

Theme Session 3: RETROSPECTIVE ANALYSES OF ASSESSMENTS AND MANAGEMENT ADVICE FOR BARENTS SEA FISH STOCK

AN EVALUATION OF THE METHODOLOGY FOR PREDICTION OF CAPELIN BIOMASS

by

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Abstract

The one-year prediction of capelin made as part of the assessment after the annual joint acoustic capelin survey during the autumn, is evaluated. Such predictions were made for the period from 1981 till present, and compared to observed stock sizes. The results show that the predictions underestimate the stock size in about half of the years and overestimate the stock size in the others, but in 18 out of the 23 years the observed stock sizes are within the 90% confidence interval of the predictions. It is found that there is a tendency for overestimating stock size in periods when the stock decreases and vice versa. The ratio between predicted and observed stock sizes is variable and some times quite high for stock sizes below one million tonnes (collapsed stock size) but varies between about 0.5 and 1.5 and is unrelated to stock size for larger stock sizes. These results are discussed in light of the various components of the models involved in the predictions.

1. Introduction

The capelin (*Mallotus villosus*) stock in the Barents Sea is surveyed by an annual acoustic survey in September/October (Gjøsæter *et al.*, 1998). Almost all capelin die after spawning, and the capelin stock is managed by a target escapement strategy. The quota (TAC) is calculated based on a ½-year prediction of spawning stock size 1 April the year after. The quota is set so that there is a 95% probability for the SSB to be above 200 000 tonnes (ICES, 2005). The Joint Norwegian-Russian Fishery Commission accepted this harvest control rule in 2003.

The capelin stock, as well as the capelin catches, has fluctuated strongly (ICES 2005, Fig. 1). The stock abundance has varied between 0.1 and 7 million tonnes. The maximum annual catch recorded is close to 3 million tonnes, but the fishery has been closed in several periods (1987-1990, 1994-1998, 2004-present).

The current methodology for assessment of the Barents Sea capelin stock, using a combination of the multispecies model Bifrost (Tjelmeland, 2002) and the spreadsheet model CapTool (Gjøsæter *et al.*, 2002) run in the @RISK add-in to MS Excel, has been applied since 1997. Up to 1998 the models served the purpose of giving a ½-year prediction of spawning biomass from the survey in autumn to the spawning next spring, for use in the quota calculations for the winter fishery. The models have been steadily enhanced, and from 1999 a one-year prediction of biomass of 1+ capelin from the autumn survey to the time of the next autumn survey was included. Such predictions include many sources of uncertainty. However, even an uncertain prediction might be of value for some purposes, e.g. for giving a first

prediction of the amount of capelin available as food for cod (*Gadus morhua*) and other predators during the coming year (see e.g. Bogstad *et al.* 2000 for a description of predator-prey interactions in the Barents Sea). The amount of capelin available for cod may affect both individual cod growth and cod cannibalism. Another use of the one-year prediction might be to give the management authorities an early indication of the expectancies for the capelin fishery one-and-a-half year ahead of time.

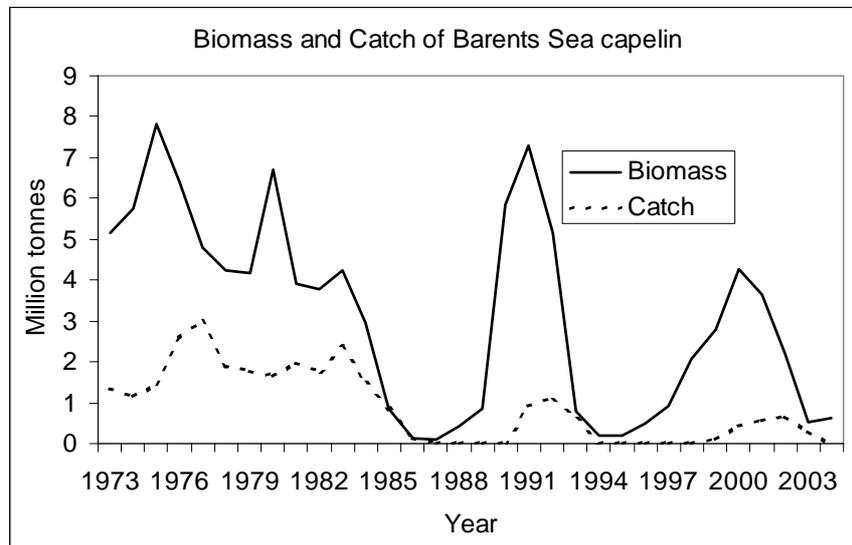


Figure 1. Biomass and catch of the Barents Sea capelin

The aim of this paper is to evaluate the current methodology for one-year-predictions of capelin biomass by comparing them to observed stock sizes, and to discuss the goodness of the predictions in light of the total information about the stock. We will not review the actual one-year predictions made during the period 1998-2004, when varying methodologies were used. We also outline how more biological knowledge could be taken into account in the predictions.

2. Material and methods

The period 1981-2004 was chosen. The reason for this is that before 1981, the coverage of 1-group capelin during the acoustic survey was incomplete (Gjøsæter *et al.*, 1998).

The calculations were performed using Excel spreadsheets with the @RISK add-in. Five thousand simulations were made for each year.

2.1. Input data:

- Capelin abundance and size at age (number by age and length group, mean weight and length at age) measured by an acoustic survey in September (Gjøsæter *et al.*, 1998, updated numbers given in ICES (2005). The uncertainty in the capelin stock estimates is based on resampling the September estimates (both total acoustic abundance and biological samples), as described by Tjelmeland (2002). A CV of 0.2 is used for all years; this is close to the long-term average. The same CV is applied for all age groups, and the CV for the various age groups are assumed to be uncorrelated.

- Capelin 0-group abundance from the annual 0-group survey in August-September (ICES, 2005).

2.2. Models for population dynamics

The following population dynamics processes are modeled: Mortality-Maturation-Recruitment-Growth.

When making the sub-models for these population dynamics processes, we assume that current knowledge (time series from 1981-2004) is available when making the predictions.

2.2.1. Mortality

Two kinds of mortality are modeled: Spawning mortality and residual mortality. Fishing mortality on immature capelin is ignored, and since total spawning mortality on mature capelin is assumed, the fishing mortality on mature capelin is not of interest for the 1-year prediction.

2.2.1.1. Spawning mortality

All mature capelin are assumed to die on April 1, due to spawning mortality. The calculation of the proportion mature is described in Section 2.2.2.

2.2.1.2. Residual mortality

The residual mortality was drawn from the historical time series of natural mortality of immature capelin from the period 1983 till present, calculated as described in Section 2.2.2. Predation by cod on mature capelin in the period January-March is modeled in Bifrost. However, the development of the immature capelin stock from year y to year $y+1$ is independent of this predation mortality.

2.2.2. Maturation

The proportion mature, $PM(l)$, is modeled in the following way:

$$PM(l) = \frac{1}{1 + e^{4P_1(P_2-l)}} \quad (1)$$

where l is the fish length.

The maturation function is applied on the acoustic stock estimate in autumn (October 1), in order to separate the modeled stock into a mature and an immature part. The parameters P_1 and P_2 are estimated with uncertainty using the model Bifrost (Gjøsæter et al. 2002, see also www.assessment.imr.no). The estimations are done by simulating one year ahead using the model, assuming total spawning mortality, and comparing the number of modeled fish at ages 3 and 4 with the observations from the survey one year later. The estimations were made using data from 1972-1980, and an M-value for this period was also estimated. The reason for not using the full time series is that during the chosen time range the population dynamics was stable, with relatively constant M-values. Later there were large variations in M as herring (*Clupea harengus*) re-entered the Barents Sea, and possibly also connected to large

fluctuations in the harp seal (*Phoca groenlandica*) stock. For years after 1980, annual mortality parameters are estimated using the estimated maturation parameters for the period 1972-1980. P_1 was set to 3.5, which makes the maturation function close to a step-function in compliance with earlier treatment of maturation. The mean value of P_2 is 13.89, which is close to the value estimated by Tjelmeland and Bogstad (1993).

2.2.3. Recruitment

Gundersen and Gjørseter (1998) established a linear regression between the logarithm of the 0-group area based indices and the logarithm of the 1-group acoustic abundance 1 year later.

This regression has been annually updated with new data, and used in the predictions of capelin stock size. Revised 0-group indices calculated using the method described by Dingsør (2005) and Anon. (2005) are now available (ICES, 2005). Using those indices without correction for length-dependent selectivity in the trawl, we found that a linear regression gave better fit than a log-log regression. The new regression, using data from the 1981-2003 year classes, is shown in Fig. 2.

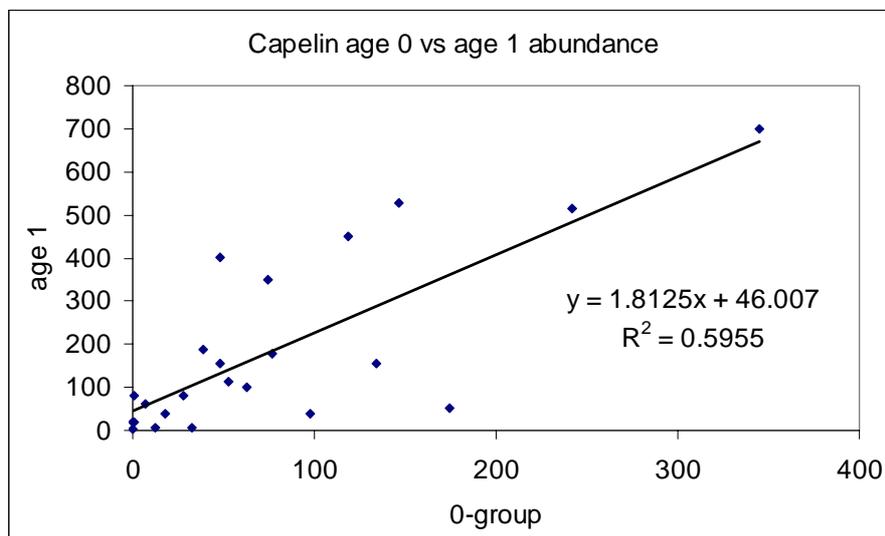


Figure 2. Regression of abundance of capelin at age 0 and age 1

2.2.4. Individual growth

The individual growth in length (cm/year) for each age group can be calculated from values obtained by comparing the mean length at age of immature capelin one year with the mean length at age of the total stock next year, for the period 1981-2004. The individual growth (in cm/year) for age 1 and older fish, i.e. for age groups (1-2, 2-3, 3-4) is drawn randomly from the time series. The length distribution of age 1 fish is drawn from the historical time series. The growth of fish from age 4 to 5 is assumed to be the same as for ages 3-4. The draws from the time series are made separately for each age group, i.e. we do not draw the same year's growth for all ages. However, it might be more logical to change this into drawing one year and use that year's growth for all age groups.

The length growth is implemented by shifting the distribution of immature capelin upwards with the number of 0.5cm length intervals, which corresponds to the growth in length, for each age group and year.

The capelin length-weight relationship for use in the 1-year prediction is drawn randomly from historical data for the period 1981-2004.

3. Results

3.1. Prediction of total stock size

Table 1 shows the results of the simulations for the total stock.

Table 1. Comparison of predicted (with confidence limits) and observed total capelin stock size during the period 1981 to 2003

Year	Stock abundance (1+) in year y (million tonnes)	Predicted stock abundance (1+) in year y+1 (million tonnes)	Lower Confidence Limit (5%)	Upper Confidence Limit (95%)	Observed stock abundance(1+) in year y+1 (million tonnes)	Ratio predicted/observed	Residual/observed
1981	3.90	4.15	1.35	9.64	3.78	1.10	0.10
1982	3.78	4.63	1.76	9.88	4.23	1.09	0.09
1983	4.23	4.59	1.37	10.50	2.96	1.55	0.55
1984	2.96	2.73	0.98	5.35	0.86	3.18	2.18
1985	0.86	1.05	0.39	2.15	0.12	8.73	7.73
1986	0.12	0.35	0.18	0.58	0.10	3.45	2.45
1987	0.10	0.29	0.10	0.58	0.43	0.69	-0.31
1988	0.43	0.66	0.34	1.17	0.86	0.76	-0.24
1989	0.86	3.37	1.75	5.62	5.83	0.58	-0.42
1990	5.83	4.84	1.00	12.56	7.29	0.66	-0.34
1991	7.29	6.47	1.37	16.46	5.15	1.26	0.26
1992	5.15	3.73	0.60	9.84	0.80	4.69	3.69
1993	0.80	0.64	0.18	1.55	0.20	3.19	2.19
1994	0.20	0.38	0.16	0.68	0.19	1.95	0.95
1995	0.19	0.26	0.09	0.51	0.50	0.52	-0.48
1996	0.50	0.95	0.47	1.69	0.91	1.04	0.04
1997	0.91	1.39	0.62	2.66	2.06	0.68	-0.32
1998	2.06	1.82	0.58	4.01	2.78	0.66	-0.34
1999	2.78	2.24	0.92	4.48	4.27	0.52	-0.48
2000	4.27	2.96	0.78	6.96	3.63	0.82	-0.18
2001	3.63	2.06	0.42	5.13	2.21	0.93	-0.07
2002	2.21	1.32	0.42	2.91	0.53	2.47	1.47
2003	0.53	1.64	0.93	2.55	0.63	2.61	1.61

In 18 out of the 23 years, the observed stock size is within the 90% confidence interval of the predicted stock size (Figure 3). However, the confidence intervals are rather wide in most years, and the difference between predicted and observed values is quite large in many of the years. In half of the years the stock sizes are underestimated, in the other years they are overestimated. However, the sign of the residuals is not randomly distributed along the time

series; it is evident that there is a trend in the data, where periods of overestimation alternate with periods of underestimation. With a few exceptions, the stock size is underestimated in periods when the stock is increasing, and overestimated in periods when it is decreasing (Figure 3). When the ratio between predicted and observed stock sizes are plotted versus observed stock size during the period, it is seen that the positive ratios (overestimation) are larger than the negative ratios, and there is seemingly a tendency for the highest ratios to occur when the stock size is at a minimum (Figure 4). This tendency is confirmed when the ratios are plotted versus observed stock size (Figure 5), but above an observed stock size of about 1 million tonnes, the relationship between the ratio and the observed stock size flattens out (linear regression, $b=-0.03$, $R^2=0.02$).

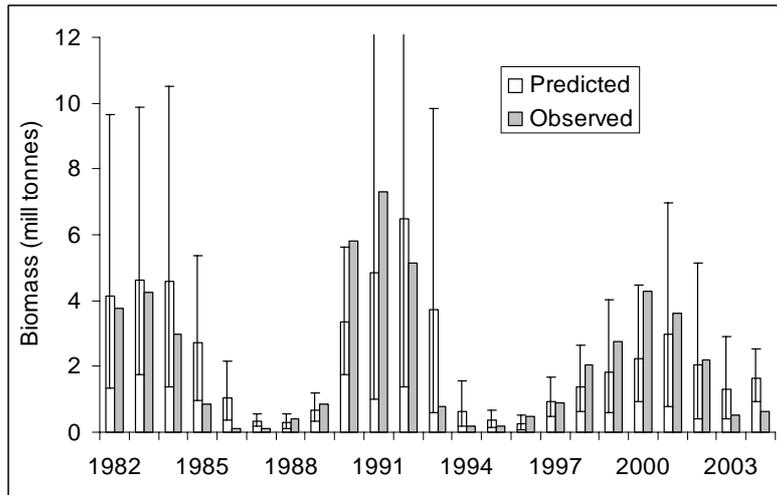


Figure 3. Predicted (with 90% confidence interval) and observed total stock sizes during the period 1982 to 2004

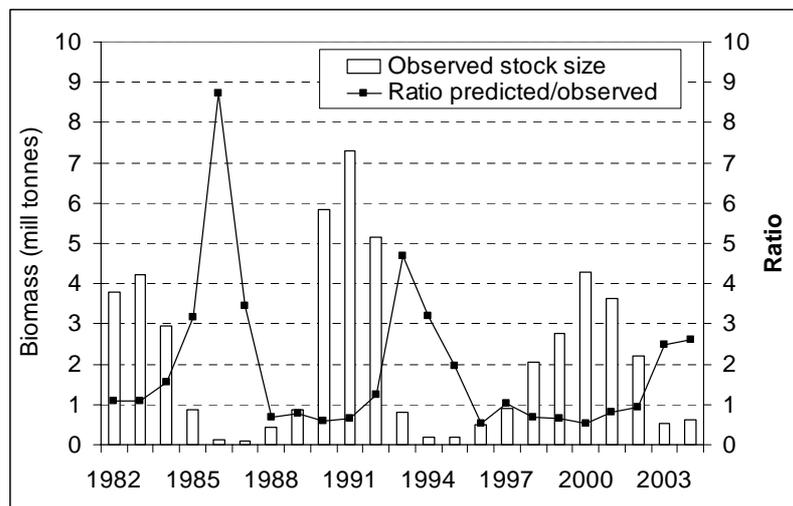


Figure 4. Time series of observed stock size and corresponding ratio between predicted and observed stock size during the period 1982 to 2004

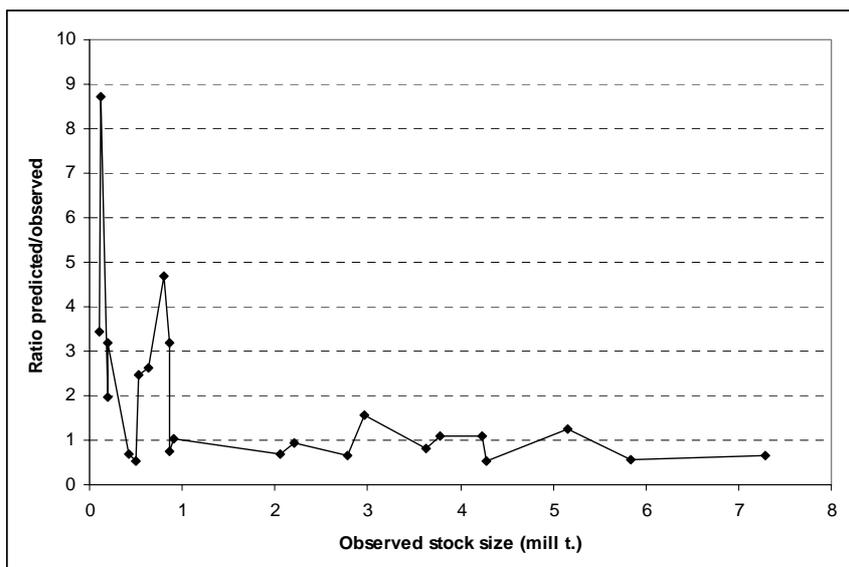


Figure 5. Ratio between predicted and observed stock size plotted versus observed stock size

There is no clear trend in the relative residuals $((\text{predicted} - \text{observed})/\text{observed})$ when plotted versus the observed stock size (Figure 6). The residual for the year 1985 is more than twice as large as any of the other residuals. That year, the stock collapsed and the predicted stock size for 1986 was almost 9 times as large as the observed stock size.

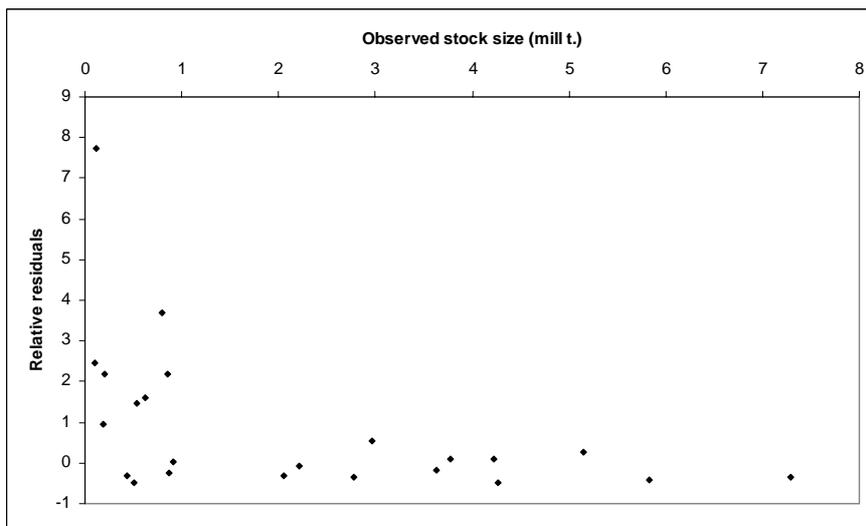


Figure 6. Relative residuals plotted versus observed stock size

3.2. Year class strength of the 1-year-olds

In addition to the simulations of total stock size of one-year-olds and older capelin, the part of the prediction constituting the one-year-olds was analyzed separately. The results are given in Table 2.

Table 2. Comparison of predicted (with confidence limits) and observed biomass of 1-year-old capelin during the period 1981-2003

Year	Predicted abundance of age 1 in year y+1 (million tonnes)	Lower Confidence Limit (5%)	Upper Confidence Limit (95%)	Observed abundance of age 1 in year y+1 (million tonnes)	Ratio predicted/observed	Residual/observed
1981	1.11	0.64	1.65	1.22	0.91	-0.09
1982	1.73	1.00	2.60	1.60	1.08	0.08
1983	1.04	0.61	1.55	0.57	1.81	0.81
1984	0.80	0.47	1.19	0.17	4.59	3.59
1985	0.38	0.21	0.60	0.02	16.23	15.23
1986	0.28	0.13	0.48	0.08	3.60	2.60
1987	0.17	0.03	0.36	0.07	2.40	1.40
1988	0.42	0.24	0.65	0.61	0.68	-0.32
1989	2.40	1.33	3.57	2.66	0.90	-0.10
1990	0.48	0.28	0.72	1.52	0.31	-0.69
1991	0.65	0.39	0.96	1.25	0.52	-0.48
1992	0.17	0.04	0.35	0.01	22.08	21.08
1993	0.18	0.03	0.37	0.09	2.04	1.04
1994	0.25	0.10	0.45	0.05	5.23	4.23
1995	0.18	0.04	0.36	0.24	0.75	-0.25
1996	0.58	0.33	0.86	0.42	1.38	0.38
1997	0.67	0.39	0.99	0.81	0.83	-0.17
1998	0.48	0.27	0.72	0.65	0.73	-0.27
1999	0.94	0.54	1.38	1.70	0.55	-0.45
2000	0.51	0.29	0.77	0.37	1.36	0.36
2001	0.22	0.08	0.41	0.23	0.92	-0.08
2002	0.35	0.18	0.56	0.20	1.74	0.74
2003	1.29	0.73	1.93	0.20	6.61	5.61

For the one-year-olds, the observed values are within the confidence limits of the predicted values in only 13 out of the 23 years (Figure 7). That means that the prediction of one-year-olds constitutes a “weak part” of the prediction of total stock size. Similarly to the predictions of total (1+) biomass there is also in this case a trend of overestimation in cases of an increasing stock and underestimation when the stock is declining. However, the trend is not as systematic as found for the total predictions. On average, there is an annual overestimation of about 21 thousand tonnes of one-year-olds during this period.

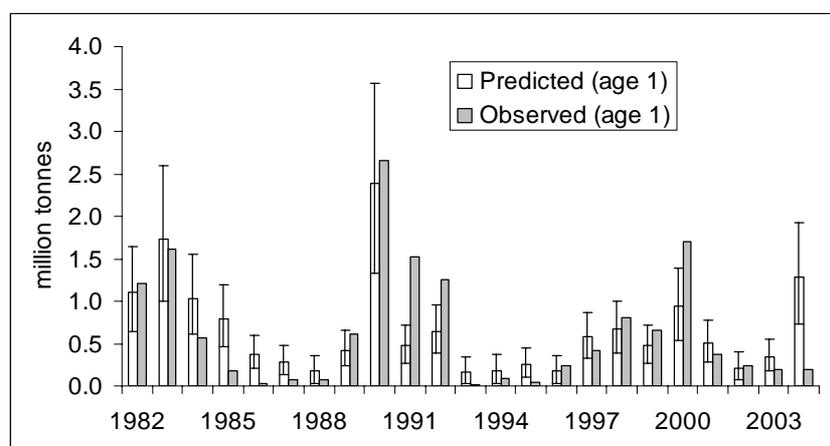


Figure 7. Predicted (with 90% confidence limit) and observed biomass of one-year-old capelin during the period 1982 to 2004

4. Discussion

4.1. Precision of predictions and time lag

The average overestimation of stock size is 96 thousand tonnes, out of which 21 thousand tonnes stem from the one-year-olds, showing that the model has had a slight tendency to overestimate stock size compared to observed values in this period. The predictions obviously “lags behind” the development of the stock, since the model overestimates the stock size when it is declining and underestimates the stock when it is increasing.

4.2. Effect of ignoring catch of immature capelin

Ignoring catch of immature capelin in 1981-1986, 1991-1993 and 2000-2003 leads to overestimation in prediction for these years. The amount of immature fish taken during these periods has varied considerably, but especially for the first of these catch periods catch of immature capelin was quite high, amounting to between 131 and 435 thousand tonnes annually. For 1981 and 1982, the catch of immatures was in fact 118% and 33% of the difference between predicted and observed stock size respectively. For the other years the catch of immatures makes up less than 15% of the difference. This clearly shows the need to take account of these catches, at least when analyzing historical data. Because it is quite time consuming to implement this in the model, it was not possible to do before this symposium. This is a task for the near future.

4.3. Year class strength of the 1-year-olds

The analysis of one-year-olds separately shows that there is a slight tendency for overestimation, but the sign and value of the residuals are less related to stock situation than those for the total predictions. It has not been possible to check the various components of the predictions of one-year-olds, so it is unknown whether it is the natural mortality or the growth that constitutes most of the residuals. Since the mortality is large and variable during this phase (see Figure 2), it seems probable that the rather low accuracy and precision in the predictions of one-year-olds mostly stem from the regression of one-year-olds on the 0-group index. The regression of one-year-olds on 0-group index has a positive intercept. This will inevitably cause a relative increase in overestimation for smaller stock sizes, and may partly explain the increase in ratio between predicted and observed stock sizes seen for smaller stock sizes in figure 5. Further work will include implementation of a regression through the origin, to avoid this effect.

4.4. Natural mortality

One possible reason that the predictions lags behind the stock development is the way the natural mortality is handled, by drawing at random a natural mortality (as observed by the decrease of one year class from one year to the next when fishing and spawning mortality is accounted for) observed during previous years. The rationale behind this method is that the natural mortality is unknown, but may vary randomly within the observed limits. However, it is observed that in periods of stock decline, the natural mortality is increasing and vice versa. If this could be taken into account, a better prediction for natural mortality could be made. However, it is not a straightforward task to implement this in the model, since it is unknown

whether the stock will increase or decrease during the next year. One possibility would be to draw the natural mortality at random from e.g. the last 2-3 years, since the trends in stock size normally changes in a cyclic manner, and recent years would better reflect current level of natural mortalities.

An even better idea would be to model the natural mortalities with external factors as driving forces. The most obvious factors to try would be density dependence, predation pressure from cod, or rather, a combination of these. The most probable mechanism for an increased natural mortality when the capelin stock is decreasing is that a high predation pressure will exert a galloping mortality (M) as the capelin stock gets smaller. When the capelin stock is above a certain level, one may suppose that M would be inversely proportional to the cod/capelin ratio. When the capelin stock falls below this critical level, the cod may have problems with encountering capelin, and may even actively switch to other food sources. The hypothesized relationship would then break down. Unfortunately time has not allowed us to pursue these ideas further, so this is for the future.

4.5. Growth

The growth from year y to $y+1$ is implemented in an analogous way to the natural mortality. Assuming the actual growth is unknown, the growth rate is drawn at random from previously observed growth rates independently for each age group. In the future, this might be changed into drawing one year and use that year's growth for all age groups. It would be possible to compare the length frequencies in the predictions with those observed, but this is a quite laborious task and has not been done. However, if trends in these residuals could be demonstrated, a logical enhancement would be to model how individual growth from year y to year $y+1$ would depend on some or all of the following factors:

Mean length at age of immature capelin in year y
Total stock abundance in year y
Oceanographic variables in year y
Plankton abundance in year y

This was studied by Bogstad et al. (2005), who found that individual growth from age 1 to 2 was density-dependent, i.e. negatively correlated with the biomass of capelin in year y . They also found how the individual growth from year y to $y+1$ was correlated with the mean length at age of immature capelin in year y . These relationships will be built into the CapTool model.

1.6. Additional possible improvements:

- Use annual estimates of uncertainty of number at age in surveys (including how these numbers are correlated), to get more appropriate measure of uncertainty in survey estimate.
- Try to account for other uncertainties in survey estimate than those modeled by Tjelmeland (2002)

5. Acknowledgements

We thank Sigurd Tjelmeland, Institute of Marine Research, for help with implementing the 0-group/1-group regression in CapTool.

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RETROSPECTIVE REVIEW OF MANAGEMENT ADVICE FOR THE NORTHEAST ARCTIC COD

by

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Introduction

The history of fishery of the Northeast Arctic cod is almost a millennium (Rollefson, 1966; Dyrvik et al., 1979), while the history of its management is much shorter. We reviewed 100 years period of managements measures development.

Currently for all commercially important fish stocks in the Barents Sea area, Norwegian and Russian management authorities receive annual advice from ICES on total allowable catches (TAC's) and other management measures. The advice is based on the stock monitoring and research carried out by PINRO and IMR.

Material and methods

All data are taken from the annual ICES reports (ACFM reports) as well as the Joint Soviet-Norwegian Fisheries Commission, later the Joint Russian-Norwegian Fisheries Commission protocols. Each year ICES produces an updated version of the assessment of all previous years, and we have compared the results from the annual assessments; i.e. the assessment that is the basis for the decision on next years TAC, with the results from the 2005 assessment for the same years.

Results

History of the management

First regulations of the cod fishery aimed at preventing the conflicts among fishers operating on the same fishing grounds are almost a century old. The development and practical application of regulatory measures began to be a more regular practice only from the mid-20th century. The need for development and subsequent implementation of regulatory measures on the cod fishery was called forth by an abrupt decline of the efficiency of this fishery in the second half of the 1950s.

Before that, a minimum mesh size established by the “Convention on regulation of the mesh size in fishing gear and minimal legal fish size” (London, 23 March 1937) was recommended for use to limit the cod fishery. However, decisions under this Convention were not binding for all nations exploiting the stock.

Under the next Convention, which was signed in London on 5 April 1946 and came into force on 5 April 1953, it was recommended that the minimum mesh size be increased to 110 mm (the USSR acceded the Convention in 1958 and ratified it in 1961). So, this technical regulatory measure was the first direct regulatory measure in the history of cod fishery.

A later history of exploitation of cod in the Barents Sea showed, that application of technical regulatory measures alone could not help avoiding sudden variations and repeated decline of the efficiency of fishery, variations in the size composition of catch and its decline.

Reduced catch rates and disappearance of large cod from catches, near Lofoten including, in the second half of the 1950s gave grounds for the Russian and Norwegian researchers to conclude that the trawl fishery had a strong impact on the cod stock (Maslov, 1957a; Sættersdal and Hysten, 1964). It was formulated, that “a method to manage the biological processes in a water body lies in regulating the fishery by establishing science-based catch limits strictly complied with by the industry (Maslov, 1957b)”.

A more effective measure to ensure rational exploitation is fishery regulation through establishing a science-based total catch limit (TAC) based on a stock status. Therefore, the subsequent history of the cod fishery management was based on giving the priority to establishing a TAC on the basis of scientific advice with simultaneous development of other regulatory measures for the fishery.

In 1958 the first meeting of the Arctic Fisheries Working Group (AFWG) under the International Council for the Exploration of the Sea (ICES) was held in Bergen, where for the first time assessment of the Barents Sea commercial fish stocks, cod including, was undertaken. Russian and Norwegian scientists Yu.Yu.Marti, V.I.Travin, G.Rollefsen, A.Hysten participated. After that the assessment of stocks was conducted on an annual basis. In 1964 to assess the cod stock the Virtual Population Analysis (VPA) was applied for the first time.

It should be noted, that before mid-1970s although the AFWG provided scientific advice on catch options, no binding decisions were taken to regulate the fishery by quotas. This left the total fishing effort unrestrained from increasing, as a result of which the fishing mortality of juvenile cod, not having used its potential for growth, increased in the 1970s, when even strong year classes could not support yet long-term mean, let alone high, catch rates (Ponomarenko, 1982).

Introduction of national economic zones and negative trends in the Barents Sea commercial fish stocks dynamics were major reasons for establishing the Joint Soviet-Norwegian Fisheries Commission, later the Joint Russian-Norwegian Fisheries Commission, in January 1976 with the objective to ensure a coordinated effective management of joint stocks.

Annual cod quotas have been setting up by the Joint Fisheries Commission since late 1970s. It should be noted that at some of its annual meetings the levels of commercial harvest adopted by the Commission were higher than recommended by Russian and Norwegian scientists. In addition, until mid-1980s there were no limitations for fishing of cod by net, line and jigger, which increased the harvest beyond recommended levels.

A revision of established limits in order to reduce them for critical status of the cod stock was needed only once – in 1988. The reduction of catch limits led to a reduction of fishing mortality (Jacobsen, 1992) and gradual growth of the stock. In 1992 the catch limit was revised with the aim to increase it.

Later on a higher accuracy of management advice for the cod fishery was achieved through refining the methodology for estimating a TAC, taking into account predator-prey relations and cannibalism.

The next step in optimizing the cod fishery was an agreement concerning “a 3-year harvest control rule” adopted by the 31st session of the Joint Russian-Norwegian Fisheries Commission and effective from 2004. Under this agreement, seeking to achieve a year-to-year stability of TACs and create conditions for high long-term yield from the stock the Parties decided:

- estimate the average TAC level for the coming 3 years based on Fpa. TAC for the next year will be set to this level as a starting value for the 3 years period;
- the year after, the TAC calculation for the next 3 years is repeated based on updated information about the stock development, though such that the TAC should not be changed by more than +/-10% compared with the previous year’s TAC;
- if the spawning stock falls below Bpa, the Parties should consider a lower TAC than according to the decision rule above.

Simultaneously with the scientific advice for the management of cod stock being improved technical measures to regulate this fishery were also modified. For instance, minimum mesh size was revised several times (from 80/90 mm for Norwegian/Soviet trawlers in 1946 to 135/125 mm in 1982) and minimal landing size for cod as well (from 34 cm in 1964 to 47/42 cm for Norwegian/Russian fishing vessels in 1988/1990). Furthermore, in order to reduce the by-catch of juvenile cod sorting grids were made mandatory for use on the trawl fishery from 1997. In mid-1980s a limit for allowable by-catch of juvenile *Gadidae* on the shrimp fishery was established and in mid-1990s a mandatory use of sorting grids on this fishery was introduced.

Table 1. The history of alteration of management measures applied on the Northeast Arctic cod fishery

Year	Management measures
1961	Introducing minimal mesh size in trawls of 110 MM
1963	Introducing minimal mesh size in trawls of 120/130 MM
1978	Establishing annual TAC for trawl fishery
1979	Introducing measures to improve spawning conditions
1981	Introducing minimal mesh size in trawls of 125 MM
1982	Introducing minimal mesh size in trawls of 135 MM*
1983	Establishing annual TAC for the cod fishery (for all fishing gear, including fixed engines)
1984	Limiting the by-catch of juvenile <i>Gadidae</i> on shrimp fishery
1992	Limiting the by-catch of juvenile <i>Gadidae</i> on capelin fishery
1993	Introducing sorting grids on shrimp fishery
1997	Introducing sorting grids on cod fishery

**Applies to all vessels operating in the Norwegian economic zone.*

The use of unified management measures such as TAC, mandatory use of sorting grids and others, by all nations exploiting the cod stock is certainly advantageous. At the same time, differing minimal mesh size in trawls, minimal landing size of fish applied in different economic zones complicate the development of scientific advice. Therefore, a long-term objective for Russia and Norway would be the development and implementation of unified management measures for the cod fishery overall.

The current management system

The management system for cod stock is based on three sources of information about its status (Fig.1). The first is fisheries statistics, which includes information on catch, catch per effort, mean weight at age and age composition of commercial catch provided to ICES by all nations engaged in cod fisheries.

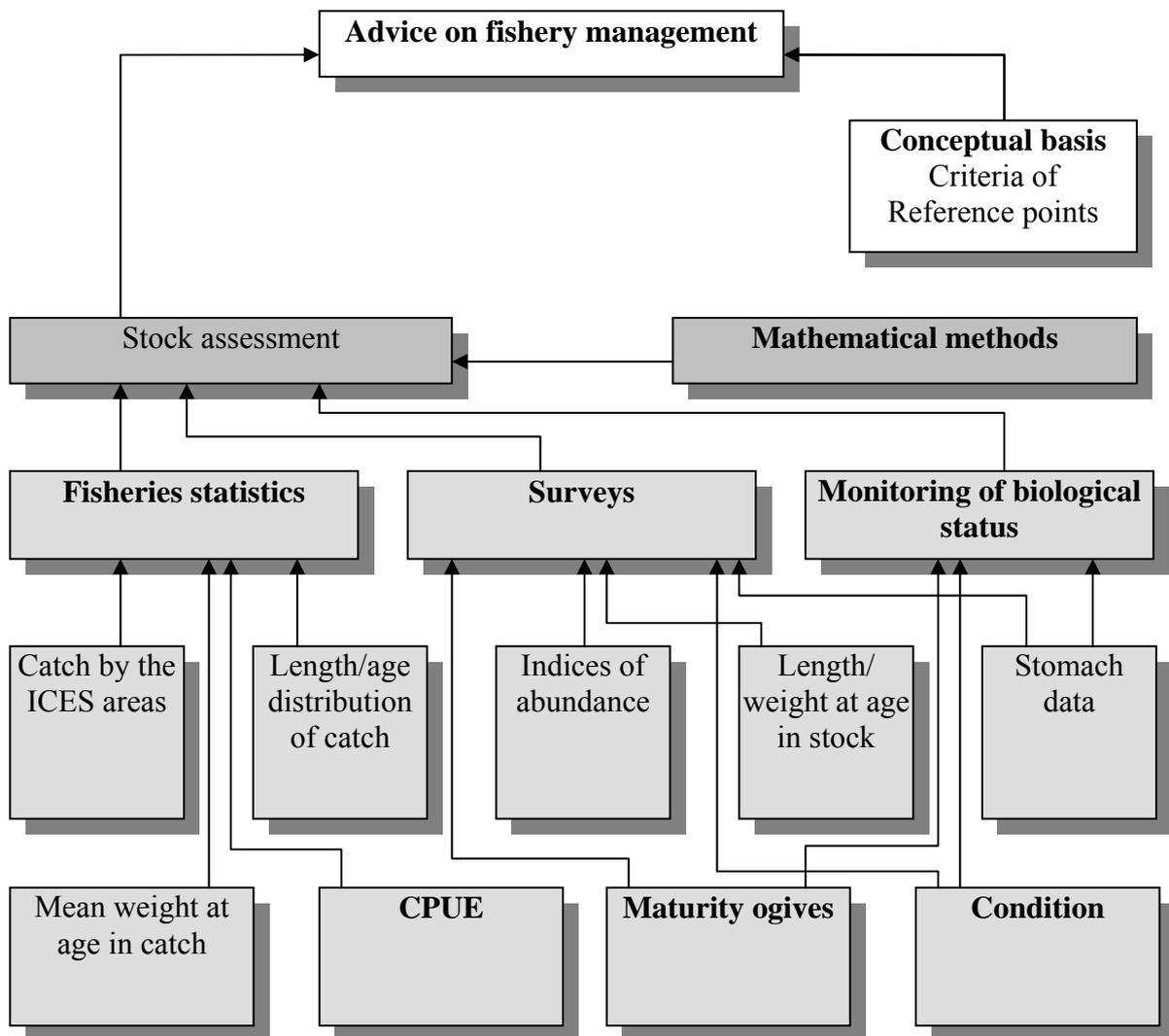


Fig 1. Diagram to show schematically how management advice for the Northeast Arctic cod is developed

The second important source of information is trawl-acoustic surveys conducted by Russia and Norway, which provides data for estimating the abundance indices, length and weight at age and maturity ogives. Survey data are supplemented by environmental data.

The third source of information is a year-round-run observer program on fishing vessels and coastal plants, which provides information on cod feeding conditions, maturation rate and abiotic conditions in its habitat.

All information compiled is used for stock assessment for which a variety of mathematical methods are applied, of them the key method is VPA. This method permits to develop a science-based advice on the level of fishing mortality (F).

In choosing the optimal fishing mortality rate various biological reference points set on the basis of the relationship between catch and F as well as recruitment and spawning stock biomass are taken into consideration. Some history of the ICES framework for advice given in Aglen et al. (2004). An optimal level of the chosen F means that a principle of maximizing the long-term yield is met (to prevent overfishing). Besides, the need to avoid excessive outtake of juvenile fish, recruits to the commercial stock, and maintain the spawning stock biomass (SSB) at the level preventing from impaired recruitment is taken into account.

