of the 0-group surveys (ANON. 1994b) and from the Norwegian combined bottom trawl and acoustic surveys (Mehl and Nakken 1994). VPA abundance estimates are from ANON.(1994a). All statistical analysis were done using SAS software (Proc Reg, Proc Anova, ANON. 1988).

These data from different sources were scaled by adjusting catchability (q) so that the estimates varied in comparable ranges throughout the time series. The bottom trawl survey indices have been increased by a factor of 2 and the 0-group indices by a factor of 1000. The relation between the survey and VPA abundance estimates is called R, where

R = Survey/VPA.

If VPA is assumed to be correct and stable throughout the time series, variation in R will reflect variation in q.

Three factors of importance for the reliability of survey estimates were studied.

Firstly, if it is assumed that q is constant, then the relation between the estimates of abundance from surveys and VPA estimates are expected to behave similarly independent of year-class, period etc.. The validity of such an assumption is examined by comparing changes in survey estimates of year-class abundance with age and VPA estimates. VPA abundance estimates of age groups below 3 for a year-class are set to the abundance at age 3.

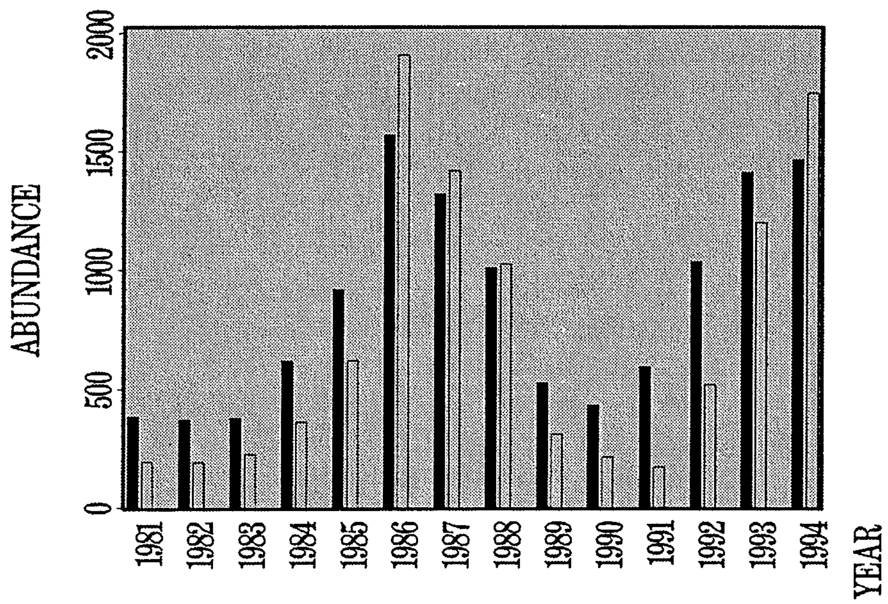

Figure 1 Estimates of the abundance of age 3-5 cod for 1981 through 1994 - survey indices (open columns) and VPA estimates (black columns).

Secondly, information about fish vertical distribution from the simultaneous acoustic sur vey is used to study the possible association between fish availability to the survey trawl and the disagreement between survey abundance and VPA estimates (Godø and Wespestad 1993). The percentage of the acoustically recorded fish found in a 10 m channel above the bottom is used as a measure of the availability of fish to the survey trawl (Mehl and Nakken 1994, Table 5.2) Finally, alternative relations between survey abundance estimates and VPA are considered.

RESULTS

Comparison of survey and VPA abundance estimates

A comparisons of the VPA and survey abundance estimates of the partially recruited age groups (ages 3-5) for the survey time series is in Fig. 1. The two time series show a similar pattern. However, the survey abundance estimates tend to be lower than the VPA at low stock

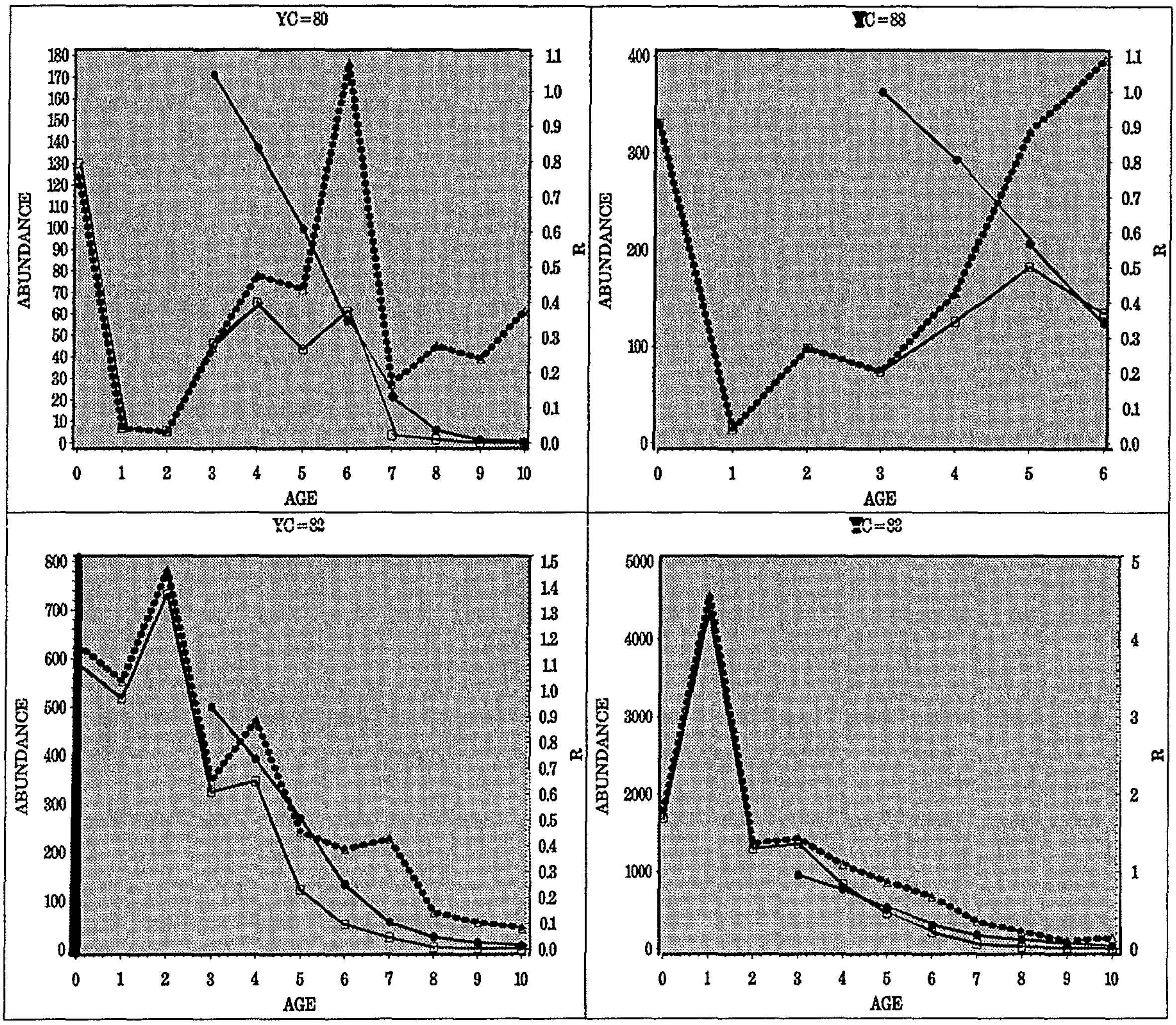

Figure 2. Cod abundance estimated from surveys (square, continuous line) and from VPA's (dot, continuous line), and the R ratio (triangle, dotted line) by age for low abundance situation (year-classes 1980 and 1988) high abundance situation (year-classes 1982 and 1983).

abundance and higher than the VPA when abundance is high.This tendency is more closely studied by following year-classes from periods of high and low abundance. The estimates of abundance for year-classes 1980 and 1988, which recruited when abundance was low, drop substantially from the 0-group index to age 1. Thereafter the survey indices increase until ages 4-5. The ratio, survey/VPA (R) remains below 1 until age 6 where a maximum occurs (Fig. 2). In contrast, during a period of good recruitment, the survey indices for year-classes 1982 and 1983 decrease from ages 1-2 and onwards, i.e. the pattern in abundance for a year-class which is expected due to mortality. R is continuously decreasing from age 1 (Fig. 2). Due to maturation and migration out of the survey area, R is expected to decrease after ages 6-7, which is observed in most cases. Observe also that R for age 0 is below 1 for the poor recruitment period and well above 1 during the period of good recruitment. In Fig. 3. are plots of R for all year-classes 1979 - 1989 for ages 2-9, which clearly demonstrate the difference between rich and poor recruitment periods, indicating that the variation in q for recruiting and partially recruited age groups is related to stock abundance

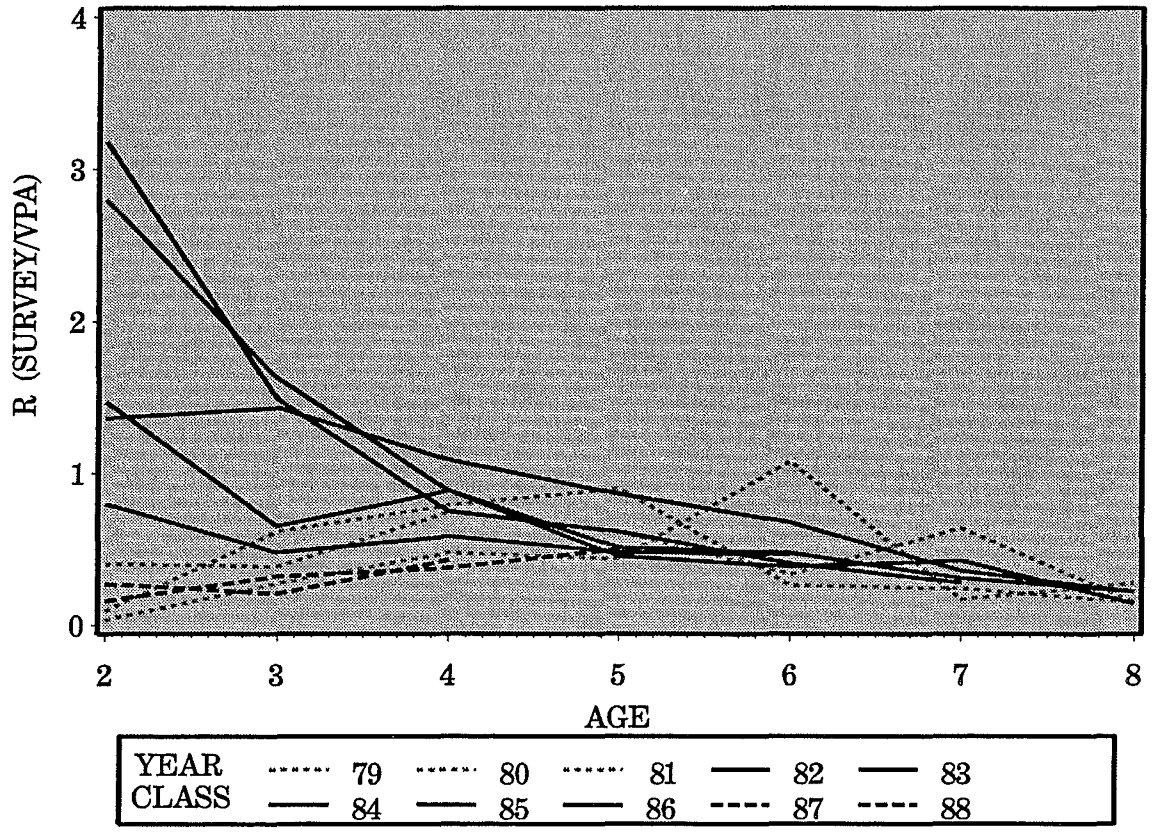

Figure 3. R versus age for the year-classes 1979, 1988.

Survey abundance estimates and availability

If the vertical distribution of cod varies amongst years, then the stock abundance should be underestimated during years when fish are pelagically distributed compared to years when the stock is concentrated close to the bottom. But the relation between survey and VPA abundance estimates of ages 3-5 cod (R) and availability indicate that there is a tendency for the opposite to occur (Fig. 4). Although the regression model does not explain more than 25% of the total variability, it does indicate that there is an inverse relation between R and availability (significant at the 90% level) and not a positive relation as expected.

Survey/VPA relation

The above results indicate a density dependent variation in q for young cod in the Norwegian surveys, and more surprisingly, an inverse relation between availability and q (R, which reflect changes in q). To study this more closely, various regressions and variance analysis were made (Table 1). The R-squares show that the log linear regression gave the best fit (Table 1, Fig. 4). To study the effect of availability, the percent of fish in the bottom channel (PCT) was added as a factor in the regressions (the statement in Proc reg was "Model VPA = survey pct /options"). The two last columns in Table 1 demonstrate that all fits are improved. The effect is clearest for the linear regression through the origo and insignificant for the log-linear regression. When adding availability to the model, the R-squares are all similar. This indicates that availability effects and density dependent effects are not independent, which is also demonstrated in Fig. 5.

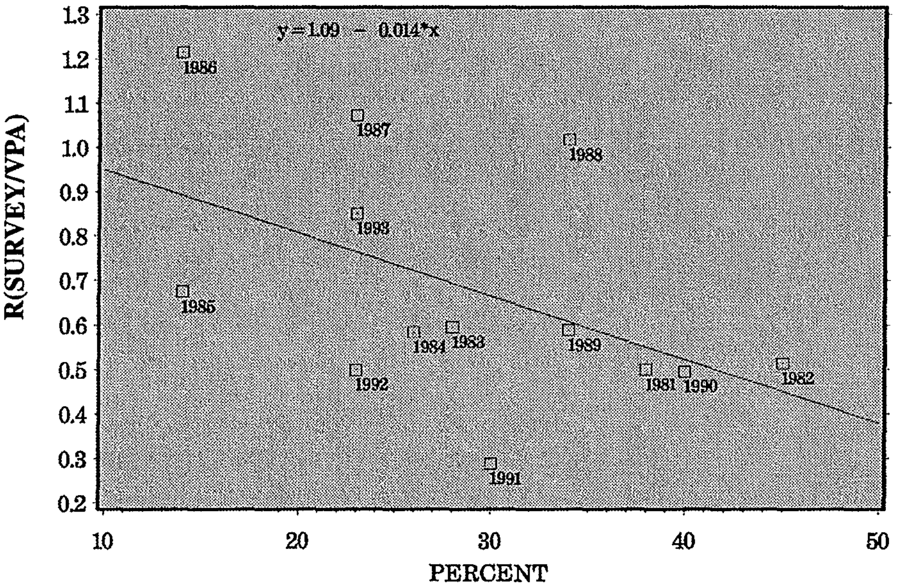

Figure 4. The survey/VPA relationship (R) against availability (percent of fish in the bottom channel).

Table 1. Regressions models relating survey and VPA abundance estimates. In the two last columns are the parameter estimates (PCT-eff) and R-square values (R-square2) for the regressions which include PCT as a factor. Data are from the period 1981-1990.

Reg. type	Formula	R-square	Prob>F	PCT-eff	R-square2
Linear through origo	vpa=0.96*sur	0.9382	0.0001	6.8498	0.9804
Linear with intercept	vpa=300+0.7*sur	0.9663	0.0001	-6.5354	0.9808
Log linear	$vpa=14.83*sur^{0.2}$	0.9813	0.0001	-0.0047	0.9854

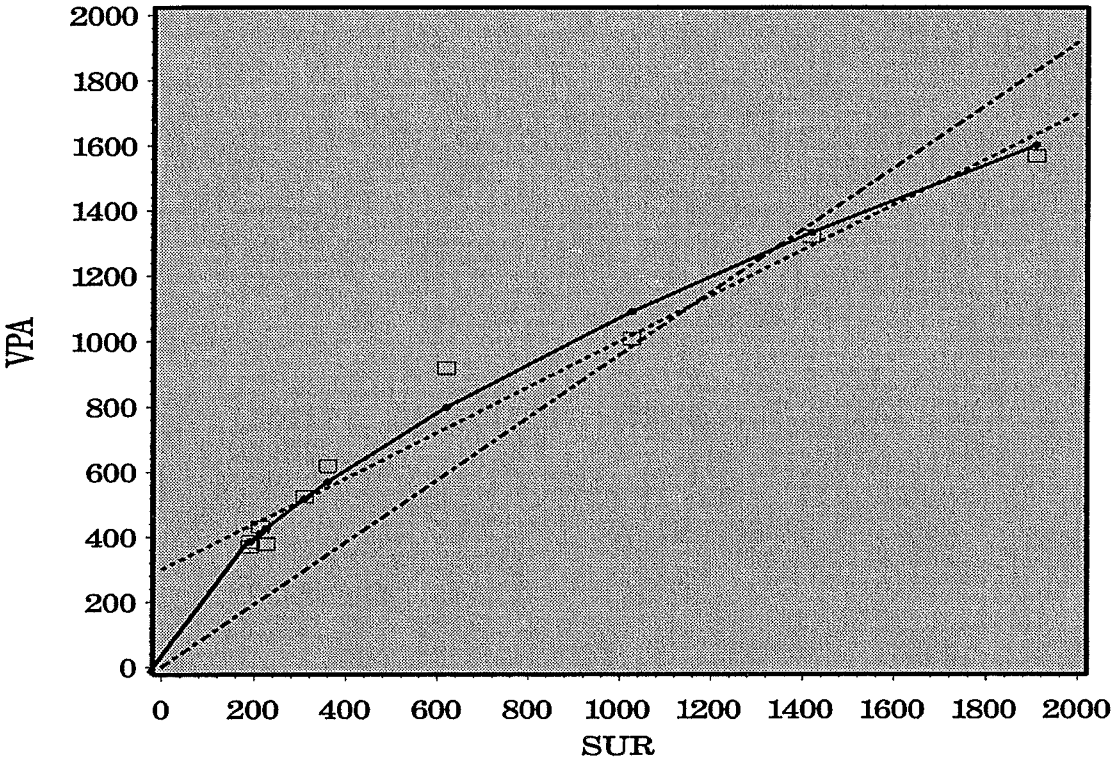

Figure 5. Survey abundance estimates (sur) versus VPA estimates for the period 1981 -1990 for ages 3-5. Squares indicate the data points, dotted and broken lines show regressions with and without intercept and continuous line estimated abundance with the log model (Table 1.).

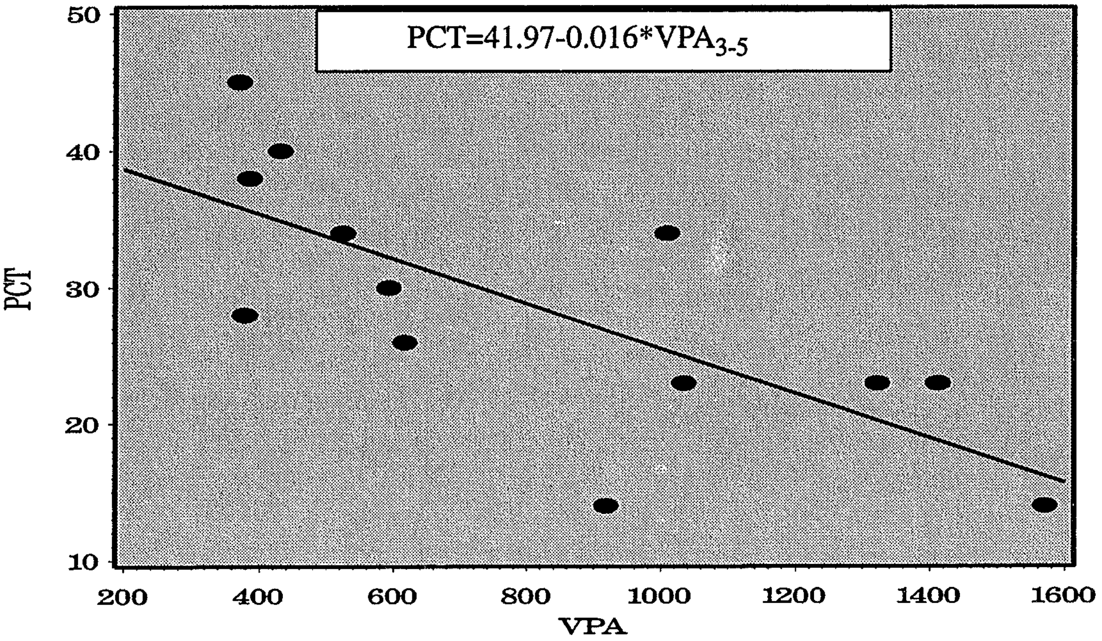

Figure 6. The relation between availability(PCT) and stock abundance (ages 3-5, VPA) for the years 1981-1994.

DISCUSSION

The validity of the analysis might be lessened by several shortcomings of the data, which should be more closely examined:
Firstly, the time series is short and contains only one period of rich recruitment. Furthermore, most of the time series is adjusted for a size dependent loss of fish under the trawl (see Godø and Sunnanå 1992, Aglen and Nakken 1994). Such compensations may be susceptible to variability and bias over time, due to, e.g. density dependent factors affecting escapement (Godø 1994). It should, however, be noted that the adjustment factors are based on several experiments conducted in the period 1985-1989 and are assumed to provide a representative mean. There is no reason to believe that the time series should represent a less accurate data base than the original data (Godø and Walsh 1992). If escapement is strongly density dependent as suggested by Godø (1994), the result would be that low estimates of abundance are underestimated compared to the high estimates as observed.
Secondly, the VPA is assumed to represent the truth in the present analysis. Since the survey abundance estimates are used to tune the VPA's, the latest VPA estimates and survey abundance estimates are not independent. Therefore, data after 1990 was not used in the statistical analysis. Also, a VPA is liable to errors caused by unreliable port sampling and catch reports by the industry. It is, however, difficult to find any explanation of how such errors may have caused the present findings. A VPA assumes a constant natural mortality (M) over time. If M is strongly density dependent, then this may, to some extent, level out the differences between survey and VPA estimates (Fig. 1). The difference in the pattern of the survey indices for an ageing year-class under low and high abundance situations (Fig. 2) is, however, a problem independent of M, and of great importance for the reliability of recruitment estimates.

Originally I intended to study the reliability of pre-recruit estimates of cod, and develop methods to improve them. But because of the low efficiency of the pre-1989 standard trawl to catch small fish, the reliability of the adjustments of ages 1 and 2 fish will be lower than that for the partially recruited age groups (3-5) (Godø and Sunnanå 1992). The present findings also indicate that these young age groups are most susceptible to density dependent changes in catchability. Further analysis of the effect on q for a year-class caused by varying abundance of preceding and succeeding year-classes should be carried out with the aim of developing models which may improve the reliability of prerecruit abundance estimates. Such models also need to take into account possible changes in M.

In spite of the above mentioned shortcomings of the data, I think that the analysis highlights important features of the time series, which can be used to improve the reliability of assessments and management. The most plausible explanation of the findings is probably found in density dependent differences in social behaviour as described by Godø (1994). At low densities cod will behave as individuals and search all possible ways to escape during trawling. At high densities, cod organize in schools and behave as schooling fish, i.e. when one individual in the school react to a stimulus, the whole school or part of it will follow. This kind of social behaviour will improve herding and reduce escapement in the catching process. For recruiting age groups with limited migratory capacity, the probability that an individual is part of a school, is assumed to increase with increasing stock abundance. This tendency appears to decrease with age, e.g. the relation found in Fig. 6 was clearest for ages 3-4 cod and was absent for fish above ages 5-6. Apparently, the phenomenon may affect 0-group catches, giving high R for rich and low R for poor year-classes. The standard pelagic sampling trawl has low q due to loss of fish through the large meshes in the front part (Godø *et al.* 1993). When schools of fish enter the trawl, the catchability will be improved compared to a single- fish-entrance-situation because the school are warned and stimulated (herded) when the first individuals are observed to respond after collision with the meshes. Catchability of larger fish (age 5+) may probably vary more independent of stock size. Large fish may use their migratory capacity to concentrate in small areas, and hence give high densities and high q independent of stock size.

REFERENCES

AGLEN, A. and **NAKKEN, O.**1994. Length dependent correction of survey estimates of cod and haddock in the Barents Sea. *ICES CM 1994*/G: 27, 14pp.

ANON. 1988. *SAS Institute Inc. SAS/STAT User's Guide, Release 6.03 Edition.* Cary, NC: SAS Institute Inc., 1988. 1028pp.

ANON. 1994a. Report of the Arctic Fisheries Working Group. Copenhagen, 24 August - 2 September 1993. *ICES CM 1994*/Assess:2, 252pp.

ANON. 1994b. Preliminary report on the International 0-group fish survey in the Barents Sea and adjacent waters in August-September 1993. *ICES CM 1994*/G:3, 38pp

GODØ, O.R. 1994. Natural fish behaviour and catchability of groundfish. *ICES CM 1994*/G:14, 12pp.

GODØ, O.R. and **SUNNANÅ, K.**1992. Size selection during trawl sampling of cod and haddock and its effect on abundance indices at age. *Fish. Res., 13*: 293-310.

GODØ, O.R. and **WALSH S.J.** 1992. Escapement of fish during bottom trawl sampling - implication for resource assessment. *Fish. Res., 13*: 281-292.

GODØ, O.R. and **WESPESTAD, V.** 1993. Monitoring changes in abundance of gadoids with varying availability to trawl and acoustic surveys. *ICES J. mar. Sci., 50*: 39-51.

GODØ, O.R., VALDEMARSEN, J.W. and **ENGÅS, A.** 1993. Comparison of efficiency of standard and experimental juvenile gadoid sampling trawls. *ICES mar. Sci. Symp., 196*: 196-201.

MEHL, S. and **NAKKEN, O.** 1994. Investigations on demersal fish in the Barents Sea winter 1994. *FiskenHav. 1994*(6).1-72.

METHODS OF INDEX CALCULATION AND PRESENTATION OF FISH ABUNDANCE DATA USING STANDARD COMPUTER PROGRAMS

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ABSTRACT

Standard 0-group indices and distribution maps are now produced based on hand-drawn maps using AutoCad with some additional procedures. This paper briefly describes the method. The paper further describes ways of importing coastlines and survey data directly into standard computer programs such as AutoCad and SAS. Standard methods are used for gridding data, producing isolines and further calculation of abundance indices and presentation of distributions. Interactive editing of distribution maps are made, which makes corresponding automatic updating of indices possible.

INTRODUCTION

In many cases a measure of abundance of fish is given both as an index of abundance and as an isopleth diagram of density distribution. In this paper we will present some methods to combine the two and to enhance the calculation of abundance indices.
Cod in the north-east Atlantic is one of the most important species and the abundance of fry in the first year of living (0-group fish) is used as an indication of recruitment.

0-group abundance indices are based on the number caught of each species and its area of distribution. The indices are estimated as the sum of areas of dense and scattered consentrations, with areas of high densities weighed by 10 (Haug and Nakken 1977). The criteria for discriminating between dense and scattered concentrations are given in Anon. (1980).

Until 1992 the calculations were based on a procedure placing a transparent "areafan" on the top of hand-drawn maps (Mercartor projection) and counting each square of the "areafan" falling inside each density, both whole and parts of squares, to get the sum of squares and thereby the total area of each density. This is a laboursome procedure and the hand-drawn maps had to be re-drawn for presentation purposes.

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At Institute of Marine Research the computer program AutoCad (Anon. 1992) is used for presentation purposes. Since this program also has an area calculation part, a routine was developed, combining both the drawing of a distribution map and calculating the "old" area and density based indices.

A description of methods for producing distribution maps with isolines outside AutoCad (e.g. in SAS, Anon. 1993) and then importing them into AutoCad for calculation of "new" abundance indices are also given in this paper.

MATERIAL AND METHODS

Drawing of maps and calculating "old" indices in Autocad

The basic 0-group data is the catch in number per 1.0 nautical mile trawling. A hand-drawn map is prepared for each species, dense and scattered distributions are delimited by isolines. To ease the further work, we have given some standard values of the frame and coastlines. These standards were set when the map was digitized onto AutoCad. The standard 0-group map are within latitude 67° to 80° 30' N and longitude 4° to 57 E. In Figure 1 the standard 0-group map is shown.

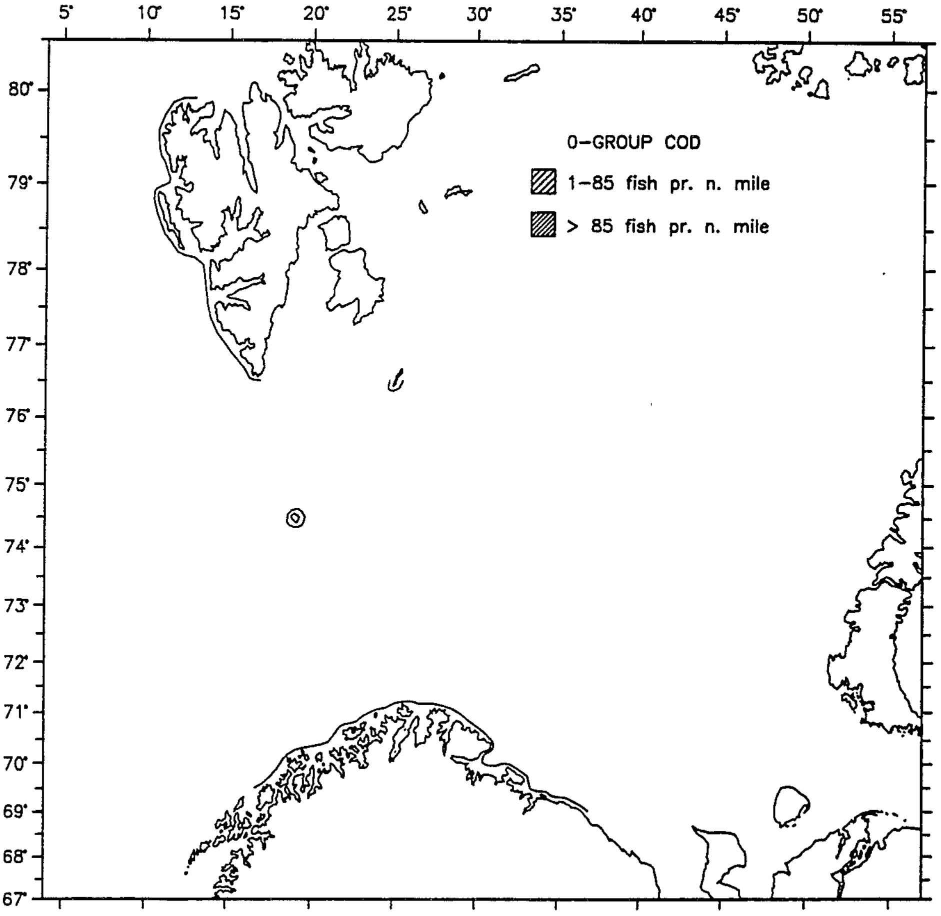

Figure 1. Standard 0-group map.

The isolines from the hand-drawn maps are then digitized onto premade standard 0-group maps in AutoCad, using an A3 digitizer. First the digitizer is calibrated to get a relation between the hand-drawn map and the corresponding map (i.e. standard 0-group map) in AutoCad. Each isoline is converted to a polygon and placed on AutoCad-layers, depending on its density value. The polygons can now be adjusted in AutoCad, stretched or joined with other polygons. The 0-line is finally drawn in AutoCad together with "0-islands" in the distribution.

Before calculating the area of different layers, the Mercartor map-projection has to be re-projected to a "true area" projection. This is done by a small extra routine (ACAD.LSP) written in programming language LISP and running in AutoCad. After the reprojection is done, the same routine automatically starts the area calculations in the different layers. The area of the layer representing dense concentrations is multiplied by 9 and not 10, because scattered distributions is supposed to cover the area including the dense ones. The area of "0-islands" in both densities is subtracted before the total area is calculated. Control calculations using the old counting method has given a deviation normally less than 5 %, except when the distributions are very small and far to the north.

Importing iso-, coast-lines and survey data directly into, and between, standard computer programs such as AutoCad and SAS

Up to now we have had no useful way to import a drawn map from SAS onto AutoCad. The map must be vectorized first and plotted in a readable format.

We have made an extra driver in AutoCad. This driver can import data as lines of ascii text corresponding to polylines, layers and coordinates (x,y,z) of each corner in the isolines (polygons). All z values in the 3D coordinates are set to zero. Thus, the map is actually drawn in 2D. AutoCad can now draw lines onto the specified layers. The layers are defined in the ascii file and may not exist before use, that means that the layers can be determined in the external program, e.g. SAS. Below is an example of such a file where longitude and latitude coordinates have been transformed into kilometre east and north.

```
        Longitude  Latitude   Z-coordinates

POLYLINE
LAG3
        405.3      7515.6      0.0
        404.5      7516.3      0.0
        405.4      7517.8      0.0
        405.7      7517.6      0.0
        405.5      7516.7      0.0
        405.3      7515.6      0.0
POLYLINE
LAG2
        416.0      7531.6      0.0
        414.3      7530.1      0.0
        413.6      7530.6      0.0
        413.0      7529.5      0.0
```

Also the coastlines can be imported in similar ways. Standard maps can be made by digitizing maps and by importing coordinates by lines. The example above is coastlines taken from a map of the Lofoten area.

Calculations of abundance indices

The index is calculated by multiplying the area of each layer by the value of density assigned to the layer. The layers are separated by levels of density. We therefore need an algorithm to handle layers, levels and values and their transform into indices. We also need an algorithm to compute true areas from mercartor projection.

Layers, levels and values

The ascii file representing layers, level and values may be edited. The name of the layers corresponds to identical name of layers in the map. No other layer would give any positive contribution to the calculation of the indices.

The standard chosen to set levels are as follows:An isoline is the drawn line at the density given by the level. The value associated with a level is the density representing the area between the isoline at the level and the isoline at the next level above. It is necessary to draw isolines in steps, that is you can't bypass an isoline without drawing it. An example of the levels and values in layers is given below.

Example: Import of ascii file which contains name of layer, level and value.

Layer	Level	Value
LAG1	1	1
LAG2	10	10
LAG3	100	100

How to calculate areas from polylines

The transformation from mercartor projection to a true area projection is explained elsewhere in the paper. The standard area calculation in AutoCad is used to compute the area inside a polygon. The isolines of a layer are converted to polygons by closing the polylines. The area computed are weighted with the values of the levels given in the asciifile.

The size of the areas can thus be transferred to summarised densities of fish.

Every layer corresponds to an antilayer with the same, but negative, density value associated to it. The antilayers are needed to eliminate inner polygons already counted for in other layers. If not, then "islands" within "islands" would be counted more than once. These layers and antilayers must be allocated and adjusted by the drawer before calculating the abundance indices.

The antilayers have the same absolute value as the layer itself, but a negative sign, and marks polygons of negative areas and therefore negative amount of indices. In Figure 2 there are three layers and the use of antilayers are shown in Figure 3.

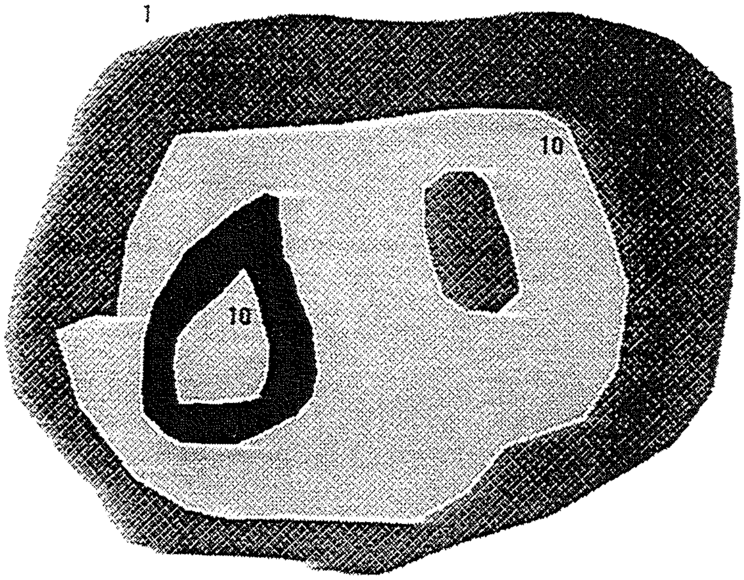

Figure 2. A layer map.

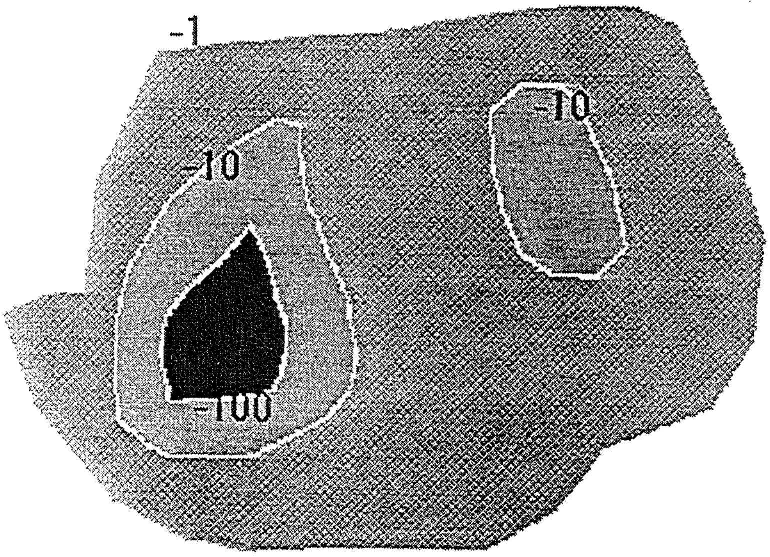

Figure 3. The corresponding antilayer map.

RESULTS

To verify the method we selected the distribution of 0-group cod in 1991. The index was counted to 766 (Anon. 1991). We used both AutoCad methods described in this paper. The first AutoCad-draw method, which was restricted to the use of layers "en" and "ti" with values 1 and 9 respectively, gave the result of 788, indicating a deviation from "areafan" method of 2,8%. The drawn map is shown in Figure 4 and the detailed results in Table 1.

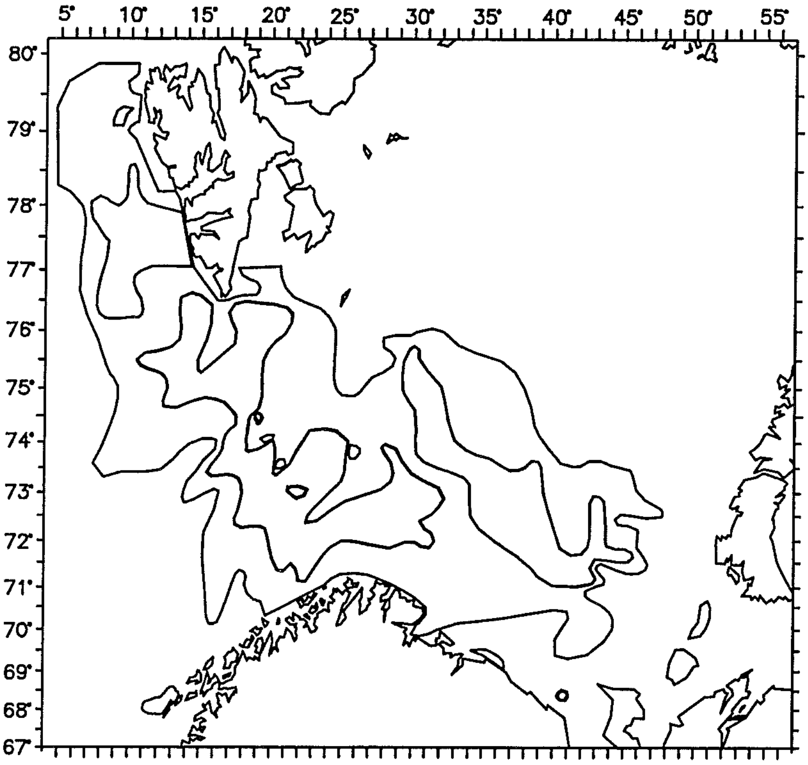

Figure 4. Distribution of 0-group cod in 1991 (AutoCad drawn).

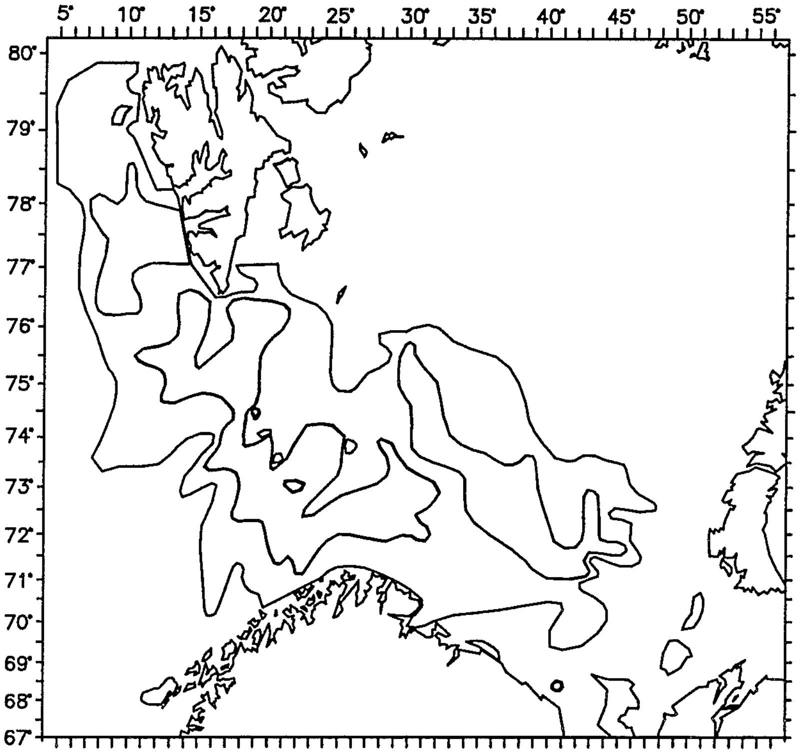

Figure 5. Distribution of 0-group cod in 1991 (AutoCad drawn). This method use the layers "LAG1" and "LAG2" and the antilayers "ANTILAG1" and "ANTILAG2". The original drawn map (Figure 4) used only two layers. This is no limitation any longer, but as a demonstration that the computer routine (acad.lsp) could reproduce the same result, we did not split the two layers in more and narrower levels.

The newly computerized method in which layername, levels and values can be set freely, and up to 8 layers may be used was applied on a similar map. The result is shown in Figure 5, both layers and antilayers are drawn. Since only 2 layers are use, the figure is identical with Figure 4. In Table 2 we have split the result from each polyline in the specified layers. The total value of the indices was computed to 783, indicate a deviation of 2,2% from the "aerafan" method.

Table 1. Indices split on two layers. Layer to contribute ten times layer one.

Layer	Value	Area	Weighted area	Result
One	1	194,15	194,15	
Ten	9	65.98	593,82	788,0

Table 2. The contribution of each polyline in the layers.

Layer	Level	Value	Area	Weighted area	Result
LAG1	10	10	37,754	377,537	
ANTILAG1	1	1	6,5798	-6,5798	
LAG1	1	1	191,46	191,463	
LAG1	1	1	1,2555	1,2555	
ANTILAG1	1	1	37,808	-37,8077	
LAG2	10	10	6,579	65,7895	
LAG2	10	10	0,1264	1,2641	
ANTILAG1	1	1	0,1264	-0,1264	
LAG1	1	1	0,4587	0,4587	
LAG2	10	10	0,1506	1,5064	
LAG1	1	1	0,2099	0,2099	
ANTILAG1	1	1	0,1507	-0,1507	
LAG1	1	1	0,7339	0,7339	
ANTILAG1	1	1	21,17	-21,1701	
LAG2	10	10	21,18	211,796	
ANTILAG1	1	1	0,0797	-0,0797	
ANTILAG1	1	1	0,0892	-0,0892	
ANTILAG2	10	10	0,2353	-2,3531	
ANTILAG1	1	1	0,2012	-0,2012	
LAG1	1	1	0,2012	0,2012	
ANTILAG1	1	1	0,1034	-0,1034	
ANTILAG1	1	1	0,1604	-0,1604	783,39

REFERENCES

ANON. 1980. Preliminary report of the International 0-group fish survey in the Barents Sea and adjacent waters in August-September 1978. *Annls biol., Copenh., 35*: 273-280.

ANON. 1991. Preliminary report of the International 0-group fish survey in the Barents Sea and adjacent waters in August-September 1991. *ICES CM 1991/G*: 50, 33 pp.

ANON. 1992. AutoCAD ® Release 12. Manual, 687 pp. Autodesk BV, 2000 Neuchatel, Switzerland.

ANON. 1993. SAS ® Language: Reference, Version 6, first edition, 1042 pp. SAS Institute Inc., Cary, NC, USA.

HAUG, A. and **NAKKEN, O.** 1977. Echo abundance indices of 0-group fish in the Barents Sea, 1965-1972. *Rap. P.-v. Reun.Cons.int.Explor.Mer., 170:* 259-264.

SHORT NOTE ON ABUNDANCE OF *SEBASTES MENTELLA* IN THE 0-GROUP AND YOUNGFISH SURVEYS AS INDICATOR OF RECRUITMENT OVERFISHING

by

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ABSTRACT

Abundance indices of 0-group *Sebastes mentella* from the international 0-group survey in the Barents Sea showed a sudden decrease from 1990 to 1991 to a low level which remained for three years. The strength of these weak yearclasses has been confirmed in later youngfish surveys, and is supposed to be a result of a historic low spawning stock. A big directed fishery in former years, and huge by-catches and discards of small *Sebastes mentella* in other fisheries have due to the late maturity of this species not until now resulted in a serious reduction of the spawning stock. A directed trawl fishery in more recent years on mature fish on new fishing grounds has probably speeded-up this negative development.

INTRODUCTION

Up to the middle of the 1980-ies, former USSR and GDR were the two countries taking most of the *Sebastes mentella* catches in ICES Sub-areas I and II (Anon. 1991). The fishery was mostly going on in the western part of the Barents Sea between the Malangen Bank and Bear Island (Kopytov area). Although it has been difficult to achieve reliable assessments of the *Sebastes mentella* stock, assessment based on information from the Barents Sea fishery, and biological data from this area, showed that at least this part of the stock was decreasing towards 1987 (Anon. 1991, 1994a). Despite this decrease, the abundance of 0-group in the Barents Sea and Svalbard areas maintained the same stable level as observed in all previous comparable years, i.e., back to 1979 (Anon. 1994b). In 1985-1987 a new fishery started along the continental slope, at around 500 meters depth, from the Malangen Bank and southwards beyond Møre (Figure 1). Only adult, mostly mature fish bigger than 28-30 cm inhabit these areas, where also spawning takes place. Fishing for *Sebastes mentella* on these grounds had never occurred before in history. Although the stock has not been reliably estimated, and no time series exists on survey results covering the entire area of the *Sebastes mentella* stock's distribution, this short note gives some indications of recruitment failure that should be kept

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Institute of Marine Research, Bergen, Norway. ISBN 82-7461-039-3.

in mind and further investigated.

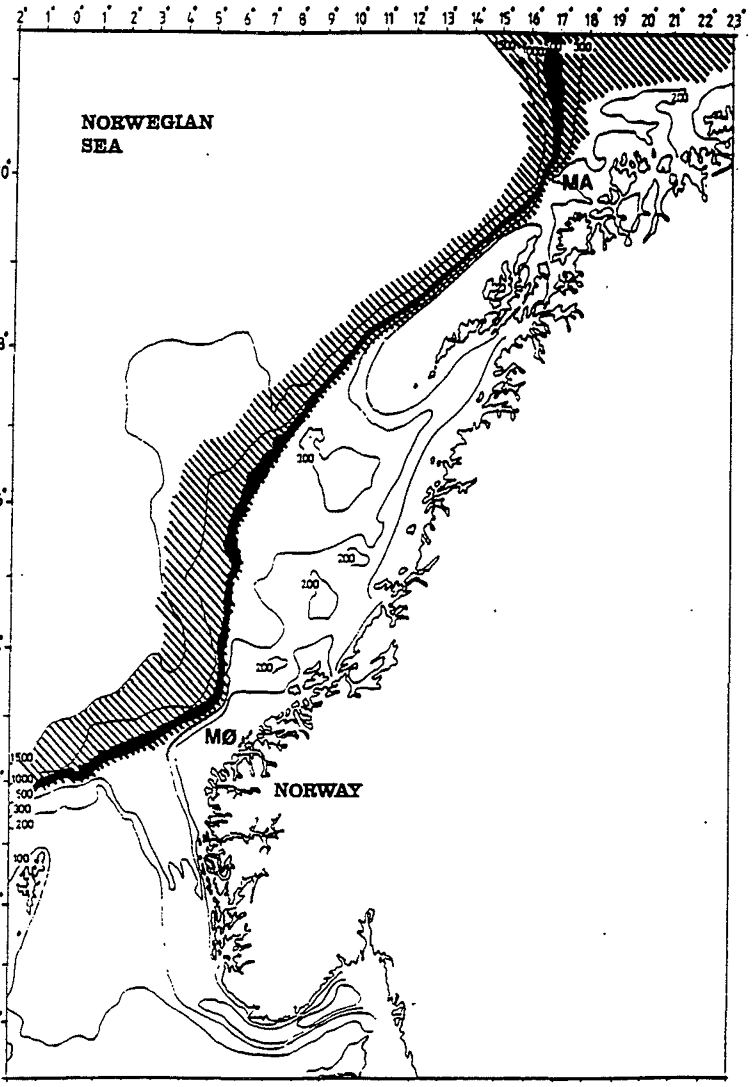

Figure 1. Distribution of *Sebastes mentella* along the continental slope south of 70°30' N. Spawning area has been emphasized (black area around 500 meters depth). When the bottom depth become greater than approximately 550-600 meters the *Sebastes mentella* are found pelagic at 450-600 meters depth from the slope and outwards some distance into the Norwegian Sea. The main fishing areas are north of 65°N and southwest of Møre. MA - Malangen Bank, MØ - Møre.

