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A comparison between abundance estimates of the Barents Sea capelin (*Mallotus villosus* Müller) at the larval, 0-group and 1-group stage, for the year classes 1981–1994

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Three abundance estimates – larval abundance estimate (June surveys), a 0-group index (August surveys) and an acoustic estimate of 1-group (September surveys) – were compared for the year classes 1981–1994 of Barents Sea capelin (*Mallotus villosus* Müller). There was a significant linear correlation ($p=0.0001$) between the 0-group index and the 1-group estimate, allowing for predictions to be made about year-class strength at the 1-group stage based on the 0-group indices. No correlation was found between the larval abundance estimate and the 0-group index, or between the abundance estimates at the larval and the 1-group stage.

Key words: surveys, acoustics, forecasting.

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Introduction

The capelin (*Mallotus villosus* Müller) is a small pelagic schooling salmonid fish inhabiting boreal and Arctic regions. The Barents Sea capelin stock is potentially the largest capelin stock in the world, but its actual size has varied from 7 million tonnes to a few hundred thousand tonnes over the last decades. In the 1970s this stock supported annual catches in the order of 1–3 million tonnes, but the fishery was banned in 1987 when the stock collapsed (Gjøsæter, 1995). The fishery was re-opened in 1991 on a recovered stock, but was stopped only 3 years later when the stock once more decreased in size.

The capelin matures and spawns at an age of 3–5 years, depending on growth rate, and at least the males are semelparous. Some females may survive spawning, but the spawning concentrations are heavily preyed upon by young cod, and consequently few capelin survive to spawn a second time. Individuals older than 4 years are therefore rarely found (Gjøsæter, 1995).

The fishery takes place during two seasons, a summer fishery on immatures and maturing fish at the feeding grounds in the central and northern Barents Sea, and a winter fishery on prespawners in the southern parts of the sea. The summer fishery exploits mainly 2- and 3-year-old fish, but to some extent even 1-year-olds, while 3- to 5-year-old mature fish are caught in the winter fishery.

In this situation, where the stock consists of a few cohorts only, when the fish recruit to the fishery as 1- or 2-year-olds, and where the recruitment varies to a large degree (ICES, 1995), reliable estimates of year-class strength at an early stage are indispensable, because they may serve as early warnings in case of recruitment failures. There are, however, limitations to how early year-class strength can be assessed if the objective is to forecast year-class strength, e.g. at the time of recruitment to the fishery. An estimate of abundance during the first few weeks may, even if reliable at that particular time, be of little value in forecasting the abundance some months later, due to high and variable mortality.

The abundance of capelin in the Barents Sea is monitored annually during Norwegian larval surveys in June, during the international 0-group surveys in August, and during a joint Norwegian–Russian acoustic survey in September, when estimates of the number of individuals in age-groups 1 and older are obtained. After 1980, the acoustic estimate of the 1-year-old capelin is

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considered to be quite reliable (ICES, 1995, Appendix A), and is assumed to represent the recruitment to the stock.

The aim of this paper is to compare the abundance estimates or indices of each year class obtained during these annual larval, 0-group, and 1-group surveys. The discussion of the findings addresses the question: when can we obtain the first reliable forecast of the size of a recruiting year class?

Materials and methods

Larval surveys

The larval surveys for capelin (Table 1) on which the larval abundance estimates were based, have been conducted annually since 1981 at nearly the same time every year, and according to the methods outlined by Alvheim (1985) and Fossum (1992). The aims of the surveys are to determine abundance and distribution of larval capelin 1–2 months after hatching. Further, the survey is important as a contribution to ecological understanding of the early stages of the Barents Sea capelin stock, and has also served as an indication of spawning, both extent and locality. Survey routes are usually adjusted to cover the larval distribution, but in some years the western or eastern borders are not completely determined due to lack of survey time.

Sampling has been conducted with a high speed planktonic sampler, Gulf III (Zijlstra, 1971), in the upper 60 m of the water column. Larval densities at the sampling stations are integrated over the whole distribution area. Standard procedures of sampling and computation of larval abundance are described by Alvheim (1985). The indices for the period 1981–1993 are published in ICES (1995). The estimate for 1986 is missing, because that year the capelin spawned in late spring, and the few larvae produced hatched too late to be detected during the larval survey.

Fossum (1992) found that all modes in the length frequency distributions of capelin larvae measured on the surveys in 1987–1991 were quite equal, and concluded that the surveys were conducted at the same time every year relative to the major pulse of larval emergence from the spawning areas. We assume that this is also valid for the period prior to 1987, and consequently, no adjustment of abundance according to mean larval length was made.