Comparison of the annual and the most recent stock assessments

In a review of the exploitation and management of several stocks in the area some years ago (Nakken 1998, 2002) it was shown that agreed and actual catches frequently exceeded the advised ones. In addition, it was shown that the annual stock assessment tended to be biased, particularly for North-East Arctic cod; i.e. the annually estimated fishing mortalities were as a rule substantially lower than those arrived at in later assessments for the same year. On an average the fishing mortality rates seemed to be about 20 percent too low and consequently the stock estimate, on which the annual advice was based, was about 20 percent too high. Nakken (1998, 2002) therefore recommended that considerably more caution ought to be used by management authorities when deciding on TAC's in the future.

In the present paper we have updated the information on advised and agreed TAC's as well as actual catches, and we have also compared the annually estimated fishing mortalities, SSB and recruitment numbers (age 3) with the figures arrived at in the most recent assessment; i.e. the 2005 assessment. The results indicate that in recent years the errors in the annual assessments have been minor as compared with previous periods and than the large downward bias in fishing mortality rate (upward bias in stock estimate) has been absent since 1998.

Table 1 and Figure 1 present advised, agreed and actual catches of North-East Arctic cod in the period 1984-2004 as given by ICES. For some of the years ICES has advised on an upper limit of fishing mortality rate and we have calculated the corresponding TAC. The comparison (Fig.1) shows that since 1998 the TAC's decided on, have been much higher than the advised ones, and in most recent years the actual catches have also exceeded to a considerable extent the TAC's decided on by the authorities.

In Table 2 and Fig.2 are also shown comparisons of the main results (SSB, fishing mortality rate and recruitment) of the assessment carried out annually and those from the ICES' stock assessment in spring 2005. The figure 2 indicates that spawning stock biomass has been estimated "precisely" since 1998. It also appears that the gross underestimation of fishing mortality rate (and overestimation of SSB) in the annually estimated figures experienced in the mid 1980s and the period 1990-1997 has been absent since 1998, and there is a slight tendency to the opposite for 2000-2003. Apart for 2-3 years in the early 1990s recruitment figures seem to have been estimated with good precision (lower panel of Figure2).

Table 2. North-East Arctic cod: Advised, agreed and actual catch (thousand tonnes), and assessment results, both from annual assessments and from the 2005 assessment. SSB is the spawning stock biomass (thousand tonnes), F is fishing mortality and R3 is recruitment at age 3 (millions spec.)

Year	Catch (000 tonnes)			SSB (000 tonnes)		F 5-10		R3	
	Advised	Agreed	Actual	Annually	2005	Annually	2005	Annually	2005
1984	150	220	278	354	251	0.59	0.89	300	398
1985	170	220	308	407	193	0.62	0.8	677	524
1986	446	400	430	397	170	0.65	0.91	1000	1036
1987	645	560	518	275	118	0.96	1.01	443	286
1988	530	590	459	189	202	0.9	0.9	156	204
1989	335	300	351	151	194	0.67	0.72	175	173
1990	172	160	212	327	340	0.27	0.29	136	242
1991	215	215	319	680	674	0.19	0.34	227	412
1992	250	356	513	1047	869	0.39	0.44	642	721
1993	256	500	582	1024	737	0.43	0.55	808	896
1994	649	700	771	774	599	0.51	0.86	908	811
1995	681	700	740	570	499	0.58	0.79	717	655
1996	746	700	732	720	569	0.57	0.7	474	437
1997	993	850	766	694	564	0.79	1.04	763	717
1998	514	654	561	419	387	0.91	0.92	819	851
1999	360	480	485	266	256	0.96	1	585	599
2000	110	390	415	223	229	0.91	0.86	591	688
2001	263	395	427	298	334	0.84	0.71	462	542
2002	181	395	535	505	520	0.69	0.64	498	447
2003	305	395	552	643	585	0.46	0.5	502	502
2004	398	486	579	714	714	0.57	0.57	276	276

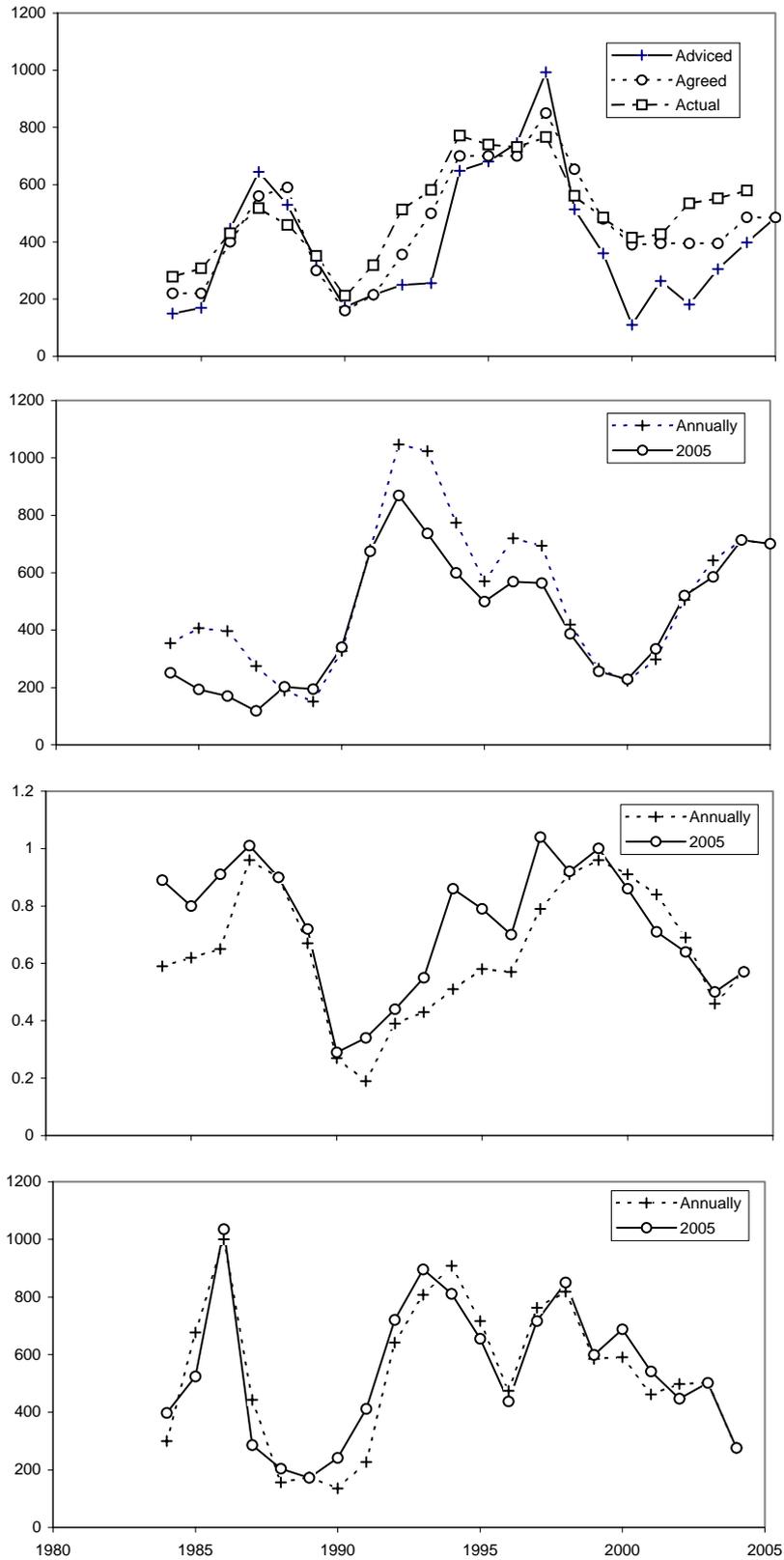


Figure 2. North-East Arctic cod. Panels from top: Catch (thousand tonnes), spawning stock biomass (thousand tonnes), fishing mortality, and recruitment at age 3 (millions spec.). Data as shown in Table 1

Statistical and political geography of the NEA cod's distribution range

There are several international and national schemes of division of the NEA cod's distribution range into areas, which directly or indirectly serve the purpose of management of biological resources, cod stock including.

For instance, the split into areas established by ICES aims at addressing a wide range of issues, such as catch statistics, assessment and distribution of stocks (Fig. 3A).

One of the reasons of establishing a system of economic, fishing and fish protection zones in the Barents Sea (Fig. 3B) in 1976 de jure and 1978 de facto was also a need for more effective management of stocks. All fishery regulations concerning fishing gears to be used, fishing seasons and areas, by-catch limits etc. are zone-specific or related to international agreements in force.

Russian trawl-acoustic and trawl surveys of stocks in the Barents Sea, cod including, use a map of fishing areas, which are in turn divided into rectangles of 10x10 n.miles² each (Fig. 3C). The same map is used for temporal closure of areas, when the by-catch of juveniles of commercial fishes on the trawl fishery of *Gadidae* and shrimp exceeds the established limit.

In Norwegian trawl-acoustic surveys of bottom fish a system of strata is applied (Fig.3D) and a system of statistical areas for harvest control.

This diversity of schemes, which serve to address a wide range of tasks, does not, at present, represent any impediment to accurate assessment of the cod stock. However, one of the steps towards deriving more accurate abundance indices by surveys could be establishing a unified scheme of division of the cod distribution area into strata.

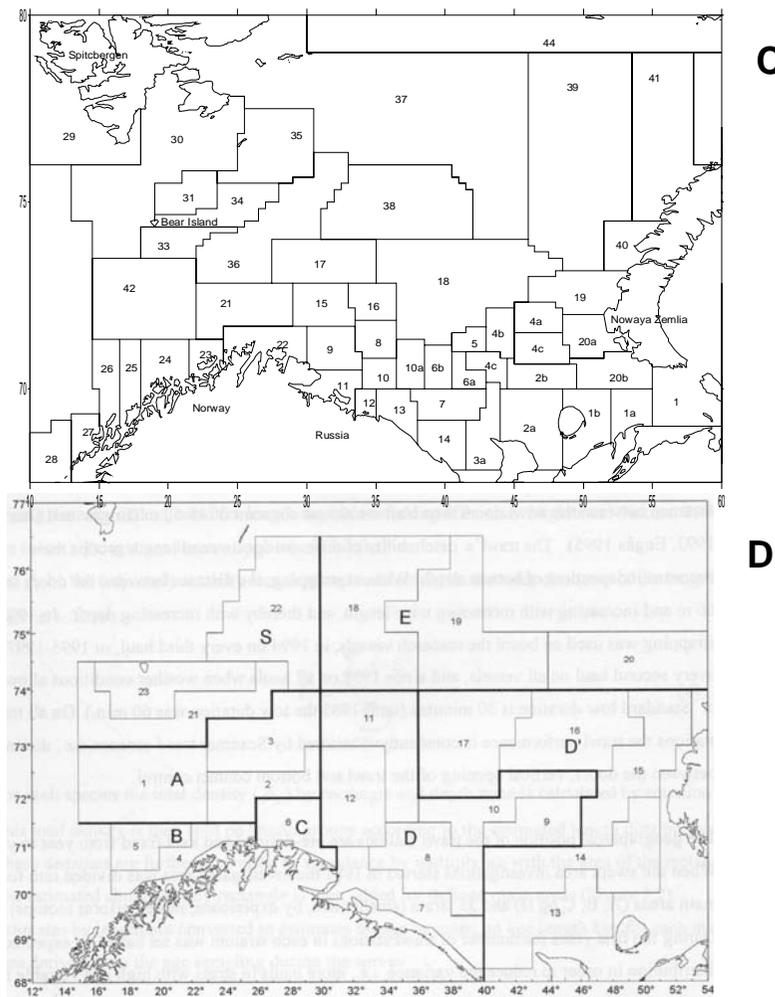
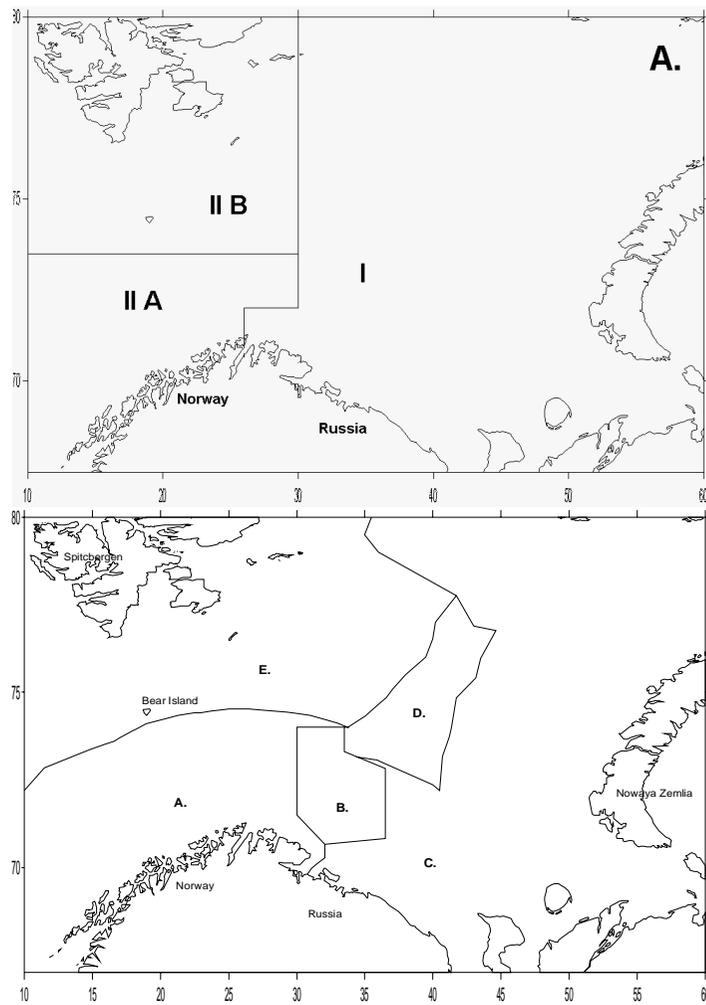
Future of management

Despite a fairly long history of research on the Northeast Arctic cod and its extensive scope many aspects of the biology of this species still remain inadequately studied. To fill the gaps it is, for instance, important to undertake a more thorough analysis of the spawning stock/recruitment relationship with the focus on the phenomenon of skipped spawning, sex composition of the parent stock etc.

In our view, the stock assessment should place higher emphasis on biological aspects of cod's life history.

Moreover, some political problems has to be solved, such as

- unification of fishery management rules within the margin of cod area
- getting of reliable fishery statistics.



B

C

D

Fig.3. International and national division of the NEA cod distribution range into areas (A – ICES areas; B – Economic and fishing zones; C – Russian fishery areas; D – Norwegian strata and main areas)

Legend to fig 3:

Fig.3C. The Russian fishery areas (Trudy PINRO, vyp. 10, 1957).

Eastern areas (1; 1a; 1b; 2a; 2b; 3a; 3b; 20b).

Central areas (4a; 4b; 4c; 5; 6a; 6b; 7; 18; 19; 20a).

Coastal areas (12; 13; 14).

Western areas (8; 9; 10a; 10b; 11; 15; 16; 17; 21; 22).

Norwegian coast (23; 24; 25; 26; 27; 28).

Northwestern areas (29; 30; 31; 32; 33; 34; 35; 36; 37; 38; 42).

Northeastern areas (39; 40; 41).

Fig.3B. Economic and fishing zones in the Barents and Norwegian Seas

A. Exclusive Economic Zone of Norway;

B. Area of joint fisheries between Russia and Norway;

C. Exclusive Economic Zone of Russian Federation;

D. Area outside Economic Zones of Russia and Norway (Enclave);

E. Bear Island – Spitsbergen area.

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THE USE OF B_{PA} REFERENCE POINT WHEN DETERMINING TAC FOR THE NEA COD: HOW VALID IS IT?

by

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Abstract

Management of fishery using TAC constraint is intended to maintain such number of spawners (usually the term “spawning stock biomass (SSB)” is used), which would provide the stability, and preferably an increase, in the stock reproduction. In compliance with the precautionary approach (PA), considerable research efforts are made to determine the optimum level of $SSB = B_{pa}$, which supposedly can reduce to a minimum the risk of poor recruitment (R) when $SSB \geq B_{pa}$. It implies the presence of the required direct or curvilinear positive relationship between SSB and R that does not contradict the logic. However, in fact, many numerous highly fecund species, to which the NEA cod belongs undoubtedly, do not show such a relationship. Apparently, in such species, recruitment depends on survival conditions at their early life stages rather than on quantity of eggs spawned. Therefore, with regard to each fishable population, before assessing the B_{pa} level it is necessary to evaluate contribution of SSB to R compared to that of the other factors. As for the NEA cod, the variance analysis showed that the effect of SSB on the number of survivors at age 3 is limited to the range of 4,3 to 14,7% (the significant estimate is 7,5 %). In our opinion, since the contribution of SSB to R is quite low, it makes no practical sense to establish B_{pa} , which can be just of theoretical interest. The primary emphasis should be placed on identification and prognosis of those environmental factors, on which survival of eggs, larvae and juveniles depends first and foremost.

Introduction

Scientific advice on the annual establishment of the Total Allowable Catch (TAC) for commercial fish populations is the most widespread sort of advice in the international practice of fisheries management. It is quite reasonable in the aspect of efficient fisheries, because the TAC limitation that takes into account the current status of the population helps to preclude both growth (biomass) overfishing, and recruitment overfishing.

The latter consideration (i.e. prevention of recruitment overfishing) is of particular importance because it is aimed at limiting catches of mature fish. Abundance of fish that escaped from previous fishing and is engaged in reproduction of potential spawners is usually associated with succeeding recruitment (R), e.g. which is to occur in 2, 3, or 4 years. It is expected that today's restrictions on catches will ensure recruitment increase in the nearest future.

Therefore for each relatively valuable fishery species, experts calculate spawning stock biomass (SSB) levels that are supposed to ensure success in reproduction (Serebryakov, 1990; Jakobsen, 1992; O'Boyle, 1993; Bondarenko et al., 2003). In accordance with the

precautionary approach (pa) concept, considerable research efforts are taken to identify or specify an optimal level of $SSB = B_{pa}$ to minimize risks of a poor recruitment.

There are no doubts about the biological validity of such an approach to fisheries management when we speak about species whose retrospective study confirms a connection between the spawning stock and the produced number of recruits to the fish stock. Conversely, other species do not reveal such connections and their recruitment seems to be determined by survival rates at the pre-recruitment stage rather than the original abundance of produced eggs.

We consider it inappropriate to determine B_{pa} for such populations. No matter how precautionary it is there will always be a risk that Nature may dispose of the yield of our conserved spawning stock. This raises doubts about propriety of establishing lower TACs mainly or only in order to maintain $SSB \geq B_{pa}$ as well as propriety of use the B_{pa} reference point to set up TACs.

Therefore it would be reasonable to check the SSB effect on the R formation against other relevant factors prior to determination of the fish population B_{pa} level and use the latter for TAC setting. This approach has already been taken to the north-eastern arctic cod stocks on the basis of dispersion analysis (Borisov et al., 2004). The results convince us that such studies should be expanded and intensified. Here we have systemized additional information on this issue.

Materials and Methods

The main source of the original data is reports of the ICES AFWG containing assessments of the cod annual spawning stock biomass since 1946 and abundance of year-classes that survived till the age of 3 (N_3) in each spawning stock (Anon., 2005). Correspondence between these indicators for both the entire data array (56 sets of $SSB-N_3$) and individual data groups was assessed by the correlation coefficient.

In order to identify the percentage of year-classes which abundance corresponded to small-sized, medium-sized, large-sized, and very large-sized spawning stock, (<300,000 tons; 300,000-600,000 tons; 600,000-900,000 tons; and >900,000 tons, respectively), the N_3 values were classified into four traditional groups (Boytsov et al., 2003): poor, medium, rich, and very rich year-classes (<300,000,000 ind.; 300,000,000-500,000,000 ind.; 500,000,000-900,000,000 ind.; and >900,000,000 ind., respectively). Figure 1 presents a diagram of this correspondence.

The spawning stock influence on abundance of the progeny is traced through five stages of the year-class formation (Figs. 2 and 3) with the help of: the estimated number of produced eggs or population fecundity (PF); the abundance indices for pelagic juveniles (Pel.j.) and young fish at the demersal stage, i.e. fish at the age of 0+, 1+, and 2+ (Borisov et al., 2001; Sokolov et al., 2004).

A single-factor dispersion analysis of the N_3 dependence on SSB was done with several variations (namely, 6 variations) because the results were influenced by the scope and number of the SSB groups (Table 1).

Practical advice on the commercial cod stock conservation and maintenance at a relatively high level takes into account the yearly average individual increase in weight and the average survival ratio for each age group. The original data are taken from the ICES AFWG reports (Anon., 2005); the indicators were averaged for the last ten year-classes (Fig. 5). The author thanks Dr. Tretyak (PINRO) for his help with the data fitting and extrapolation in this study.

Results

Study of correspondence between the cod spawning stock biomass and the respective recruitment-stock abundance revealed a virtual absence of such correspondence. The correlation coefficient calculated for 56 sets of SSB- N_3 data appeared statistically insignificant (0.23). An objection could be made that a small value of the total correlation coefficient was associated with implicit curvilinear relationship between these indicators with substitution of the positive correspondence (for some SSB values) for the negative one (for other SSB values).

For the sake of study, the entire range of the SSB values was divided into 2, 3, 4, 5, and 6 groups with respective sets of the N_3 data. Then individual correlation coefficients were calculated for each group (Table 1). Our results indicated that the SSB values of <250,000 tons and < 200, 000 tons were the only groups which correlation coefficients were significant (0.44 and 0.46, respectively, at the significance level of 0.05). The rest of the groups did not reveal any significant correspondence.

Even this simple analysis throws doubt on the claim that conservation of a large spawning stock through the TAC limitations would definitely bring about growth in the population. At least the statistics does not confirm that. Generally, however, it is a priori thought that a larger spawning stock has more chances to produce an abundant recruitment than a smaller one which often produces poor year-classes.

Studying correspondence between the number of three-year-old cods and various levels of the spawning stock biomass, we divided the SSB- N_3 coordinate field with 56 points into 16 squares (Fig. 1) in accordance with the classification described in *Materials and Methods*.

The picture shows that only one third of all year-classes comes into the zone of correspondence, while two thirds (37 out of 56 sets) lack correspondence between the number of three-year-old cods and the brood stock biomass. Out of 26 year-classes produced by a small-sized spawning stock (<300,000 tons): ten generations (38.4%) were rich and very rich, five generations (19.2%) were medium, and less than half the year-classes (42.4%) were poor and corresponded to a low SSB.

The medium SSB group showed still less correspondence between the number of three-year-old cods and the level of the brood stock biomass. Out of 22 year-classes produced only five generations (22.7%) were "medium". The medium SSB was most preferable for production of rich year-classes; they almost attained 59% in this range of the SSB values. The following SSB ranges, large-sized and very large-sized spawning stocks, did not show any obvious relationship with the recruit number. Only three out of eight year-classes came into the zone of correspondence. Figure 1 also illustrates the fact that five out of nine most abundant year-

classes ($>900 \times 10^6$ ind.), i.e. more than a half, were produced by the spawning stock that did not exceed 230,000 tons.

The presented attempts to find correspondence between the cod spawning stock and recruitment persuaded us of its absence rather than presence. However, it is hardly possible that SSB does not influence abundance of a year-class and, consequently, a number of three-year-old cods entering exploited stock. The question is how important will this influence be, compared to other factors?

A single-factor dispersion analysis allows us to assess a degree of the SSB effect on recruitment (Table 1). Because of sensitivity of the method not only to the number of groups differentiated in the data array, but also to the scope of individual groups, there were six variants of calculations. Only one of these calculations was statistically significant; the SSB values were divided into two groups ($<600,000$ tons and $> 600,000$ tons). The SSB effect on the recruitment formation made 7.55%.

Though the rest of the variants were insignificant and the SSB effect varied from 4.34% to 14.7%, we did not discard them. Taking into account the reservation made, we have to note that in the case of cod stocks the effect of spawners' biomass on formation of recruitment is not likely to exceed 10 %; the rest and, consequently the major driving force in recruitment formation belongs to a set of other factors which have no direct relations with abundance/biomass of the spawning cod. Let us leave identification of the actual causes that directly influence the young cod survival at the pre-recruitment stage beyond the scope of our discussion and concentrate our attention of the following.

The period from production of eggs till entrance of survived recruits into the commercial cod stock lasts three years at the least. During this period there occurs a significant "correction" of the year-class abundance that breaks the inherent relation with the spawning stock. A series of curves could answer this question (Figs. 2 and 3).

There could be no doubts that abundance of produced eggs depends on the spawning stock (Fig. 2a) not only because the PF calculations are based on SSB (i.e. on the number of females in each age group and their mean individual fecundity determined for the respective age group). The relation is objectively true because the higher SSB we observe, the more mature females will come to spawning grounds, and the more eggs will be produced.

Contrary to the conventional view that this relation is broken during the "critical period", i.e. at the stage when the yolk sac resolves and the larva transits to self-feeding (Hjort, 1926; Ellertsen et al., 1977; Last, 1978), the major correction of generation abundance seems to occur somewhat later. It is proved by a rather good agreement ($r = 0.8$) of the relative abundance of pelagic juveniles with the biomass of the respective spawning stock (Fig. 2b). The autumn-winter survey of demersal juveniles, however, showed that at the succeeding stage, abundance indices for young fish at the demersal stage did not correspond to SSB ($r = 0.08$; Fig. 3a). Naturally, there was no correspondence between SSB and the respective generations at the age of 1+ and 2+ (Figs. 3b and 3c). Here we should note that observations made during the autumn-winter survey were rather objective. It is indicated by a quite satisfactory synchronism in dynamics of juveniles from the same year-classes observed at different age (Fig. 4).

Comparison of abundance indices for various age groups of young cod with SSB rather definitely indicates the most vulnerable period in recruitment formation which occurs at the beginning of the juveniles' transition to the bottom life stage. Apparently, marine biology forecasters should pay attention to this stage of the cod life cycle and identify major factors causing massive elimination of demersal young cod at the age of 1+. To be more exact, we should use our modern technical and research capacity to continue studies which were actively carried out by our predecessors in the 1960s – 1980s.

The evidence presented supports our conviction about uncertainty of measures aimed at conserving some "indispensable" number of cod spawners today in order to provide a high level of the fish stock in three or four years. This approach should be treated as theoretical rather than applied.

The aim of the fish stock increase could be achieved through a more straight and efficient approach, i.e. introducing conservation measures for young fish which survived to the age of 2, 3, or 4 despite unfavorable habitat conditions. This age group contains relatively strong fish able to survive temporary food deficit and other poor conditions. At this age survival of the juveniles depends on frequency of their interactions with larger-sized cods, i.e. on cannibalism rates. Apropos the strategy of sustaining a high SSB brings about increase in cannibalism rates.

Another important cause of decline in number of the young fish and consequently the potential commercial stock is associated with practices of bycatch and discards (Dingsor, 2001; Sokolov and Tretyak, 2001).

According to Sokolov's studies (2003), annual discards of juveniles of non-target species or undersized fish often attained 15-20,000,000 individuals. We have attempted to assess effect of such discards on the total commercial stock for 13 years of a year-class participation in the fishery (Table 2). The assessment was performed with averaged weights and survival coefficients arranged by the cod age-groups (Fig. 5). An example of one generation with the initial number of two-year-old fish totaling 500,000,000 individuals shows a significant effect of the survival coefficient (S) for three-, four-, and five-year-old cods that grew from 0,657, 0,655, and 0,547 to 0.7, 0.7 and 0.6, respectively. Here the assumed S increase approximately totals 20, 15, and 10 mln. cods respectively. This is close to estimated discards for these age groups. We can see that decrease in discards of these age groups only by 0.043 – 0.053 will increase the total biomass of all age groups in the commercial stock by more than 200,000 tons. If targeted conservation of young fish, including measures to decrease bycatch and discards, allow us to increase the survival coefficients for three-, four-, and five-year-old fish by 0.8; 0.8 and 0.7, respectively, the long-term total biomass of the commercial stock with the same initial abundance could be larger by 745,000 tons (Table 2).

Such strategy for the commercial stock increasing seems quite feasible. It is more realistic and effective than measures aimed at obligatory maintaining $SSB \geq B_{pa}$.

Discussion

As it was shown in Figure 2, the B_{pa} strategy applied to cod stocks can sustain only population fecundity and abundance of pelagic juveniles. As for recruitment abundance, this measure is inefficient. Therefore it is inevitable that we doubt validity and expedience of the B_{pa} use to establish TACs. We believe that the B_{pa} importance as a biological reference point in fisheries management is also precarious. Unlike the parent indicator of B_{lim} , it is a statistical rather than biological indicator. While B_{lim} has actually got some biological meaning indicating the lowest safe SSB inherent to the given population, B_{pa} is only the upper statistically determined bound with the confidence coefficient of 95%: $B_{pa} = B_{lim} \exp(1.645 s)$. However, the B_{pa} reference point is often considered a biologically sound optimal level of SSB which is almost mandatory for TAC establishment though the objective could be achieved through other ways.

Development of traditional production models (Schaefer, 1954; Fox, 1970; Shepherd, 1982) to forecast annual growth in biomass and yield seems more promising and biologically sound. At least, we could, with reason, regard the model annual growth of production (including increase, decrease, and variation forecasts for these indicators) as a true biological reference point to be used to establish TACs.

For the same purpose we could discuss the following scheme (Fig. 6) where SSB is only a part to the entire commercial stock rather than the major reference point for TAC assessment. Necessity of this forecast element is very doubtful. This is true not only for cod stocks, but also for many other abundant and highly fecund species with the population yield depending rather on survival conditions at early ontogenesis than on the initial egg production, i.e. the spawning stock biomass.

The presented scheme includes all traditionally measured principal features of the stock and the respective fishery output as well as analysis and forecast of factors determining state of the former and the latter. Special attention is given to studies of period and factors which play a key role in recruitment formation. The only novelty in the scheme is a special accent on attaining correspondence between annual relative variations in catches ($\Delta C\%$) and stock ($\Delta S\%$). The TAC for the next year is increased/decreased against previous years by the same percentage as the forecasted increase/decrease in the commercial stock.

On the other hand, correspondence between $\Delta C\%$ and $\Delta S\%$ should not be regarded as a dogma (compare: once determined precautionary reference point of the fishing mortality (F_{pa}) that is used for ages). On the eve and in years of positive trends in the stock development a reasonable excess of $\Delta C\%$ over $\Delta S\%$ could be possible, whereas in the case of negative forecasts $\Delta C\%$ should be decreased against $\Delta S\%$. In both cases, fisheries is a damper that helps maintain the stock at a relatively stable level.

The scheme allows us to implement a more sound approach at which stocks are not managed through fisheries, but current and forecast fluctuations of the stock make the fisheries change to fit them. Despite high ambitions of managers who claim that they manage fish stocks, this kind of management is at best an attempt to mitigate adverse anthropogenic impact which cannot be regarded as management of fish stocks. On the other hand, people are able and ought to manage fisheries in such a manner that negative anthropogenic impacts on fish

stocks would inevitably be minimized and fisheries ultimately would not interfere with natural reproduction.

Concerning commercial stocks, it is realistic and extremely important for us to follow the principle, "no harm done". While the global task of fish stock management has always been and will remain within the scope of Nature.

Conclusion

The performed analysis shows that common use of the B_{pa} reference point to set up TACs is not always reasonable. At least in the case of species with R dependent on survival conditions for pre-fishery juveniles rather than SSB, this indicator cannot be regarded as properly biologically based. Therefore it would be reasonable to check the SSB effect on the R formation prior to determination of B_{pa} and use it for TAC setting.

According to statistics, the SSB effect on the R formation in cod stocks made 7.55%. The rest and, consequently the major driving force in recruitment formation belongs to a set of other factors.

Presence of relation between SSB and abundance indices for pelagic juveniles (the summer survey) and absence of such relation in the case of demersal young fish (the autumn-winter survey) support conclusions that young cod is most vulnerable at the onset of the first wintering and transition to the bottom life stage. The reasons for such changes need further detailed studies.

Cautious attitude towards young fish, including a ban on trawl fishing in areas of its highest concentrations and decrease of discards of undersized fish, should be considered a principal source of the commercial stock growth.

As to species with significant natural fluctuations in recruitment that are not connected with SSB, it is preferably to set TACs taking the "achieved level" as a start-point. The achieved level of catches is adjusted for the forecast year in accordance with the estimated growth/decrease in the stock. However, the degree of such accordance should account for annual and also much longer trends in the stock development.

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**Table 1. Estimation of the SSB role in forming of the cod recruitment (N₃)
(data of one way variance analysis)**

SSB groups	Correl. coef. by groups (r)	Generations in group (n)	Sum of deviations' square			SSB role for N ₃ SSa/SSx100%	Average sums of		Fisher's calculat. criterion (Fc)	Fisher's standart criterion (Fs)
			between groups (SSa)	inside groups (SSe)	total (SS)		mSa	mSe		
< 600 > 600	0.13 -0.37	47 9	598553	7331635	7930188	7.55	598553.4	138332.7	4.32691*	4.02301
< 400 401-800 > 800	0.16 0.31 -0.17	39 13 4	361173	7569015	7930188	4.55	180586.6	145558.0	1.24065	3.17515
< 250 251-500 501-750 > 750	0.44 0.24 0.32 -0.17	23 20 9 4	343837	7586351	7930188	4.34	114612.3	148752.0	0.77049	2.78623
< 300 301-600 601-900 > 900	0.32 -0.03 -0.42 -0.73	26 21 6 3	665753	7264435	7930188	8.40	221917.5	142439.9	1.55797	2.78623
< 250 251-500 501-750 751-1000 > 1000	0.44 0.24 0.32 - -0.73	23 20 9 1 3	350802	7579386	7930188	4.42	87700.5	151587.7	0.57855	2.55718
< 200 201-400 401-600 601-800 801-1000 > 1000 Common	0.46 -0.29 -0.01 -0.35 - -0.73 0.23	16 23 8 5 1 3 56	1166624	6763564	7930188	14.71	233324.8	138031.9	1.69037	2.40438

Comments: SSa - factor mutability (for studied factor); SSe - variate mutability;
 SS - total mutability; mSa - deviation of group averages of studied factor;
 mSe - deviation of group averages of nonstudied factors; Fc = mSa/mSe; Fs for P=0.95;
 blue figures are statistically significant;
 * - Fc>Fs indicates the confidence of the effect of the factor considered

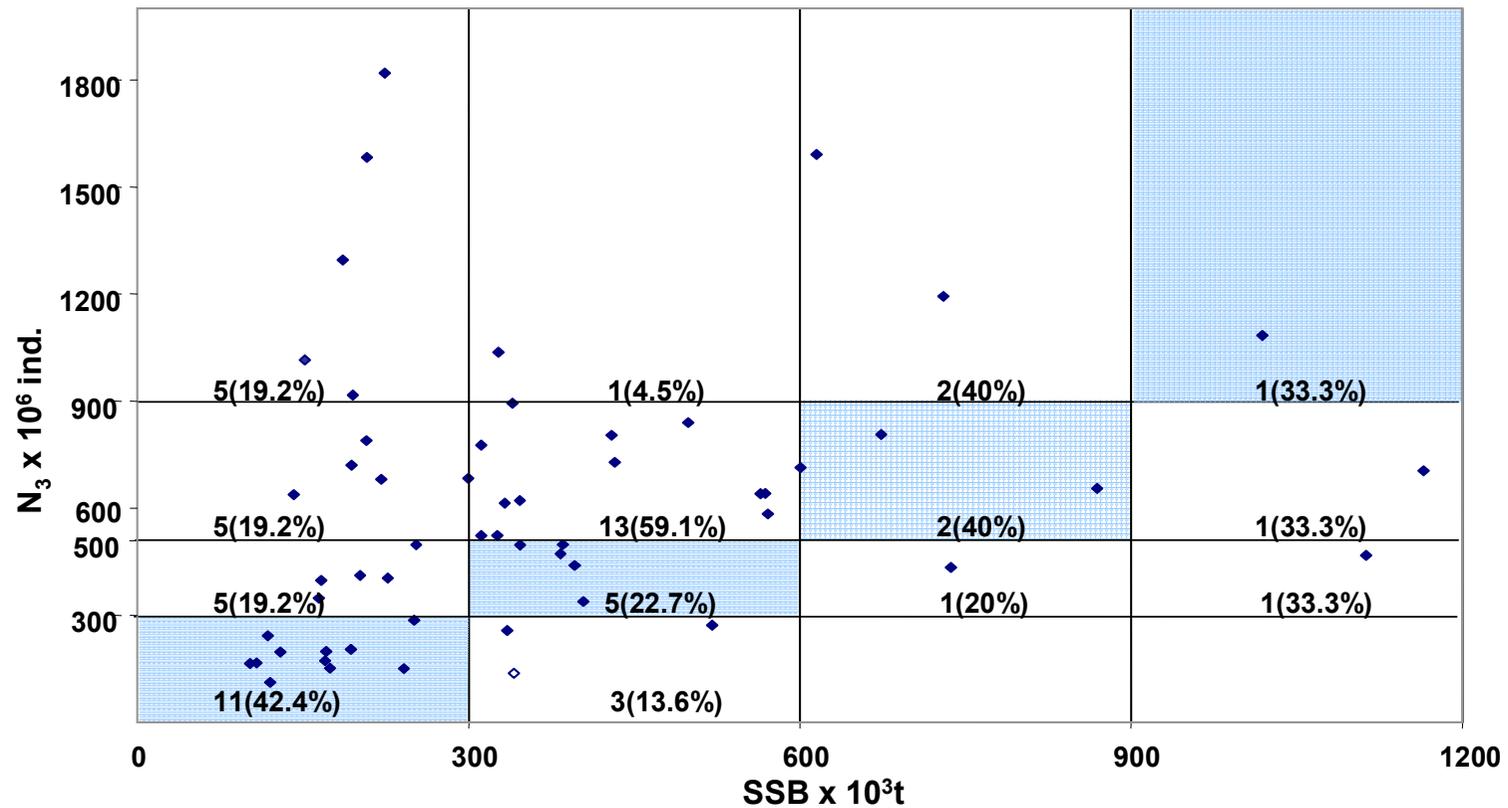


Fig. 1. Strength of the year-classes (N_3) born from different SSB levels. *Figures in the rectangles point quantity /percentage of the year-classes by N_3 groups in every SSB range. Shaded rectangles show the zone of correspondence among N_3 and SSB range.*

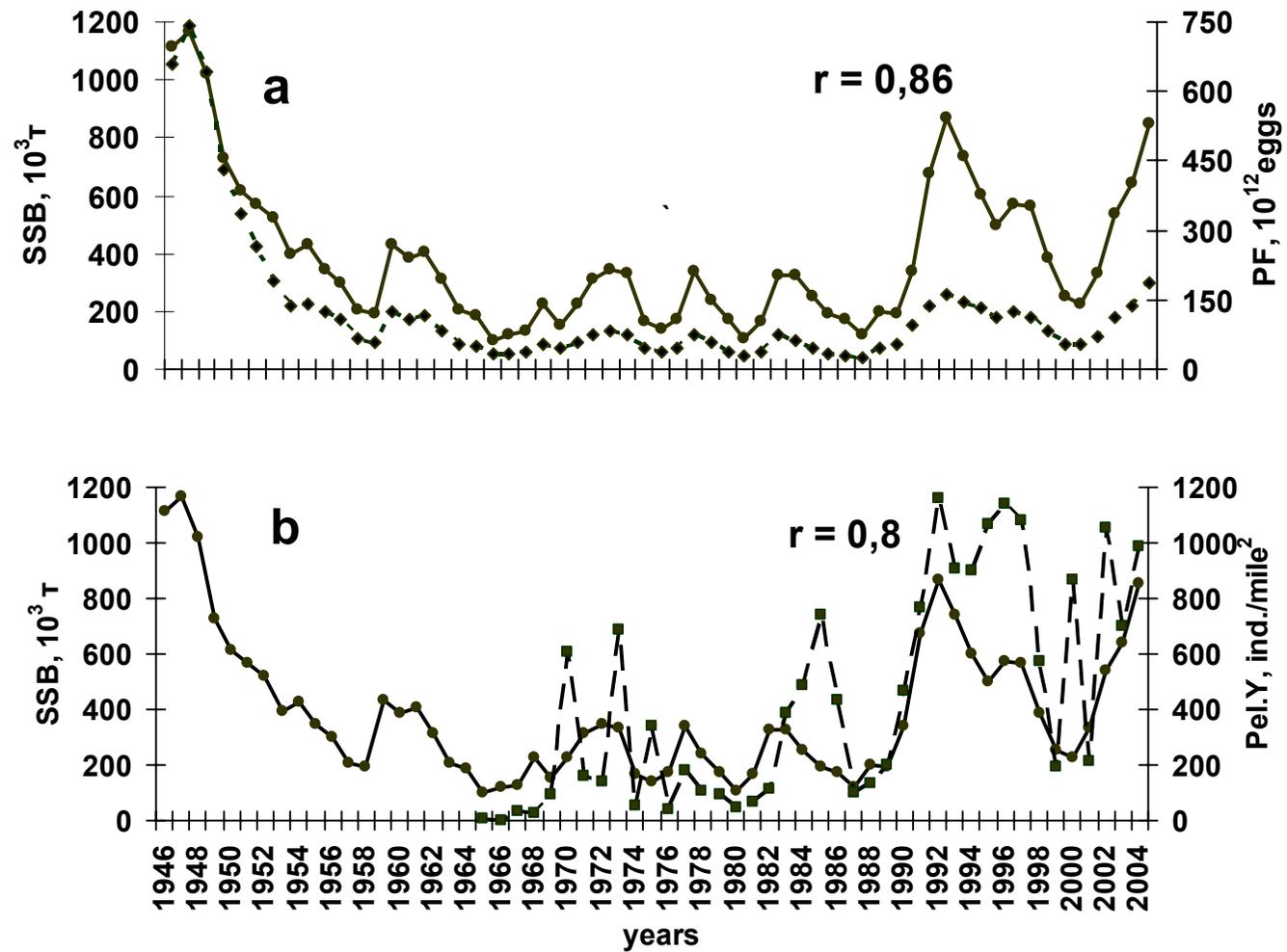


Fig.2. NEAcod. Spawning stock biomass (SSB), population fecandity (PF) and pelagic young (Pel.Y.) (-●- SSB; - -◆- - PF; -■- Pel.Y.)