RESULTS AND DISCUSSION

The fishery on these new fishing grounds increased towards 1991. This is illustrated by the Norwegian *Sebastes mentella* landings which mainly were taken along the slope from south of Bear Island to beyond Møre (Figure 2). At the international 0-group survey in the Barents Sea and Svalbard areas in 1991, approximately 5 years after the new fishery began, the 0-group index of redfish suddenly decreased to only 1/4 of the stable historic level in 1979-1990 (Figure 3). Although not splitted on redfish species as a routine, genetic analyses which have been conducted have shown that the bulk of this 0-group are *Sebastes mentella* (Nedreaas and Nævdal 1991). This low 0-group level, even down to 20% of the historic level, was observed in three subsequent years, i.e., 1991-1993 (Anon. 1994b), hence indicating a suddenly and alarming change in the reproduction of the *Sebastes mentella* stock. The 0-group survey in 1994 showed, however, a slight increase, but only to a level 58% of the stable level in 1979-1990.

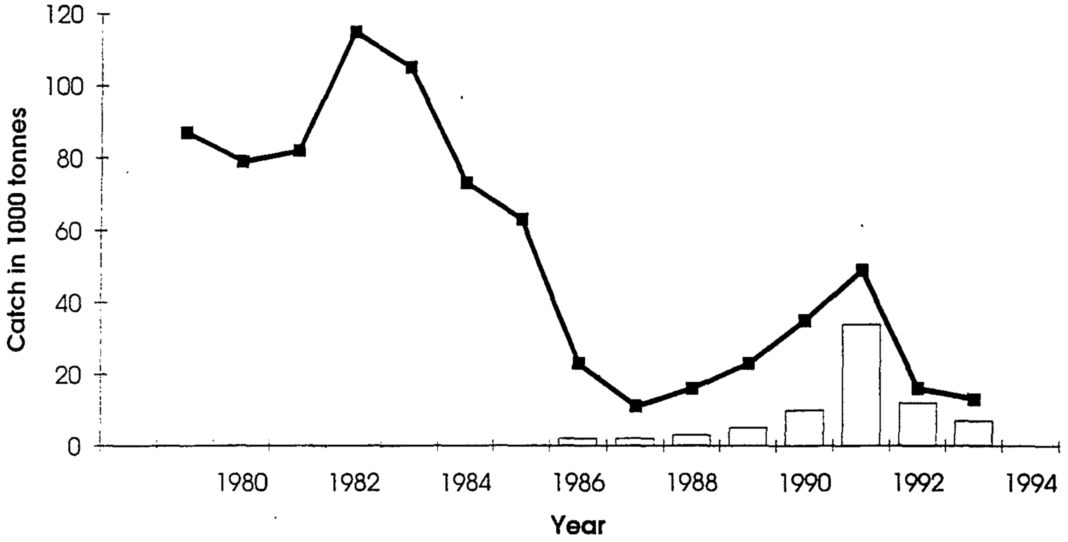

Figure 2. Total international catch of *Sabestes mentella* in ICES Sub-areas in I and II (solid line) and the Norwegian catch (columns).

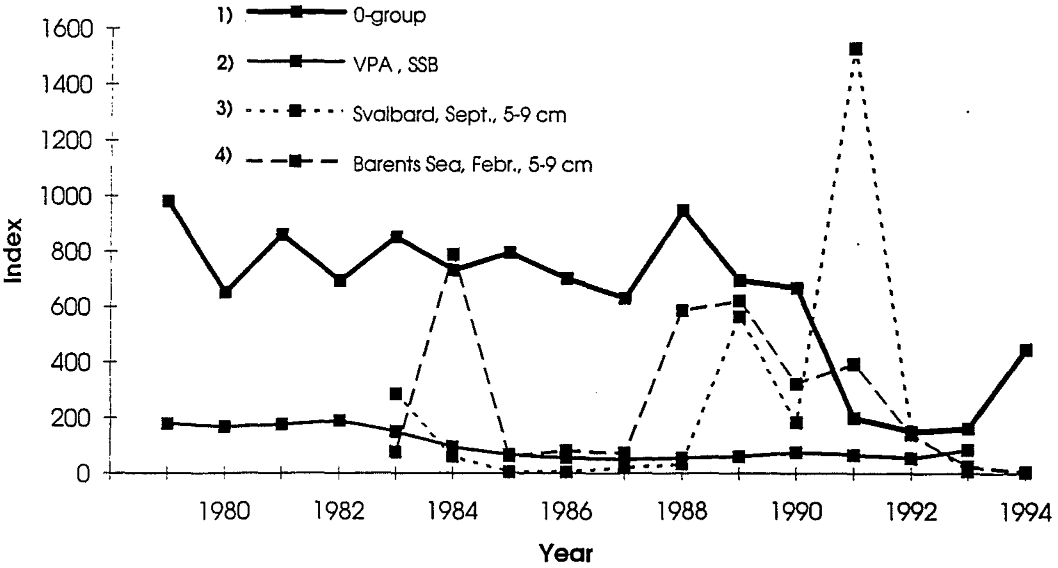

Figure 3. *Sebastes mentella* in ICES Sub-areas I and II. Diagram showing 1) the 0-group index (Anon. 1994b), 2) the spawning stock biomass estimated by VPA (Anon. 1994a, although not accepted by ACFM), the abundance of 5-9 cm fish in two Norwegian stratified bottom trawl surveys 3) in September at Svalbard (Hylen *et al.* 1993) and 4) in February in the Barents Sea (Mehl and Nakken 1994).

If the 0-group survey is representative for the recruitment, then a decrease in the abundance of juveniles, 1-group and older, should be observed in the routine youngfish surveys one or more years later. Since no age data are available from the Norwegian bottom trawl survey time series at present, swept area estimates for 5-9 cm *Sebastes mentella* from the survey in February in the Barents Sea and the survey in September at Svalbard are shown in Figure 3. Although low abundance of 5-9 cm fish was observed during these surveys in 1985-1987 when the 0-group index still was at the high stable level, a clear decrease is observed after 1991, thus confirming the three most recent years' low level in the 0-group survey. This is also confirmed by Russian survey results (Anon. 1994a, Drevetnyak 1995). By-catches of small redfish in fisheries for other species, mainly shrimp, should be looked upon when searching for explanations for the low 5-9 cm indices in 1985-1987 (Hylen and Jacobsen 1988). The descent of young *Sebastes mentella* from a pelagic to a more near-bottom habitat may not take place before the fish is at least two years old, and it may also differ from year to year and with year-class strength (Drevetnyak 1995). This may therefore be a part of the explanation for the low 5-9 cm indices that should be looked closer upon.

An explanation for why a reduction in the 0-group index was not observed although the stock (or more correct, the Barents Sea/Svalbard component) decreased towards 1987, is that a certain part of the spawning stock was living outside the fishing area and thereby serving as a buffer, i.e. continuing giving birth to a lot of larvae. However, when the fishing then started on these grounds never harvested until the middle of the 1980-ies, then after 5-6 years of fishing, a sudden reduction in the 0-group abundance was observed. The hypothesis is that we by doing so might have hit the "Achilles' tendon" of the *Sebastes mentella* stock. However, it started already in the Barents Sea when a lot of small redfish in previous years were taken as by-catch in other fisheries (Hylen and Jacobsen 1988), and 80 000 - 200 000 tonnes were taken in the directed *Sebastes mentella* fishery (Anon. 1994a). An increasing cod stock in recent years has also preyed upon small redfish (Bogstad and Mehl 1991, Dolgaya and Tretyak 1991). Then the fishery started on the new fishing grounds, on a part of the stock which now seems to have been the last straw.

REFERENCES

ANON. 1991. Report of the Arctic Fisheries Working Group. Copenhagen 18-27 September 1990. *ICES CM 1991*/Assess:3, 127 pp.

ANON. 1994a. Report of the Arctic Fisheries Working Group. Copenhagen, 24 August - 2 September 1993. *ICES CM 1994*/Assess:2, 253 pp.

ANON. 1994b. Preliminary report of the international 0-group survey in the Barents Sea and adjacent waters in August-September 1993. *ICES CM 1994*/G:3, 38 pp.

BOGSTAD, B. and **MEHL, S.** 1991. The North-East Arctic cod stock's consumption of different prey species in 1984-1989. Pp. 59-72 *in* Bogstad, B. and Tjelmeland, S. (eds.): *Interrelations between fish populations in the Barents Sea. Proceedings of the fifth PINRO-IMR Symposium, Murmansk, 12-16 August 1991.* Institute of Marine Research, Bergen, Norway.

DOLGAYA, O.YU. and **TRETYAK, V.L.** 1991. Significance of the North-East Arctic cod for year-class strength of redfish in the Barents Sea. Pp. 39-44 *in* Bogstad, B. and Tjelmeland, S. (eds.): *Interrelations between fish populations in the Barents Sea. Proceedings of the fifth PINRO-IMR Symposium, Murmansk, 12-16 August 1991.* Institute of Marine Research, Bergen, Norway.

DREVETNYAK, K. 1995. Distribution and abundance of young *Sebastes mentella* in the Barents Sea and Norwegian Seas in 1991 and 1992. Pp. 219-228 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. Bergen, 14-17 June 1994.* Institute of Marine Research, Bergen, Norway.

HYLEN, A. and **JACOBSEN, J.A.** 1988. Estimation of commercial demersal fish species taken as by-catch in the fishery for shrimp in the Barents Sea and the Svalbard region 1983-1986. *ICES CM 1988*/G: 46, 29 pp.

HYLEN, A., KORSBREKKE, K., MEHL, S., NAKKEN, O., NEDREAAS, K. and **RAKNES, A.** 1993. Undersøkelser av torsk, hyse, uer og blåkveite i Baretnshavet og Svalbard-området høsten 1992. [Investigations on cod, haddock, redfish and Greenland halibut in the Barents Sea and the Svalbard area autumn 1992]. Institute of Marine Research, Bergen. *Interne toktrapporter 1993*(1): 1- 31 pp.

MEHL, S. and **NAKKEN, O.** 1994. Bunnfiskundersøkelser i Barentshavet vinteren 1994. *Fisken Hav. 1994*(6): 72 pp. (English summary)

NEDREAAS, K. and **NÆVDAL, G.** 1991. Identification of 0- and 1-group redfish (genus *Sebastes*) using electrophoresis. *ICES J. mar. Sci., 48*: 91-99.

DISTRIBUTION AND ABUNDANCE OF YOUNG *SEBASTES MENTELLA* IN THE BARENTS AND NORWEGIAN SEAS IN 1991 AND 1992

by

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ABSTRACT

On the basis of data collected during young fish surveys in the Barents and Norwegian Seas in autumn-winter 1991-1992, the distribution of young deep-sea redfish *(Sebastes mentella)* of the Norwegian-Barents Sea population was studied. Year-classes of *Sebastes mentella* were estimated as follows: 1984-1987 and 1990-1992 - as poor, and 1988-1989 - as average. Since the amount of some important prey for cod is decreasing, e.g. capelin, it is supposed that the predation on young redfish will increase.

INTRODUCTION

Sebastes mentella is a important commercial species among demersal fish in the Barents and Norwegian Seas. Therefore, investigations of distribution, abundance, age and length composition of immature (young) *Sebastes mentella* of the Norwegian-Barents Sea population are important for long-term prognosis. The first information on distribution of young redfish was given by Maslov (1944). On the basis of data, obtained on cruises in 1934-1939, he concluded that immature *Sebastes marinus* did not occur in the central Barents Sea, but were distributed in the western areas the whole year. Maslov supposed that redfish larvae and juveniles consentrated mainly in the Spitsbergen Current and Northern Branch of the North Cape Current.

Travin (1951) described a new species of redfish - *Sebastes mentella* Travin. Consequently, the data which Maslov used, consisted of two species: golden redfish *(Sebastes marinus)* and deep-sea redfish (*Sebastes mentella*). Surkova (1962) analysed the distribution of redfish, 4-30 cm long, in 1959-1960 and 1960-1961 in the Barents Sea, giving the abundance of single year-classes. In 1964-1972, several authers studied the distribution of deep-sea and golden redfish in the Barents and Norwegian Seas, and they also estimated the abundance of year-classes (Berger 1966; Cheremisina and Byzova 1966; Berger and Cheremisina 1965, 1968, 1969, 1970, 1973, 1974 and 1974a). However, their surveys did not covered the whole area.

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Since the beginning of the 1980-ies, the investigations have covered nearly the whole area. This made it possible to obtain more objective data on distribution of deep-sea redfish, and improve the accuracy of the year-class abundance (Shestova 1979, 1980, 1981, 1982, 1983, 1984 and 1986; Drevetnyak 1992).

The aim of the present work has been to include data from 1991 and 1992 in further studies of the distribution of young deep-sea redfish of the Norwegian and Barents Seas stock and estimate quantitativly the abundance of year-classes.

MATERIAL AND METHODS

The basis for the paper is data collected in autumn-winter (October-December) 1991 and 1992 in the Barents and Norwegian Seas during research vessels surveys from PINRO, investigating young commercial demersal fish species. Data were collected by using a special grid of trawl stations (Shevelev, Dorchenkov and Lepesevich 1992; Shevelev *et al.* 1993). The gear used for collecting young fish was a 25 meter bottom trawl with a nylon nett (mesh size 6 mm; streched mesh) inserted into the codend.

Table 1. Mean catch of young *Sebastes mentella* per 1-hour trawling in the Barents and Norwegian Sea in October - December 1991.

AREA	Number		Catch per hour trawling
	Trawling hours	Catch	
BEAR ISLAND - SPITSBERGEN			
West Spitsbergen	30	3553	118
South Cape Deep	7	242	35
Western slopte of Bear Bank	17	429	25
Kopytov area	35	1586	45
Southern slope of Bear Bank	6	76	13
Total by area	95	5886	62
NORTH - CENTRAL AREA			
Demidov Bank	5	217	43
Nordkyn Bank	17	622	36
Western Deep	7	1329	190
Eastern slope of Bear Bank	3	1499	500
Hopen area	4	681	170
Central Elevation	3	1254	418
Total by area	39	5602	144
SOUTH - WEST AREA			
Finnmarken Bank	11	112	10
Rybachya Bank	6	35	6
Murmansk Tongue	7	142	20
Norwegian Deep	8	43	5
South - Western slope pf Murmansk Bank	4	64	16
North - Western slope of Murmansk Bank	1	19	19
Central Plateau	1	43	43
Total by area	38	458	12
GRAND TOTAL	172	11946	69

Table 2. Mean catch of young *Sebastes mentella* per 1-hour trawling in the Barents and Norwegian Sea in October - December 1992.

AREA	Number		Catch per hour trawling
	Trawling hours	Catch	
BEAR ISLAND - SPITSBERGEN			
West Spitsbergen	58	19603	338
South Cape Deep	15	1389	93
Western slopte of Bear Bank	24	1096	46
Kopytov area	13	4086	314
Southern slope of Bear Bank	14	151	11
Total by area	124	26325	212
NORTH - CENTRAL AREA			
Demidov Bank	21	292	14
Nordkyn Bank	18	443	25
Western Deep	23	532	23
Eastern slope of Bear Bank	23	512	22
Hopen area	4	264	66
Central Elevation	19	526	28
Total by area	108	2569	24
SOUTH - WEST AREA			
Finnmarken Bank	16	25	2
Rybachya Bank	7	47	7
Murmansk Tongue	14	156	11
Norwegian Deep	8	21	3
South - Western slope pf Murmansk Bank	9	88	10
North - Western slope of Murmansk Bank	12	89	7
Central Plateau	10	49	5
Total by area	10	17	2
	3	13	4
	89	505	6
GRAND TOTAL	321	29399	92

The species of deep-sea redfish were identified at sea, whereas a verification was conducted in the laboratories at the institute (Magnusson 1981; Barsukov, Litvinenko and Serebryakov 1984; Power 1985). Deep-sea redfish up to 30 cm inclusive were sampled. The length was measured from the end of the snout to the end of the caudal fin rays. Length frequencies were recorded in group intervals of 1 cm. The age was determined by scales and otoliths. The available data cover nearly the whole area of young fish and the survey area was divided into four sub-areas: the Bear Island-Spitsbergen, North-Central, western Barents Sea and north-west coast of Norway (Tables 1 and 2).

RESULTS AND DISCUSSION

In 1991 and 1992, 11.946 and 29.399 specimens of *Sebastes mentella* of the age-groups 0+ to 12+ of the length groups 6 to 30 cm were caught within the survey area. Mean catch per 1 hour trawling was 69 specimens in 1991 and 92 specimens in 1992.

It is known that young fish are distributied within a wide area during the whole year and occur along currents nearly everywhere in the Barents Sea, excluding northern areas (Maslov 1968; Marti 1980). The distribution area of young deep-sea redfish of the Norwegian-Barents Sea stock extends from west of Spitsbergen, southwards along the continental slope to Bear Island including all slopes of the Bear Island Bank, as well as areas of the main branch of the North Cape Current approximately from 75°N and 30°E and along the Murman branch of the North Cape Current to the slopes of the Gusinaya Bank (Travin 1952, 1957; Borodatov and Travin 1960; Barsukov 1972; Zakharov *et al.* 1977; Barskov, Shestova and Mukhina 1986). The geographical distribution of young fish in the investigated areas did not differ from previous years (Figure 1 and 2). In 1991, the main concentrations of young fish were not recorded in the North-Central Area (the north and central branches of the North Cape Current), but on the eastern slope of the Bear Island Bank and on the Central Elevation. The mean catch per 1 hour trawling was 144 specimens within these areas, and the catches comprised mainly of the 1989- and 90-year-classes, age 2+, 1+ and length 8-12 cm (Table 1, Figures 1 and 3).

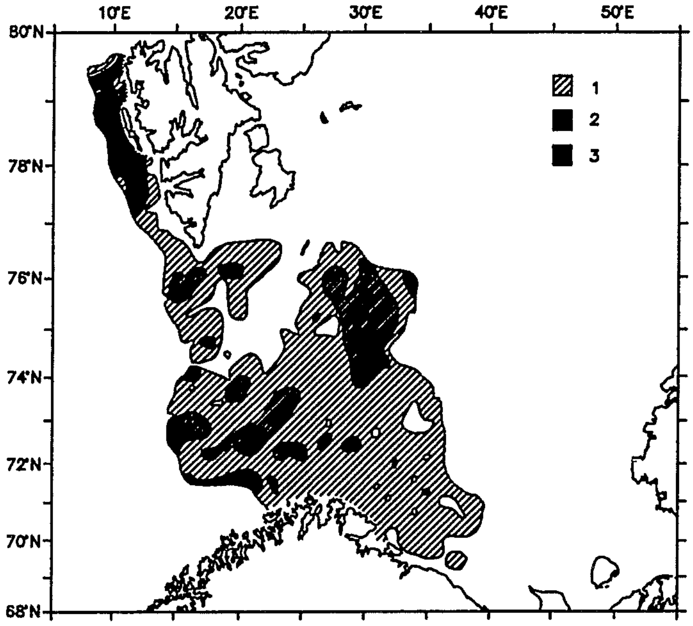

Figure 1. Distribution of *Sebastes mentella* less than 31 cm, based on survey data from October-December 1991. Number per hour traweling.
1: 1-49; 2: 50-99; 3: >100

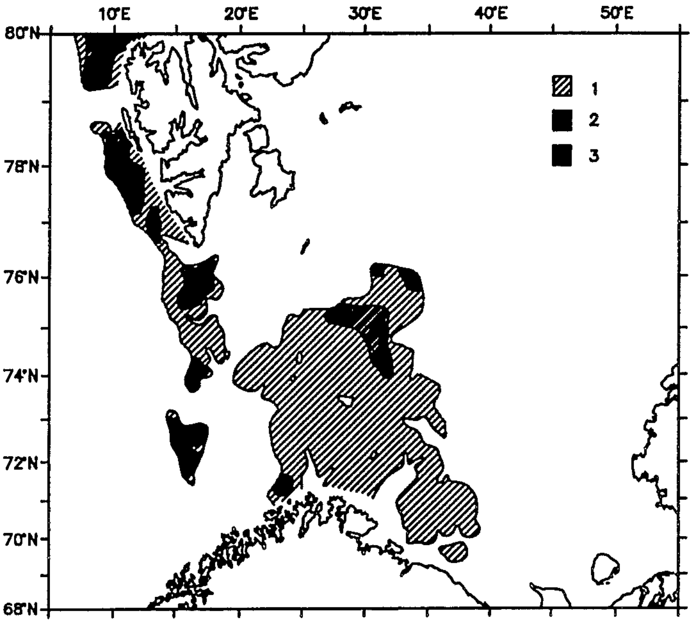

Figure 2. Distribution of *Sebastes mentella* less than 31 cm, based on survey data form October-Desember 1992. Legend as in Figure 1.

Large concentrations of young deep-sea redfish were in 1991 observed only in area west of Spitsbergen, where the mean catch per 1 hour trawling was 62 specimens. The main part of the catches was fish of the 1987-year-class, age 4+, 16-20 cm long and the 1983-year-class, age 9+, 26-30 cm long (Table 1, Figures 1 and 3).

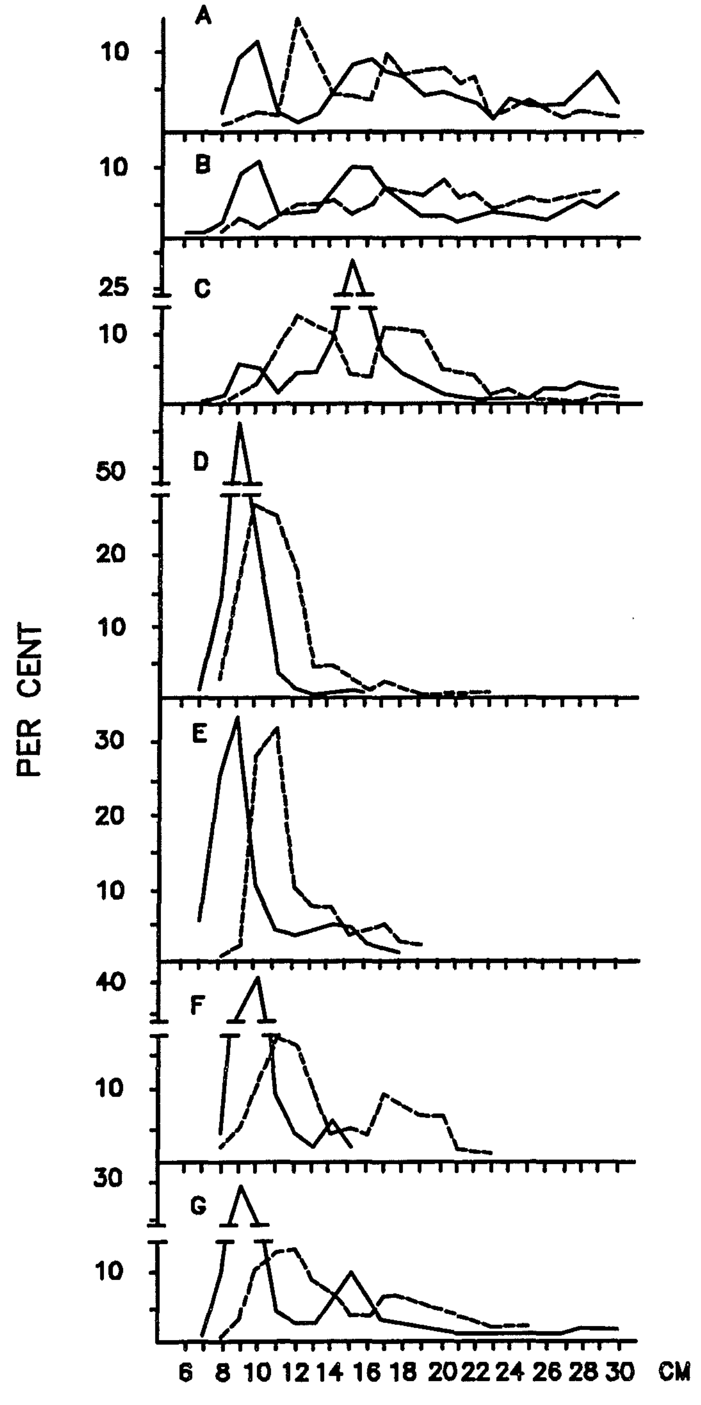

Figure 3. Length distrnibutio of young *Sebastes mentella* in 1991 (1) and 1992 (2) in the north and central Barents Sea.
A: Demidov bank
B: Nordkyn bank
C: Western Deep
D: Eastern slope of Bear Island bank
E: Hopen area
F: Central elevation
G: Total area.

In 1992, changes in the distribution of young fish were observed. The main concentrations of immature redfish were observed in the Bear Island-Spitsbergen area, and less fish in the area west of Spitsbergen and in the Kopytov area. Mean catch per 1 hour trawling in this area was 212 specimens, consisting mainly of 1988- and 1989-year-classes, age 4+ and 3+ with corresponding length of 16-20 and 12-16 cm respectivety (Table 2, Figures 2 and 4). The increasing numbers of the 1988- and 1989-year-classes caught in these areas were due to migration of young fish from the eastern slope of the Bear Island Bank and the Western Deepto the Bear Island-Spitsbergen area. In addition redfish juveniles descended to the bottom and became more accessible for the bottom trawl.

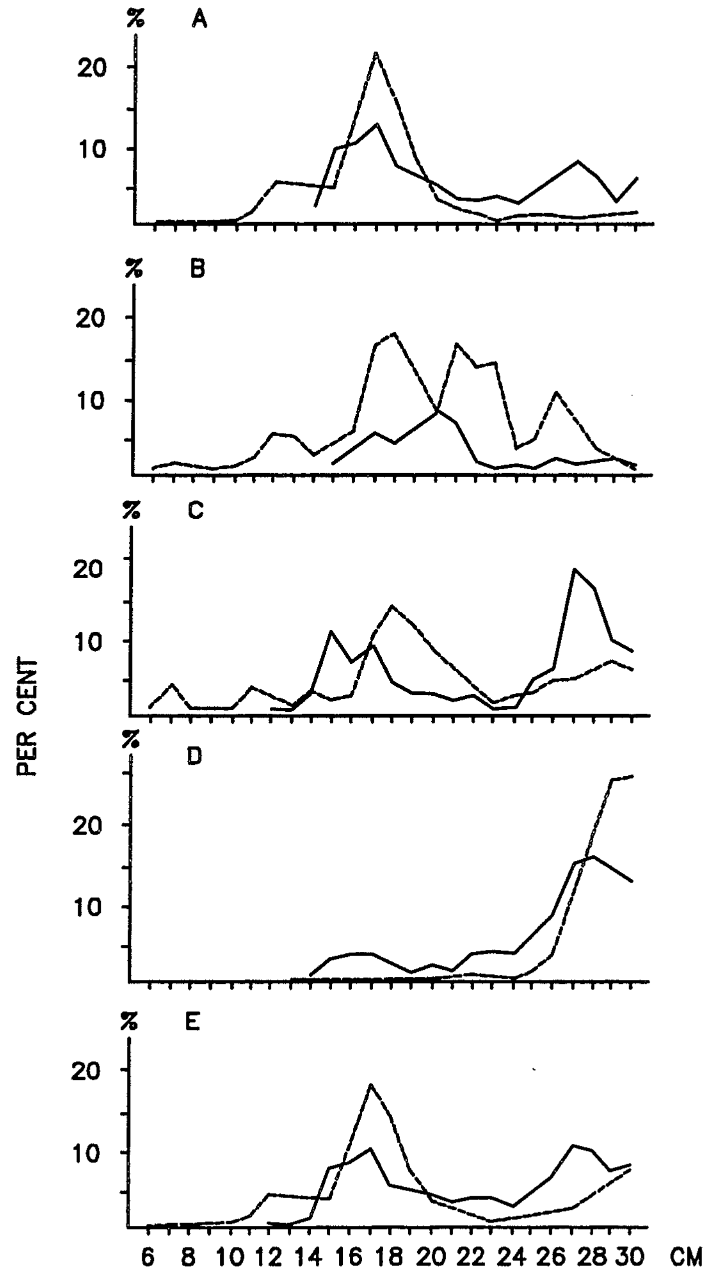

Figure 4. Length distribution of young *Sebastes mentella* in 1991 (1) and 1992 (2) in the Bear Island-Spitsbergen area.
A: West of spitsbergen
B: South Cape Deep
C: Western slope of Bear Island bank
D: Kapytov area
E: Total area.

A conciderable decrease in abundance of young immature redfish took place in 1992 in the North-Central area which resulted in reduced catches in all areas, but most extreme on the eastern slope of the Bear Island Bank and on the Central Elevation. The mean catch per 1 hour trawling 1992 in was 24 specimens in this area. Like the previous year, the 1989-year-class at the age 3+ and length 10-16 cm provided the main part of the catches (Table 2, Figures 2 and 3). However, a decrease in abundance of this year-class caused an overall reduction in catches of young fish in the area. The change in abundance of the 1989-year-class was mainly caused by high natural mortality in young age-groups in the peripher part of the area (Shestova 1982) and migration of juveniles to the south-west. In addition the trawl fishery for shrimp and demersal fish had a negative influence on abundance of young fish (Tretyak and Mukhina 1992). Predation has strongly influenced the abundance of young fish. In 1992, cod predated on young redfish age 0+ to 3+ of the 1989-1992-year-classes (6-18 cm) and young redfish constituted from 2.6% (the first three months) to 10.8% (the second three months) of the cod stomack content (A.V.Dolgov pers. comm.). The 1989-year-class, which was the most numerous one, had the greatest reduction.

In the south-western area, the density of immature redfish was not high. In 1991 and 1992, the mean catch per 1 hour trawling was 12 and 6 specimens respectively. In other areas, only single specimens of young deep-sea redfish occurred.

The analysis of abundance of redfish from the Norwegian-Barents Sea population has shown that the 1984-1987 and 1990-1992 year-classes were poor, whereas the 1988- and 1989-year-classes were avarage (Table 3).

Table 3. Average catch per hour trawling of *Sebastes mentella* of the Norwegian and Barents Sea population in October - December 1976 - 1992.

Year-class	Age - years								
	0	1	2	3	4	5	6	7	8
1968	-	-	-	-	-	-	-	-	16.2
1969	-	-	-	-	-	-	-	43.4	-
1970	-	-	-	-	-	-	85.8	-	19.8
1971	-	-	-	-	-	22.7	-	19.5	51.9
1972	-	-	-	-	9.4	-	6.7	57.6	12.3
1973	-	-	-	0.6	-	4.3	37.3	8.6	5.6
1974	-	-	4.8	-	4.9	22.8	4.8	4.8	-
1975	-	7.4	-	1.7	6.4	2.4	3.5	5.0	-
1976	7.0	-	8.1	1.2	2.5	6.8	4.9	5.0	1.0
1977	-	0.2	0.2	0.2	0.9	5.1	3.7	1.0	19.0
1978	0.8	0.02	0.9	1.0	5.0	3.8	2.0	20.0	6.0
1979	.	1.9	1.4	3.6	2.3	9.0	11.0	16.0	1.0
1980	0.3	0.4	2.0	2.5	16.0	6.0	11.0	25.0	2.0
1981	-	2.2	3.9	20.0	6.0	12.0	47.0	18.0	6.3
1982	19.8	13.2	13.0	15.0	34.0	44.0	39.0	32.6	4.3
1983	12.5	3.0	5.0	6.0	31.0	34.0	32.3	13.3	4.0
1984	-	10.0	2.0	-	5.0	18.3	19.0	2.2	2.4
1985	107.0	7.0	-	1.0	5.2	16.2	1.7	1.7	-
1986	2.0	-	1.0	1.8	8.4	3.6	2.1	-	-
1987	-	3.0	37.9	1.3	8.0	4.1	-	-	-
1988	4.0	58.1	4.3	13.3	25.8	-	-	-	-
1989	8.7	9.0	17.0	23.4	-	-	-	-	-
1990	2.5	6.3	6.1	-	-	-	-	-	-
1991	0.3	1.0	-	-	-	-	-	-	
1992	0.6								

Investigations in 1991-1992 have shown that settling of young redfish took place in the Spitsbergen Current and in the north and central branches of the North Cape Current. The main part of small immature redfish (aged 0+ - 3+) are living in the north and north-east part of the species' distribution area. Older fish migrate to the south, south-west to the Kopytov area and to the western slope of the Bear Island Bank.

In 1991-1992, more favourable conditions for survival of young deep-sea redfish were observed in the Bear Island-Spitsbergen area than in the North-Central area of the Barents Sea. This conclusion is based on observations of mass descending of specimens of the avarage 1989-year-class to the near-bottom layer. In the first area, young fish descended to near-bottom layer at the age of 3+, and in the other area at age 2+. Apparently, mass descending to near-bottom layer of 0-group fish does not take place. However, only 0-group redfish of rich year-classes which are distributed in the whole water column, are recorded in bottom trawl catches.

When food supply becoming worse, at a low stock of capelin and a big Arcto-Norwegian cod stock, predation by cod on young *Sebastes mentella* would probably increase as observed in the 80-ies (Yaragina 1988; Orlova *et al.* 1988; Ajiad *et al.* 1992; Dolgaya and Tretyak 1992). This might to some extent reduce recruitment to the commercial stock of redfish in the near future, caused mainly by cod predation on the poor 1990-1992-year-classes.

CONCLUSIONS

Young *Sebastes mentella* of the Norwegian-Barents Sea population is dispersed into the Barents Sea mainly by the Spitsbergen Current, and by the northern and central branches of the North Cape Current. The drift is less by the Murman Current and the coastal branch of the North Cape Current. Mass descent of deep-sea redfish into the near-bottom layer take place in the second year of life or later. In the years of investigation, the main part of young redfish, age 0+-3+, were distributed in the north and north-east part of the area, while older fish were dominating in the southern part of the area.

The 1984-1987-year-classes were estimated as poor ones, whereas those of 1988 and 1989 were estimated as average ones. In 1991-1992, the most favourable conditions for survival of young deep-sea redfish were observed in the Bear Island-Spitsbergen area (the Spitsbergen Current). However, reduced availability of food organisms for cod might increase the predation on young redfish which would generate reduction in year-class abundance.

REFERENCES

AJIAD, A.M., MEHL, S., KORSBREKKE, K., DOLGOV, A.V., KORZHEV, V.L., TRETYAK, V.L. and YARAGINA, N.A. 1992. Trophic relationships and feeding-dependent growth in the North-East Arctic cod. Pp. 45-58 in Bogstad, B. and Tjelmeland, S. (eds.) in: *Interrelations between fish populations in the Barents Sea. Proceedings of the fifth PINRO/IMR symposium, Murmansk, 12-16 August 1991.* Institute of Marine Research, Bergen, Norway.

BARSUKOV, V.V. 1972. Systematics of Atlantic redfish species. In: *Trudy polyar. nauchno.-issled. Inst. morsk. ryb. Khoz. Okeanogr. 28*: 128-14.1. (In Russian)

BARSUKOV, V.V., LITVINENKO, N.I. and SEREBRYAKOV, V.P. 1984. *Methods of determination of redfish species of the northern part of the Atlantic Ocean and adjacent seas. Atl. nauchno-issled. Inst. ryb. Khoz. Okeanogr.* Kaliningrad, 8 pp. (Preprint in Russian)

BARSUKOV, V.V., SHESTOVA, L.M. and MUKHINA, N.V. 1986. Redfish species of *Sebastes genus*. Pp. 48-55 in: *Ichthyofauna and conditions of its life in the Barents Sea.* Polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr. Murm. morsk. biol. Inst. Apatity. (In Russian)

BERGER, T.S. 1968. Soviet investigations on young redfish (*S. mentella* and *S. marinus*) in the Barents Sea in 1966 and 1967. *Annls biol. 23:* 204-206.

BERGER, T.S. and **CHEREMISINA, R.A.** 1967. Soviet investigations on young redfish in the Barents Sea in 1964-1965. *Annls biol. 22:* 178-181.

BERGER, T.S., CHEREMISINA, R.A. and **BYZOVA, O.A.** 1966. Distribution of the young of redfish in the Bear Island-Spitsbergen area and in the southern part of the Barents Sea during the autumn-winter period 1964-1965. *Mater. rybokhoz.-issled. sev. Basseina. 6*: 32-38. (In Russian)

BERGER, T.S. and **CHEREMISINA, R.A.** 1968. Distribution and age of young redfish, *mentella* and *marinus*, in the Barents Sea in 1967. *Annls biol. 24*: 193-195.

BERGER, T.S. and **CHEREMISINA, R.A.** 1969. The distribution and age of young redfish *mentela* and *marinus* in, the Barents Sea in 1968. *Annls biol. 25*: 247-250.

BERGER, T.S. and **CHEREMISINA, R.A.** 1970. The distribution of young redfish in the Barents Sea in 1967. *Mater. rybokhoz.-issled. sev. Basseina. 14:* 53-58. (In Russian)

BERGER, T.S. and **CHEREMISINA, R.A.** 1973. Distribution and age of young redfish, *mentella,* Travin and *marinus* L. in Subarea I in 1971. *Annls biol. 28*: 209-210.

BERGER, T.S. and **CHEREMISINA, R.A.** 1974a. Distribution and age of redfish fry, (*mentella* and *marinus*), in autumn and winter 1971-1972 in the Barents Sea. *Annls biol. 29*: 174-175.

BERGER, T.S. and **CHREMISINA, R.A.** 1974b. Distribution and age of young redfish *Sebastes mentella* Travin and *Sebastes marinus* L. in the Barents Sea in autumn and winter period 1972-1973. *ICES 1974*/F: 26, 7 pp.

BORODATOV, V.A. and **TRAVIN, V.I.** 1960. The main stages of Soviet investigations on redfish of the North Atlantic. Pp. 277-284 in: *Soviet fisheries investigations in the seas of the European North.* Vses. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., Moscow. (In Russian)

DOLGAYA, O.Yu. and **TRETYAK, V.L.** 1992. Significance of the north-east Arctic cod for year-class strength of redfish in the Barents Sea. Pp. 39-44 in Bogstad, B. and Tjelmeland, S. (eds.): in Interrelations between fish populations in the Barents Sea. *Proceedings of the fifth PINRO-IMR Symposium, Murmansk, 12-16 August, 1991.* Institute of Marine Research, Bergen, Norway.

DREVETNYAK, K.V. 1992. The distribution and abundance of young *Sebastes mentella* of the Norwegian-Barents Sea stock in 1989 and 1990. Pp. 121-133 in: *Materials of final session on results of research of PINRO in 1991.* Polyar. nauchno-issled. Inst. morsk. Ryb. Khoz. Okeanogr., Murmansk. (In Russian)

MAGNUSSON, J. 1981. Identification of *Sebastes marinus, Sebastes mentella, Sebastes viviparus* in 0-group redfish. *Rapp. P.-v.Reun.Cons. int. Explor. Mer. 178*: 76-93.

MARTI, Yu.Yu. 1980. *Migrations of marine fish.* Moscow, 248 pp. (In Russian)

MASLOV, N.A. 1944. Demersal fish of the Barents Sea and fisheries for them. *Trudy polyar. naychno.-issled. Inst. morsk. ryb. Khoz. Okeanogr. 8*: 3-186. (In Russian)

MASLOV, N.A. 1968. The influence of natural factors and fisheries on age composition, abundance and areas of demersal fish of the Barents Sea. *Trudy polyar. naychno.-issled. Inst. morsk. ryb. Khoz. Okeanogr 23:* 86-103. (In Russian)

ORLOVA, E.L., BERESTOVSKY, E.G., ANTONOV, S.G., KARAMUSHKO, L.I., NIZOVTSEV, G.P. and **YARAGINA, N.A.** 1988. *Dynamics of yearly cod feeding.* Kola Section of the Russian Academy of Science, Murm. morsk. biol. Inst., Apatity, 16 pp. (Preprint in Russian)

POWER, D.J. 1985. Morphometric differences between golden redfish (*Sebastes marinus*) and beaked refish (*Sebastes mentella*) and *Sebastes fasciatus. J.Northwest. Atl. Fish. Sci. 6:* 1-7.

SHESTOVA, L.M. 1979. Soviet investigation on young beaked redfish (*Sebastes mentella*) in the Barents and Norwegian Seas in 1976/1977. *Annls biol. 34*: 218-219.

SHESTOVA, L.M. 1980. Abundance of young beaked refish in the Barents and Norwegian Seas in 1977/1978. *Annls biol. 35*: 241-243.

SHESTOVA, L.M. 1981. Abundance of young beaked redfish (*Sebastes mentella*) in the Barents and Norwegian Seas in 1978/1979. *Annls biol. 36*: 186-188.

SHESTOVA, L.M. 1982. Distribution of immature *Sebastes mentella* in the Barents and Norwegian Seas. Pp. 75-88 in: *Ecology and fisheries of demersal fish in the North-European Basin. Sbornik nauchnykh Trudov.* Polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., Murmansk. (In Russian)

SHESTOVA, L.M. 1983. Immature redfish *(Sebastes mentella)* up to 31 cm long in the Barents and Norwegian Seas in autumn and winter of 1979/1980. *Annls biol. 37*: 223-225.

SHESTOVA, L.M. 1984. Assessment of immature redfish (*Sebastes mentella*) in the Barents and Norwegian Seas in 1980/1981. *Annls biol. 38*: 197-199.

SHESTOVA, L.M. 1986. Assessment of young redfish (*Sebastes mentella*) in the Barents and Norwegian Seas in the winter of 1983/1984. *Annls biol. 41*: 149.

SHEVELEV, M.S., DORCHENKOV, A.E. and **LEPESEVICH, Yu.M.** 1992. Investigations of cod and haddock in the Barents Sea and adjacent waters in 1991. *ICES CM 1992*/G:53. 16 pp.

SHEVELEV, M.S., GOTOVTSEV, S.M., LEPESEVICH, Yu.M. and **RATUSHNY, S.V.** 1993. Russian investigations of cod and haddock in the Barents Sea and adjacent waters in 1992. *ICES CM 1993*/G:57. 17 pp.

SURKOVA, E.I. 1962. Results of account of young redfish in the Barents Sea in 1959-1960 and 1960-1961. *Res.bull. PINRO, 4*(22): 14-16. (In Russian)

TRAVIN, V.I. 1951. A new species of redfish in the Barents Sea (*Sebastes mentella* Travin sp. nov.). *Dokl. Akad. Nauk SSSR.. 77*(4): 741-744. (In Russian)

TRAVIN, V.I. 1952. A family of Scorpaenidae. Pp. 183-198 in: *Commercial fishes of the Barents and White Seas*. Nauka, Leningrad. (In Russian)

TRAVIN, V.I. 1957. Fishery for redfish in the southern part of the Barents Sea in the Kopytov area. *Trudy polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., 10*: 161-171. (In Russian)

TRETYAK, V.L. and **MUKHINA, N.V.** 1992. Grounds for measures on protection of young fis of the Barents Sea during the trawl fishery. Pp. 89-120 in: *Materials of the final session on results of research of PINRO in 1991*. Polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., Murmansk. (Preprint in Russian)

YARAGINA, N.A. 1988. Importance of young redfish in the Barents Sea cod feeding. Pp. 82-83 in: *Feeding of marine fishes and the use of the nutritive base as an element of catch predictions. Abstracts of reports to the All-Union Conference*. Polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., Murmansk. (In Russian)

ZAKHAROV, G.P., Nikolskaya, T.L., SOROKIN, V.P., CHEKHOVA, V.A. and **SHESTOVA, L.M.** 1977. Deepwater redfish. Pp. 72-88 in: *Commercial biological resources of the North Atlantic and adjacent waters of the Arctic Ocean* (Part II). Moscow. (In Russian)

PRE-RECRUIT STUDIES OF THE NORTH-EAST ARCTIC GREENLAND HALIBUT STOCK

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ABSTRACT

Abundance indices of 0-group Greenland halibut (*Reinhardtius hippoglossoides*) from the international 0-group surveys in the Barents Sea showed a sudden decrease from 1987 to 1988 to a low level which has remained for the last 5-6 years. The strength of these weak year-classes has been confirmed in later youngfish surveys, and this has caused strong regulations of the fishery at a time when the fishery itself was good. The drop in recruitment is discussed and related to a reduction of the spawning stock.

INTRODUCTION

Already in 1989, ICES Advisory Committee on Fishery Management (ACFM) stated that the Greenland halibut stock in ICES Sub-areas I and II appeared to be small compared to historic levels, and that a strategy for rebuilding the stock should be adopted (ANON. 1990). This was mainly based on an observed increase in effort coupled with a decrease in catch-per-unit-effort (CPUE), indications of a shift in effort towards younger fish, and very low 0-group indices in 1988 and 1989 (ANON. 1989). In 1991 the Norwegian-Russian Fishery Commission decided to put strong regulations on the fishery in 1992, at a time when the landings were increasing, and the regulations therefore had a great sudden impact on the fishery. It thus became important to increase the research in order to confirm or invalidate the announced recruitment failure. This paper shows the results from the 0-group survey and youngfish surveys, how this early indication of recruitment failure in the 0-group survey has been confirmed in later surveys as 1-year olds and older. In order to enforce necessary regulations in time, this paper also stress the importance of different and independent pre-recruit studies in order to cross-check the results before advices are given.

MATERIALS AND METHODS

The international 0-group survey has been conducted in the Barents Sea and Svalbard areas in August-September every year since 1965. The survey design has however improved since

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then, but the same design has more or less been used since 1979 (e.g., ANON. 1994). Figure 1 shows, as an example, the pelagic trawl stations taken during the survey in 1987 and 1992.

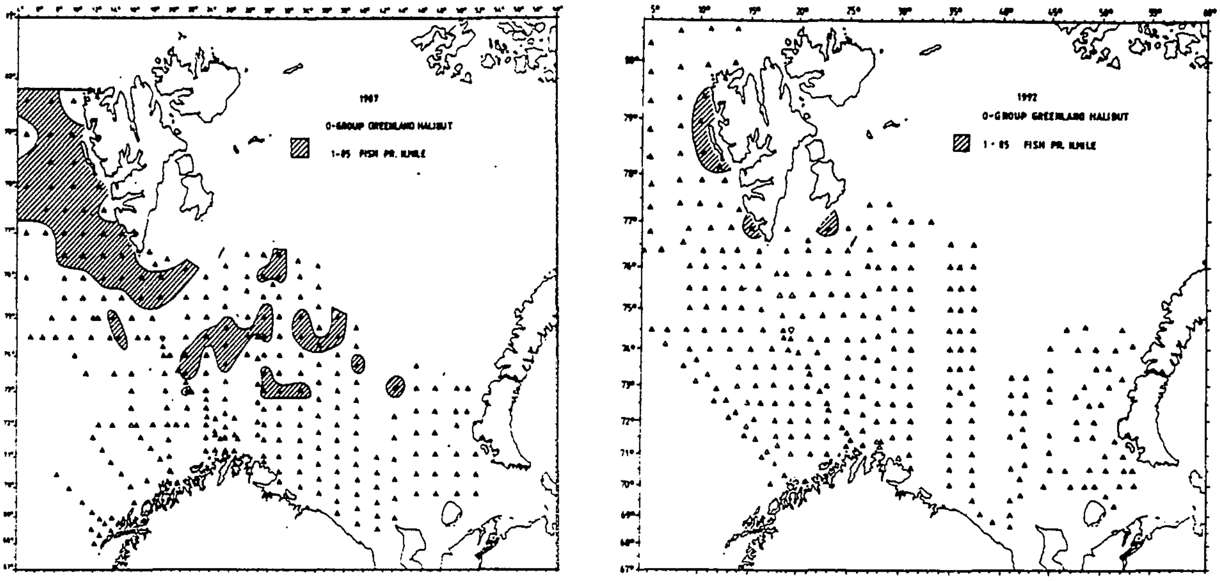


Figure 1. Distribution of 0-group Greenland halibut in August-September 1987 (left) and 1992 (right).