0-group surveys

The 0-group fish surveys in the Barents Sea have been conducted since 1965. The surveys are made in late August to early September. The aims of the survey are to map the distribution and determine year-class strength of commercial fish species of the Barents Sea and adjacent waters, including capelin.

Table 1. Larval estimate (10^{12}) (ICES, 1995), 0-group index (without units) (Ushakov and Shamray, 1994), acoustic estimate of 1-group and 2-group capelin (10^9) (ICES, 1995).

Year class	Larval estimate	0-group index	1-group estimate
1981	9.7	570	574
1982	9.9	393	613
1983	9.9	589	174
1984	8.2	320	43
1985	8.6	110	11
1986	*	125	49
1987	0.3	55	21
1988	0.3	187	181
1989	7.3	1300	700
1990	13.0	324	405
1991	3.0	241	395
1992	7.3	26	3
1993	3.3	43	27
1994	0.1	58	8

*No observations were made – the survey was conducted too early compared to the main hatching time.

0-group fish are sampled by a pelagic trawl, originally a commercial trawl for capelin fisheries: "Harstadtrawl". Since 1981 the trawl and the trawling procedures described by Randa (1984) have been used. A small meshed inner net (5–8 mm mesh size) is mounted in the codend. Trawling was conducted for 0.5 nautical miles in three depths: 0 m, 20 m and 40 m, starting on 40 m. Total hauling time is approximately 30 min. Supplementary trawling down to 60 m was made when the echo registrations showed layers of 0-group fish deeper than 40 m.

The 0-group indices are based on a combination of distribution and density of the fish species (Table 1). The abundance index is calculated as the area where 1–1050 individuals are caught in each standardized haul, plus ten times the area where more than 1050 individuals are caught (Haug and Nakken, 1977). The time series was presented by Ushakov and Shamray (1994).

Acoustic surveys

The acoustic surveys that yield the 1-group estimates have been conducted on an annual basis since 1972. The surveys are made during September–October. Standard published methods for acoustic stock measurements are used (e.g. Nakken and Dommasnes, 1977; Foote, 1991; MacLennan and Simmonds, 1992), where echo abundance data sampled by echosounders and echo integrators are allocated to species and age groups according to information from trawl samples of the registrations. The target strength value used for capelin was $TS = 19.1 \log L - 74.0$ dB (Dommasnes and Røttingen, 1985). The survey is a co-ordinated multi-ship survey carried out jointly by Norway and Russia. The acoustic equipment

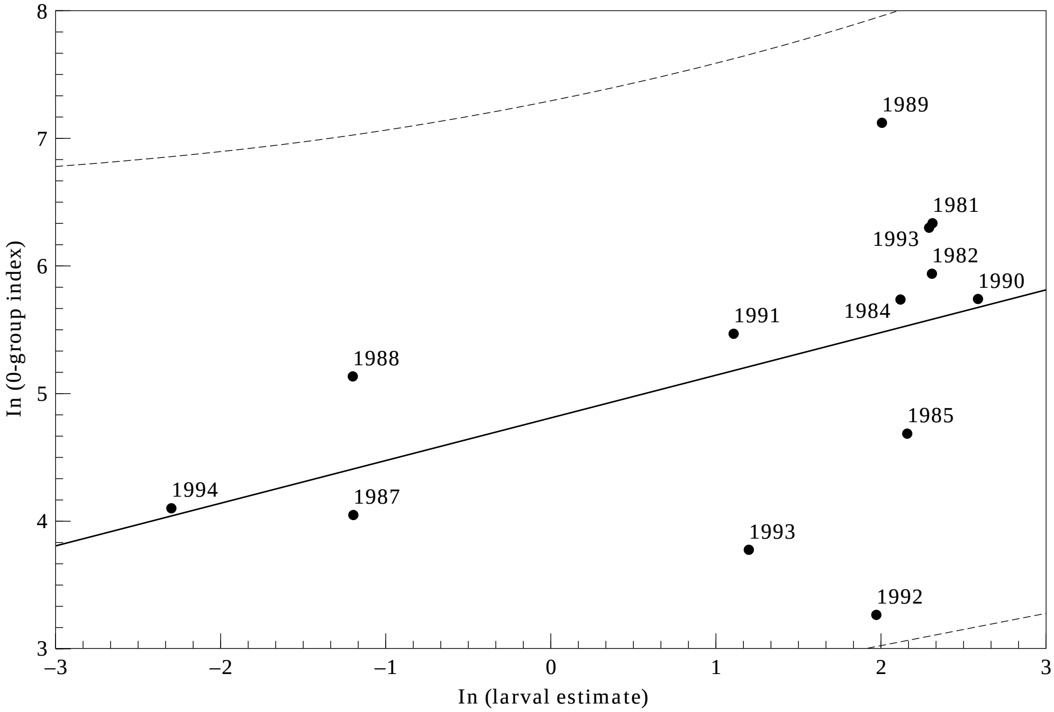

Figure 1. The relationship between the natural logarithms of the larval abundance estimate and 0-group index for capelin. The datapoints are labelled with year class. The regression line with 95% confidence bands for predicted values are also shown.