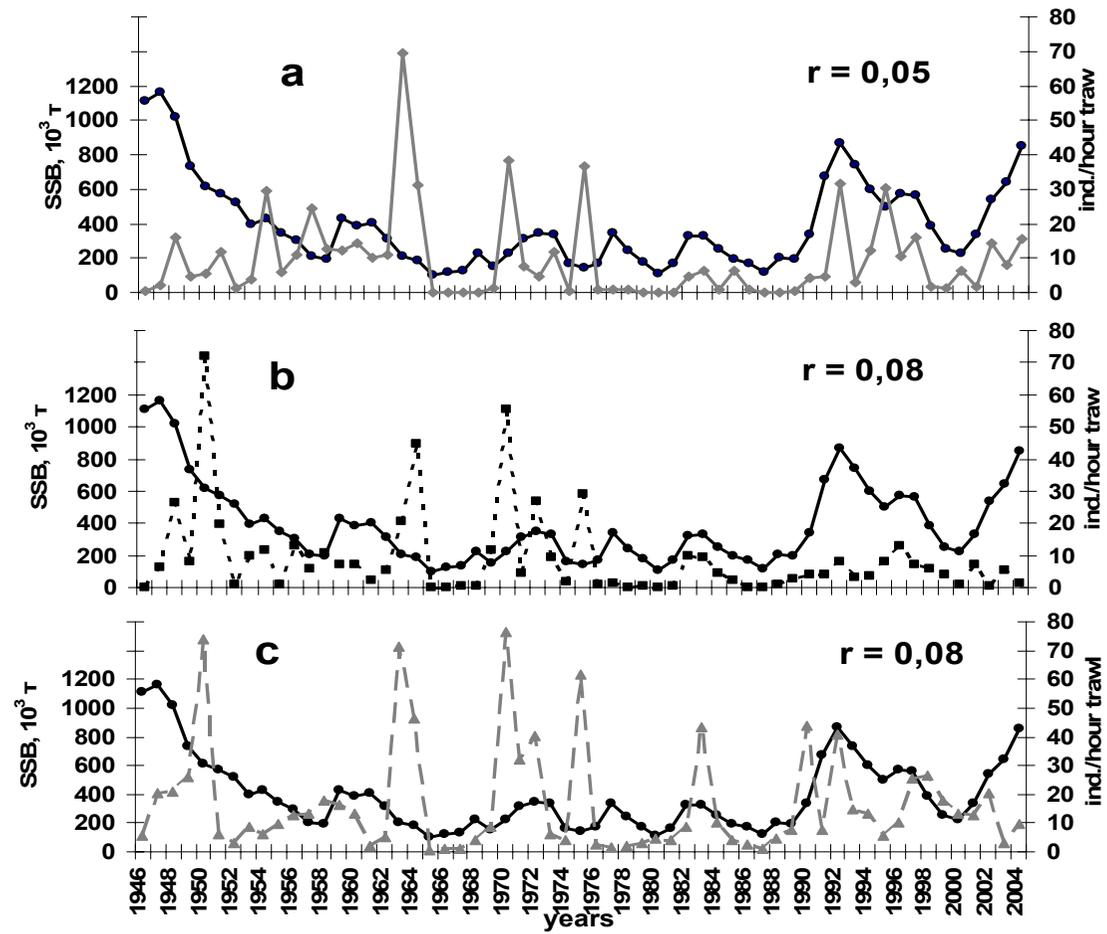


Fig.3. NEAcod. Spawning stock biomass and relative abundance of the benthonic young of age "0+"(-◆-); "1+"(-■-); "2+"(-▲-)

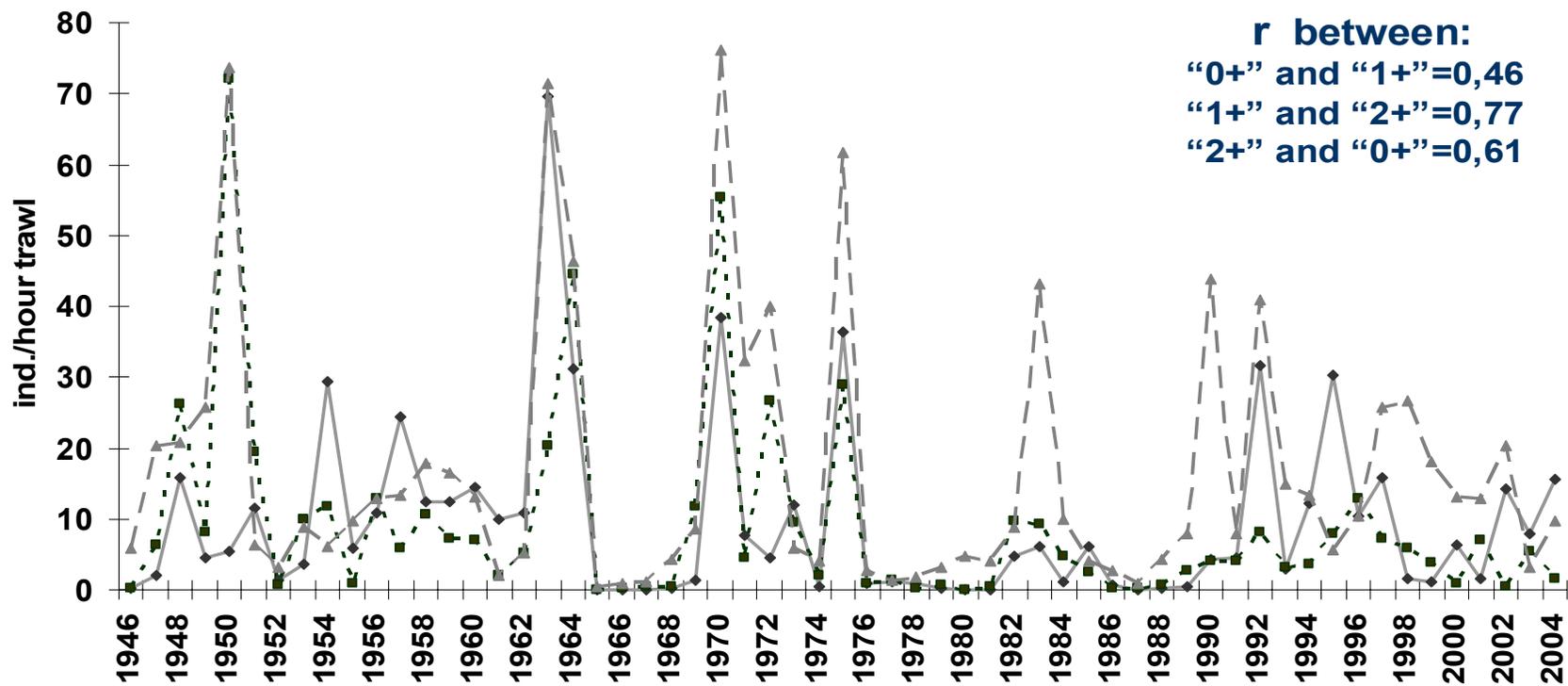


Fig.4. NEAcod. Relationship between relative abundance of the benthonic young at age "0+"(-◆-); "1+"(- ■ - -); "2+"(-▲-)

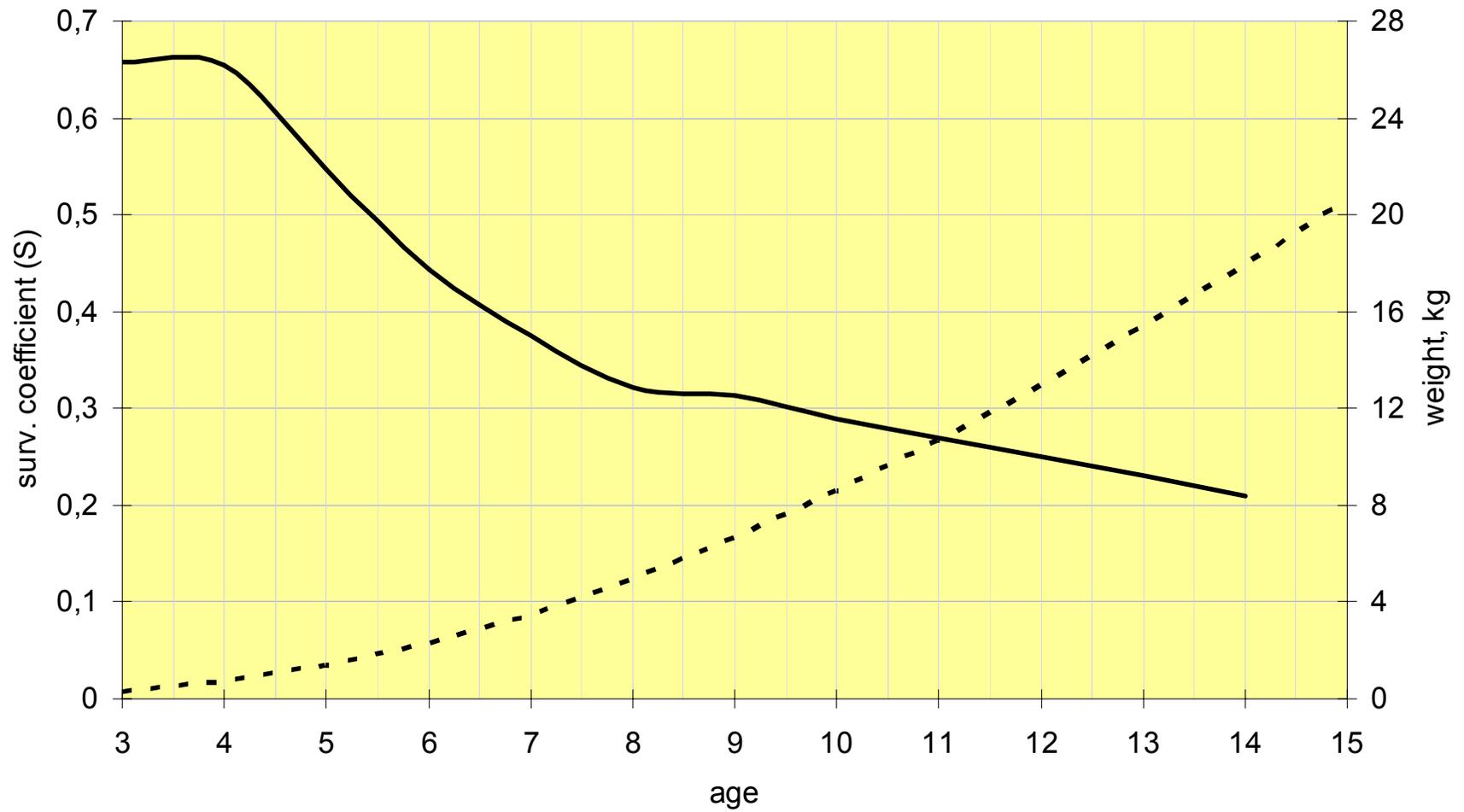


Fig.5. NEAcod. Survival coefficients (—) and weights (- -) at age 3-15

Table 2. Change in the fishing stock biomass (FSB) at different survival levels in 3-5-age cod

Age	Weight, kg	S₁	N₁ · 10³ ind.	FSB₁ 10³t	S₂	N₂ · 10³ ind.	FSB₂ 10³t	S₃	N₃ · 10³ ind.	FSB₃ 10³t
3	0.27	0.657	500000	135000	0.700	500000	135000	0.800	500000	135000
4	0.69	0.655	328500	226665	0.700	350000	241500	0.800	400000	276000
5	1.35	0.547	215167	290475	0.600	245000	330750	0.700	320000	432000
6	2.28	0.443	117700	268356	0.443	147000	335160	0.443	224000	510720
7	3.47	0.375	52140	180926	0.375	65121	225970	0.375	99232	344335
8	4.93	0.321	19552	96391	0.321	24420	120391	0.321	37212	183455
9	6.63	0.314	6276	41610	0.314	7839	51973	0.314	11945	79195
10	8.55	0.289	1971	16852	0.289	2461	21041	0.289	3751	32071
11	10.67	0.270	569	6071	0.270	711	7586	0.270	1084	11566
12	12.96	0.250	154	1996	0.250	192	2488	0.250	293	3797
13	15.39	0.230	38	585	0.230	48	765	0.230	73	1123
14	17.95	0.210	9	161	0.210	11	197	0.210	17	305
15	20.59		2	41		2	41		3	62
Sums FSB_i				1265			1473			2010
Difference between sums: FSB₂-FSB₁=208000 t FSB₃-FSB₂=537000 t FSB₃-FSB₁=745000 t										

MAIN ELEMENTS OF TAC

Analysis of previous and current status of the stock:
*assessment of fishing stocks (S),
relative interannual changes ($\Delta S\%$);
Influence of S on recruitment (R_s), growth (W_s), natural mortality (M_s)*

Analysis of previous and current status of fisheries:
*catches (C), relative interannual changes ($\Delta C\%$);
assessment of CPUE, F, correspondence of $\Delta C\%$ with $\Delta S\%$, influence of C on S*

Forecast $S_{i+1} = S - C - M_s + R_s + W_s$,
*where R_s prognosis is based on surveys of young fish and assessment of conditions
of its survival on the stages from eggs to R_s ; M_s includes cannibalism,
discards, and other accountable losses of S*

Assessment of $\Delta S_{i+1}\%$ *based on $S - S_{i+1}$*

Choice of reasonable $\Delta C_{i+1}\%$
*based on $\Delta S_{i+1}\%$, tendencies in S and CPUE assessments, and consideration
of W_s and M_s trends*

Setting of TAC_{i+1}
based on ΔS_i and chosen $\Delta C_{i+1}\%$

RETROSPECTIVE ANALYSES, IMPROVEMENT OF ASSESSMENT AND PREDICTION METHODS FOR THE NORTH-EAST ARCTIC HADDOCK STOCK

by

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Abstract

North-East Arctic haddock – given of methods used for stock assessment and prediction of haddock and an attempt is made to improve these methods by using alternative software and investigating part of the uncertainty in stock assessment and projection of haddock.

For uncertainty investigations (deviations in estimates of parameters) in stock assessment and projection, i.e. observation errors given a particular model specification, an ADAPT model is set up in Excel, similar to the one described by Gavaris (1988).

The retrospective estimates and forecasts of spawning stock biomass (SSB), recruitment (numbers of fish at age 3) at start of 1980-2007 and associated fishing mortality (F) in previous years from xADAPT and obtained by AFWG versus XSA estimates are slightly different for period 2001-2007. However, working group estimates lies within the bootstrap error distribution.

Terminal year estimates of SSB and F obtained by xADAPT model lie outside the limit reference points with high estimated probability, but the given model allows only part of the total uncertainty. The prototype of the used algorithm, program ADAPT, can be applied as an alternate approach for the estimation of population dynamics of haddock at AFWG.

Introduction

North-East Arctic Haddock (*Melanogrammus aeglefinus* Linne.) – the second main commercial species (after North-East Arctic cod) in the Barents Sea. Since 1960 the total annual catch of this species was ranged from 17 to 322 thou. t. In recent years Norway and Russia have accounted for more than 90% of the landings and total catches was about 100 thou. t. Fishery takes approximately 30 % of stock. The dynamics of haddock stocks are defined by productivity of its generations, which can differ considerably in number. The tendency of an increase in number of haddock was outlined in 2001-2004, due to the introduction of some strong yearclasses.

The divisions of ICES – Arctic Fisheries Working Group (AFWG) and Arctic Committee of Fisheries Management (ACFM) assess the haddock stock annually and give advises to decision makers – Joint Russian-Norwegian Fishery Commission (JRNFC). At present the ICES takes account of the uncertainty in assessment by making advice in relation to defined reference points. In principle ICES has defined B_{lim} as level of SSB which produces only poor

recruitment, has been observed from 4 years of $SSB < 50\,000\text{ t}$, and B_{pa} – as level of SSB which produces good recruitment with 95% probability. Corresponding values of F set as fishing mortality reference points.

The distance between B_{pa} and B_{lim} and F_{pa} and F_{lim} are 30 thou. t and 0.14 accordingly. Thus point estimates of SSB and fishing mortality are evaluated and advice is given in relation to pa -reference points. This is considered to ensure, given the uncertainty, that the advised fishing mortality and resulting spawning stock biomass do not exceed the limit points.

But point estimates vary depending on data series used in assessment and model assumptions: tuning fleet's data series used as well as assumptions in the model configurations (F shrinkage and assumption about the relationship between survey indices and stock size (type of model)). E.g. changing from moderate (default) shrinkage ($SE=0.5$) to low shrinkage ($SE=1.5$) changes the perception of the 2003 SSB from 104 454 to 120 947 (16% increase) (Anon. 2004).

In this case it is necessary to investigate differences between reference points, because if possible variation in estimates is higher than that interval stock needs more detail analysis.

There are several categories of uncertainty in fish science: natural variation, observation errors in input data, model misspecification, uncertainty in transaction scientific advice into management, imperfect implementation of management strategies and others (Mace and Sissenwine, 2002). Current project aims at investigating a part of the uncertainty, i.e. observation errors given a particular model specification.

The AFWG states (Anon., 2004a) that the uncertainty may be underestimated and that difference between B_{lim} and B_{pa} may be too small. In this project an attempt will be made to investigate at least part of the uncertainty in the assessment by the use of bootstrap techniques. The overall objective is to investigate if current assessment and prediction procedures can be improved. Such improvements are expected to be incorporated in AFWG assessments in the future and hopefully improve the scientific advice for North-East Arctic haddock.

Data collection and current assessment and prediction methods for providing annual advice

This section provides short information about the previous and current data collection and assessment methods used by the AFWG.

Haddock are harvested throughout the year. In years when the commercial stock is low they are mostly caught as bycatch in cod trawl fishery. When the commercial stock abundance and biomass are high haddock is targeted directly by a specific fishery.

Bottom trawling accounts for approximately 75% of the catches on average. Conventional gears, mostly longline, used almost exclusively by Norway accounts for most of the rest of the catch. Part of the longline catches are from a directed fishery. National quotas from 1976 have restricted the fishery.

Data collection from commercial catches started from late 40s, but it was episodically observations, mostly land-based measurements of catches. As the regulation of the haddock

stock was based on an assessment of the stock, more representative data were collected from the early 1980s. The current schedule sampling is described in detail in the Quality handbook for Standard Procedure for Assessment and available on ICES website (Anon., 2004b).

Table 1. Information from commercial catches different countries of NEA haddock used by AFWG in stock assessment

Country	Kind of data				
	Caton (catch in weight)	Canum (catch at age in numbers)	Weca (weight at age in the catch)	Matprop (proportion mature by age)	Length composition in catch
Norway	x	x	x		x
Russia	x	x	x	x	x
Germany	x	x	x		x
United Kingdom	x				
France	x				
Spain	x				
Portugal	x				
Ireland	x				
Greenland	x				
Faroes	x				

Annually, Russian scientists make length measurements and take age samples from catches onboard commercial vessels. Data on length distribution of haddock in catches are collected in areas of cod and haddock fishery by a "standard" fishery trawl (mesh size is 125 mm in the Russian Economic zone and Spitzbergen area and 135 mm in the Norwegian Economic zone) and summarized by three ICES sub-areas (I, Ila and I Ib). Previously the PINRO area divisions were used, differed from the ICES sub-Divisions.

The main Norwegian sampling program is sampling the landings. Additional samples from catches are obtained from the coast guard, from observers and from crewmembers reporting according to an agreed sampling procedure.

All countries, which harvest haddock, send information on commercial catches to AFWG as input for estimating total nominal catch and additional information (see table 1).

At the AFWG all the data combined for recalculation age compositions of the landings: catch-at-age or catch in numbers and the mean weights-at-age in catches.

Survey measurements

Russian surveys of cod and haddock in the southern Barents Sea started in the late 1940s as trawl surveys of young demersal fishes. Since 1957 such surveys have been conducted over the whole feeding area including the Bear Island – Spitzbergen area during September-February.

Time of survey conducting has reduced from 5-6 months in 1946-1981 to 2-2.5 months (October-December) since 1982. AFWG used data from Russian bottom trawl – acoustic

survey from 1983 (Figure 1A). The survey covers the main areas where haddock settle down as well as the commercial fishery takes place in ICES areas I, II a and II b, including Russian coastal zone.

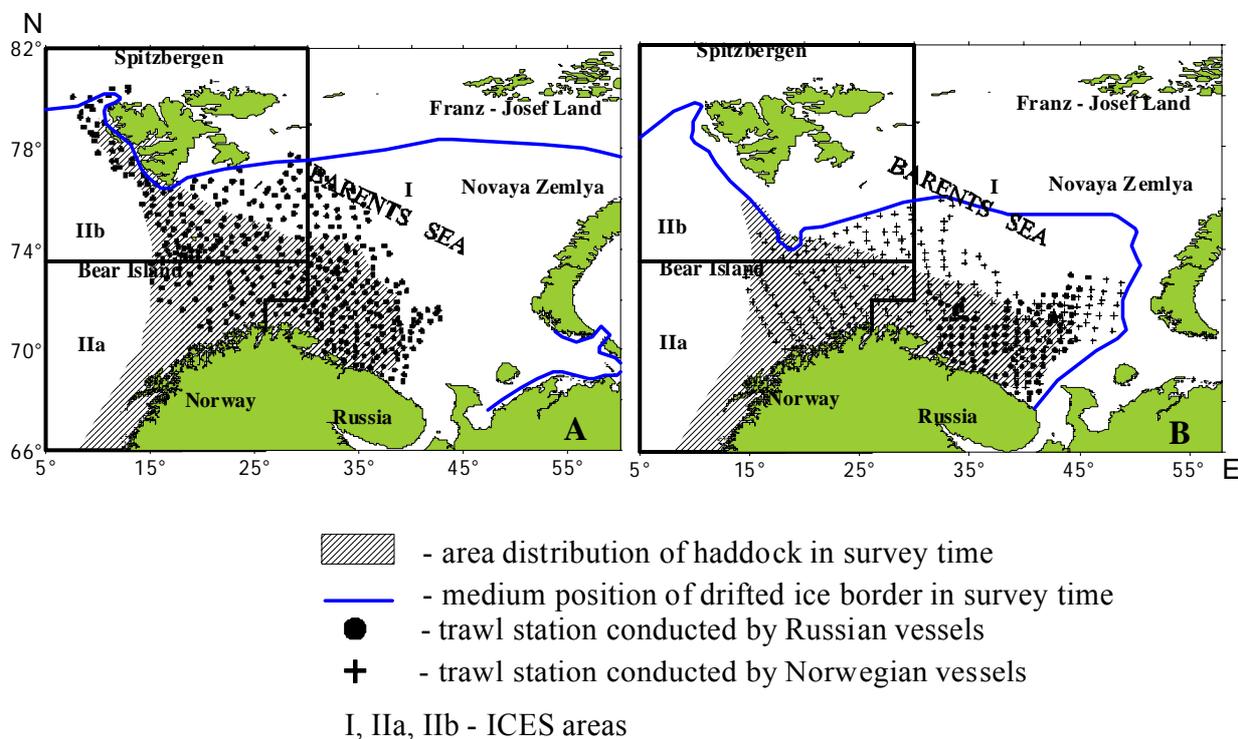


Figure 1. Area of Russian (A) and Norwegian (joint) (B) trawl-acoustic scientific surveys in Barents Sea

Norway conducted sporadic surveys in the Barents Sea between 1970 and 1981. The regular survey started in 1981 and conducts bottom trawl and acoustic survey in the Barents Sea in January-March, which also covers the ice-free part of the Barents Sea in ICES areas I, II a and II b, including Norwegian coastal zone. Before 2000 this survey was made without participation of Russian vessels, while in the three latest surveys Russian vessels have covered important parts of the Russian zone (Figure 1B).

Data from survey provided estimation mean weights of fish in stock (weight at age), also survey data combined with data from catches to calculation proportion of mature haddock at age, numbers of consumed haddock by NEA cod using data from cod stomach samples, and survey “trawl indices”, calculated as relative numbers per age per hour and “acoustic indices” of absolute numbers (in thousands) computed from the acoustic registrations.

Assessment and predictions models

The haddock is assessed using a catch at age model Virtual or Sequential Population Analysis (VPA or SPA) was introduced in fish stock assessment by Gulland (1965). In common with computing machinery evolution the software for stock assessment and projection was changed but calculations were made on the same principal as previously (Anon., 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995a,b, 1996, 1997, 1998, 1999a, 2000a,b, 2001a,b, 2002, 2003a, 2004a, 2005). The table 2 shows the

software used at the AFWG from 1978. All are standard ICES software based on catch-at-age analyses.

The classical VPA analysis that uses measurement of the number of fish caught in each age group and age. Given that the catches are treated as exact the historical part of the stock estimates (N-values) are principle the cumulative sum of catches given certain assumption of annual natural mortality. The VPA solves the Baranov (Baranov, 1918) equation directly by numerical methods and it is not a statistical analysis, however, it is an important basis for the ADAPT and other statistical methods. ADAPT, based on VPA, uses the fishing mortality of the terminal year and of the oldest age as the unknown parameters.

*Table 2. The standard software and methods used for stock assessment and projection of NEA haddock at AFWG**

Year	Assessment methods	Short-term projection catch and biomass	Recruitment projection
1978-1985	IFAP module (VPA)	IFAP module (management options table)	(Survey indices ratio)
1986-1991			RCRTINX2 (regressions of yearclasses)
1992-1993	VPA version 3.1(SVPA/XSA), ADAPT		RCT3 (regressions of yearclasses)
1994-1998	VPA version 3.11 (SVPA/XSA)		
1999-2002	VPA version 3.2 - VPA95 (SVPA/XSA)		
2003-2005		MFDP(management options table)	

**In brackets – methods.*

At present, the AFWG uses VPA95 software package (Darby and Flatman, 1994), including Extended Survivors Analysis (XSA) (Shepherd, 1992), to estimate stock abundance and fishing mortality of cohorts that have entered the fishery. XSA method uses the number of survivors of the each age group as the unknowns.

Estimation numbers of fish, which have not entered the fishery in the assessment and two followed years, previously were estimated by VPA using survey indices are estimated using the RCT3 software package (Shepherd and Darby*).

Assumptions of weight-at-age in the catch and in the stock, maturity and selection patterns, which are needed in the projection, are derived from *ad hoc* expert judgment. These data are then the basis for short-term projection procedure (using MFDP software, Anon., 1999), which provides a management option table.

All outputs are point estimates and include estimates of SSB, recruitment, and catch under various fishing mortality scenarios. These point estimates in relation to defined reference points (that are considered to reflect uncertainty in the assessment) form the basis of the

* Work is in secretary ICES, year of the edition is unknown.

annual advice provided by the ACFM – department of International Council for the Exploration of the Sea (ICES).

The current uncertainty is reflected in the distance between the limit and the precautionary reference points (lim and pa points). B_{lim} is defined to be the limit SSB below which only poor year classes have been observed, B_{pa} is considered to be the minimum SSB required to provide a 95% probability of maintaining SSB above B_{lim} , taking into account the uncertainty in the assessments and stock dynamics. F_{lim} is the fishing mortality associated with potential stock collapse and F_{pa} is considered having a high probability of keeping F below F_{lim} (Anon., 2003). At the moment $B_{lim}=50\ 000$ t, $B_{pa} = 80\ 000$ t, $F_{lim}=0.49$ and $F_{pa}=0.35$. The reference points will, however, be revised in 2006.

Materials

Materials for investigation were input data for stock assessment and projection, which used in AFWG 2005 (Anon., 2005). These include catch at age, mean weight in stock and catch, maturity ratio for period 1980 – 2005 and survey indices for period 1981-2005.

Methods for improvement stock assessment and prediction of haddock stocks

Estimation of stock size

The estimates of stock numbers at age ($N_{a,y}$) and fishing mortality at age were made using an ADAPT model set up in Excel. In principle this model is similar to the one described by Gavaris (1988), where catches are treated as being measured without error. The ADAPTive Framework uses a non-linear least-squares fit to calibrate the cumulative catch, given assumption of natural mortality (the virtual population) against independent indices of abundance. The data used were the estimated catch-at-age from 1980-2004, with age groups 1-11+. The last age group contains all catches equal to and higher than that age and is thus treated as a plus group. The following survey indices were used in the tuning:

- Russian bottom survey (Fleet 1), year ranges 1991-2004, age ranges 0+-7 in survey time assumed as start of year 2005 year ranges 1-8, year range 1992-2005;
- Norwegian acoustic survey (Fleet 2), year range 1990-2005, age ranges 1-8 survey time as start of year;
- Norwegian bottom trawl survey (Fleet 4), year range 1990-2005, age ranges 2-9 survey time as start of year.

Estimates of predation of cod on haddock was added as natural mortality (M_2) as done by the AFWG. This is in addition to the constant mortality assumption (M_1) of 0.2.

In the Excel spreadsheet Pope's approximation (Pope, 1972) of the transformed Baranov (Baranov, 1918) equation was used:

$$N_{a,y} = N_{a+1,y+1} * e^{M_{a,y}/2+C_{a,y}} * e^{-M_{a,y}/2} \quad (1)$$

Fishing mortality of the oldest true age group (age 10) was derived recursively as the average fishing mortality of the three younger age groups:

$$F_{10,y} = \frac{F_{7,y} + F_{8,y} + F_{9,y}}{3} \quad (2)$$

Fishing mortality of the plus group (age 11+) was set the same as for age 10. Population estimates of the oldest true age group (age 10) and the plus group were then obtained by the transformed Baranov equation:

$$N_{a,y} = \frac{C_{a,y}}{\frac{F_{a,y}}{F_{a,y} + M_{a,y}} * (1 - e^{-(F_{a,y} + M_{a,y})})} \quad (3)$$

For tuning the relationship between population size and survey was the same as that set by the AFWG 2005. Thus for ages 1-6 power relationship was assumed:

$$U_{a,y} = \alpha * N_{a,y}^{\beta}, \quad (4)$$

and for ages 7-9 – proportional relationship was assumed:

$$U_{a,y} = \alpha * N_{a,y} \quad (5)$$

Year class 1996 which has consistently been much lower in the survey than in the catches. The AFWG has resolved that by excluding it from tuning but here a special multiplier was added to the relationship between survey and stock size:

$$U_{a,y}^{YC96} = k^{YC96} \alpha_a * N_{a,y}^{\beta_a}, \quad (6)$$

where k is a parameter estimated by the model. The objective function in the model was:

$$SSE_{MIN} = \sum_{Surveys} \sum_a \sum_y \frac{(\ln U_{a,y} - \ln \hat{U}_{a,y})^2}{\sqrt{2\sigma_a^2}}. \quad (7)$$

Surveys indices of different age groups are generally measured with different degree of precision. In the absence of direct information of variance in the survey a proxy for the survey errors were estimated internally in the model and was done as follows: 1) In the first run the denominator in equation x was set to 1 and an optimal fit was obtained. 2) The standard deviation of the residuals for each age group was calculated. 3) These estimates were then used as a proxy for variance (σ) in the objective function for the final fit of the model.

Effectively this means that age groups with higher variance have lower influence in the final population estimates than those with lower variance.

The parameters estimated in the model were thus: Numbers of fish at age 1-10 at 2005 and α and β for each age group for each survey.

Predictions

The objective function provides the estimates of the population numbers in the start of 2005. Calculation of catch in 2005 and 2006 and population numbers in 2006 and 2007 were done

by the use of the catch and stock equations. As input data for projection were used estimated values of mean weight in stock and catch as used in AFWG 2005.

The catches were constrained to yield of 117 thou. t. in 2005 and 112 thou. t. in 2006 as set by the AFWG. The selection patterns used was the average of the last three years and the assumed mortality (M1 and M2) set the same as set by AFWG.

It should be noted that the plus group in 2005 and onward was estimated using equation:

$$N_{a,y} = N_{a-1,y-1} * e^{-(F_{a-1,y} + M_{a-1,y-1})} + N_{a,y-1} * e^{-(F_{a,y-1} + M_{a,y-1})} \quad (8)$$

Estimation of uncertainty

Spreadsheets gave the possibility to characterize the uncertainty in model fit using a bootstrap method (Efron and Tibshirani 1993, Haddon, 2001) – resampling of the residuals from the observed-predicted tuning indices.

In nonlinear least-squares estimates (Haddon, 2001) of a solution estimates of population abundance were chosen that provided the best fit to the tuning indices. The residuals of that fit were bootstrapped 1000 times and new values of N produced. The distribution of the associated Fs and SSB provided an indication of variation and the bias (deviations).

Each data set has the same number of observation (n) as the original data set. Recalculating the model to each bootstrap data set receive the statistics of interest (probability profile, standard deviations, confidence intervals) from the results for each model fit. Thus the bootstrap samples were:

$$U_{a,y}^b = \hat{U}_{a,y} \left(\frac{U_{a,y}}{\hat{U}_{a,y}} \right)^{boot} \quad (14)$$

The random sampling was maintained within each survey and each sample consisted of the whole residuals for the randomly selected year.

Spreadsheets gave a possibility to investigate also uncertainty in projection procedure. For this aim the same procedure as for stock assessment was used. For the projection period 2005-2007 calculation of parameters were based on total allowable catch (TAC) for 2005, which established JRNFC at November 2004. Fishing mortality at age calculated as “TAC constraint” according to algorithm used in standard ICES projection software MFDP (Anon., 1999). Using standard equations of stock and catch for projection period were estimated values of numbers of fish in 2006 and 2007 as well as spawning stock biomass and fishing mortality. Selectivity in the year 2005 and 2006 was randomly selected in each run from the selectivity pattern estimated in each year 2001 to 2004.

For all parameters confidence intervals were estimated and compared with point estimations of N at age 3, F and SSB obtained by AFWG in 2005 (Anon., 2005).

Results

Summary of the results of xAPAPT calculations, bootstrap estimations of fishing mortality, numbers of fish at age 3 (recruits) and SSB are given in figures 2, 4 and 6. The dark shaded areas shows 80% probability and the light shaded areas the 95% uncertainty. Cumulative distribution of the estimates are shown in figures 3, 5, and 7. These figures enable detail determination of the probability that the parameters exceed or are below a certain value.

The historical point estimates of SSB, fishing mortality and recruitment from xADAPT are, as expected, the same as estimated by the AFWG. Given the constraint in yield for 2005 (117 thou. t) and 2006 (112 thou. t) is expected that the SSB will most likely continue to increase from a low in 1999 (Figure 2). This is both due to an expected continuous good recruitment (Figure 6) as well as reasonable fishing mortalities in recent years (Figure 4).

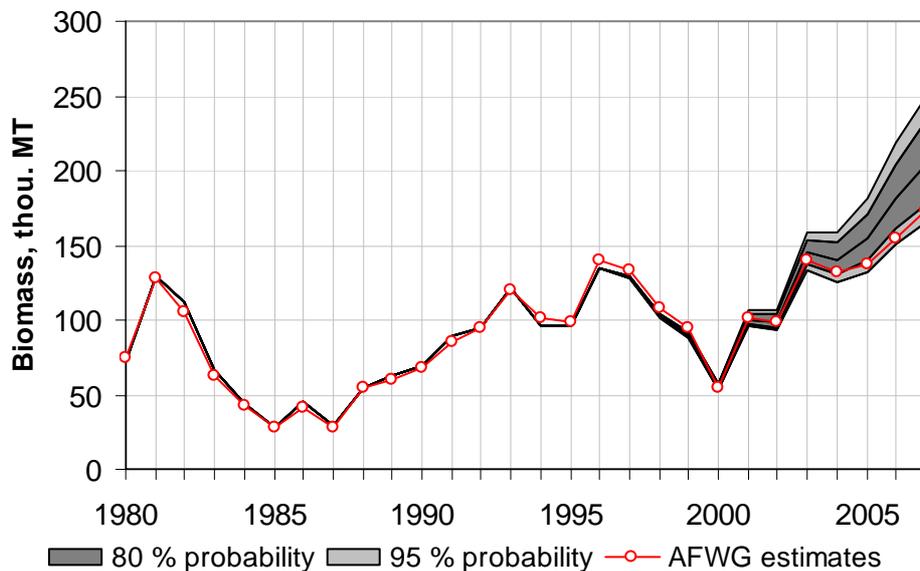


Figure 2. Dynamic of SSB estimated by AFWG and confidence intervals obtained from xADAPT for period 1980-2005 and forecast for 2006-2007

The uncertainties in the historical part of the time series are none since it is assumed that the catches are exact. The uncertainties in the more recent years increase, this because of reduced numbers of observations and a greater influence of the surveys on the current estimates. The point estimates from the final adopted XSA run by the AFWG are slightly different for the period 2001-2007, but working group estimates lies within the 95% bootstrap error distribution (Figure 2, 4 and 6).

Standard deviation (uncertainty) of estimated SSB value at the start of 2005 according to calculation using bootstrap procedure is about 50 thou. t. ($CV = 0.07$). The medium estimate of SSB in 2005 is 150 thou. t and there the 95% bootstrap confidence interval is between 124 and 181 thou. t. The medium fishing mortality (F_{bar}) in 2004 was 0.32 and 95% bootstrap confidence interval is between 0.28 to 0.36 ($CV=0.07$), and the bias in the SSB and F bootstrap estimates was insignificant (below 1%).