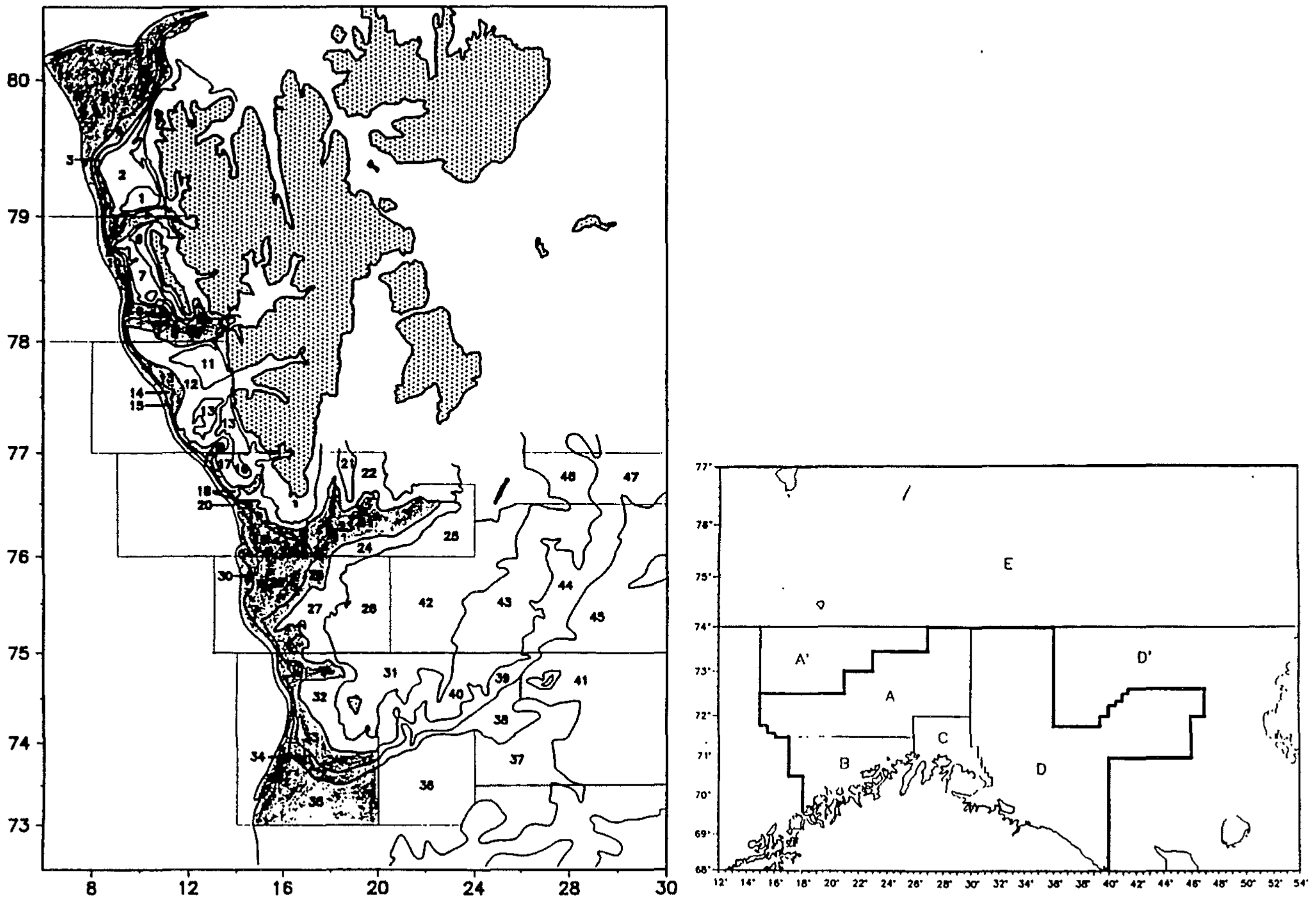


Figure 2. The areas surveyed during the Norwegian bottom trawl surveys at Svalbard (left) and in the Barents Sea (right). The area surveyed during the shrimp survey at Svalbard has been hatched (i.e. only strata deeper than 200 meters).

In the Svalbard area, a Norwegian stratified bottom trawl survey, mainly designed for cod, has been conducted in September every year since 1981. This survey covers depths from less than 100 meters to maximum 550 meters (Figure 2). Data on Greenland halibut are available on length for the time period 1984-1993, and on age for the years 1989-1993. In this study an attempt was made to use a procedure described by e.g., MACDONALD and PITCHER (1979), to split the 1988 length-distribution into age groups having information about mean length-at-age and corresponding standard deviation.

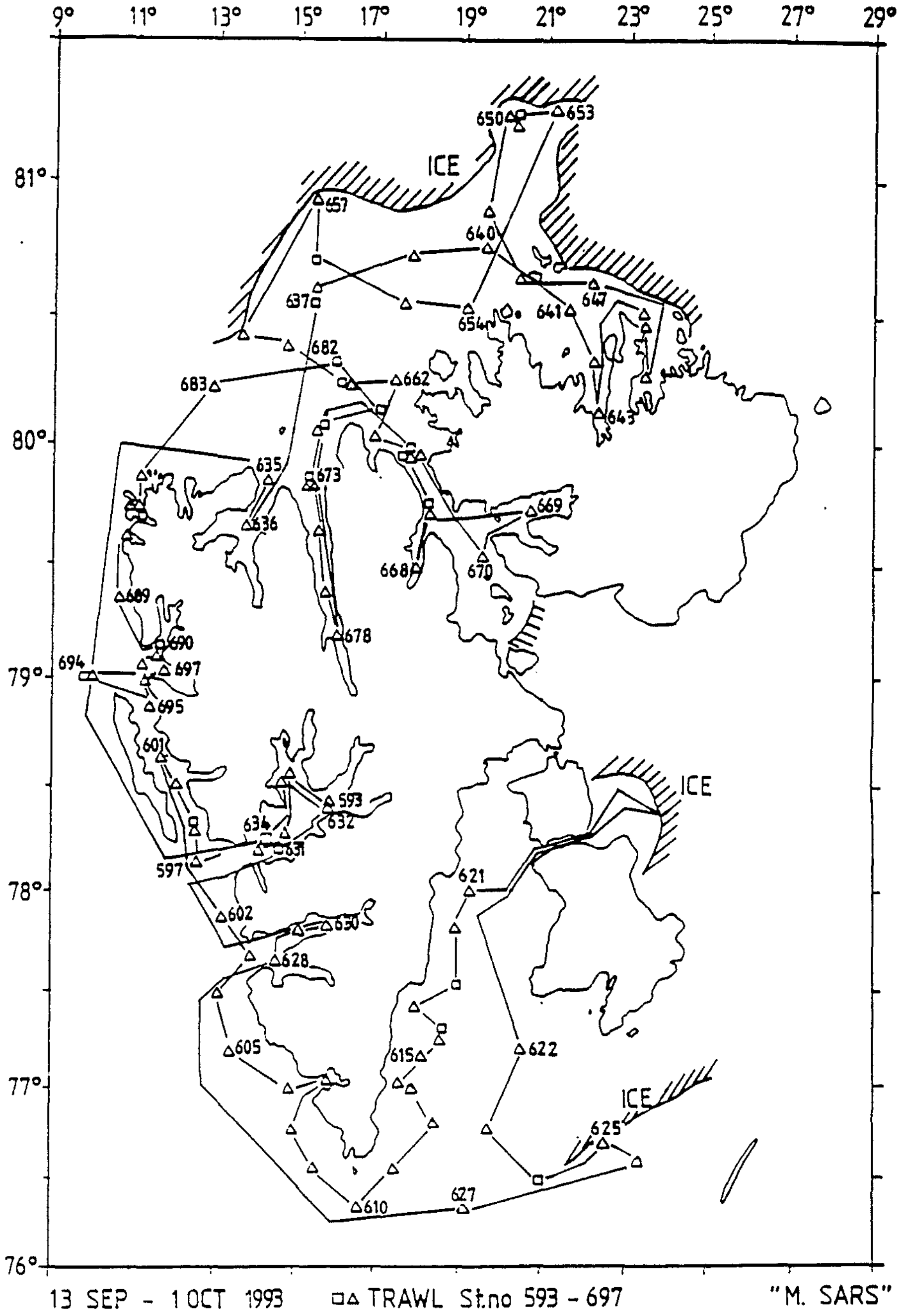


Figure 3. Area surveyed during the trawl survey around Spitsbergen 13 September - 1 October 1993. Squares = bottom trawl stations, triangels = pelagic trawl stations using the standard 0-group sampling trawl (capelin trawl with 8 mm stretced meshes in cod-end).

In the Svalbard area, a trawl survey for shrimp has been conducted in July-August up to 1992 and in June 1993. This survey uses the same stratification as the cod survey, but covers only the area deeper than 200 meters, but down to a maximum depth that usually exceeds that in the cod survey (Figure 2). Reliable age distribution of Greenland halibut in this survey exists for the years 1989-1993. In addition, the 1988 length-distribution was splitted into age groups according to the method described above.

Sporadic trawling in the fjords of Spitsbergen and northeast and east of the island have shown occurrence of juvenile Greenland halibut. In September 1993 a trawl survey, including both pelagic and bottom trawling, was conducted in these areas to improve the coverage of mainly 0-2-group Greenland halibut (Figure 3). Most of the pelagic trawling was conducted from the surface and down to approx. 50 meters, but some pelagic trawling were also carried out deeper than 50 meters.

In the Barents Sea, a Norwegian stratified bottom trawl survey, mainly designed for cod and haddock, has been conducted in February every year since 1981 (Figure 2). In 1992 and 1993 the survey was enlarged to cover a bigger area than before, but in order to analyse a time series, survey indices for the area ABCD are presented.

RESULTS AND DISCUSSION

Figure 1 shows distributions of 0-group Greenland halibut representative for the years prior to the decrease in 1988, and for the years after. After the 0-group collapse, almost none 0-group have been found inside the Barents Sea, and only few individuals off Spitsbergen. 0-group indices are given in Table 1. Although the 0-group survey do not cover the entire area of the 0-group Greenland halibut distribution, no information exist though that can put doubt on the reliability of the low indices in 1988-1993 compared to the years before.

Table 1. Abundance indices of 0-group Greenland halibut in the Barents Sea and Svalbard areas in 1979-1993.

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987
Index	22	12	38	17	16	40	36	55	41

Year	1988	1989	1990	1991	1992	1993
Index	8	5	2	1	3	11

The survey in the fjords and northeast and east of Spitsbergen in 1993, which was conducted to enlarge the more or less standard areas of investigation, was to some extent hampered by ice between Edge Island and the Northeastland. However, only minor catches of 0-2 group were made, and then mainly north and northeast of Spitsbergen. Unfortunately, no time series exists for making comparisons. The survey showed that no 0-group Greenland halibut at that time, i.e., September, had settled on the bottom. But although some pelagic trawling which was conducted at greater depths during this survey did not catch any Greenland halibut, this can't exclude the possibility of 0-group Greenland halibut living in deeper pelagic layers outside the the reach of a standard 0-group haul down to 50-60 meters during the international 0-group survey.

Table 2. Greenland halibut. Abundance indices on age from the Norwegian bottom trawl survey at Svalbard for cod (ICES Division IIb), September 1988-1993.

Year	Age									Total
	1	2	3	4	5	6	7	8	9	
1988[1]	1276	5283	1588	9888	18012	3775 (6+)				39822
1989	712	3232	8158	7493	7069	2374	1753	353	744	31888
1990	115	336	5050	7130	7730	4490	2330	918	544	28643
1991	71	877	3080	6720	9270	5450	2800	1660	524	30452
1992	33	30	338	1190	3520	4420	2280	1280	474	13565
1993	25	60	51	1049	2369	2056	2772	1114	665	10161

[1] The length distribution splitted on age according to Macdonald and Pitcher (1979).

Tables 2 and 3 present the results from the cod survey at Svalbard, which show a decrease of Greenland halibut from the 1988-yearclass and onwards. The decrease is however most pronounced for the 1989- and later yearclasses. The results from the shrimp survey at Svalbard (Table 4) are very similar.

Table 3. Greenland halibut. Abundance indicies on length from the Norwegian bottom trawl surveys at Svalbard of cod (ICES Division IIb) 1984-1993 (number in thousands).

Year	Length group (cm)											Total
	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60+	
1984	1179	1834	1175	1925	3654	5912	6733	5309	3952	2140	2630	36443
1985	867	708	1679	1787	3598	6114	9234	7201	4431	1880	1934	39433
1986	59	59	506	1071	2453	2940	4790	3524	1830	915	1304	19451
1987	463	333	370	1110	2904	4311	4162	2738	1184	499	259	18333
1988	797	1642	3424	2435	4922	8202	7910	5846	2792	1203	648	39821
1989	357	1014	3090	3702	5808	5799	5649	3567	1986	489	427	31888
1990	115	267	428	1806	4359	5218	6516	4637	3078	1291	917	28643
1991	71	45	711	1447	2901	5957	8006	5260	3440	1823	791	30452
1992	29	10	11	60	342	863	3209	4400	3063	855	723	13565
1993	8	68	23	38	25	833	2106	2732	2549	1114	665	10161

Table 4. Greenland halibut. Abundance indices on age from the Norwegian trawl survey for shrimp at Svalbard. July-August 1988-1992 (number in thousands).

Year	Age									Total
	1	2	3	4	5	6	7	8	9+	
1988[1]	4163	14278	8259	8354	2594	6+144				37792
1989[2]	4653	9777	9943	4855	4057	1054	542	83	372	35336
1990	247	1569	8324	9800	6910	2148	295	245	175	29713
1991	25	577	2465	4969	5362	2541	1380	158	278	17755
1992	95	57	505	1780	2914	1129	713	333	200	7726
1993[3]	39	54	50	814	1572	433	589	395	512	4458

[1] The length distribution was splitted on age according to Macdonald and Picher (1979).

[2] An age-length key from the bottom trawl survey for cod at Svalbard in September 1989 was used to convert the indices from length to age.

[3] An age-length key from the bottom trawl survey for cod at Svalbard in September 1993 was used to convert the indices from length to age.

The results from the Barents Sea winter survey also show a clear decrease in the abundance of small Greenland halibut (Table 5). Also from this survey some uncertainty can be put on the strength of the 1988-yearclass, which do not seem to be as weak as the more recent ones. By including the enlarged area in winter 1994, no Greenland halibut less than 30 cm were, however, added to the index.

Table 5. Greenland halibut. Abundance indicies on length from the Norwegian bottom trawl surveys in the Barents Sea area ABCD) winter 1988-1994 (number in thousands).

Year	Length group (cm)															Total
	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80+	
1988	141	426	226	258	810	1858	2997	1800	869	402	203	166	201	58	104	10518
1989	457	508	647	478	786	1680	3890	2856	1287	610	149	19	75	0	55	13493
1990	21	199	777	785	1205	1657	1829	2043	1349	479	159	160	40	82	0	10800
1991	0	42	262	618	655	868	954	1320	1875	1577	847	165	34	51	0	9270
1992	14	35	64	149	509	843	1096	1072	1029	827	633	108	31	27	26	6500
1993	0	0	17	67	117	484	1415	1255	1418	846	589	358	89	31	34	6720
1994	0	0	16	99	118	957	1631	2379	1473	800	307	264	25	0	0	8069

Figure 4 shows the geographical distribution of Greenland halibut during the Svalbard cod survey in 1992 and the Barents Sea winter survey in 1994.

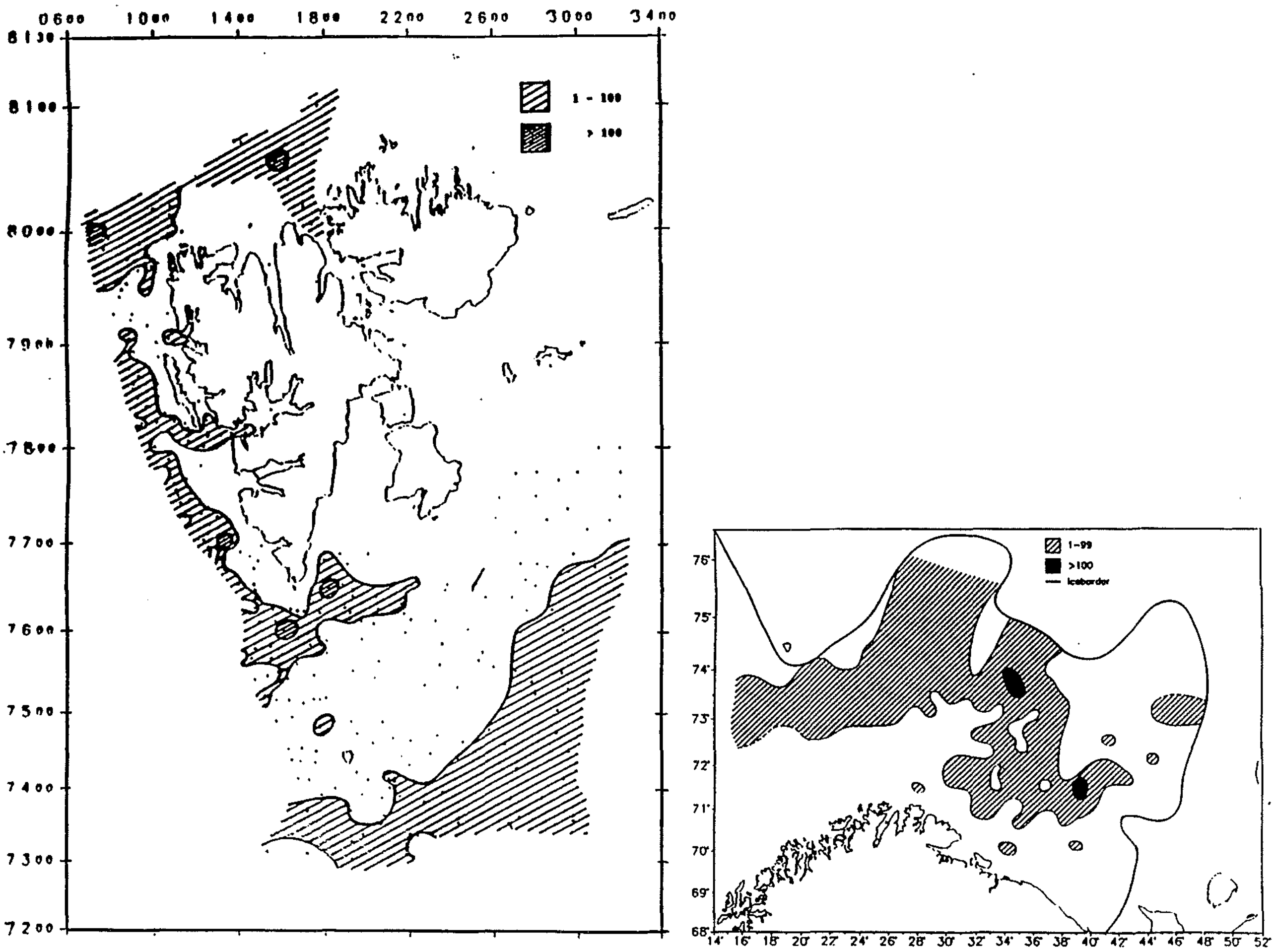
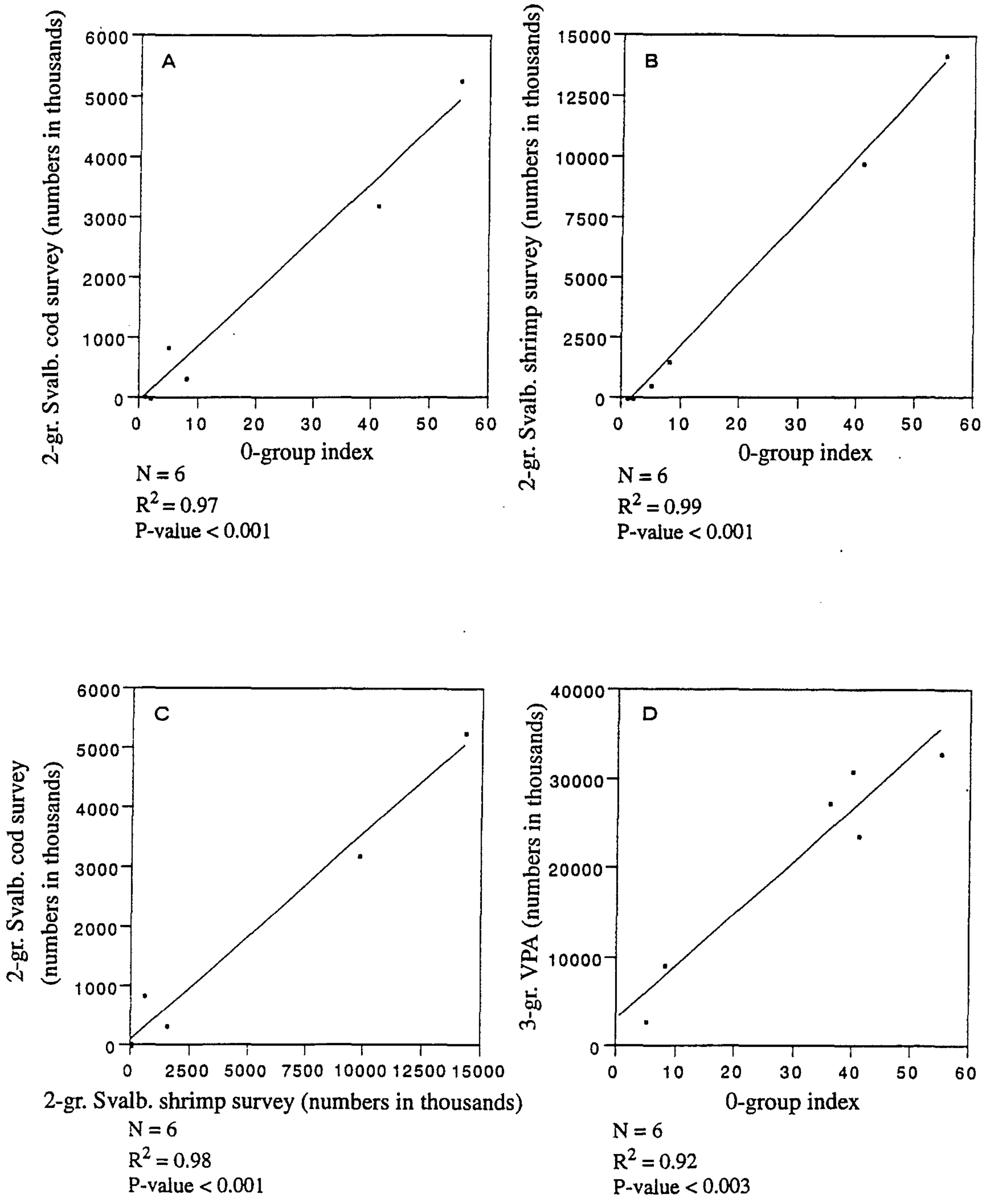


Figure 4. Distribution of Greenland halibut (all sizes) during the bottom trawl survey for cod at Svalbard in September 1992 (left), and in the Barents Sea in February 1994 (right).

Regression analyses of different survey indices (e.g., for different age groups) versus indices for other age groups from the same survey, or versus the same age group in other surveys, or versus VPA, showed that the 2-group survey indices produced the best linear fit. This probably has to do with the migration of Greenland halibut from shallow to deeper waters as it grows combined with the different area coverage of the surveys. In Figure 5 some of these analyses are shown.



N = 6
$R^2 = 0.97$
P-value < 0.001

N = 6
$R^2 = 0.99$
P-value < 0.001

N = 6
$R^2 = 0.98$
P-value < 0.001

N = 6
$R^2 = 0.92$
P-value < 0.003

Figure 5. Results from the regression analyses of the Greenland halibut year-class indices at the 0-group stage versus the same year-classes measured at the 2-group stage during the trawl surveys for cod and shrimp at Svalbard (A,B), and versus the number of the year-class at age 3 as measured by the VPA (D). The 2-group indices from the cod and shrimp surveys are also compared versus each other (C). A short regression summary is shown in each case.

Russia has since 1990 conducted a stratified trawl survey to assess the Greenland halibut stock (SMIRNOV *et al.* 1993). In 1992 this survey showed a decrease of Greenland halibut smaller than 36 cm, which is in agreement with the results from the Norwegian research surveys. This is further discussed in a paper by SMIRNOV (1995).

The assessments of the Greenland halibut stock did for many years show a stable recruitment of 3-year-olds despite an estimated decrease of the spawning stock (Figure 6). Although the assessments may not have succeeded in estimating the spawning stock accurately, this will only move the curve in Figure 6 left-right. We don't have any answer to the recruitment's independance of spawning stock size above a certain level of the spawning stock, but a lower critical level of the spawning stock size seems to have been passed. We also notice an increase in both recruitment and spawning stock just before the collapse, this probably accounting for satisfactory recruitment to the fishery at the same time when strong regulations were enforced.

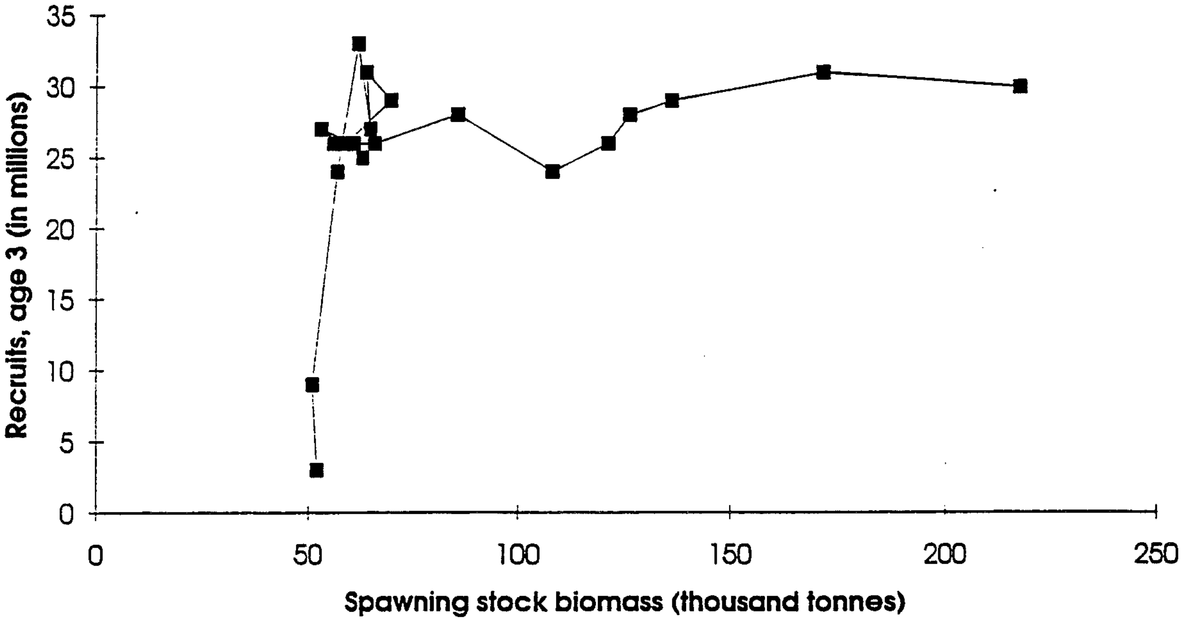


Figure 6. Greenland halibut. Spawning stock biomass vs. recruitment at age 3 as estimated by VPA during the Arctic Fisheries Working Group in Copenhagen in August-September 1994 (Anon. 1995).

ACKNOWLEDGEMENT

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REFERENCES

ANON. 1989. Preliminary report of the international 0-group survey in the Barents Sea and adjacent waters in August-September 1989. *ICES CM 1989*/G:40, 40 pp.

ANON. 1990. Reports of the ICES Advisory Committee on Fishery Management, 1989. *ICES Co-op.Res.Rep. 168* (part I): 361 pp.

ANON. 1994. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September 1993. *ICES CM 1994*/G:3. 38 pp.

ANON. 1995. Report of the Arctic Fisheries Working Group. Copenhagen, 23 August- 1 September 1994. *ICES CM 1995*/Assess: 3, 252 pp.

MACDONALD, P.D.M. and **PITCHER, T.J.** 1979. Age-groups from size-frequency data: a versatile and efficient method of analyzing distribution mixtures. *J.Fish.Res.BoardCan. 36*: 987-1001.

SMIRNOV, O.V. 1995. Dynamics of Greenland halibut recruitment to the Norwegian-Barents Sea stock from the 1984-1993 trawl survey data. Pp. xx-xx in Hylen, A. (ed.): *Precision and relevance of pre-recruit studies for fishery management related to fish stocks in the Baretns Sea and adjacent waters. Proceedings of the Russian-Norwegian symposium. Bergen, 14-17 June 1994.* Institute of Marine Research, Bergen, Norway.

SMIRNOV, O.V., LEPESEVICH, YU.M. and **SHEVELEV, M.S.** 1994. Results of Russian investigations for Greenland halibut from the Norwegian/Barents Sea stock in 1993. *ICES CM 1994*/G: 31, 12 pp.

DYNAMICS OF GREENLAND HALIBUT RECRUITMENT TO THE NORWEGIAN-BARENTS SEA STOCK FROM THE 1984-1993 TRAWL SURVEY DATA

by

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ABSTRACT

Number of Greenland halibut at age 3 in the eastern Norwegian and western Barents Seas was calculated for the period 1984-1993 based on data from stratified bottom trawl surveys, including data of age-composition of the stock. It is noted that in the two most recent years the abundance of recruitment has been lower than the mean long-term level.

INTRODUCTION

As a result of too high exploitation of the Norwegian-Barents Sea stock of Greenland halibut, it was severely depleted, and a prohibition of direct fishing was introduced in 1992. These conservation measures will surely have a positive effect on the stock status. However, a low level of the spawning stock and a limited fishery of Greenland halibut in the Norwegian coastal areas by conventional gears and a by-catch fishing in in international trawl fishery for other fish species do not allow for a quick recovery of the stock. To obtain adequate evaluation of the present situation it is important to study dynamics of Greenland halibut stock recruitment. This paper deals with this ithem.

MATERIALS AND METHODS

The number of 3-year old Greenland halibut has been measured during annual multi-species trawl-acoustic surveys in the autum-winter period, carried out by the PINRO since 1990. Abundance of 3-year old fish have been calculated on the basis of data from these investigations, representing a measure of the recruitment to the stock (Shevelev and Lepesevich 1991).

The survey area include areas between 71°N and 80°N and between the 900 m and the 300 m isobath on the continental shelf on the eastern edge of the Western Deep. West of Spitsbergen hauls were made at 200 m depth and deeper (Figure 1). The survey area was

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conventionally devided into two sub-areas (A and B) with the border along 73°30' N in order to facilitate the analysis of the results. In the process of work, the results from 26 expeditions of PINRO research vessels were analysed.

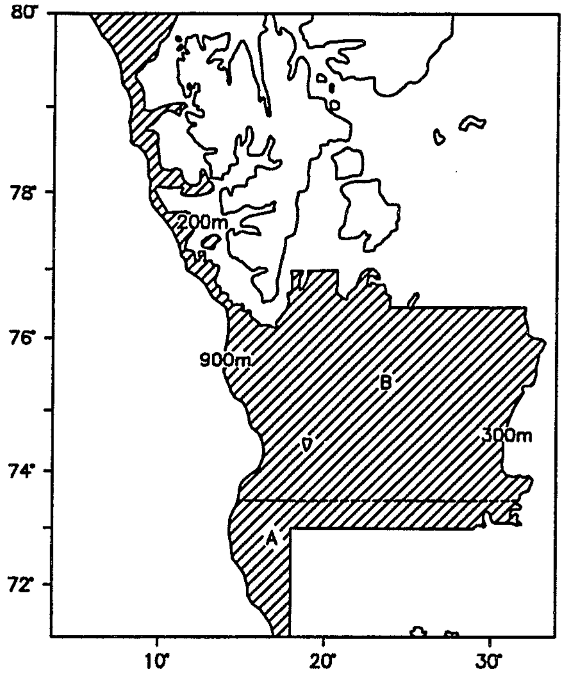

Figure 1. Survey area.

Number of Greenland halibut at age 3 in October-December 1984-1993 were calculated within standard areas in the eastern Norwegian and western Barents Seas, based on data from the surveys mentioned as well as data on age-length composition of the stock.

RESULTS AND DISCUSSION

Results from calculations are given in Table 1 and illustrated in Figure 2.

Table 1. Abundance of Greenland halibut at age 3 in October- December 1984-1993 (Nos.10^{-3}).

Year	Sub-area		
	A	B	C
1984	15,6	1060,9	1076,5
1985	0,7	2055,3	2056,0
1986	5,4	2162,0	2167,4
1987	-	111,7	111,7
1988	79,6	1574,3	1653,9
1989	57,6	1014,6	1072,2
1990	286,9	1849,3	2136,2
1991	no data	no data	no data
1992	149,1	490,8	639,9
1993	138,4	296,2	434,6
Average for 1984-1993	81.5	1179.5	1261.0

Immature Greenland halibut is distributed over an extensive area of the Barents Sea (Nizovtsev 1983). The surveys did not cover the whole area of distribution. Areas with high concentrations in the south-east part of the Central Deep and the northern area near the Franz Josef Land remained uncovered. This might explain the low abundance indices of the 3-year olds in 1987 (Table 1).

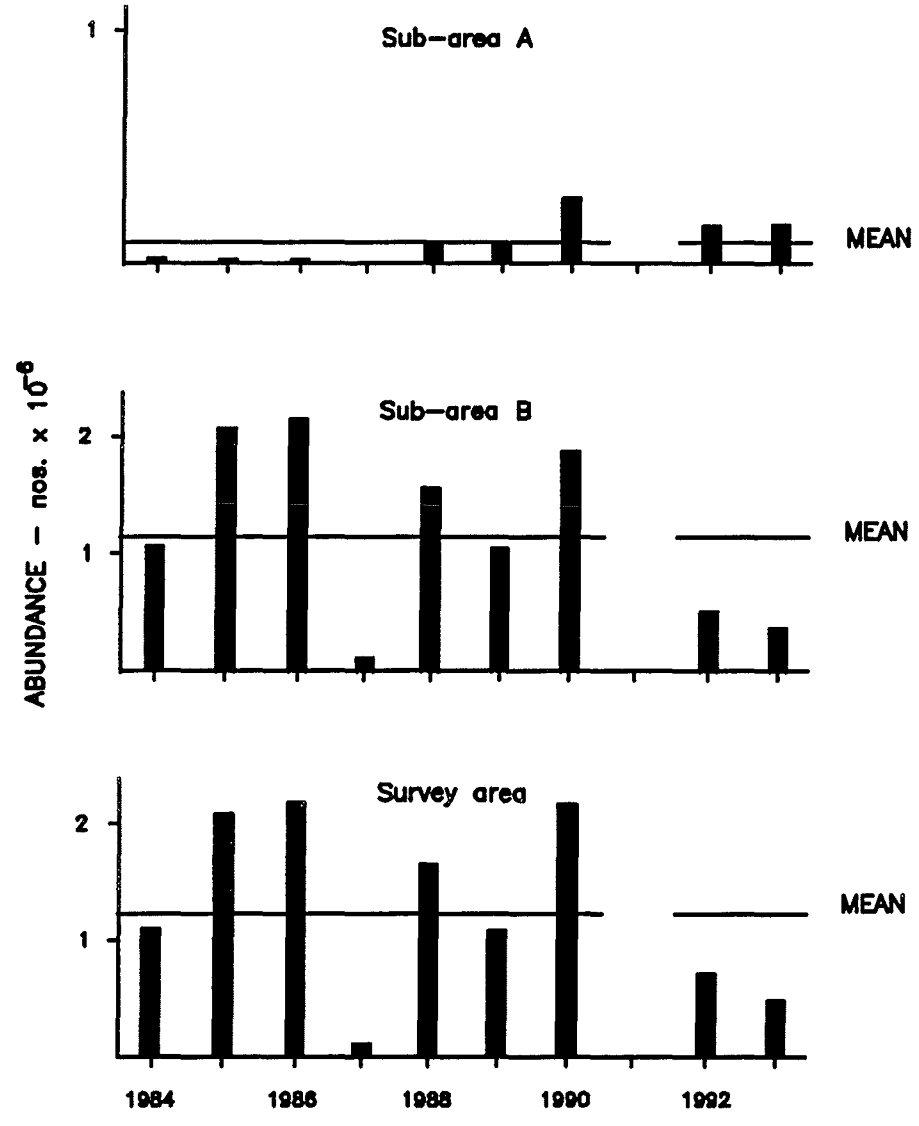

Figure 2. Abundance of 3-year old Greenland halibut. Sub-areas see Figure 1.

According to experts (pers. comm.) not more than 20% of actual amount of Greenland halibut at age 3 are recorded in the surveys, due to incomplete coverage of the area and the bathypelagic distribution life of juveniles. However, the figures obtained reflect variations in abundance of recruitment to the Greenland halibut stock. The abundance of recruitment in the survey area show a variation in the period 1984-1990 between 1 and 2 mill. fish, without any clear upward or downward trend (Table 1). Such stability can first of all be explained by the fact that unlike other fish species (cod, haddock etc.) juvenile Greenland halibut are not exposed to considerable fishing pressure in the early stages of their life because they do not concentrate in traditional cod/haddock fishing areas. However, the fishery for shrimps generate some pressure of the juveniles (Hylen and Jacobsen 1988).

Recruitment in 1992 - 1993 was at a low level. Such situation was most pronounced in areas of traditional concentrations of juveniles (as Subarea B). Recruitment in these years was only 40-60% of the long-term mean (Figure 2). This might be a consequence of the decline in the spawning stock which has been observed in the mid-80's (Anon. 1995). Minimum level of the spawning stock was recorded in 1988 - 1989 and poor year-classes were produced which might have contributed to the production of the poor 1992 - year-class (Anon. 1995). By the end of the 1980's an increase of abundance of Greenlanf halibut at age 3 was observed in the southern and south-eastern part of the survey area (Sub-area A). Such increase was also observed in the area south-east of the survey area (Murman Tongue, Murman Bank), probably related to some redistribution of the stock induced by warming of the Barents Sea in the end of the 80's - beginning of the 90's (Figure 2). However, since 1990 a decreased recruitment was observed in this area (Table 1).

CONCLUSIONS

Too high exploitation of the Greenland halibut stock resulted in a decrease in the spawning stock. This might have been responsible for the reduction in recruitment observed in the early 1990's. In 1990-1991 the Greenland halibut catch considerably exceeded the recommended TAC, and a rapid recovery of the stock would require that the spawning stock produces good year-classes in the near future.

REFERENCES

ANON. 1995. Report of the Arctic Fisheries Working Group, ICES Headquarters, 23 August - 1 September, 1994, *ICES CM 1995*/Assess: 2, 250 pp.

HYLEN, A. and **JACOBSEN, J.A.** 1988. Estimation of commercial demersal fish species taken as by-catch in the fishery for shrimp in the Barents Sea and the Svalbard region 1983-1986, *ICES CM 1988*/G:46, 29 pp.

NIZOVTSEV, G.P. 1983. Distribution of juvenile Greenland halibut in the Barents and eastern Norwegian Seas. *Ryb. Khoz. 1983* (12): 26-28.

SHEVELEV, M.S. and **LEPESEVICH, YU.M.** 1991. Results of Soviet investigation of the Norwegian-Barents Sea Greenland halibut stock assessment in 1990, *ICES CM 1991*/G: 24, 13 pp.

MODELLING AGE-DEPENDENT NATURAL MORTALITY OF JUVENILE NORWEGIAN SPRING-SPAWNING HERRING (*Clupea harengus* L.) IN THE BARENTS SEA

by

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ABSTRACT

Understanding the patterns of mortality in the juvenile stages is essential for improving current stock assessment procedures. A crucial aspect is at which stage in the life cycle of fish is year-class strength determined. Most of the research on "the recruitment problem" has focused on the larval stages, but recent work indicates that a large part of the variability in year-class strength may be associated with variable mortality during the juvenile stages. A statistical model, including age and year-class effects, was built, and fitted to the data on abundance of juvenile Norwegian spring-spawning herring in the Barents Sea collected by the Bergen Institute of Marine Research between 1983 and 1993. The results indicate that mortality is strongly age-dependent, and that most of it occurs during the first year of life. There is also a large inter-cohort variability in juvenile survival. Survival from the start of the 0-group stage to age 3 years may have varied from very low to around 30% for the cohorts investigated..

INTRODUCTION

Most of the natural (non-fishing) variability in fish population abundance is associated with recruitment (Sissenwine 1984), but recruitment variability remains the single least understood problem in fisheries science (Houde 1987). Most fishes are extremely fecund, and by the time a cohort recruits to the fishery, its abundance will typically have been reduced by several orders of magnitude (Cushing 1974). Among the pre-recruit stages, it is in the larval stages that mortality rates are highest, and small changes in these rates have the potential to account for large changes in recruitment (Wooster and Bailey 1989).

In this framework, it is hardly surprising that most studies of recruitment variations are still based on Hjort's (1914) hypothesis that year-class strength is determined in the early larval

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stages (Wooster and Bailey 1989). Recently, it has been suggested that a) variable mortality during the juvenile phase may account for a large part of the observed variability in recruitment (Sissenwine 1984 1986; Smith 1985; Daan 1987; Sparholt 1990; Fogarty *et al.* 1991) and b) this mortality should be strongly size- (and age-) dependent (Vetter 1988; Beyer 1989; Caddy 1991).

Despite several studies on this variability, there have been very few studies which have convincingly demonstrated the existence of appreciable inter-cohort variability in juvenile survival. Also, we know of none, other than those based on MSVPA (Sparholt 1990), showing that this mortality is size- or age-dependent. This is in most cases due to the difficulty in separating variable mortality from errors in the abundance estimates. To actually demonstrate the existence of changes in mortality rate with age or cohort, it is thus necessary to explicitly account for these errors, including them in the modelling procedure.

The Norwegian spring-spawning herring stock is one of those with largest recruitment variability in the Northeast Atlantic (Dragesund 1970; Serebryakov 1991), and it is often dominated by a couple of strong year-classes. In periods of low stock abundance, recruitment of a single good year-class may more than double the spawning stock biomass. Exceptional year-classes seem to occur only in years when a large part of the juveniles are distributed in the Barents Sea area (Dragesund 1970; Østvedt 1958; Seliverstova 1990a 1990b). The fish whose nursery is located in this area have a long juvenile period (3 years), meaning that recruitment will be quite sensitive to changes in mortality rate at this stage. It is therefore one of the most suitable stocks for testing whether variable juvenile survival may significantly affect year-class strength, measured at recruitment to the adult stock.

In this work, we develop a statistical model for abundance-at-age, which allows for age- and cohort-dependent mortality. This model is fitted to the series of abundance estimates of young herring in the Barents Sea collected by the Institute of Marine Research in Bergen (IMR) between 1983 and 1994 (Toresen and Barros 1995) The fit of the model to the data is analysed to test the null hypotheses that 1) the observed inter-cohort variability in juvenile mortality can be attributed to measurement errors and 2) mortality through the juvenile period is constant. For use in stock assessment work and for later investigations, we also present estimates of the actual mortality levels experienced by the different cohorts in the data set, and investigate the precision of these estimates.

MATERIAL AND METHODS

The data

The work presented in this paper is based on an analysis of a series of acoustic abundance estimates of pre-recruit herring in the Barents Sea nursery area collected between 1983 and 1984 as a part of the routine surveys undertaken in this important fishery area by IMR, which are presented and discussed by Toresen and Barros (1995). These estimates cover the juvenile period of the herring year-classes 1983 to 1993, with the exception of the year-classes 1986 and 1987, which recruited in so low numbers to the 0-group stage that they were taken as non-existent in the Barents Sea (Anon. 1994a).

The age of the herring corresponding to each estimate was calculated by computing the time interval (in years) between the assumed hatching date and the date assigned to the estimate. It was assumed that all fish in one cohort hatched simultaneously in April 1st. This choice of the hatching date was based on a study of hatching curves (Fossum 1993).

Not all estimates are equally reliable. Problems arising during some surveys led to estimates which are recognised as having a poorer quality than the others. However, they still convey important information, and were included in the analysis. To reflect their lower reliability, they were downweighted, by being assigned a relative "external weight" of 0.75. (Figure 1). The "external weight" assigned to the other estimates was 1.

The model

The research work done during the last decades has established that the young stages of fish suffer, in general, by a pattern of high instantaneous mortality rate, M, declining rapidly as the fish grow older, and achieve a relatively stable level as the fish approach maturity (Beyer 1989; Caddy 1991; Vetter 1988; McGurk 1993). The instantaneous mortality rate M may thus be modelled as a function of age and denoted M(t).

In this study, the Pareto function (Arnold 1985) has been used to model the relationship between M and age. This means that the expression for M at age t, M(t), may be written

$$M(t) = M_\infty + \beta\, t^{-\alpha} \quad (1)$$

where M_∞ is the mortality rate at (theoretical) infinite age, β is the difference between mortality at age 1 and asymptotic mortality, and α is a 'shape parameter', defining how fast the mortality change from the high mortality level typical of the young stages to the relatively stable and lower mortality of the adults. This model is able to reproduce most of the patterns of M-at-age considered for this phase of life, from a constant mortality ($\beta = 0$) to a rapidly declining mortality to a stable level. This equation may be reparametrized to consider the mortality at the start age, $M(t_0)$ as a parameter rather than at age 1, becoming

$$M(t) = M_\infty + \left(M_{t_0} - M_\infty\right)\left(\frac{t}{t_0}\right)^{-\alpha} \qquad (2)$$

where M_{t_0} is the mortality rate at age t_0, and the other parameters are as described above. Specifying $M(t)$ by expression (2), survival between ages t_0 and t_1 becomes

$$S(t_0,t_1) = \frac{N(t_1)}{N(t_0)} = e^{-\int_{t_0}^{t_1} M(x)\,dx} = \begin{cases} e^{-\left(M_\infty(t_1-t_0)+\frac{\left(M_{t_0}-M_\infty\right)t_0}{1-\alpha}\left(\left(\frac{t_1}{t_0}\right)^{(1-\alpha)}-1\right)\right)} & \text{if } \alpha \neq 1 \\ e^{-\left(M_\infty(t_1-t_0)+\left(M_{t_0}-M_\infty\right)t_0 \ln\left(\frac{t_1}{t_0}\right)\right)} & \text{if } \alpha = 1 \end{cases} \qquad (3)$$

And the abundance of the cohort at age t, $N(t)$ may therefore be written as

$$N(t_1)=\begin{cases} N(t_0)e^{-\left(M_\infty(t_1-t_0)+\frac{(M_{t_0}-M_\infty)t_0}{1-\alpha}\left(\left(\frac{t_1}{t_0}\right)^{(1-\alpha)}-1\right)\right)} & \text{if } \alpha \neq 1 \\ N(t_0)e^{-\left(M_\infty(t_1-t_0)+(M_{t_0}-M_\infty)t_0 \ln\left(\frac{t_1}{t_0}\right)\right)} & \text{if } \alpha = 1 \end{cases} \qquad (4)$$

expressing the expected number of survivors at age t_1, $N(t_1)$, as a function of the number initially present $N(t_0)$, the initial age t_0 and M_∞ , M_{t_0} and α .

Model (4) describes the abundance-at-age for one cohort. Stronger inferences can be made by using a model which can be fitted simultaneously to all cohorts in the data set, since this will allow us to make use of the regularities in the survival patterns among cohorts in the estimation process. Mortality experienced by the herring during the juvenile stages will most probably depend on the absolute abundance of its predators, on the relative sizes of the herring and the predators and on the degree of geographical overlap among the two. While the first of these factors varies from one year to the next, the two latter have a strong seasonal character. It is thus reasonable to assume that the level of mortality experienced by the different cohorts will vary, but that the pattern of decline in this mortality with age will be more or less the same for all cohorts. After recruiting to the adult stock, they will all more or less share the same environment, and will be subjected to the same conditions. Model (4) may thus be generalized by

$$N_c(t_1)=\begin{cases} N_c(t_0)e^{-\left(M_\infty(t_1-t_0)+\frac{(M_{t_0 g}-M_\infty)t_0}{1-\alpha}\left(\left(\frac{t_1}{t_0}\right)^{(1-\alpha)}-1\right)\right)} & \text{if } \alpha \neq 1 \\ N_c(t_0)e^{-\left(M_\infty(t_1-t_0)+(M_{t_0 g}-M_\infty)t_0 \ln\left(\frac{t_1}{t_0}\right)\right)} & \text{if } \alpha = 1 \end{cases} \qquad (5)$$

This model considers a different start number and a different mortality level for each cohort. The pattern of decline in mortality with age (represented by α) and the asymptotic mortality M_∞ are assumed to be common for all cohorts. If at least some cohorts have experienced so similar mortalities that they can be treated as if they had followed the same survival curve, the model can be simplified further by forcing these cohorts to share the same M_{t_0} parameter. In the model above, c and g index, respectively, each cohort and each group of cohorts assumed to have followed the same survival curve.