on board each ship is calibrated by means of standard targets prior to each survey, and compared during the survey by standard methods for inter-ship comparison (MacLennan and Simmonds, 1992).

The acoustic abundance allocated to capelin is converted to number of fish based on the TS-relation given above and the length-frequency distributions obtained from trawl samples (Table 1). The number of fish in each length group is divided on age groups by means of age-length keys constructed from aged trawl samples within subareas with homogeneous length-at-age distributions.

Because in some years 1-year-old capelin were caught in the autumn fishery, the estimated number of 1-year-olds obtained during the acoustic survey was back-calculated to 1 August, adding the number of 1-year-olds taken in commercial catches prior to the survey and adjusting for natural mortality during two months (ICES, 1995).

Statistical analysis

Linear regression analyses were used to analyse the relationship between the three series of observations. The variance of the dependent variables increased with increasing values of the independent variables. In addition, there were some signs of a curved relationship between the variates. Therefore the logarithm (to base e) was taken of all variables before the regression analyses were performed. Plots of residuals versus predicted values and residuals versus time order were used as diagnostic tools when examining the analyses. SAS software (SAS Institute Inc., 1990) was used to make the statistical analyses.

The analyses were performed in three steps:

(i) comparing larval estimate with 0-group index;

(ii) comparing larval estimate with 1-group estimate; and

(iii) comparing 0-group index with 1-group estimate.

The null hypothesis in all three analyses was that there is no linear correlation between the variables.

Results

No significant linear correlation was evident either between larval estimate and 0-group index ($p=0.09$, Table 2, Fig. 1) or between larval estimate and 1-group estimate ($p=0.23$, Table 2, Fig. 2). There is no single outlier explaining the bad fits, and low values of r^2, 0.23 and 0.13, show that there was no evidence of linear relationships.

A highly significant linear correlation was found between the 0-group index and 1-group estimate; $p=0.0001$ (Table 2, Fig. 3). In this case, about 75% of the total variation is explained by the regression model.

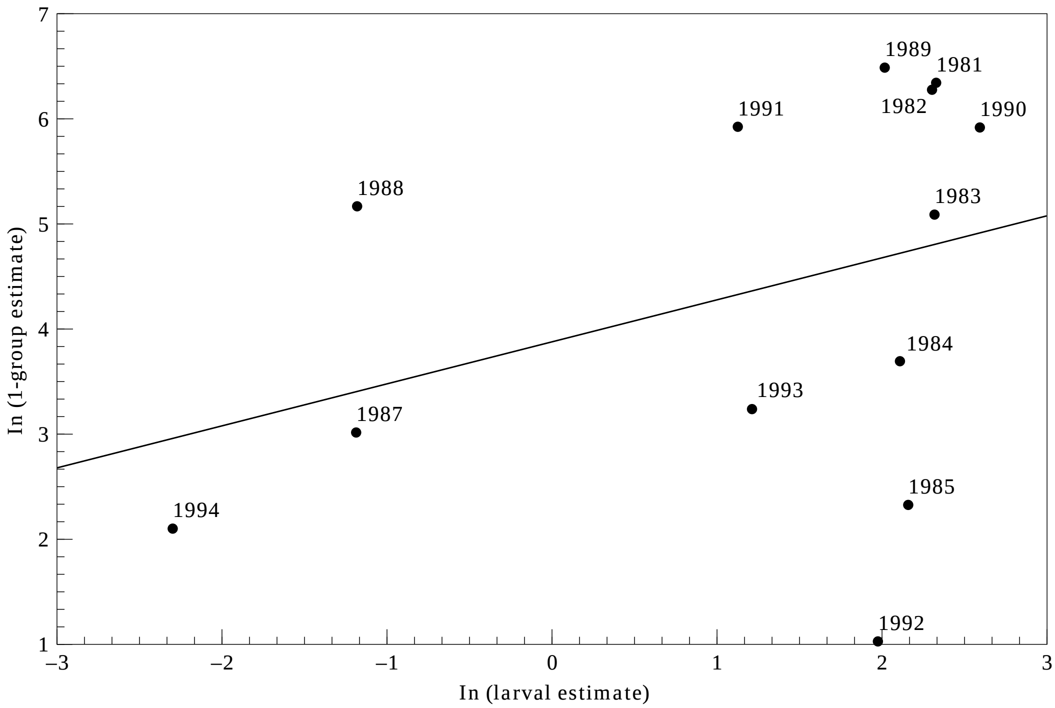

Figure 2. The relationship between the natural logarithms of the larval abundance estimate and the acoustic abundance estimates of 1-year-old capelin. The datapoints are labelled with year class. The regression line is also shown.

