THE BARENTS SEA CAPELIN STOCK 1972-1997. A SYNTHESIS OF RESULTS FROM ACOUSTIC SURVEYS

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The abundance of the Barents Sea capelin stock has been monitored using acoustic methods since 1972. Today, 25 years later, it is one of the few stocks within the ICES area for which an annual acoustic stock size estimate serves as the only basis for stock assessment and management. The methods have changed and a large development has taken place in the technical equipment since the early 1970s. The time series of acoustic estimates from the annual autumn surveys, as well as the development of methods in the period 1972-1984 were reviewed in previous reports. Since then, another 13 years have been added to the time series and the development of methods has continued. Some amendments and corrections have been made to the software used for calculation of stock abundance, and in the present review all stock size estimates have been recalculated. Therefore, the estimates presented here may deviate somewhat from those presented earlier.

An assessment of the goodness of the acoustic stock size estimates is attempted, but the lack of independent estimates makes this difficult. The accomplishment of a fishery regulation based on these stock size estimates in the past, where recruitment overfishing has been avoided, is put forward as an argument that no large, systematic, overestimation is probably taking place. On the other hand, when a small stock size has been estimated by acoustic methods, the situation has been confirmed by low availability of capelin to the fishing fleet, indicating that a gross underestimation is probably not taking place either. Results from studies on cod consumption confirms that the availability of capelin has varied in time with the acoustic estimates. However, the absolute consumption estimates on capelin by cod seem to be high compared to the acoustic estimates, and indicates that the acoustic method is underestimating the stock size to a certain degree.

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KEYWORDS: Capelin; *Mallotus villosus*; Barents Sea; stock size; acoustics.

Йосетер Х., А.Доммаснес, Б.Реттинген. Оценки запаса баренцевоморской мойвы акустическими методами в 1972-1997 гг. (Обзор).

Контроль за численностью запаса баренцевоморской мойвы с использованием акустических методов с ведется 1972 г. И сегодня, 25 лет спустя, - это один из немногих запасов в районе ИКЕС, ежегодная акустическая оценка величины которого служит единственной основой для оценки и регулирования этого вида. Изменялись методы съемки, значительно усовершенствованы по сравнению с началом 70-х годов технические средства. Временные ряды акустических оценок ежегодных осенних съемок, а также совершенствование методик в период с 1972 по 1984 гг. рассматривалось в предыдущих отчетах. С тех пор к временным рядам прибавилось еще 13 лет и продолжалось усовершенствование методики. Были внесены некоторые дополнения и изменения в программное обеспечение, используемое для расчета численности запаса, и в данном обзоре все оценки величины запаса были пересчитаны. Поэтому представленные здесь оценки могут несколько отличаться от данных, представленных ранее.

Делается попытка определить качественные критерии акустических оценок величины запаса, что, правда, затрудняется недостаточностью независимых оценок. Регулирование промысла, базировавшееся на этих оценках величины запаса в прошлом, когда избегали перелова пополнения, выдвигается в качестве аргумента того, что большой систематической переоценки запаса нет. С другой стороны, когда акустическими методами оценивалась величина небольшого запаса, ситуация подтверждалась низкой доступностью мойвы для облова промысловым флотом, что указывало на то, что запас оценивался без существенной недооценки. Результаты исследований питания трески подтверждают, что доступность мойвы менялась во времени параллельно акустическим оценкам. Однако оценки абсолютного потребления мойвы треской представляются завышенными по сравнению с акустическими оценками, что указывает на то, что акустический метод до некоторой степени недооценивает величину запаса.

Ключевые слова: мойва, Mallotus villosus, Баренцево море, величина запаса, акустика.

INTRODUCTION

Capelin (*Mallotus villosus* Müller) is a small relative of the salmon (suborder Salmonoidei, family Osmeridae) which at times is a dominating element in the ecosystem of the Barents Sea. The females grow to approximately 16 cm, and the males to approximately 19 cm. Spawning takes place mostly in March-April at the coasts of northern Norway (north of 69°N) and further eastwards along the Russian coast, at depths of 30 to 100 m. The age at spawning varies from two to five years, and most of the females and practically all of the males die after spawning. The population biology, fisheries and management of the Barents Sea capelin stock are described elsewhere in a comprehensive review (GJØSÆTER 1998).

Various methods have been tried for estimation of capelin abundance, see review mentioned above. Methods like mark-recapture and back-calculation of spawning stock size from larval surveys have been abandoned and acoustics have been chosen as the most preferred method. The main reason is that acoustic methods have been found to give realistic estimates of stock size and, in addition, is the only method which can give an estimate of the spawning stock size some months prior to spawning. This is a prerequisite for the management of this stock, since the fishery takes place on the mature stock prior to spawning and the catch quota is set on the basis of spawning stock size.

Stock size estimation using acoustic methods during the autumn period was introduced in 1971. In the following years alternative survey periods were tried but, taking account of the various factors affecting acoustic surveying like weather conditions, fish distribution and migration, it was concluded that September was the most suitable time for doing this survey.

During the whole period, the same basic method and survey design have been used, with echo sounder recordings and trawling along transects over the area of distribution (NAKKEN & DOMMASNES 1975, 1977). The surveys during the period 1972-1984 and the methods used were reviewed by DOMMASNES & RØTTINGEN (1985).

Since 1985, the knowledge of the biology and dynamics of the Barents Sea capelin stock has increased considerably. There have also been developments, contributing to the understanding of the interaction between acoustic signals and fish, and in acoustic instrumentation. Some minor errors in the calculation program, used in the early years have been discovered and corrected and all estimates recalculated.

It is now pertinent to extend the time series for another 13 years and document the recalculated estimates for the whole time series. The results presented here represents condensed data based on detailed information on abundance by age- and length-group, as well as maps showing the capelin distribution each year. A complete set of tables and figures can be found in the report series 'Fisken og Havet' (GJØSÆTER & al. 1998), available from the senior author.