This model can now be used as a tool for investigating (1) which cohorts can be taken as having suffered at least approximately the same mortality (the null hypothesis states that all had the same mortality), (2) what kind of differences in mortality can be demonstrated with the data at hand, and (3) whether the assumption of an age-independent mortality can be justified by this data set.

Questions (1) and (2) can be investigated by forcing M_{t_0} to have a common value for those cohorts for which we want to test the hypotheses of a common mortality, and evaluating how well the resulting model describes the data. Question (3) can be studied by allowing a different M_∞ for each group of cohorts considered to have suffered the same mortality pattern, and forcing M_{t_0} to be equal to M_∞ for all these cohorts, resulting in model

$$N_c(t_1) = N_c(t_0)e^{-M_g(t_1 - t_0)} \qquad (6)$$

where M_∞ is replaced by M_g to indicate that it is no longer an asymptotic value, but rather a mortality rate which is independent of age, and exclusive to the group of cohorts to which it is associated.

Variance structure

In modelling fish abundance, it is generally reasonable to express the error in the abundance estimates as a proportion of the expected abundance. If the average size of the herring schools does not change systematically with the herring abundance, the number of schools will increase when abundance increases, and may therefore be more evenly distributed than in situations of low abundance. Under these circumstances, it seems reasonable to assume that the relative error in the abundance estimates will tend to decrease when total abundance increases.

Based on these considerations, it is assumed that the observed values, $N(t)$, are related to the values expected from the model, $E[N(t)]$, by the multiplicative error model

$$N(t) = E[N(t)]e^{\varepsilon} \qquad (7)$$

Where $E[N(t)]$ is the $N(t)$ value given by (7) or (8), and ε is a random variable with

$$E[\varepsilon] = 0 \qquad (8)$$

and standard error $Se(\varepsilon)$ inversely proportional to $\ln(E[N(t)])$,

$$Se(\varepsilon) = \frac{1}{\ln(E[N(t)])}\sigma \qquad (9)$$

Fitting the model

The model was fitted by minimizing the sum-of-squares of the weighted residuals $\sum_i (w_i e_i)^2$,

where

$$e_i = \ln(N_i(t)+1) - \ln(E[N_i(t)]+1) \qquad (10)$$

and

$$w_i = (\text{external weight})_i \ln(E[N_i(t)]+1) \qquad (11)$$

Each residual is thus weighted by the inverse of its variance.

Since model (5) for $N(t)$ is intrinsically non-linear (McCullagh and Nelder 1989), a non-linear regression procedure must be used for the estimation of the parameters.

In this case, a direct-search routine, the Nelder-Mead Simplex method (Mittertreiner and Schnute 1985; Nash and Walker-Smith 1987) was used. This method was preferred to other more sofisticated methods due to the ease of its implementation and its robustness to local minima.

Hypothesis testing and evaluation of the goodness of the fit

Having defined plausible hypotheses for the patterns in mortality of young herring during the period covered by our data, it is necessary to verify which of these hypotheses agrees best with the data. Besides the most restrictive null hypothesis (that all cohorts had the same mortality), available information suggest that it may be of interest to test the alternative hypotheses that there are (a) two different mortality levels, (b) three different mortality levels or (c) nine different mortality levels (that is, each cohort experienced a different level of mortality). Since each of these hypotheses can be formulated as a different model, it is possible to test them by comparing how well the different models fit the data. The procedure of comparing the fit of the models is eased if they can be defined as a special case of a more general model (the full model).

Question (1), which cohorts could be considered to have suffered the same mortality, was investigated first. This was achieved by comparing the different groupings of the M_{t_0} parameters suggested by earlier observations. Each of these models is a special case of a model where each cohort is associated to its own M_{t_0} parameter. The full model, in this case, is model (5), with one M_{t_0} for each cohort (9 M_{t_0} -parameters).

Each candidate model is compared with the full model, using F-ratio tests in an extra-sums-of-squares analysis (Bates and Watts 1988; Draper and Smith 1981). If the model does not give a significantly worse fit than the full model, is retained for the second step of the evaluation.
In the second step, the residual plots are examined to detect possible lack of fit due to inadequacy of the model specification (Bates and Watts 1988) which would not have been detected by the first test. Models which are shown to have lack of fit are rejected at this step, even if they had non-significant F-ratios. The final model selected is the simplest model of those which passed both tests.

After selecting the best grouping for the different cohorts, the hypothesis of age-independent natural mortality was tested. Model (6), in which the M_g's were grouped according to the best grouping selected earlier, was fitted to the data, and its fit was compared to the corresponding age-dependent model. The procedure followed was the same as that used to select the best grouping of the cohorts. In this case, neither of the models is a special case of the other. They must therefore be compared to an even more general model. This model was built by expanding model (5), to consider a different M_∞ for each group of cohorts,

$$N_c(t_1)=\begin{cases} N_c(t_0)e^{-\left(M_{\infty g}(t_1-t_0)+\frac{\left(M_{t_0 g}-M_{\infty g}\right)t_0}{1-\alpha}\left(\left(\frac{t_1}{t_0}\right)^{(1-\alpha)}-1\right)\right)} & \text{if } \alpha \neq 1 \\ N_c(t_0)e^{-\left(M_{\infty g}(t_1-t_0)+\left(M_{t_0 g}-M_{\infty g}\right)t_0\,\ln\left(\frac{t_1}{t_0}\right)\right)} & \text{if } \alpha = 1 \end{cases} \qquad (12)$$

Determining significance of the test statistics

The use of a non-linear model with a non-additive error term whose distribution is not completely specified, prevents us from using the tabulated F-distributions to determine the significance level of the observed F-ratios. To overcome this problem, a bootstrap procedure (Efron 1982; Efron and Tibshirani 1993; Leger *et al. 1992*) was used to compute the significance of the observed F-ratios.

Both the full and the reduced model were fitted to the original data. The residuals of the fit from the full model were computed, standardized and 1000 random samples, with replacement, were taken. These randomized residuals were then combined with the values expected from the fit of the reduced model, to construct 1000 bootstrap resamples. The full and the reduced models were then refitted to each of these bootstrap resamples, and the F-ratio was recalculated for each of them. The distribution of the resulting 1000 F-ratios was taken as the distribution of the F-ratios under the null hypothesis (Hall and Wilson 1991), and used to ascertain the significance level of the observed F-ratios. The uncertainty in the "best" model was then calculated, and presented as the confidence region around the estimated survival curves. These confidence regions were also computed using a bootstrap procedure based on resampling the residuals from the fit of this "best" model. 1000 bootstrap samples were constructed, and the survival curves were estimated by fitting the model to each of them. The age interval of interest (ages 0.4 to 3 years) was divided in 500 equal intervals, and the survival at the limits of these intervals was calculated for each survival curve. The estimated survivals at each of these points were ranked, and the 2.5% and the 97.5% percentiles of these were calculated. The upper limit of the 95% confidence regions were thus defined by the set of the 97.5% percentiles of the estimated survivals at all these points, while the lower limits were built from the 2.5% percentiles.

RESULTS

The abundance-at-age values estimated for the different cohorts by fitting the full model to the acoustic abundance estimates are compared to the corresponding acoustic estimates in Figure 2. The model succeeds in reproducing the main trends in the data, and shows no lack of fit. It is therefore reasonable to base the analysis of the mortality patterns on this model.

Considering only the survival curves, i.e., removing the effect of the different recruitment levels (Figure 3), it is seen that these survival curves have a markedly clustered appearance. The curves for the 1983, 89, 90 and 91 year-classes are clearly very similar, at a high level, while those for the 1984, 85, 88 and 1993 are also relatively similar, but at the other end of the range. The estimated survival curve for the 1992 cohort lies somewhat between these two extremes, but is closer to the high-survival group.

The extra-sum-of-squares analysis (Table 1) confirms this qualitative appreciation, but indicates also that the available data do not allow us to reject the hypothesis that the difference between the survival curve estimated for the 1992 cohort and those considered as "high survival" is due to errors in the estimates of abundance.

Table 1. Extra-sum-of-squares analysis comparing the fit of different alternative models for the similarity in mortality patterns among the cohorts studied. Cohorts joined between two '/' symbols are assumed to share the same mortality pattern. d.f.- Degrees-of-freedom; ESS - Extra Sum of Squares; MES - Mean Extra Square

Model	Parameters	d.f.	ESS	MES	F-ratio	P-value
/83,84,85,88,89,90,91,92,93/	12	8	1539.06	192.38	6.949	< 0.001
/83,89,90,91,92/84,85,88,93/	13	7	81.37	11.63	0.420	0.757
/83,89,90,91/92/84,85,88,93/	14	6	67.87	11.31	0.409	0.787
/83,89,90,91,92/84,85/88/93/	16	4	12.11	3.03	0.109	0.906
/83,89,90,91/84/85/88/92/93/	17	3	1.04	0.35	0.013	0.980
Full model	20	30	830.50	27.68		

All values presented in table (except the last row, which represents the fit of the full model) refer to the extra sum-of-squares relatively to the full model. It is therefore concluded that the data do not allow us to distinguish more than two levels of survival, a very low one and a more "normal" level.

The survival curves estimated under the hypothesis of only two distinct mortality levels (Figure 4) manage to follow quite well the main patterns in the individual survival curves for each cohort, making the results of the extra-sum-of-squares analysis more intuitive.
From a stock assessment point of view, the quantity of interest is usually the survival through the juvenile period. For young herring in the Barents Sea, this may be approximated by survival to age 3 (Table 2). These estimated survivals show the same pattern which was already apparent on the survival curves plots. Survival for the whole juvenile period is estimated to be around 17% for the 1983, 89, 90 and 91 cohorts, while for the 84, 85, 88 and 93 cohorts it is estimated to be close to 0%, and 10% for the 1992 cohort. These values are again quite well approximated by the two-level model.

Table 2. Survival from age 0.4 to age 3 for the different groups of survival curves estimated. The confidence intervals were computed using a bootstrap technique.

Mortality model	Survival level	Survival to age 3 (%)	
		Point estimate	95% Confidence Interval
Two levels	High	15.8	9.4-26.8
	Low	0.3	0.0- 0.6
All Cohorts different	83	15.8	3.2-77.6
	84	0.2	0.0-1.2
	85	0.1	0.0-0.4
	88	0.4	0.0-3.5
	89	17.6	5.7-50.5
	90	17.0	9.7-28.5
	91	18.8	13.0-32.7
	92	10.4	5.2-20.1
	93	0.7	0.1-1.5

Age-independent versus age-dependent natural mortality

Since only two mortality levels could be distinguished, the test of the hypothesis of an age-independent natural mortality was performed under the two-level model. The extra sum-of-squares analysis (Table 3) clearly indicates that the hypothesis of age-independent mortality does not match the observed patterns in the data for abundance-at-age. Comparison of the residual plots of the age-dependent and the age-independent mortality models (Figure 5) reveals that the latter shows a clear lack of fit, as it does not manage to reproduce the pattern of fast decline in abundance in the youngest ages which is a main feature of the data.

Table 3. Extra-sum-of-squares analysis comparing the fit of the age-independent and the age-dependent mortality models. d.f.-Degrees-of-freedom; ESS - Extra Sum of Squares; MES - Mean Extra Square

Model	Parameters	d.f.	ESS	MES	F-ratio	P-value
Age-independent	11	3	543.56	181.19	7.155	< 0.001
Age-dependent	13	1	0.19	0.19	0.008	0.858
Full model	14	36	911.68	25.32		

All values presented in the table (except the last row, which represents the fit of the full model) refer to the extra sum-of-squares relatively to the full model.

Assessment of precision in model fitting

The confidence regions for the estimated survival curves are presented in Figure 6 a-c). To ease the interpretation, the confidence regions for the survival curves are summarised by the 95% confidence intervals for survival between ages 0.4 and 3 years in Table 2. When estimating separate survival curves for each cohort the intervals have a very large degree of overlap. The widest confidence intervals for the high-survival cohorts even overlap with those computed for some of the low-survival cohorts. The survival curves estimated under the assumption of only two different mortality levels, on the other hand, are much better determined, and are well separated, even if the confidence intervals are still relatively wide. In both cases, the confidence regions are widest at the intermediate ages, where the degree of curvature of the curves is highest. Under both alternatives, however, survival through the juvenile phase for the 1984, 85, 88 and 93 cohorts is in the neighbourhood of 0%, while that for the other cohorts is clearly positive.

DISCUSSION

The analysis presented in this paper was based on the assumptions that the acoustic abundance estimates are unbiased estimates of the true abundance of the fish in the sea, and that the model correctly describes the true trajectory of the abundance-at-age of the different cohorts. None of these assumptions is completely satisfied, and it is necessary to evaluate the magnitude and the direction of the errors incurred in by taking them as true.

Reliability of the data

Acoustic estimates of abundance of pelagic schooling fish are subject to a number of sources of error, which decrease the precision of the estimated abundances (Simmonds *et al.* 1992). The sources of error and the reliability of the abundance estimates used in this study were discussed by Toresen and Barros (1995), and will not be dealt with further here. From the point of view of this study, the main points of interest lie in the relative degree of underestimation of the different age-groups. If the older herring are more strongly underestimated than the 0-group, then the true mortalities will be lower than those estimated here, but the age effect will be stronger. If the converse is true, then the effect will be the opposite. As discussed by Toresen and Barros (-1995), the information available today, however, does not allow us to evaluate which, if any of these situations applies to the data used here. This possibility must, however, be taken into account when evaluating the results from this study.

For some estimates, there are nevertheless indications of more or less important errors, which may have influenced the results from this study. This is the case for the two first and the two last estimates of the 1983 year-class, which are considered to be strongly underestimated (Toresen and Barros 1995).

Another difficulty is the data for the 1989 cohort. The estimates of abundance-at-age for this cohort increase regularly after age 1, indicating a systematic error in the estimation of the abundance of this cohort. This cohort was exceptionally abundant in the fjords of Finnmark, as 0-group fish (Anon. 1994a), and its size-at-age at the older ages of the juvenile stage was much higher than the average for Barents Sea herring (I. Røttingen, I.M.R., pers. comm.). This indicates that there was most probably a significant emigration of young herring from the Finnmark fjords into the Barents Sea after age 1. To investigate the consequences of these possible errors for the conclusions of the work, we repeated the analysis by downweighting the dubious estimates in two different ways. First, we assigned a weight of 0.2 to the two first and the two last estimates for the 1983 cohort. Second, the estimates of the 1989 year-class after age 1 were downweighted in the same way. Downweighting the estimates of the 1983 year-class caused a doubling of the absolute abundance estimates of the cohort at all ages, but the estimated mortality and the inferences were relatively unchanged. The second modification led to an appreciable reduction of the estimated age-3 survival of 1989 cohort under the full model (-8%), but none of the other results were significantly affected (neither in the estimated survivals of the other cohorts nor in the inferences). It was therefore considered that none of these errors, even if they indeed existed, would significantly affect the main conclusions of the work.

The precision of the survival parameters estimated for the 1993 year-class is obviously difficult to evaluate, as only two data points are available. Yet, the observed changes in abundance are so large that the conclusion that this cohort suffered a very high mortality is difficult to impugn.

Formulation of the model

Age- and cohort effects were considered when modelling mortality. Although it can be considered that it would be more appropriate to model mortality as a function of size, rather than age, using age leads to a simpler model than if size had been considered, and we considered that it did not implicate a large loss of information, since size is also a function of age (Cushing 1974). A more relevant argument could be the one that mortality should be modelled as a year-effect, rather than a cohort-effect. In this case, however, a cohort-effect was considered a more adequate formulation. Younger and smaller fish are likely to be more affected by these changes in the environment than the larger herring, and the one-year interval between consecutive cohorts makes each cohort well individualised, while defining the changes as year-effects would imply setting an arbitrary cut-point between years.

Evaluation of the results

The results obtained in this study show that the statistical modelling approach may give quite useful contributions to the study of inter-cohort variability in survival of juvenile Norwegian spring-spawning herring. This variability in survival is very high, and mortality rates during this life-stage are strongly age-dependent. Both null hypotheses which were put forward at the start of the study can therefore be rejected with a high degree of confidence.

The time series investigated are quite short, and cover only one period in which the herring stock is increasing (a "one-way trip", in the terminology of Hilborn and Walters 1992). One must therefore be careful when extrapolating the conclusions of this work. Nevertheless, some aspects revealed by this study may have a general relevance, and are worth discussing.

The sheer magnitude of the differences in survival among the cohorts investigated is overwhelming. The mortality experienced by the cohorts in the "high-mortality group" was so high that they were practically extinct by the end of the juvenile period. Given this large difference, and that only two levels of mortality could be conclusively demonstrated, the dynamics of the juvenile herring in the period investigated can be described as an "all or nothing" situation. Cohorts can accordingly be classified as either "success" or "failure", setting another dimension to the evaluation of the effects of variable mortality in recruitment. In this perspective, the high proportion of cohorts which can be classified as "failures" (4/9, or practically 50%) must be considered as a strong evidence that year-class strength of this stock can (and most probably frequently is) determined by variable mortality at the juvenile stage. This study is thus a test of Hjort's (1914) hypothesis that year-class strength is determined in the larval stage. The results obtained indicate that this hypothesis must be rejected for the Norwegian spring-spawning herring stock. Most other studies addressing this question could not reject Hjort's hypothesis (Myers and Cadigan 1993). This may be due to the fact that for very few stocks is there data series of the quality and length of the one used in this study, especially data including the youngest juvenile stages, where large variability in mortality is most likely to occur.

The age-dependent effect in mortality was estimated to be very strong. This implies that most of the juvenile mortality occurs during the first year of life, and that older herring (2-group and late 1-group) are much less susceptible to these variations in mortality. The existence of a strong size-dependent mechanism conditioning mortality is therefore strongly suggested by this study. Studies of this aspect would probably shed some light on the actual processes mediating mortality in this stock (which might be generalizable to other stocks), and would probably be worth investigating deeper.

In a management perspective, the main application of studies on the mortality of juveniles lies in improving the forecasts of recruitment. This requires the capacity to predict the changes in juvenile survival. The procedure developed here can be used to describe the patterns in juvenile herring mortality and to test hypotheses about their variations, once these have occurred. It can also be used to forecast recruitment, once at least one estimate of abundance and the mortality level expected for the given cohort are available. It does not provide a means to predict this mortality, however, and consequently it cannot be directly used for prediction.

Hamre (1988 1994) has suggested that the variations in mortality of young herring in the Barents Sea are due to variable predation pressure by Northeast Arctic cod, and studies of cod stomach contents (e.g. Mehl 1989) seem to support this hypothesis. For applying this in assessment work, it is necessary to develop a suitable measure of the cod's predation pressure on the young herring, and to quantify the relationship between this measure and herring mortality. It is also required to demonstrate convincingly that the observed variations in herring mortality can be explained by corresponding variations in the cod predation pressure, and that the latter can be used to effectively predict the changes in herring mortality. This will require careful consideration of the species interactions in the Barents Sea, and stresses the relevance of the current work aimed at expanding the multispecies modelling efforts for the area (e.g. Tjelmeland and Bogstad 1993) to include the juvenile herring, which is getting increasing importance in this ecosystem (Hamre 1994; Anon. 1994b).

REFERENCES

ANON. 1994a. Report of the Atlanto-Scandian Herring and Capelin Working Group. *ICES CM 1994*/Assess: 8, 78 pp.

ANON. 1994b. Ressursoversikt 1994. Fisken og Havet 1994, Særnummer 1, 104 pp. (In Norwegian)

ARNOLD, B. C. 1985. Pareto distribution. Pp. 568-574 in Kotz, S., Johnson, N. L. and Read, C. B. (eds.). *Encyclopedia of Statistical Sciences*. John Wiley & Sons. New York.

BATES, D. M. and **WATTS, D. G.** (eds.). 1988. *Nonlinear Regression Analysis and Its Applications*. Wiley. New York. 365 pp.

BEYER J. E. 1989. Recruitment stability and survival - simple size-specific theory with examples from the early life dynamics of marine fish. *Dana, 7*: 45-147.

CADDY, J. F. 1991. Death rates and time intervals: Is there an alternative to the constant natural mortality axiom?. *Rev.Fish Biol.Fish., 1*(2): 109-138.

CUSHING, D. H. 1974. The Possible Density-Dependence of Larval Mortality and Adult Mortality in Fishes. *The Early Life History of Fish*, in Blaxter, J.H.S. (ed.). Springer-Verlag. New York.

DAAN, N. 1987. Multispecies versus single-species assessment of North Sea fish stocks. *Can.J.Fish.Aquat.Sci., 44*: 360-370.

DRAGESUND, O. 1970. Distribution, Abundance and Mortality of young and adolescent Norwegian spring spawning herring (*Clupea harengus* L.) in relation to subsequent year-class strength. *FiskDir.Skr.Ser. HavUnders. 15*(4): 451-556.

DRAPER, N. R. and **SMITH, H.** 1981. *Applied Regression Analysis*. 2nd ed. John Wiley & Sons. New York. 709 pp.

EFRON, B. T. 1982. *The jackknife, the bootstrap and other resampling plans*. Society for Industrial and Applied Mathematics. Philadelphia, Pennsylvania. 92 pp.

EFRON, B. T. and **TIBSHIRANI, R.** 1993. *An introduction to the Bootstrap. Monographs on Statistics and Applied Probability*. Chapman and Hall, London. 436 pp.

FOSSUM, P. 1993. A study of first-feeding herring (*Clupea harengus*) larvae during the period 1985-1993. *ICES CM 1993*/H: 21, 19 pp.

FOGARTY, M. J., SISSENWINE, M. P. and **COHEN, E. B.** 1991. Recruitment variability and the dynamics of exploited marine populations. *Tr.Ecol.Evo.6*(8): 241-247.

HALL, P. and **WILSON, S. R.** 1991. Two guidelines for Bootstrap Hypothesis testing. *Biometrics 47*: 757-762.

HAMRE, J. 1988. Some aspects of the interrelations between the herring in the Norwegian Sea and the stocks of capelin and cod in the Barents Sea. *ICES CM 1988*/H:42, 14 pp.

HAMRE, J. 1994. Biodiversity and exploitation of the main fish stocks in the Norwegian-Barents Sea ecosystem. *Biodiv.Conserv. 3*: 473-492.

HJORT, J. 1914. Fluctuations in the great fisheries of Northern Europe Viewed in the Light of Biological Research. *Rapp. P.-v.Reun.Cons. Int.Explor.Mer., 20*: 1-228.

HILBORN, R. and **WALTERS, C. J.** 1992. *Quantitative fisheries stock assessment. Choice, dynamics and uncertainty*. Chapman and Hall, London. 569 pp.

HOUDE E. D. 1987. Fish early life dynamics and recruitment variability. *Am.Fish.Soc.-Symp. Ser., 2*: 17-29.

LEGER, C., POLITIS, D. N. and **ROMANO, J. P.** 1992. Bootstrap Technology and Applications. *Technometrics, 34*(4): 378-398.

MCCULLAGH, P. and **NELDER, J. A.** 1989. Generalized Linear Models. 2nd ed. Monographs on *Statistics and Applied Probability 37*, 511 pp. Chapman and Hall. London.

MCGURK, M. D. 1993. Allometry of Herring Mortality. *Trans. Am. Fish.Soc.,122*(6): 1035- 1042.

MEHL, S. 1989. The Northeast Arctic Cod Stock's consumption of commercially exploited prey species in 1984-1986. *Rapp.P.-v. Réun.Cons. int. Explor.Mer, 188*: 185-205.

MITTERTREINER, A. C. and **SCHNUTE, J.** 1985. SIMPLEX: A manual and software package for easy nonlinear parameter estimation and interpretation in fishery research. *Can. Tech. Rep. Fish. Aquat. Sci.*, 1384 pp.

MYERS, R. A. and **CADIGAN, N. G.** 1993. Is juvenile natural mortality in marine demersal fish variable?. *Can. J.Fish. Aquat.Sci., 50*: 1591-97.

NASH, J. C. and **WALKER-SMITH, M.** 1987. *Nonlinear Parameter Estimation - An Integrated System in BASIC.* Marcel Dekker, New York. 493 pp.

SELIVERSTOVA, E. I. 1990a. Spawning stock structure and population fecundity of the Atlanto-Scandian herring. Pp. 41-88 in Monstad, T. (ed.): *Biology and fisheries of the Norwegian spring spawning herring and blue whiting in the Northeast Atlantic. Proceedings of the fourth Soviet - Norwegian Symposium. Bergen-Norway, 12-16 June 1989.* Institute of Marine Research, Bergen, Norway.

SELIVERSTOVA, E. I. 1990b. Growth and maturation rate of Atlanto-Scandian herring in the 1950-1980s. *ICES CM 1990*/H:7, 25pp.

SEREBRYAKOV V. P. 1991. Predicting year-class strength under uncertainties related to survival in the early life history of some North Atlantic commercial fish. Management under uncertainties related to biology and assessments, with case studies on some North Atlantic fisheries. *NAFO Sci.Coun.Stud., 16*: 49-55.

SIMMONDS, E. J., WILLIAMSON, N. J., GERLOTTO, F. and **AGLEN, A.** 1992. Acoustic survey design and analysis procedure: A comprehensive review of current practice. *ICES Coop.Res.Rep.* No. 187, 131pp.

SISSENWINE, M. P. 1984. Why do fish populations vary?. Pp. 59-94 in May, R. M. (ed.): Exploitation of Marine Communities. *Report of the Dalhem Workshop on Exploitation of Marine Communities, 1-6 April, Berlin 1984.*

SISSENWINE, M.P. 1986. Perturbation of a predator- controlled continental shelf ecosystem in Sherman, K. and Alexander, L.M. (eds.). Variability and *Management of Large Marine Ecosystems, 99*: 55-85

SMITH, P. E. 1985. Year-class strength and survival of 0-group clupeoids. *Can. J.Fish.Aquat.Sci., 42*: 69-82.

SPARHOLT, H. 1990. Improved estimates of the natural mortality rates of nine commercially important fish species included in the North Sea Multispecies VPA model. *J.Cons.int.Explor.Mer, 46*(2): 211-223.

TJELMELAND, S. and **BOGSTAD, B.** 1993. The Barents Sea Capelin Stock Collapse: A Lesson to Learn. *Can.Spec.Publ.Fish.Aquat.Sci., 120*: 127-139.

TORESEN, R. and **BARROS, P.** 1995. Acoustic estimates of abundance-at-age of juvenile Norwegian spring-spawning herring (*CLUPEA HARENGUS* L.) in the Barents Sea from 1983 to 1993. Pp. 167-178 in Hylen, A. (ed.): *Precition and relevnace of pre-recruit studies ofr fishery management related to fish stocks in the Barents Sea and adjacent waters. Proceedings of the sixth IMR-PINRO symposium. Bergen, 14-17 June 1994.* Institute of Marine Research, Bergen, Norway.

VETTER E. F. 1988. Estimation of natural mortality in fish stocks: A review. *Fish. Bull., 86*(1): 25-43.

WOOSTER, W. S. and **BAILEY, K. M.** 1989. Recruitment of marine fishes revisited. *Can. Spec. Publ. Fish. Aquat. Sci., 108*: 153-159.

ØSTVEDT, O. J. 1958. Some considerations concerning the homogeneity of the Atlanto-Scandian herring. *Rapp. P.-v. Réun.Cons.int.Explor.Mer, 143*: 53-57.

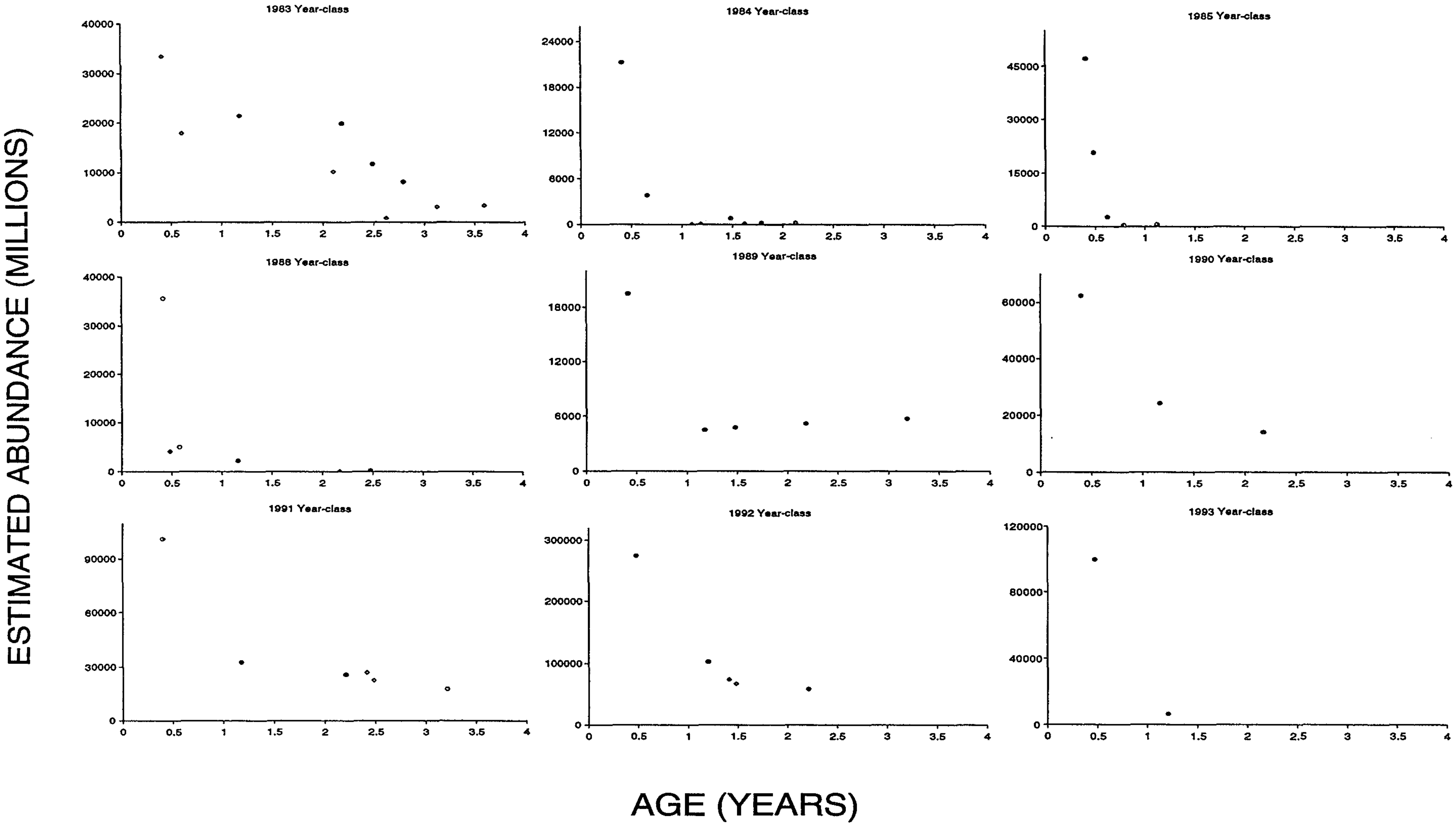

Figure 1. Acoustic abundance estimates available for the 1983-1985 and 1988-1993 year-classes. Estimates of “normal” quality; Estimates of dubious quality

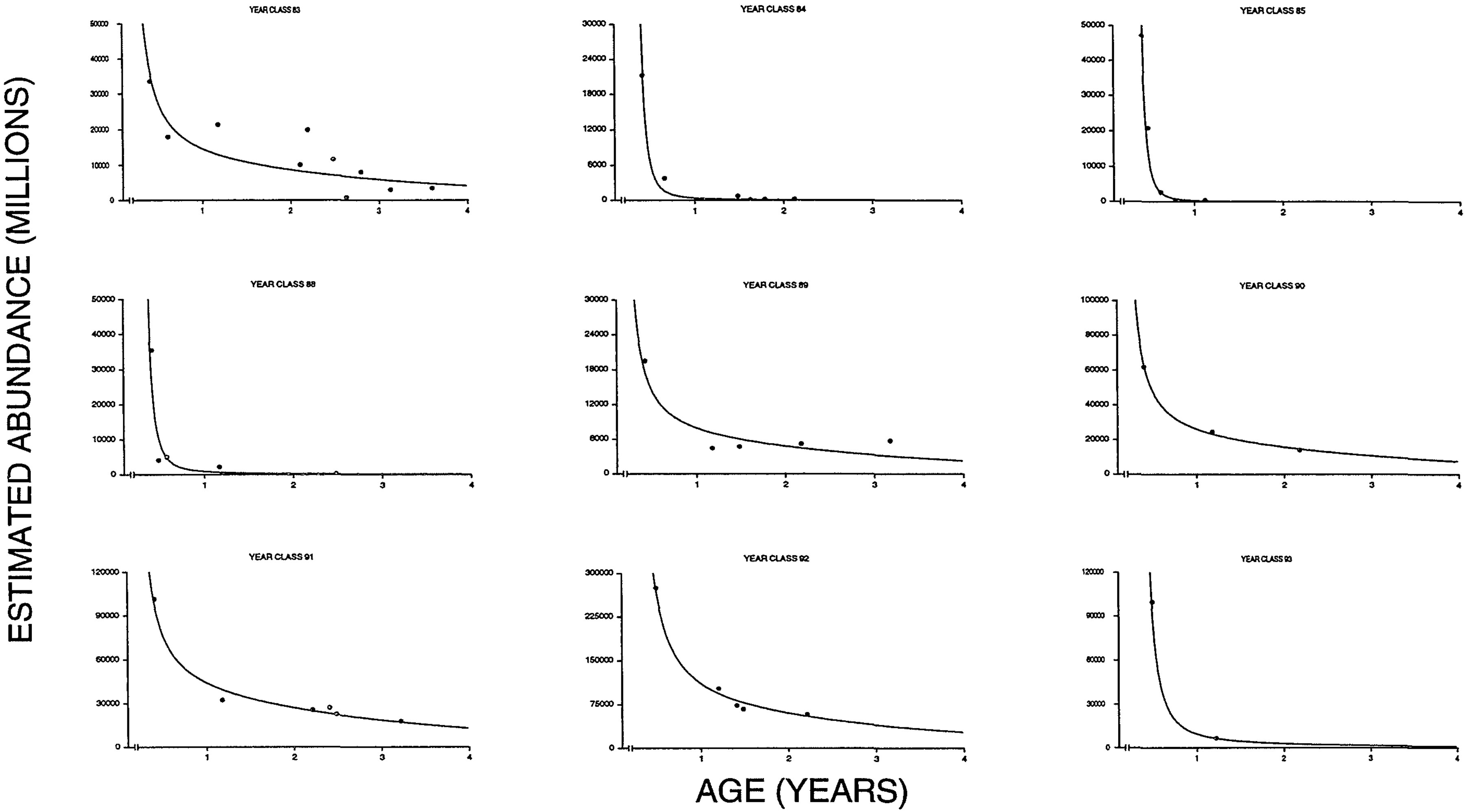

Figure 2. Abundance-at-age predicted from the full model and corresponding acoustic estimates, for juvenile stage of cohorts 1983-1993 in the Barents Sea.

Figure 3. Survival curves estimated under the full model.

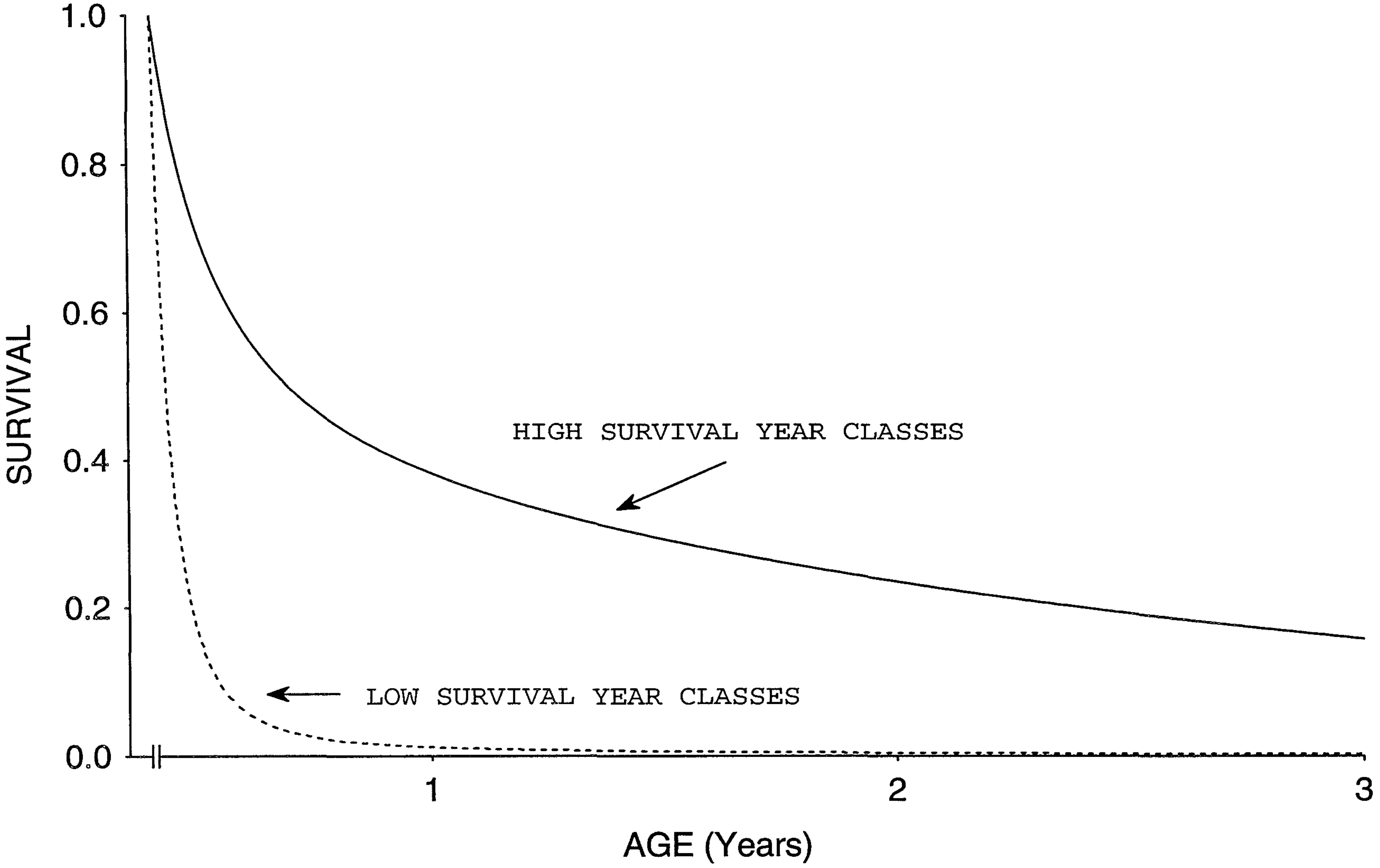

Figure 4 Survival curves estimated under the two-mortality levels model.

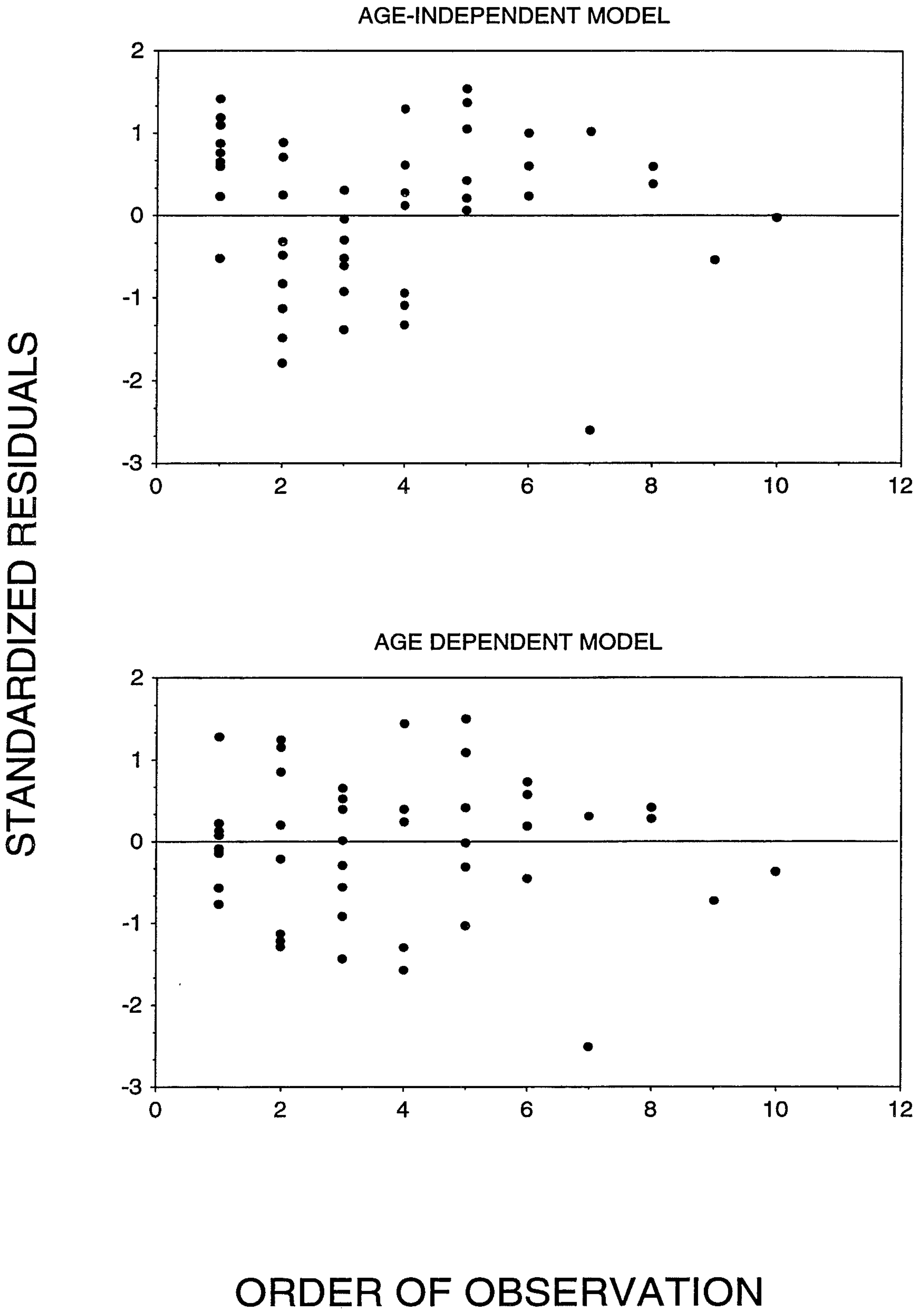

Figure 5. Comparison of residual plots for fit of age-independent and age-dependent mortality models.

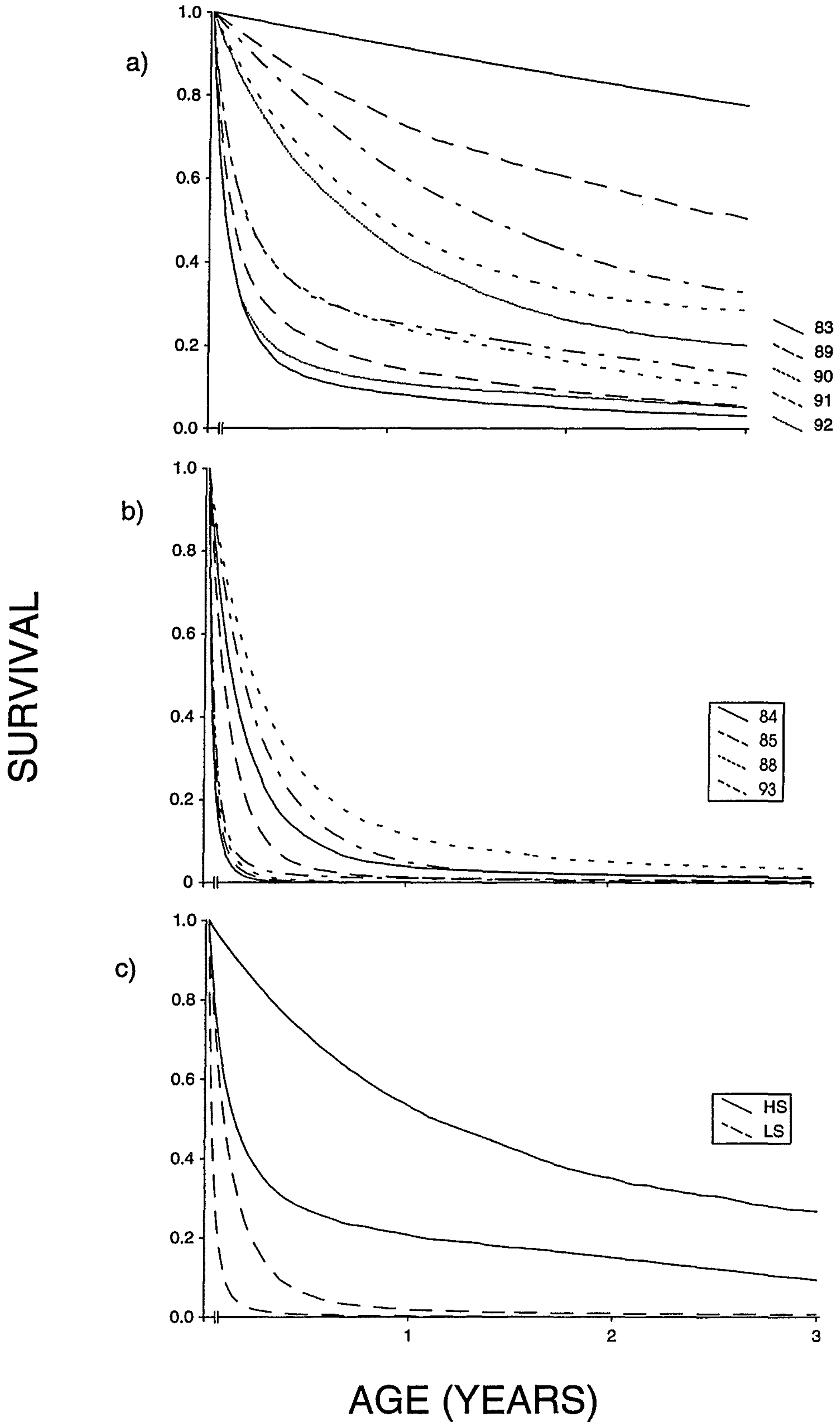

Figure 6. Confidence regions for survival-at-age during the juvenile stage of herring in the Barents Sea. a) Full model, high-survival cohorts. b) Full model,low-survival cohorts. c) Reduced model, high-and low-survival cohorts.

STOCK STATUS AND DYNAMICS OF NORWEGIAN SPRING-SPAWNING HERRING FECUNDITY IN 80'S

by

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ABSTRACT

Absolute individual fecundity of herring from the 1980's year classes increased with age and growth of fish, similar to that in previous decades. In 1993, spawning stock biomass of herring constituted 2.4 mill. tonnes and population fecundity 281×10^{12} eggs. These figures correspond to the critical level of population fecundity, at which rich year classes can be produced by maximum favourable survival conditions. At present, the reproduction of spring-spawning herring (also the fishery for this species) are based mainly on the 1983-year class. A intensified fishing can have a serious effect on the future year class strength.

INTRODUCTION

The increased fishing pressure on adult and immature spring-spawning herring in the 1950-60's at the same time as poor year classes recruited to the stock, resulted in serious reduction of the herring stock and collaps of the fishery in the Norwegian Sea. Rebuilding of the spring-spawning herring stock started in the 1970's with the recruitment of the 1969-, 1973-, 1979- year classes to the spawning stock. The spawning stock increased from 1.3 billion fish in 1980 to 7.3 billion fish in 1992, corresponding to a spawning biomass of 0.5 and 2.4 mill. tonnes respectively (Anon.1990, 1994a). The main part of the recruits to the spawning stock belonged to the Barents Sea component of the 1983-year class. Maturation of this year class was completed in 1989 which make it possible to follow variations in individual herring fecundity and the population fecundity in the 1980's and compare these figures with those obtained the in 1950-70's.