Table 2. Results of the regression analyses. p is the probability of this outcome if the null hypothesis, that $r^2=0$, was true.

Regression	r^2	p	Intercept	Slope
ln (larvae) vs. ln (0-group)	0.23	0.09	4.80	0.35
ln (larvae) vs. ln (1-group)	0.13	0.23	3.93	0.41
ln (0-group) vs. ln (1-group)	0.75	0.0001	− 2.79	1.38

The points are evenly scattered around the regression line (Fig. 3) and there is no sign of a curved relationship between the variables. A plot of residuals versus time order shows that there is no systematic pattern (Fig. 4). The year classes 1983–1985 and 1989, 1992 and 1994 are below the regression line, while the rest of the year classes are found above the line. It may be concluded that there is a strong correlation between the 0-group index and the 1-group estimate. The relationship is described by the equation:

$$\ln N_{1\text{-gr}} = -2.80 + 1.38 \cdot \ln I_{0\text{-gr}}$$

where

$N_{1\text{-gr}}$ is the number of 1-year-olds and $I_{0\text{-gr}}$ is the 0-group index for capelin.

Discussion

A significant linear correlation between the acoustic estimate of capelin at age 1 and the 0-group estimates was found, whereas there was no significant correlation either between the larval abundance estimate and the 0-group estimates or the larval abundance estimate and the 1-group estimate. The lack of relationship between the abundance estimates of larval capelin and those of older stages is not surprising. It seems likely that the capelin experience high and varying mortality during its first months of life as demonstrated for other species in the area (cod – Sundby *et al.*, 1989, herring – de Barros, 1995), whereas the mortality is less variable after the 0-group stage. A prediction of year-class strength at later stages based on observed larval abundance estimates is, in any case, not feasible.

The larval survey is nevertheless important as an early forecast about larval distribution and production. The capelin spawning area differs from one year to another. An extention of the spawning towards the western coast of Troms may lead to a considerable amount of the young capelin being transported to the areas west of Spitsbergen, as a result of the circulation pattern of the bank areas outside Troms, as described for cod larvae (Bjørke and Sundby, 1984). It has been found that in years with high concentrations of 0-group capelin west of Spitsbergen, weak year classes