MATERIAL AND METHODS

Acoustic stock size estimation procedure

A full discussion of the acoustic methods, including descriptions of acoustic instruments and their calibration, can be found in textbooks on the subject, e.g. MACLENNAN & SIMMONDS (1992). The basic relationship between the echo density, or area backscattering coefficient s_A (the output from the echo integrators), and the area density (number of fish per unit area) ρ_A is:

$$s_A = \overline{\sigma} \cdot \rho_A \quad (1)$$

where the proportionality factor $\overline{\sigma}$ is called the mean acoustic cross section (MACLENNAN & SIMMONDS 1992) and is a measure of the fish's ability to reflect sound. When the mean echo density in a unit area and the sound reflection characteristics of the fish targets are known, the number of fish, N, can be found:

$$N = \rho_A \cdot A = \frac{s_A}{\overline{\sigma}} \cdot A \quad (2)$$

If the mean weight $\overline{w}$ of these fishes is known, the biomass, B, can be calculated:

$$B = N \cdot \overline{w} \quad (3)$$

The acoustic cross section of a fish (the logarithmic form is called target strength, TS, where $TS = 10 \log \sigma/4\pi$) is length dependent. The relationship between target strength and fish length is empirically established for each species. When the acoustic method was first applied on capelin in the early 1970s, no target strength measurements were available for this species. A conversion factor between integrator output and number of fish was established by counting fish traces on the echograms (MIDTTUN & NAKKEN 1971). This gave rise to quite varying conversion factors during the early 1970s (DOMMASNES & RØTTINGEN 1985). A part of this variation was probably due to variations in the performance of the acoustic systems. Gradually, estimates of capelin target strength and its dependence on length became available (DOMMASNES & RØTTINGEN 1985), and estimates obtained in previous years were recalculated accordingly. Since 1985, a TS-length relation of $TS = 19.1 \log L - 74.0$ (where L is total length of capelin in cm) has been used for capelin in the Barents Sea, corresponding to $\sigma = 5.00 \cdot 10^{-7} L^{1.91}$. All estimates presented in this paper are based on this target strength value. The evolution of the method of acoustic stock size estimation and in particular its application on the Barents Sea capelin stock was thoroughly described by DOMMASNES & RØTTINGEN (1985). They also recapitulated the history of conversion factors applied for the capelin in the period 1972 to 1984.

Since the target strength is length dependent, the conversion from s_A to number of fish has to be based on an observed length distribution of capelin. In practical work, mean s_A values along the cruise tracks are averaged over rectangular blocks with known area. Normally, blocks of two degrees of longitude by one degree of latitude (basic acoustic block) are used in the Barents Sea capelin surveys. For each of these blocks, a length distribution of capelin is constructed, based on representative trawl samples within each block.

The total number of fish in each block is then obtained by using equation 2. To divide the total number on age groups, an age/length key is used and biomass is calculated using weight/length keys. These age/length keys are not based on the basic acoustic blocks, but represent aggregates of blocks with nearly identical length-at-age and weight-at-length which are combined to form subareas (typically 3-5 subareas are used). Separate keys are constructed for each of these subareas.

Historical aspects of the acoustic surveys

An acoustic survey of the Barents Sea capelin stock was carried out with the new Norwegian research vessel *G.O. Sars* in August-September 1971 (DRAGESUND & NAKKEN, 1972). Attempts to calculate the stock size of capelin from acoustic data, collected during this cruise, were so promising that another acoustic survey was carried out in August-September 1972 (GJØSÆTER & al. 1972), this time with the two research vessels *G.O. Sars* and *Johan Hjort* working together. Since then, systematic acoustic surveys of the Barents Sea capelin stock have been carried out annually in September-October by personnel and research vessels from the Institute of Marine Research in Bergen (IMR). A summary of the surveys is given in Table 1.

A Russian research vessel participated in the survey for the first time in 1975 (Table 1). Since then, the surveys have been carried out as co-operative projects between IMR and the Polar Research Institute of Marine Fisheries and Oceanography in Murmansk (PINRO). As practical procedures for co-operation and data handling gradually improved, the Russian participation allowed a better coverage of the area of distribution of the capelin stock.

The echosounders on board each vessel were always calibrated according to standard methods (MACLENNAN & SIMMONDS 1992) before the surveys. In addition, inter-ship comparisons were performed during the surveys, to ensure that the acoustic equipment on board the different vessels gave similar results under working conditions.

Description of sampling design

A c o u s t i c s a m p l i n g. The cruise tracks are laid out in order to cover the main distribution area of capelin by regularly spaced east-west transects, normally with 30 nautical miles between each transect. Since each acoustic block is 2° longitude by 1° latitude, the number of miles inside each block will vary with latitude, from about 25 in the northern part to 40 in the southern part of the Barents Sea. From four to six vessels normally took part in the survey (When the survey was carried out by the Institute of Marine Research alone, only two vessels participated). The total area is partitioned among the vessels so that they start working together in the centre of the area and spread out towards east and west. This is done to achieve maximum synoptical coverage of the main area, in order to minimise the effects of capelin migration. The integrated echo abundance (area backscattering coefficient – s_A) along the cruise tracks, is averaged over consecutive five nautical miles. All such five-mile values inside each basic acoustic block are averaged to give a mean s_A for the block.

B i o l o g i c a l s a m p l i n g. To convert the echo density to number of fish, to apportion the number on age groups, and to estimate the biomass of each species, biological samples are needed. Such samples are taken at irregular intervals along the cruise tracks, using pelagic trawl. The echosounders are watched continuously, and a trawl haul is taken whenever the characteristics of the echograms change (to check if changes in species or length distribution have taken place) or at regular intervals even if the echograms look the same (to check for changes in the biological characteristics of the fish).

Various types of pelagic trawls have been used during the period. On the Norwegian vessels, a small capelin trawl 'Harstad-trawl' has been most widely used. In later years, a somewhat larger trawl 'Åkra-trawl', which is more suitable for catching both herring and capelin, has been used. Both trawl types have been equipped with a small mesh (4 mm) net in the cod end. On the Russian vessels larger trawls, designed for commercial fishing, have been used. These trawls have also been equipped with a small mesh net in the cod end when used as a sampling trawl for capelin. Comparisons of the trawls have shown that there were minor differences in the length distributions of capelin caught in these trawls, but the experiments gave no firm evidence for concluding that there were systematic differences in the trawl selec-

Table 1. Acoustic surveys of the Barents Sea capelin stock in August - October 1971 - 96.