MATERIAL AND METHODS

Data on age composition and fecundity of spring-spawning herring in 1985-1993 were collected on the spawning grounds along the Norwegian coast. Gonads were fixed in 4% of formalin. Number of eggs were counted in 1 g of ovary and then raised to the total weight of the gonad. A total of 949 ovaries were analysed. A method described by Serebryakov (1988)

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was applied to calculate the reproductive potential of the herring population under different environmental conditions.

INDIVIDUAL FECUNDITY OF THE 1983-YEAR-CLASS

Herring of the 1983-year-class which matured at an age of 3 to 5 years, have been dominating the spawning grounds up to present time (Figure1). Individual fecundity of year-classes of the 1980's increased with age as in previous decades (Seliverstova 1990, Table 1). Variations in mean fecundity of herring during the study period were caused by dominance of single year-classes and changes in the age-composition (Figure 2A).

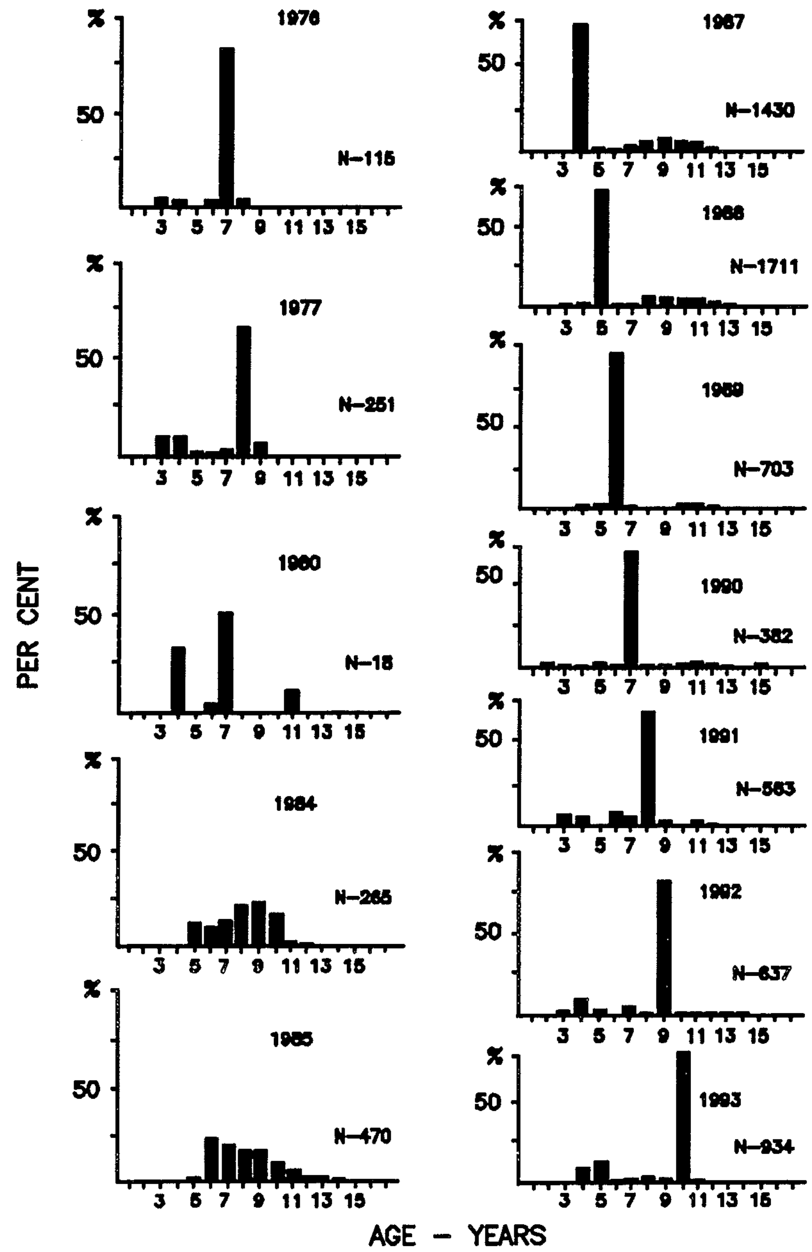

Figure 1. Age distribution of Norwegian spring spawning herring on the spawning grounds 1976-1993.

Table 1. Absolute individual fecundity of spring spawning herring in 1985, 1987-1993. (Nos.·10^{-3}).

Age	Year of investigation [1]							
	1985	1987	1988	1989	1990	1991	1992	1993
3	-	-	29.2- 29.2(1)	-	17.5-37.1 27.3(2)	10.1-57.9 35-8(14)	38.1-46.8 40.8(3)	-
4	-	19.9-49.7 35.5(6)	-	-	-	40.6-59.5 48.3(14)	22.0-70.6 46.7(14)	14.9-54.6 35.4(22)
5	-	37.6-55.7 46.6(6)	15.1-69.0 37.2(104)	48.8- 48.8(1)	23.6-74.8 46.5(8)	33.6- 33.6(1)	44.6-87.3 67.7(7)	27.4-59.3 47.6(23)
6	48.3-80.1 67.1(3)	55.8-80.0 66.6(3)	47.4-71.8 57.5(5)	23.6-77.7 47.8(82)	50.1-66.1 56.5(3)	40.1-82.9 59.2(15)	60.3-78.1 69.2(2)	56.2-66.0 60.0(3)
7	58.0-69.9 64.7(3)	52.9-84.5 71.0(8)	42.3-77.3 57.1(8)	54.4-78.7 66.5(2)	41.0-103.0 58.9(98)	39.5-88.6 70.4(7)	54.6-101.2 67.8(9)	-
8	68.9-98.7 81.8(4)	46.1-100.0 67.4(27)	41.4-79.4 61.6(18)	-	60.7-134.3 97.5(2)	37.2-101.1 67.4(83)	82.0-97.2 89.6(2)	47.9-107.6 77.2(8)
9	111.1- 111.1(1)	51.4-104.6 73.2(31)	49.5-105.1 68.1(18)	-	55.6- 55.6(1)	68.6-98.6 80.1(5)	51.1-159.1 79.9(86)	49.6-81.4 67.1(3)
10	66.3-103.9 79.6(5)	58.9-104.0 80.1(14)	55.2-98.7 77.1(11)	-	72.2-87.7 80.6(3)	90.9-94.5 92.7(2)	67.2-75.9 71.5(2)	48.6-118.4 75.1(59)
11	91.5- 91.5(1)	51.5-89.6 71.9(11)	53.5-150.1 84.8(16)	80.3- 80.3(1)	61.5-106.9 87.4(3)	64.8-117.1 94.2(7)	95.8-105.9 100.8(2)	-
12	78.5- 78.5(1)	47.7-109.1 76.9(6)	54.6-123.6 76.2(10)	-	93.8-110.5 102.1(2)	73.2-109.6 93.6(3)	97.2- 97.2(1)	-
13	-	-	58.8-105.6 84.0(7)	83.8- 83.8(1)	100.1-152.1 126.1(2)	-	-	-
14	-	74.0- 74.0(1)	71.4- 71.4(1)	-	87.6-102.4 95.0(2)	128.8- 128.8(1)	111.8- 111.8(1)	-
15	-	94.2- 94.2(1)	83.2-83-5 83.3(2)	-	88.7-100.1 94.4(2)	-	-	-
Mean	48.3-103.9 77.9(18)	19.9-109.1 68.1(118)	15.1-150.1 53.5(201)	23.6-83.8 49.0(87)	17.5-152.1 62.2(126)	10.1-128.8 64.7(152)	22.0-159.1 74.5(129)	14.9-118.4 61.9(118)

[1] Above line - maximum and minimum fecundity, below line - mean fecundity and number of fish studied.

In the 1950's, a large part of the stock consisted of herring from the abundant 1950-year-class which appeared on the spawning grounds from age 4. Fish maturing for the first time is characterized by low fecundity. Mass maturation of the 1950-year class at age 5 and 6 reduced the mean fecundity from 75 000 eggs in 1954 to 56 000 eggs in 1956. Nearly 30% of this year-class matured at 7 and 8 years (Seliverstova 1978), but their low fecundity did not affect the mean absolute fecundity in 1957 and 1958 because fish of older age-groups with high fecundity constituted nearly 37-28%. A small reduction in individual fecundity in 1959 and 1960 was connected with recruits from the poor 1955-1956-year-classes. After 1956 individuel fecundity increased to 100 000 eggs in a two years time.

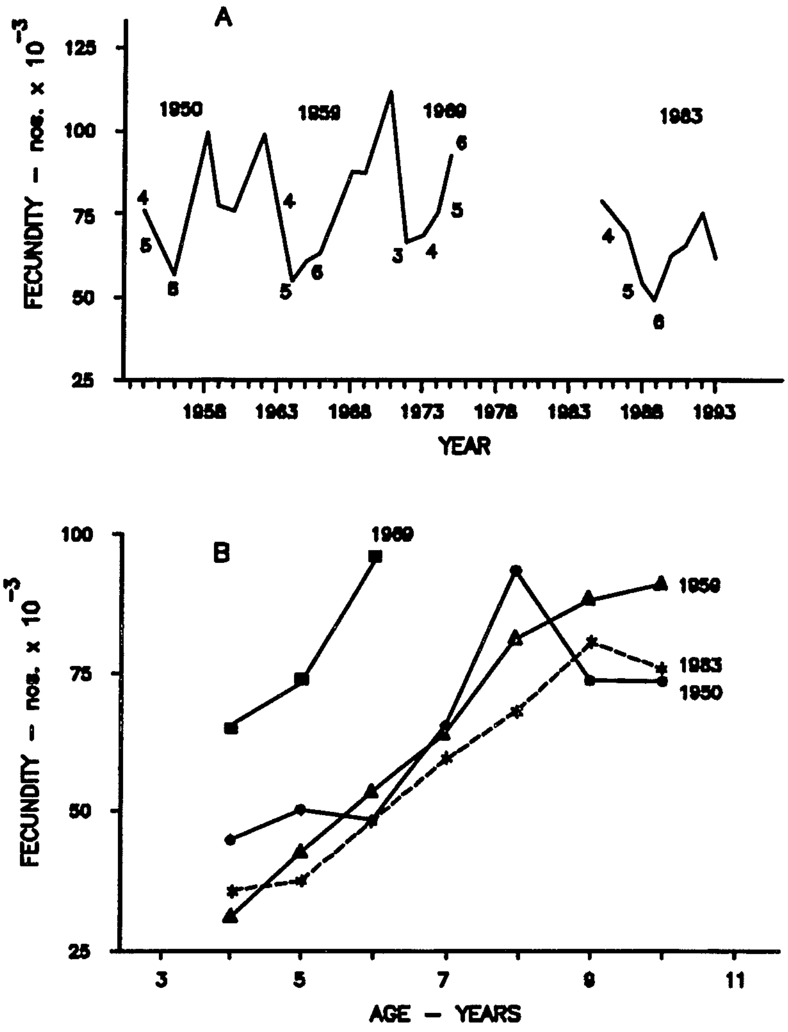

Figure 2. Mean absolute individual fecundity of Norwegian spring spawning herring by sampling year (A) and by age in year-classes of different strength (B). Strong 1950-, 1959- and 1983-year-classes (Selivestova 1990) and poor 1969-year-class.

The next major decline in fecundity was observed in the 1960's with the recruitment of herring from the strong 1959-year-class. Mean individual fecundity was reduced from 99 000 eggs in 1962 to 75 000 eggs in 1963 and futher to 55 000 eggs in 1964, caused by mass maturation of the 1959-year-class. This is caused by the recruitment of the 1959-year-class at age 4 and 5, amounted to 70% of the spawning stock, comparable with 54% of the 1950-year-class (Seliverstova 1978). Age structure of the spawning stock has changed considerably. Fish older than 16-17 years were not observed in the 80's, while fish at age 19-22 occurred in the 1950's. The number of fish of the year-classes proceeding the 1959 fluctuated from 26% to 5%. Recruitment to the spawning stock of the abundant 1960-year-class, maturing mainly at age 5-6, was also a factor which delayed the increase of fecundity in subsequent years (Seliverstova 1990).

Recruitment of the poor 1969-year-class to the spawning stock reduced mean absolute fecundity to a small extent even when poor year-classes which at all ages are characterized by considerable higher individual fecundity compared to fish of abundant year-classes (Figure 2B).

In 1987-1988 when herring from the abundant 1983-year-class recruited to the spawning stock, the mean individual fecundity was reduced and the level of decrease was larger than in previous decades. The mean individual fecundity in the population several years after recruitment of the 1983-year-class to the spawning stock was equal to only 74 000 eggs (1992). Then it decreased again when recruits from the 1988- and 1989-year-classes appeared on the spawning grounds (Table 1, Figure1, 2A).

Analysis of the 1950-70 data has shown that the year-classes of spring-spawning herring consist of fish of southern, northern and Barents Sea components, with varying composition. High fecundity is observed in herring of the southern component, the lowest in the Barents Sea component. The difference in absolute individual fecundity in fish of the same age from these two components was 10-25 thou. eggs (Seliverstova 1990).

The components were observed in year-classes from the 1980's. Up to 1988 fish from the southern and northern components were dominanting the spawning stock. With mass maturation of the Barents Sea component of the 1983-year-class at age 5, the Barents Sea component accounted for 68% (Figure3). Low individual fecundity in herring from that year-class (Table 2) and its dominance in the spawning stock was responsible for the decrease in the mean absolute fecundity in 1988 and 1989.

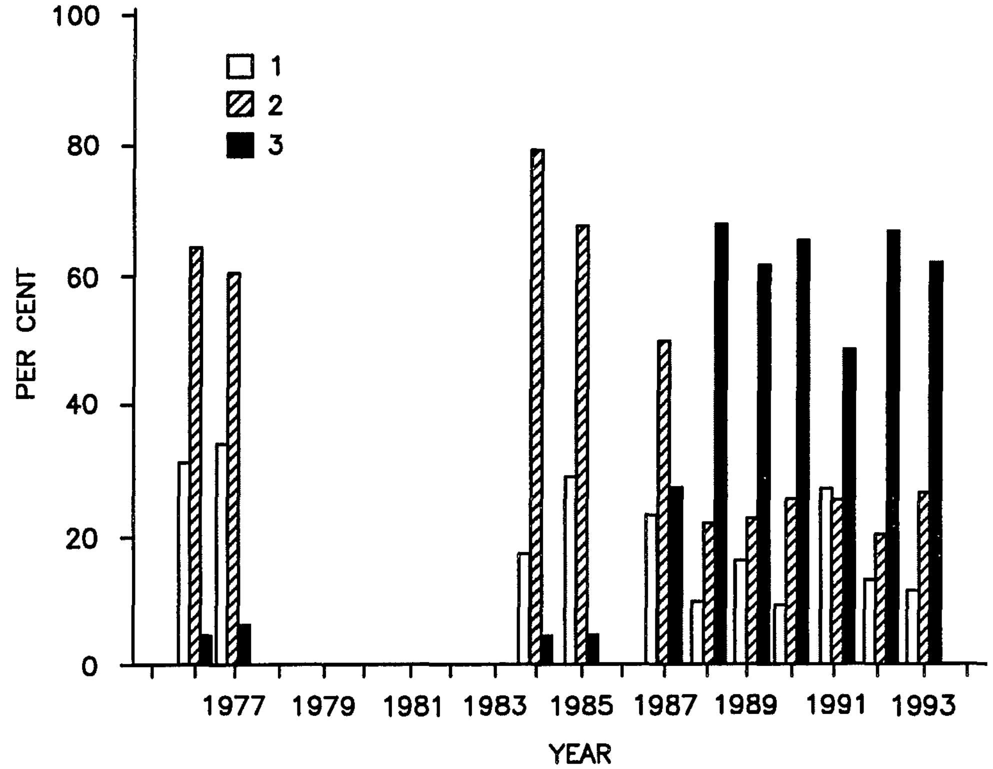

Figure 3. Different components in the spawning stock of the Norwegian spring spawning herring 1976-1993;
1: Southern component
2: Northern component
3: Barents Sea component.

Table 2. Absolute individual fecundity of spring-spawning herring of the 1983 year-class by components (Nos.$\cdot 10^{-3}$).

Year	Southern component			Northern component			The Barents Sea component		
	Fecundity[1]		Number analyed	Fecundity[1]		Number analyed	Fecundity[1]		Number analyed
		Mean			Mean			Mean	
1987	33.5-49.7	41.6	4	19.8-36.3	29.6	5	-	-	-
1988	34.2-69.0	51.2	7	19.5-63.3	41.5	15	15.2- 58.7	34.9	80
1989	49.4-60.4	53.4	3	23.6-71.7	46.5	13	33.3- 77.8	48.2	56
1990	46.8-81.1	60.5	6	46.3-84.9	59.8	9	34.5-103.5	59.7	63
1991	55.8-64.8	59.8	4	54.7-85.8	65.5	11	37.2- 96.5	67.7	64
1992	51.1-95.0	72.3	7	52.2-95.2	81.2	11	54.7-159.1	80.7	64
1993	84.2	84.2	1	52.9-83.7	71.6	4	48.6-118.4	75.2	46

[1] Minimum - maximum

Decrease of the mean fecundity in the period when the 1983-year-class recruited the spawning stock turned out to be more important than in the period when herring from the 1950- and 1959-year-classes recruited the stock (Figure 2A). This is connected with the fact that herring from the Barents Sea component of the 1983-year-class with a low fecundity reached 83.6% of the spawning stock while the 1950- and 1959-year-classes constitued 33.5% and 59.5% respectively (Seliverstova 1990). Besides, fish from the Barents Sea component of the 1983-year-class had lower fecundity compared to fish from the same component of the 1959-year-class at the same length (Figure 4).

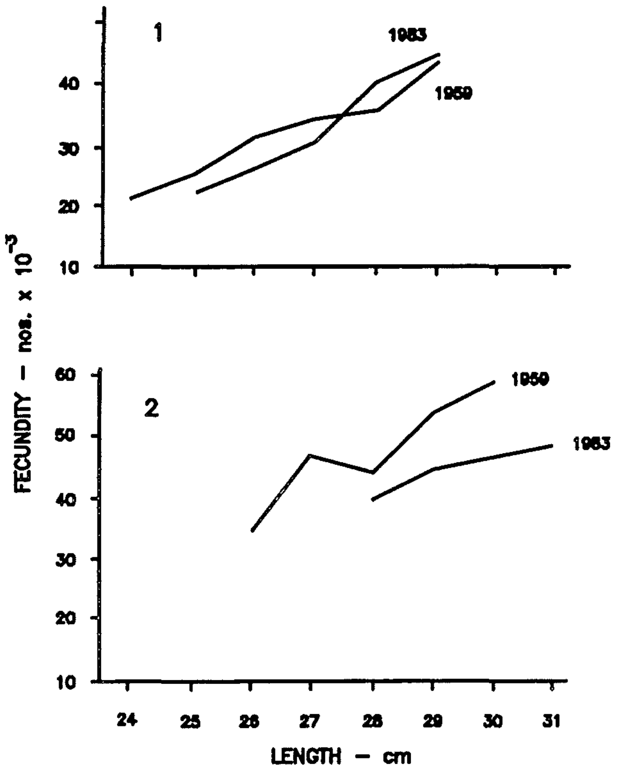

Figure 4. Absolute individual fecundity by length for the strong 1959- and 1983-year- classes of the Barents Sea component;

1: Herring maturing at age 5

2: Herring maturing at age 6.

POPULATION FECUNDITY IN 1980'S

In 1988, with mass recruitment of the 1983-year-class to the spawning stock the population fecundity increased 2 times compared to early 1980's and 4 times in 1993, caused by fish from the Barents Sea component (Table 3, Figure 5).

Table 3. Abundance of mature females from different components in the spawning stock of spring-spawning herring and population fecundity in 1984-1993.

Year	Abundance of mature females (Nos.$\cdot 10^{-6}$)				Population fecundity (Nos.$\cdot 10^{-12}$)			
	Component				Component			
	southern	northern	Barents Sea	Total	southern	northern	Barents Sea	Total
1984	148.5	679.9	40.6	869.0	12.7	57.3	3.3	73.3
1985	220.7	509.3	43.4	773.4	17.8	42.3	3.4	63.5
1987	377.5	767.0	366.3	1510.8	26.8	51.6	9.2	87.6
1988	368.9	723.8	2224.3	3316.0	26.9	47.7	79.2	153.8
1989	327.4	529.9	2138.6	2995.9	22.9	29.1	104.4	156.4
1990	243.7	574.2	1594.6	2412.5	14.4	28.5	95.1	138.0
1991	602.0	481.0	1122.0	2205.0	27.8	24.5	75.1	127.4
1992	514.4	737.0	2397.1	3648.5	32.0	48.8	193.1	273.9
1993	541.3	1148.1	2676.1	4365.5	27.7	55.3	198.3	281.3

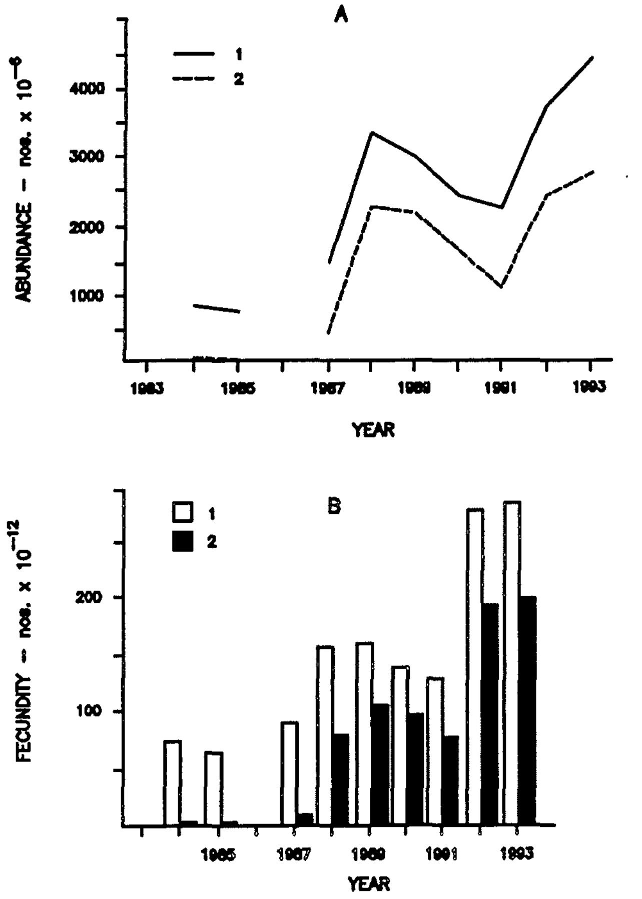

Figure 5. Abundance of mature females (A) and population fecundity of herring (B) 1984-1993;

1: Total spawning stock

2: Barents Sea component.

Based on population fecundity, Serebryakov (1988) developed a method to determin the level of reproductive ability of commercial fish populations for changing survival of year-classes, caused by different environmental conditions in the early ontogenesis. The highest possible level of population fecundity estimated on the basis of the 50-70's data (Seliverstova 1990), is 1911×10^{12} eggs, produced by a biomass of 16 million tonnes. Such population fecundity produce a strong year-class under average survival conditions. Minimal population fecundity, 839×10^{12} eggs, is generated by a spawning stock biomass of 7 mill. tonnes. This level of population fecundity is able to maintain natural fluctuations in fecundity. Critical level of population fecundity of 76×10^{12} eggs corresponds to spawning stock biomass of 0.6 million tonnes. Strong year-classes would only be produced by such level of spawning stock biomass under maximum favourable survival conditions.

The population fecundity estimated by taking into account ratio of fish from southern and northern components in the spawning stock and older age-groups with high individual fecundity showed that strong year-classes may be produced by a spawning stock biomass of 0.6 million tonnes. However, the survival conditions in early ontogenesis have to be maximum favourable. In 1983, combination of the above factors facilitated the production of an abundant year-class. Therefore, estimates obtained by the 1950-70's data were proved by the 1980 data.

Critical population fecundity for spawning stock consisting mainly of fish from the Barents Sea component, fluctuate over decades from 152×10^{12} to 380×10^{12} eggs, corresponding to spawning stock biomass of 1.3 and 2.9 million tonnes respectively (Seliverstova 1990). In 1988 and 1989, when the strong 1983-year-class had recruited to the spawning stock which was dominated by the Barents Sea component (Table 3, Figure 4,5), the population fecundity was estimated to $153\text{-}156 \times 10^{12}$ eggs (Table 4) and biomass to 1.8-2.0 million tonnes. In 1993, the spawning stock biomass was 2.4 million tonnes and the population fecundity was estimated to 281×10^{12} eggs (Table 4; Anon., 1993, 1994). The population fecundity given, correspond to critical level of population fecundity, and strong year-classes could only be produced under maximum favourable conditions.

Table 4. Population fecundity, abundance of 3-year-olds, year-class strength and survival conditions of spring-spawning herring in the early ontogenesis in the 80's.

Year	Population fecundity (nos.$\cdot 10^{-12}$)	Abundance of 3-year-olds (nos.$\cdot 10^{-6}$)	Year-class Strength	Coefficient of survival to age 3 (%)	Survival conditions
1984	73.3	237$^{1)}$	poor	0.000323	Average
1985	63.5	499$^{1)}$	poor	0.000786	Average
1987	87.6	344$^{1)}$	poor	0.000393	Average
1988	153.8	2009$^{2)}$	average	0.001306	Favourable
1989	156.4	6107$^{2)}$	above average	0.003904	Favourable
1990	138.0				
1991	127.4				
1992	273.9				
1993	281.3				

1) Anon. 1990   2) Anon. 1994a

Low reproductive ability of the population in recent years (1983-1993) has been confirmed by the International 0-group fish surveys in the Barents Sea and adjacent waters with the aim of estimating the abundance and distribution of 6 month old fish (Anon. 1994b). Even under conditions of increased water heat content in the Norwegian and North Cape Currents, year-classes appeared to be average and poor, except the 1991- and 1992-year-classes which were estimated to be abundant (Table 5). Mass recruitment to the herring spawning stock from these year-classes is expected in 1996 and 1997. The recruits would mainly be of the Barents Sea component, which make up 70% of the total year-classes. At present, reproduction and fishery are to a great extent based on the 1983-year-class which might have an adverse effect on further year-class strength. A to high fishing in the near future might have a negative effect on future recruitment.

Table 5. Anomalies of water temperature (Dt°C) in hydrographic sections and abundance index of 0-group herring in the Barents Sea in 1983-1993 (Anon. 1994b).

Year/	Section							Abundance index of 0-group herring
	"Kola meridian" (70°30’N-72°30’N, 33°30’E)			Cape Kanin (68°45’N-72°05’N, 43°15’E)	Cape Kanin (71°00’N-72°00’N, 43°15’E)	North Cape-Bear Island (71°33’N,25°02’E - 73°35’,20°46’E)	Bear Island - West (74°30’N, 06°34’E-15°55’E)	
Depth	0-50	50-200	0-200	0-bottom	0-bottom	0-200	0-200	
1983	+0.8	+1.0	+0.9	+0.9	+1.0	+0.6	+0.5	1.77[1]
1984	+0.4	+0.3	+0.3	+0.3	+0.4	+0.2	+0.4	0.34[1]
1985	-0.2	-0.3	-0.3	-0.8	+0.2	-0.4	+0.0	0.23
1986	+0.2	-0.3	-0.2	-0.3	-0.0	+0.1	-0.2	0.00
1987	-1.1	-0.5	-0.7	-1.5	-0.7	-0.5	-0.7	0.00
1988	-0.3	-0.1	0.2	-0.4	-0.3	-0.2	-0.4	0.32
1989	+1.3	+1.6	+1.1	+2.3	+1.1	+1.2	+0.3	0.59
1990	+0.8	+0.6	+0.6	+0.8	+0.7	+0.6	+1.1	0.31
1991	+0.4	+0.7	+0.6	+0.6	+1.0	+0.3	+0.8	1.19
1992	+0.2	+0.8	+0.6	+0.8	+0.8	+0.4	+0.4	1.06
1993	+0.2	+0.2	+0.2	+0.2	+0.2	+0.1	+0.8	0.75

[1] Toresen 1985

REFERENCES

ANON. 1990. Report of the Atlanto-Scandian Herring and Capelin Working Group. Copenhagen, 12-20 October 1989. *ICES CM 1990*/Assess: 5, 49 pp.

ANON. 1993. Report of the Atlanto-Scandian Herring and Capelin Working Group. Copenhagen, 19-23 October 1992. *ICES CM 1993*/Assess: 6, 74 pp.

ANON. 1994a. Report of the Atlanto-Scandian Herring and Capelin Working Group. Copenhagen, 18-22 October 1993. *ICES CM 1994*/Assess: 8, 78 pp.

ANON. 1994b. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September 1993. *ICES CM 1994*/G:3, 38 pp.

SELIVERSTOVA, E.I. 1987. The structure and growth rate of the Atlanto-Scandian herring generations, *Trudy polyar. nauchno.-issled. Inst. morsk. ryb. Khoz, Okeanogr. 41*: 97-151. (In Russian)

SELIVERSTOVA, E.I. 1990. Spawning stock structure and population fecundity of the Atlanto-Scandian her ring. Pp. 41-88 in Monstad, T. (ed.). *Biology and fisheries of the Norwegian spring spawning herring and blue whiting in the Northeast Atlantic. Proceedings of the fourth Soviet-Norwegian symposium. Bergen, 12-16 June 1989.* Institute of Marine Research, Bergen, Norway.

SEREBRYAKOV, V.P. 1988. Population fecundity and year-class strength of some commercial fish species. *ICES. The early life history of fish. The third ICES symposium. Bergen, 3-5 October 1988*: No. 14, 28 pp. (An abstract in *Rapp.P.-v.Reun.Cons.int.Explor.Mer, 191*: 473.

TORESEN, R. 1985. Recruitment indices of Norwegian spring spawning herring for the period 1965-1984 based on the international 0-group fish surveys. *ICES CM 1985*/H:54, 9 pp.

SUBSTANTIATION OF MEASURES FOR CONSERVATION OF YOUNG FISH IN THE BARENTS SEA DURING TRAWL FISHERY

by

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ABSTRACT

A method for assessment of the total annual allowable by-catch (TAB) of young cod, haddock and *Sebastes mentella* is proposed. Necessarly data are changes in abundance of young fish. Examples of calculation of TAB and criteria for allowable by-catch in shrimp catches of 1 tonne are presented.

INTRODUCTION

The Barents Sea and adjacent waters are the eastern edge of the distribution area of commercial fish species as cod, haddock and *Sebastes mentella*. Immature cod and haddock are distributed predominantly in coastal, central and western areas, whereas *Sebastes mentella* - mainly occours in the central, western and north-western areas (Baranenkova and Baranova 1962; Baranenkova and Khokhlina 1968; Berger and Cheremisina 1974; Baranova, Ponomarenko and Trambachev 1974; Sonina 1990; Shevelev 1985). In the first year of life, these species are living the whole year along currents within a great part of the Barents Sea, except in the northern areas (Breitfus and Gebel 1908; Maslov 1944; Borodatov and Travin 1960; Maslov 1968; Marti 1980). The distribution of young fish depends on length and age composition of the population, as well as on the abundance of year-classes and heat content of water masses (Konstantinov 1964; Milinsky 1967; Midttun 1965). With increasing abundance or higher water temperature, the area of young fish expands. The most widely distributed species are cod, haddock and *Sebastes mentella* specially as young age-groups when they are numerous. With increasing age, the eastern edge of winter concentrations moves westwards: 34-41 n.miles per year for cod and 34-39 n.miles for haddock. In periods, mainly with poor year-classes of cod and haddoch, the 3 year olds have their main distribution west of 34°E (Shevelev 1985; Shevelev, Tereshchenko and Yaragina 1987).

In the Barents Sea and adjacent waters, a large-scale intensive fisheries for demersal and pelagic fish and shrimp are conducted during the whole year. Fishing for capelin and shrimp are conducted by trawl with mesh size 16 and 35 mm respectively; and for cod by trawls with mesh size not less than 125 mm in the Russian Economic Zone (REZ) and 135 mm in the

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Norwegian Economic zone (NEZ). In some periods of the year, when fishing areas overlap area with high abundance of young demersal fish, some tens and even hundreds of millions specimens are caught as by-catch. The effect of the shrimp fishery is an additional decrease in abundance of year-classes in the first year of life. To ensure a rational fishery for cod, haddock and *Sebastes mentella* a minimum mesh size in fishing gear and introduction of a total allowable catch are requred. Therefore, the problem of protection of young fish should be taken into account as well.

This paper presents methods and examples of calculation of annual allowed by-catch of young cod , haddock and *Sebastes mentella* during the trawl fisheries for shrimp, cod and haddock.

MATERIAL AND METHODS

Due to fishing regulation in REZ, cod up to 42 cm in length and haddock up to 39 cm, are considered as young specimens. In NEZ the respective minimum length's are 47 and 42 cm. The minimum length for *Sebastes mentella* is set at 23 cm in this paper. Total allowable by-catch (TAB) of young cod was calculated for age-group 1+ and 2 and for *Sebastes mentella* - 4+ and 5. They were estimated under three assumption: ¹⁾ the last critical stage in ontogenesis, during which mass death is still possible, ends at the beginning of age-group 1. Coefficients of natural mortality at the age 1 and older are supposed to be known; ²⁾ the year-class abundance (number) at the age of recruiting to the commercial stock is known and divided into age-groups, ³⁾ a total by-catch of young fish from the year-classes are accepted as legal if the year-class abundance would remain within the confidence interval of the overall average abundance at the recruiting age to the commercial stock.

Year-class abundance at the age of recruitment to the fishery is taken from the reports of the ICES Working Group on Arctic Fisheries. The year-classes of cod, haddock and *Sebastes mentella* are classified on the basis of the abundance at the respective recruitment age, as poor, average and rich. Recruitment age to the commercial stocks are taken as 3 years for cod and haddock (Anon. 1994) and 6 years for *Sebastes mentella* (Anon. 1993). The classification of year-classes is presented in Table 1.

The following symbols are used in this paper:

t_r - the age of fish entering the commercial stock, years

t_k - the first age after the last critical stage in ontogenesis, during which the mass mortality of specimens takes place, years

$\bar{N}_{t_r}$ - selected mean arithmetic abundance of year-classes at the age of t_r , mill. specimens;

N_{t_r} - general mean arithmetic abundance of year-classes at the age of t_r , mill. specimens;

m - number of year-classes;

Table 1. Year-class abundance (nos. · 10^{-6}) at age 3 for cod and haddock (N_3) and age 6 for *Sebastes mentella* (N_6) in sub-area I and II. Year-classes grouped in poor, average and rich.

No	Cod[1]						Haddock[1]						*Sebastes mentella*[2]					
	Poor		Average		Rich		Poor		Average		Rich		Poor		Average		Rich	
	Year-class	N_3	Year-class	N_3	Year-class	N_3	Year-class	N_3	Year-class	N_3	Year-class	N_3	Year-class	N_3	Year-class	N_3	Year-class	N_3
1	1966	113	1961	342	1947	711	1980	5	1952	53	1963	242	1984	80	1980	131	1963	351
2	1977	142	1974	351	1943	736	1978	6	1954	54	1959	244	1985	80	1960	144	1972	404
3	1979	159	1988	363	1959	736	1979	8	1971	54	1957	246	1979	90	1959	149	1968	422
4	1986	159	1981	398	1962	786	1981	8	1973	57	1982	257	1976	91	1961	150	1967	432
5	1978	160	1968	409	1957	800	1986	13	1949	63	1970	272	1975	102	1974	156	1969	495
6	1987	162	1944	424	1954	813	1966	17	1947	67	1960	277	1978	110	1982	201	1966	531
7	1980	171	1953	444	1958	929	1987	18	1955	70	1964	293	1977	113	1962	228	1971	569
8	1965	171	1945	445	1983	952	1977	19	1988	72	1961	323	1983	123	1973	252	1970	570
9	1967	199	1946	471	1969	1027	1965	20	1984	82	1956	329	1981	128			1964	590
10	1976	201	1960	478	1948	1095	1985	28	1968	97	1983	333					1965	591
11	1985	243	1982	499	1949	1202	1972	49	1962	101	1948	559						
12	1952	276	1955	502	1964	1306			1958	110	1969	1028						
13	1984	288	1971	530	1963	1598			1974	115	1950	1041						
14			1973	621	1950	1607			1951	124								
15			1972	629	1970	1837			1976	135								
16			1989	642					1989	164								
17			1975	646					1967	166								
18			1951	650					1953	171								
19			1956	692					1975	172								

[1] Anon. 1994, [2] Anon 1993.

σ - mean standard deviation;

p - significance level, accepted equal to 0.05;

t_{1-p} - t -criterium under p significance level;

n_{t_r} - a value accepted as error in estimated general mean abundance of year-classes at the age of t_r, mill. specimens;

M_t - coefficient of natural mortality of fish at age t;

ΔN_t - allowable by-catch of young fish at the age of t, mill. specimens;

The confidence limit of the general average abundance of each group at the age t_r is obtained under the assumption that the distribution in each year-class group coincides with the normal distribution;

$$\bar{N}_{t_r}-(\sigma/\sqrt{m})*t_{1-p}\leq N_{t_r}\leq \bar{N}_{t_r}+(\sigma/\sqrt{m})*t_{1-p}. \tag{1}$$

However, only unilateral confidential estimation of the general average abundance is of interest in this context;

$$N_{t_r}\geq \bar{N}_{t_r}-(\sigma/\sqrt{m})*t_{1-p} \tag{2}$$

It is further assumed that fish taken as by-catch would survive, and n_{t_r} specimens would survive to age t_r, reduced only by natural mortality. This abundance is accepted to be equal to the error of the estimated general average abundance under the confidential probability , $1-p$ that is:

$$n_{t_r}=(N_{t_r}-\bar{N}_{t_r})\leq(\sigma/\sqrt{m})*t_{1-p}. \tag{3}$$

Abundance N_t and allowed by-catch of young fish ΔN_t at the t age are determined by the formulae:

$$N_t=N_{t+1}*\exp(M_t), \tag{5}$$

$$\Delta N_t=\Delta N_{t+1}*\exp(M_t). \tag{4}$$

It is further accepted that the abundance of fish at age t_r in each group is equal to the mean abundance of fish N_{t_r} from this group, and $\Delta N_{t_r}=n_{t_r}$ But ΔN_t is the allowed by-catch at one (and only at one) age t . In fact, young fish of age 0+(1) to t_r-1 occur in the by-catch. Therefore, it is important to know the distribution of the allowed by-catch by age from t_k to t_r-1 . For all described fish species, age t_k is accepted to be equal to 1 year.

Table 2. Russian and total International landings of shrimp and assumed by-catch of cod, haddock and *Sebastes mentalla* in the shrimp fishery in sub-area I and II.

Year	Shrimp (tonnes)		By-catch (tonnes)						Calculated by-catch of young fish								
			Cod		Haddock		*Sebastes mentella*		Cod			Haddock			*Sebastes mentella*		
									Russia		Total	Russia		Total	Russia		Total
	Russia	Total	Russia	Total	Russia	Total	Russia	Total	Spec. /t1)	Thou. spec.	Thou. spec.	Spec. /t1)	Thou. spec.	Thou. spec.	Spec. /t1)	Thou. spec.	Thou. spec.
1989	12252	62908	11027	56617	10438	38827	1814	24081	20	221	1132	42	438	1631	819	1486	19722
1990	20295	80827	18266	72744	10616	43318	9679	37509	94	1717	6838	289	3068	12519	2772	26830	103975
1991	27199	66828	24479	60145	10468	30251	16731	36577	277	6781	16660	481	5035	14551	11553	193293	422574
1992	20216	61249	18194	55124	6442	28708	13774	32541	74	1346	4079	179	1153	5139	4827	66487	154758
19932)	21290	53706	19161	48335	6013	22369	15277	31337	114	2184	5510	95	571	2125	1939	2962	6076

1) Nos./tonne fish species

2) Trawls with sorting grid. Preliminary shrimp catch.

Taking into account the fact that

$$N_t / \sum_{t=1}^{t_r-1} N_t = \Delta N_t / \sum_{t=1}^{t_r-1} \Delta N_t, \qquad (6)$$

and supposing that mortality of young fish in the allowed by-catch slightly changes the ratio of the survived fish in the adjacent age groups, the distribution of the allowed by-catch by ages was determined by the following approximate equality:

$$\Delta n_t \approx \Delta \bar{N} \frac{\Delta N_t}{\sum_{t=1}^{t_r-1} \Delta N_t}, \qquad (7)$$

where

$$\Delta \bar{N} = \frac{1}{t_r - 1} * \sum_{t=1}^{t_r-1} \Delta N_t.$$

Catch of young cod and *Sebastes mentella* in 1989-1993 is calculated from observations of by-catch on board Russian vessels (Tables 2 and 3). Areas of fishing for shrimp and cods are determined by current statistical data. During the shrimp fishery cod occur in by-catches taken in ICES Sub-area I and Divisions IIa and IIb, haddock in Sub-area I and Division IIa and *Sebastes mentella* in Division IIb. Assuming that areas of the Norwegian and Russian fisheries for shrimp mainly coincide and the Russian and Norwegian data on by-catch of young fish are approximately the same.

Table 3. Catch of young cod and haddock by Russian vessels during the directed fisheries for these species (nos.$\cdot 10^{-3}$)

Year	Cod	Haddock
1989	4679	625
1990	177	190
1991	2038	161
1992	1416	2223
1993	2606	4156

We do not have any data on the numbers of young cod and haddock caught by Norwegian fishermen during directed fisheries for these species. Therefore, only Russian data are used in this paper. Year-class abundance are estimated from data of trawl acoustic surveys of demersal fish, conducted annually in October-December by Russian vessels. Coefficients of natural mortality of young fish are assumed slightly higher compared with older age-groups.

By-catches of young fish in the shrimp fishery are calculated, assuming that 90% of the total catch of shrimp are caught with a by-catch of young cod and 50 per cent for haddock and *Sebastes mentella.* The by-catch of young fish is calculated on the basis of the 1990 data and compared with the by-catch observed for this year. A similar calculations of the expected by-catch is made for 1994, knowing the year-class abundance and assuming different expected catch of shrimp.

RESULTS AND DISCUSSION

The by-catches of young cod, haddock and *Sebastes mentella* at the age from t_k to $t_r - 1$ were calculated by equations 3-7 and presented in Tables 4, 5 and 6. For 1990, the estimated by-catch include the 1988-1989-year-classes of cod and haddock, described as average year-classes at 3-year-old. The estimated by-catch of *Sebastes mentella in 1990* include the poor 1985-1987-year-classes and the average 1988-1989-year-classes. According to our calculations, the by-catch in 1990 was 72 mill. young cod, 28 mill. young haddock and 57 mill. *Sebastes mentella* (Table 6). As shown in Tables 2 and 3, actual by-catch of young fish constituted 7.03 mill. cod, 12.7 mill. haddock and 104 mill. *Sebastes mentella.* The actual catch of young cod and haddock was found to be 10.3 and 2.2 times lower than the estimated and 2.5 times higher for *Sebastes mentella.*

Table 4. Errors in estimates of mean abundances of the group of year-classes of cod, haddock and *Sebastes mentella* at the age of recruitment to the fishermy and paraeters used in the assessments.

Fish species	Year-class strength	Number year-classes (m)	$N_{t\%}$ (nos.· 10^{-6})	σ (nos.· 10^{-6})	t_{1-p}	$n_{t\%}$ (nos.· 10^{-6})
Cod	Poor	13	183	52	1,78	26
	Average	19	502	113	1,73	45
	Rich	15	1076	362	1,76	165
Haddock	Poor	11	17	13	1,81	7
	Average	19	101	43	1,73	17
	Rich	11	307	90	1,81	49
Sebastes mentella	Poor	9	102	18	1,86	11
	Average	8	176	45	1,90	30
	Rich	10	496	88	1,83	51

Table 5. Abundance (N_t), of grouped year-classes and estimated by-catch (ΔN_t) of cod, haddock and *Sebastes mentella* at age t (nos.· 10^{-6}).

Fish species	Age (t)	M_t[1]	Year-class abundance (nos.· 10^{-6})			Estimated by-catch from an year-class (ΔN_t) (nos.· 10^{-6})		
			Poor	Average	Rich	Poor	Average	Rich
Cod	1	0,30	343	915	1962	47	82	301
	2	0,30	254	678	1453	35	61	223
	3		188	502	1076	26	45	165
Haddock	1	0,30	31	184	764	12	31	89
	2	0,30	23	136	566	9	23	66
	3		17	101	419	7	17	49
Sebastes mentalla	1	0,30	332	531	1492	35	92	154
	2	0,26	246	393	1105	26	68	114
	3	0,22	189	302	852	20	52	88
	4	0,18	152	242	684	16	42	71
	5	0,14	122	202	571	13	35	59
	6		102	176	496	11	30	51

[1] Natural mortality rate

Table 6. Estimated by-catch of the mean abundance of grouped year-classes at age 1 and 2 for cod and haddock and age 1-5 for *Sebastes mentalla* (nos. · 10^{-6}).

Fish species	Age	Year-class strength		
		Poor	Average	Rich
Cod	1	24	41*	151
	2	18	31*	112
Haddock	1	6	16*	45
	2	5	12*	33
Sebastes mentella	1	7	18*	31
	2	5	14*	23
	3	4*	10	18
	4	3*	8	14
	5	3*	7	12

* - Estimated by-catch in 1990

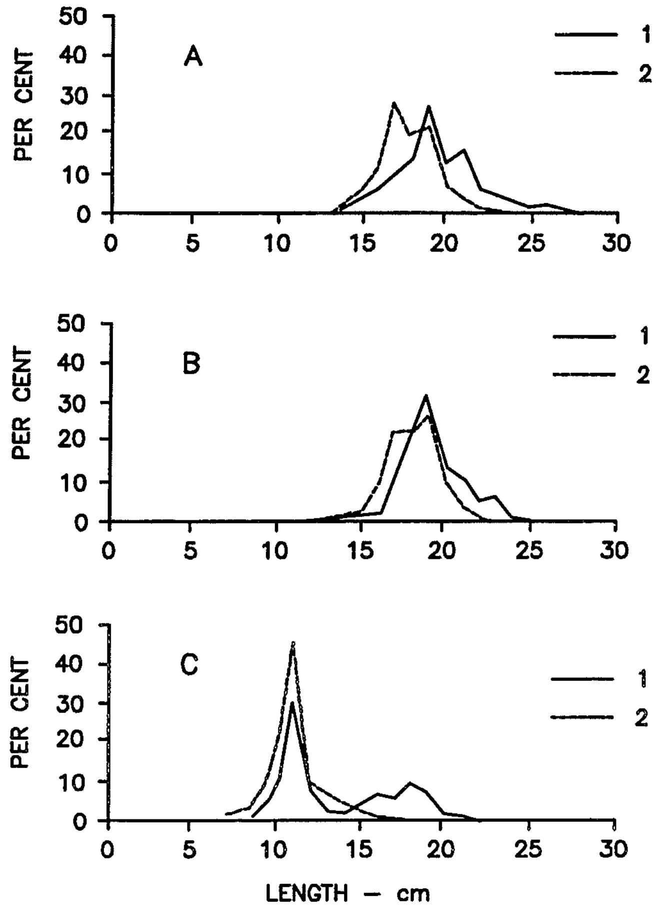

Figure 1. Length distribution of cod (A), haddock (B), *Sebastes mentella* (C) caught in 1993 by shrimp trawl without sorting grid (1) and equipped with sorting grid (2).

In 1993, the shrimp fishery was conducted by trawls with sorting grids, which reduced the by-catch of all fish species. Length compositions of young fish caught by Russian shrimp trawlers with sorting grid is presented in Figure 1. Mean length of cod was 17.2 cm, of haddock 18.1 cm and of *Sebastes mentella* 11.1 cm. In 1993, the 1993-year-class of cod and haddock and the 1992-year-class of *Sebastes mentella* were mainly taken as by-catch and therefore used in the assessment of by-catches for 1994. During the directed fishery for cod, only the 1992-year-class of cod and haddock were taken into account. Based on data from the Russian trawl-acoustic surveys, the 1992-and 1993-year-classes of cod and haddock were estimated as average, whereas the 1992-year-class of *Sebastes mentella* as poor. Total estimated by-catch of juvenile cod, haddock and *Sebastes mentella* in different catches of shrimp are presented in Table 7. In the directed fishery for cod and haddock young fish at the age of 2 years are caught, and the estimated by-catch is given for cod and haddock in Table 8. With increasing abundance of year-classes and decreasing catch of shrimp and cod, the total by-catch of young fish increases (Tables 7 and 8).

Table 7. Estimated by-catch of cod, haddock and *Sebastes mentella* by different shrimp catches by groups of year-class strength (nos./tonnes shrimp).