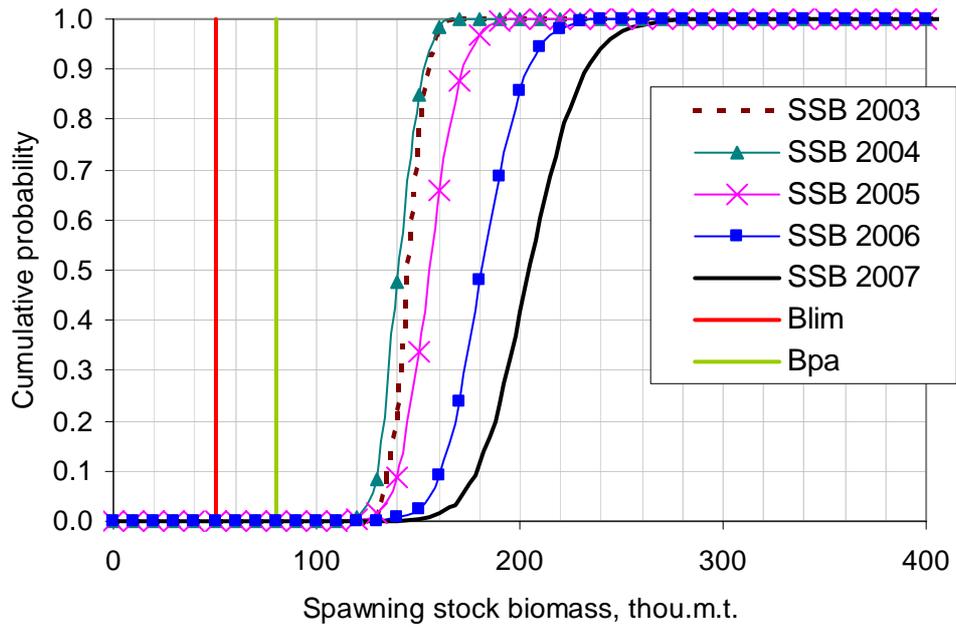


Figure 3. Cumulative probability distribution of SSB obtained from xADAPT for period 2003-2005 and forecast for 2006-2007 in relation with reference points

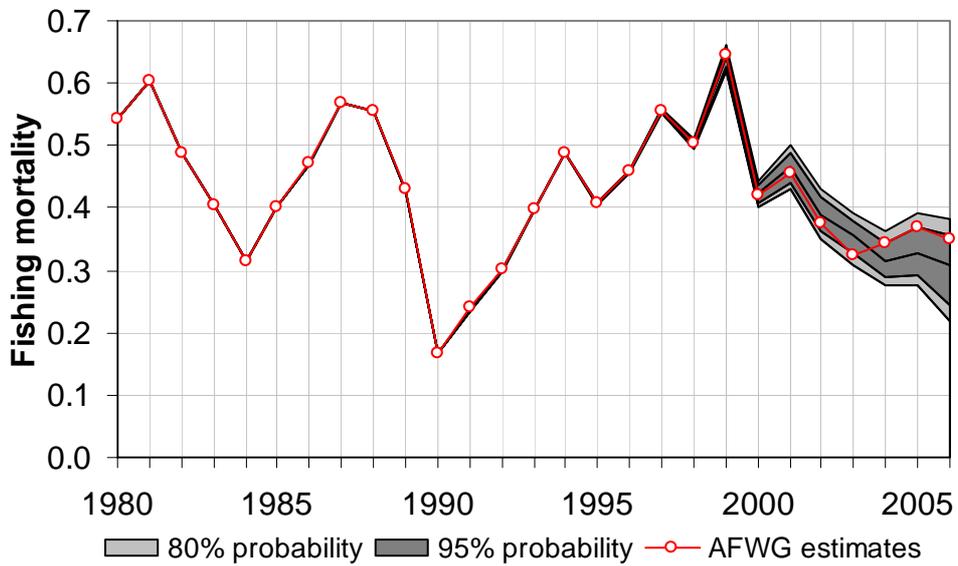


Figure 4. Dynamic of F (age 4-7) estimated by AFWG and confidence intervals obtained from xADAPT for period 1980-2004 and forecast for 2005-2006

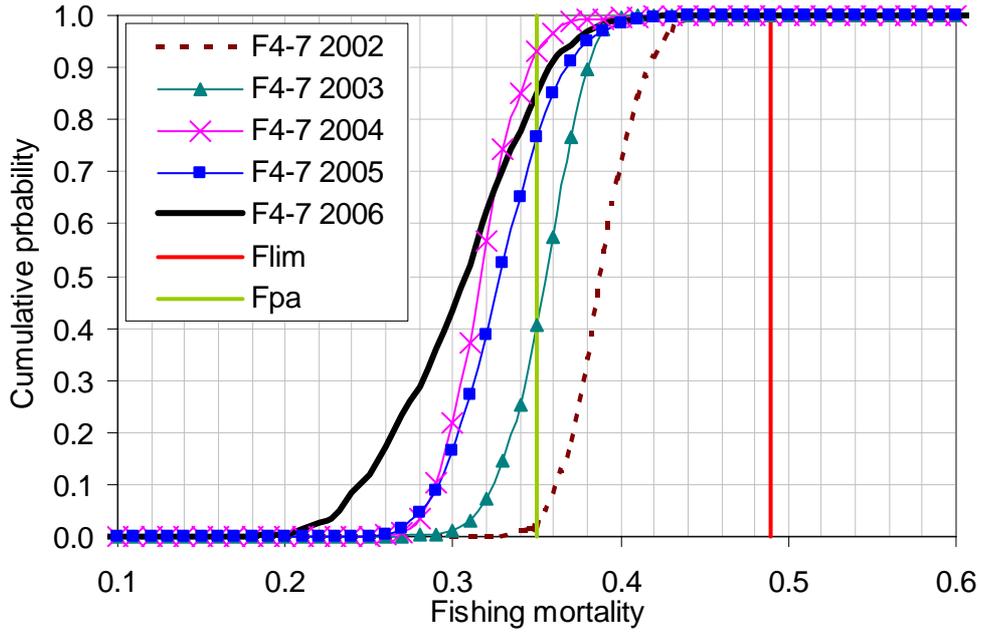


Figure 5. Cumulative probability distribution of F (age4-7) obtained from xADAPT for period 2002-2004 and forecast for 2005-2006 in relation with reference points

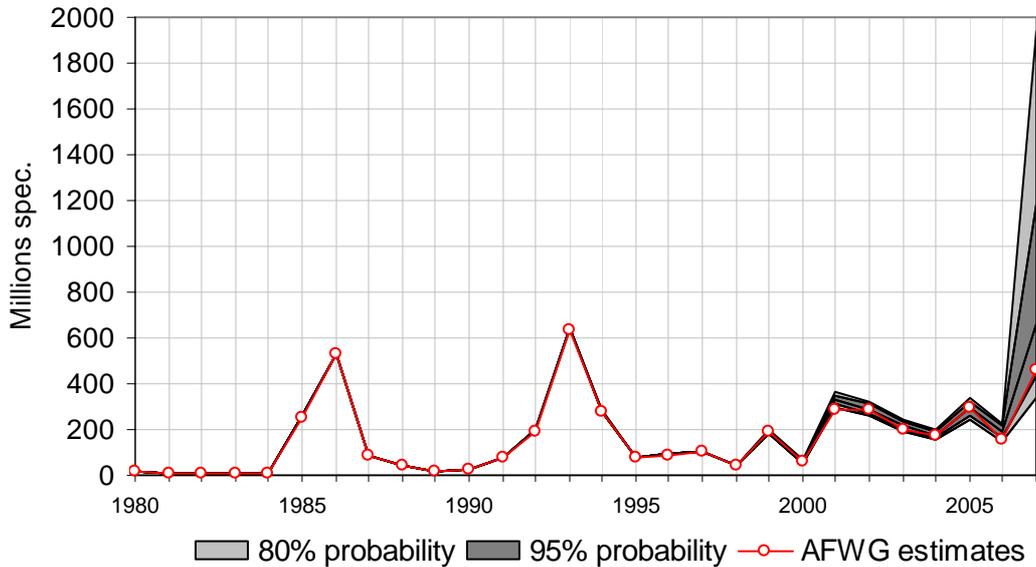


Figure 6. Dynamic of recruitment (N_3) estimated by AFWG and confidence intervals obtained from xADAPT for period 1980–2005 and forecast for 2006-2007

The 95% bootstrap confidence interval indicate, given the yield constraint for 2005 (117 thou. t.), that the F_{bar} in 2005 is between 0.26 to 0.41 (mean is 0.33 and the bias in the F estimates is 4%, CV=0.11) and that accordingly the estimated SSB value at start of 2006 is expected to be between 142 thou. t. to 223 thou. t. (with median value 180 thou. t., CV= 0.12).

The 95% bootstrap confidence interval indicate, given the yield constraint for 2006 (112 thou. t.), that the F_{bar} in 2006 is between 0.21 and 0.38 (mean is 0.3 and the bias in the F estimates is 5%, CV=0.15) and that accordingly the estimated SSB value at start of 2007 is expected to be between 163 thou. t. to 271 thou. t. (mean value 211 thou. t., bootstrap bias 1.6%, CV= 0.13).

The results also show trends of mean estimates in F and SSB in recent and projection years. The fishing mortality after decreasing from 1999 to 2003 stayed on more or less the same level with high probability. Accordingly, spawning stock size shows a small tendency of an increase from 2000. Unsignificant decreasing at 2004 can be explained by increasing density of the population.

Increasing numbers of fish in population usually lead to decreasing mean weight of haddock in consequence of increased feed competition between individuals.

The 95% bootstrap confidence interval indicates that variances in recruitment estimates (numbers at age 3) increase during the time. In 2005 varyies from 273 to 397 mln. spec. with mean value about 332 mln. spec. Expected value of recruitment in 2006 varying from 152 to 254 mln. spec. with mean value about 200 mln. spec. and in 2007 from 339 to 1942 with mean 664 mln. spec. (Figure 6).

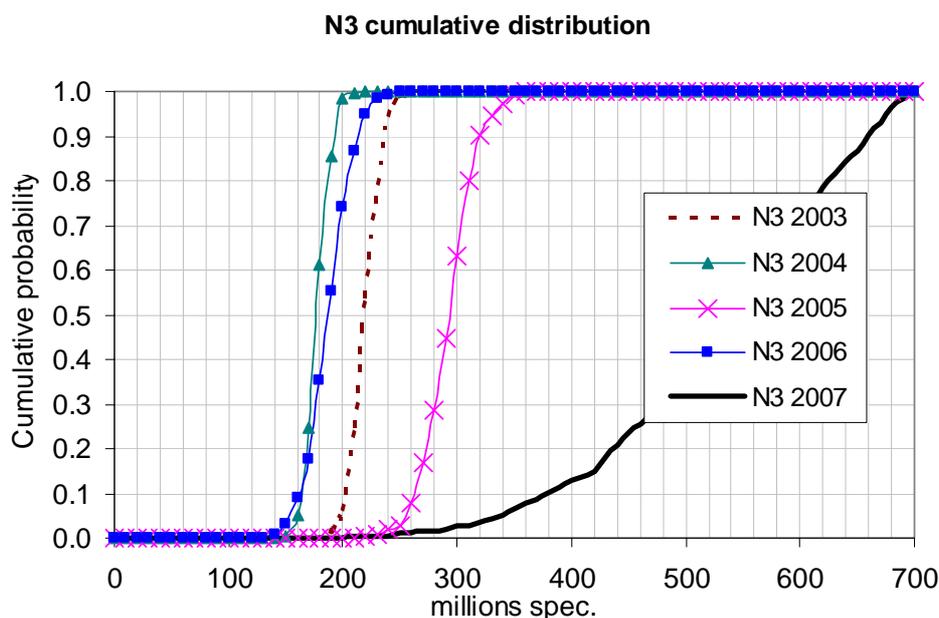


Figure 7. Cumulative probability distribution of recruitment (N_3) obtained from xADAPT for period 2003-2005 and forecast for 2006-2007

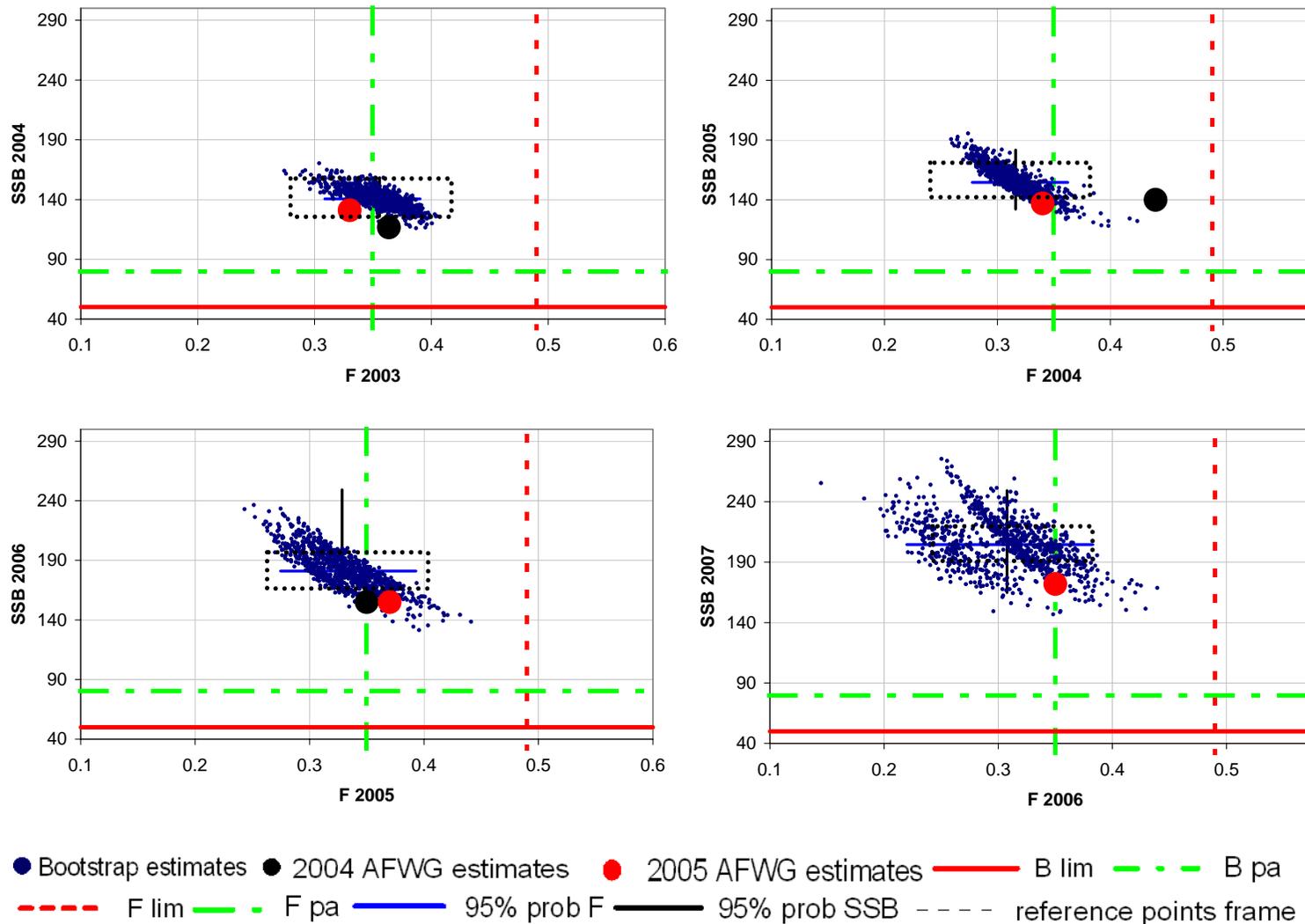


Figure 8. Point estimates of SSB and F in previous year made by AFWG and obtained by xADAPT with 95% confidence intervals in relation with adopted reference points for period 2002-2006

This mean that incoming yearclass 2004 has a very high abundance, 2003 has a lower abundance than yearclass 2002, but it is just preliminary estimates and can be changed using the new observation. The probability profile of estimates (Figure 7) shows that decreasing in recruitment from 2005 to 2006 is very likely but increasing in recruitment from 2006 to 2007 is not very likely. Figure 8 demonstrates the uncertainty in estimates of SSB and corresponding F associated with adopted reference points. Dotted line frame in pictures matched with imaginary frame between precautionary approaches values of F and SSB.

The 95% bootstrap confidence interval indicates that variances in that estimates also increase during the time, but most of point estimates lie inside imaginary “reference point’s frame”.

Conformably to estimates in terminal year (F in 2004 and SSB at start of 2005) which most important in assessment procedure we can suppose:

- (1) estimates of spawning stock and F of NEA Haddock lies in adjusted by ACFM safe biological limits with high (95%) probability;
- (2) investigated part of uncertainty given by observation errors comparable to distance between lim and pa borders of SSB and F.

Discussions

Mean estimates of SSB obtained by xADAPT are generally higher and estimates of F are somewhat lower than the finally adopted point estimates of SSB and F by AFWG. This is expected because there are differences in the handling of data and in model configurations in the two models. The major differences are:

- 1) In XSA the estimates of the population parameters are done in two steps, the historical values are determined from observations of ages 3 and older but the estimates of the younger ages are determined from a separate software, RCT3. In xADAPT all the observations, both recruits and older were dealt with in the same model setup. The latter should be the preferred option because all available measurements are available for the terminal estimates.
- 2) XSA is used with shrinkage of the terminal F, but there is no shrinkage in the xADAPT. If there are changes in fishing mortality in the recent past, as observed for the NEA haddock, this by assumption of shrinkage will result in higher terminal (2004) F estimates in XSA. And consequently lower estimates of SSB.
- 3) The weighting of different survey indices is done differently in XSA compared with xADAPT. Further studies are needed to understand how this influences the terminal estimates.
- 4) The year class 1996 is treated as a missing value in the XSA but is modelled, albeit with a multiplier factor, in xADAPT. The influence of that was not evaluated in this study. It should be noted that although the point estimators differ between XSA and xADAPT, the XSA point values lie within the 95% bootstrap confidence interval of the xADAPT.

The 95% bootstrap confidence interval in terminal year estimates of SSB obtained by the xADAPT model lies within the distance between adopted reference points. It must however be stressed that the bootstrap confidence interval contains only one part of the total

uncertainty in stock assessment, i.e. the uncertainty related to the precision in the estimates of survey abundance given the model configuration.

However, all models of population dynamics have uncertainties that are related to the assumption that are made within any model. Uncertainty is unpleasant commonplace in stock assessment and how best to approach it is a growing and vital part of fisheries modeling (Haddon, 2001).

Main weakness of current methods for stock assessment and projection is in using several partly different, partly similar models, which turn to account more or less the same input data but receives different estimation of population numbers and fishing mortality, therefore level of uncertainty increasing with each step. Suggested method probably allows combining input data and receiving one and only one value for each parameter.

Using the algorithm of ADAPT framework with the bootstrap procedure allows to estimate at least some part of the uncertainty – from errors in measurements, uncertainty in stock assessment parameters and the statistics of interest (probability profile, standard deviations, confidence intervals) from the results for each model fit.

It thus provides an opportunity to make statistical tests of differences between model assumptions, like natural mortality or selection pattern.

One of the problems in the management of NEA Haddock stock is estimating the reference points, which will be revised in 2006. Estimated population parameters using standard models with a bootstrap procedure can be applied in stock assessment and projection. Estimated confidence intervals of parameters can be good candidates in estimating values and intervals between reference points!

This uncertainty analysis, using bootstrap, is only the first step in the construction of a full analysis of uncertainty in stock assessment. Additional work to more fully characterize all important sources of uncertainty in the assessment process, including modeling errors, should be used to estimate the applicability of the current biological reference points as well as any harvest control rules.

Conclusion

Suggested algorithm based on ADAPT framework allow to investigate part of uncertainty in stock assessment and projection procedure and its prototype – programm ADAPT can be applied as an alternative approach for the estimation of population dynamics of NEA haddock.

The framework should allow for a procedure making decisions more simple, objective and robust to criticism. Working Group members can then develop a process for weighting the risks and reaching an agreement on the best management actions given all of the inherent uncertainties in the analysis.

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POSTERS

STOCOBAR MODEL FOR SIMULATION OF THE COD STOCK DYNAMICS IN THE BARENTS SEA CONSIDERING THE INFLUENCE OF ECOSYSTEM FACTORS

by

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Introduction

Practical realization of the ecosystem approach to the management of marine bioresources requires development of multispecies and ecosystem based models designed for fisheries objectives. For the Barents Sea, specific research in this field began in mid-1980s. At that time the stocks of major commercial species and consequently catches dramatically decreased due to large-scale structural and functional changes in the ecosystem of the sea caused by both natural and human factors (Kovtsova, 1991; Nakken, 1998). One of the reasons of the fisheries crisis in the Barents Sea in the mid-1980s was ineffective fisheries management. The management strategy in the Barents Sea based on single species approach did not allow us to take into consideration the changes of trophic interactions between commercially important populations in the period of changing ecosystem conditions.

In 1996 the conceptual basis and general scheme of model design for commercial species in the Barents Sea were developed in the framework of PINRO plan of scientific researches. The work had several stages. Firstly, we planned to develop population models for main commercial species and then fuse them in one model. Cod as the most studied species that is of great importance for fisheries and functioning of biocenosis in the Barents Sea has to be the crucial element of this model.

The model of dynamics of the Northeast Atlantic cod stock reflecting both intrapopulation and interspecies relationships in the Barents Sea has been developed in PINRO since 1997. The model is intended for optimisation of management of cod fisheries and for quantitative estimation of cod predation on stocks of capelin, shrimp, haddock and polar cod in the Barents Sea.

In 2001, the first version of the model called STOCOBAR (STOCK of COd in the BARENTS Sea) was created. This model is a successor of separate model blocks and two of those were designed as separate models that is CONCOD (to describe feeding and growth of NEA cod) and STRAFICOD (to analyse different harvest strategies for cod stock in the Barents Sea taking into consideration capelin stock dynamics) (Filin 2000; Filin, Gavrilik, 2001). The work on improvement of model structure and time discreteness of calculation was carried out in 2002-2004.

1. General characteristics of the model

STOCOBAR is a complex model that describes population parameters and species interactions of cod based on successive running of separate processes that are crucial for cod stock dynamics in the Barents Sea within one functional system. This model is designed to

improve the harvest management of cod stock taking into account species interactions. It can be applied for prediction of cod stock dynamics and expected catch as well as for model analysis of effectiveness of different harvest strategies.

The conceptual basis of the model consists of the following:

- a proportion of prey species in a predator's ration reflects the proportion of these species in nature;
- maximum consumption by fish depends on a their body weight and environment temperature;
- a coefficient of proportionality between real and maximum consumption by a predator is the function of the biomass of available food;
- quantity of available food as a particular prey item is determined by the total biomass of prey in nature, a coefficient of its suitability as food and the coefficient of food competitiveness of the predator when consuming this prey;
- a coefficient of food suitability of prey for a predator is a coefficient of proportionality between prey portion in the predator stomach and their portion in nature in relation to all other categories of prey;
- a coefficient of a predator's food competitiveness reflects the relative rate of consumption of the prey in comparison with other predators;
- growth of cod is the function of body weight, water temperature and ration expressed as energy units;
- maturation rate of fish is determined first of all by their linear growth.

All calculations in the model are carried out in cohort mode. Time step of the model (discontinuity of calculations) can be established as equal to one year or half a year. The model is spatially unstructured, i. e. the processes are simulated without area differentiation.

The model includes seven prey species of cod (capelin, shrimp, polar cod, herring, euphausiids and juveniles of haddock and cod) that are divided in age groups except for shrimp and euphausiids (Table 1).

Table 1. Age composition of species included in the model

Species	Age group, years
Cod	1-15
Haddock	1-12
Capelin	1-5
Herring	1-4
Polar cod	1-6
Shrimp	Without regard for age
Euphausiids	Without regard for age

Euphausiids that occur in the Barents Sea in four commonest species are included into the model as one group without specification. Species structure of the model is not permanent and it is set according to the tasks of the model analysis and available input data. Therefore, based on common algorithms the model can be used in different structural modifications. It can be reduced from seven-species version to a simple modification where all prey species are considered as one food category. In this case, food resource of cod is considered as constant for the whole modelling period and thermal conditions and abundance of cod population become the factors that affect growth rate of fish.

A strategy of the management of the cod stock in the model is realized on the basis of a concept of the precautionary approach accepted in the ICES. In accordance with that, the rules of a control of the intensity of the cod stock exploitation in the model are based on biological reference points B_{lim} , B_{pa} , F_{lim} , F_{pa} .

The model can be run in three modes:

- 1) retrospective analysis;
- 2) prediction;
- 3) scenario modelling.

In retrospective analysis and prediction, the following parameters are calculated:

- portion of prey species included in the model in cod diet;
- cod ration expressed in kg;
- cod ration expressed in kilocalorie;
- cod ration expressed in % of body weight;
- total annual consumption of cod specified by prey species in thousand tonnes;
- annual growth of cod at age of 1 and older in kg;
- annual growth of cod at age of 1 and older expressed in % of weight;
- mean age based weight of cod in the beginning of year in kg;
- cod maturation ogive in the beginning of year;
- biomass of cod fishing stock in the beginning of year in thousand tonnes;
- biomass of spawning stock in the beginning of year in thousand tonnes;
- abundance of cod at age 1-3 in million individuals;
- biomass of cod at age 1-3 in thousand tonnes;
- cod juveniles mortality caused by cannibalism;

In prognostic calculations mode, the model also provides predicted annual catch of cod and coefficient of cod fishing mortality according to the set harvest level.

In scenario modelling mode, the model provides quantitative estimates of:

- 1) The effect on feeding, growth and maturation rate of cod by the following factors:
 - biomass dynamics of prey species included in the model;
 - abundance and age structure of the population;
 - water temperature.
- 2) dependence of cod cannibalism level on food resources and population abundance;
- 3) long-term effectiveness of different management strategies for cod in the Barents Sea taking into account species interaction.

A computers program of the STOCOBAR model is designed in programming language Delphi 7. Calculation results are produced as graphs and tables. When doing calculation with the use of several versions of the model tuning, the results are converted to the common graph and can be presented as a common table.

2. Input data

The model is based on monitoring data on species included in the model and water temperature in the Barents Sea as well as on fishing statistics.

The following data are needed to estimate the parameters of the model:

- 1) age based abundance of cod in the beginning of the year;
- 2) age based individual weight of cod in the stock in the beginning of the year;
- 3) age based mean annual weight of cod in catch;
- 4) annual age based coefficient of cod fishing mortality;

- 5) cod maturation ogive in the beginning of the year;
- 6) age based catch of cod in the first and second part of the year;
- 7) mean temperature (in one year or half of the year) on the Kola section;
- 8) abundance and biomass of capelin, herring and polar cod in the Barents Sea according to the results of acoustic survey;
- 9) abundance and biomass of haddock stock;
- 10) indices of shrimp abundance according to the data of trawl surveys;
- 11) indices of euphausiids abundance in the Barents Sea according to the results of macroplankton survey;
- 12) quantitative composition of cod stomachs content in each half of the year and by ages.

The following input data is used in prognostic calculations:

- abundance of cod at age 1;
- mean individual weight of cod at age 1 in the beginning of the year;
- coefficient of cod fishing mortality F_{bar} or TAC calculation rules;
- biomass (age composition if necessary) of cod's prey populations included in the model in the beginning of the year;
- mean annual (or mean in half of the year) water temperature on the Kola section at the depth of 0-200 m.

Sources of the data used in the model:

- report of ICES AFWG;
- joint Russian-Norwegian database on cod stomachs in the Barents Sea;
- results of trawl and acoustic surveys in the Barents Sea;
- fishing statistics;
- observation data on the water temperature on the Kola section.
-

In the mode of stochastic simulation, the input data is randomly taken from the corpus of retrospective data.

3. Model calculations

The general scheme of model calculations is given in the Fig. 1. The food resources of cod are included in the model in separate food categories that differ in species and age of prey. "Other food" covers all prey species except the species included in the model and it recognised as a separate category. The number of food categories for cod in different versions of the model differs according the number of species included in the model and their age structure. Each food category except for the "other food" is characterised by biomass and the coefficient of food suitability. The coefficient of food suitability of different prey categories was set according to age groups and it shows the relationship between the biomass proportion of prey species in cod stomachs and biomass proportion of populations of these species in the environment. The coefficients of food suitability are the parameters of the model and the values of these parameters vary from 0 to 1 and it is set in tuning of the model.

Calculation of proportion of other food in the diet of cod is not based on estimates of its biomass due to the lack of such data. It is based on comparison of total biomass of prey populations in the given year with the mean long-term value of this parameter. The calculated

proportion of “other food” in cod diet cannot be lower than it is set according to the observed data of minimal value despite the prey biomass.

The rations of cod are calculated in the model according to the maximum ration and feeding level, which is a proportionality coefficient between maximum and true rations (Ivlev, 1955; Andersen, Ursin, 1977). The equation obtained by M. Jobling (1988) as a result of experimental work was used for estimation of maximum ration.

$$H = 0,7e^{0,104T - 0,000112T^3} W^{0,8}, \quad (1)$$

where W – cod weight in kg;
 T – water temperature

However, in the model calculations the experimentally obtained coefficients of equations (1) are substituted with model parameters that are estimated in the process of model tuning according to the observed data.

The level of cod feeding f was calculated as a function of available food that varied in the model depending on biomass of prey populations included in the model and abundance of cod. Since “other fish” category is ignored in this approach to the estimation of f , the parameter of minimum level of feeding f_0 is applied. The f_0 parameter does not depend on abundance of prey species included in the model but it depends on the size of cod population:

$$f_0 = Ke^{-\alpha B} \quad (2)$$

where K, α – coefficient;
 B – biomass of cod stock in thousand tonnes.

Coefficient α that shows the effect of density factor on cod feeding level differs in the model for cod at age 1-3 and other age groups.

The experimentally obtained equation of Jones is used as a basic level for calculation of cod growths in the model (Jones, 1978):

$$E_d = 0,0075W^{0,8}e^{0,081T + 0,76V} + 1,27\Delta W_d W^{0,15}, \quad (3)$$

where E_d – daily ration expressed in energy units;
 W – body weight in kg;
 T – water temperature;
 V – mean relative (expressed in body length) swimming speed;
 ΔW_d – daily growth.

In the model, this equation was transformed with consideration to time step (1 year or 6 month) and additional tuning of coefficient according to observed data.

The dynamics of cod abundance is calculated according to the coefficients of fishing mortality and natural mortality. The coefficients of fishing mortality are set in the model according to TAC calculation rules, while the value of the coefficients of natural mortality for all age groups is constant and it is equal to 0,2. Besides, mortality caused by cannibalism is also taken in to account for juveniles at age 1-5. For these age groups of cod, natural mortality

includes two components that are mortality as a cause of cannibalism and remaining natural mortality.

4. Estimation of model parameters

The values of the model parameters are estimated in the tuning by minimizing the discrepancies between simulated and observed data. The parameterization of STOCOBAR model is based on algorithms realised in Excel (options for search of optimal solution). Total scheme of estimation of the model parameters is given in Fig. 2.

Model tuning is performed in several stages. At the first stage, the values of the parameters used in calculations of diet composition are set. These values are calculated by minimisation of the sum of squares of deviations between modelled diet composition and food composition based on observed data.

At the second and third stages of model tuning, the parameters of the equations used in calculation of ration and cod growth rate are estimated. This is done in the following way:

- maximisation of squares of correlation coefficient between modelled cod rations and corresponding values of mean annual weight of stomach content according to the quantitative feeding analysis;
- minimisation of the sum of squares of deviation between observed weight values of fish in the stock and the modelled ones;
- minimisation of the sum of squares of deviation between observed values of mean annual weight of fish in catch and the modelled ones;

At the fourth stage of model tuning, the parameters of equations that describe cod maturation rate depending on growth rate are estimated. These values are obtained by minimisation of squares of deviation between observed data on maturation at age and the modelled values.

The limits of parameters variations are of great importance for parameterization of the model. These limits are set according to the principles of truth or to avoid situation when further calculations are impossible (dividing by zero etc.). The following limits based on true principle were used in the model:

- total consumption of capelin shall not exceed the biomass of capelin stock in the beginning of the year;
- coefficients of food suitability for preys species of cod shall exceed zero;
- maximum proportion of prey in cod diet can not exceed a definite level, which means that cod cannot feed on one prey species in the whole year even if its abundance is very high;

The achieved correspondence between observed and calculated data on diet composition and mean weight of cod is given in fig. 3-4.

Conclusions

The developed model STOCOBAR is intended to improve the management of cod stock exploitation taking into account the effect of species interactions and ecosystems factors. It

can be used both for the prediction of cod stock dynamics and for the model analysis of various fisheries strategies.

Besides, STOCOBAR model can be accepted as conceptual and structural basis to develop ecosystem model of the Barents Sea designed for fisheries purposes. The development of STOCOBAR based model that describes interactions between capelin and cod can be the first step forward. In this model, capelin stock dynamics shall expose not only the effect of harvest but also predation of cod. It will allow us to make both quantitative estimation of the effect of cod fisheries on capelin stock dynamics and estimation of effect of fisheries for capelin on cod stock.

It is suggested that the work on development of STOCOBAR model will be carried out according to the joint Russian-Norwegian research programme on estimation of long-term optimal yield of marine organisms in the Barents Sea taking into account species interactions and the effect of ecosystem factors. At the first stage of this programme, the developed model can be applied as analytical tool to analyse the variations of cod growth, maturation and cannibalism depending on capelin stock, water temperature and population abundance. The formalisation of these relationships based on model calculations will allow us to make relevant changes in the single species models that are used to analyse the effectiveness of harvest strategies for cod, which in its turn will make these models more true to life.

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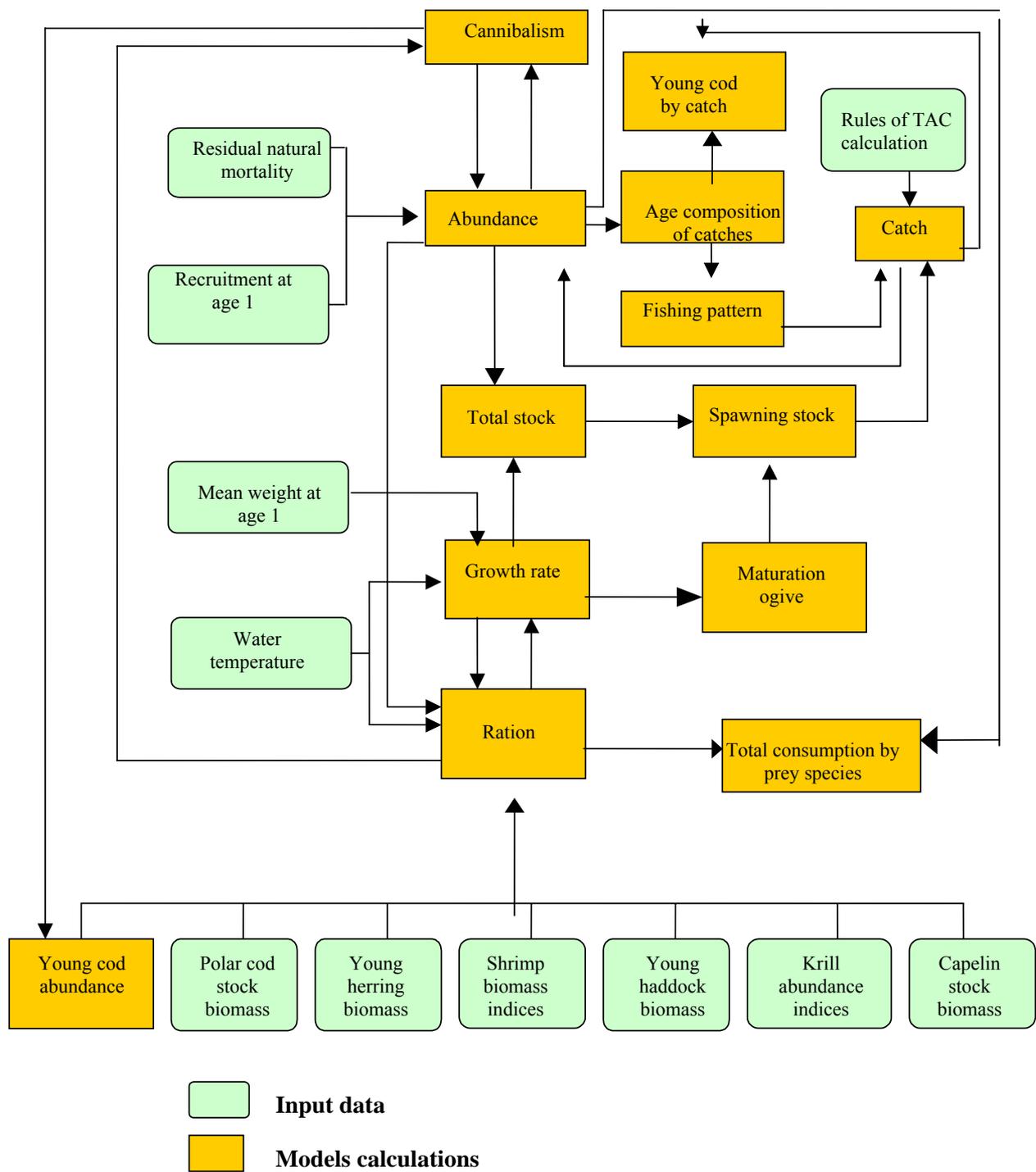


Fig. 1. A scheme of functional links realized in the STOCOBAR model

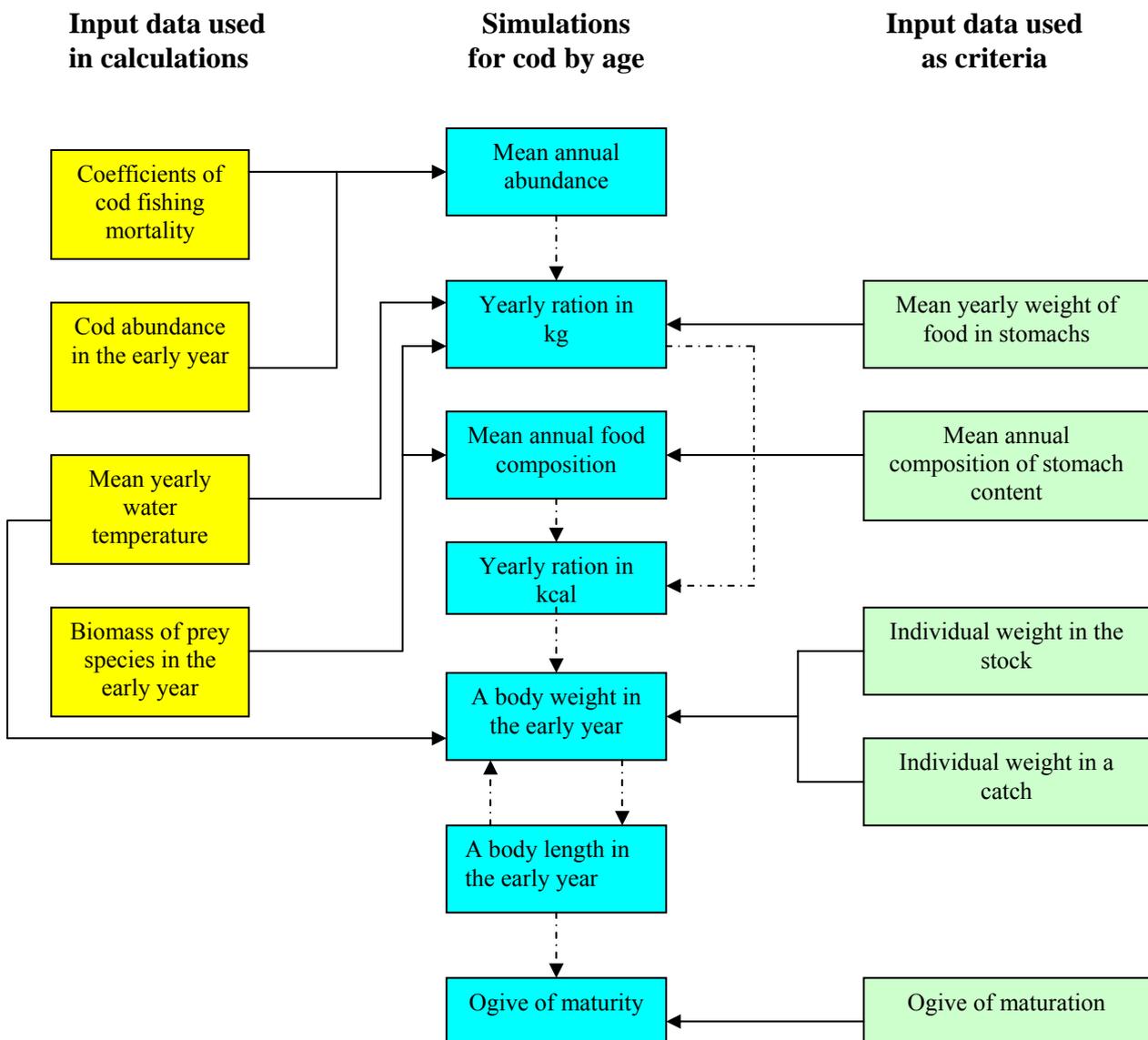


Fig. 2. A scheme of calculations and input data used at the model tuning with 1-year time step