Year	Time period	Vessels	Reference
1971	23 Aug. - 29 Sep.	*G.O. Sars*	Dragesund & Nakken 1972
1972	5 Aug. - 11 Sep.	*G.O. Sars, Johan Hjort*	Gjøsæter & al. 1972
1973	16 Sep- - 8 Oct.	*G.O. Sars, Johan Hjort*	Dommasnes & al. 1974
1974	15 Sep. - 12 Oct.	*G.O. Sars, Havdrøn*	Buzeta & al. 1975
1975	12 Sep. - 15 Oct.	*G.O. Sars, Johan Hjort, Poisk*	Dommasnes, Nakken & Røttingen 1976
1976	11 Sep. - 1 Oct.	*G.O. Sars, Johan Hjort, Odissey*	Dommasnes & Røttingen 1977
1977	16 Sep. - 7 Oct.	*G.O. Sars, Johan Hjort, Odissey*	Monstad & Røttingen 1977
1978	14 Sep. - 11 Oct.	*G.O. Sars, Johan Hjort, Poisk*	Dommasnes, Loeng & Monstad 1979
1979	30 Aug. - 28 Sep.	*G.O. Sars, Johan Hjort, Poisk*	Mamylov & Dommasnes 1979
1980	10 Sep. - 5 Oct.	*G.O. Sars* 10.9 - 5.10 *Johan Hjort* 10.9 - 5.10 *Poisk* 10-26.9	Anon. 1980
1981	7 Sep. - 4 Oct.	*G.O. Sars* 8.9 - 4.10 *Johan Hjort* 7 - 28.9 *Persey III* 8.9 - 4.10	Anon. 1981
1882	7 Sep. - 10 Oct.	*G.O. Sars* 7.9 - 3.10 *Johan Hjort* 7.9 - 3.10 *Persey III* 10.9 - 3.10 *Poisk* 10.9 - 10.10	Anon. 1982
1983	6 - 30 Sep.	*G.O. Sars* 6 - 30.9 *Michael Sars* 6 - 30.9 *Persey III* 6 - 30.9 *Poisk* 17 - 30.9	Anon. 1983
1984	4 - 24 Sep.	*G.O. Sars* 4 - 24.9 *Michael Sars* 5 - 24.9 *Persey III* 5 - 24.9 *Kokshaysk* 5 - 24.9	Anon. 1984
1985	6 Sep - 6 Oct	*G.O. Sars* 6.9 - 6.10 *Michael Sars* 6.9 - 6.10 *Vilnius* 6.9 - 6.10 *Kokshaysk* 6.9 - 6.10	Anon 1985
1986	3 Sep - 13 Oct	*G.O. Sars* 6.9 - 6.10 *Michael Sars* 6.9 - 6.10 *Eldjarn* 7.9 - 13.10 *Vilnius* 6.9 - 6.10 *Kokshaysk* 6.9 - 6.10	Anon. 1986
1987	6 Sep - 12 Oct	*G.O. Sars* 4.9 - 12.10 *Michael Sars* 16 - 25.9 *Eldjarn* 6.9 - 12.10 *Vilnius* 6.9 - 12.10 *Artemida* 6.9 - 12.10 *Persey III* 6.9 - 12.10	Anon. 1987
1988	8 Sep - 21 Oct	*G.O. Sars* 10.9 - 18.10 *Michael Sars* 8.9 - 13.10 *Eldjarn* 10.9 - 21.10 *Prof. Marti* 12.9 - 15.10 *Artemida* 19.9 - 15.10 *Pinro* 11.9 - 14.10	Anon. 1988

Table 1. (continued)

Year	Time period	Vessels	Reference
1989	13 Sep - 3.Oct	*G.O. Sars* 13.9 - 3.10 *Michael Sars* 13.9 - 3.10 *Eldjarn* 13.9 - 27.10 *Prof. Marti* 13.9 - 1.10 *Persey III* 14.9 - 4.10 *Pinro* 16.9 - 2.10	Anon. 1989
1990	7 Sep - 6 Oct	*G.O. Sars* 8.9 - 7.10 *Michael Sars* 7.9 - 6.10 *Eldjarn* 6.9 - 7.10 *Prof. Marti* 12.9 - 4.10 *Vilnius* 14.9 - 4.10 *Pinro* 9.9 - 2.10	Anon. 1990
1991	12 Sep - 6 Oct	*G.O. Sars* 13.9 - 6.10 *Michael Sars* 12.9 - 4.10 *Johan Hjort* 12.9 - 1.10 *Prof. Marti* 13.9 - 6.10 *Fridtjof Nansen* 19.9 -6.10 *Pinro* 20.9 - 6.10	Anon. 1991
1992	10 Sep - 6 Oct	*G.O. Sars* 10.9 - 7.10 *Michael Sars* 10.9 - 7.10 *Johan Hjort* 12.9 - 5.10 *Prof. Marti* 12.9 - 6.10 *Fridtjof Nansen* 10.9 - 6.10	Anon. 1992
1993	9 Sep - 3 Oct	*G.O. Sars* 9.9 - 3.10 *Johan Hjort* 9 - 28.9 *Prof. Marti* 13.9 - 3.10 *Fridtjof Nansen* 9.9 - 3.10 *Pinro* 9.9 - 3.10	Anon. 1993
1994	8 Sep - 3 Oct	*G.O. Sars* 9.9 - 3.10 *Johan Hjort* 8 - 30.9 *Prof. Marti* 13.9 - 3.10 *Fridtjof Nansen* 10.9 - 3.10 *Atlantida* 10.9 - 3.10	Anon. 1994
1995	12 Sep - 1 Oct	*G.O. Sars* 13.9 - 1.10 *Johan Hjort* 13.9 - 1.10 *Prof. Marti* 13.9 - 1.10 *Fridtjof Nansen* 13.9 - 1.10	Anon. 1995
1996	12 Sep - 2 Oct	*G.O. Sars* 12.9 - 2.10 *Johan Hjort* 12 - 30.9 *Atlantida* 12.9 - 1.10 *Persey III* 12 - 30.9	Anon. 1996
1997	12 Sep - 2 Oct	*G.O. Sars* 12.9 - 1.10 *Johan Hjort* 12.9 - 2.10 *Atlantida* 12.9 - 2.10	Anon. 1997

tivity for capelin (ANON 1992).

A standard capelin sample consists of 100 individuals (GJØSÆTER 1985), where length (total length, cm), weight (g), sex, age and other characteristics are recorded for each individual. Such samples are taken from most catches. In addition to this type of sample, length distributions are recorded for all additional catches. All length measurements are used for constructing length distribution of capelin in the basic acoustic blocks. The weight and age are used to construct the weight/length keys and the age/length keys in sub-areas (cf Acoustic stock size estimation procedure).