Fish species	Year-class strength	Shrimp catch (nos. $\cdot 10^{-6}$)			
		40	*52	65	120
Cod	Poor	667	513	369	200
	Average	1139	876	701	380
	Rich	4194	3226	2581	1398
Haddock	Poor	300	230	184	100
	Average	800	615	492	266
	Rich	2250	1730	1385	750
Sebastes mentalla	Poor	1300	1000	800	433
	Average	3400	2615	2092	1133
	Rich	5700	4385	3508	1900

Note: * Assumed catch of shrimp in 1994.

Table 8. Estimated by-catch of cod and haddock at age 2 during the directed fishery for this species (nos./tonne).

Fish species	Catch (tonnes $\cdot 10^{-6}$)	Year-class strength		
		Poor	Average	Rich
Cod	300	60	103	373
	700	26	44	160
	*740	24	42	151
	1000	18	31	112
Haddock	50	100	240	660
	100	50	120	330
	*120	41	100	275
	300	167	40	110
Cod and haddock	350	66	123	414
	800	29	54	181
	*860	27	50	169
	1300	23	43	145

Note: * Total allowable catch in 1994.

The assessment of total by-catch of young cod and haddock in the shrimp fishery during 1994 turned out to be 5 times higher than those established by the Joint Russian-Norwegian Fisheries Commission (300 specimens of cod and haddock together per tonne of shrimp) and nearly 1.3 times lower in the directed fishery for cod and haddock.

CONCLUSIONS

Young demersal fish are distributed within a wide area in the first year of life. Therefore, the demersal species occur as by-catch in the trawl fishery for shrimp in all areas. The number of young fish caught during these fisheries depend on the abundance of year-classes, size of shrimp and bottom fish catch and their overlapping on the fishing grounds as juveniles.

The proposed method takes into account changes in abundance of current year-classes and allows to determine the annual total by-catch of young age-groups different in abundance. The by-catch changes from year to year, depending on total allowable by-catch of young fish of each protected species (*Sebastes mantella* is not a protceted species in this relation) and total catch of shrimp, cod and haddock. Within the limitation of by-catch of young fish by TAB, the commercial shrimp fishery and fisheries for demersal fish species would be possible by redistribution at the fishing fleets, from areas with high by-catch of young fish to areas with low by-catch.

During the period 1989-1993 the total by-catch of young cod and haddock was calculated to 8-33 mill. specimen and 20-423 mill. of young *Sebastes mentella* in the Barents Sea and adjacent waters. Since the by-catches of young protected species change from year to year, it would be necessary to give yearl advice of total allowable by-catch by species.

REFERENCES

ANON. 1993. Report of the Arctic Fisheries Working Group. Copenhagen, 25 August - 3 September 1992. *ICES CM 1993/*Assess: 2, 169 pp.

ANON. 1994. Report of the Arctic Fisheries Working Group. Copenhagen, 24 August-2 September 1993. *ICES CM 1994/*Assess: 2, 254 pp.

BARANENKOVA, A.S. and **KHOKHLINA, N.S.** 1968. Distribution and abundance of eggs and larvae of the Arctic-Norwegian stock of cod and comparative data on survival of bottom stages of 0-group in 1962-1965. *Trudy polyar. nauchno.-issled. Inst. morsk. ryb. Khoz. Okeanogr.. 23*: 217-261. (In Russian)

BARANENKOVA, A.S. 1968. PINRO investigations on estimation of abundance of commercial fish of the Barents Sea and its reasons. *Trudy polyar. nauchno.-issled. Inst. morsk. ryb. Khoz. Okeanogr.. 23*: 193-216. (In Russian)

BARANOVA, Z.P., PONOMARENKO,V.P. and **TRAMBACHEV,M.F.** 1974. Results of accounting of young cod and haddock in autumn-winter, 1970/71, 1971/72 and 1972/73. *Trudy polyar. nauchno.-issled. Inst. morsk. ryb. Khoz. Okeanogr. 33*: 119-135. (In Russian)

BERGER, T.S. and **CHEREMISINA, R.A.** 1974. Distribution and age of young redfish in the Barents Sea in 1969-1971. *Mater. rybokhoz. issled. sev. Basseina. 21*: 109-116. (In Russian)

BORODATOV, V.A. and **TRAVIN, V.I.** 1968. Main stages of Soviet investigations on redfish of the North Atlantic. Pp. 277-284 in: *Soviet fishery investigations in the seas of the European North.* Moscow. (In Russian)

BREITFUS, L.L. and **GEBEL, G.** 1908. *Expedition for the fishery research nearby the Murman coast.* Sanct-Petersburg. 159 pp. (In Russain)

KONSTANTINOV, K.G. 1964. Influence of water temperature on the fish resources objected to the trawl catch in the Barents Sea. *J. ikhtiol. 4, 2(31)*: 255-269. (In Russian)

LEBED, N.I. and **PONOMARENKO, I.Y.** 1984. Distribution and age- length composition of the Lofoten-Barents Sea cod in 1981. *Annls biol. 38*: 85-87.

MARTI, Yu.Yu. 1980. *Migrations of marine fish.* Pishchevaya promyshlennost, Moscow. 248 pp.

MASLOV, N.A. 1944. Demersal fish of the Barents Sea and fishery for them. *Trudy polyar. nauchno.-issled. Inst. morsk. ryb. Khoz. Okeanogr. 8*: 3-186. (In Russian)

MASLOV, N.A. 1968. Influence of natural factors and fishery on the age composition, abundance and areas of demersal fish of the Barents Sea. *Trudy polyar. nauchno.-issled. Inst. morsk. ryb. Khoz. Okeanogr. 23*: 86-103. (In Russian)

MIDTTUN, L.S. 1965. The relation between temperature conditions and fish distribution in the southeastern Barents Sea. *Int. Comm. Northwest. Atl. Fish.* Spec.Publ. 6: 213-219.

MILINSKY, G.I. 1967. Influence of water temprature on the distribution of cod in the southern Barents Sea. *Trudy polyar. nauchno.-issled. Inst. morsk. ryb. Khoz. Okeanogr. 20*: 11-122. (In Russian)

SHEVELEV, M.S. 1985. Report on the trawl survey of demersal fish stocks in the Barents and Norwegian Seas in April/May 1982. *Annls biol. 39*: 194-197.

SHEVELEV, M.S., TERESHCHENKO, V.V. and **YARAGINA, N.A.** 1987. Distribution and behaviour of demersal fish in the Barents and Norwegian Seas, and the factors influencing them. Pp. 181-190 in Loeng, H. (ed.): *The effect of oceanographic conditions on distribution and population dynamics of commercial fish stocks in the Barents Sea. Proceedings of the third Soviet-Norwegian symposium. Murmansk, 26-28 May 1986.* Institute of Marine Research, Bergen, Norway.

SONINA, M.A. 1990. Relation of immature and mature haddock Melanogrammus aeglefinus (L.) and their distribution in the Barents and Norwegian Seas. Pp. 233-249 in: *Biological resources of shelf periphery seas. Sbornik nauchnykh Trudov.* Vses. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., Moscow. (In Russian)

SOROKIN, V.P. and **SHAFRAN, I.S.** 1969. Estimation of absolute abundance of commercial stock of Sebastes mentella in the Barents Sea. Pp. 153-162 in: *The Union Conference of Young scientists. Sbornik nauchnykh Trudov.* Polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., Murmansk. (In Russian)

PRECISION IN RECRUITMENT ESTIMATES AND ITS IMPLICATIONS FOR MANAGEMENT OF DEMERSAL FISH STOCKS

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ABSTRACT

Errors in abundance indices of recruiting year-classes will affect stock predictions. The contribution of recruiting year-classes to the predictions of catch and spawning stock biomass for the stocks of Northeast Arctic cod, haddock and saithe is investigated. The effect various levels of error in the recruitment indices would have had on the predictions during the last two decades is calculated. The error in the index has frequently gone in the same direction for consecutive year-classes and errors of less than 30% have been relatively rare. Longer time series and new methodology will probably reduce the errors in the future, but substantial errors in the stock predictions must therefore be anticipated, even in the short term. Management aimed at moderate exploitation and stability can minimize the problem and the use of risk-analyses is desirable. Medium-term predictions rely to a large extent on assumptions of average recruitment and must be used with great caution.

INTRODUCTION

In age-based stock assessments, one age has to be given as the age of first recruitment to the fishery. This will then be the reference age for recruitment. However, for long-lived species recruitment to the fishery usually is a gradual process, extending over more than one year. Which age of recruitment is used for a given stock is to some extent a subjective choice. Thus, in some cases there may be some individuals caught before the age defined as the recruiting age, in other cases the catches at the age of recruitment are too small to be of any significance.

Estimates of abundance of the year-classes recruiting to the fishery are necessary inputs to predictions of catch and stock biomass. In the predictions recruiting year-classes can be defined as those year-classes where the abundance estimates are not based on any information from the commercial catches. While the abundance of the year-classes in the VPA (virtual population analysis) is estimated by combining information from research vessel surveys and commercial catches, the methods for estimating abundance of the recruiting year-classes rely

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only on surveys. It is, however, not unusual in predictions that abundance indices are not available for one or more of the recruiting year-classes. When no index of abundance exists, some historical mean level (recent or long-term, arithmetic or geometric) of year-class strength is used.

Even in the cases where survey indices are available, some error in the recruitment estimate must be expected. Such errors are not necessarily only measurement errors, but may also be the result of variable mortality between year-classes in the time interval between establishing a survey index and the recruitment to the fishery. The resulting error in the predictions will be dependent on the catch and biomass of the recruiting year-classes relative to the total catch and stock biomass, which again is dependent on growth, mortality, exploitation pattern and variation in recruitment. The error is potentially largest for short-lived, heavily exploited stocks with high variation in recruitment. However, a lot will still depend on the precision of the abundance estimates.

The present paper deals with the stocks of Northeast Arctic cod, haddock and saithe and examines the potential for errors caused by lack of precision in the recruitment estimates. The three species are all relatively long-lived, but with a different degree of variation in recruitment. The exploitation has historically been mostly above a sustainable level (Anon. 1994, Jakobsen 1992).

Short-term projections are used as basis for setting the TAC (total allowable catch). The normal procedure in the biological advice given by ICES is to present to the managers tables giving a number of options for the catch in the year for which the TAC is to be decided and the corresponding spawning stock biomass the year after, while predictions for the total biomass are ignored.

In some cases, medium-term projections are also considered, as basis for decisions on management strategies covering longer periods than one year.

MATERIALS AND METHODS

For Northeast Arctic cod and haddock, age at first recruitment is defined as 3 years. Catches at age 2 occur, but contribute only a negligible part of the total. In these stocks a number of abundance indices are available for ages 0-3 years from both Norwegian and Russian surveys. Practice for accepting or rejecting the results of the VPA on the youngest year-classes has varied, but in the present exercise the current practice of taking estimates for age 4 and older from the VPA is assumed. The year for which a TAC is to be decided upon is normally two years after the last year included in the VPA. This means that in the catch predictions for the TAC, the number of individuals at age 3-5 in the TAC year will be based on the recruitment indices and it is the effect of the error on these age groups which is examined.

For the Northeast Arctic saithe the age at first recruitment is set to 1, although catches at age 1 are negligible. There are survey estimates available for both age 2 and 3, but the time series is short and there is still uncertainty about the precision of the estimates (Anon. 1994). Although VPA estimates of abundance at age 3 have normally been used in the predictions, recent examination of the data indicates that this may not be appropiate. For this exercise it was therefore chosen, as for cod and haddock, to consider the ages up to 5 in the TAC year as being based on recruitment estimates.

The standard predictions used as basis for management decisions represent the starting point for the present exercise. All the data are taken from the ICES Report of the Arctic Fisheries Working Group (Anon. 1994).

To examine the potential for error in predictions caused by errors in the recruitment estimates, the contribution by weight of these age groups to the total catch and spawning stock biomass in the last two decades was calculated. Both short-term (2 years ahead) and medium-term (6 years ahead) predictions were considered. For cod and haddock the relevant ages are 3-5 and 3-9 in the catches for short-term and medium-term, respectively, and correspondingly the ages 3-6 and 3-10 for the spawning stock biomass. For saithe the ages 1 and 2 are also included, although age 1 can be ignored for all practical purposes.

In the simulations, the most recent estimates of historical year-class strength (Anon. 1994) are assumed to represent actual recruitment. The potential error in prediction from recruitment indices is dependent on the fishing mortality, which for all three stocks has been considerably reduced in recent years. Therefore, to simulate a pattern of errors representing the present exploitation rate, a fishing mortality of 0.4 throughout and prior to the period examined has been assumed. The exploitation patterns, weights at age and maturity ogives are taken from the most recent predictions (Anon. 1994). When average recruitment has to be assumed, the long-term arithmetic mean is used. The label "true" on the y-axis in the figures refers to the values that would have been obtained in the predictions using the recruitment figures from the most recent VPA.

In order to find appropriate levels of errors to use in the simulations, the recruitment estimates for the year-classes 1976-1988 were compared with the final VPA estimates (Table 1). The deviations are given in both relative and absolute terms. Starting with the 0-group, there are four estimates in consecutive years. In some cases, especially the early estimates for saithe year-classes, an average recruitment figure has been used.

It is evident that the relative error can be very large for cod and haddock. However, the extremes are linked to small year-classes and are not so dramatic in absolute terms.
Also, some of the largest errors for cod occurred in the mid-1980s when the capelin stock collapsed and abundant year-classes were rapidly reduced during the first couple of years by cannibalism (Bogstad *et al.* 1994) and possibly other mortality. Nevertheless, the errors on cod and haddock have been substantial also in more normal circumstances. The errors on the saithe have been less extreme, which reflects the use of average recruitment as estimates and a relatively small variation in the recruitment level for this stock.

It is difficult from this table to infer what can be expected in terms of errors in recruitment estimates in the furture. If the mid-1980s are considered as abnormal and ignoring the errors on the smallest year-classes, errors up to 50-60% are still quite frequent. Furthermore, errors of less than about 30% are rare. As basis for the simulations of predictions over the last 20 years, it was therefore chosen to use 30% and 60% error, up or down.

A closer examination of Table 1 reveals that there is a tendency, at least for cod and haddock, to either over- or underestimate all recruiting year-classes in a given assessment. Thus, in the simulations all recruiting year-classes are assumed to be over- or underestimated by the same percentage.

RESULTS

Each of the figures comprise the results for cod, haddock and saithe. Figure 1 shows the contribution of ages up to 5 in the historical catches, corresponding to the recruiting year-classes in short-term predictions. For all three species the contribution has been substantial in some years. For cod it has varied from 4% to 76%, and for haddock from 11% to 97%. For saithe the contribution has been more stable, from 40% to 80%.

Figure 2 shows the corresponding contribution, of ages up to 6, to the spawning stock biomass. The pattern for haddock is slightly less variable, ranging from 13% to 90%, but otherwise similar to that of the catch. The contribution to the cod stock is also variable but generally smaller, from 4% to 46%. For the saithe, with assumed knife-edge maturity at age 6, the level was fairly stable at about 20% for a long period, but has increased considerably in more recent years, with a maximum value of 78%.

Figures 3 and 4 show the contribution of the recruiting year-classes corresponding to a medium-term prediction, i.e. ages up to 9 in the catch and ages up to 10 in the spawning stock. The contributions are very large, mostly in the range 80-100%. The exception is the earliest period for the cod where the contribution both to catch and spawning stock was considerably smaller.

Figures 5-8 and Figures 9-12 show the results of the simulations in relative and absolute terms, respectively. In the short-term predictions of catch and spawning biomass (Figures 5, 6, 9, 10), the effect of simulating over- and underestimates of recruitment by the same percentage is to create a symmetrical pattern for cod and haddock, but not for saithe. This difference is caused by the use of average recruitment for the youngest age groups of saithe.

The effect of using average recruitment is clearly pronounced in the medium-term predictions (Figures 7,8,11,12). In the long periods of poor recruitment in recent years the use of average recruitment in the predictions leads to large overestimates of both catch and spawning stock.

Figure 5 shows errors in the catch predictions of up to 29% for cod, 57% for haddock and nearly 47% for saithe. In absolute terms, maximum errors are 344,000 t for cod, 77,000 t for haddock and 62,000 t for saithe (Figure 9).

The errors in relative terms in the predictions of spawning stock biomass of haddock and saithe are of a similar magnitude as in the catch predictions, but for cod the errors are smaller, not exceeding 20% (Figure 6), and this is reflected also in the absolute errors (Figure 10).

The discrepancy between the observed recruitment and the long-term average creates most of the errors in the medium-term predictions (Figures 7,8,11,12) and the tendency to periodicity in the recruitment is clearly illustrated. The figures also reflect the fact that recruitment in this period has been mostly below average.

In relative terms the medium-term prediction error is in some cases very large for haddock, with both catch and spawning stock biomass predictions at more than 4 times the "true" level in the most extreme year.

The relative error is large also for cod where future catch is overestimated by up to 100% and spawning stock biomass by a slightly lower percentage.

The error in spawning stock biomass of saithe exceeds 100% in one year, more than twice the maximum error in catch prediction.

In absolute terms, the maximum errors in medium-term catch and spawning biomass predictions, respectively, are: Cod 471,000 t and 645,000 t; haddock 135,000 t and 185,000 t; saithe 58,000 t and 96,000 t.

Figure 13 shows how the average error from recruitment indices in short-term catch predictions depends on the fishing mortality. Thus, reduction of fishing mortality from historical high levels of exploitaion, (about 1.0 for cod, 0.9 for haddock and 0.7 for saithe) to current levels at about 0.4, reduces the average error to approximately half. The effect on short-term predictions of spawning stock biomass is similar. Errors in medium-term predictions, however, are less dependent on the fishing mortality.

DISCUSSION

There are substantial errors in the recruitment estimates used in the assessment. These are large enough to cause considerable errors in short-term predictions of catch and spawning stock. Recruitment indices from surveys are of little importance to medium-term predictions where the crucial factor is the actual level of recruitment compared to the historical mean level assumed for year-classes not born or measured.

The errors in the recruitment estimates for cod and haddock reflects to some extent measurement errors in the surveys. However, the abnormal development of some year-classes in the mid-1980's and a relatively short time series of survey data create at present problems in the estimation of recruitment figures from the survey indices. During more stable periods and with a longer time series the recruitment estimates should be more reliable. Nevertheless, there are few indications that it will be possible in the near future to restrict potential errors to less than about 50% on abundant and average year-classes. For poor year-classes, the likelihood of large relative errors is higher.

The severity of errors in the recruitment estimates are worsened by the tendency to go in the same direction for all the recruiting year-classes. What causes this tendency is not clear, but it may be due to periodical variation in natural mortality and in catchability and area coverage of the surveys.

Because of the large variation in the errors in earlier estimates, improved data series and development of new methodology, it is difficult to assess what errors in predictions should be expected in the future. In short-term predictions, it must probably be expected that errors in the catch and spawning stock corresponding to 30% error in all the survey indices will occur relatively often. This would mean that errors in the catch predictions of 10-15% for cod and 20-30% for haddock and saithe should be considered as "normal". In absolute terms, this translates into errors of up to 100,000 t for cod and 40,000 t for haddock and saithe. The errors on the spawning stock will be of a similar magnitude.

Medium-term predictions are mostly based only on the assumption of some sort of average recruitment. Thus, the error will depend largely on how much the actual recruitment deviates from the average. The tendency for periodicity in the recruitment considerably increases the potential for errors in the predictions. For all three stocks, recruitment in the period simulated comprise the worst periods of bad recruitment on record. The maximum errors shown in the figures therefore demonstrate how large overestimates can be expected in periods of very poor recruitment. However, the distribution of year-class size is not symmetrical and in periods of very good recruitment deviation from the average level can be larger. This would create errors, in the form of underestimates, which are higher than the errors shown in the figures.

Because of the periodical variation in recruitment it is not very meaningful to define some "normal" error in the medium-term predictions. The large potential error in these predictions shows that one must be extremely cautious to use them as basis for management decisions.

The recruitment indices is not the only source of error in catch and stock predictions. The total stock and its age structure, growth and (for the spawning stock) sexual maturation, are some of the factors which may cause errors in the predictions. These errors may add to the errors in recruitment or they may tend to cancel them. Which source of error is most important in a given assessment varies, but in recent years recruitment and growth have been the most problematic factors in the predictions.

The large potential errors caused by recruitment alone might indicate that the reliability of the predictions is too poor to be used as basis for setting a TAC. Clearly, it is not possible to keep the exploitation rate at an exactly fixed level, but this is not necessarily desirable. All three species are relatively long-lived, which means that there is some time to correct for errors before they produce significant losses in long-term yield. Furthermore, good management can minimize the effect of the errors by aiming at low exploitation and stability in yield, where the first is a necessity in order to achieve the other. As shown in Figure 13, this will also limit the prediction error caused by the recruitment indices.

In view of the uncertainties, management based on risk analyses would be desirable, and if medium-term predictions are considered, necessary. Such analyses will usually define the risk of something "bad" happening to the stock, e.g. that the spawning stock falls below a certain level. Risk analyses are developed and available for use. They require, however, knowledge about the likely distribution of error on the varios parameters in the predictions, and there is need for a careful examination of historical data and assessments to decide on the input to the models.

Medium-term predictions have at present limited value as basis for management decisions. However, there is scope for improvement if better models for environmantal influence on the recruitment can be developed and predictions of changes in the environment can be improved. Ongoing development of multispecies interaction models will also gradually improve these projections.

REFERENCES

ANON. 1994. Report of the Arctic Fisheries Working Group. Copenhagen, 24 August-2 September 1993. *ICES CM 1994* /Assess 2, 240 pp.

BOGSTAD, B., LILLY, G.R., MEHL, S., PÁLSSON, O.K. and **STEFÁNSSON, G.** 1994. Cannibalism and year-class strength in Atlantic cod (*Gadus morhua* L.) in Arcto-Boreal ecosystems (Barents Sea, Iceland and eastern Newfoundland). *ICES mar. Sci.Symp., 198*: 576-599.

JAKOBSEN, T. 1992. Biological reference points for North-East Arctic cod and haddock. *ICES J.mar.Sci., 49*: 155-166.

Table 1. Year class strength from VPA compared with recruitment estimates

NORTHEAST ARCTIC COD

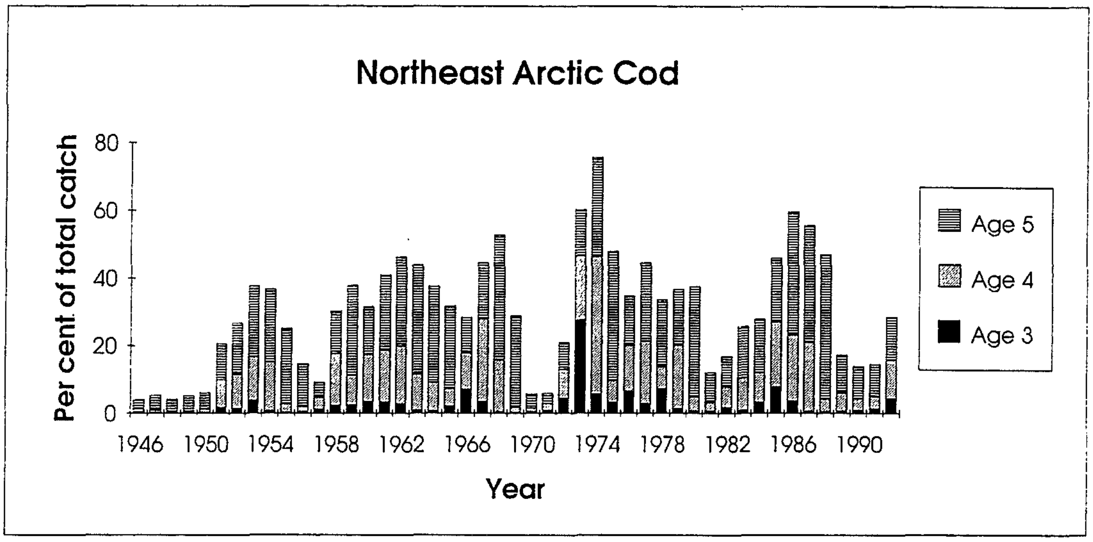
year-	vpa	recruitment estimates				relative error				absolute error (mill.)			
class	age 3	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1976	201				325				1.62				124
1977	142			195	81			1.37	0.57			53	-61
1978	160		100	100	257		0.63	0.63	1.61		-60	-60	97
1979	159	100	100	191	108	0.63	0.63	1.20	0.68	-59	-59	32	-51
1980	171	100	100	30	69	0.58	0.58	0.18	0.40	-71	-71	-141	-102
1981	398	100	30	66	144	0.25	0.08	0.17	0.36	-298	-368	-332	-254
1982	499	400	400	800	678	0.80	0.80	1.60	1.36	-99	-99	301	179
1983	952	1500	1500	1500	1000	1.58	1.58	1.58	1.05	548	548	548	48
1984	288	1600	800	430	443	5.56	2.78	1.49	1.54	1312	512	142	155
1985	243	1100	346	384	136	4.53	1.42	1.58	0.56	857	103	141	-107
1986	159	391	258	199	175	2.46	1.62	1.25	1.10	232	99	40	16
1987	162	186	171	146	136	1.15	1.06	0.90	0.84	24	9	-16	-26
1988	363	222	184	240	227	0.61	0.51	0.66	0.63	-141	-179	-123	-136

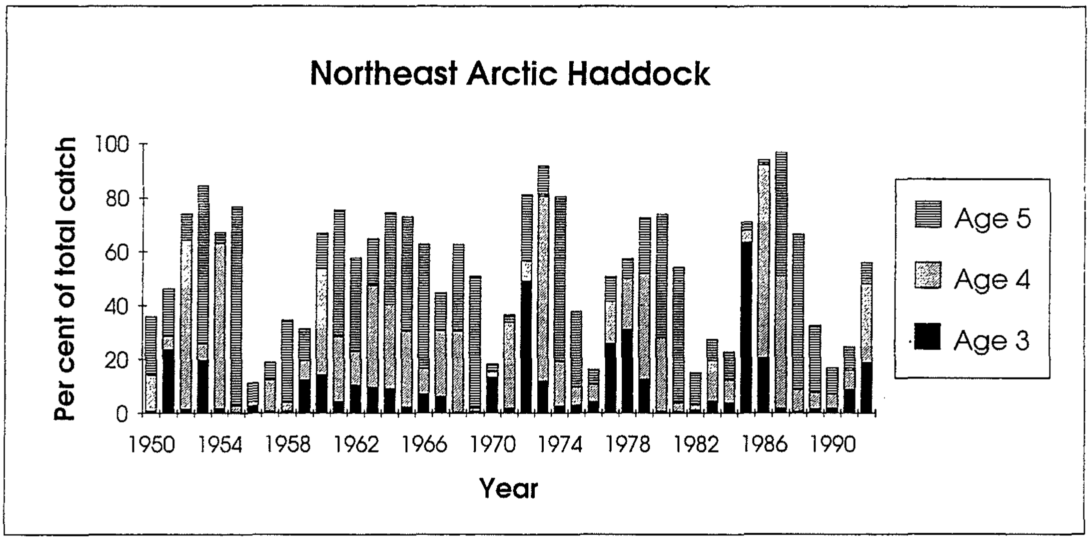
NORTHEAST ARCTIC HADDOCK

year-	vpa	recruitment estimates				relative error				absolute error (mill.)			
class	age 3	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1976	135				225				1.67				90
1977	19			50	50			2.63	2.63			31	31
1978	6		50	50	21		8.93	8.93	3.75		44	44	15
1979	8	50	50	55	18	6.25	6.25	6.88	2.25	42	42	47	10
1980	5	50	50	14	21	10.87	10.87	3.04	4.57	45	45	9	16
1981	8	50	20	23	10	5.95	2.38	2.74	1.19	42	12	15	2
1982	257	165	200	300	424	0.64	0.78	1.17	1.65	-92	-57	43	167
1983	333	300	400	700	591	0.90	1.20	2.10	1.77	-33	67	367	258
1984	82	75	200	162	140	0.91	2.44	1.98	1.71	-7	118	80	58
1985	28	100	31	25	32	3.57	1.11	0.89	1.14	72	3	-3	4
1986	13	30	14	14	11	2.31	1.08	1.08	0.85	17	1	1	-2
1987	18	8	9	9	10	0.42	0.50	0.47	0.54	-11	-9	-10	-8
1988	72	10	25	30	130	0.14	0.35	0.42	1.81	-62	-47	-42	58

NORTHEAST ARCTIC SAITHE

year-	vpa	recruitment estimates				relative error				absolute error (mill.)			
class	age 1	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1976	346				342				0.99				-4
1977	207			342	184			1.65	0.89			135	-23
1978	436		342	334	327		0.78	0.77	0.75		-94	-102	-109
1979	187	342	334	183	151	1.83	1.79	0.98	0.81	155	147	-4	-36
1980	171	334	332	229	113	1.95	1.94	1.34	0.66	163	161	58	-58
1981	145	332	337	133	144	2.29	2.32	0.92	0.99	187	192	-12	-1
1982	169	337	318	170	332	1.99	1.88	1.01	1.96	168	149	1	163
1983	327	318	200	190	139	0.97	0.61	0.58	0.43	-9	-127	-137	-188
1984	245	200	200	200	158	0.82	0.82	0.82	0.64	-45	-45	-45	-87
1985	119	200	200	270	99	1.68	1.68	2.27	0.83	81	81	151	-20
1986	105	200	270	161	174	1.90	2.57	1.53	1.66	95	165	56	69
1987	123	270	200	200	273	2.20	1.63	1.63	2.22	147	77	77	150
1988	358	200	200	200	460	0.56	0.56	0.56	1.28	-158	-158	-158	102





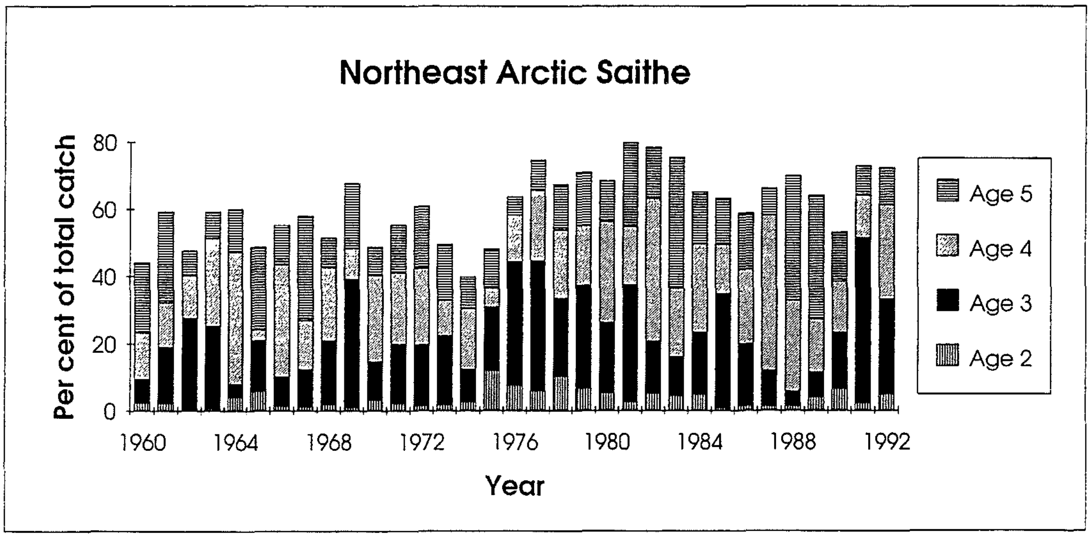
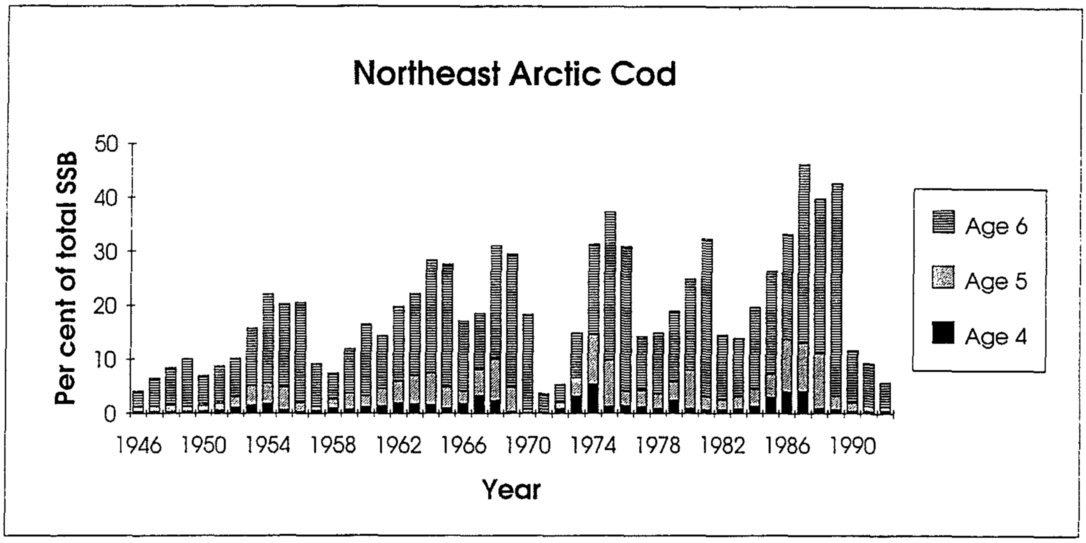
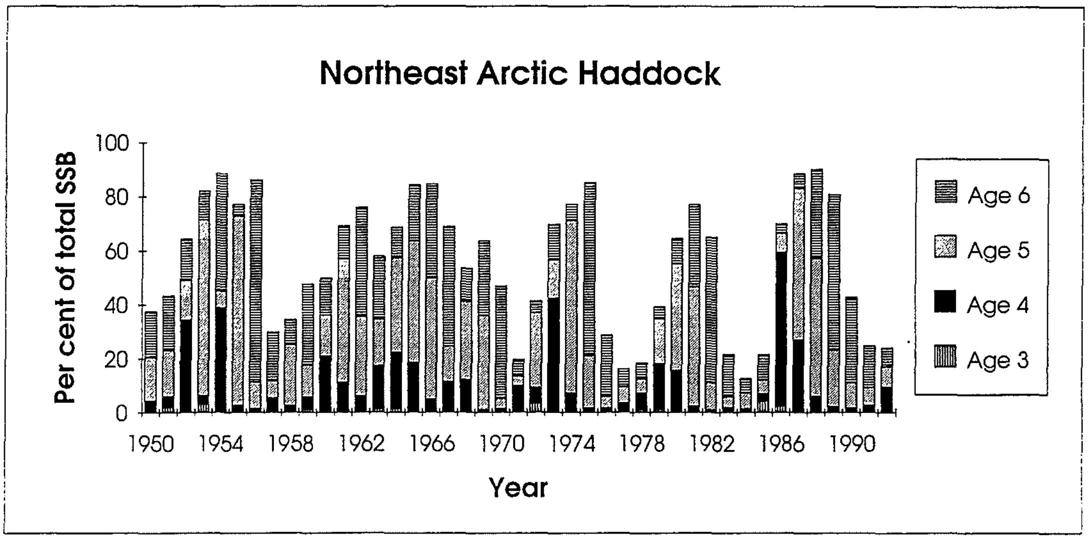


Figure 1. Contribution (%) to the catch (in weight) of the age groups 3-5 of cod and haddock and 2-5 of saithe.





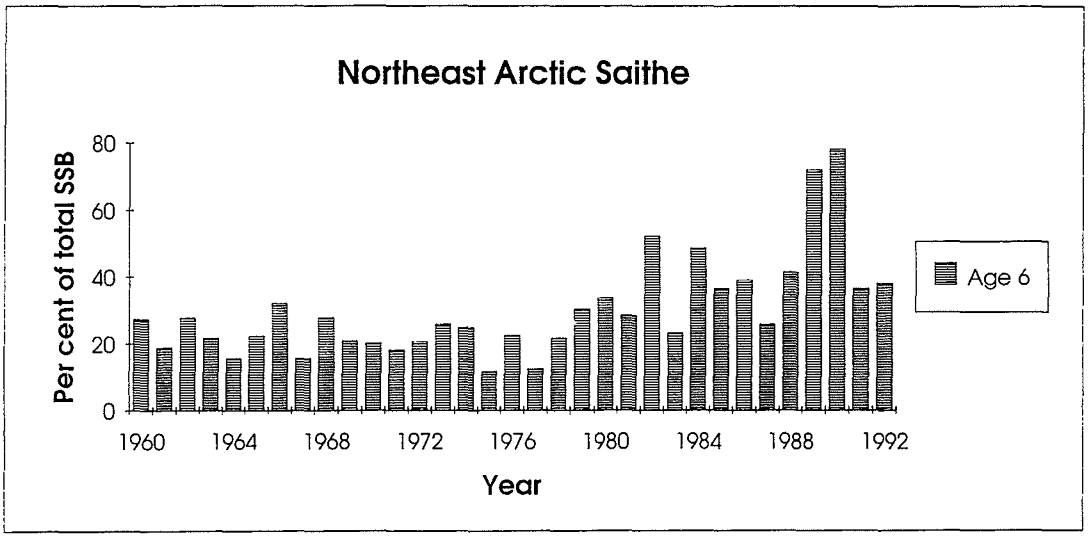
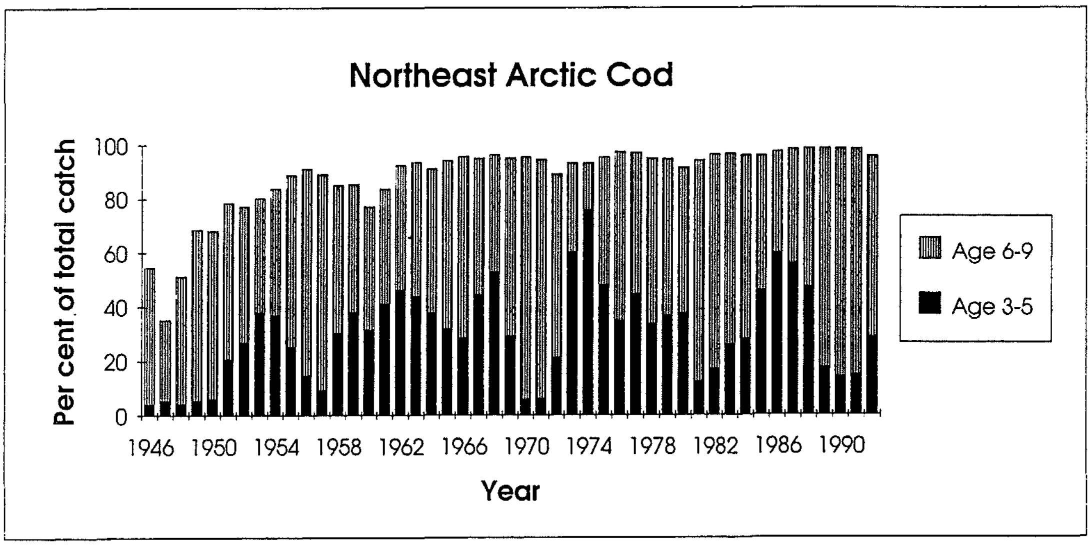
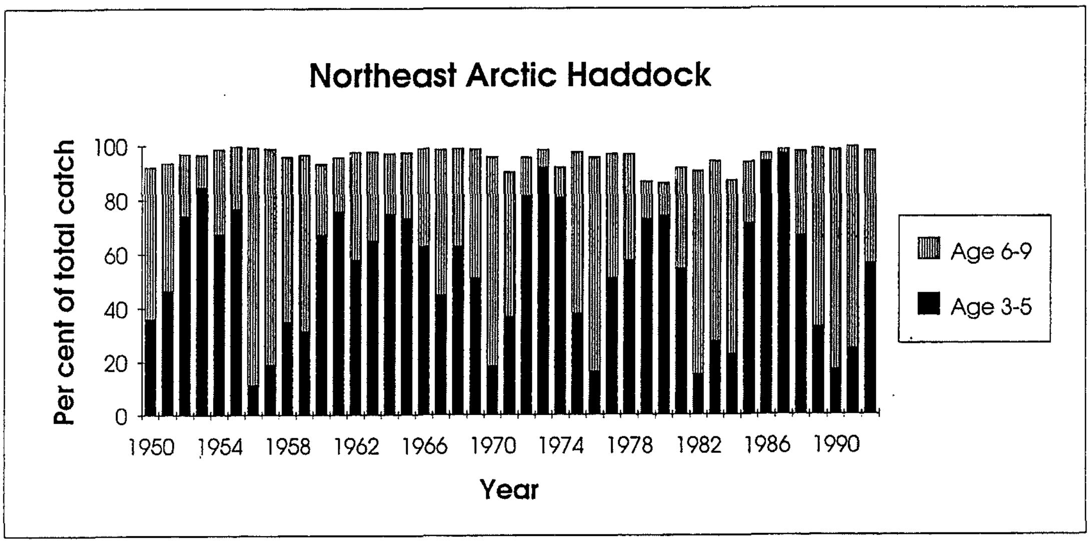


Figure 2. Contribution to the spawning stock biomass of the age groups 4-6 of cod, 3-6 of haddock and 6 of saithe.





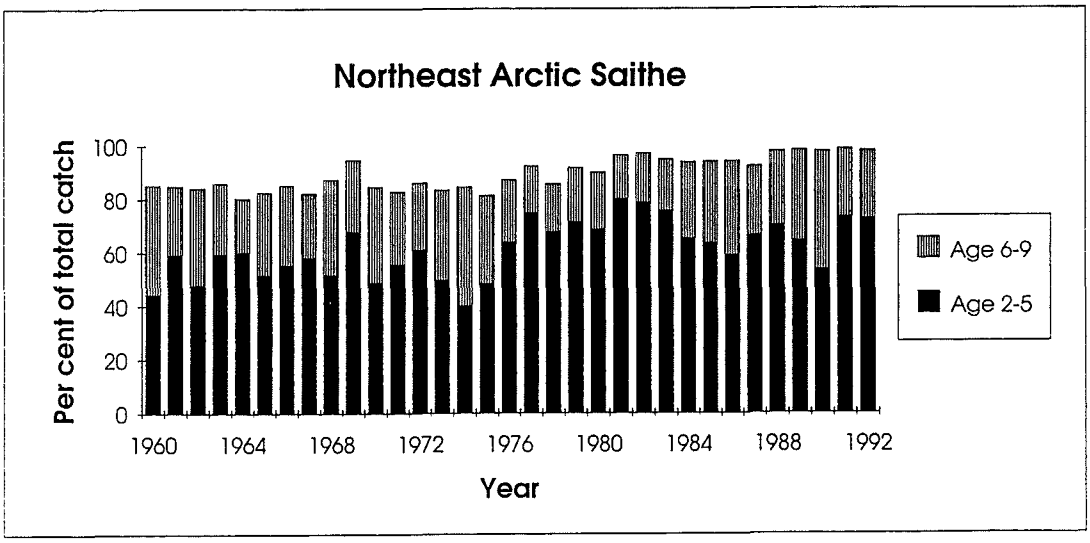


Figure 3. Contribution (%) to the catch (in weight) of the age groups 2-5 and 6-9 of coc and haddock and 2-5 and 6-9 of saithe.

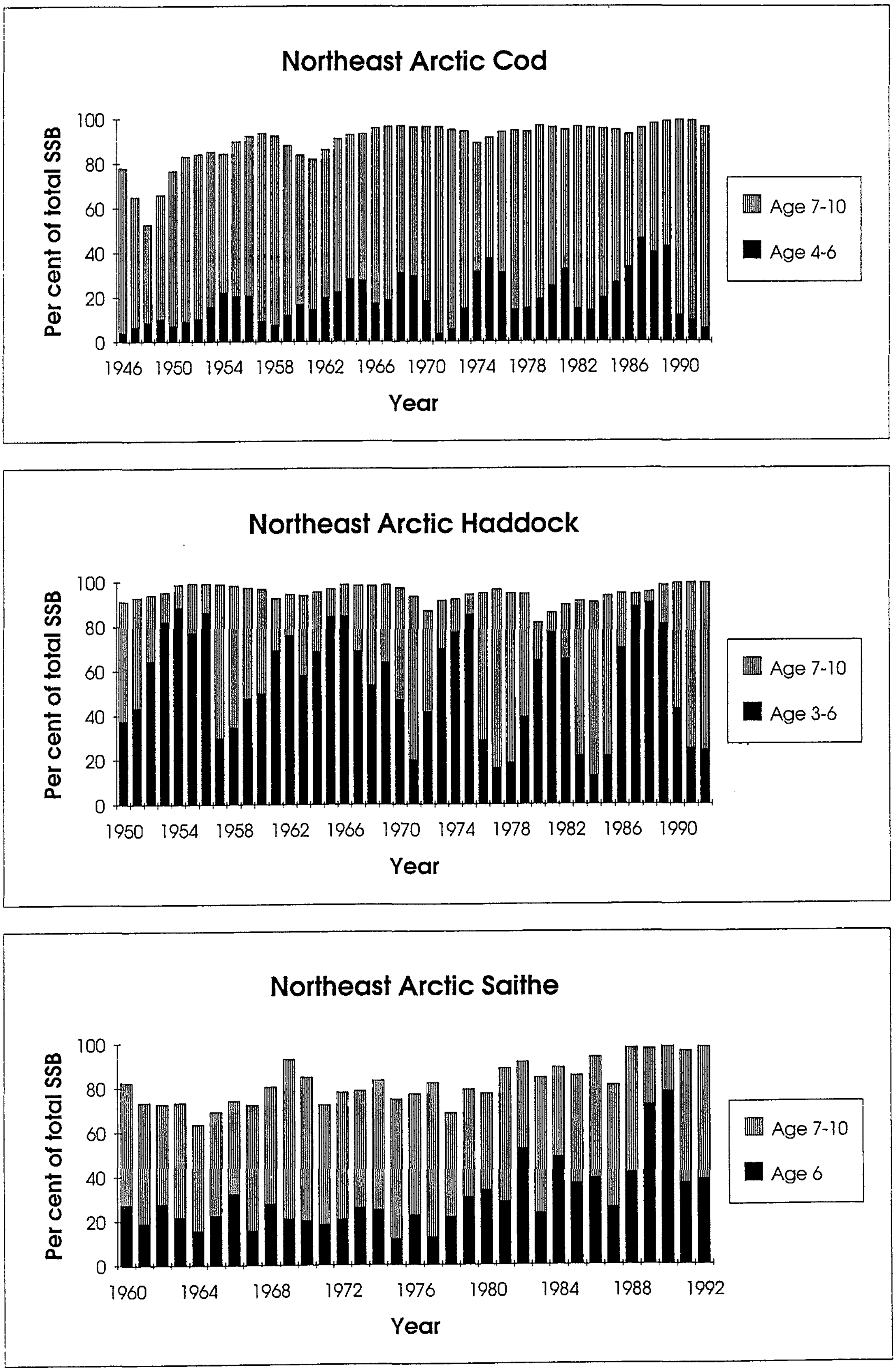
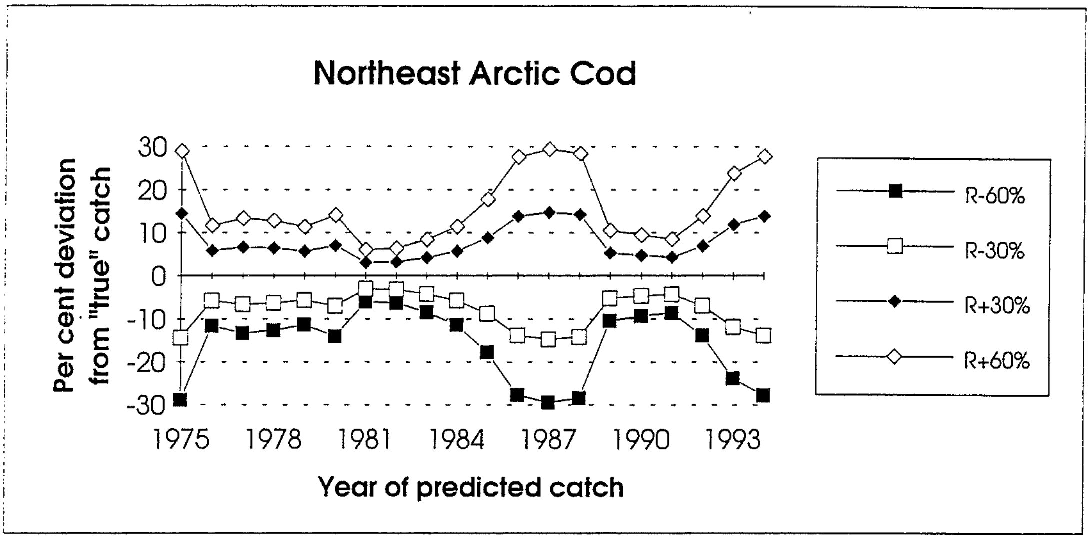
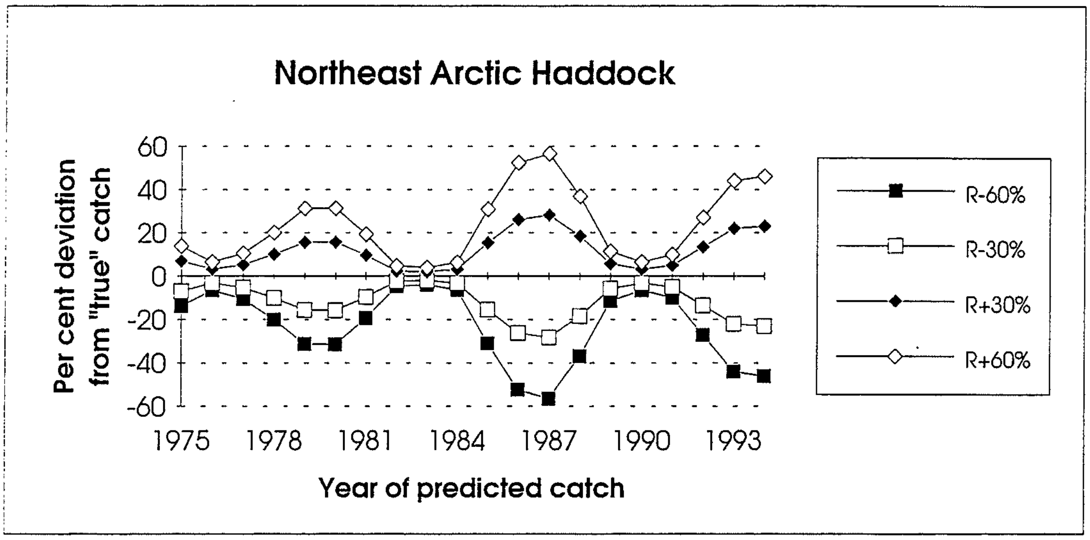


Figure 4. Contribution to the spawning stock biomass of the age groups 4-6 and 7-10 of cod, 3-6 and 7-10 of haddock and 6 and 7-10 of saithe.