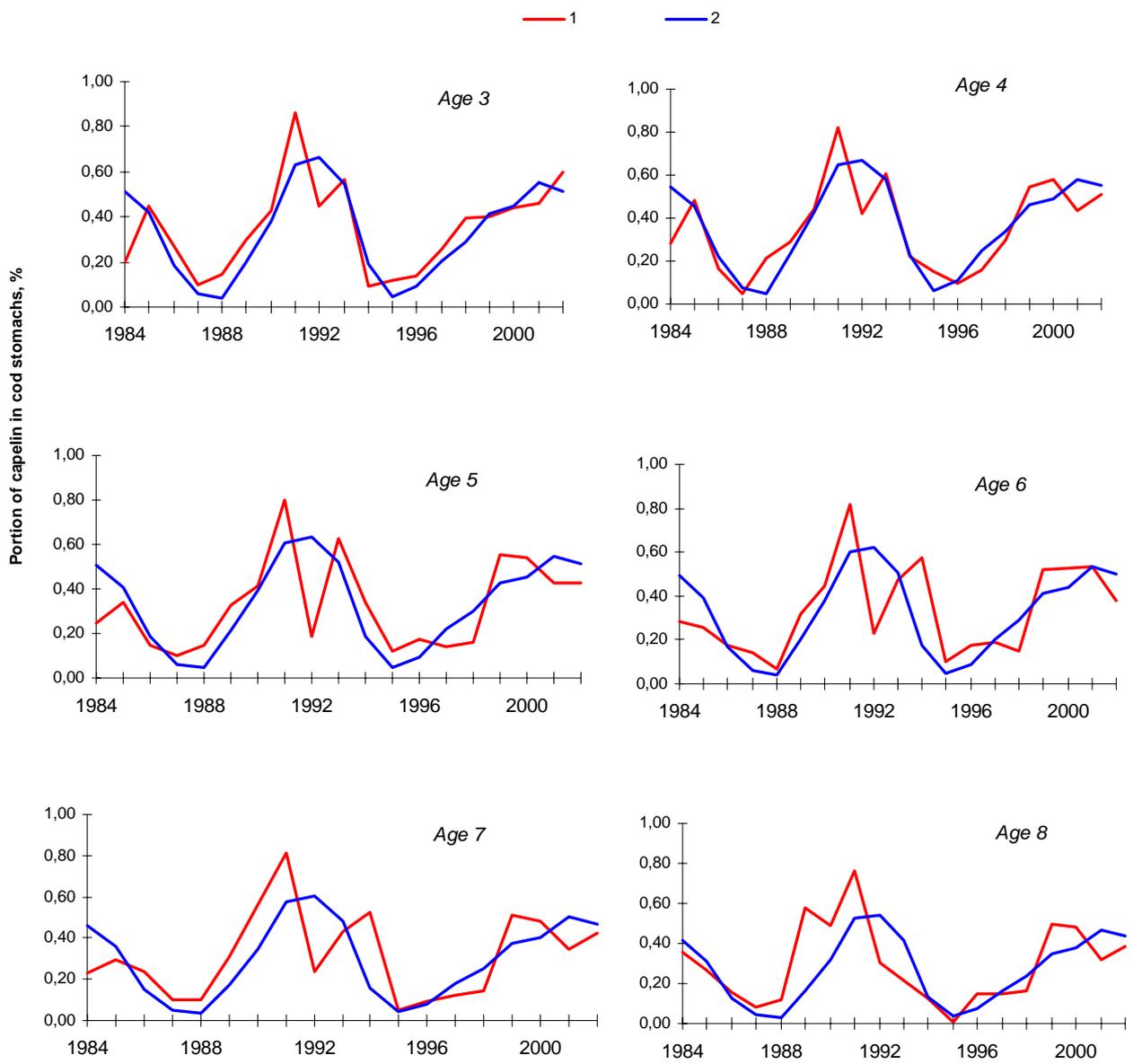


Fig. 3. Consistency between the observed and simulated portion of capelin in cod stomachs: 1– observed, 2 – simulated

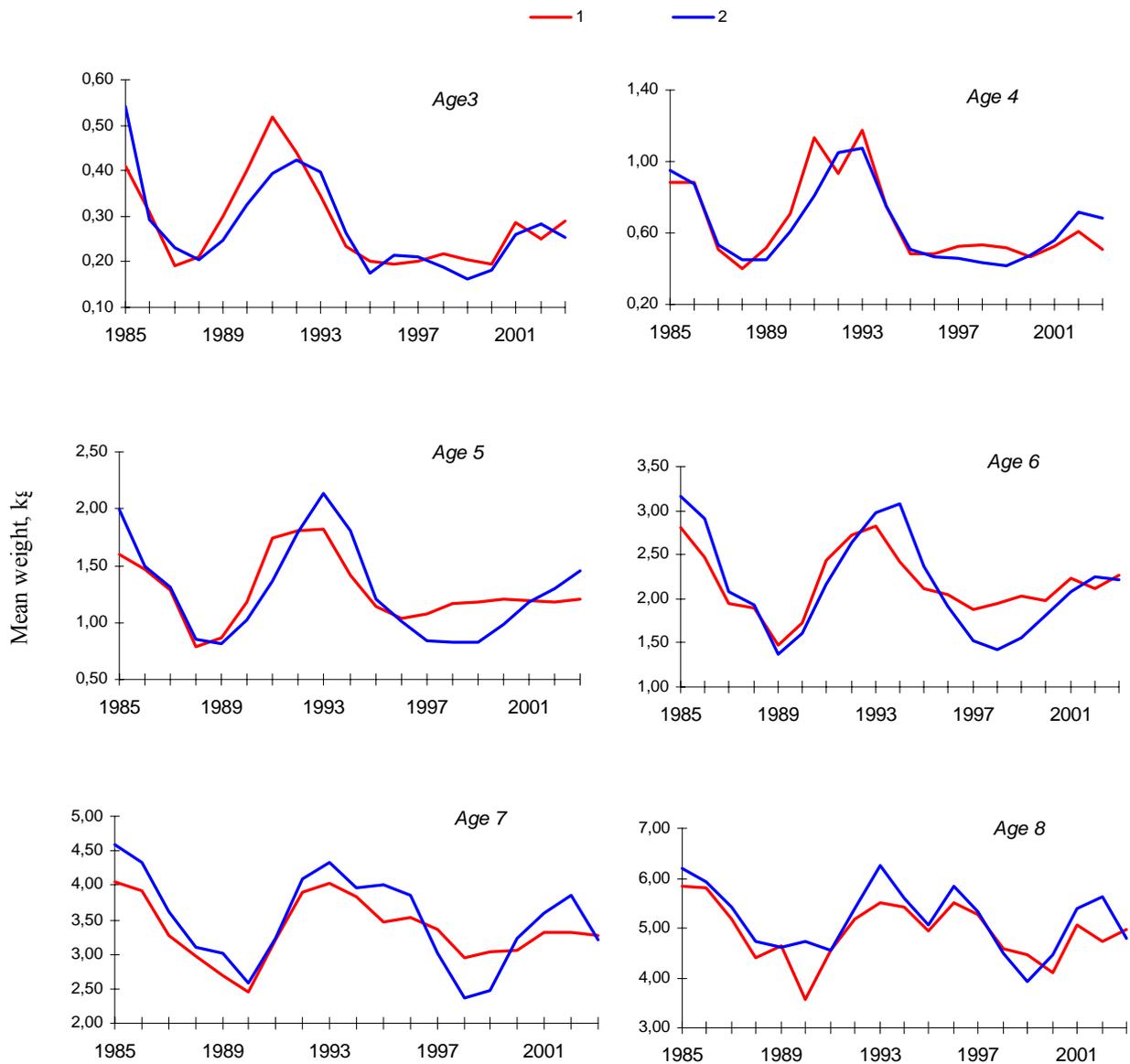


Fig. 4. Consistency between the observed and simulated cod growth rates achieved during tuning the model: 1 – observed, 2 – simulated

STRUCTURAL CHANGES IN THE PLANKTON COMMUNITIES OF THE BARENTS SEA UNDER THE INFLUENCE OF BIOTIC AND ABIOTIC FACTORS

by

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When studying biological resources of seas, plankton is historically considered as a part of the pelagic biota, trophically connected with the latter one. Analysis of the component composition of the zooplankton community is paramount at determining of its functioning system, the production level, as well as at the assessment of the mass plankton-eaters' food base, the most of which are the commercial objects or serve as a food for organisms of the higher trophic levels. The most mass groups in the Barents Sea are copepods, euphausiids, amphipods and chaetognaths.

Objects of the traditional investigations are copepods and euphausiids. The first ones are the main food for larvae and young commercial fish, including herring, as well as for adult plankton-eaters (capelin, polar cod and blue whiting). Euphausiids have a wider circle of consumers, as follows: young and adult Gadoidae, pelagic fishes, marine mammals and birds.

Hyperiid were investigated to a less extent. Only in the end of the previous-beginning of the present century they attracted the attention in connection with the increase of abundance and a role in the feeding of marine organisms of various trophic levels (Drobysheva and Nesterova, 1992; Dolgov, 2000, 1995; Dalpadado, 2002; Orlova et al., 2003, 2004a,b).

There are a lot of data on the population structure and abundance of chaetognaths and on the local and seasonal differences of life cycles of these animals in the Arctic seas (Kaufman, 1967; Bogorov, 1974; Mishin and Adrov, 1980; Pearre, 1981; Timofeev, 1990, 1994; Falkenhaus, 1993). The food requirements of chaetognaths were investigated under different temperature conditions (Mironov, 1960; Cospere and Reeve, 1975; Falkenhaus, 1991). Morphological peculiarities of the *Sagitta* digestive tract structure permit them to use large prey as a food, which exceed in size the *Sagitta* themselves. They are very active and gluttonous predators, and their influence on the plankton community is quite big. The main prey species of *Sagitta* are copepods and tunicates. A daily consumption of copepods by the adult individual of *Sagitta elegans* can reach 75 mg in dry weight (Falkenhaus, 1991). At the same time, *Sagitta* themselves very rarely become prey.

The aim of the given paper is to investigate the long-term dynamics and structural peculiarities of the Barents Sea plankton communities and a role in them of both biotic and abiotic factors.

Materials and Methods

Materials of annual surveys of macroplankton carried out in the Barents Sea in autumn/winter with the use of a pre-trawl net in the pre-bottom layer (6-10 m from the bottom) are used. Under the quantitative assessment the index of abundance was calculated as a mean arithmetic value of catches expressed in individuals/1000 m³ per 1 trawling hour.

Results and Discussion

The abundance of macroplankton organisms fluctuated very much during the recent 20-year period. The largest fluctuations were observed in euphausiids both in the southern and northwestern sea (Fig.

1). Maxima and minima of euphausiids' abundance coincided with the sharp fluctuations of the stock size of their main consumer – capelin. Besides, large-scale climatic fluctuations also influenced the dynamics of abundance of warm-water and cold-water species and their spatial distribution. Beginning from 1999-2000 a quite high and stable abundance of these crustaceans has formed. Probably it was a result of the influence of two mentioned above factors: large-scale decrease of the capelin stock value (at the simultaneous diminishing in the population of a portion of fish of older age groups, which are the main consumers of euphausiids) and a stable warming up accompanied by the intensification of the Atlantic waters advection.

In spite of the lower concentrations of euphausiids in the autumn-winter period of 2003 (compared to warmer year of 2002), the distribution of crustaceans was wider (Fig 2). Density of their concentrations in the northwest was comparable with that in the southern sea including the most productive coastal areas. Minimal concentrations of euphausiids were traditionally registered on the Great Perseus Bank and the Eastern Basin. At the same time, it should be mentioned that sampling in two latter areas in all years of investigations was insufficiently complete that influenced the concentrations values. This is proved by data for 2004. When investigating the northern areas (78°N), the density of the euphausiids concentrations exceeded 5 000 individuals/1 000m³ (Fig. 3).

Recent years, data on the species composition of euphausiids also prove a large importance of the warm-water species inflow. In 1999-2000, a big inflow of the boreal species *Meganyctiphanes norvegica* in the southern part of the sea was registered (Drobysheva et al., 2003). A big number of crustaceans of this species was observed in the southern part of the sea in 2001 as well. In 2002 and 2003, diminishing of the *M. norvegica* portion under the simultaneous increase of abundance of the other warm-water species *Thysanoessa longicaudata* (9-12 % in 2003) was observed. The relative abundance of *T. longicaudata* was approximately at the same level in 2004 (Fig. 4).

Dense local near-bottom euphausiids concentrations (> 1000 ind./1000 m³) were observed in the northern part of the Hope Island area in October 2004. The maximal catch was recorded at 77° N 28° E (6806 ind./1000 m³), the minimal one – at 76° N 25° E (14 ind./1000 m³). On the whole, in the area, the abundance of wintering stock of euphausiids was at the high level. The mean index of euphausiids abundance made up 771 ind./1000 m³.

Thysanoessa inermis was a dominant species among euphausiids – 92 % of the total abundance of euphausiids in samples. Relative abundance of *T. longicaudata* made up 5 %, *T. raschii* – 3 %, and *M. norvegica* – 0,3 % (Fig. 5).

Individuals of *T. inermis* and *M. norvegica* at age 2+, with the length of 20-28 and 30-40 mm, respectively, and of *T. longicaudata* aged 0+, 8-11 mm in length, prevailed (Fig. 6). The population of *T. raschii* was represented by one-year-old and two-years-olds (15-26 and 22-27 mm, respectively). The youngest age groups of *T. inermis*, *T. raschii* and *M. norvegica* were not observed virtually in the catches by a net attached to the trawl net.

By data of the pre-trawl net, the abundance of hyperiids (*Themisto*) is lower than that of euphausiids (Fig. 1). Two species dominate in the Barents Sea: a smaller one *Th. abyssorum* and a large Arctic species *Th. libellula*. The largest abundance fluctuations of this group of crustaceans were registered in the southern sea, where the first species dominates. However, there are two reasons to believe that catches in the low layers reflect the density of hyperiids concentrations inadequately. Firstly, the large *Themisto* are able to avoid the fishing gear; secondly, they stay for a long time in the water column. There, hyperiids feed on *Calanus* and compete with capelin because of them. Therefore, at a disastrous decrease of capelin stock in 1986-1987 an outbreak of hyperiids abundance took place. This influenced the cod feeding. Cod consumed regularly the grown young and adult crustaceans *Th.*

libellula in autumn 1987 (Table 1). In the other years a high level of consuming of *Themisto* by cod was registered in the northwest at their values of 25-29 % (1986, 1987 and 1996) and 6-10 % by weight (1984, 1993-1995, 1998 and 2000). By data of recent years (Figs. 2 and 3) and in warm years, hyperiids have quite high abundance, especially in the northern areas, where *Th. libellula* dominate.

The well-expressed nonlinear trends are present in the interannual dynamics of Euphausiidae and Hyperiididae abundance indices (transformed by finding of the decimal logarithm) for the southern part of the sea. Their contribution into the total variability of these indices constitutes 30-32 %. It is possible that the similar tendency was in the fluctuations of the Chaetognatha index of abundance (Fig.1). In the northwestern part of the Barents Sea, a linear trend was revealed only in the Euphausiidae variability. It takes about 40 % of the summarized dispersion. The rest species of the macroplankton have no such a trend.

The macroplankton abundance nearby the bottom in September has well-expressed intra-daily fluctuations. In all three species the largest abundance is observed in the morning and daytime (Fig. 7). At night, their quantity is much less, that can justifies on their migration into the water column. However, data collected in October-November show that the expressed differences in the macroplankton abundance between the dark and daytime are absent (Fig. 8), that means that migrations of the main mass of crustaceans are terminated. In that period their availability for fish is maximal.

Compared to euphausiids and hyperiids, which play an important role in the trophic structure of the plankton community, chaetognaths are weakly used as food by plankton-eaters (capelin, herring). It probably is connected with a high level of their provision with more favourite food (copepods and euphausiids) under diminishing of fish abundance and with a sharp decline in the capelin population of fish of older age groups. In the mature capelin chaetognaths constituted up to 20 % of the mass of food in the feeding period in the northern areas (the 1970's). By our data (Fig. 9), which prove the data of S. F. Timofeev (1994), the population of *Sagitta. elegans* in the northern areas (76-78°N) is characterized by the 3-year life cycle, farther to the south – by the 2-year cycle that supposes the presence of larger individuals in the north.

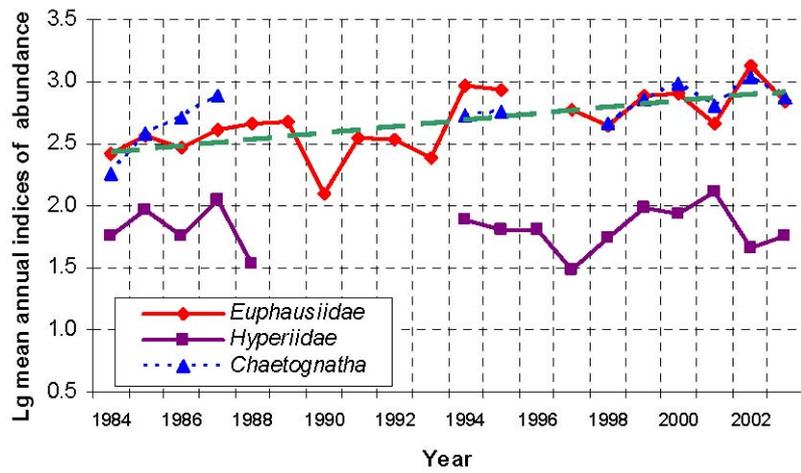
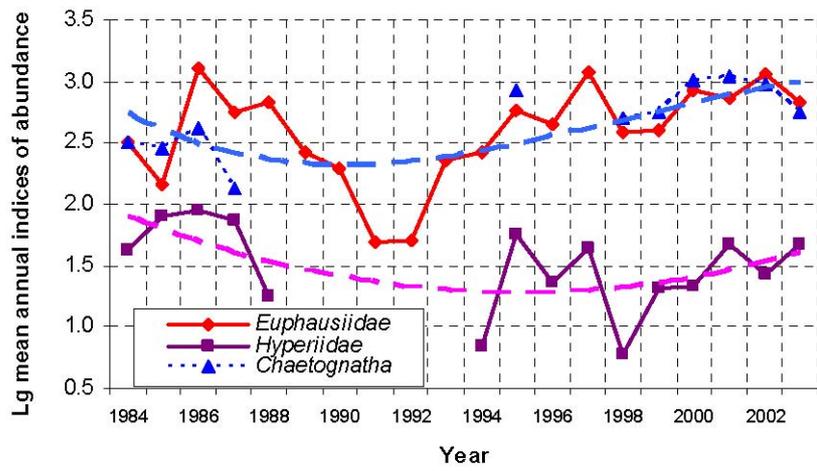
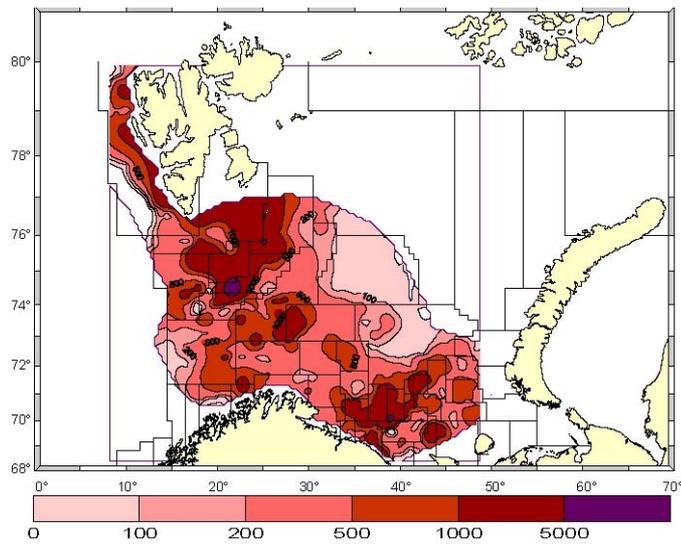
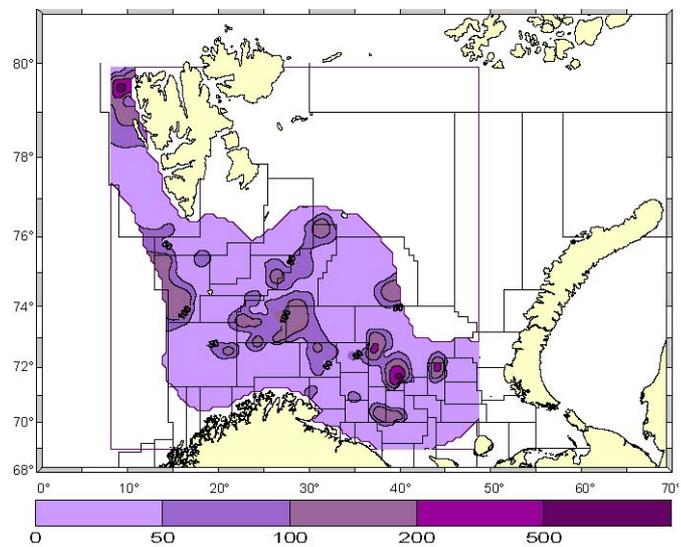


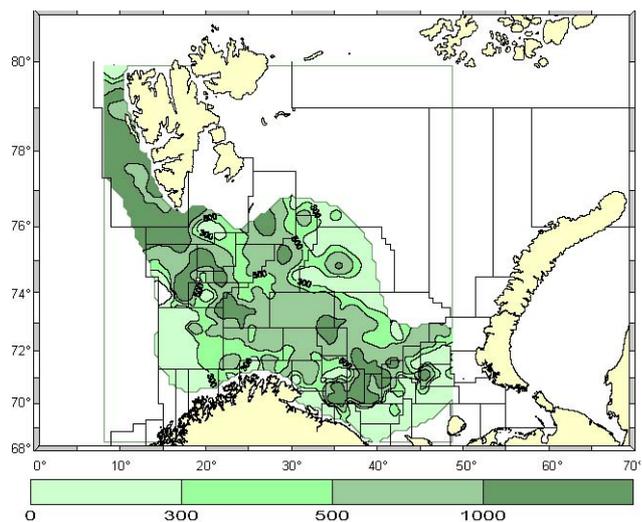
Fig.1. Dynamics of mean annual indices of macroplankton abundance in the Southern (A) and Northwestern (B) parts of the Barents Sea in October-February



A

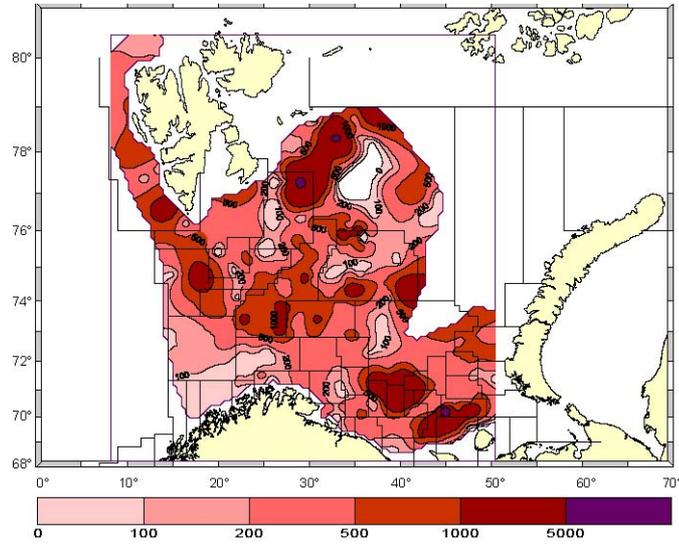


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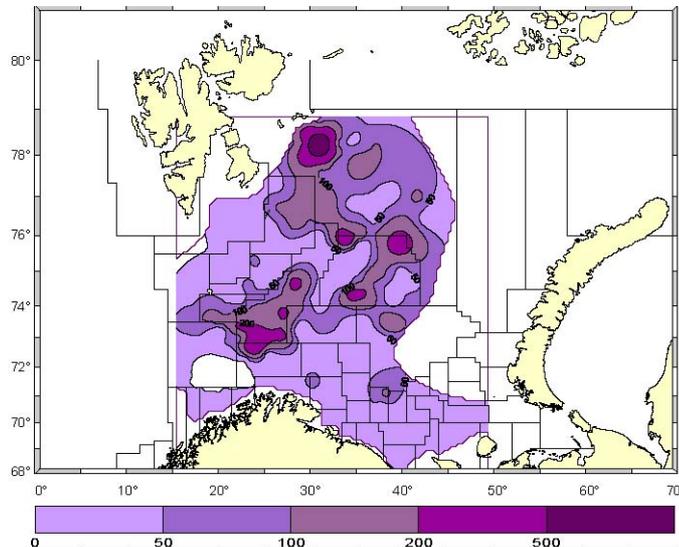


C

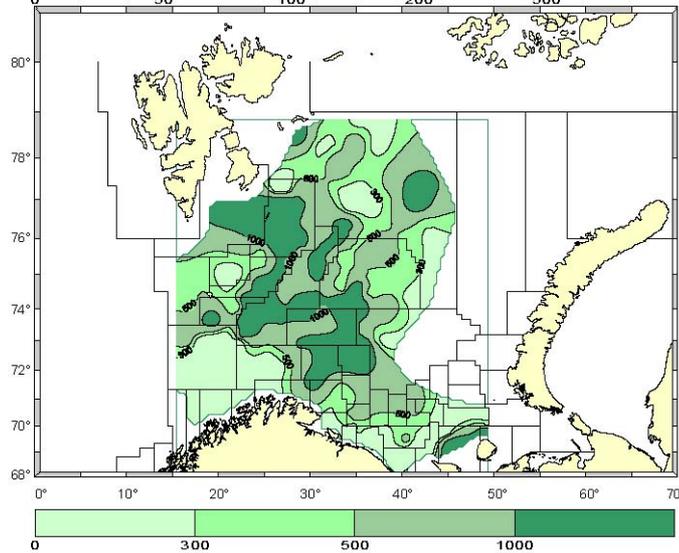
Fig.2. Distribution of euphausiids (A), hyperiids (B) and arrowworms (C) in the near-bottom layer in October-February 2003/04, ind./1000 m³ (by the data from the catches by a net attached to the trawl)



A



B



C

Fig.3. Distribution of euphausiids (A), hyperiids (B) and arrowworms (C) in the near-bottom layer in October-February 2004/05, ind./1000 m³ (by the data from the catches by a net attached to the trawl)

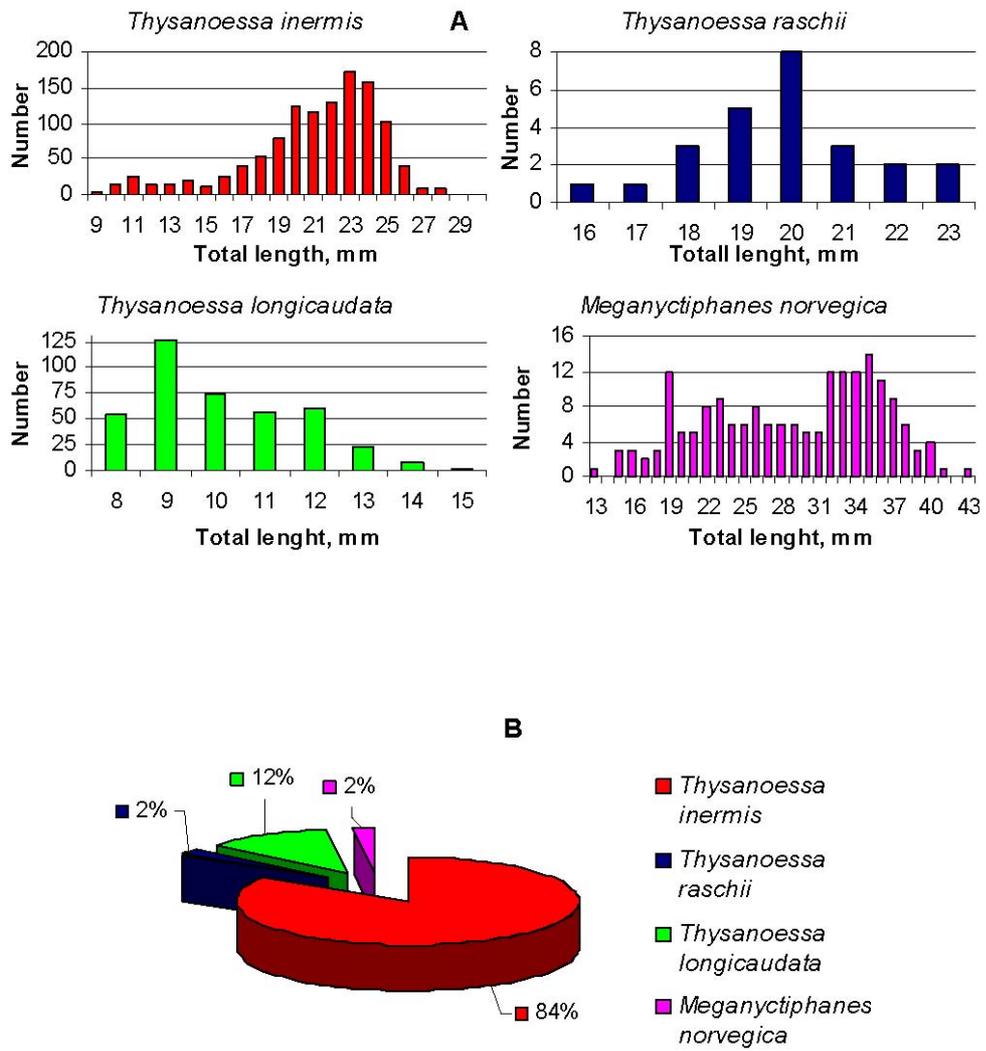


Fig.4. Size frequency (A) and species composition (B) of krill in the Northwestern areas of the Barents Sea in October-February 2004/05

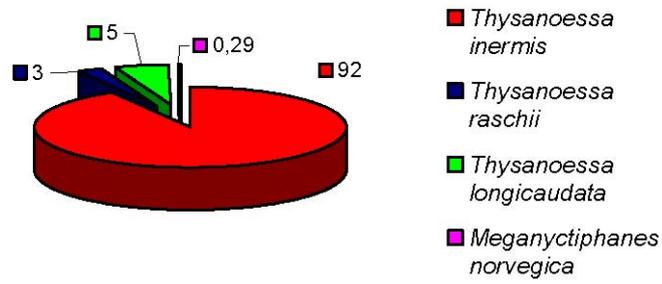


Fig. 5. Species composition of euphausiids in the area of the Hope Island in October 2004

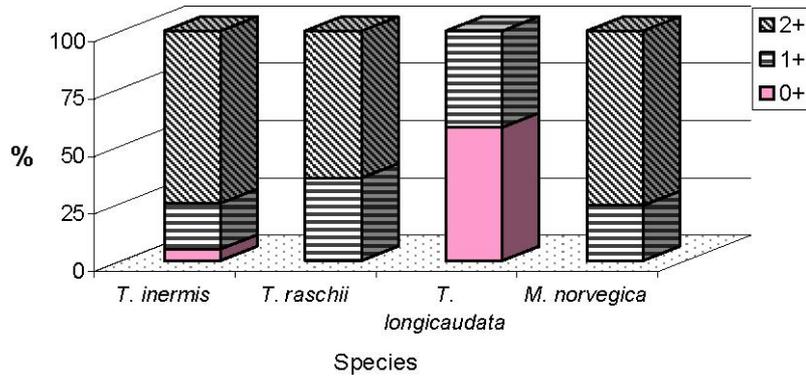


Fig. 6. Age frequency of euphausiids in the area of the Hope Island in October 2004

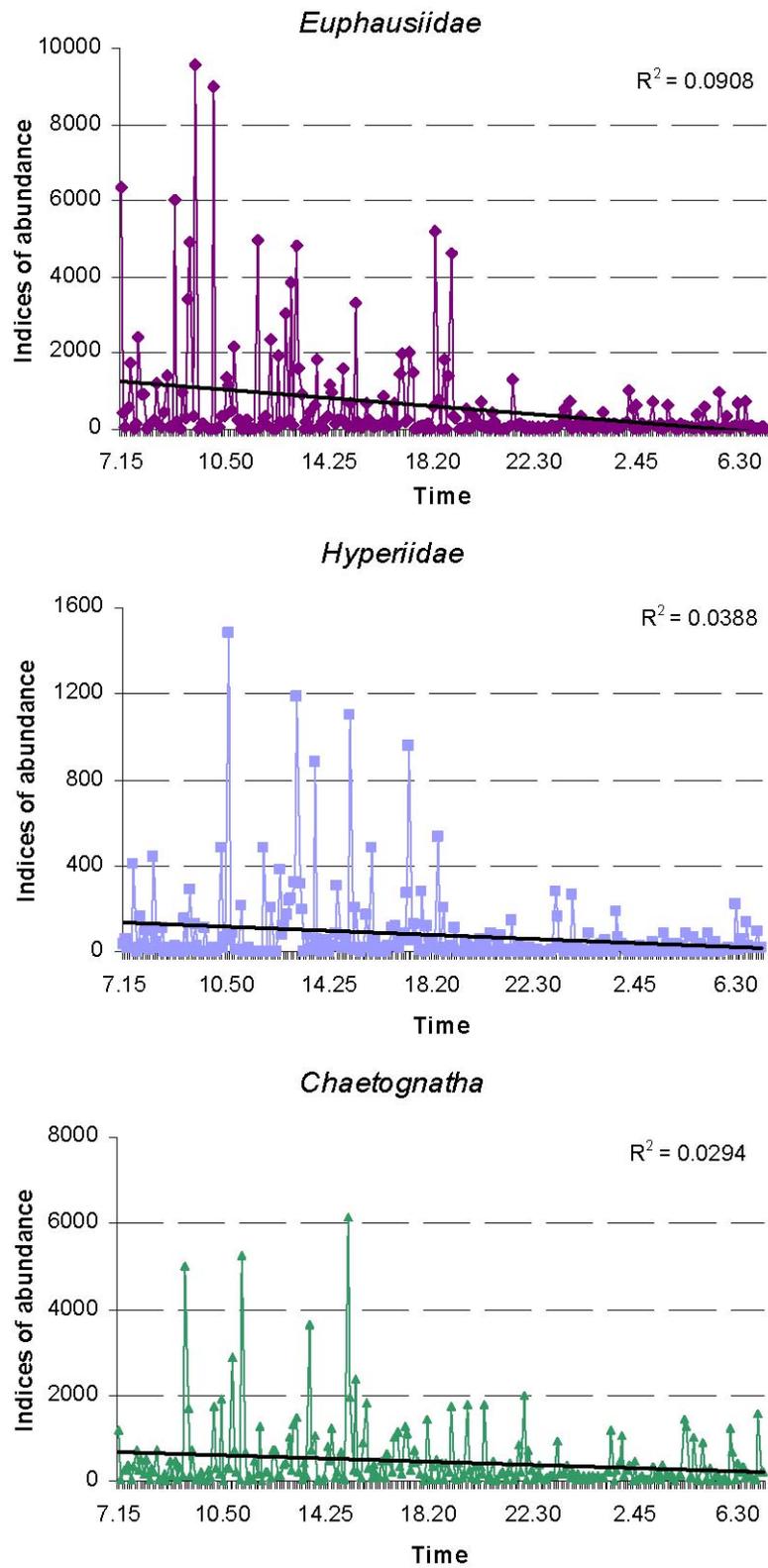


Fig.7. Distribution of macroplankton in the near-bottom layer in different time in September 1987 (by the data from the catches by a net attached to the trawl)

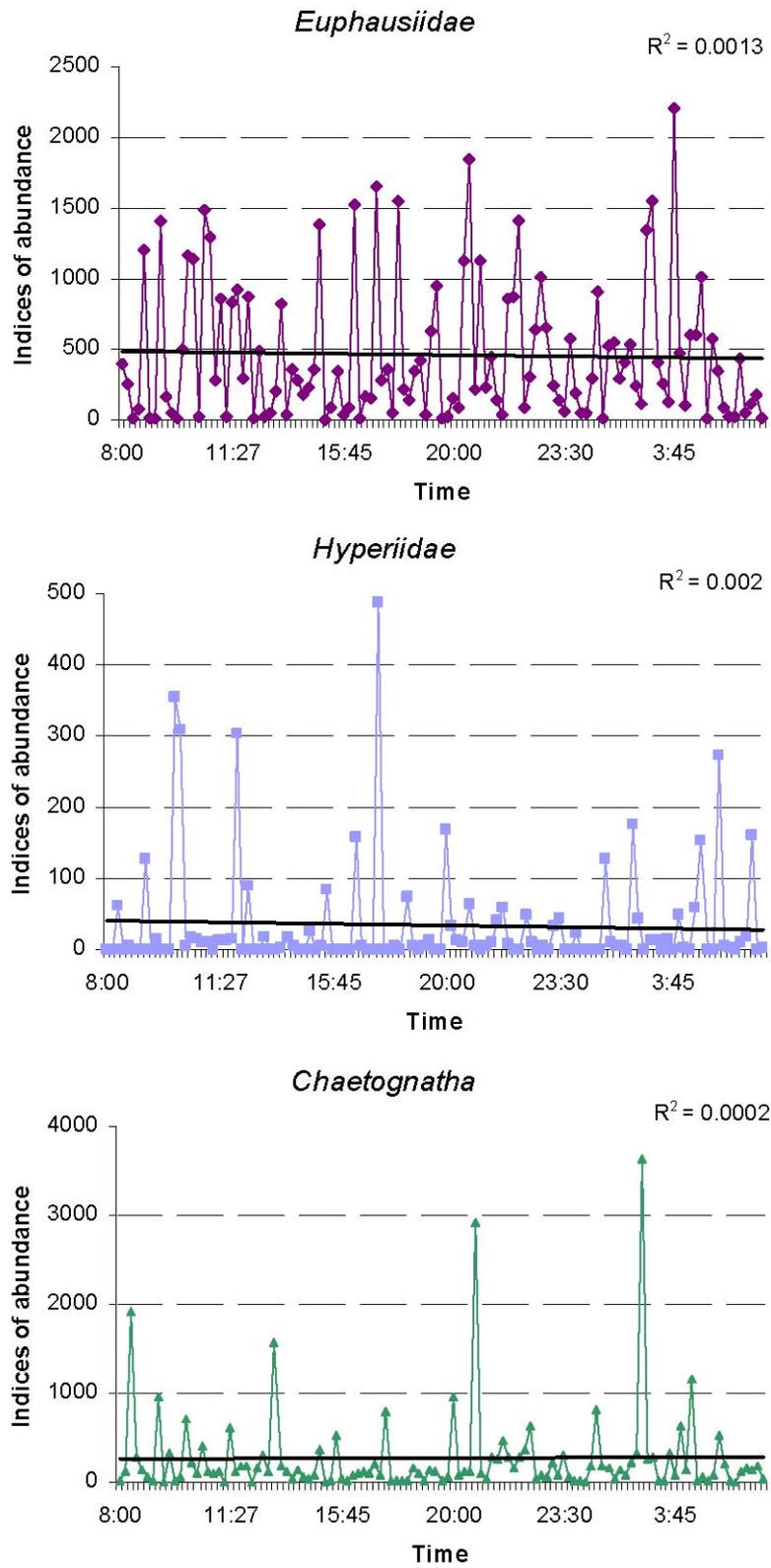


Fig 8. Distribution of macroplankton in the near-bottom layer in different time in October-November 1987 (by the data from the catches by a net attached to the trawl)

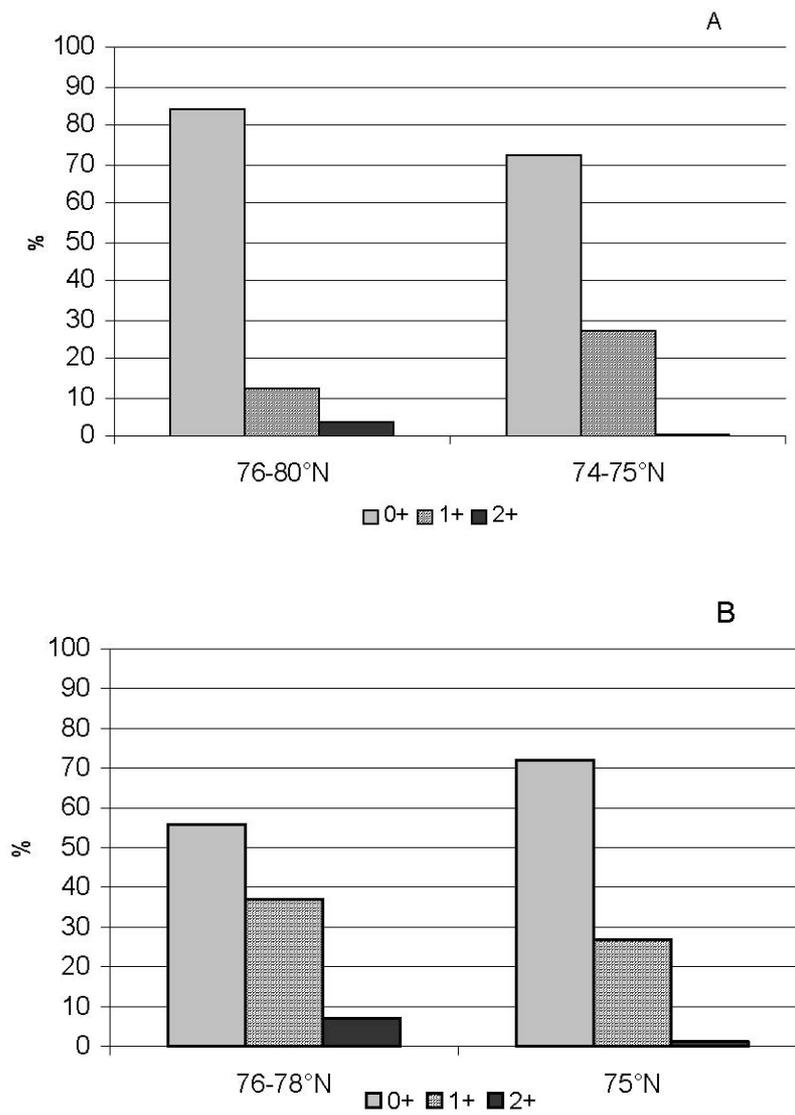


Fig 9. Age composition of Chaetognatha (0+ – youth, 1+ – growth youth, 2+ – adults) in the western part of the Barents Sea in July 1983 (A) and 1987 (B)

The significance of Th. libellula in the food of different size cod in 1985-1988

Month	Areas	20-40 cm			41-60 cm			61-80 cm		
		% of frequency	% by weight	Average length, cm	% of frequency	% by weight	Average length, cm	% of frequency	% by weight	Average length, cm
1985										
November	Western area	-	-	-	36.1	0.1	15	50.0	0.1	11
August	North-western area	28.6	6.3	15	61.1	34.4	13	22.2	0.3	10
August	Central area	63.6	7.6	10	57.1	1.9	11	-	-	-
August	Murman coast	100.0	47.2	20	13.3	5.8	10	-	-	-
1986										
August	Western area	14.0	2.0	10	17.0	1.7	10	-	-	-
August	North-western area	23.6	4.9	5	28.2	8.2	10	-	-	-
1987										
September	Western area	-	-	-	44.8	32.5	21	12.6	37.6	24
October		40.0	87.9	30	61.5	83.1	30	55.6	74.0	28
November		-	-	-	30.8	35.5	28	28.6	33.3	30
August	North-western area	40.0	93.8	20	55.3	52.7	19	71.4	22.0	17
September		25.0	91.0	20	42.1	44.4	21	-	-	-
September	Central area	-	-	-	-	-	-	25.0	13.2	25
November		-	-	-	6.2	0.2	16	3.1	0.1	15
October	Eastern area	66.7	47.6	30	69.7	51.9	28	50.0	38.8	30
1988										
August	Central area	5.5	0.7	20	23.9	10.4	17	33.3	10.5	20
August	Murman coast	14.3	1.0	18	-	-	-	-	-	-

Means lack of data.