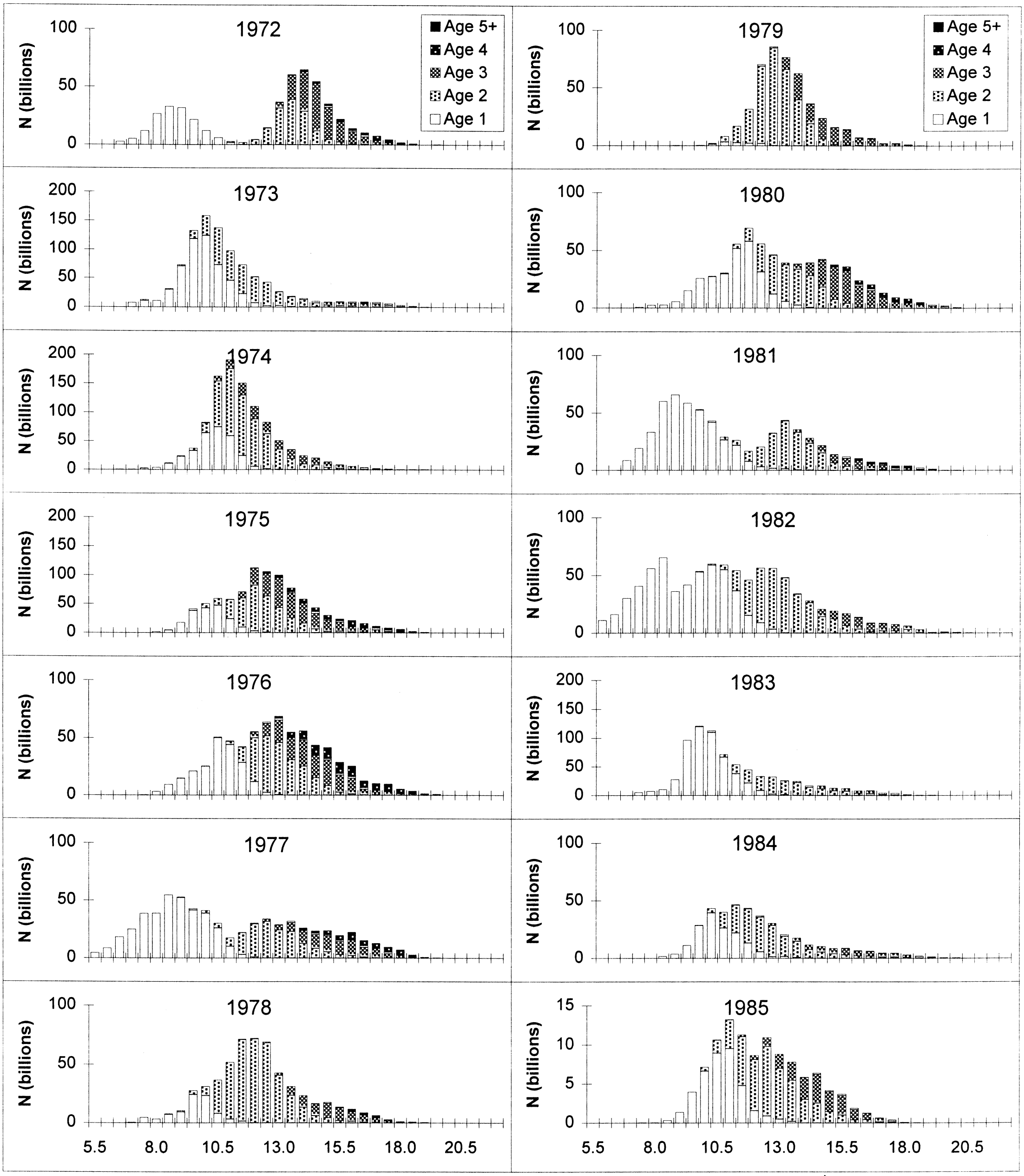

Fig. 1. Acoustic estimates of capelin (number of individuals in each age and length group) 1972-1985.

RESULTS

The results of the abundance estimation are presented in Figs 1 and 2 as histograms of number per age- and length-group for the years 1972-1997. Figs 3-5 show examples of geographical distribution. The abundance estimate from 1971 has not been reconstructed, because the methods applied at that first survey were somewhat ad hoc and neither the method nor the basic data used were well documented.

The number-at-age of each year class 1971 to 1995 is shown in Fig. 6, and charts summarising the time series of abundance estimates by number and biomass for the