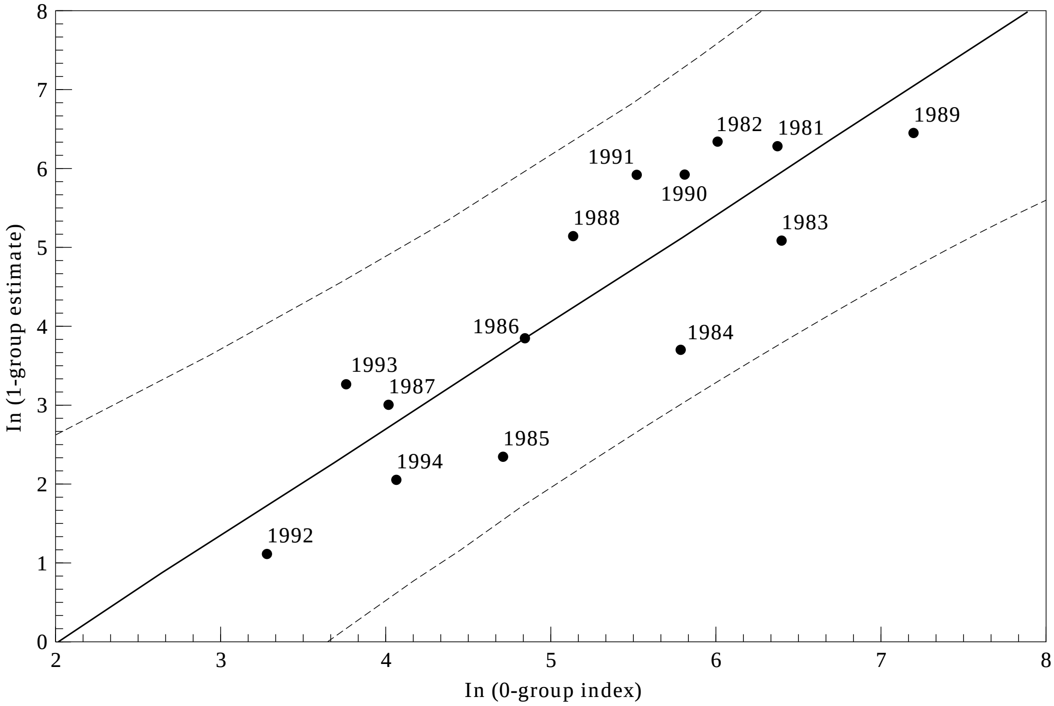

Figure 3. The relationship between the natural logarithms of the 0-group abundance index and the acoustic abundance estimates of 1-year-old capelin. The datapoints are labelled with year class. The regression line with 95% confidence bands for predicted values are also shown.

of capelin are produced (Gjøsæter, 1972; Gundersen, 1995).

The regression of the 1-group estimate on the 0-group index accounts for about 75% of the total variation. There is about 0.0001 probability for such an outcome if the null hypothesis of no correlation between the variables was true. Considering the long time span (13 months) between the observations and the uncertainty associated with the reliability of both estimates, the regression is surprisingly good and indicates that at the time of the August survey, the strength of that year's capelin year class is more or less established. A large variation has been demonstrated in annual mortality of older capelin (Tjelmeland and Bogstad, 1993), and such variability is also probably affecting the mortality during the period between these two estimates. If the mortality varies from year to year, this will add to the measurement errors, and show up as variation around the regression line. If the underlying relationship between the estimates is strong, the amount of deviation from the regression line each year may even give clues to quantify this mortality.

The reliability of the various estimates may be questioned. The 0-group estimates of capelin were left out of the survey reports from 1980–1993 due to uncertainty of whether the catch rates were representative for capelin density. Much of the 0-group capelin tends to stick to the trawl meshes and may be washed away during hauling in bad weather. However, the times series of 0-group estimates is now presented in the survey reports (ICES, 1996) and referred to in the assessment reports (ICES, 1995).

The reliability of the acoustic 1-group estimate is unknown (e.g. Anon, 1994). Firstly the near surface distribution of the 1-group may at times make it inaccessible to the echosounders, secondly the validity of applying the target strength/length relationship established for larger capelin to these small individuals may be questioned. The year classes 1983–1985, and 1989, 1992 and 1994, have negative residuals in the regression of 1-group vs. 0-group while for the other year classes the opposite is true (Fig. 4). One possible interpretation of this is that the mortality between the two times of estimation is larger than the mean for those years with a negative residual. The mechanisms causing the mortality of 0–1 and 1–2-year-old fish are not necessarily the same. The main part of the mortality is probably caused by predation at both stages, but the main predator on the youngest stages is probably herring (Huse and Toresen, 1995) while cod is the main predator on 1- and 2-group capelin (Mehl, 1991). Therefore, it is not directly relevant to use mortality estimates for older age groups as independent estimates of mortality rates of the youngest stages. However, when comparing the residuals from

Figure 4. The residuals resulting from the regression analysis of the 1-group acoustic estimate on the 0-group abundance index plotted vs. time order.

the regression with the mortality estimates stemming from the acoustic abundance estimates of older fish (ICES, 1995) some interesting similarities appear: the year classes 1983–1985, 1992 and 1994 emerged in the periods 1983–1986 and 1992–1995, corresponding to the two collapses in the capelin stock (Gjøsæter, 1995), when very high mortality rates were observed for older age groups. In the years 1982, 1988, 1990 and 1991, when the year classes that showed the largest positive residuals were 0- and 1-year-old, the natural mortality on older fish, as estimated from acoustic estimates, was much lower (ICES, 1995). However, some year classes do not fit to this pattern and obviously, the variation not accounted for by the regression is a combination of measurement errors and variations in mortality.

In conclusion, the variation around the regression line cannot be directly interpreted as a measure of natural mortality. The dispersion due to measurement errors probably make up too much of the variability to make such an interpretation feasible.

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 the year-class strength (measured as number of 1-year-old capelin) is, to a large extent, established in August in the first year of life (0-group stage). This allows for a prognosis of year-class strength to be made on the basis of an 0-group abundance index. Such a point estimate will have a relatively low precision. A more useful approach would be to pick predicted values from inside the confidence intervals shown in Figure 4, to study the most probable outcome in a risk analysis.

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