THE INFLUENCE OF ENVIRONMENTAL CONDITIONS ON THE YEAR-TO-YEAR PECULIARITIES OF FEEDING, GROWTH AND SURVIVAL OF THE BARENTS SEA JUVENILE COD

by

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Introduction

It is known that the abundance of year-classes entering fishery depends on juvenile cod survival at the stage from 0+ to 2+ (Ponomarenko, Mukhina, 1998). Fish survival at some stages of life history is different. The most critical periods in the life of fish are: the period of embryo emergence from eggs, larva transition to independent feeding and the biotope change by juveniles. Cod fry going from pelagial to the sea bottom layers starts in August-September. At present, the questions on rates and duration of juvenile cod settling period, the change of its biological parameters at this time, feeding and others have remained to be under discussion (Sysoeva, 1972; Wiborg, 1949).

The paper is aimed at studying biological parameters and their variability, feeding and survival of cod fingerlings from 2002-2003 year-classes when fish change the pelagic mode of life to the bottom one.

Material and methods

In August-September 2002 and 2003, Russian data from international survey for assessment of 0-group fish abundance were used. In October-December 2002-2003, analyzed were the data from Russian TASs to estimate the stocks of the main commercial fishes in the Barents Sea. In February 2003 and 2004, Russian data from TAS for joint Russian-Norwegian methods were applied.

Length, weight and their increments, food composition, stomach fullness index (SFI), fatness and Fulton's condition factor of fingerlings were studied separately by seasons (from the first ten-day period of August to the late September, from the last ten-day period of October to the late December and for February). The stomach content of 3740 fish was analyzed.

To analyze growth chosen were the two time intervals: from 15 August to 15 November and from 15 November to 15 February if we assume that fish grew with a constant rate within the studied period (Ozhigin et al., 1996).

The paper uses Russian the data on the abundance of cod fingerlings from 2001, 2002 and 2003 year-classes (Anon., 2003). Calculations of the survival of fingerlings aged to three and the forecast of their abundance at this age were made according to the equation proposed by I.Ya.Ponomarenko (1979).

To analyze the effect of water temperature on growth and feeding of cod fingerlings the fishing areas were integrated into groups by distribution of dominating water masses entering the Barents Sea (Fig.1).

Weighted means of water temperature in 0-50 m (August-September) and bottom (October-December, February) layers were calculated and the charts of spatial distribution of temperature were made for the area groups separated. The thermal condition was estimated on the whole and separately by seasons and water masses in 2002-2003 and 2003-2004 and they were compared by the difference of average temperatures.

The paper uses statistical methods of correlation analysis. All the initial data were processed applying software “Surfer”, “Excel” and “Statgraf”.

Results and discussion

Biological data on fingerlings of cod from 2002 and 2003 year-classes by seasons

When fish grow their biological parameters change. From August to February the increase in mean length and weight of fingerlings against the decrease in their fatness and condition was observed (Fig.2). Fish index of fullness (IF) was also reducing from August-September to October-December (especially intensively in fingerlings from 2002 year-class) and somewhat rising by February. Average length and weight of 2002 year-class fingerlings were higher while their condition was lower than of those ones from 2003 year-class.

The greatest difference between maximal and minimal biological parameters of fingerlings was recorded in October-December (Fig.3). Such variability is connected with a quality of fish from a single year-class (Drebuadze, 2001) and the environment impact (Alev, 1980). The population of the northeast arctic cod has a multiage structure of spawners and a long spawning period that, undoubtedly, affects all the biological processes of the following year-classes. In our opinion, the decrease in the range between the minimal and maximal biological parameters of fingerlings from the stage of a pelagic fry (August-September) to the true bottom juveniles (February) is a result of adaptation to the new conditions of living that leads to the natural selection of more adaptable individuals. Usually in a year-class having survived are larger fish that results in smaller range of mean biological parameters. Variations of cod fingerling biological parameters are connected with the change of their growth.

The growth of cod fingerlings when biotope changes

Cod is characterized by isometric growth, which is the most intensive in the first year of life. The closest links between weight and length of cod fingerlings were observed in April-September and February (Fig.4). This relationship becomes weaker in October-December. Different factors may be the reason of such variations. We calculated a relative increment of length and a specific rate of fingerling weight growth by each season in different water masses of the southern Barents Sea (Table 1). The analysis of the data revealed the total trend in changes of parameters of cod fingerlings from the given year-classes. Linear weight increments of fingerlings abruptly reduced in all the water masses from November to February. The highest values of growth were registered in the areas of coastal and main

branches of the Murman Current influence. A relative length increment and the weight growth specific rate of 2003 year-class were somewhat higher than those ones of 2002 year-class.

To clarify the reasons of the reduction in linear-weight increments and other biological parameters of fingerlings we studied food and temperature factors.

Food composition of fingerlings in different seasons

From August to February, euphausiids, fish, hammarids, hyperiids, polychaetes and copepods occur in cod feeding the most often (Figs.5, 6).

In August-September, the diet of fingerlings consisted of, mainly, euphausiids and different juvenile fish among which larvae and juveniles of capelin, herring, polar cod, sand eel, gobies and eelblennies prevailed. The diet was quite various: the category of “other marine organisms” (to 25 %) was represented by juveniles of different shrimps and crabs, mysids, cladocerans, mollusks, chaetognates, appendicularies, ctenophores.

In October-December, in the ration of fingerlings the representatives of bottom fauna – gammarids and polychaetes appear. Hyperiids were a secondary feeding object since their weight portion in the stomachs of juveniles from both year-classes did not exceed 12% though the frequency of occurrence corresponded to 15%.

In February, the specific composition of fingerlings did not significantly change as compared to the previous period, having changed were only a qualitative ratio of food components in year-to-year aspect and the significance rate of some kinds of food.

Water temperature and biological parameters of fingerlings in the period of the biotope change

The influence of water on growth of cod and their juveniles was noticed by many authors, at this, the most of them pointed out to the presence of positive links (Anon., 1996).

From August to November an abrupt reduction in growth rates of cod fingerlings was observed. In these periods an active cooling of the Barents Sea water masses takes place (Tereschenko, 1999) that is traced well by seasons (Fig.7).

From August to February, water temperature reduced in all the water masses. The most intensive cooling was in the effect area of the central branch and along the main one in the Murman Current from August-September to October-December. In 2002, in the Central Current and the main branch of the Murman Current the difference in temperature between August-September and October-December reached 5.29°C and 4.44°C, in 2003 – 5.43°C and 4.15°C, respectively.

In 2002 and 2003, from August to February, in the southern Barents Sea, the most favourable temperature conditions were observed in water masses of the coastal branch in the Murman Current (Fig.7b). There, a high positive water temperature was registered in all the seasons. The most unfavourable temperature conditions for the life of fingerlings in the southern part of the sea were in the influence areas of the Central Current.

Table 1. Linear and weight growth of cod fingerlings from 2002-2003 year-classes in different seasons.

Currents	2002 year-class				2003 year-class			
	Relative length increment, %		Specific rate of weight growth		Relative length increment, %		Specific rate of weight growth	
	от 15.08.02 до 15.11.02	от 15.11.02 до 15.02.03	от 15.08.02 до 15.11.02	from 15.11.02 to 15.02.03	from 15.08.02 to 15.11.02	from 15.11.02 to 15.02.03	from 15.08.02 to 15.11.02	from 15.11.02 to 15.02.03
Murmansk (coastal branch)	43,4	2,7	0,097	0,001	58,2	0,1	0,119	0,001
Murmansk (main branch)	44,4	6,7	0,097	0,011	41,4	5,0	0,109	0,011
Novaya Zemlya and Kanino-Pecherskoe	34,6	1,9	0,065	0,011	24,4	2,6	0,033	0,022
Central	31,3	5,5	0,076	0,001	34,2	5,1	0,076	0,001
North Cape (north and central branches)	28,9	-*	0,054	-	16,7	-	0,033	-
Average by areas	34,2	3,8	0,076	0,005	35,6	4,5	0,087	0,008

*Data were not collected.

In the southern Barents Sea, in the seasons of 2002-2003, the temperature conditions, on the whole, corresponded to the level of the normal ones, in the seasons of 2003-2004 – to that one of anomalous warm years. There is a considerable positive relationship between water temperature in the different water masses of the Barents Sea and the growth of fingerlings (Fig.8). The more water temperature in the previous season, the higher growth rates of fingerlings. The highest linear weight increments of fingerlings were observed in the areas of the Murman Current coastal and main branches.

Temperature affects fish growth through the changes in the intensity of metabolism, which, in its turn, determines fish behaviour. By our data, in the period of biotope change, as a result of sharp reduction in water temperature, the physical activity of cod fingerlings decreases that leads to the feeding intensity decline and the rise of the non-feeding fish portion. In October-December, these two parameters are the lowest (Fig.2). We assume that in October-December fingerlings have not adapted to the sharp change of temperature conditions. Growth rate deceleration and lowering of mean biological parameters are often observed both in natural conditions, and in aquaculture (Brett, 1983).

Calculation of three-year-old cod abundance using the data from the assessment of their fingerlings

The north-east arctic cod is characterized by a high mortality during the first three years of life (Mukhina, Marshall, Yaragina, 2003). The ratio of the average catch of three-year-olds per a hauling hour to the mean catch of fingerlings from the same year-class was taken as an index of juvenile survival in some year-classes. This index does not characterize absolute survival of year-classes, but allows us to give a comparative quantitative estimate of different year-class survival in the same period. Used was a forecast equation of multiple correlation (1) including only biological arguments:

$$Y = 15.05x_1 + 1.112x_2 + 0.017x_3 - 16.789 \quad (1)$$

$$R_y(x_1x_2x_3) = 0.854 \pm 0.06$$

where Y – the index of juvenile cod survival at the stage of from fingerling to three year old age;

- x1 – mean condition factor of fingerlings in October-December;
- x2 – mean fatness of fingerlings in October-December, %;
- x3 – the rate of fish containing food in the stomachs

Applying this equation the survival indices of juvenile cod from 2001, 2002 and 2003 year-classes were obtained and then their abundance at age 3 was determined (Table 2).

Table 2. Survival indices (K_B) of cod juveniles and its abundance at age 0+ and 2+ in the southern Barents Sea (Area I)

Year-class	True abundance of fingerlings, ind. per hauling hour	Forecasted abundance of three-year-olds, ind. per hauling hour	K_B
2001	1	2	1.67
2002	20	23	1.15
2003	8	23	2.87

Obtained estimates of the three-year-old cod recruitment showed that 2001 year-class was poor, those ones of 2002 and 2003 were moderate in abundance. Considering favourable temperature conditions in the Barents Sea and a good state of fingerlings one may hope that the year-classes of 2002 and 2003 will remain at the level of year-classes, which are moderate in abundance.

Conclusions

1. When cod fingerlings change the biotope, starting is the period of adaptation, which shows itself in the decrease of feeding activity, fatness and condition of fingerlings that leads to deceleration of their growth. The indices of linear-weight increments of fingerlings sharply decrease from November to February.
2. One of the reasons of noticeable changes in the life activity of fingerlings is an abrupt change of temperature conditions in the period of their going from pelagial to the bottom layers. October-November should be considered as one of the critical periods in the life history juvenile cod in the first year.
3. From August to February predominating food objects in diet of fingerlings from 2002 and 2003 year-classes were euphausiids, fish, gammarids, hyperiids, polychaetes and copepods. Their ratio in feeding depended on season.
4. Based on the indices of fingerling condition and fatness, as well as the role of feeding fish the survival indices of fingerlings from 2001-2003 year-classes were obtained. The obtained estimates of the three-year-old cod commercial stock recruitment placed the year-class of 2001 as being poor while those ones of 2002 and 2003 as to be moderate in abundance.

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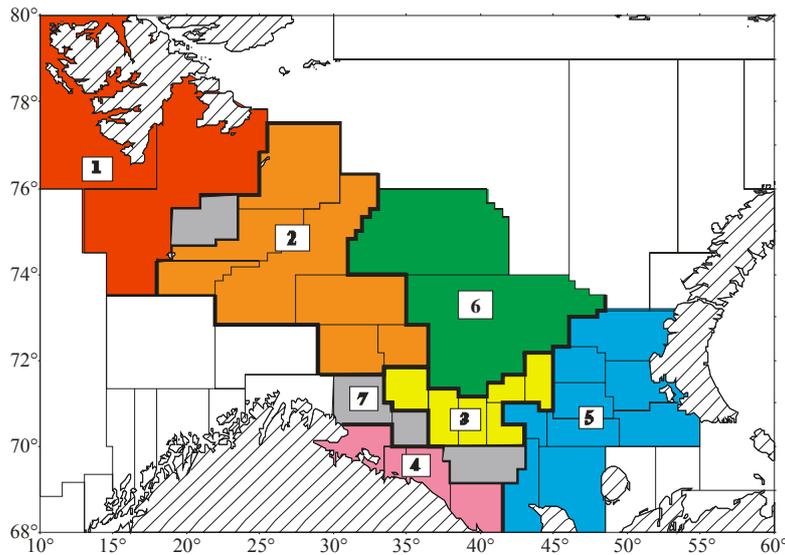


Fig.1 Areas of cod fingerling distribution by the main branches of the Barents Sea currents (Tantsura, 1973): 1- the Spitsbergen Current; 2 – the North Cape Current (northern and central branches); 3 – the Murman Current (main branch); 4 – the Murman coastal current; 5 – the Novaya Zemlya and Kanino-Pecherskoe Currents; 6 – the Central Current; 7 – areas not included into analysis

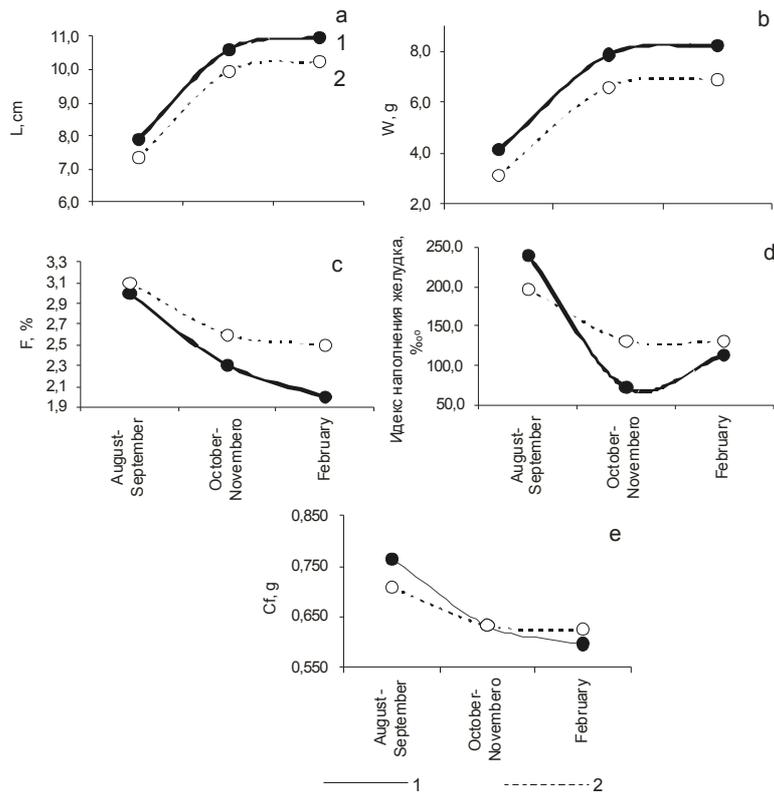


Fig.2. Variations of mean length (a), weight (b), fatness (c), stomach fullness index (d), condition (e) of cod fingerlings from 2002 and 2003 year-classes at the first year of life from August to February

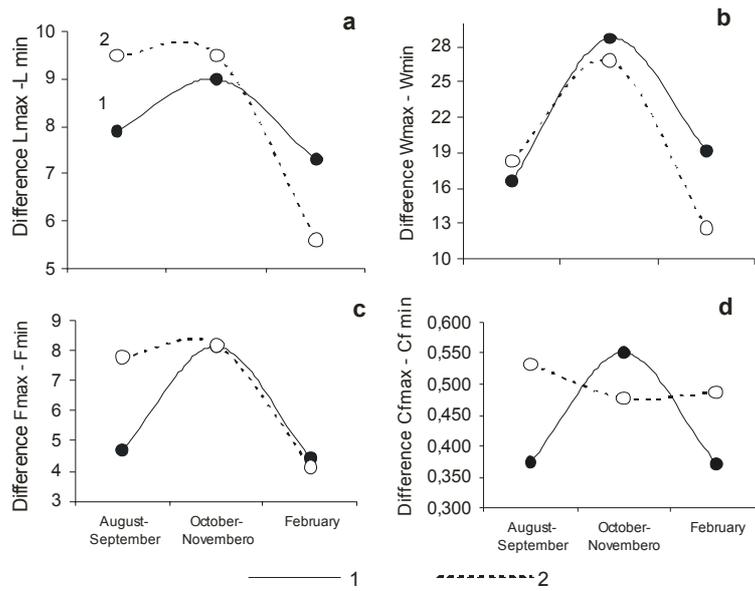


Fig.3. Dynamics of difference between maximal (max) and minimal (min) length (L, a), weight (W, b), fatness (F, c) and condition (Cf, d) of cod fingerlings from 2002 (1) and 2003 (2) year-classes

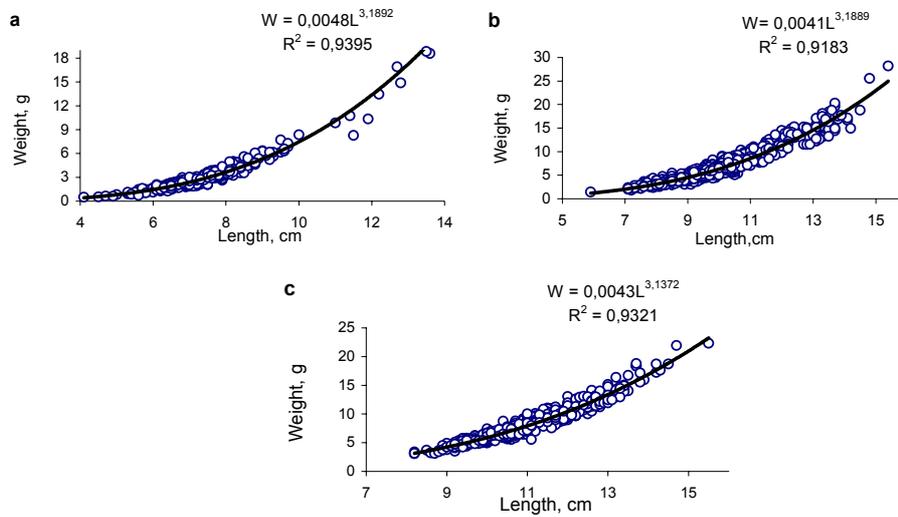


Fig.4. Dependence of cod fingerling weight on their length in August-September (a), October-December (b) and February (c)

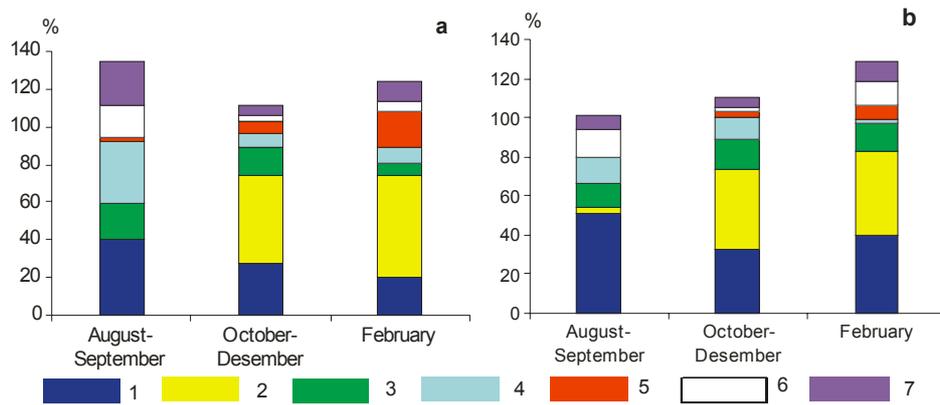


Fig.5. Food item occurrence frequency in stomachs of cod fingerlings from 2002 (a) and 2003 (b) year-classes in different seasons: 1 – euphausiids; 2 – gammarids; 3 – hyperiids; 4 – fish; 5 polychaetes; 6 – copepods; 7 – other marine organisms

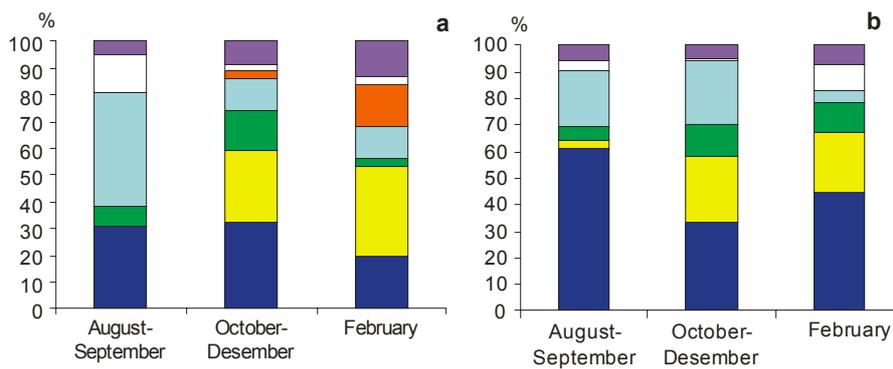


Fig.6. Ratio of main food items in stomachs of cod fingerlings from 2002 and 2003 year-classes in different seasons, % by weight in a bolus. Legends in Fig.5

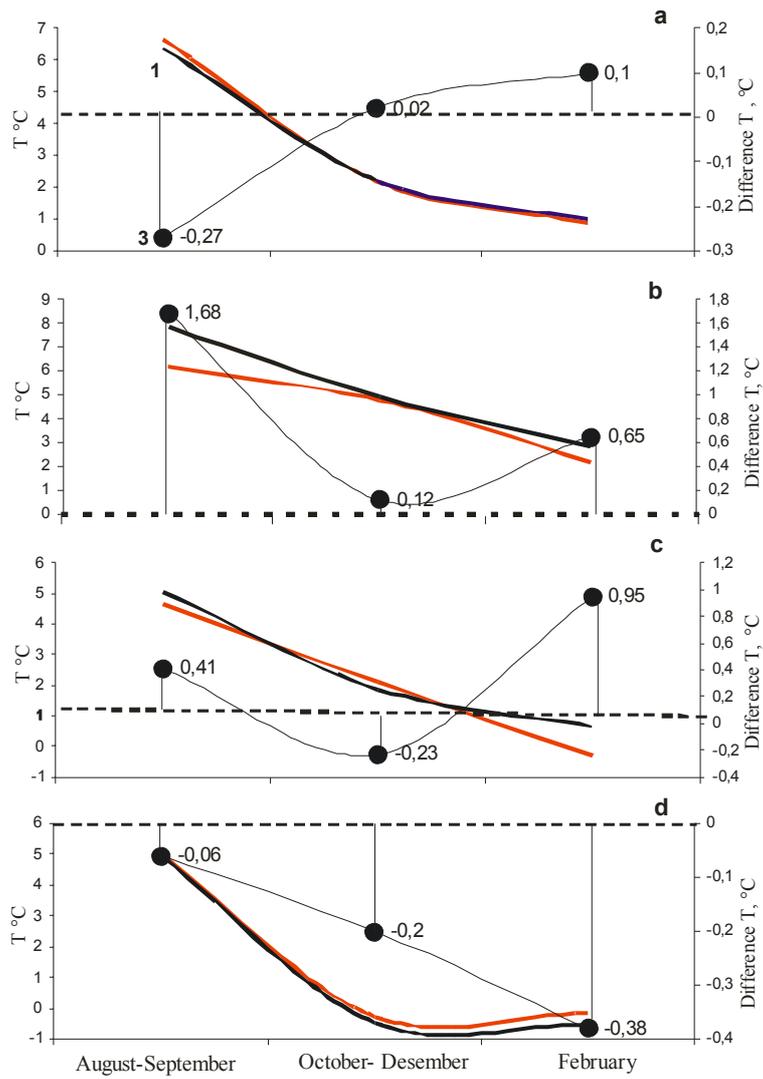


Fig.7. Seasonal dynamics of mean water temperature along the main (a) and coastal (b) branches of the Murman Current, in the Novaya Zemlya and Kolguevo-Pechyorskoe (c) and Central (d) Currents in the layers of concentration of fingerlings: 1 – year-class of 2002; 2 – year-class of 2003; 3 – difference of water temperature between seasons in 2003-2004 and 2002-2003

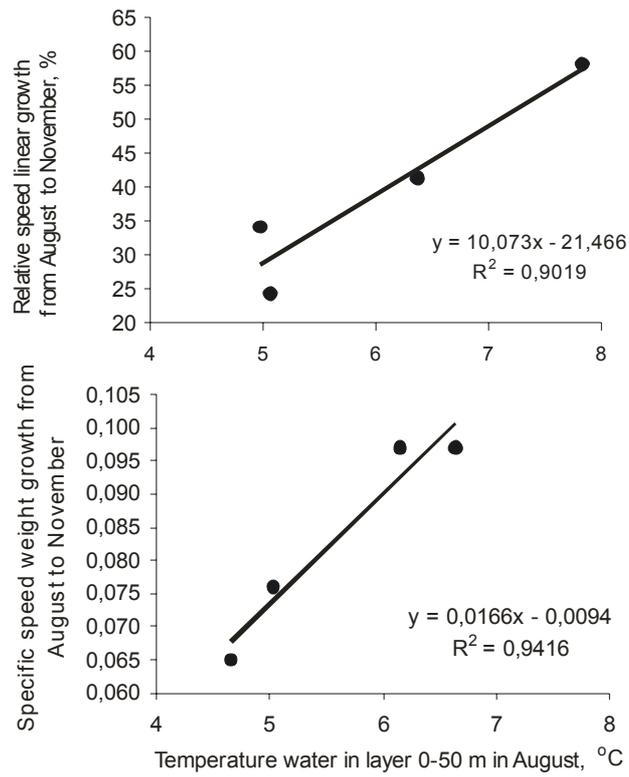


Fig.8. Relationship between water temperature and growth of cod fingerlings in different water masses when the biotope changes

SPECIFIC FEATURES OF DISTRIBUTION AND ABUNDANCE OF THE MOST ABUNDANT PISCIVOROUS SEA BIRDS IN THE BARENTS SEA IN RELATION TO THE DISTRIBUTION OF THEIR PREY IN 2003-2004

by

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The objective of this study undertaken on the basis of data from aerial surveys conducted by research aircraft AN-26 "Arktika" in summer and autumn 2003 and 2004 is to investigate the distribution of the most abundant sea birds – northern fulmar (*Fulmarus glacialis*) and black-legged kittiwake (*Rissa tridactyla*) in relation to the distribution of abundant pelagic fish in the Barents Sea – capelin and polar cod. Abundance estimates for these species of sea birds are given as well as those ones of potential consumption of fish by them.

A comparison of the distribution pattern of sea birds in the Barents Sea in 2003 and 2004 showed considerable differences in the character of their distribution in the Barents Sea area which might probably be related to varying abundance of their main prey, capelin, in particular.

Introduction

Investigations of food relations at the level of highest vertebrates have been one of the priority topics in studies of marine ecosystems over the past 10-15 years. Against the background of intensive exploitation of fish resources in the Barents Sea more and more important becomes the issue of effective management of stocks of commercial fishes, and hence potential outtake, which cannot, in fact, be possible in the absence of reliable information about main organisms impacting on their abundance.

Understanding of the trophic role of those organisms in the ecosystem and assessment of their abundance is of particular importance. Unfortunately, against man's activities in utilizing the aquatic biological resources the populations of sea birds still undeservedly receive too little attention.

At present, fairly well studied are species composition of sea birds in the Barents Sea, location and approximate abundance of their breeding colonies (Belopolsky, Shuntov, 1980; Uspeky, 1959; Krasnov et al., 1995). However, virtually absent or very scarce is information on their distribution and diet beyond their breeding season (Borkin et al., 1992; Erikstad, 1990; Erikstad et al., 1990; Barrett et al., 2002). It is exactly in that period of their life, which encompasses a larger part of the year, the sea birds are distributed over large areas, perform extensive migrations, and gather sometimes in large numbers in areas with rich availability of food. The papers by a number of researchers (for instance, Greenstreet et al., 1999) showed that the abundance of sea birds as well as successful reproduction are mainly caused by productivity of the marine systems, i.e. the available food supply (primarily, crustaceans and

fish species). The influence of abundant populations of sea birds on fish resources (direct or indirect, through fish food supply) may be, thus, enough great.

This paper contains results from observations carried out by research aircraft AN-26 “Arktika” in summer and autumn 2003 and 2004. Analysis of the distribution of the most abundant piscivorous sea birds – northern fulmar (*Fulmarus glacialis*) and black-legged kittiwake (*Rissa tridactyla*), and reasons behind them gathering in aggregations of high density is made. The relationship between distribution of these birds and their main prey – abundant pelagic fishes in the Barents Sea – capelin (*Mallotus villosus*) and polar cod (*Boreogadus saida*) is analysed. Estimates of abundance of northern fulmar and black-legged kittiwake and potential consumption of fish by them are given.

Material and methods

Surveys of birds to assess their numbers were undertaken from the research aircraft AN-26 “Arktika” under the program of integrated aerial surveys in the Barents Sea in the period from 22 August to 1 October 2003 and from 22 August to 30 September 2004. Specially trained observers (by two specialists from each board) carried out visual control of the sea surface parallel with board research equipment. The observations were made through standard bubble windows without using optics. The vertical angle of observation was equal to 45 degrees, on the average.

With survey altitudes between 150-200 m, flight speed 250-350 km per hour the width of visual strip was between 200-400 m. In subsequent data analysis this parameter was flight-specific. Observers’ reports about observed objects, including species, number, observer’s aircraft side, additional information, were sent via intranet to an operator of the onboard automated data collection system. The operator recorded all data into automatically logged flight log-book. During the flight all data were linked to positions and time by using information from satellite navigation system in real time.

In 2003, the survey area was 792 000 km² and, in 2004, it was 680 000 km². Fig.1 shows survey tracks.

In visual surveys all birds were counted and their species identified. It should be noticed that all the gulls (black-legged kittiwake, herring and great black-backed, glaucous gulls and others) and *Procellariiformes* (northern fulmar) are differentiated well and identified to species under different illumination and vision. It is more difficult to assess *Alcidae* (murre, Atlantic puffin, black guillemot and others), which may be hardly identified from the aircraft board by different reasons.

The routes of aerial observations are given in Fig.1, the numbers of assessed birds and their percentage – in Table 1.

Results from aerial surveys of sea birds were analysed using a special software, by which the transect width was determined on the basis of flight altitude information and the number of birds of each species per 10 km² of the transect area was estimated. A major requirement to survey design was a uniform coverage of the survey area by transects, the spacing between them was no more than 50-70 km.

Table 1. Sea bird species registered during the aerial observations, the numbers of assessed birds and percentage of occurrence

Species		2003		2004	
		ind.	%	ind.	%
Great cormorant	<i>Phalacrocorax carbo</i>	6	0.0	0	0.0
Glaucous gull	<i>Larus hyperboreus</i>	88	0.1	4	0.0
Common eider	<i>Somateria mollissima</i>	0	0.0	0	0.0
Northern fulmar	<i>Fulmarus glacialis</i>	31549	52.1	11709	69.1
Murre	<i>Uria spp.</i>	5675	9.4	2310	13.6
Black-legged kittiwake	<i>Rissa tridactyla</i>	16734	27.7	1769	10.4
Great black-backed gull	<i>Larus marinus</i>	5	0.0	6	0.0
Gannet	<i>Sula bassana</i>	3	0.0	4	0.0
Pomarine jaeger	<i>Stercorarius pomarinus</i>	107	0.2	296	1.8
Herring gull	<i>Larus argentatus</i>	9	0.0	6	0.0
Common gull	<i>Larus canus</i>	0	0.0	0	0.0
Swan	<i>ordo Anseriformes</i>	2	0.0	0	0.0
Unid.gull	<i>fam Laridae</i>	33	0.1	382	2.3
Unid.bird	-	6286	10.4	452	2.7
Total		60497	100.0	16938	100.0

Aerial surveys were undertaken at the same time and over the same area as an annual joint Russian-Norwegian multispecies trawl-acoustic survey involving a number of vessels. Data on capelin and polar cod provided by this survey were used in analysing the data on the distribution of sea birds.

The results of calculations presented in Table 2 show significant difference between abundance and distribution density values by years. This fact is probably indicative of not only a great heterogeneity of bird distribution in the area, but of their evident underestimation in the northwestern sea, where higher biological productivity of the sea is usually noticed annually, in 2004.

Table 2. Abundance (10^3 ind.) and average density (ind./km²) of northern fulmar and black-legged kittiwake in the Barents Sea in August-September 2003-2004

Year	Northern fulmar		Black-legged kittiwake		Total	
	10^3 ind.	Ind./km ²	10^3 ind.	Ind./km ²	10^3 ind.	Ind./km ²
2003	14074	17,8	3483	4,4	17657	22,3
2004	4555	6,7	499	0,7	5054	7,4

Results and discussion

Aerial surveys conducted in summer and autumn of 2003 and 2004 showed that despite a general diversity of species in the open part of the Barents Sea the avian fauna there was dominated by northern fulmar, black-legged kittiwake and guillemots (89.2-93.2%). Northern fulmar accounted for 52-69%, black-legged kittiwake 10-28% of the total number of sea birds observed.

The analysis of survey findings showed that in both years northern fulmar being a dominant species was observed almost everywhere in the area surveyed (Figs. 2,3). However, the

density of its distribution was different. The densest aggregations of this species in 2003 were found in the central and northwestern part of the sea near Hope Island and on the Great Perseus Bank. The density of abundant flocks was occasionally as high as 1000 – 2000 birds per 10 km² and more at some locations. In the southeast of the sea the aggregations were less dense and observed on slopes of the Goose Bank near Novaya Zemlya.

In 2004 most abundant flocks of northern fulmar were observed only in the central part of the sea.

The distribution of black-legged kittiwake was on the whole similar to the distribution of the species reviewed above (Figs. 2,3). However, in both years it was predominantly distributed in the north and northwest of the sea, mainly to the east of the Hope Island. Average densities in those areas were more than 50 birds per 10 km², occasionally as high as 1000-2000 birds per 10 km². Less significant aggregations were observed in central areas and in the east near Novaya Zemlya.

Since the occurrence of abundant aggregations of birds in the areas with concentrations of prey is a well-known fact (Shuntov, 1972; Belopolsky, Shuntov, 1980; Borkin, 2004) we undertook analysis of data from the international multispecies trawl-acoustic survey (Anon., 2003; 2004).

A comparison of distribution maps showed that most dense aggregations of northern fulmar in 2003 were found in areas, where capelin was concentrated, with 2-year-olds of prevailing length of 8-10 cm predominant in its population (79%). In 2004, when the abundance of capelin dropped dramatically, aggregations of birds were mainly observed in areas with polar cod concentrations (Figs. 4,5).

Overall, the distribution of black-legged kittiwake was very well correlated with the distribution of capelin, which was indicative of a stronger relationship between the two. At the same time, in 2003 abundant flocks of black-legged kittiwake were also noted in central parts of the sea, where schools of juvenile Atlanto-Scandian herring were distributed in the surface layer of the frontal zone. While in 2004 black-legged kittiwake was observed together with northern fulmar in aggregations near Novaya Zemlya, in the areas, where polar cod massed with 2-year-olds of 8-11 cm being predominant (79%) in its population (Figs. 3,5).

Estimating the potential consumption of fish by these sea birds in the Barents Sea is of big practical value. To this effect we undertook preliminary calculations according to which the abundance of northern fulmar and black-legged kittiwake in areas surveyed in the Barents Sea in 2003 was 14.1×10^6 and 3.5×10^6 birds and in 2004 – 4.6×10^6 and 0.5×10^6 birds, respectively (Table 2).

Unfortunately, the 2004 aerial survey did not cover the northwestern part of the sea, where major aggregations of birds were, as a rule, found, this was the reason why the abundance of northern fulmar and black-legged kittiwake was considerably underestimated compared to 2003.

According to the evidence currently available the abundance of northern fulmar and black-legged kittiwake in breeding colonies along the coast and on islands in the Barents Sea can be

roughly estimated at around 2×10^6 and 1.8×10^6 birds, respectively (The status of..., 2000). Taking into consideration that young birds spend most of their life migrating and mature only at age 3-6 years (seldom at age 1-2), the estimates we have derived for the open part of the sea suggest the possibility that they could well be close to real abundance.

It is known, that the diet of northern fulmar is predominantly composed of small fish (polar cod and capelin), 10-35%, and invertebrates, mostly crustaceans and cephalopods, around 50% (The status of..., 2000). Therefore, on the basis of daily consumption of food in the range of 200-300g, according to different sources, the proportion of fish in the diet can, on the average, be estimated at 50-75 g.

The diet of black-legged kittiwake is by 50-100% composed of fish (capelin, herring, polar cod, cod, sand eel) with capelin being predominant in the majority of cases. On the basis of daily consumption of food of 100-140 g, the proportion of fish in the diet of this sea bird can be estimated at 75-105 g.

Simple calculations showed that consumption of fish, capelin and polar cod in the first place, by birds in the open part of the Barents Sea could be quite considerable. For instance, in 2003 the consumption of fish by the population of fulmar was, on the average, $257-376 \times 10^3$ t, by the population of black-legged kittiwake – $83-125 \times 10^3$ t (Table 3).

Table 3. Consumption of fish by northern fulmar and black-legged kittiwake in the open part of the Barents Sea in 2003 and 2004

Species	Year	Abundance of birds, $\times 10^3$	Daily consumption		Yearly consumption	
			By one bird, g	By population, t	By one bird, kg	By population, $\times 10^3$ t
Northern fulmar	2003	14074	50-75	704-1056	18,3-27,4	256,9-375,8
	2004	4555	50-75	228-342	18,3-27,4	83,1-124,7
Black-legged kittiwake	2003	3483	75-105	261-366	27,4-38,3	95,4-133,5
	2004	499	75-105	37-53	27,4-38,3	13,7-19,1

Conclusions

Studies undertaken have shown that northern fulmar and black-legged kittiwake prevail in the avian fauna in the open part of the Barents Sea. Total estimated abundance of these species in 2003 was around 18×10^6 birds (14.1×10^6 and 3.5×10^6 birds, respectively), in 2004 it was 5×10^6 birds (4.6×10^6 and 0.5×10^6 birds, respectively). Unfortunately, it was not possible to estimate the abundance of guillemots for scarcity of data and difficulties with conducting an aerial survey of these birds.

These findings together with other evidence on the abundance of birds in breeding colonies along the coast in the Barents Sea currently available in the literature suggest the possibility to acknowledge that the estimates we have derived are close to real abundance.

Analysis of the distribution of northern fulmar and black-legged kittiwake has shown, that the occurrence of the largest aggregations of these birds in the open part of the Barents Sea is

largely linked to the presence of concentrations of small pelagic fish, capelin and polar cod, there, which are their main prey. The largest overlap between the distribution of sea birds and the distribution of fish was noted for capelin feeding in the northwest of the sea in summer-autumn and black-legged kittiwake, which prefers to feed on exactly this fish for the most part of the year.