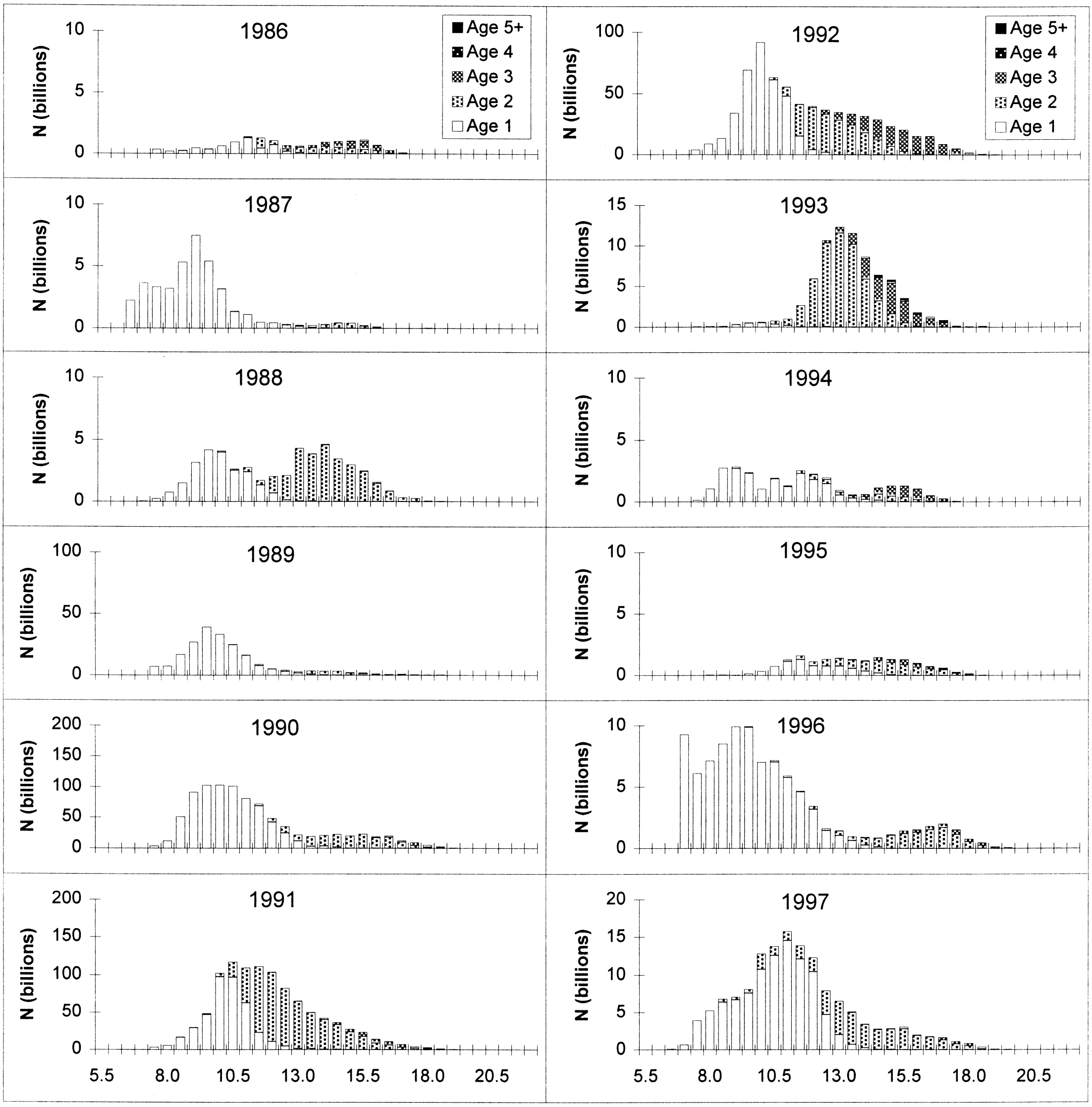

Fig. 2. Acoustic estimates of capelin (number of individuals in each age and length group) 1986-1997.

two years old and older capelin are shown in Figs 7 and 8 respectively.

The distribution of capelin is known to change with the hydrographic conditions of the Barents Sea (OZHIGIN & LUKA 1985). By comparing the distribution charts (Figs 3-5) which show one 'normal' year (1984, Fig. 3), one year characterised by a north-eastern distribution (1975, Fig. 4), and one characterised by a south-western distribution (1982, Fig. 5) it is seen that the total distribution area in autumn may change substantially from year to year. In 1972-1976 the capelin were distributed in the north-eastern part of the Barents Sea, and practically no capelin were found south of 74°N or west of Hopen island. From 1977 the distribution area shifted south-westward to reach a maximum southern and western distribution in 1982 (Fig. 5). In 1983-1985 the northern boundary shifted northwards, but there were capelin both in the western and eastern areas north of 74°N (GJØSÆTER & al. 1998). During the stock collapse in 1986-1989 the total distribution area was somewhat smaller and located centrally in the Barents Sea. During 1990-1992, the recovered stock was distributed over a wide area, extending almost as far north and east as it did during the period 1973-1976. During the next stock collapse in 1993-

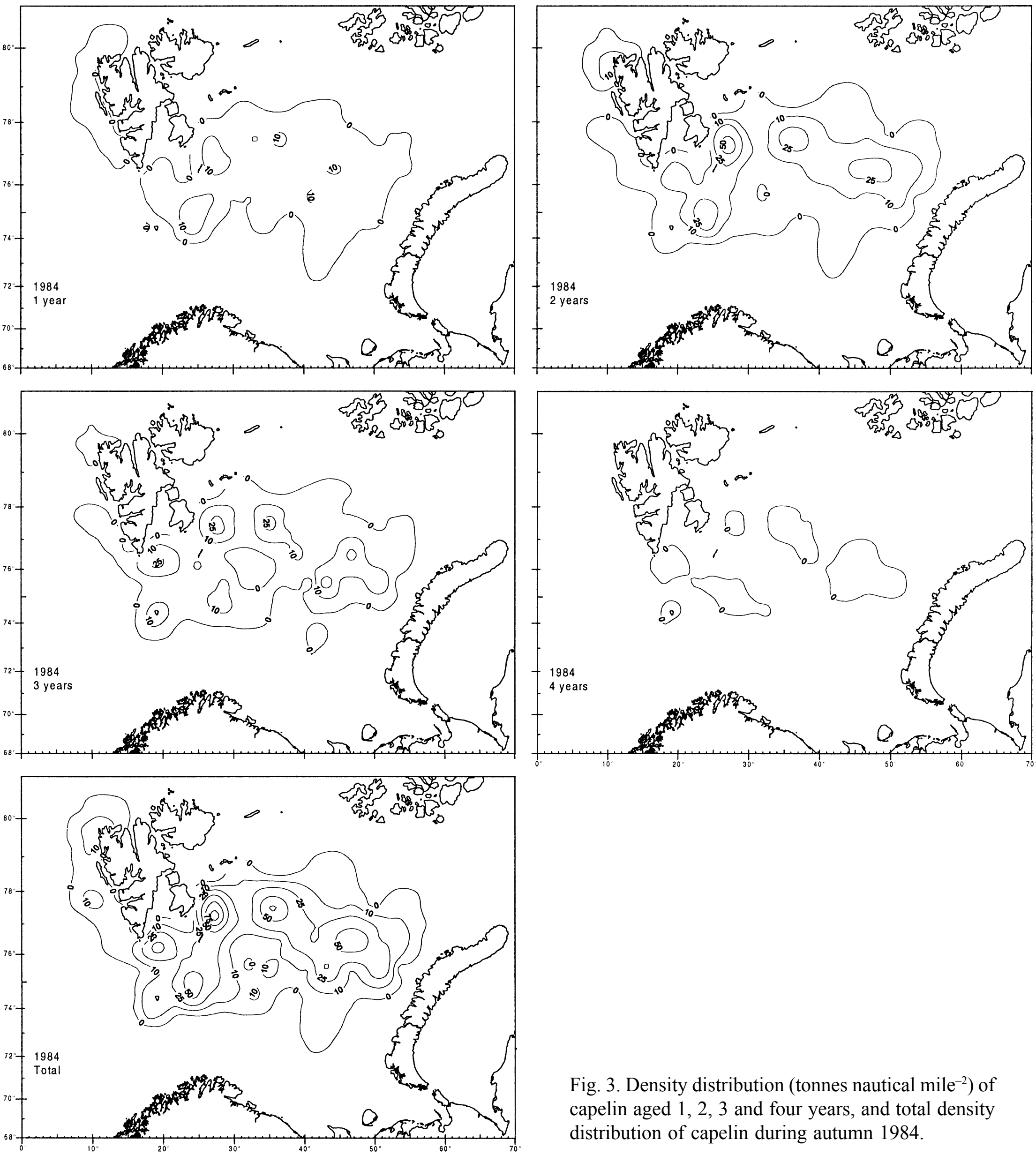

Fig. 3. Density distribution (tonnes nautical mile^{-2}) of capelin aged 1, 2, 3 and four years, and total density distribution of capelin during autumn 1984.

