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.

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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.

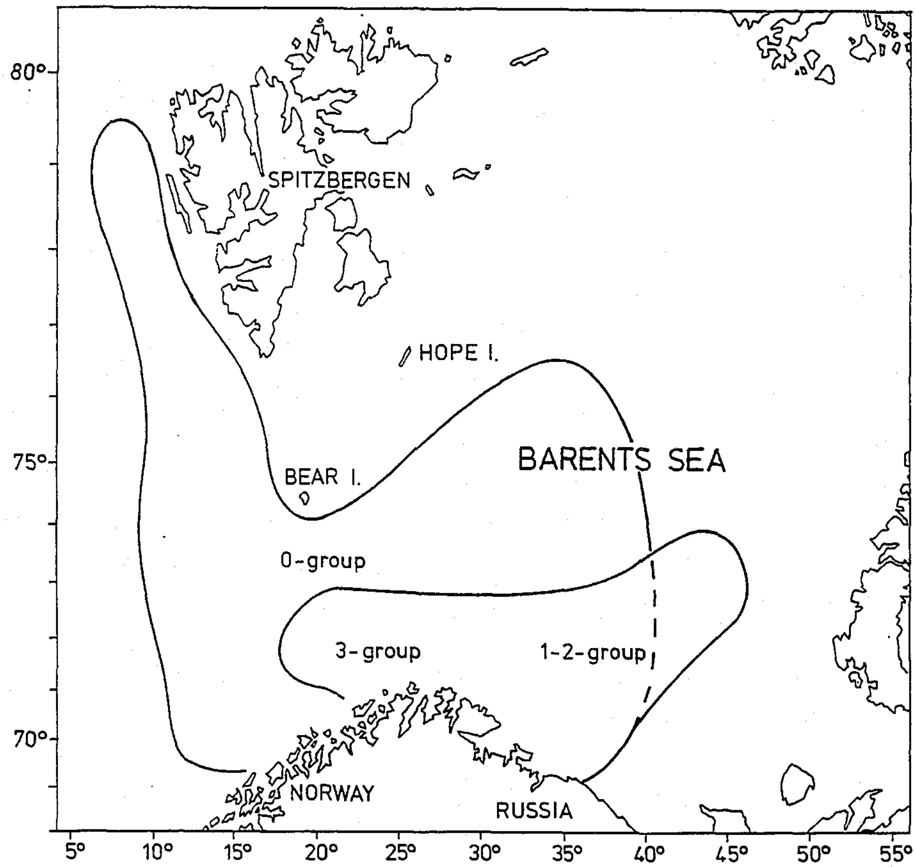

Figure 1. Schematic representation of the distribution areas of the different age-groups of Norwegian spring-spawning herring in the Barents Sea.

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

$$\rho_{Ai} = \frac{S_{A_H}}{\overline{\sigma}} p_i ,$$

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):

$$TS = 10 \cdot \log\left(\frac{\sigma}{4\pi}\right) = 20 \log L - 71.9\, dB, \text{ or}$$

$$\overline{\sigma} = 8.13 \cdot 10^{-7} \cdot \overline{L^2}$$

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).