Consumption of fish, capelin and polar cod in the first place, by birds could be quite considerable. According to Barret et al. (2002) northern fulmar and black-legged kittiwake annually consume around 124×10^3 t of fish in the Barents Sea (39×10^3 t and 86×10^3 , respectively). Total yearly consumption of fish by sea birds in the Barents Sea is estimated at 621×10^3 t, of which 52% by guillemots (the same source). According to our estimates in 2003 the population of northern fulmar consumed $257-376 \times 10^3$ t of fish and of black-legged kittiwake between 83×10^3 and 125×10^3 t, however, these estimates were much higher than those given in Barret et al. (2002). Therefore, further studies are needed to refine the estimates of consumption of fish by sea birds.

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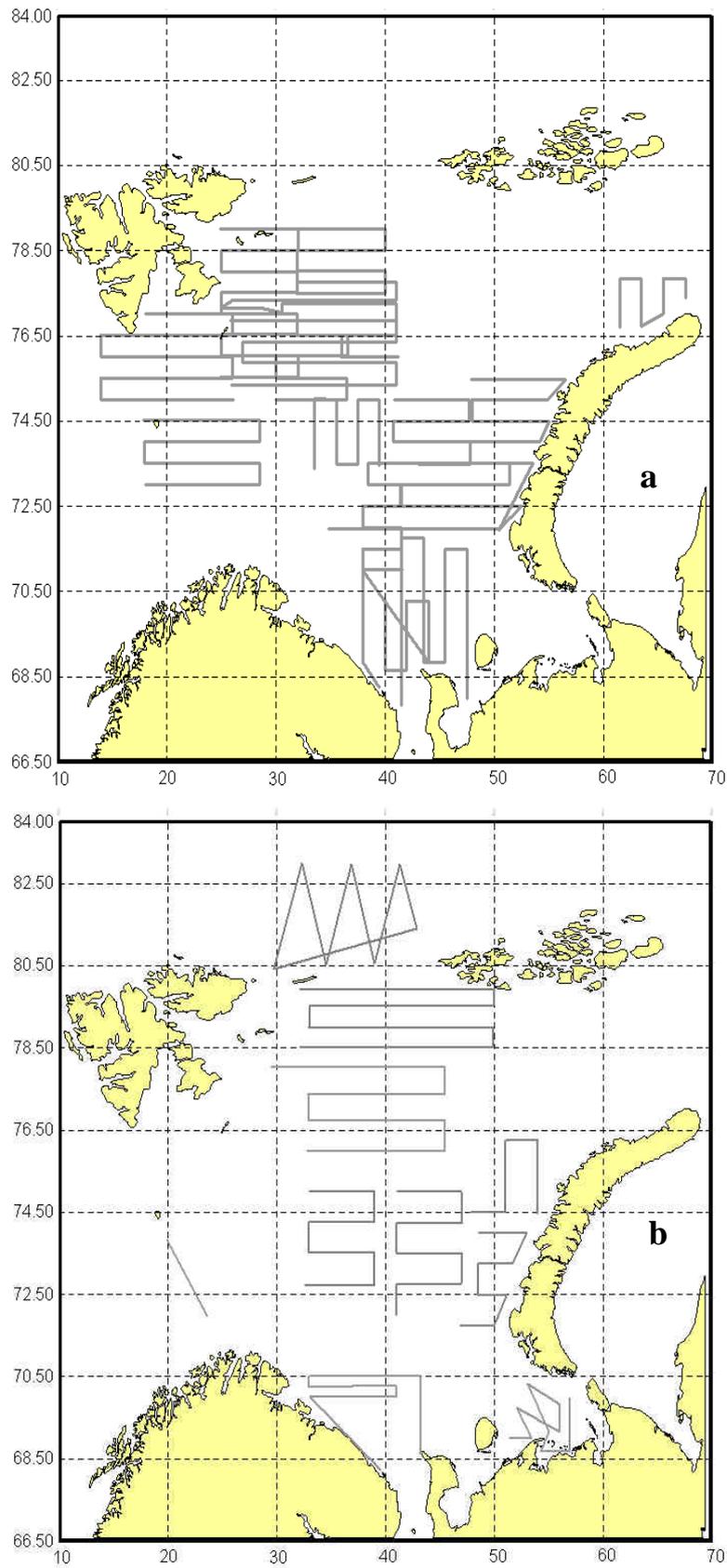


Fig.1. Areas and position of transects in the aerial survey by An-26 “Arktika” in autumn 2003 (a) and 2004 (b)

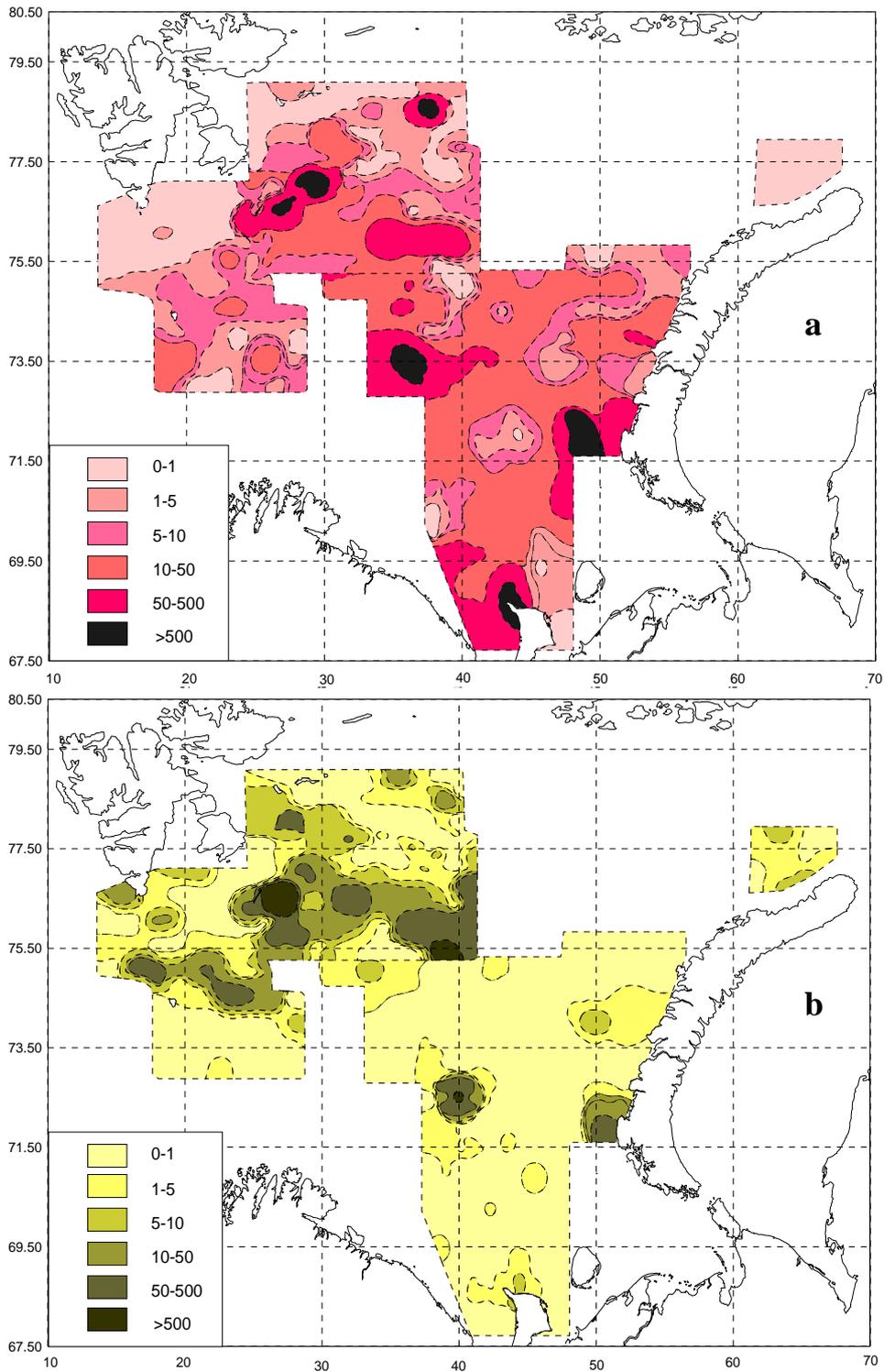


Fig. 2. Distribution of sea birds in the Barents Sea in summer and autumn of 2003, birds per 10 km²: a – northern fulmar, b – black-legged kittiwake

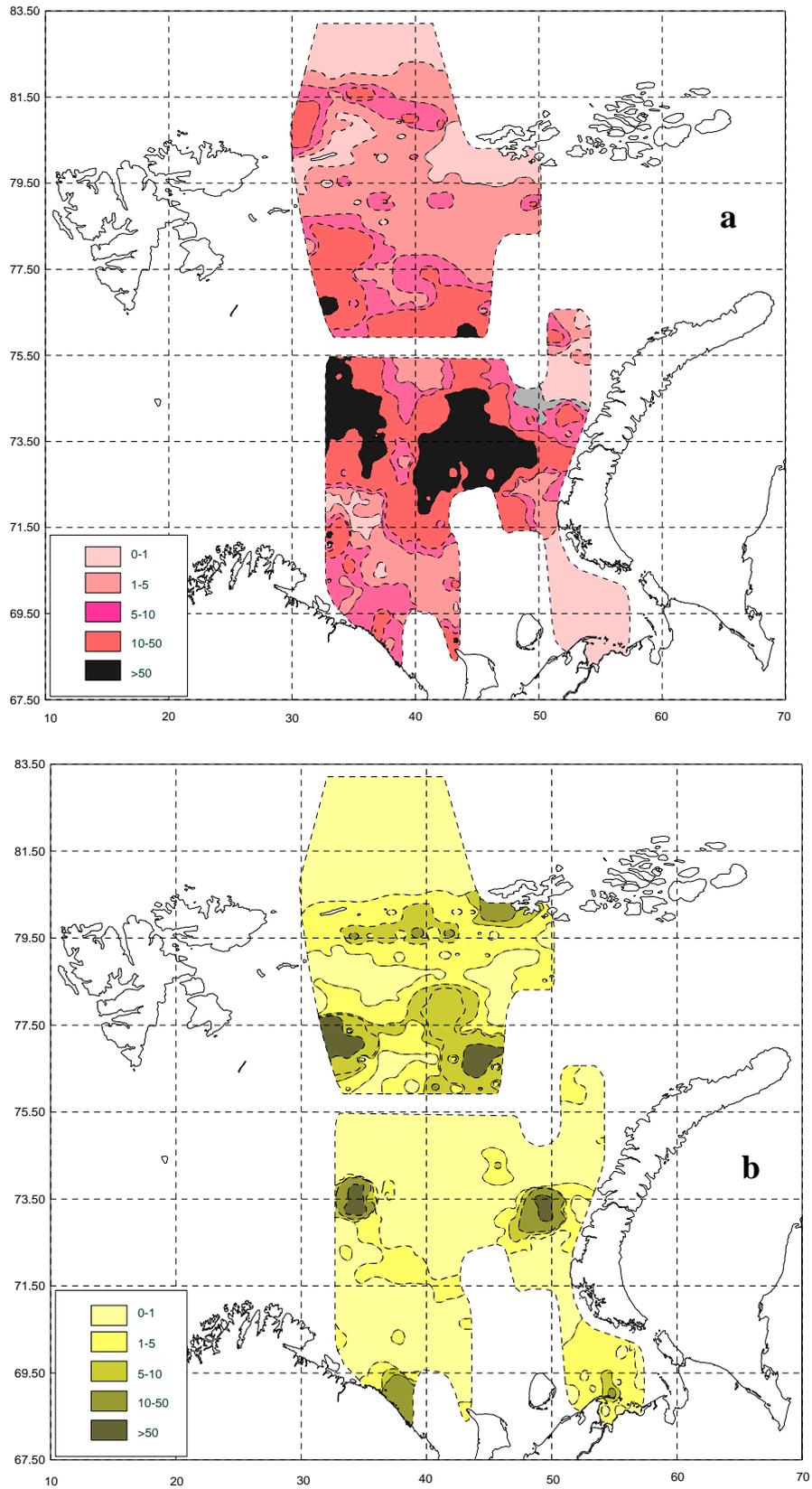


Fig. 3. Distribution of sea birds in the Barents Sea in summer and autumn of 2004, birds per 10 km²: a – northern fulmar, b – black-legged kittiwake

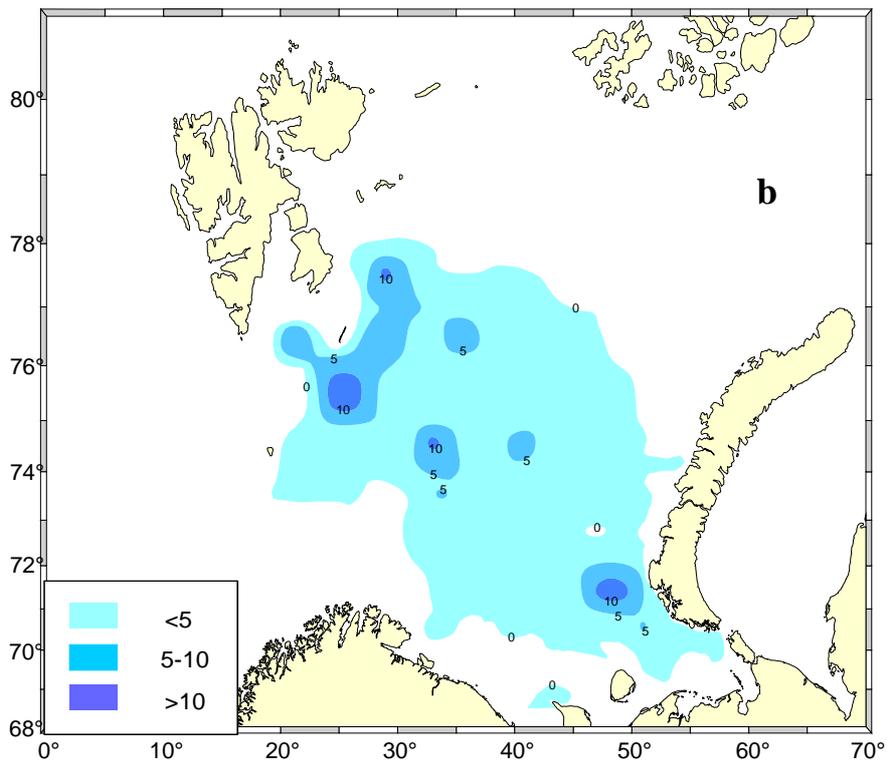
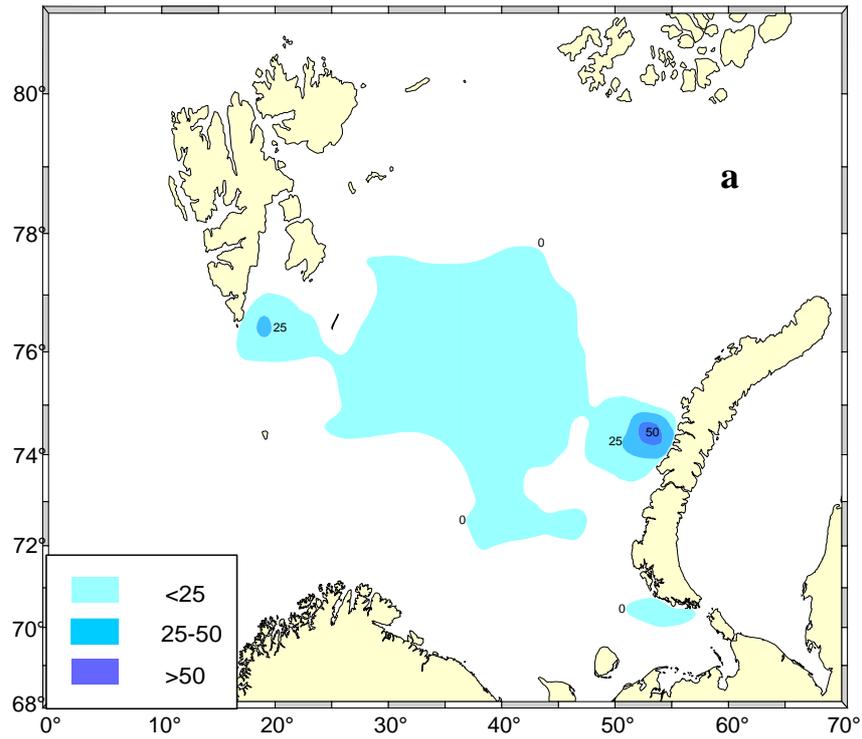


Fig. 4. Distribution of polar cod (a) and capelin (b) as mapped by the trawl-acoustic survey in September-October 2003, t per sq.mile

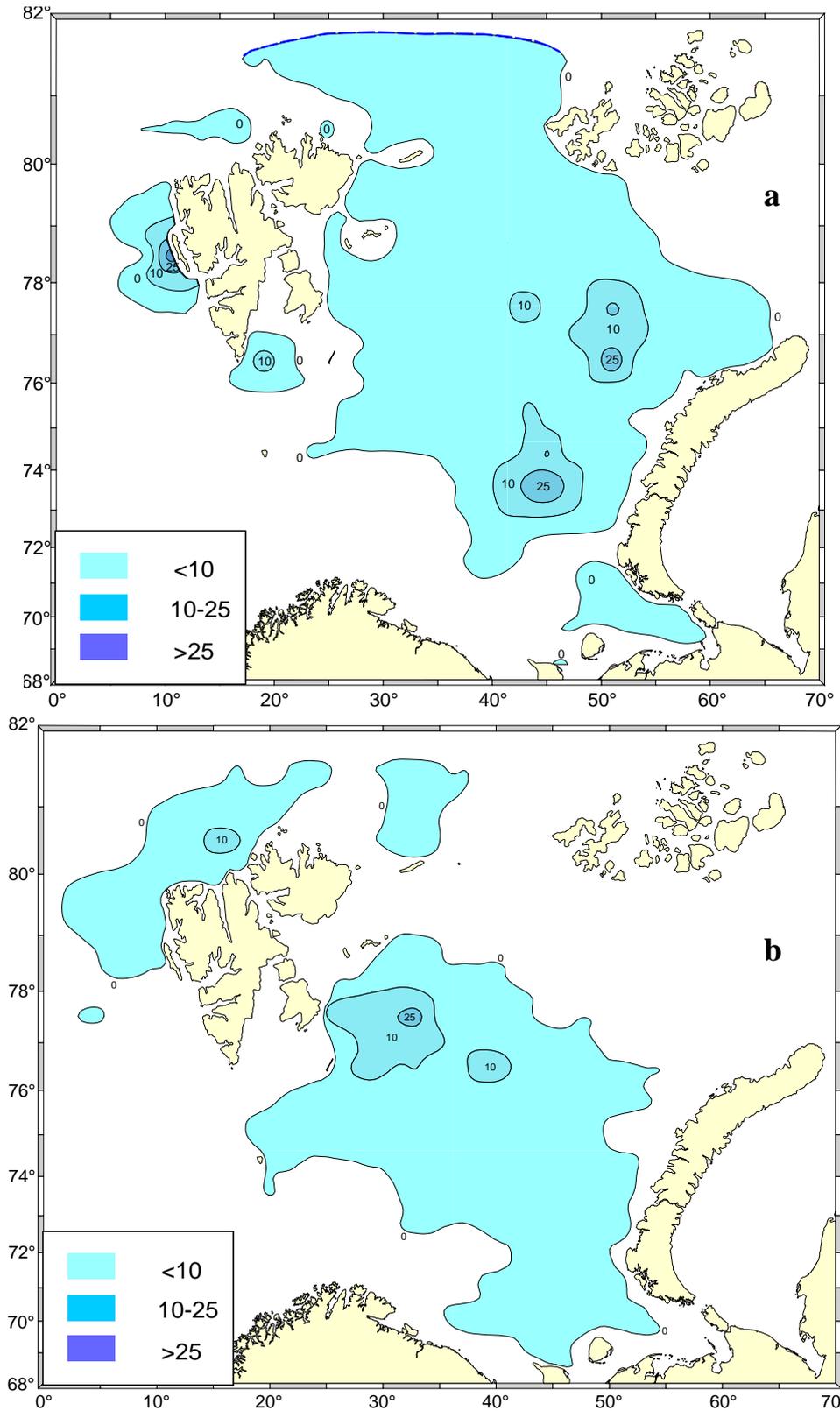


Fig.5. Distribution of polar cod (a) and capelin (b) as mapped by the trawl-acoustic survey in August-September 2004, t per sq.mile

IN THE BARENTS SEA

by

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Primary productivity in the Barents Sea ecosystem depends on structural and functional characteristics of four principal phytocenoses: phytoplankton, macrophytes, ice algae, and microphytobenthos. Productivity peculiarities of these phytocenoses are directly associated with hydrological and climatic conditions which have considerable variations in different parts of the sea. Variations in biocenoses structure and climatic conditions of the Barents Sea allow us to identify there the Arctic area with the Polar front as the southern boundary, and the Boreal area located in the south-western part of the sea. In their turn, these areas could be divided into subareas which essentially make transition zones.

The distribution area of the mentioned phytocenoses is determined by their adaptability to particular habitats. The microphyte distribution in the Barents Sea is limited to the littoral zone free of the ice coverage and the sublittoral zone up to the photic layer boundary whose depth varies in different areas from 10 to 30 m. Microphytobenthos inhabits the littoral zone down to 15-20 m. Ice biotope covers almost two thirds of the sea surface. Phytoplankton has the largest biotope among the mentioned phytocenoses (Table).

The Table shows that the principal role in primary productivity within coastal waters belongs to microphyte communities. Generally speaking, all coastal phytocenoses make a rather significant contribution to the total PP of the Barents Sea ecosystem.

With the biotope 23 times less than the one of the open-sea phytoplankton, coastal phytocenoses synthesize 11 % of the total PP in the Barents Sea.

Nutrient stocks accumulated as a result of bacterial metabolism and convection mixing provides favorable conditions for an intensive photosynthesis of the autotrophs. The only factor restraining this process is the solar energy deficit in winter and early spring. Autotrophs which are the first to start intensive primary production through photosynthesis are macrophytes from the south-western part of the Barents Sea. Already in February when the solar radiation totals 50-70 cal/cm² daily, photosynthesis of the principal representatives of this phytocenosis attains considerable rates. Macrophytes from the Arctic area of the Barents Sea (e.g. coastal waters of the Franz Josef archipelago) undergo more rigorous climatic conditions. Lightness and temperature are considerably lower in these areas, compared to the southern Barents Sea. Therefore, the arctic macrophytes are characterized by a much more primitive community structure and species composition than the boreal macrophytes (Makarov & Shopina, 1986). Because of the climatic conditions photosynthesis and respiration rates of coastal macrophytes off the Franz Josef archipelago are lower by 20% and 50%, respectively, compared to those in the southern Barents Sea (Kusnetsov et al., 1994).

Productivity Characteristics of Phytocenoses in the Barents Sea

Area of distribution (biotope)		Phytocenosis	The biotope area (ths km ²)	Production mln.tC/year
Sublittoral (the 20 m isobath)	The Cola Peninsula	Phytoplankton	5.4	0.324
		Microphytobenthos	5.4	0.189
		Macrophytes	5.4	2.700
	Novaya Zemlya (western part)	Phytoplankton	5.2	0.101
		Microphytobenthos	5.2	0.077
		Macrophytes	5.2	0.691
	Franz Josef Land	Phytoplankton	14.0	0.234
		Microphytobenthos	14.0	0.177
		Macrophytes	14.0	1.862
	Svalbard (eastern part)	Phytoplankton	15.8	0.263
		Microphytobenthos	15.8	0.201
		Macrophytes	15.8	2.101
	The Pechora Sea	Phytoplankton	20.5	0.246
		Microphytobenthos	14.5	0.087
	TOTAL: (coastal area)			60.9
Pelagic waters		Phytoplankton	1438.4	60.400
Ice		Ice algae	1078.8	10.700
TOTAL:				80.020

In spring the earliest intensive photosynthesis starts in coastal waters and at the ice edge where a highly productive marginal zone develops. This process usually starts in April that is two months later than in the case of macrophytes. The solar radiation level required to trigger the phytoplanktonic photosynthesis approximates 150 cal/cm² daily (Bobrov, 1982; Kusnetsov, 1988). The phytocenoses of ice algae and microphytobenthos join intensive photosynthesis simultaneously with phytoplankton or a bit earlier. The phytoplankton productivity rates in the open Barents Sea differ considerably from those in the coastal area. Seasonal dynamics of the phytoplankton photosynthesis in the open sea are characterized by one peak in spring and the following decline which is associated with depletion of nutrient stocks (they are almost completely consumed during the short spring). The subsequent input of nutrients from deep waters is limited by density stratification in the water column; therefore, the photosynthesis rates are limited by nutrient recycling. Upwelling areas characterized by a continuous nutrient input from deep waters make the exception. Similar zones comprise the Polar front, coastal and shallow waters where advection can be caused by tidal and inward/downward currents. The spring maximum of phytoplankton photosynthesis in the coastal zone is followed by several other peaks in the phytocenosis development. According to observations presented by Kuznetsov and Volkovskaya (1994), the vegetation period was characterized by a continuous nutrient influx from the bottom biotopes to the pelagic community; this input sustains high rates of the phytoplanktonic photosynthesis in the coastal zone.

Ample stocks of nutrients developed in the process of metabolism of local bacteria and heterotrophs can sustain high rates of microphytobenthic production during the entire vegetation period. Additionally, studies of the seasonal dynamics of chlorophyll “a” in

the microphytobenthic community indicated that the coastal microphytobenthos preserves photosynthetic biomass all the year round. It suggests that in absence of light during the polar night benthic microalgae change their feeding regime to the mixotrophic-heterotrophic one.

The ice algal photosynthesis is limited in the Barents Sea by the short spring. PP of this phytocenosis can attain very high rates and be comparable to the spring PP rates of phytoplankton. Effects of environmental factors, such as the snow thickness that limits the light penetration or the ice thickness and texture, can produce a significant effect on production rates of the ice phytocenosis. For this phytocenosis, the period of intensive vegetation ends with destruction of the ice biotope during the ice melting.

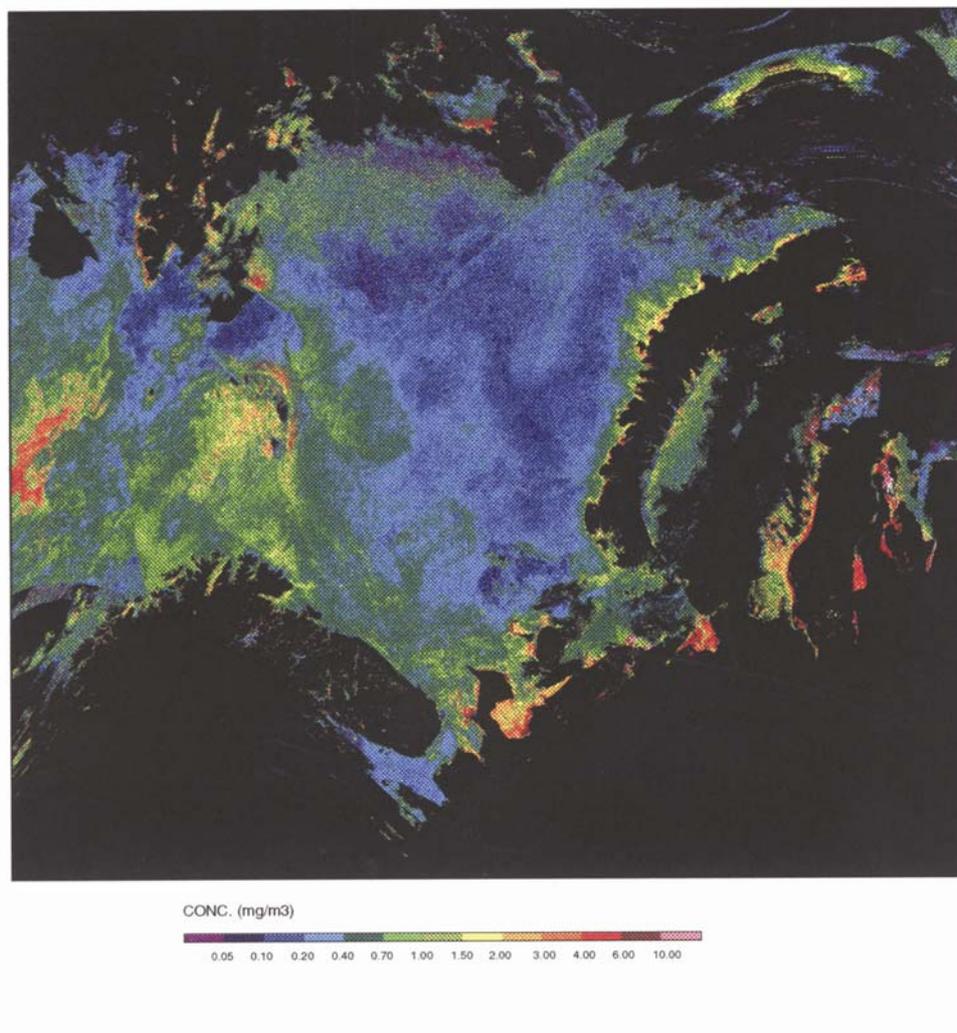


Fig.1. CZCS composite over the Barents Sea for July
(Average estimate of chlorophyll-like pigments)

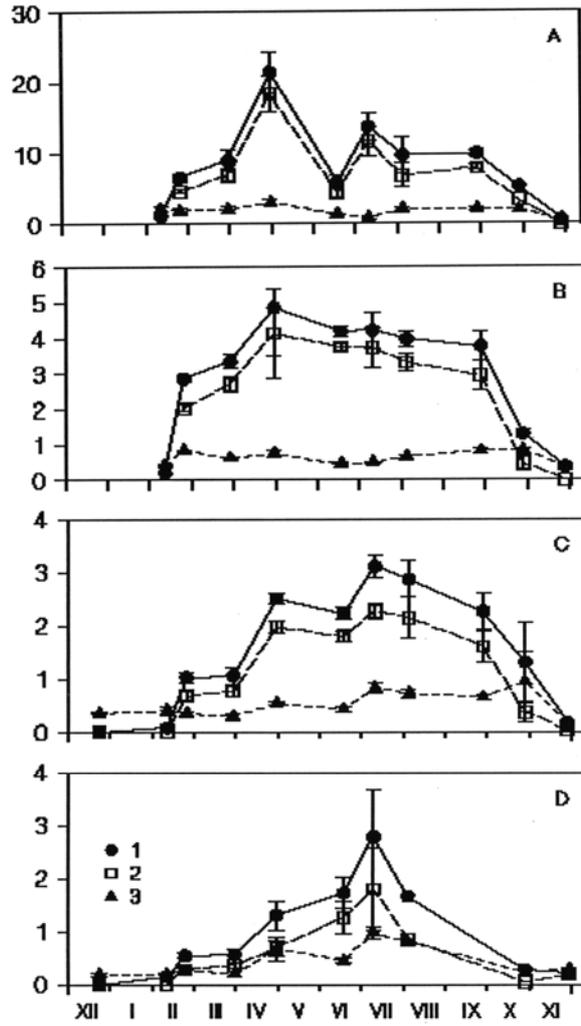


Fig.2. Seasonal dynamic of production-destruction characteristic of some macrophytos (Ulvaria (a), Palmaria (b), Lamunaria (c, d))

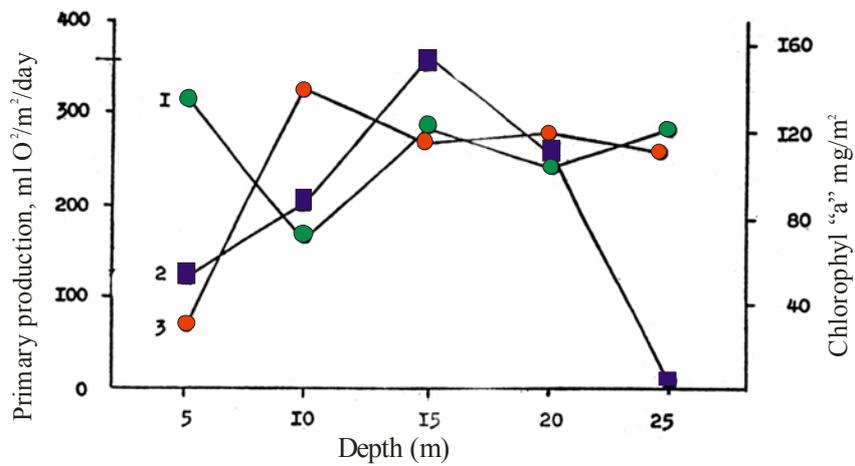


Fig.3. Production-destruction characteristics of microphytobenthos 1 – oxygen consumption; 2 – primary production; 3 – chlorophyll "a"

FROM REPRODUCTION TO RECRUITMENT IN NORTH-EAST ARCTIC COD

by

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Introduction

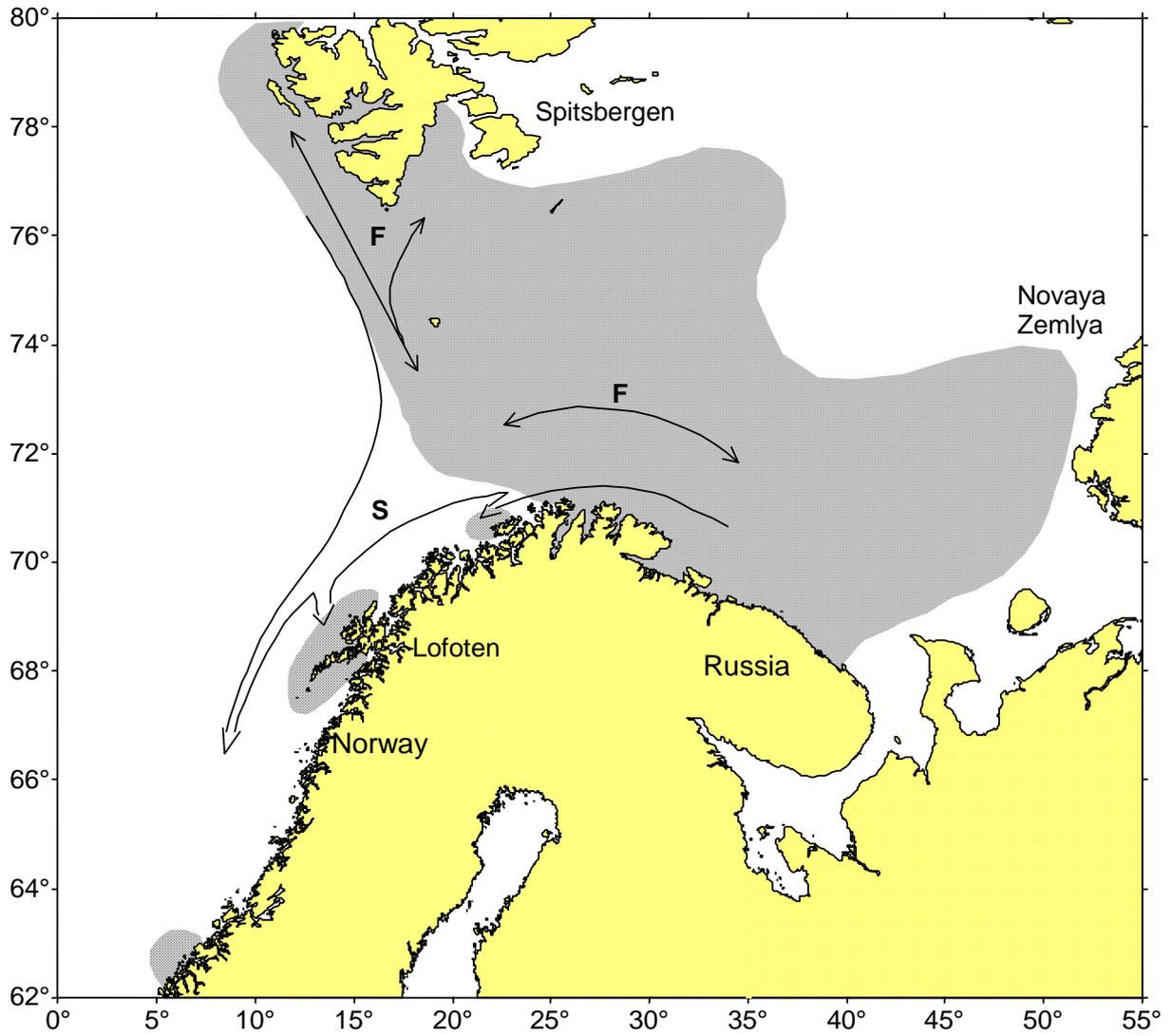
Most current fisheries management models do not include biological detail for processes occurring between spawning and recruitment. This means that temporal trends present in biological or environmental factors can and have been ignored.

The temporal and spatial trends in stock reproductive potential (SRP) have been largely ignored, however, variation in SRP can have a fundamental influence on recruitment. However, there are many processes occurring between spawning and recruitment that are not influenced by the parental stock.

Materials and methods

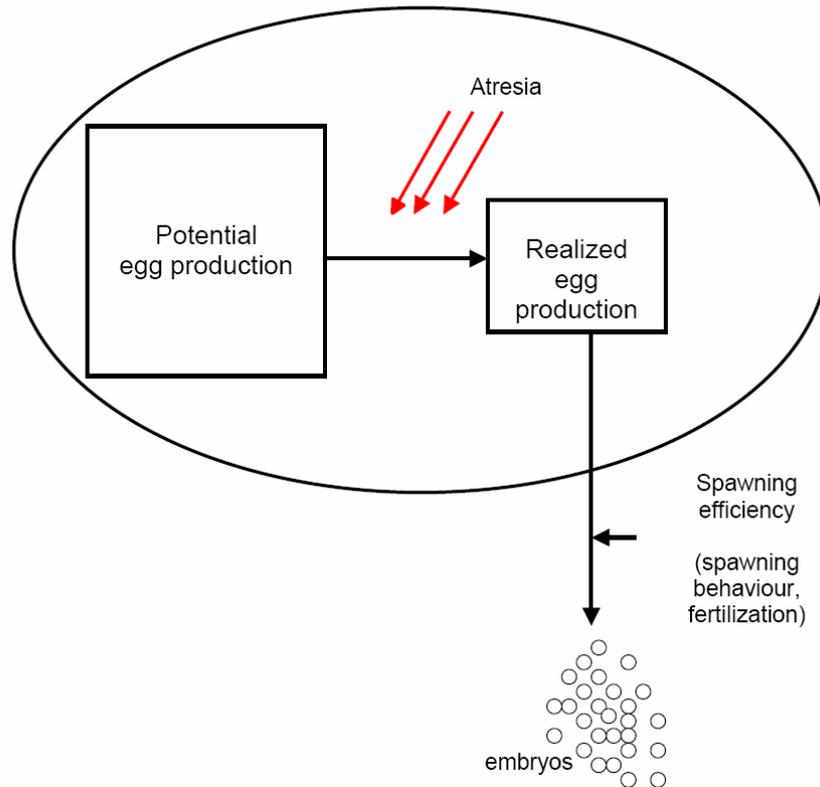
North-east Arctic cod biomass/abundance estimates, obtained by analytical methods (VPA, XSA) and trawl-acoustic surveys, were used (ICES CM 2003/ACFM:22). Portion of mature fish were taken from the Arctic Fisheries Working Group report, whereas sex composition from Norwegian database. Individual fecundity was calculated using C.T. Marshall and co-authors method (submitted). Potential fecundity was calculated for each year, taking into account length-age composition and mean length/weight.

Spawning and feeding grounds



Stock Reproductive Potential (SRP)

Reproductive Potential



The transition from potential to realized egg abundance is a critical stage in the evolution of year-class strength of NA cod (connected with atresia, influenced by condition of spawners).

Furthermore, the signal in year-class strength undergoes substantial modification between the egg and larval stages. Thus, the signal in year-class strength of NA cod is determined in the earliest life history stages (Sundby et al., 1989; Mukhina, Marshall & Yaragina, 2003) before young fish settlement.