1996 the distribution area shrunk and was again located centrally in the Barents Sea (Gjøsæter & al. 1998).

The abundance of capelin has changed considerably during the period 1972-1997. Since the 1-year-olds were not properly covered before 1980, this age group is not presented in the time series charts in Figs 7 and 8. From 1972 to 1984, the stock was relatively stable, the average number of individuals and biomass were 400 billion and 4 million tonnes respectively. From 1986 to 1989 and from 1994 to 1996, these figures declined to 25 billions and 0.3 million tonnes, respectively. The declines of stock size occurred very abruptly, but so did the recovery. For example, the average stock size in 1990 to 1992 was 380 billion individuals and 4.3 million tonnes.

The differences between the present estimates and those presented before are generally small, and are mainly of two types. First, an error in the program used prior to 1978 when the lower limit in each ½ cm length group

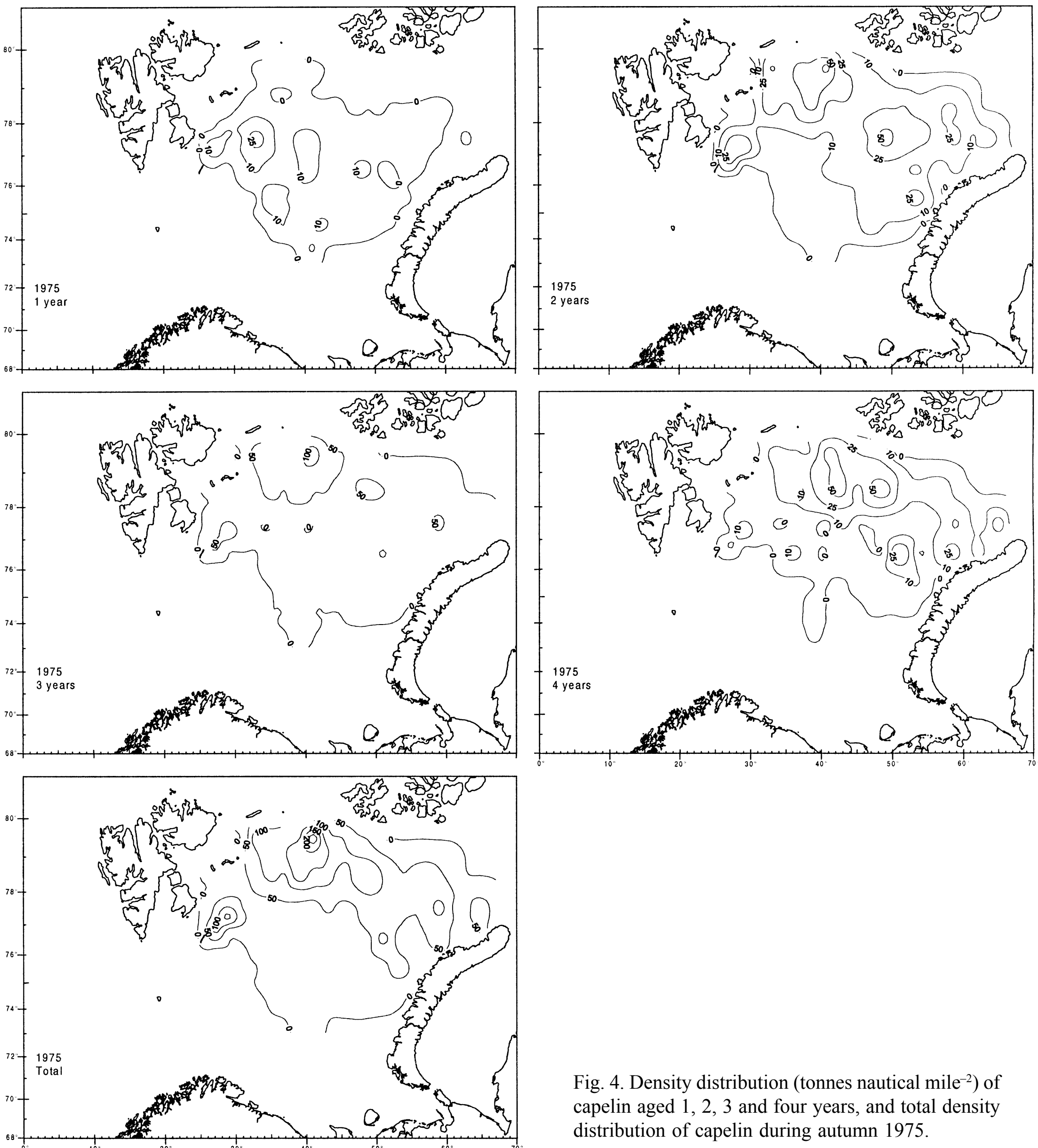

Fig. 4. Density distribution (tonnes nautical mile^{-2}) of capelin aged 1, 2, 3 and four years, and total density distribution of capelin during autumn 1975.

was used as basis for the calculations in stead of the mid-point, caused an overestimation in the order of 2-3 %. Second, by inspecting the length distributions of the first age group in the estimates and comparing it to length distribution of 0-group capelin, it was found that part if the 0-group must have been included in the 1-group estimates in some of the years. Furthermore, some small corrections have been made, e.g. where one or more blocks containing capelin were accidentally left out in some of the estimates. The maximum difference between the present estimates and those originally presented was 6 % in number (1973), but after 1980 the differences were generally negligible.