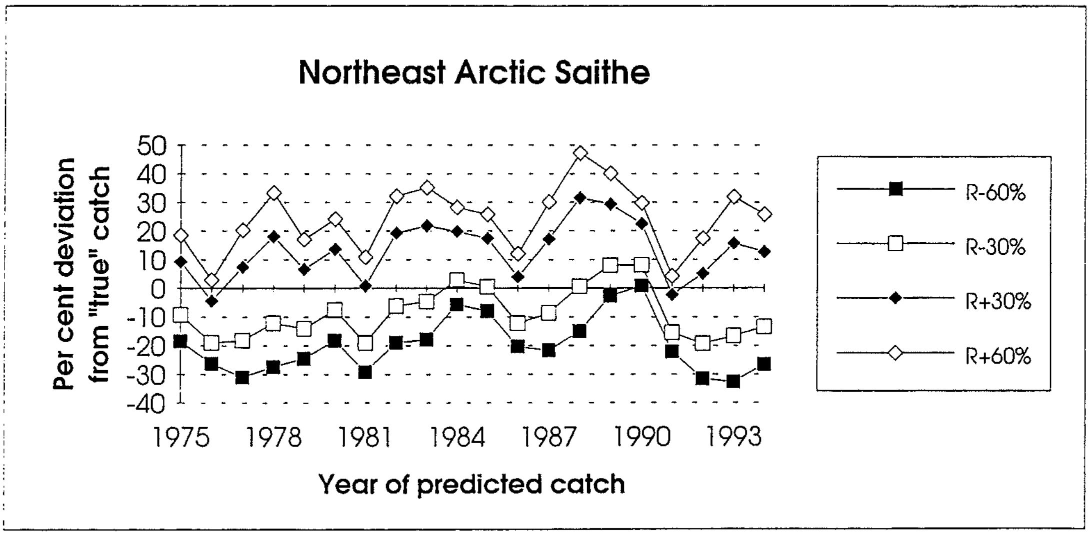
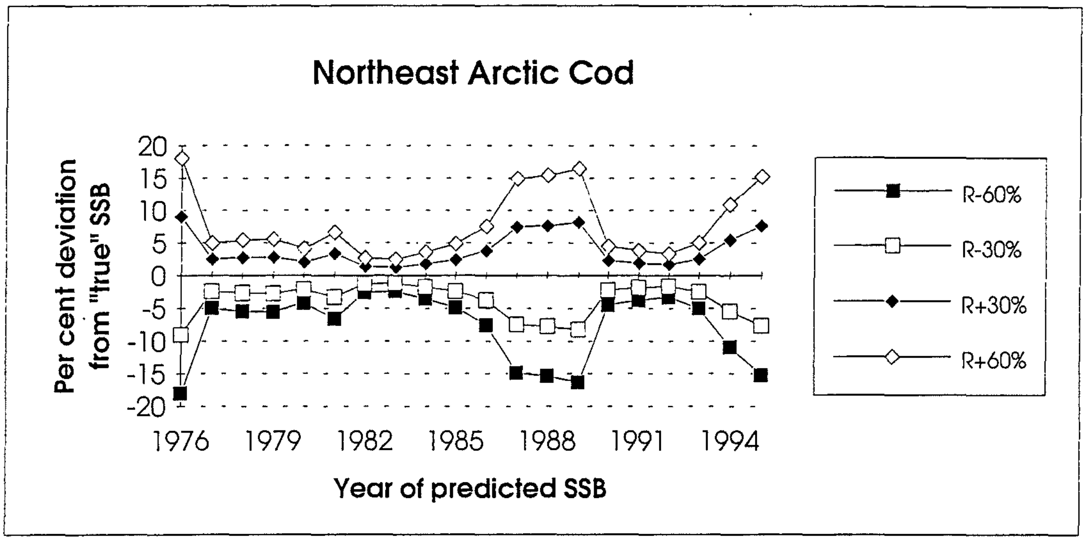
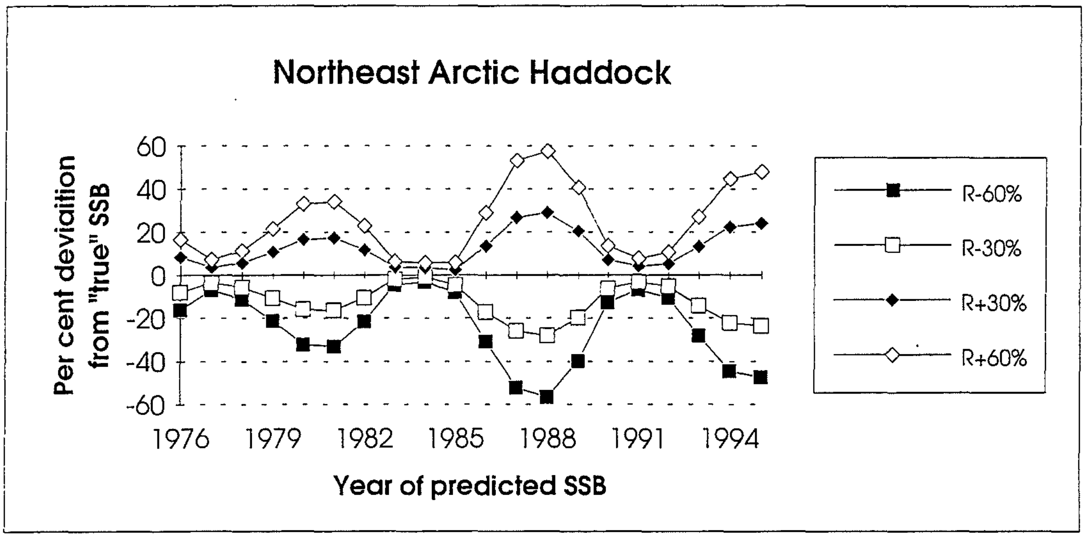


Figure 5. Per cent deviation over the last 20 years in short-term prediction of catch (in TAC year) caused by errors in the range -60% to +60% in the indices of recruitment (R).
(Simulation based on actual recruitment and F=0.4)





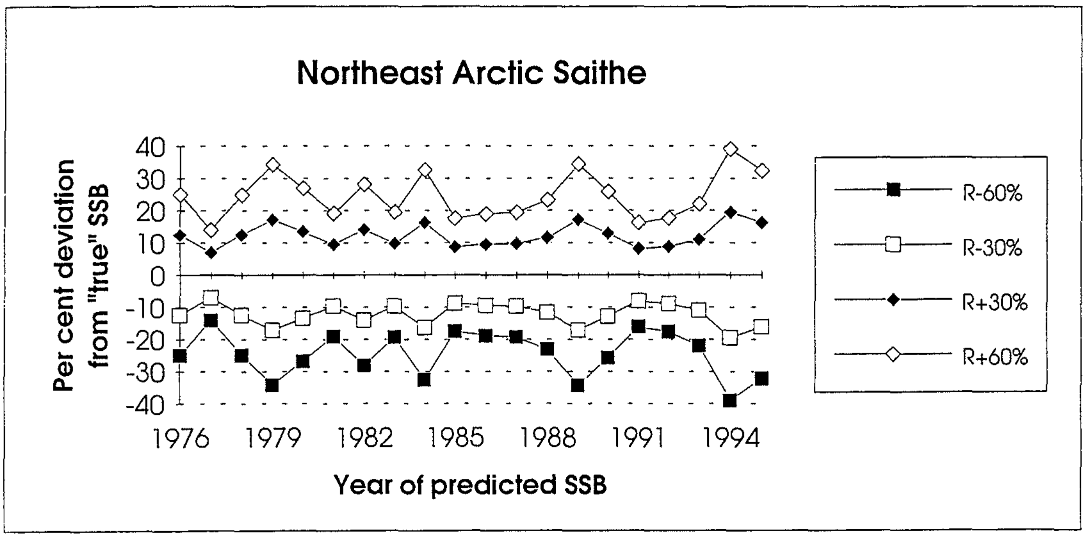
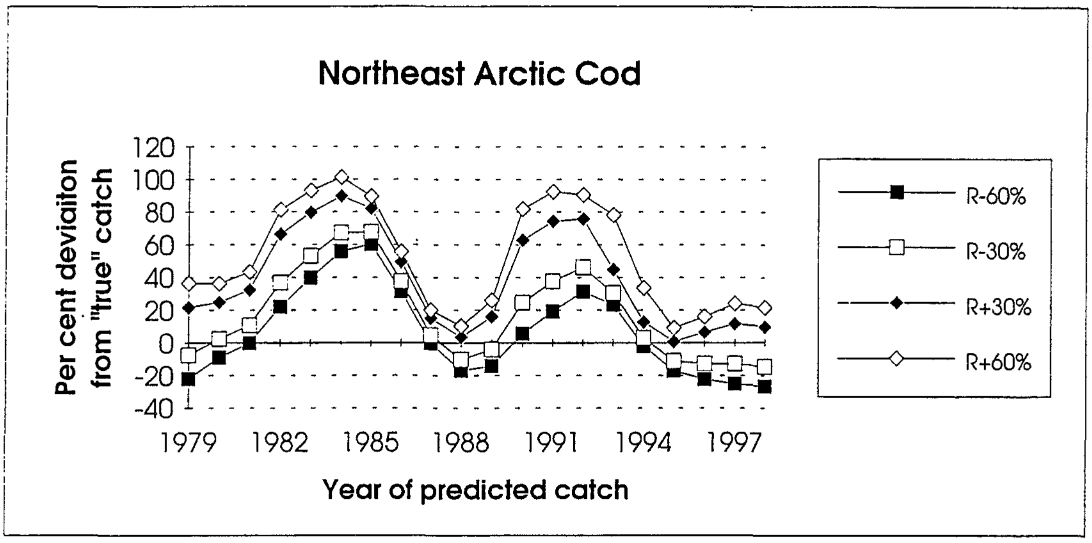
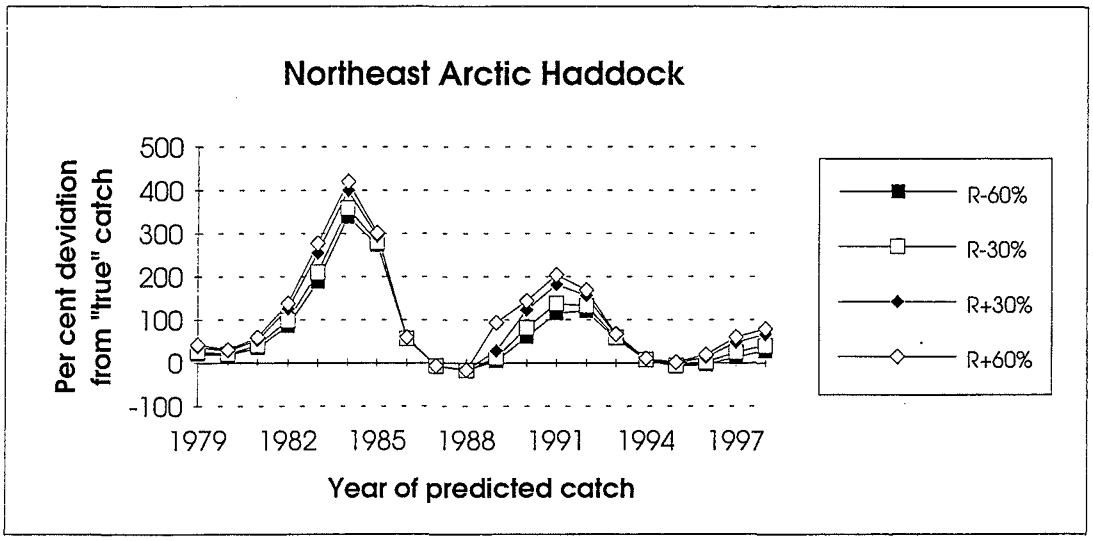


Figure 6. Per cent deviation over the last 20 years in short-term prediction of SSB (in TAC year + 1) caused by errors in the range -60% to +60% in the indices of recruitment (R).
(Simulation based on actual recruitment and F=0.4)





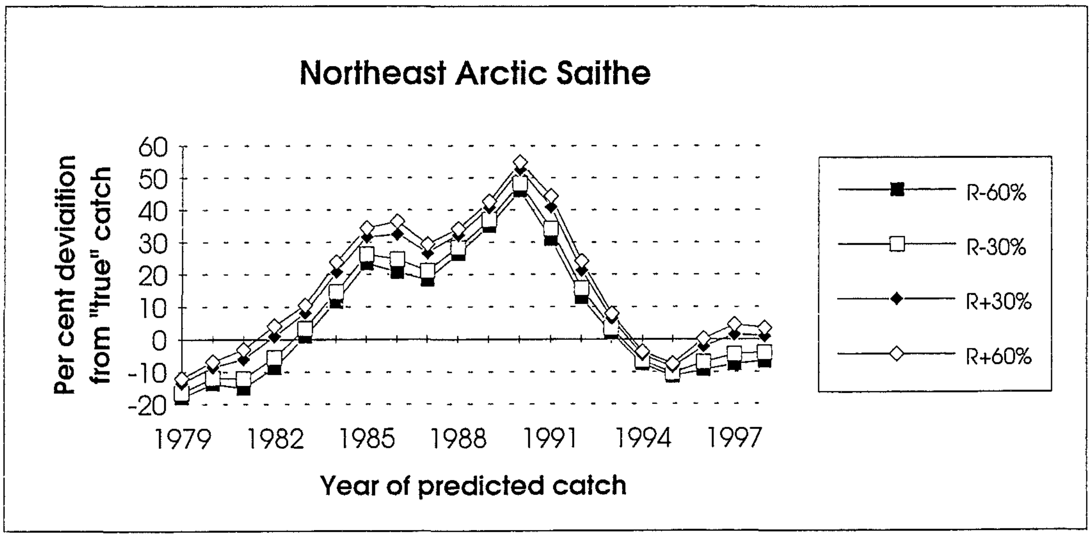


Figure 7. Per cent deviation over the last 20 years in medium-term prediction of catch (in TAC year + 4) caused by errors in the range -60% to +60% in the indices of recruitment (R).
(Simulation based on actual recruitment and F=0.4)

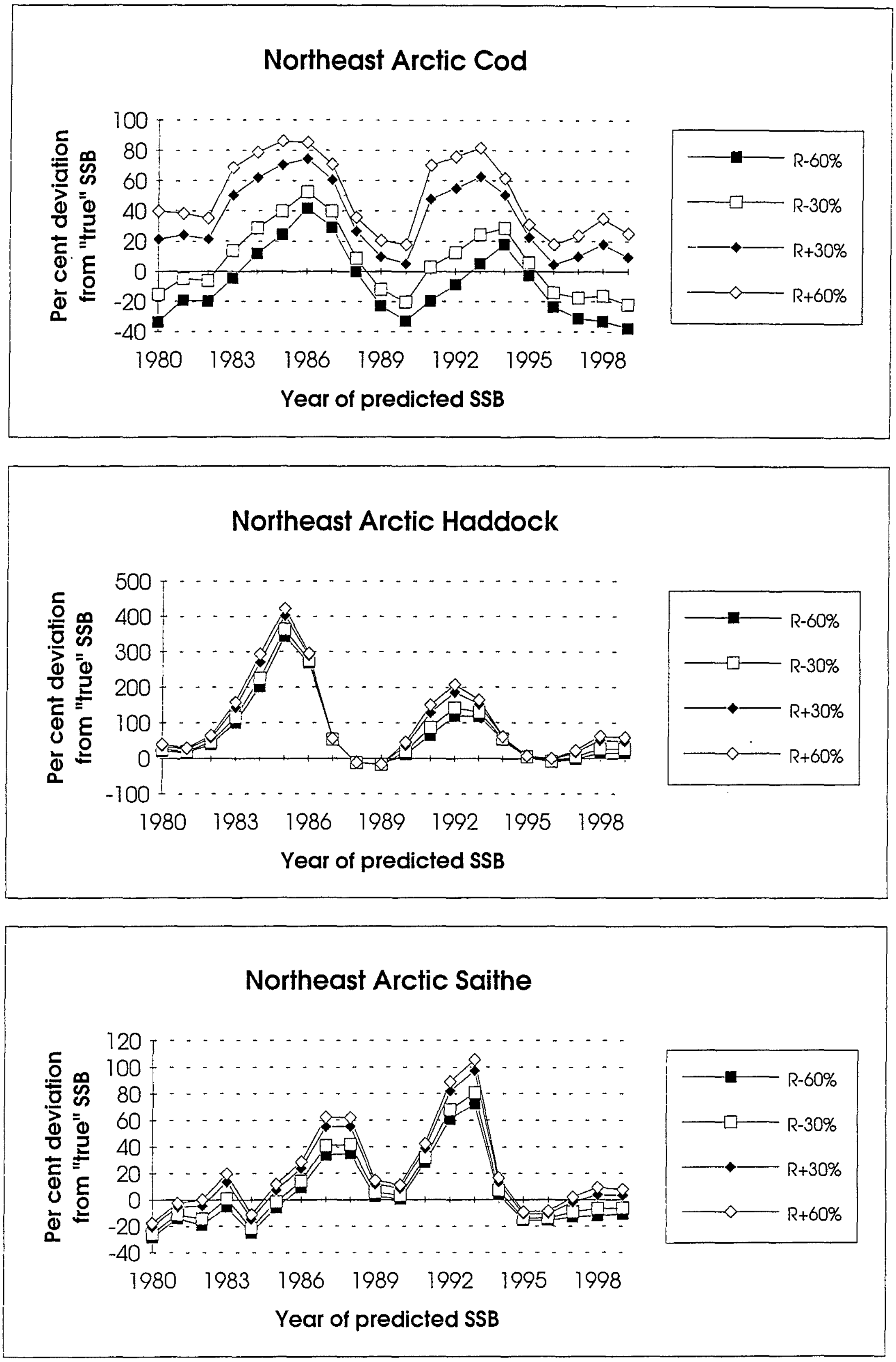
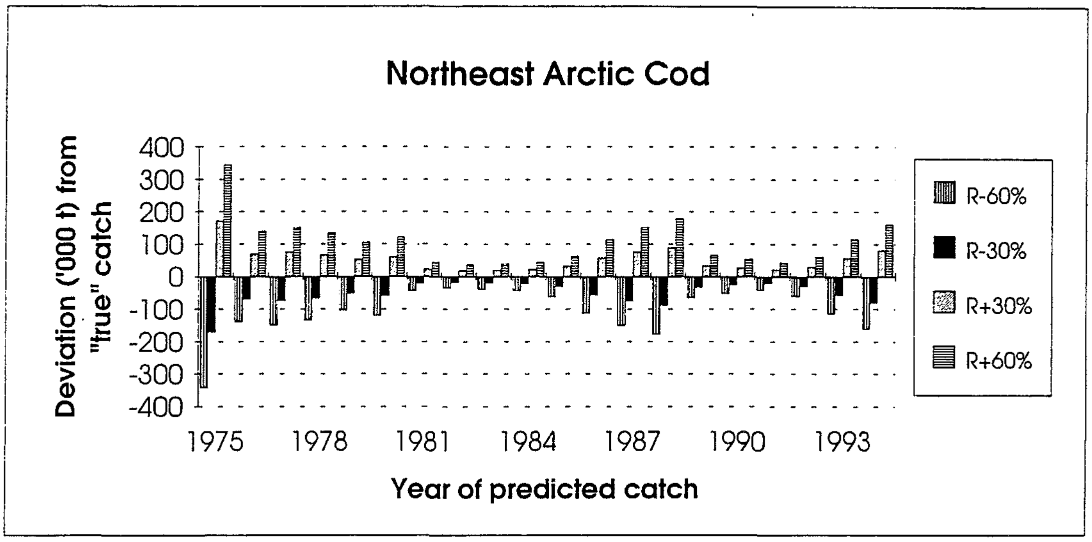
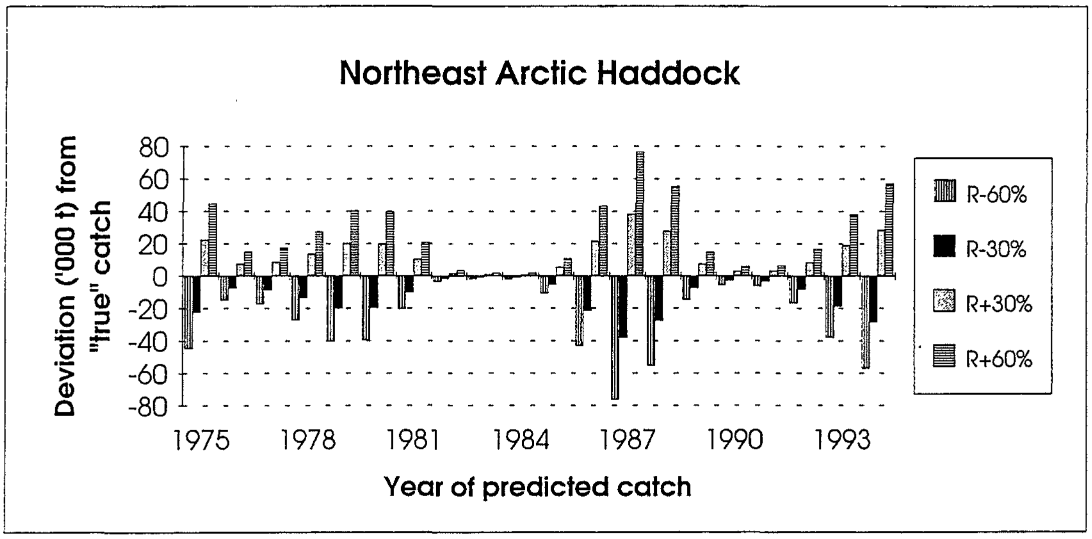


Figure 8. Per cent deviation over the last 20 years in medium-term prediction of SSB (in TAC year + 5) caused by errors in the range -60% to +60% in the indices of recruitment (R).
(Simulation based on actual recruitment and F=0.4)





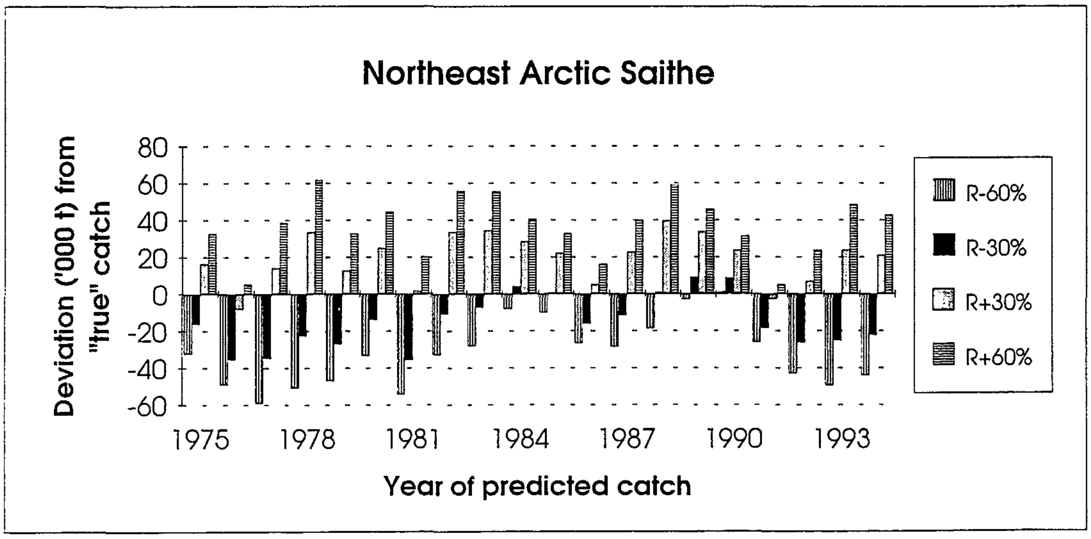
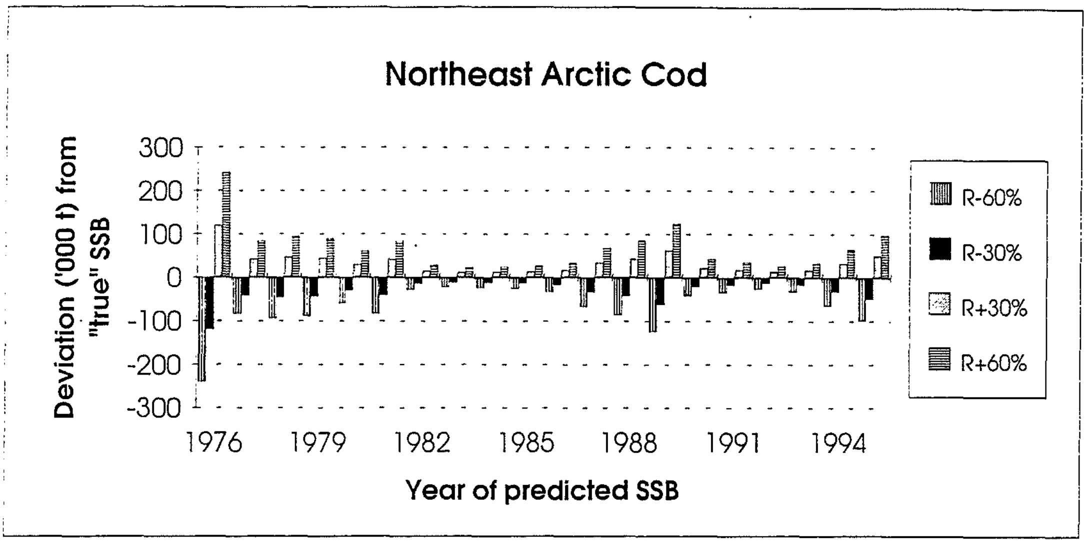
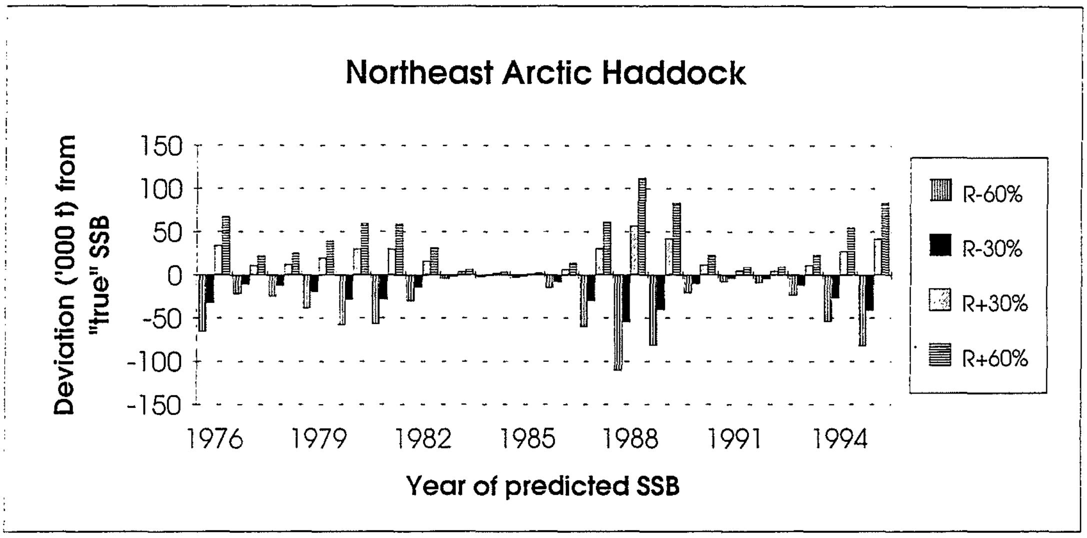


Figure 9. Deviation ('000 t) over the last 20 years in short-term prediction of catch (in TAC year) caused by errors in the range -60% to +60% in the indices of recruitment (R).
(Simulation based on actual recruitment and F=0.4)





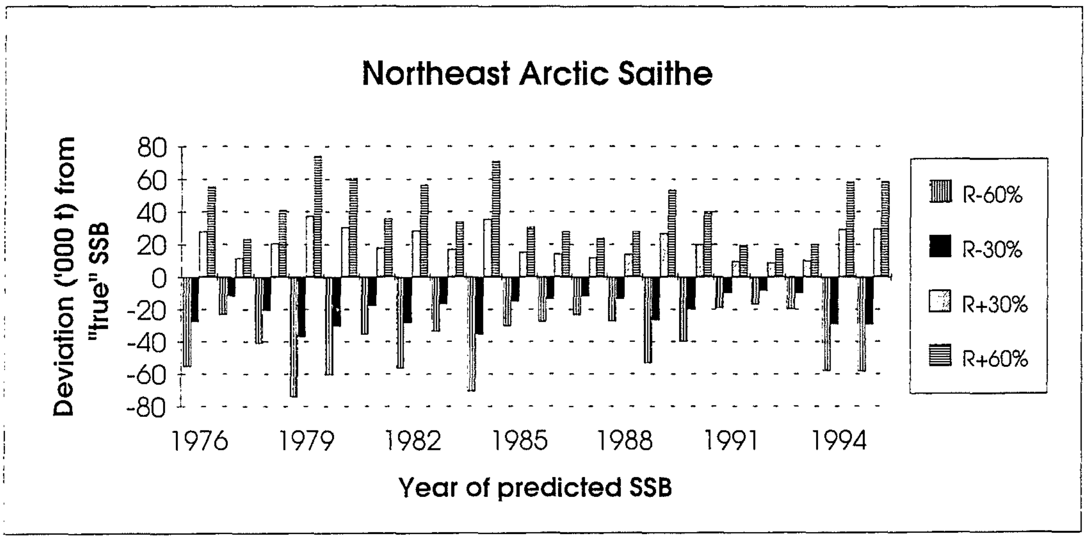


Figure 10. Deviation ('000 t) over the last 20 years in short-term prediction of SSB (in TAC year + 1) caused by errors in the range -60% to +60% in the indices of recruitment (R).
(Simulation based on actual recruitment and F=0.4)

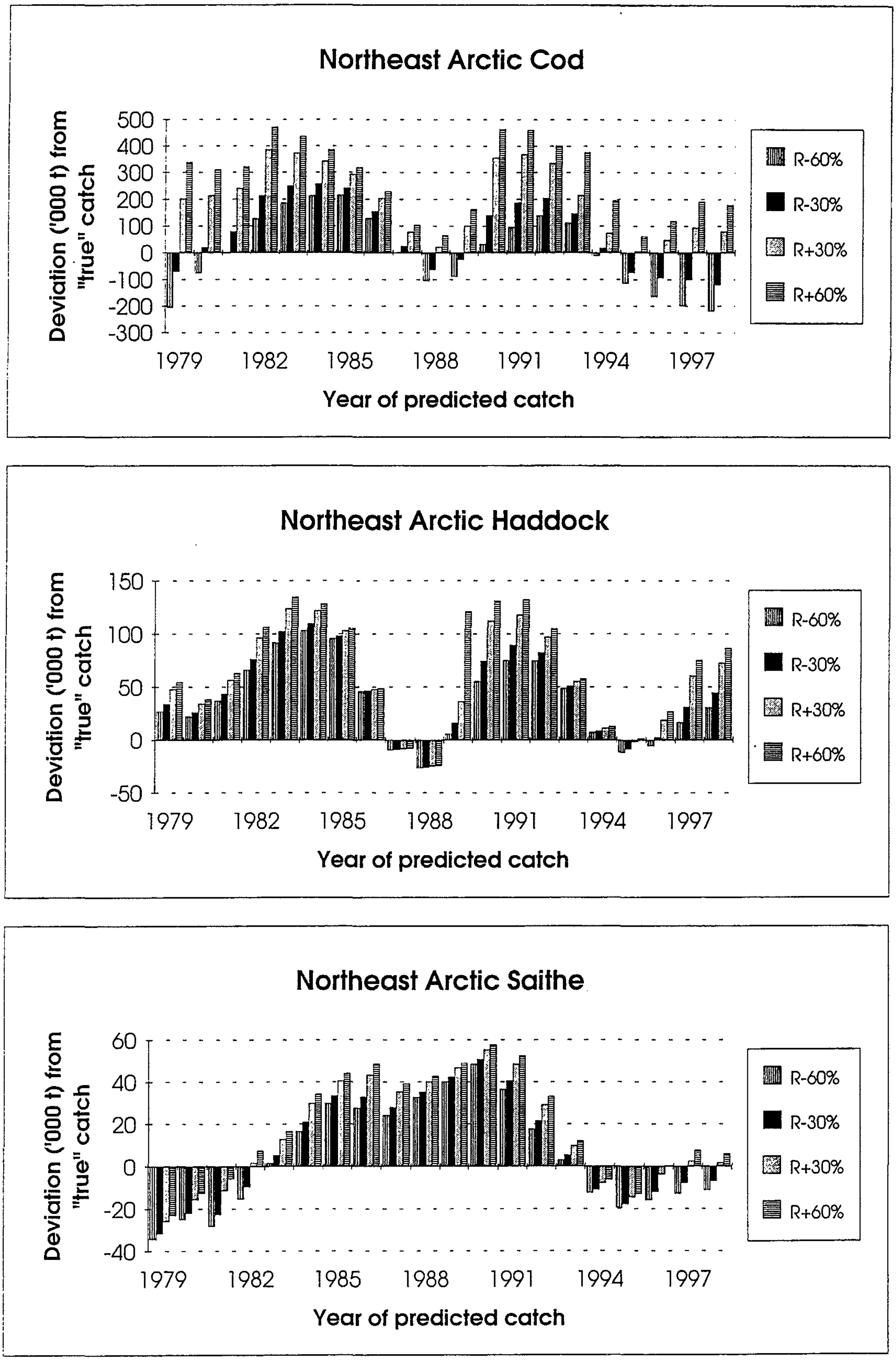
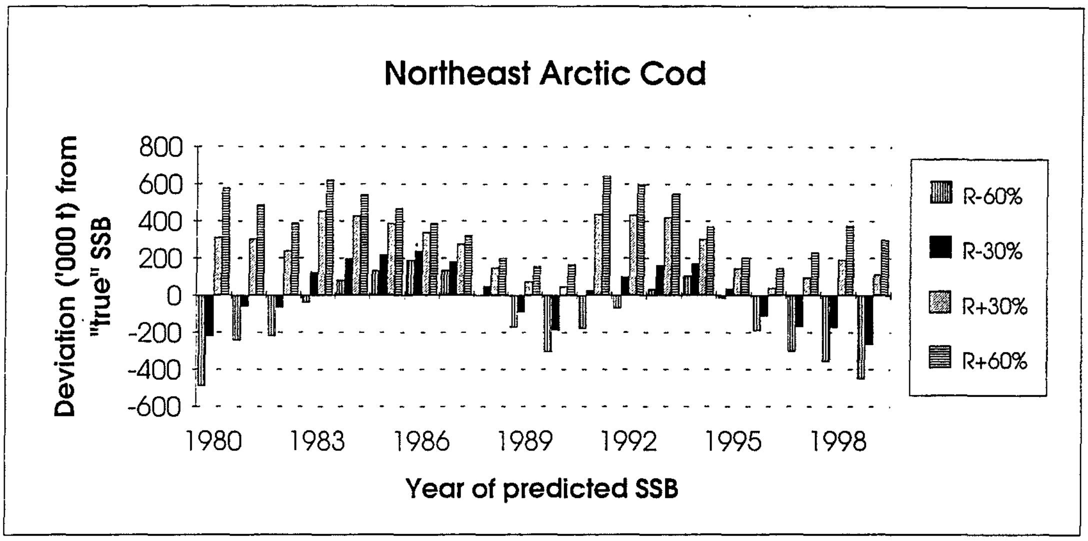
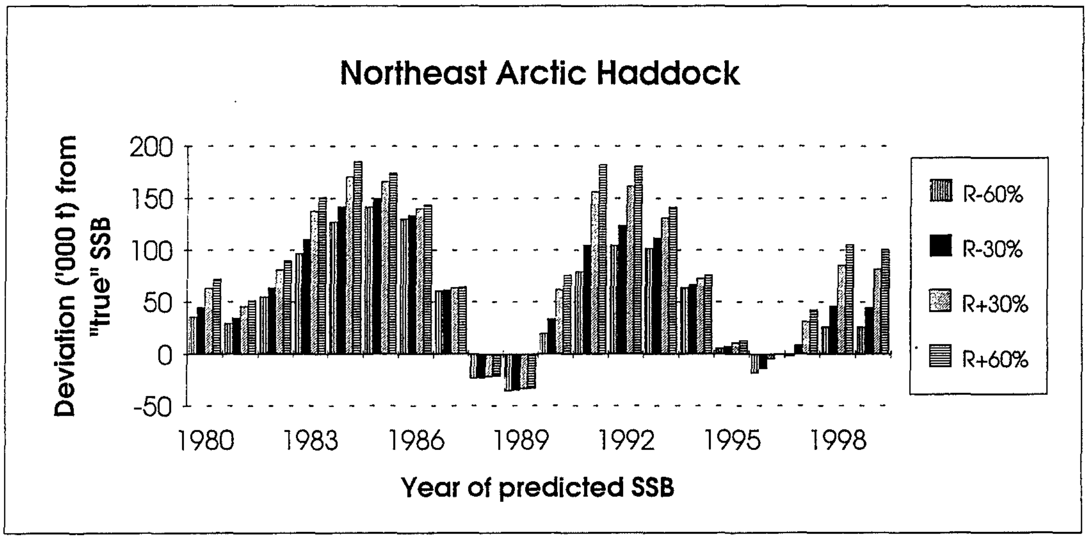


Figure 11. Deviation ('000 t) over the last 20 years in medium-term prediction of catch (in TAC year + 4) caused by errors in the range -60% to +60% in the indices of recruitment (R).
(Simulation based on actual recruitment and F=0.4)





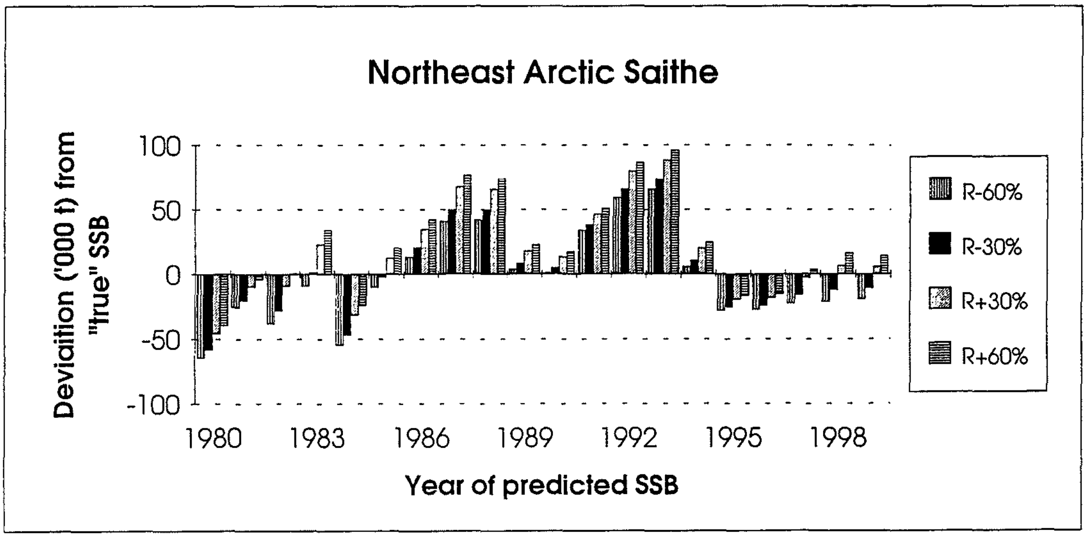


Figure 12. Deviation ('000 t) over the last 20 years in medium-term prediction of SSB (in TAC year + 5) caused by errors in the range -60% to +60% in the indices of recruitment (R).
(Simulation based on actual recruitment and F=0.4)

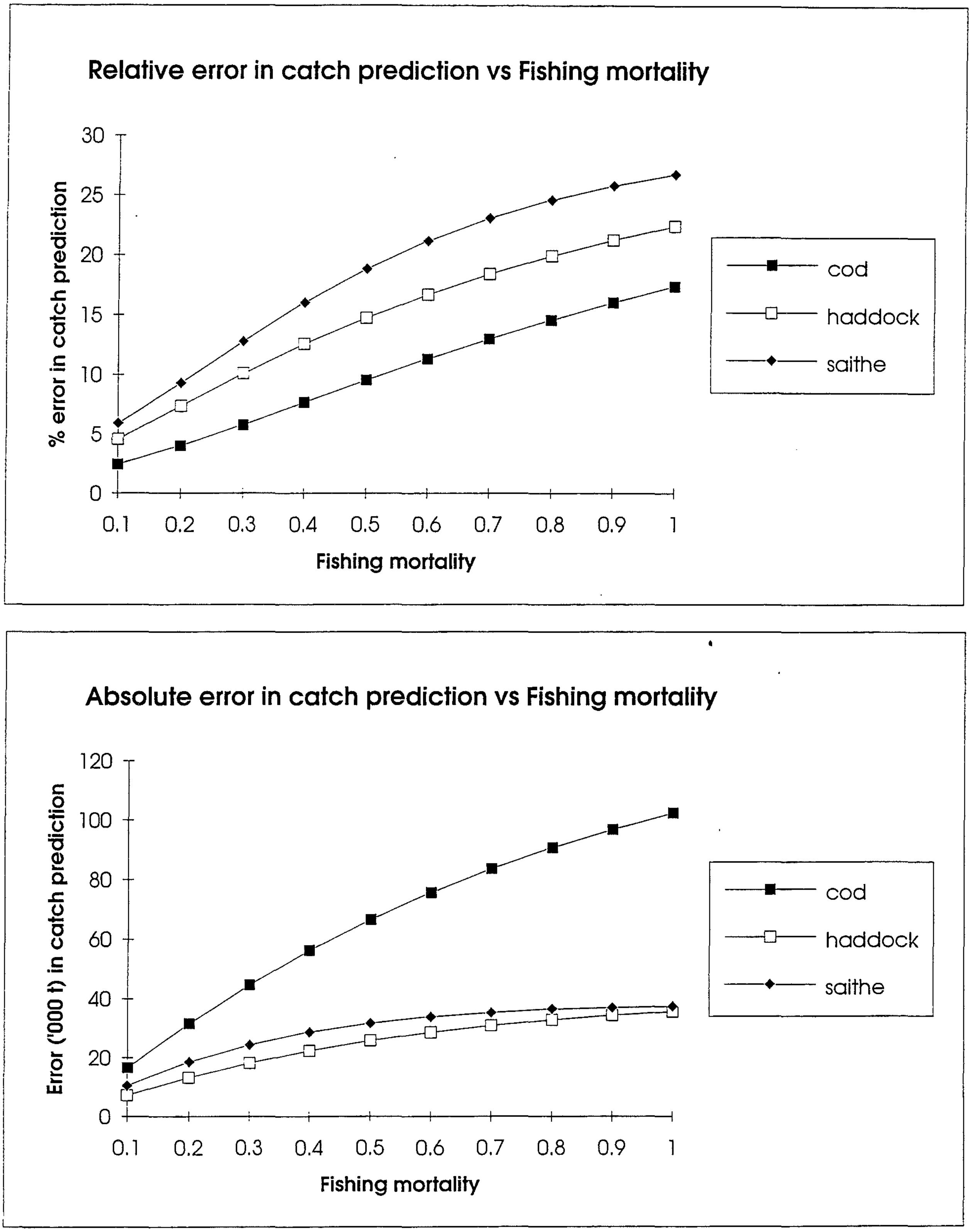


Figure 13. Relative and absolute error in short-term catch prediction as a function of fishing mortality, assuming 30% error in the recruitment indices.

THE DEPENDENCE OF MANAGEMENT STRATEGIES FOR BARENTS SEA COD AND CAPELIN ON THE RECRUITMENT MODELS

by

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ABSTRACT

The least studied subject in the assessment and management of Barents Sea cod and capelin is the management strategy. Using a cod-capelin-herring model, the uncertainty in the management strategy of cod and capelin arising from uncertainty in the spawning stock-recruitment relationship is investigated using stochastic methods.

INTRODUCTION

The Barents Sea ecosystem is to a large extent dominated by North-East Arctic cod, capelin and Norwegian spring spawning herring (Hamre 1990). Cod and capelin spend their entire life in the Barents Sea (although a part of the cod stock may spawn far south on the Norwegian coast and then return to the Barents Sea area) while herring larvae flows into the Barents Sea when there on irregular intervals are good recruitment conditions for herring. At about age 3 the herring leaves the Barents Sea. Capelin and herring are food items for cod. The consumption by cod is an important part of the natural mortality on cod and capelin.

The management strategy used at present for North-East Arctic cod and Barents Sea capelin does not utilize the biological knowledge at present available for the ICES Arctic Fisheries and Atlanto-scandian Herring and Capelin working groups.

The management of North-East Arctic cod has been discussed by Jakobsen (1993). He argues that there appears to be no argument for allowing fishing mortalities to be on the average above the F_{med}= 0.46 level, and that simulations using historical data indicate that it would be safer to aim at a somewhat lower level of exploitation. The spawning stock biomass should also be kept above a critical level of about 0.4 million tonnes, above which the recruitment has not failed. Trying to keep the cod stock at a high level may, however, backfire if there is not enough food to support it. The guidelines given in that paper are used in the management of North-East Arctic cod at present. There are, however, important data deficiencies in the historical time series of cod (Anon 1994a), which when corrected may give different results for the biological reference points underlying the management.

Keeping the fishing pressure at F_{max} would be a logical management rule if one ignored the effect the spawning stock has on the recruitment. If the recruitment is monotonically increasing with the spawning stock (Beverton-Holt type) one would expect that inclusion of recruitment considerations would lead to a lower target F-value than F_{max}. If there is a well-defined maximum (Ricker type) as would be the case if cannibalism were important, both a lower and a higher optimum F-value than

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F_{max} could be possible. However, it is very unlikely that the value of the spawning stock giving maximum recruitment would be lower than 0.4 million tonnes. An argument against using F_{max} is its sensitivity towards the (guesstimated) natural mortality (Jakobsen 1993). The nearly non-systematical relations between recruitment and spawning stock obtained by running the standard tuned VPA have till date precluded any "fine-tuning" of the cod management procedure. The fact that all considerations lead to the conclusion that the fishing mortality should be lowered from the pre—1990 level has given sufficient rationale for the present management policy.

Now that the cod stock has increased and the food supply is diminished because of the recent capelin stock collapse, possibly leading to increased cannibalism, this may not necessarily longer be so. The present paper seeks to overcome some of the methodological difficulties connected with including recruitment processes into the management scheme for cod. The model used and the stochastic way of treating it in experimenting with management strategies may be a useful tool in the management of the North-East Arctic cod stock in the future.