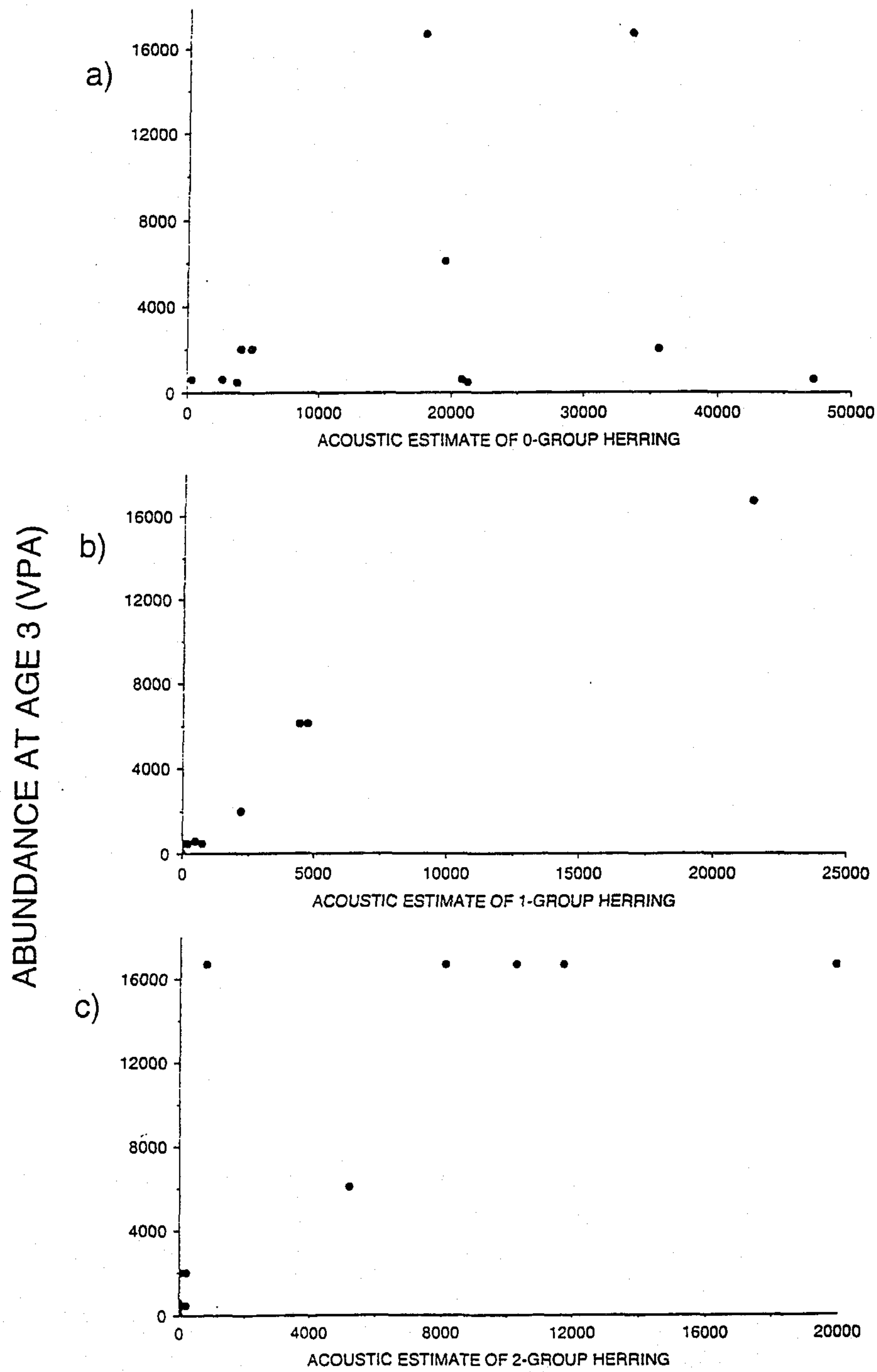

Figure 2a-c. Acoustic estimates of abundance of 0-, 1-, and 2-group herring in the Barents Sea vs. VPA estimates of abundance at age 3 years.

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)
1983	83/08/29	0	33470
	83/11/09	0	17900
	84/06/05	1	21400
	85/05/06	2	10250
	85/06/08	2	19900
	85/09/23	2	11699
	85/11/13	2	817
	86/01/13	2	8100
	86/05/15	3	3000
	86/11/04	3	3380
1984	84/08/28	0	21238
	84/11/26	0	3800
	85/05/06	1	56
	85/06/08	1	55
	85/09/23	1	768
	85/11/13	1	94
	86/01/13	1	225
	86/05/15	2	215
1985	85/08/28	0	47214
	85/09/23	0	20800
	85/11/13	0	2700
	86/01/13	0	387
	86/05/15	1	501
1988	88/08/31	0	35594
	88/09/24	0	4060
	88/10/29	0	4900
	89/05/30	1	2200
	90/06/03	2	54
	90/09/22	2	221
1989	89/08/21	0	19472
	90/05/23	1	4436
	90/09/7	1	4748
	91/05/25	2	5200
	92/05/25	3	5700
1990	90/08/15	0	62215
	91/05/25	1	24300
	92/05/25	2	14027
1991	91/08/9	0	101312
	92/05/25	1	32614
	93/06/01	2	25800
	93/08/15	2	27000
	93/09/10	2	22800
	94/06/03	3	18000
1992	92/09/10	0	274800
	93/06/01	1	102700
	93/08/15	1	74470
	93/09/10	1	67330
	94/06/03	2	59200
1993	93/09/09	0	100000
	94/06/03	1	6600

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.

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