The estimate obtained in 1982 presents a special problem. When that estimate was compared to those obtained in 1981 and in 1983, it was evident that the 1982 estimate was too high and at variance with the others (ICES 1984). Investigations revealed that the most probable

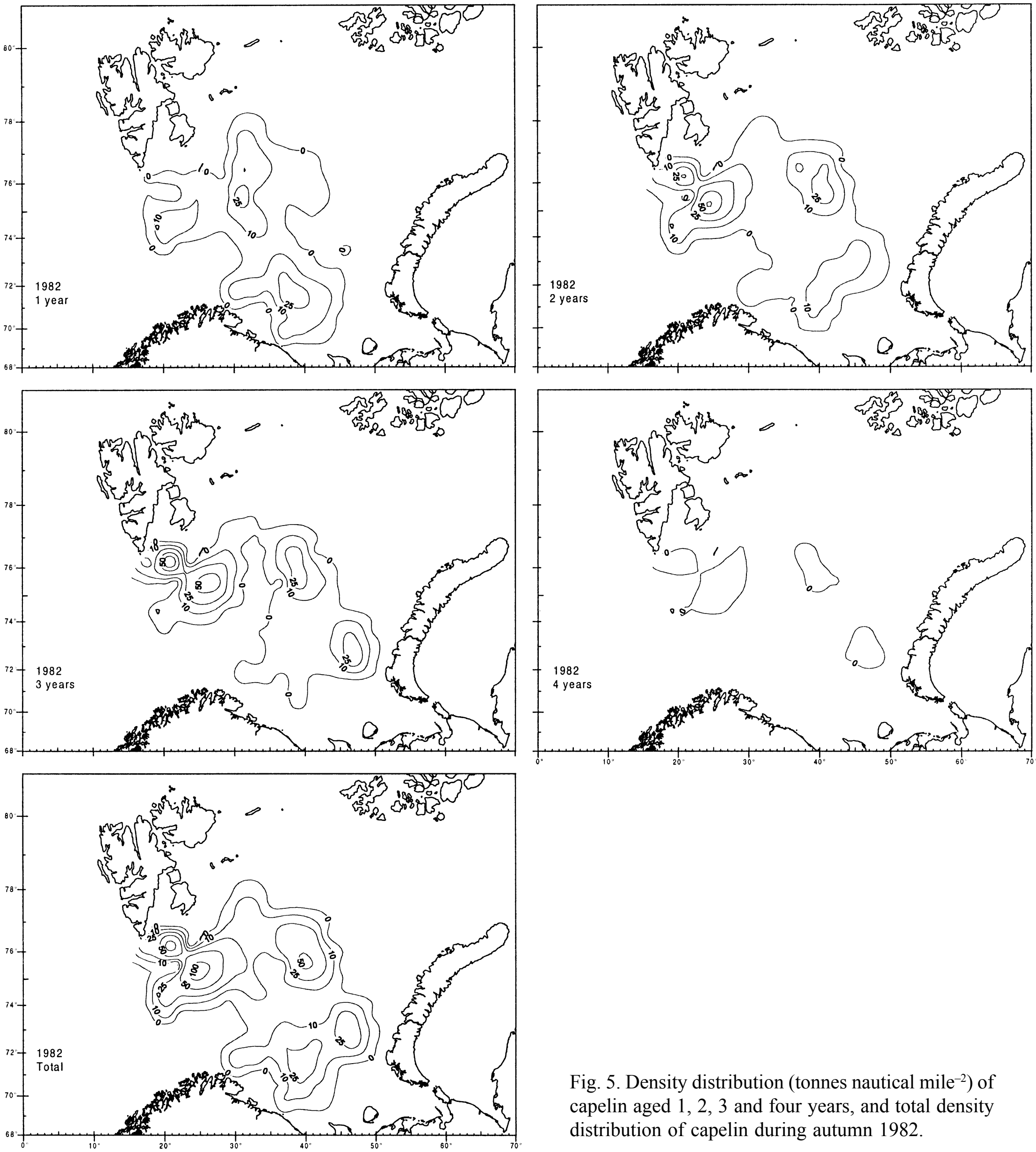

Fig. 5. Density distribution (tonnes nautical mile^{-2}) of capelin aged 1, 2, 3 and four years, and total density distribution of capelin during autumn 1982.

reason for the severe overestimation in 1982 was that, while the calculations were based on the premise that a nickel transducer was used on one of the vessels, a ceramic transducer with quite a different sensitivity may accidentally have been used during parts of or the whole survey. This did not affect the 1-group estimate to any noticeable degree, because that age group was not found in the area covered by that vessel. Since it was not possible to determine exactly what had happened, it was decided to disregard the 1982 estimate for age groups 2-5, and replace it by estimated values calculated from previous and later estimates, obtained of the same year classes. These calculations were made using the model 'capelin' (TJELMELAND 1985). The 1-group estimate is, however, the original obtained in 1982.

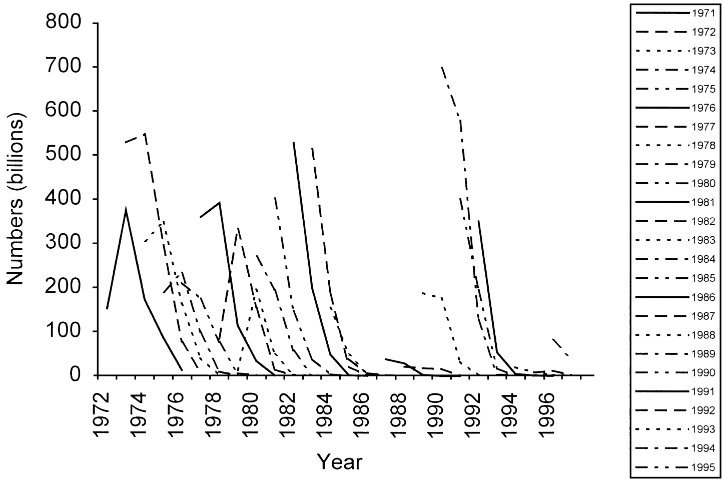

Fig. 6. Number of individuals (billions) of capelin at age 1-5 in the year classes 1971-1995, estimated during annual acoustic surveys in autumn 1972-1997.

DISCUSSION

The acoustic method of fish abundance estimation by echo integration (Dragesund & Olsen 1965) has become one of the most important fishery independent tools in stock assessment for species which are conveniently located, i.e. not too close to the surface or the bottom (MacLennan & Simmonds 1992). The capelin is one of the species which lends itself especially suitable for acoustic abundance estimation, and the time series of abundance estimates of the Barents Sea capelin stock is almost as long as the history of the echo integration technique itself. However, in comparative terms, the results that could be obtained in the early days were subject to large errors. The calibration methods were imprecise, and the acoustic characteristics of the species were uncertain. Also, a tremendous development has taken place in the technical equipment since the early 1970s. High-performance scientific echosounders have now been introduced with larger dynamic range, more stable gain characteristics and better compensation for propagation losses (MacLennan & Simmonds 1992). From 1989 the digital echo sounder Simrad EK 500 (Bodholt & al. 1988) and a combined echo integrator and echo sounder post processing system BEI (Foote & al. 1991) were introduced on the Norwegian vessels. In recent years this equipment, which has several advantages over earlier equipment, has also appeared on the Russian vessels participating in this survey. Better knowledge of fish behaviour and distribution has also aided the development towards more accurate stock size estimates of the Barents Sea capelin.