The Barents Sea capelin stock has been managed using a constant escapement strategy, i.e. a quota has been set that allows a target amount of capelin to spawn. When the regulation of the capelin fishery started by the end of the 70's the target spawning stock was set to 0.5 million tonnes without any other justification than the biologists "gut feeling", there were simply not adequate data to estimate an optimal strategy. By the mid 80's a single species capelin model was developed that yielded an optimal spawning stock of about 0.4 million tonnes (Hamre and Tjelmeland 1982). In the present-day management of the capelin stock, the spawning stock is calculated by taking the effect of the predation from cod into account using the extensive PINRO-IMR stomach content data base and models for the gastric evacuation rate of cod (Bogstad and Gjøsæter 1994). However, no target spawning stock has yet been estimated taking into account the actual size of the cod stock, so that the former target spawning stock level of about 0.5 million tonnes is still used. A first attempt to estimate the target spawning stock level taking predation from cod into account, has been done by Tjelmeland and Bogstad (1993).

The present paper gives a method for including into the development of new management strategies the significance of uncertainties in spawning stock-recruitment relationships. This work is done with a new model and must be viewed as being preliminary. However, it is important that the method suggested in the paper for estimating management strategies is thoroughly discussed among scientists working with Barents Sea management problems.

THE AGGMULT MODEL

The Aggmult model is developed in connection with the Norwegian research programme "Multispecies management" initiated by the Norwegian Fisheries Research Council (later merged with other research councils to Norwegian Research Council) in 1990 and finished in 1994. The idea behind the programme was to link biological research with bioeconomical and social sciences research hoping to improve the management strategies used at present in the Barents Sea. At the initiation of the programme two multispecies models were in development at IMR, the Multspec model that is an area distributed multispecies model for the Barents Sea and the Capsex model that primarily is a capelin model, but that is augmented with some cod dynamics and herring influence on capelin recruitment. However, neither of these models could serve as the bridge between biological and economical modeling, the former because of its complexity rendering it impractical for direct use in bioeconomical management considerations and the latter because it is too restricted in scope. Therefore, it was decided to develop a new model that in essence would be an area- and length integrated version of the Multspec model: the Aggmult model.

Since an important goal of the programme was to incorporate species interactions into new management schemes it was mandatory to have a model that could be usable for experimenting with management strategies, both of short-term and long-term nature. That is, the model had to have the recruitment process for the various species as an integrated part, rooted in data as well as possible. The focus for work with the Multspec model has to date been on cod-capelin interactions, and only little experience with this model was available for the recruitment processes. Therefore, the recruitment part of the Aggmult model had to be developed with no aid from Multspec.

A vital part of the Aggmult model is the plankton submodel. It serves two purposes: The plankton abundance 1) governs the growth of the plankton feeders and 2) serves as a buffer for the predation mortality. In the present paper, the emphasis is on the latter aspect. The feeding level halfvalue for the plankton feeders is set so low that the feeding level is close to 1 for all levels of plankton abundance that have been used. Therefore, the growth of the plankton feeders is totally determined by the historically observed growth rates. The predation mortalities, however, are dramatically influenced by the plankton levels, especially in the 0–group stages.

The biological entities in the Aggmult model are:

1. Small plankton organisms in the northern Barents Sea, primarily food for capelin.
2. Small plankton organisms in the southern Barents Sea, food for capelin and herring.
3. Large plankton organisms, food for cod, herring and capelin.
4. Herring, age distributed.
5. Capelin, age distributed.
6. Cod, age distributed.

A thorough description of the model and the estimation process is given in the model documentation (Tjelmeland 1995). Here, a more brief and sketchy overview of the model is given.

The time sequencing of the model is the same as for the Multspec and Capsex model. The time step is one quarter (three months) compared to one month in Multspec and Capsex. Aggmult uses 6 age groups (zero group and age 1–5) for capelin and 11 age groups (zero group and age 1–10) for cod and herring.

Single-species dynamics

Plankton

All three plankton 'stocks' have the same dynamics. The equation used is:

$$\frac{dB_{pl}}{dt} = P_{plprod}\left(B_{plmax} - B_{pl}\right) - C \tag{1}$$

where B_{pl} is the plankton biomass, C is the consumption rate from fish and P_{plprod} is a production parameter. B_{plmax} is the maximum plankton abundance. The parameters have different values in the different quarters of the year.

In the present model the plankton parameters have not been estimated from data. It should be an important future activity to relate the plankton development to observations. This might be done in two possible ways, either by using a fish-plankton model to evaluate the plankton production throughout historic years or by using the present model to estimate the plankton parameters using plankton measurements each year. Plankton data collected onboard Norwegian vessels during the joint IMR–PINRO autumn cruise since 1986 should be available for this purpose. For the present use of the Aggmult model the setting of the plankton parameters is somewhat arbitrary and represents a fundamental uncertainty. Therefore, a plankton scaling factor is introduced so the model can be tested against different levels of plankton abundance. Only the maximum plankton biomass is scaled.

Fish

Feeding level

The feeding level concept (Andersen and Ursin 1977) is crucial to the Aggmult modeling of growth and predation. The feeding level f is given by:

$$f = \frac{\varphi}{P_3 + \varphi} \tag{2}$$

where

$$\varphi = P_{23} + \sum_{j,a} S_{j,a} B_{j,a} \tag{3}$$

is the total perceived food abundance, i.e. the abundance of food organisms scaled with their suitability as food for the predator, and P_3 is a parameter, referred to as the feeding level half value parameter. This parameter determines the predation response to changes in food abundance. For cod, this parameter is taken from estimation work with the Multspec model (Bogstad and Tjelmeland 1992). For capelin and herring the parameter has been arbitrarily set to a relatively low value compared to the levels of plankton abundance used in the present paper. P_{23} is a parameter for other food, $B_{j,a}$ is the biomass abundance of prey item j at age a and $S_{j,a}$ is the suitability for prey item j at age a as food for the predator.

Growth

The growth in length is given by the equation:

$$\frac{dl}{dt} = P_4 f l^{P_5} \tag{4}$$

where l is the mean length in each age group and P_4 and P_5 are parameters.

The growth in weight is given by the equation:

$$\frac{dw}{dt} = P_8(f - P_{10}) w^{P_9} \tag{5}$$

where w is the mean weight in each age group and P_8, P_9 and P_{10} are parameters. P_{10} is set to 0.15 for all species.

Maturation, spawning and recruitment

The proportion mature $m(l)$ is given by the equation:

$$m(l) = \frac{1}{1 + e^{4P_1(P_2 - l)}} \tag{6}$$

where l is the mean length in each age group and P_1 and P_2 are parameters. This equation is used to split each population into an immature and a mature part at January 1 where the mature part spawns at April 1 and the resulting number of recruits is given by the Beverton-Holt formulation:

$$R = P_{13} \frac{B_{sp}}{P_{14} + B_{sp}} \tag{7}$$

Before the recruits enter the fishable population they are preyed on by larger fish. Therefore, the spawning stock — recruitment relation arising from the above equation will not have a smooth or even monotonically increasing appearance even when the model is run deterministically. The recruitment of herring is drawn directly from the historical time series, as the herring stock is not modelled as adults when they are outside the Barents Sea. A spawning stock — recruitment relationship can thus not be applied for herring. However, there is work being done to connect Multspec to a herring model (Dommasnes and Hiis Hauge 1994). Since Aggmult is not length-distributed, the mean length has been used in formula 7. Tests indicate that the difference in numbers of mature fish by age between using the mean length and the length distribution is small.

Predation

The consumption per individual is given by the equation:

$$C = P_{22}(0) f w^{P_{22}(1)} \tag{8}$$

where w is the mean weight in an age group an P_{22} is a vector parameter of two elements.

The consumption is partitioned on the prey items (including plankton) according to their suitability scaled contribution to the total food abundance. Immature cod preys on capelin in all quarters. Mature cod preys on capelin only during the last quarter of the calendar year.

DATA

The model starts in 1972, i.e for all species data from 1972 have been used, if existing.

For cod, the outputs from the 1993 assessment has been used. As a consequence, the number at age input to Aggmult is dependent on the natural mortality M of 0.2 used by the Arctic Fisheries Working Group (Anon. 1994a). Another M-value would yield different Aggmult results. The sensitivity of Aggmult to the cod M-value has not been tested yet. Also, the weight at age and length at age are taken from the 1993 assessment. The weight at age data are not available prior to 1983. For historic catch, the F-values from the assessment have been used, rather than the actual catch. The recruiting age is 3 years. The cod input to Aggmult closely parallels the cod input to Multspec.

For herring, the abundance estimate obtained during the yearly cruise in the Barents Sea in May-June has been used for the input in number by age, length by age and weight by age. The recruiting age is 1 year.

For capelin, the abundance estimate obtained during the joint IMR-PINRO September cruise has been used for the input in number by age, length by age and weight by age. This is the same input as used for the Multspec model.

PARAMETER ESTIMATION

Most of the parameters get their values from an estimation process, and many parameters are estimated year by year, later to be drawn at random each year when the model is run into the future for experimenting with various management strategies. Here, the estimation processes are described in the same sequence as they were performed. Two different plankton scaling factors are used, 2.0 and 5.0. The estimation results are shown in tables in the appendix.

Growth

As a first step, the growth parameters P_4, P_5, P_8 and P_9 are estimated under the assumption that the feeding level is unity. Using the estimated values of P_4 and P_8 as start values and fixing the parameters P_5 and P_9, P_4 and P_8 are estimated year by year.

There is a severe problem with the growth in weight of cod. Weight data are not available prior to 1983, which leads to incorrect values of the cod stock size prior to 1983. This affects the simulated growth and predation on capelin. In particular, the historical values for the capelin spawning stock biomass may be severely in error, making it difficult to work out reliable spawning stock — recruitment relations. There is, however, a project under way to work up historic time series. Thus, there is some hope for improvement in the not too distant future.

Recruitment

The number of recruits as 0-group is entered at the beginning of the third quarter of the calendar year. The number of recruits are estimated annually by running the model forward to the recruiting age for each species and comparing to data.

The length and weight of the recruits are estimated annually by running the model to age 1 for each species and comparing to data.

The parameters of the recruitment function are not estimated in the traditional way, where constancy over the historic period is assumed. Rather, P_{13} is fixed at 1.1 times the highest estimated number of 0-group. P_{14} is then calculated for each year. Usually, one tries to fit spawning stock-recruitment data to a model where the recruitment is a function of the spawning stock and perhaps one or more environmental variables. The procedure of using halfvalues seems to have advantages when correlations between environment and the temperature is sought, which is illustrated in the following example:

Figure 1 shows the recruitment with time calculated from a Ricker model that is fit to VPA data. In working with cod the Ricker model seems appropriate since the effect of cannibalism is embedded into the functional form. Figure 2 shows the recruitment calculated by first calculating the yearly halfvalues and then fitting the halfvalues to a linear regression model where the temperature in the Kola section (Bochkov 1982) in September is the only variable in addition to the constant term.

Figure 1 Recruitment using a Ricker model on VPA data

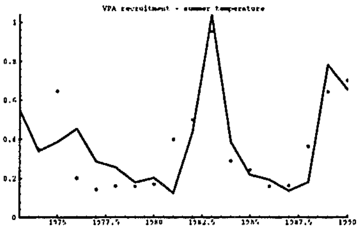

Figure 2 Recruitment using halfvalues calculated from VPA data regressed to temperature

In both cases there is a regression involving two variables, but regressing on halfvalues gives seemingly a better possibility of picking up environmental signals to the recruitment.

Figures 3 and 4 shows the time series of recruitments by regressing halfvalues to the Kola section September temperature for a plankton scaling of 2.0 and 5.0, respectively.

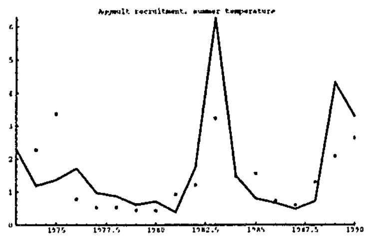

Figure 3 Recruitment using halfvalues calculated from Aggmult with plankton scaling 2.0 regressed to temperature

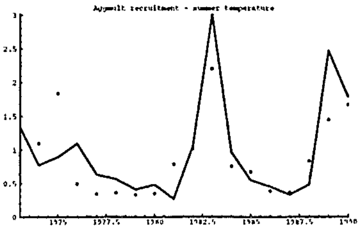

Figure 4 Recruitment using halfvalues calculated from Aggmult with plankton scaling 5.0 regressed to temperature

This analysis seems to give possibilities for strongly reducing the stochastic uncertainty in the model by drawing a temperature randomly (or autocorrelated) from a distribution that is modeled from historic data and calculating halfvalues from the regression formula, instead of drawing halfvalues from historically estimated halfvalues. The regression explained only 42% and 49% of the variance in halfvalues for plankton scaling of 2.0 and 5.0, yet the prediction of recruitment seems to be fairly good. However, further analysis where a variety of environmental indices are tried should be done before this method is adopted in management-related analyses. Also, more experience with the Aggmult model is needed, especially with the fish-plankton interaction. The potential for a predation model like Aggmult to remove predation effects from the uncertainty around the stock-recruitment relation seems promising.

Residual natural mortality

The residual mortality, i.e. the mortality generated by other causes than predation from modeled species, is estimated year by year for fish older than recruiting age. Constancy over age for each year is assumed.

Maturation of capelin

The maturation of capelin has been estimated using the Capsex model (Tjelmeland and Bogstad 1993). However, because Aggmult uses mean length by age and Capsex uses a length distribution for each age group, these values are not readily transferred from Capsex to Aggmult. In the next version of Aggmult, the maturation parameters should be estimated using the Aggmult model.

Parameters that are not estimated

Plankton

The production parameter is set so that the plankton increase time, i.e. the time to increase from zero to half the maximum with no predation is one time step (quarter of year). The quarter number refers to the simulation cycle, i.e. the first quarter is the fourth quarter of the calendar year. Table 1 shows the unscaled values used in the model.

Table 1 Baseline plankton parameters.

Quarter	Plankton 1		Plankton 2		Plankton 3	
	P	B_{max}	P	B_{max}	P	B_{max}
1	1.0	15	1.0	25	1.0	30
2	0.5	15	0.5	25	0.5	30
3	1.0	15	1.0	25	1.0	30
4	2.0	15	2.0	25	2.0	30

Fish

Cod VPA M-value

For abundance data for cod, the outputs from the tuned VPA carried out at the 1993 meeting of the Arctic Fisheries Working Group (Anon. 1994a) are used. This precludes modeling any predation mortality on cod 3 years and older, since then there would be incompatibility with the M = 0.2 used in the VPA. The whole procedure hinges on the VPA guesstimates, and there is thus no way in the present model of assessing the uncertainty in the derived management decision rules with respect to the VPA assumption of a time and age constant M of 0.2 without redoing the estimate using a different M-value. However, recent work with the 'scenario' model for the Barents Sea (Anon. 1994b) yields some hope for systematically investigating the sensitivity of the management strategies to the VPA M-value.

Maturation of cod and herring

The maturation parameters P_1 and P_2 for cod and herring are not estimated from data. Values that seem "reasonable" have been selected. The sensitivity of Aggmult to changes in these parameters has not been tested, but is probably small. It should be possible to estimate these values from available maturation data.

Suitabilities

The suitability variation that stems from size differences is shown in the appendix. The sensitivity of the final results to variations in these matrices are probably small. As for the inter-species suitabilities, the following assumptions are made, all of which should be tested in later versions of the model:

1. Herring and capelin have the same suitability for predation from cod.
2. The suitability of capelin as food for herring is set to 30 times the suitability of capelin as food for cod. This makes the capelin recruitment sensitive to herring abundance.
3. The suitability for plankton as food for fish is set to 0.5 the suitability of fish as food for fish. However, this uncertainty is probably of no significance, since this suitability could be viewed as a part of the plankton scaling factor. In later versions of the model where real plankton data are connected, it becomes of importance to assess this suitability correctly by using measurements of ambient plankton abundance together with stomach samples from plankton feeders.

Maximum consumption

For cod, the value of P_{22} that is estimated using Multspec is used (Bogstad and Tjelmeland 1992). For herring and capelin the value is calculated assuming that the ratio of consumption to growth is 5.0 at age 4. This value is somewhat arbitrarily set. The idea is that results from bioenergetic modeling could later be used to give reasonable values for P_{22} since it is difficult to use a combination of stomach content data and an evacuation rate model as it is done for cod. There simply is not enough data.

MODEL RUNS

When the model is run into the future the outcomes of the non-modeled processes are drawn from the historically estimated values. A "scenario year" is drawn at random from the range of years over which the estimation has been performed and the non-modeled processes for that year is used in the simulation. Figures 5 — 7 show 10 stochastic runs for a plankton scaling factor of 2.0 and no catch on any species.

In some cases there is a lack of estimated values (for instance, growth in weight of cod prior to 1983). Then the algorithm seeks the nearest value, which leads to an overemphasis on the year 1983 in the case of cod growth in weight.

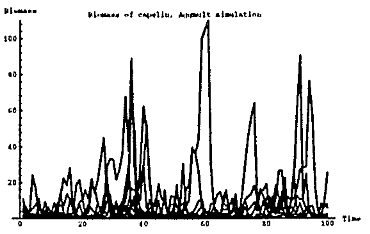

Figure 5 Stochastic development of capelin, million tonnes. Plankton scaling 2.0

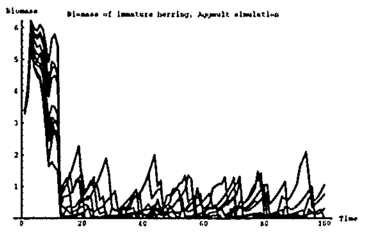

Figure 6 Stochastic development of herring, million tonnes. Plankton scaling 2.0

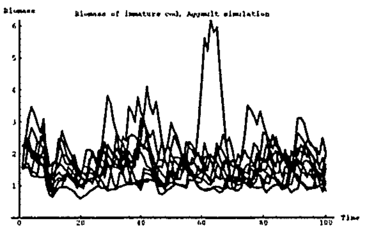

Figure 7 Stochastic development of cod, million tonnes. Plankton scaling 2.0

Figure 8 — 10 show 10 stochastic runs for a plankton scaling factor of 5.0 and no catch.

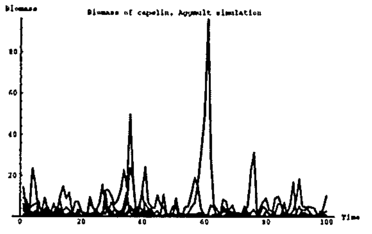

Figure 8 Stochastic development of capelin, million tonnes. Plankton scaling 5.0

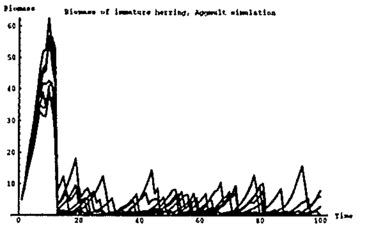

Figure 9 Stochastic development of herring, million tonnes. Plankton scaling 5.0

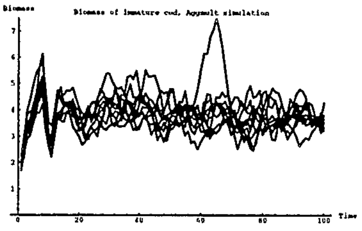

Figure 10 Stochastic development of cod, million tonnes. Plankton scaling 5.0

The maximum values for capelin are unrealistically high, showing that the recruitment relation does not give a realistic limit for abundance. The limiting factor in Aggmult is intended to be the plankton abundance, so unrealistically high capelin abundance points to a too stable plankton population. Probably, the problem lies in the food conversion factor of 5.0 being too small. However, when the model is used for evaluating management strategies this poses no problem, since then catch is applied.

Both the herring and cod stocks are on the average more abundant when a plankton scaling of 5.0 than when a plankton scaling of 2.0 is used. However, the peaks of the capelin stock show an opposite response to the plankton scaling.

For other uses of the model than experimenting with management rules in a stochastic environment, it is useful to have a standard deterministic run. It is no straightforward task, however, to define a set of deterministic parameters using the yearly estimated values. The yearly values were meaned with the exception of the recruitment halfvalues, for which the medians were used. However, using the obtained parameter values for capelin did not yield a sustainable stock when the model was run without catch. Then, the non-modeled natural mortality of capelin was tried set so that the mean value of the number of 2 year old capelin in the period 50–100 years after start of simulation was equal to the mean of the stochastic runs for that period. However, no non-modeled natural mortality meeting this demand led to a sustainable capelin stock. Therefore, the smallest non-modeled natural mortality that led to a sustainable stock was chosen. Figure 11 and Figure 12 show the deterministic runs for plankton scalings of 2.0 and 5.0, respectively. The deterministic parameter sets are shown in the Appendix.

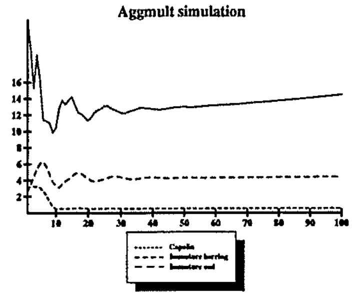

Figure 11 Deterministic run, million tonnes. Plankton scaling 2.0

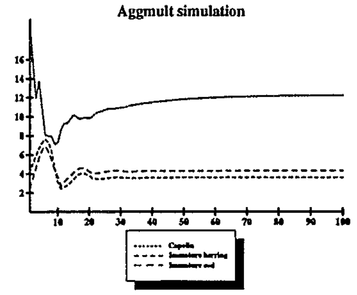

Figure 12 Deterministic run, million tonnes. Plankton scaling 5.0

In the deterministic regime, only the herring stock gets more abundant when the plankton scaling is increased from 2.0 to 5.0.

SEEKING MANAGEMENT DECISION RULES FOR COD AND CAPELIN

Figure 13 gives an overview of the method applied. For a fixed sequence of stochastic events the model was run 80 years into the future, each year applying a management rule for cod and capelin. Sampling of catch started after 20 years to avoid initial transients. This run was performed several times and an optimal strategy was found. Then the stochastic sequence was changed and a new optimal strategy was found. The process is very computer intensive, so it was only possible to obtain 10 different stochastic sequences. The analysis was done for plankton scaling of 2.0 and 5.0, using the same stochastic sequence in both cases.

The value of the random variables used for calculating the quotas are the same as the previous year, while the actual random variables used in advancing the model one year are drawn independently. In other words, the "managers" in the model made the assumption that the environmental (i.e. non-modeled) conditions in the future year would be the same as in the quota decision year. No autocorrelation is used, so we are applying a worst case scenario with respect to uncertainty: Next years random variables can be any of the historically measured random variables. In later use of the model, autocorrelation should be modeled from the historic series.

No attempt is made here to find a combined management rule for cod and capelin, which involves bringing in relative prices. Rather, a management rule for one species assuming a fixed management rule for the other species is sought. For the management of capelin it is tempting to make the management rule dependent on the size of the stock, assuming a higher price for a limited yield and a lower price for yield exceeding the limit, in an attempt to model the effect of two different markets for capelin: Human consumption and reduction. However, this is left for a future exercise.

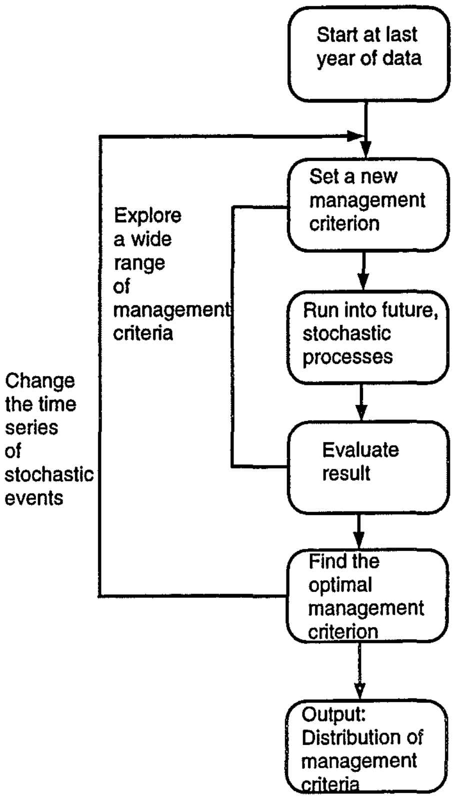

Figure 13 Illustration of the scheme for seeking management decision rules.

The management decision rule tried for cod is a target level of fishing mortality. The management decision rule tried for capelin is a target spawning stock, a rule that is much simplified from the rule recently tried using the Capsex model (Tjelmeland and Bogstad 1993). In operationalising the management rule for capelin runs one year ahead are made with different F-values and the F-value to use is calculated from the resulting F-value — spawning stock relation. During these runs the same stochastic sequence of events that applied during the previous period are used. For capelin, there is only fishing on the mature capelin in the period January-March.

The management rules tried in this paper must be considered experimental. The main purpose is to establish the method. In later uses of the model management rules incorporating probabilities of prolonged periods of stock collapses should be tried so that a trade-off between long-term high yield and long-term safeguarding against stock collapses could be experimented with. This would be an important use of the model if a public discussion about the fishing industry should emerge along the same lines as the public discussion about management of minke whales.

It was earlier shown that the stochastic uncertainty might be reduced by regressing recruitment halfvalues to environmental indices. It would then be interesting to use such a relation with the "managers" in the model knowing it and building a management strategy upon this knowledge. This is, however, left for a future exercise.

RESULTS

Tables 3 — 5 give the main results. The unit for biomass is million tonnes.

Table 2 Plankton scaling 2.0. Optimal target capelin spawning stocks.

Cod F-value	Optimal target capelin spawning stock	Mean capelin catch
0.1	0.52±0.32	0.17±0.02
0.2	0.59±0.30	0.28±0.04
0.3	0.65±0.21	0.41±0.07
0.4	0.74±0.20	0.57±0.10
0.5	0.75±0.17	0.75±0.15

Table 3 Plankton scaling 2.0. Optimal cod F-values.

Target capelin spawning stock	Optimal cod F-value	Mean cod catch (negligible variation)
0.2	0.45±0.04	0.27
0.4	0.45±0.04	0.28
0.6	0.45±0.04	0.28
0.8	0.45±0.04	0.28
1.0	0.45±0.04	0.29

Table 4 Plankton scaling 5.0. Optimal cod F-values.

Target capelin spawning stock	Optimal cod F-value	Mean cod catch (negligible variation)
0.2	0.45±0.04	0.49
0.4	0.45±0.04	0.49
0.6	0.45±0.04	0.49
0.8	0.45±0.04	0.49
1.0	0.45±0.04	0.49

Table 5 Plankton scaling 5.0. Optimal target capelin spawning stocks.

Cod F-value	Optimal target capelin spawning stock	Mean capelin catch
0.1	0.43±0.34	0.11±0.03
0.2	0.40±0.28	0.16±0.04
0.3	0.47±0.27	0.21±0.06
0.4	0.52±0.27	0.27±0.07
0.5	0.57±0.28	0.34±0.10

For both values of the plankton scaling parameter the optimal cod F-values are independent and the mean catch of cod is only slightly dependent of the target spawning stock of capelin. The yearly estimated cod growth was low in the period 1983–1987, probably connected to low abundance of capelin (Tjelmeland and Bogstad 1993). This decrease is reflected in the yearly estimates of the parameters P_4 and P_8, see tables in the Appendix. These estimates were obtained using the modeled feeding level value. If the decrease in growth of cod is caused by the capelin collapse, the modeled growth should be small due to small values of the feeding level. The decrease should not be reflected in the yearly estimated growth parameters. Thus, the model has not been capable of tracking the influence of capelin abundance on the cod growth, which explains the above results. The model yields an optimal F-value of 0.45, which is close to the present value of F_{med}.

The optimal spawning stock of capelin is strongly dependent on the F-value for cod, as expected. For a plankton scaling of 5.0 the optimal spawning stock for capelin is 26% lower than for a plankton scaling of 2.0, while the yield is 50% lower. Thus, there is smaller uncertainty in the management rule because of the ignorance of plankton effects than in the yield. This is particularly manifest for cod where an optimal F-value of 0.45 was obtained for both a plankton scaling of 2.0 and 5.0, while the yield was almost twice as high in the latter case. On the other hand, the uncertainty from the stochasticity of the model is much greater for the management rule than for the yield.

It might seem a little puzzling that the catch of capelin is smaller when the plankton scaling is 5.0 than when the plankton scaling is 2.0. The reason for this is probably that the cod stock is higher in the former case (see figures 7 and 10), leading to a higher predation mortality on capelin.

INADEQUACIES

In applying the procedure for evaluating management strategies using the present version of the Aggmult model, one should keep in mind that there is much that remains to be done in improving the data foundation and the parameter estimation. Of highest importance are:

1. Time series of cod weight at age prior to 1983.
2. Using real values of plankton data and, possibly, setting plankton production rates from output from a more sophisticated plankton model. This would enable setting the feeding level half value low enough to yield realistic plankton dynamics, not only using an overall plankton level as in the present paper.
3. Estimating the suitability for cod predation on capelin, herring and plankton from data.

For these reasons, the results (F-values, target spawning stocks, catches) obtained should be viewed merely as illustrations of the procedure, rather than serious suggestions for management strategies and possible outcomes of those.

SUMMARY AND CONCLUSIONS

In this paper, a method for evaluating management rules for cod and capelin in the Barents sea has been developed based on an age-distributed multispecies model. The processes in the model can be divided into modeled processes (for example maturation and predation) and non-modeled processes (for example non-modeled mortality). The non-modeled processes are estimated year by year using historic data and the estimated values are drawn at random when the model is run into the future.

A more profound uncertainty is connected to the recruitment function. In the model the plankton, besides being food for plankton eaters, partly shields the juveniles from predation. Thus, the modeled plankton has a nontrivial influence on the model spawning stock — recruitment relationship. It was not possible to connect the plankton model to data in any way, so the whole analysis was performed with two different levels of plankton abundance. It is difficult to assess whether the range in plankton abundance used covers the true uncertainty due to ignorance of plankton effects. At extremely high plankton values the model will in effect be a collection of single-species models because all three species eat some plankton in all age groups. At extremely low plankton values the fish-fish interactions become so strong that the three species hardly can coexist. More experimenting with the model is needed to find the exact range of admissable plankton abundance. The experiments made so far indicate that the chosen range covers a substantial part of the interesting area.

The difference between the results using a plankton scaling of 2.0 and a plankton scaling of 5.0 can be viewed as the non—tractable ignorance of the spawning stock-recruitment relation, and the expected future yield differ by a factor of about 2 in the two cases. However, the estimated optimal cod F-values and the estimated target spawning stocks of capelin differ to a much smaller degree, which illustrates the fact that a large predictive uncertainty not necessarily leads to a large uncertainty in the management decision. This could be interpreted in the following way: Over a great variety of possible situations the "best" action (quota) will be almost the same.

The uncertainty because of the stochasticity in the model, this might be coined the "tractable uncertainty" because it stems from the variation in yearly estimated values, has the opposite effect of being higher for the estimated optimal target spawning stock for capelin than for the estimated future yield of capelin. However, it is expected that this uncertainty might be reduced when models for the non-modeled processes are found. In particular, regressing recruitment halfvalues to environmental indices seems promising. For the cod stock, both for the optimal F-value and for the yield, this uncertainty is very small.

The present Aggmult model and the method applied for evaluating management strategies is a first attempt to give a scientific foundation for a multispecies management of the Barents Sea fish stocks. The uncertainties involved are large, but the variance can be reduced on the most vital points. However, considerable effort on constructing more refined submodels and improving the data foundation is needed before the work can be used in practical management.

REFERENCES

ANDERSEN K. P. and **URSIN E.** 1977. A multispecies extension to the Beverton and Holt theory of fishing with accounts of phosphorus circulation and primary production. *Medd. Danm. Fisk- og havunders. 7:*319–435.

ANON. 1994a. Report of the Arctic Fisheries Working Group. *ICES CM 1994*/Assess:2, 253 pp. Copenhagen, 24 August — 2 September 1993.

ANON. 1994b. Report of the Working Group on Long-Term Management Measures. *ICES CM 1994*/Assess:11. 45pp.

BOCHKOV YU. A. 1982. Water temperature in the 0–200 m layer on the Kola–Meridian in the Barents Sea. *Sb. Nauchn. Tr. polyar. nauchno–issled. inst. morsk. ryb. khoz. okeanogr. 1982:* 113–122. (In Russian)

BOGSTAD B. and **GJØSÆTER H.** 1994. A method for estimating the consumption of capelin by cod in the Barents Sea. *ICES J. mar .Sci. 51:* 273–280.

BOGSTAD B. and **TJELMELAND S.** 1992. A method for estimation of predation mortalities on capelin using a cod-capelin model for the Barents Sea. Pp. 111–138 in Bogstad B. and Tjelmeland S. (eds.): *Interrelations between fish populations in the Barents Sea. Proceedings of the fifth PINRO-IMR symposium, Murmansk, 12–16 August 1991.* Institute of Marine Research, Bergen, Norway.

DOMMASNES A. and **HIIS HAUGE K.** 1994. Hermod, a single species model for the Norwegian spring spawning herring stock. *ICES CM 1994/*H:11. 12 pp.

HAMRE J. and **TJELMELAND S.** 1982. Sustainable yield estimates of the Barents Sea capelin stock. *ICES CM 1982/*H:45. 24 pp.

HAMRE J. 1994. Biodiversity and exploitation of the main fish stocks in the Norwegian-Barents Sea ecosystem. *Biodiv. Conserv. 3:*473–492.

JAKOBSEN T. 1992. Biological reference points for the North-East Arctic cod and haddock. *ICES J. mar. Sci. 49:* 155–166.

JAKOBSEN T. 1993. Management of North-East Arctic cod: Past, Present and Future? Pp 321–338 in Kruse, G, Eggers, D.M., Marasco, R.J., Pautzke, C. and Quinn, T.J. (eds.): *Proceedings of the International Symposium on Management Strategies for Exploited fish populations. October 21–24 1992.* Anchorage, Alaska. Alaska Sea Grant College Program, University of Alaska Fairbanks, Alaska.

TJELMELAND S. and **BOGSTAD B.** 1993. The Barents Sea Capelin Stock Collapse: A Lesson to Learn. *Can. spec. Publ. Fish. Aquat. Sci. 120:* 127–139.

TJELMELAND S. 1995. Documentation of the Aggmult model. (Unpublished). Institute of Marine Research, Bergen, Norway.

APPENDIX — ESTIMATED PARAMETERS AND RESIDUALS

Standard run parameters

The parameters that are used for the standard runs as defined earlier are given in table 6. The parameters in each box apply to cod, herring and capelin, respectively.

Table 6 Standard run parameters

	Plankton scaling 2.0			Plankton scaling 5.0			Used in stochastic runs?
	Cod	Herring	Capelin	Cod	Herring	Capelin	
P_1	0.6	0.6	0.6	0.6	0.6	0.6	Yes
P_2	60.0	31.0	13.8	60.0	31.0	13.8	Yes
P_3	0.009	0.018	0.018	0.009	0.018	0.018	Yes
P_4	3.70	0.0052	463	3.42	0.013	450	No
P_5	-0.13	1.00	-2.59	-0.13	1.00	-2.59	Yes
P_8	0.15	0.0087	0.00083	0.15	0.0037	0.00080	No
P_9	0.64	0.52	-0.15	0.64	0.52	-0.15	Yes
P_{10}	0.15	0.15	0.15	0.15	0.15	0.15	Yes
P_{13}	5.69	150	5294	2.47	150	5471	Yes
P_{14}	0.52	0.25	0.76	0.42	0.25	0.94	No
P_{20}	0.047	0.00022	0.04	0.047	0.013	0.101	No
P_{22}	(1.63 - 0.8)	calc.	calc.	(1.63 - 0.8)	calc.	calc.	Yes
P_{23}	0.002	0.002	0.002	0.002	0.002	0.002	Yes

Suitabilities fish-fish interactions

The suitability tables are big, so only rows containing at least one non-zero parameter are shown. At the beginning of each line, the predator species, prey species/maturity (e.g. Imcap = Immature capelin) and prey age is given. Then the suitabilities for the various age groups of the immature and mature part of the predator species follow, as indicated in the table heading. The first quarter refers to the last quarter of the calendar year, i.e. one yearly run starts October 1.

Quarter 1

	Immature											Mature										
	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
Cod Imcod 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cod Imcod 2	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5
Cod Imher 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cod Imher 2	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cod Imher 3	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cod Imcap 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 2	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cod Imcap 3	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cod Imcap 4	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cod Imcap 5	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cod Macap 2	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cod Macap 3	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cod Macap 4	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cod Macap 5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Quarter 2

	Immature											Mature										
	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
Cod Imcod 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcod 2	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 2	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 3	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Macap 2	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Macap 3	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Macap 4	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Macap 5	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Quarter 3

	Immature											Mature										
	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
Cod Imcod 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcod 2	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 2	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 3	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 2	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 3	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 4	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Quarter 4

	Immature											Mature										
	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
Cod Imcod 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcod 2	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 1	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 2	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 3	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her Imcap 0	0.5	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 2	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 3	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 4	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Macap 2	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.3
Cod Macap 3	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.3
Cod Macap 4	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.3
Cod Macap 5	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.3

Suitabilities fish-plankton interactions

The tables are structured in the same way as the fish-fish suitability tables, except that no prey age is given as the plankton stocks are not age-structured. The following abbreviations are used for the plankton stocks: Sps = Small plankton organisms in the northern Barents Sea, Spn = Small plankton organisms in the southern Barents Sea, Lpl = Large Plankton organisms.

Quarter 1

	Immature											Mature										
	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
Cod Sps	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her Sps	1.0	0.7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap Sps	1.0	1.0	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0	1.0	0.5	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Cod Spn	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her Spn	1.0	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap Spn	1.0	1.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.0	1.0	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cod Lpl	0.0	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.0	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4
Her Lpl	0.0	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap Lpl	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Quarter 2

	Immature											Mature										
	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
Cod Sps	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her Sps	1.0	0.7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap Sps	1.0	1.0	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0	1.0	0.5	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Cod Spn	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her Spn	1.0	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap Spn	1.0	1.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.0	1.0	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cod Lpl	0.0	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.0	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4
Her Lpl	0.0	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap Lpl	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Quarter 3

	Immature											Mature										
	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
Cod Sps	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her Sps	1.0	0.7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap Sps	1.0	1.0	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0	1.0	0.5	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Cod Spn	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her Spn	1.0	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap Spn	1.0	1.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.0	1.0	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cod Lpl	0.0	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.0	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4
Her Lpl	0.0	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap Lpl	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Quarter 4

	Immature											Mature										
	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
Cod Sps	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her Sps	1.0	0.7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap Sps	1.0	1.0	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0	1.0	0.5	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Cod Spn	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her Spn	1.0	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap Spn	1.0	1.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.0	1.0	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cod Lpl	0.0	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.0	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4
Her Lpl	0.0	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap Lpl	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Plankton scaling 2.0

Spawning biomass halfvalues (P_{14})

	Cod	Capelin
1973	0.028	2.639
1974	0.225	0.954
1975	0.091	0.228
1976	0.930	2.708
1977	2.016	1.743
1978	2.639	3.103
1979	1.946	1.484
1980	1.480	0.719
1981	0.520	0.712
1982	1.022	0.052
1983	0.148	0.761
1984	0.523	2.262
1985	0.405	4.027
1986	0.836	0.708
1987	0.982	0.292
1988	0.456	0.016
1989	0.287	0.158
1990	0.438	0.294

Length growth (P_4)

	Cod	Herring	Capelin
1972	4.505	0.000	386.742
1973	4.534	0.000	254.504
1974	4.526	0.000	261.872
1975	4.526	0.000	435.455
1976	4.521	0.000	415.552
1977	4.531	0.000	385.742
1978	4.537	0.000	421.098
1979	4.525	0.000	472.605
1980	4.536	0.000	442.968
1981	3.250	0.000	556.518
1982	5.270	0.000	477.750
1983	3.945	0.000	410.245
1984	3.708	0.000	328.196
1985	2.461	0.000	555.746
1986	2.278	0.000	632.180
1987	4.047	0.000	631.717
1988	5.204	0.000	707.746
1989	4.504	0.000	752.783
1990	4.564	0.000	330.978

Weight growth (P_8)

	Cod	Herring	Capelin
1972	0.000	0.000	0.001
1973	0.000	0.000	0.000
1974	0.000	0.000	0.000
1975	0.000	0.000	0.001
1976	0.000	0.000	0.001
1977	0.000	0.000	0.001
1978	0.000	0.000	0.001
1979	0.000	0.000	0.001
1980	0.000	0.000	0.001
1981	0.000	0.000	0.001
1982	0.000	0.000	0.001
1983	0.091	0.000	0.001
1984	0.091	0.000	0.000
1985	0.091	0.000	0.001
1986	0.091	0.000	0.001
1987	0.183	0.000	0.001
1988	0.233	0.000	0.001
1989	0.201	0.000	0.001
1990	0.202	0.000	0.001

Recruits

	Cod	Herring	Capelin
1972	6.657	0.000	3022.177
1973	5.304	0.000	1402.451
1974	2.274	0.000	945.017
1975	3.377	0.000	665.925
1976	0.788	0.000	1309.633
1977	0.537	0.000	1959.028
1978	0.541	0.000	987.710
1979	0.450	0.000	1077.046
1980	0.440	0.000	2303.204
1981	0.934	0.000	3161.214
1982	1.214	0.000	4827.652
1983	3.237	27.803	1586.784
1984	1.476	0.000	508.103
1985	1.563	0.000	173.171
1986	0.732	0.000	252.699
1987	0.603	0.000	176.784
1988	1.308	0.000	1607.927
1989	2.095	5.605	1014.870
1990	2.648	33.210	1275.749

Mvalues (P_{20})

	Cod	Herring	Capelin
1972	0.049	0.000	0.000
1973	0.055	0.000	0.063
1974	0.052	0.000	0.037
1975	0.050	0.000	0.093
1976	0.051	0.000	0.051
1977	0.050	0.000	0.100
1978	0.049	0.000	0.203
1979	0.047	0.000	0.081
1980	0.048	0.000	0.256
1981	0.057	0.000	0.170
1982	0.049	0.000	0.462
1983	0.055	0.000	0.274
1984	0.049	0.000	0.446
1985	0.043	0.473	0.537
1986	0.047	0.000	0.338
1987	0.046	0.000	0.006
1988	0.052	0.000	0.405
1989	0.048	0.000	0.007
1990	0.050	0.005	0.007

Length of recruits

	Cod	Herring	Capelin
1972	9.296	0.000	0.002
1973	9.271	0.000	0.000
1974	9.271	0.000	0.000
1975	9.272	0.000	0.000
1976	9.270	0.000	0.001
1977	9.270	0.000	0.000
1978	9.270	0.000	4.094
1979	9.271	0.000	2.945
1980	9.270	0.000	0.000
1981	9.267	0.000	0.002
1982	9.268	0.000	0.000
1983	9.271	8.260	0.001
1984	9.272	0.000	2.412
1985	9.272	0.000	4.032
1986	9.272	0.000	0.000
1987	9.272	0.000	0.000
1988	5.306	0.000	0.000
1989	8.904	8.778	0.001
1990	9.271	9.928	0.001

Weight of recruits

	Cod	Herring	Capelin
1972	0.000	0.000	0.000
1973	0.000	0.000	0.000
1974	0.000	0.000	0.000
1975	0.000	0.000	0.000
1976	0.000	0.000	0.000
1977	0.000	0.000	0.000
1978	0.000	0.000	0.001
1979	0.000	0.000	0.000
1980	0.000	0.000	0.000
1981	0.000	0.000	0.000
1982	0.000	0.000	0.000
1983	0.027	0.000	0.000
1984	0.027	0.000	0.000
1985	0.027	0.000	0.001
1986	0.027	0.000	0.000
1987	0.027	0.000	0.000
1988	0.010	0.000	0.000
1989	0.025	0.000	0.000
1990	0.027	0.013	0.000

Plankton scaling 5.0

Spawning biomass halfvalues (P_{14})

	Cod	Capelin
1973	0.028	4.108
1974	0.187	1.310
1975	0.046	0.324
1976	0.599	3.284
1977	1.305	2.084
1978	1.625	3.487
1979	1.090	1.631
1980	0.765	0.798
1981	0.219	0.761
1982	0.404	0.055
1983	0.032	0.879
1984	0.477	2.600
1985	0.428	4.357
1986	0.677	0.939
1987	0.672	0.395
1988	0.267	0.023
1989	0.117	0.237
1990	0.177	0.460

Length growth (P_4)

	Cod	Herring	Capelin
1972	4.365	0.000	375.511
1973	4.371	0.000	247.189
1974	4.369	0.000	254.567
1975	4.369	0.000	423.239
1976	4.367	0.000	403.796
1977	4.370	0.000	374.808
1978	4.372	0.000	409.262
1979	4.369	0.000	459.326
1980	4.372	0.000	430.530
1981	3.135	0.000	540.584
1982	5.063	0.000	464.257
1983	3.789	0.000	398.520
1984	3.551	0.000	319.594
1985	2.349	0.000	540.503
1986	2.180	0.000	614.424
1987	3.874	0.000	613.727
1988	4.997	0.000	687.923
1989	4.344	0.000	731.789
1990	4.388	0.025	321.504

Weight growth (P_8)

	Cod	Herring	Capelin
1972	0.000	0.000	0.001
1973	0.000	0.000	0.000
1974	0.000	0.000	0.000
1975	0.000	0.000	0.001
1976	0.000	0.000	0.001
1977	0.000	0.000	0.001
1978	0.000	0.000	0.001
1979	0.000	0.000	0.001
1980	0.000	0.000	0.001
1981	0.000	0.000	0.001
1982	0.221	0.000	0.001
1983	0.170	0.000	0.001
1984	0.160	0.000	0.000
1985	0.102	0.000	0.001
1986	0.099	0.000	0.001
1987	0.173	0.000	0.001
1988	0.222	0.000	0.001
1989	0.193	0.000	0.001
1990	0.193	0.038	0.001

Recruits

	Cod	Herring	Capelin
1972	2.695	0.000	2313.402
1973	2.245	0.000	1336.903
1974	1.096	0.000	944.634
1975	1.838	0.000	674.337
1976	0.493	0.000	1327.077
1977	0.343	0.000	2000.352
1978	0.360	0.000	1022.014
1979	0.329	0.000	1117.714
1980	0.344	0.000	2352.319
1981	0.786	0.000	3260.529
1982	1.017	0.000	4973.341
1983	2.204	24.237	1539.275
1984	0.755	0.000	477.186
1985	0.671	0.000	169.189
1986	0.385	0.000	212.884
1987	0.364	0.000	148.704
1988	0.834	0.000	1447.015
1989	1.454	4.921	796.308
1990	1.671	28.259	1028.988

Mvalues (P_{20})

	Cod	Herring	Capelin
1972	0.049	0.000	0.000
1973	0.055	0.000	0.109
1974	0.052	0.000	0.088
1975	0.050	0.000	0.139
1976	0.051	0.000	0.091
1977	0.050	0.000	0.135
1978	0.049	0.000	0.238
1979	0.047	0.000	0.109
1980	0.048	0.000	0.280
1981	0.057	0.000	0.187
1982	0.049	0.000	0.475
1983	0.055	0.000	0.297
1984	0.049	0.001	0.492
1985	0.043	0.572	0.616
1986	0.047	0.000	0.415
1987	0.046	0.000	0.004
1988	0.052	0.000	0.453
1989	0.048	0.000	0.003
1990	0.050	0.002	0.003

Length of recruits

	Cod	Herring	Capelin
1972	9.471	0.000	0.000
1973	9.460	0.000	0.000
1974	9.460	0.000	0.000
1975	9.460	0.000	0.000
1976	9.460	0.000	0.000
1977	9.460	0.000	0.000
1978	9.460	0.000	4.214
1979	9.460	0.000	3.130
1980	9.460	0.000	0.000
1981	9.460	0.000	0.000
1982	9.460	0.000	0.000
1983	9.460	8.272	0.000
1984	9.460	0.000	2.651
1985	9.460	0.000	4.157
1986	9.460	0.000	0.000
1987	9.460	0.000	0.000
1988	5.495	0.000	0.000
1989	9.093	8.795	0.000
1990	9.460	9.947	0.000

Weight of recruits

	Cod	Herring	Capelin
1972	0.000	0.000	0.000
1973	0.000	0.000	0.000
1974	0.000	0.000	0.000
1975	0.000	0.000	0.000
1976	0.000	0.000	0.001
1977	0.000	0.000	0.000
1978	0.000	0.000	0.001
1979	0.000	0.000	0.000
1980	0.000	0.000	0.000
1981	0.000	0.000	0.000
1982	0.000	0.000	0.000
1983	0.027	0.000	0.000
1984	0.027	0.000	0.000
1985	0.027	0.000	0.001
1986	0.027	0.000	0.001
1987	0.027	0.000	0.000
1988	0.010	0.000	0.000
1989	0.025	0.000	0.000
1990	0.027	0.013	0.000

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