For these reasons, the quality of the estimates has no doubt improved over the years, but how much is difficult to assess. It is not even known how accurate they are today. The Northern Pelagic and Blue Whiting Fisheries Working Group, which deals with the assessment of this stock within ICES, has adopted the stock abundance estimates based on the annual acoustic survey as the sole basis for stock assessment and management purposes. However, on several occasions the group has noted that the estimates, especially of the youngest age group, are uncertain.

There are several known sources of error related to stock size estimation by acoustics, which may have affected both the accuracy and the precision of the capelin estimates. First, the coverage of the total distribution area was not complete all years. This affects the estimates in most years prior to 1980 and a few years after that. Prior to 1980, the south-eastern part of the Barents Sea, where the youngest age group is often found, was not covered mostly due to shortage of ship time. Consequently, the 1-group was not properly covered, a fact easily seen by comparing the estimated number of one-year-olds and two-year-olds of the same year class (Fig. 6). For the year classes 1971, 1973, 1974, 1977 and 1978, estimates of the number of one-year-olds were lower than the number of two-year-olds, and for the remaining of the year classes, prior to 1979, the estimates of the 1-group also seem to be too low. The same applies for the year classes 1992 and 1994. However, these two cohorts were so small and, therefore, so rare in the biological samples that the estimation error was probably relatively large. In 1980, 1989, 1990, 1991 and 1992 the coverage was reported in the cruise report as incomplete in some areas, for reasons like e.g. drift ice and rough weather. This may have lead to an underestimation of all age groups.

Second, a certain amount of capelin is known to reside near the bottom, out of reach of the echo sounders. Such 'bottom dwelling capelin' are caught in demersal trawl hauls over most of the Barents Sea in autumn, but no attempts have been made to estimate the amount of such capelin. Third, a certain part of the capelin (especially the youngest age group) is known to ascend to the near surface layers at night (Anon 1980) and may be found above the hull mounted transducers. The magnitude of the underestimation caused by such behaviour is unknown.

Other sources of variation, affecting the stock size estimates, exist. In some areas capelin is found mixed with

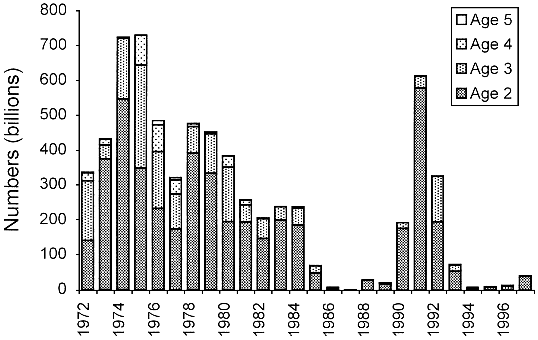

Fig. 7. Abundance (number of individuals in billions) of capelin in age groups 2-5 estimated during annual acoustic surveys 1972-1997.

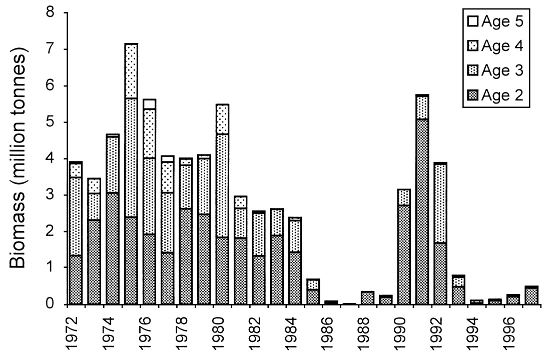

Fig. 8. Abundance (biomass in million tonnes) of capelin in age groups 2-5 estimated during annual acoustic surveys 1972-1997.

other species, most notably polar cod (*Boreogadus saida*) and in such cases it is difficult to allocate the total echo abundance to species. Furthermore, doubts have been raised about the validity of applying the same TS-relation to the smallest individuals (< 12 cm) which is applied to larger capelin (Mamylov 1988). However, at present the TS-measurements on such small capelin are few and do not provide sufficiently strong evidence for changing the TS-length relation.

There are no independent stock size estimates that could be used to assess the goodness of the acoustic estimates. A repeated survey in the same season was attempted once, but it was not possible, within the ship time allocated, to survey the total area a second time and no conclusions could be drawn. Based on the fishery management history of the capelin, it seems unreasonable that the abundance estimates should be systematic overestimates. Since the regulation of the capelin stock is based on the premise that a constant amount of the mature stock (at present 500 000 t) should be allowed to escape the fishery and to spawn, a large overestimation of stock size could easily lead to depletion of the spawning stock. However, the fishing fleet has had no problems taking the quotas allocated, and there was never any signs of recruitment overfishing which could be explained by a too optimistic stock size estimate (Gjøsæter 1995). Similarly, a large systematic underestimation seems unreasonable. For instance in winter 1996, when the maturing stock assessed in autumn 1995 was very small and the fishing fleet was given a small quota, a large fleet searched for months without detecting any fishable concentrations.

The dynamics of the stock size seem to fit quite well to what can be deduced from cod consumption estimates (Bogstad & Mehl 1997). During the two capelin stock collapses in 1986-1989 and from 1995 till present, the amount of capelin consumed by cod was greatly reduced, from 1.6 million tonnes in 1985 to 0.2 million tonnes in 1987, and from 3.6 million tonnes in 1993 to 0.8 million tonnes in 1995. The decrease in the amount of capelin consumed by cod, which was partly compensated for by increased consumption of other food, was obviously caused by reduced availability of capelin.

On the other hand, the absolute size of the 'acoustic' capelin stock seems to be too small when compared to the consumption estimates (Bogstad & Mehl 1997). The capelin stock biomass in autumn does not directly reflect the amount of capelin available for consumption during the year. But even when the consumption estimates were compared to an estimate of annual production of capelin (Gjøsæter 1997) there is a misfit in some years. The consumption estimates could be overestimates but, on the other hand, capelin are consumed by other fish species than cod and in addition eaten by seals, whales and birds (Gjøsæter 1997).

The estimates seem to be fairly consistent from year to year. Excluding the one-group estimates prior to 1980 discussed above, the reduction in numbers at age of the year classes seems in most cases to lie within a reasonable range for a forage fish (20-90 % for the youngest age groups, Fig. 6). There are changes in the reduction rate, indicating changes in natural mortality, but these are consistent from year to year, gradually increasing before the two collapses and decreasing to low levels during the periods of recovery.

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