Stock Reproductive Potential (SRP)

Spawning Stock Biomass (SSB)

- number of mature fish at age
- mean weight of mature fish at age

Stock Reproductive Potential (SRP)

Maternal
reproductive
experience
– Condition factor
– Length

Female

- proportion mature at age
- non-annual maturation of adults
- egg production (fecundity at length, age)
- viable eggs (fertilization, hatching success)
- sex ratio
- body size at age
- other factors
 - spawning duration
 - egg size, larval size
 - egg nutrient and lipid content
 - time to starvation
 - larval activity
 - first feeding success
 - compensatory growth

Paternal
reproductive
experience
– Condition factor
– Length

Male

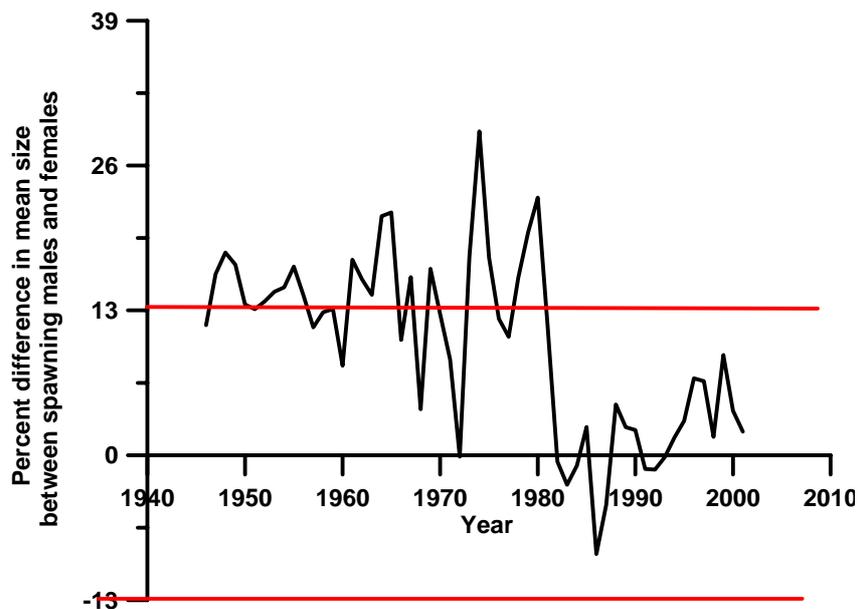
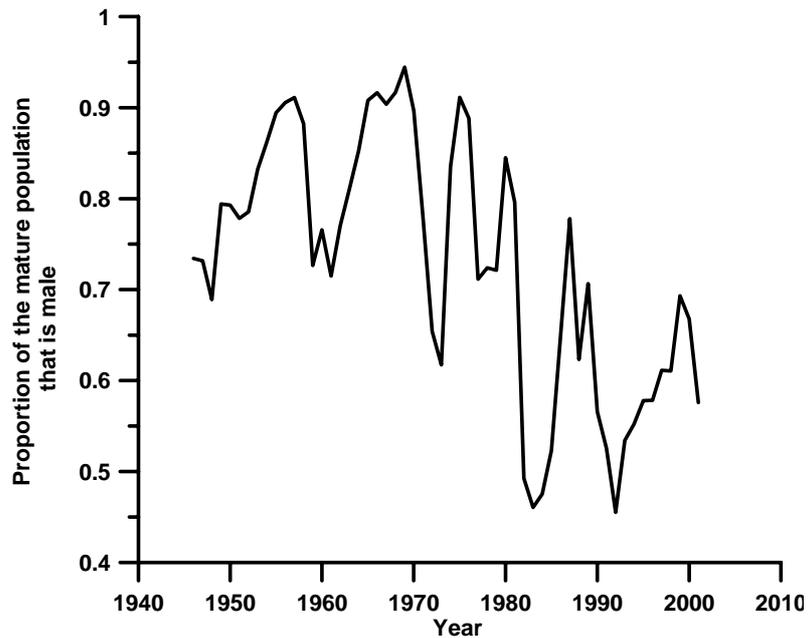
- proportion mature at age
- non-annual maturation of adults
- testes weight
- sperm motility
- effect of male on larval fitness and early life survival
- sperm density
- fertilization rates, pairedmatings, in vivo sperm competition

Other factors

Stock-specific values
Water temperature interaction/effects
Maternal-paternal interactions

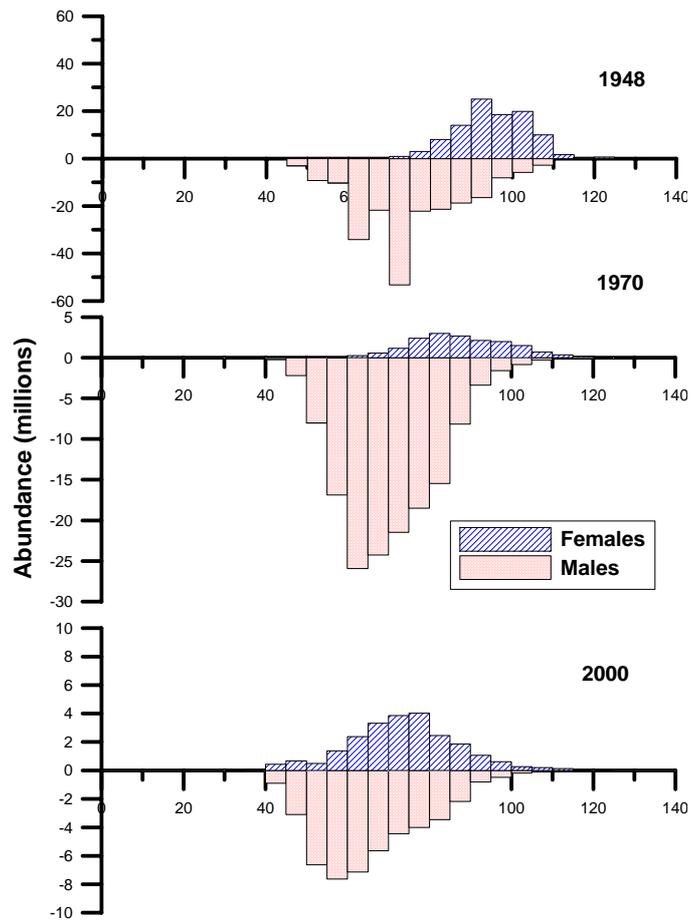
From: Trippel 1999

Males



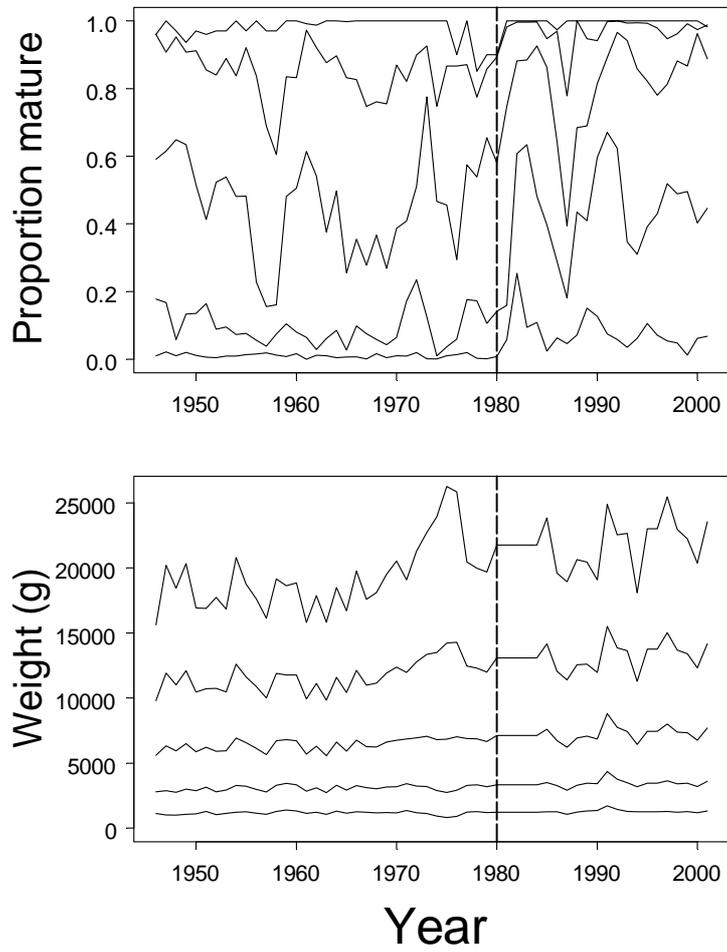
Should we be worried about the male part of the population?

Figures to the left show fairly substantial changes in the sex ratio of the mature part of the population and illustrate fairly major changes in the relationship between mean size of mature males and females. Could this have an influence on reproductive success? Do we know enough about fertilisation success and maternal and paternal effects on survivorship in early life history stages?

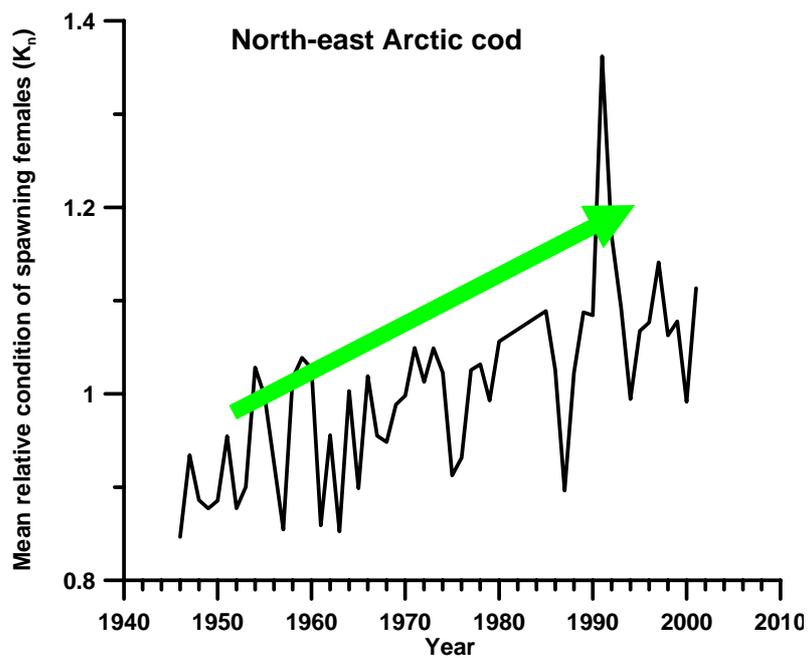
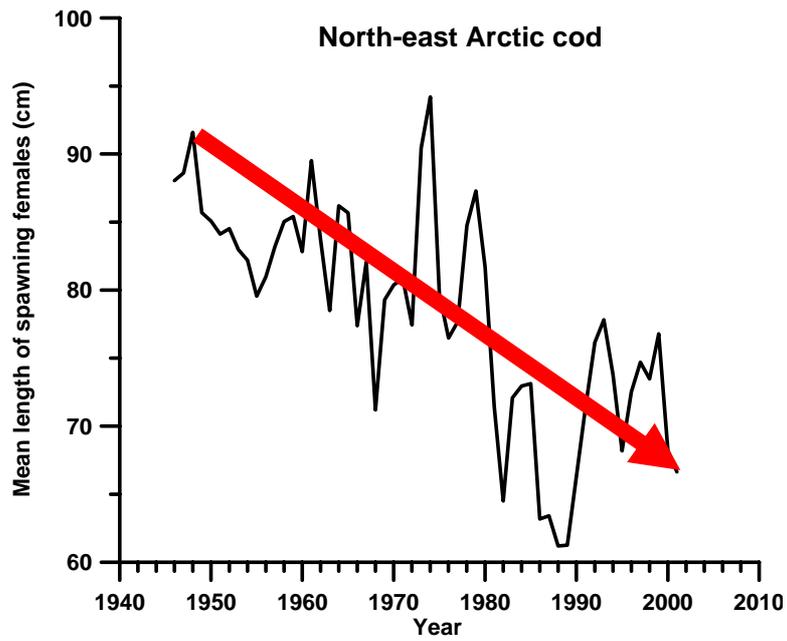


The figure above illustrates the changes in length frequency that have occurred in this stock. At present mature males and females are more similar in length

Females

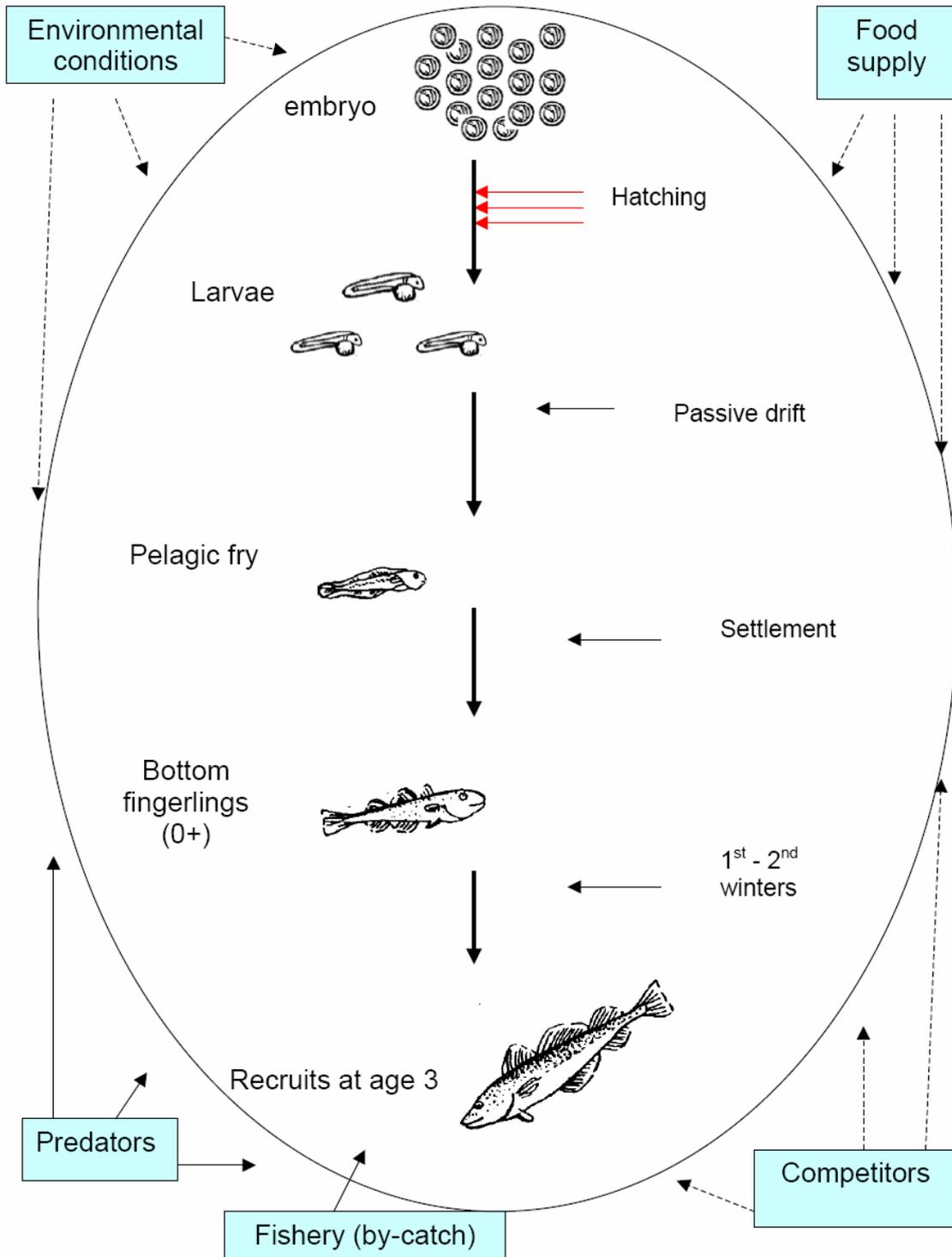


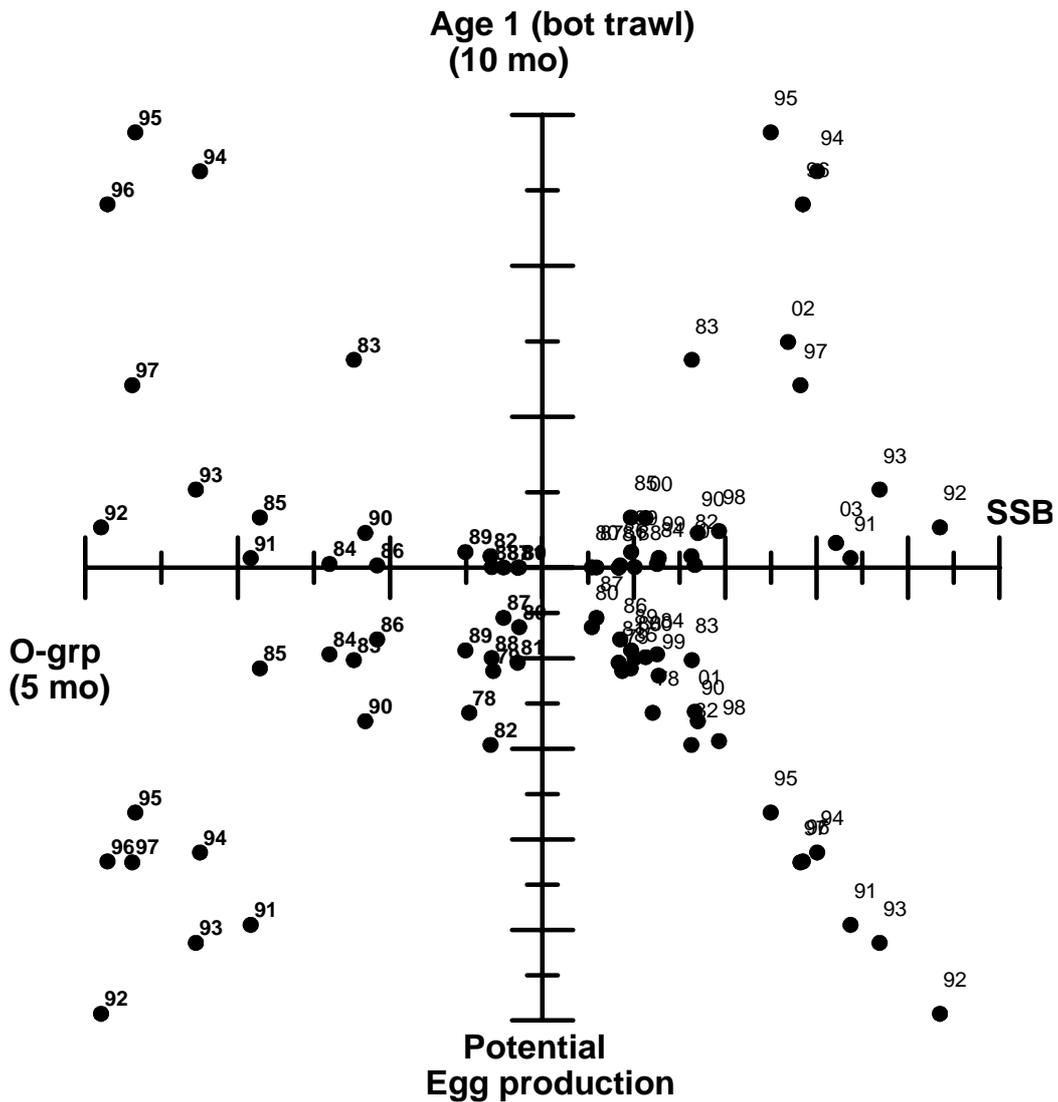
Interannual variation in maturity ogive and mean weights at length: vertical line separates pre and post 1980.



In general there has been a decline in mean length of mature females over time, however there has been a corresponding increase in mean condition . The consequence is an apparent ‘compensatory’ response in the egg production per unit SSB (see bottom right panel below).

Development of a Recruiting year class



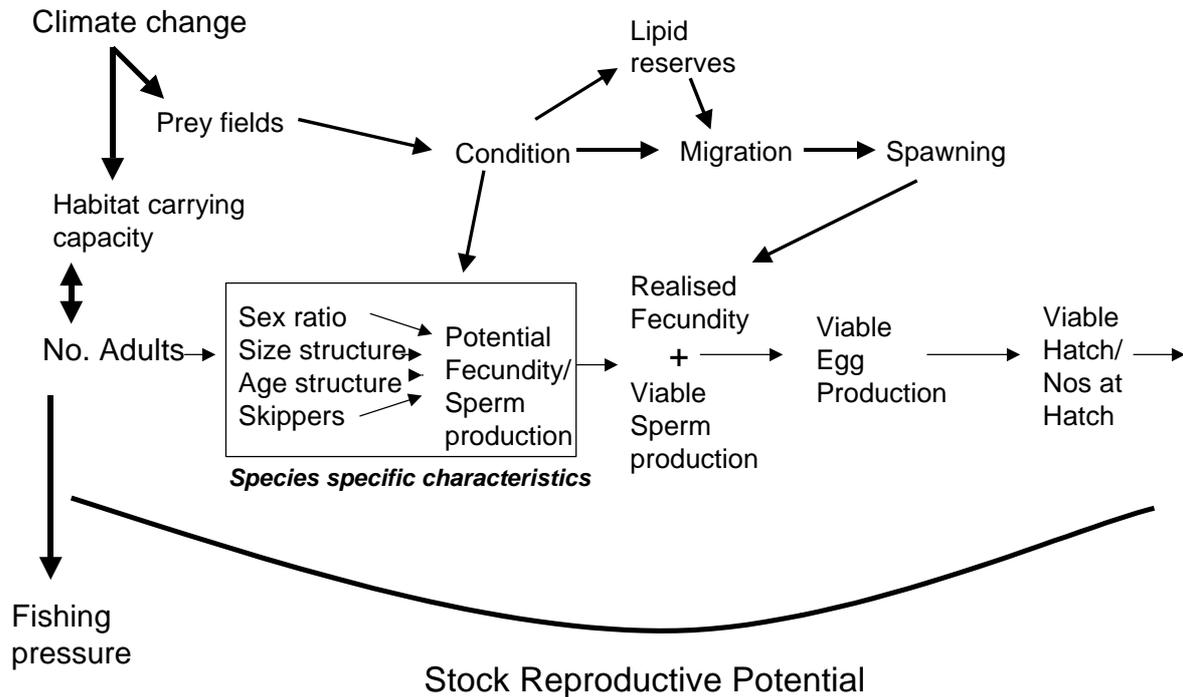


Life-history model or Paulik diagram for North-east Arctic cod. The SSB data are from the VPA, egg production data calculated from relationships determined by Marshall et al. (submitted) and O and 1 group abundances from surveys.

Some variability is generated in the transition from adult population to eggs, however, very large variability is generated through subsequent life-history stages which ultimately results in the classical stock and recruitment relationship by three years old.

These diagrams/models rely on being able to estimate the abundance of individuals at the transition boundaries e.g. metamorphosis, settlement, 1 year old etc.

The challenge for stock to recruitment studies



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ON THE EFFECT OF RED KING CRAB ON SOME COMPONENTS OF THE BARENTS SEA ECOSYSTEM

by

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Introduction

For the 40 years of successful adaptation elapsed since the red king crab introduction to the Barents Sea its distribution area and abundance have expanded (Figure 1). Trawl surveys showed that by 2003 the red king crab stock only in the Russian Economic Zone in the Barents Sea reached 20 million crabs. A start on its commercial fishery was made in 2002 in Norway and in 2004 in Russia.

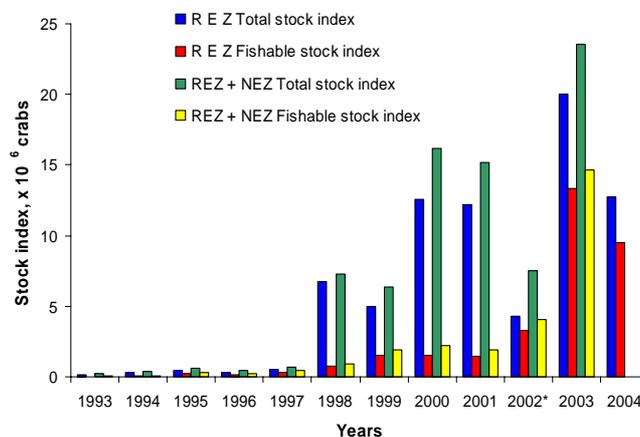


Fig. 1. Dynamics of the red king crab stock in the Barents Sea.
2002* – underestimation in the result of anomalous crab distribution during the survey period

However, it is well known that the appearance of fisheries objects extrinsic to the ecosystem is open not only to commercial benefits but also to ecological hazards. Examples of that in the world practice are numerous. Russian researchers greatly experienced in works on species introduction are aware of it quite well.

In this relation, a concern about ecological implications of the red king crab introduction has greatly increased in recent years and not only in the scientific circles. At the same time, a lack of reliable information on this issue gives cause for predictions that are not always justified and provokes the most fantastic publications.

A steep increase in the red king crab abundance in the Barents Sea during the recent decade gave rise to a deep research into this problem by a large number of scientific institutions in Russia and abroad. For a number of years this problem has been addressed to the Shellfish Laboratory of PINRO.

Implications of the red king crab introduction are being studied at both population and biocenosis levels. At the level of biocenosis, the object of the study are bottom communities; at the level of population, the study includes populations of commercial marine organisms in relation to which the red king crab acts as a direct predator (capelin and Iceland scallop) and a food competitor (haddock) (Figure 2).

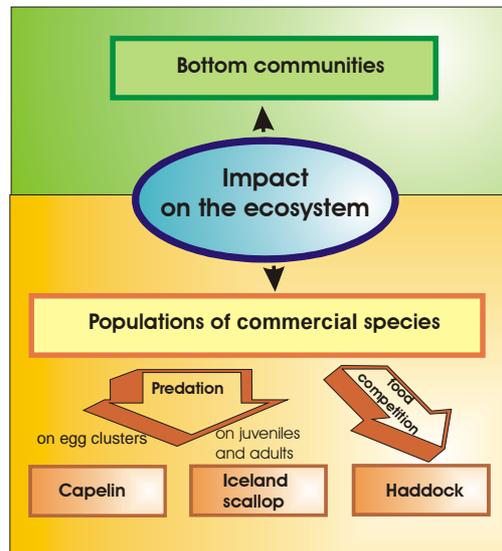


Fig. 2. The main directions of the study of the red king crab effect on the Barents Sea ecosystem being developed in the Shellfish Laboratory of PINRO.

Materials and methods

Material to evaluate the effect of the king crab on the indigenous communities was collected in the Motovsky Bay of the Barents Sea in 2003 during the cruise of R/V “Romuald Muklevich” (Figure 3). The standard methods were used for sampling (Rumohr, 1999).

To estimate the dynamics of community state the analysis of its biodiversity by the comparison of the most widely used indices (Table 1) and the relative abundance curves (ranked species biomass curves, k-dominance curves) was made; the community state was also tested by Warwick’s ABC-method.

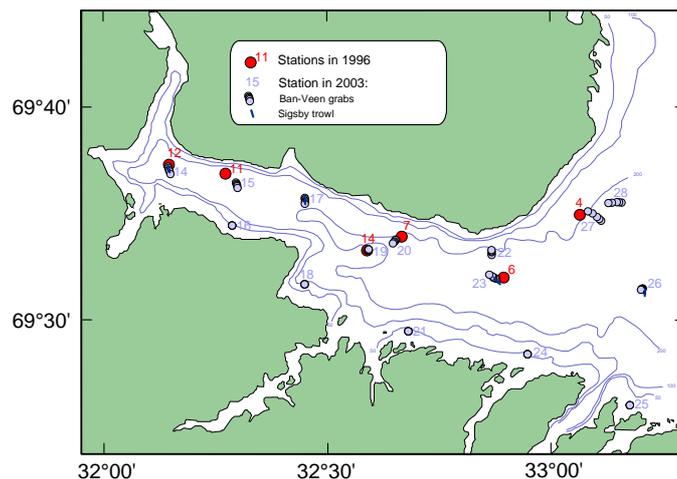


Figure 3. Location of stations during benthos survey by PINRO in 2003 onboard R/V “Romuald Muklevich” in the Motovsky Bay of the Barents Sea and stations during the survey in 1996 (Frolova et al., 2003) used for comparative data analysis

Table 1. Indices of biological diversity and density used in the analysis of the Motovsky Bay fauna

Indices	Formula	Reference
Margalef’s index of species richness (d)	$d = (S - 1) / \ln N$	Margalef, 1958
Simpson domination index (c)	$c = \sum (b/B)^2$	Simpson, 1949
Shannon-Wiener diversity index (H)	$H = - \sum b/B (\log_2 b/B)$	Shannon, Weaver, 1949
Pielou evenness index (J)	$J = H \log_2 S$	Pielou, 1966
Density index (D)	$D = \sqrt{b * \%}$	Brotskaya, Zenkevich, 1939; Leibson, 1939

Note: *S* – number of species (taxons); *N* – number of individuals; *B* – total biomass; *b* – average biomass of species (taxon) in the community; % – frequency of species occurrence in the community, %.

To evaluate the effect of the crab on scallop settlements, stomach content of 58 crabs captured at the exploited scallop settlements and 79 crabs caught at the non-exploited settlements was analyzed. To estimate the importance of main food items, the index of importance was used which was defined as the product of frequency of the item occurrence in stomachs and the average partial index of stomach fullness.

To evaluate the effect of the crab on capelin eggs, stomach content of 554 crabs taken from March to Mai in 1994-2003 in the West Murman waters (the Kola Peninsula coast from the Norwegian border to 35° E) was analyzed.

To evaluate the effect of the crab on haddock feeding, stomach content of 30541 of haddocks was analyzed. To make a comparison, 1971-1977 were chosen as reference periods (the first

stage of the king crab acclimatization) and 1995-2002 (the period of the growth in the king crab abundance).

Results

Bottom communities

The effect of the red king crab on the bottom communities was studied in the Motovsky Bay of the Barents Sea. This area was chosen for the study because the Motovsky Bay and adjacent waters is the “oldest” part of the present area of the red king crab in the Barents Sea. By the present, the red king crab has been dwelling in this area for about 40 years and a part of the population inhabiting it is at the stage closest to naturalization.

The study was based on published data from benthos surveys in the Motovsky Bay in 1931-1932 (Leibson, 1939) and in 1996 (Frolova et al., 2003) as well as on other benthos samples collected by PINRO in 2003 (Figure 3). The available series of observations permitted us to analyze the bottom fauna of the Motovsky Bay before the red king crab introduction (the survey in 1931-1932), in the period of its low abundance (the survey in 1996) and upon reaching the highest abundance (PINRO survey in 2003) (Figure 4).

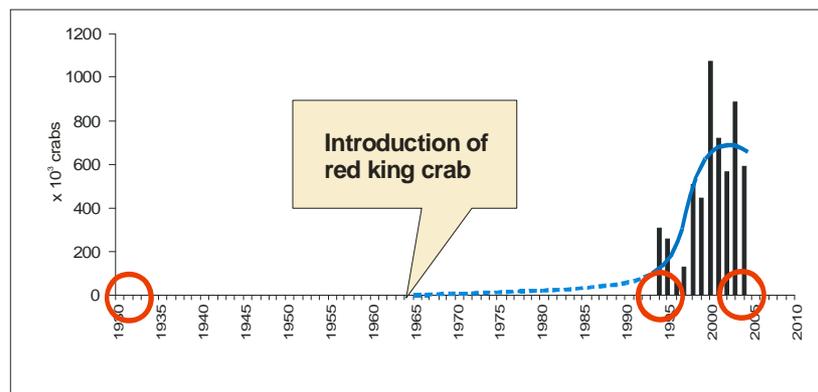


Fig. 4. Dynamics of the red king crab (legal males) abundance in the West Murman waters and benthos surveys in the Motovsky Bay

To make an analysis, a community dominated by a sedentary polychaete *Maldane sarsi* typical of the soft bottom in deep waters of the Motovsky Bay was chosen. This community is the most widespread in the Motovsky Bay and occupies almost the whole deepwater part of it. The adult red king crabs are abundant and feed intensively within this community throughout the year.

In the period from 1996 to 2003, within *M. sarsi* community, the mean biomass of benthos insignificantly, but reliably decreased from $77.4 \pm 15.3 \text{ g/m}^2$ to $63.8 \pm 11.6 \text{ g/m}^2$ (Table 2). More detailed by-station analysis showed that the reduction in biomass was only typical for the open north-west part of the bay. At the stations of central and inner parts, the biomass kept at the previous level and even increased a little at some of them.

Table 2. Total biomass of the benthos and biomass of the main taxa in community M. sarsi in 1931-1932, 1996 and 2003, g/m²

Taxon	1931-1932	1996	2003
Total biomass, g/m ²	<u>71,5</u>	<u>77,4±15,3</u>	<u>63,8±11,6</u>
Sipuncula	11,92	10,64	5,57
Polychaeta	27,83	48,13	45,39
Echinodermata	12,68	8,88	0,98
Bivalvia	12,61	8,18	5,13
Crustacea	0,27	0,22	0,36
Varia*	6,21	1,34	2,71

Varia* – *Gastropoda*, *Spongia*, *Bryozoa*, *Tunicata*, *Coelenterata*, *Nemertea*.

In the period of observations, in the area surveyed, the biomass ratio of main benthos taxonomic groups significantly changed. The biomass of echinoderms, bivalves and sipunculans noticeably decreased. In 2003, in comparison with 1996, the absolute abundance of polychaetes insignificantly reduced, and the relative one considerably increased.

Registered changes indicate that the decrease of the total biomass in the north-eastern part of the Motovsky Bay in 2003 as compared with 1996 and the reduction in biomass of echinoderms, bivalves and sipunculans in 1931-2003, most likely, are caused by different factors. One of the most probable reasons of general decrease in biomass of echinoderms, bivalves and sipunculans may be the presence of red king crab for which the mentioned groups of animals are favourite objects of feeding. A number of facts allowed us to assume that the local reduction in total biomass of benthos is caused by fishing which is the most intensive in the north-eastern bay. At that, benthos biomass is directly dependant on its intensity.

Thus, the data obtained permit us to assume that the growth of red king crab abundance is less important for benthos biomass regulation than such anthropogenous factor as fishing.

By the results of taxonomic identification of data on 2003, within *M. sarsi* community, 225 taxons (177 species) were found that was 33 taxons (33 species) more than in 1996 and 97 species more than in 1930-1931. The data obtained are surely indicative of maintaining species richness of the community.

The comparison of biodiversity indices at the level of community on the whole, showed insignificant decrease of Shannon-Wiener H' and Pilow evenness indices and the increase in the Simpson's dominance from 1996 to 2003. Index changes, nevertheless, are so insignificant that do not allow us to be fully confident of real negative changes in the community structure.

Relative abundance curves were analyzed for the entire surveyed area in 1996 and 2003, for the inner and open part of the bay in 2003, for the open part of the bay in 1996 and 2003, for the inner part of the bay in the same years. A mutual disposition and character of plotted curves for the inner part of the bay, insignificant influenced by fishery, indicate the absence of negative changes in the community structure from 1996 to 2003.

The results of ABC-testing also have not revealed the evident indications of stress disturbances at the stations of the inner part of the bay. In the open part of the bay, in the zone of bottom fishing influence poorly expressed indications of stress variations in the community structure were found.

A comparison of listed species predominating in the community in 1931-32, 1996 and 2003, showed significant changes. Of 20 species prevailing in the community in 1931-32 only a half maintained in 1996 and only 6 ones (*Maldane sarsi*, *Golfingia m. margaritacea*, *Edwardsiidae g.sp.*, *Nephtys ciliata*, *Galathowenia oculata*, *Yoldiella tenticula*) dominated in 2003. At that, by 2003, all the feeding objects of red king crab accounting for 60% of leader specific list in the 1930s (6 species of the first 10 dominants) stopped their dominating.

The analysis of stomach content of crabs caught in the Motovsky Bay at the depths of more than 200 m in 1994-2003 showed that within *M. sarsi* community distribution limits the main invertebrate groups consumed by crabs were echinoderms (44% of benthos consumed), polychaetes (21%) and bivalves (9%). The decrease in mean biomass that was more significant for echinoderms and bivalves and less expressed for polychaetes was recorded for all mentioned taxons in 1996-2003. A significant reduction in mean biomass was registered for predominating majority of benthos organisms actively consumed by crab.

Thus, the research did not reveal any evident effect of the red king crab on the total biomass of benthos and biological diversity of the studied *M. sarsi* community. However, a selective consumption by the crab of some groups of bottom organisms led to a considerable decrease in abundance of its food objects and to changes in the order of species domination within the community.

Iceland scallop

The effect of the red king crab on the population of Iceland scallop was studied by analyzing the crab feeding in the non-harvest areas of the scallop settlements and on the harvested scallop banks.

Analysis of the crab stomach content showed that the crab feeding on the harvested and non-harvested scallop settlements differed greatly (Figure 5). On the harvested scallop banks the crab fed on them actively. Partial index of stomach fullness was estimated at 1.5‰, frequency of scallop occurrence made up 20.7% and percentage of the scallop in the crab diet accounted for 51.2%. The same indices under conditions of no harvesting were far less and made up 0.4‰, 15.2% and 4.9%, respectively. In the non-harvested areas the scallop was less important in the crab diet compared to other food items. So, index of the scallop importance was equal to 6, while, for instance, that of echinoderms was 100. In the areas of the scallop harvesting its index of importance was 32, while that of echinoderms was just 16. The food spectrum of the crab on the harvested grounds was not so wide as in the non-exploited areas.

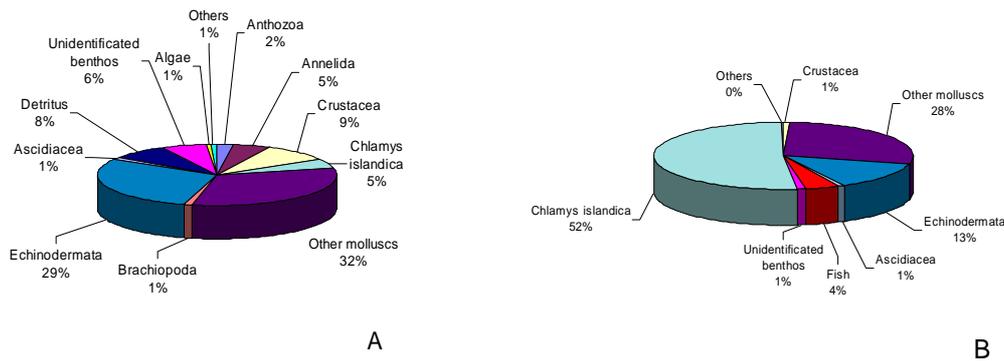


Fig. 5. Food spectrum of the crab and weight percentage of food items in the diet on the unexploited (A) and exploited (B) scallop settlements.

Examination of the scallop fragments in the crab stomachs suggested that in the areas (and in the period) of the scallop harvesting the crabs consumed mostly wastes of the scallop processing and individuals damaged by a dredge. In the areas where the scallop settlements were not harvested the crabs mainly consumed young mollusks and almost did not use the adult part of the population.

Thus, it is evident that in the wild, the red king crab predominantly consumes young scallops and almost do not affect the adult part of the population. Thereby, the red king crab having no considerable effect on the reproductive potential of the scallop population, nevertheless, can be a cause of its extra natural mortality due to elimination of juveniles.

Capelin

The fact that the red king crab in spring feed on fish eggs in the period of their mass spawning is documented. However, the long-term observations showed that on the average frequency of occurrence of fish eggs in the crab stomachs in spring was not higher than 6% and its percentage in the crab diet accounted for not more than 2%.

The most frequency of occurrence of fish eggs in the crab stomachs was noted in 2001 (19.4%). At the same time, the proportion of capelin eggs in the crab diet made up 1.2%. A rough estimation showed that in 2001, March through May, the crabs had consumed about 37 tonnes of the capelin eggs.

Is it much or not much? An approximate estimation of the damage caused by the crab to the capelin spawning grounds looks as described below.

The spawning stock of capelin in the REZ constitutes one third of the total spawning stock, which in 2001 was estimated to be 99.5 billion individuals. Weight of one clutch of eggs laid by one female capelin constitutes 8 grams on the average. Therefore, total quantity of eggs laid by capelin in 2001 in the Russian part of the Barents Sea could be approximately estimated at 130 thousand tones. A simple arithmetical calculation showed that in 2001 the red king crab consumed 0.03% of eggs laid by capelin. The figure obtained is rather rough but

adequately indicates the insignificance of damage caused by the red king crab to the spawning potential of the capelin population.

Haddock

The long-term research showed the king crab diet in the Barents Sea to be dominated by echinoderms, mollusks and worms. At the same time, all these groups are food objects of haddock; therefore, the food competition between haddock and the red king crab should manifest itself primarily in the decrease of frequency of occurrence and quantity of these objects in the haddock stomachs (Figure 6).

Analysis of the long-term data on the haddock feeding (1971-2002) allowed us to follow the haddock feeding dynamics in different periods of formation of the red king crab population in the Barents Sea. A comparative analysis of the haddock feeding in the period of the red king crab low abundance (1971-1977) and in the period of its increased abundance (1995-2002) was made. Taking into account that haddock feed on benthos in the second half of a year, the analysis was based on data for July-September. The study area was limited to the Norwegian border in the west, to 72°N in the north, to 45°E in the east and by the coastal line in the south. Within the study area such parameters as haddock catches, mean individual length in catches, feeding intensity, frequency of occurrence of plankton, worms, mollusks and echinoderms were analyzed.

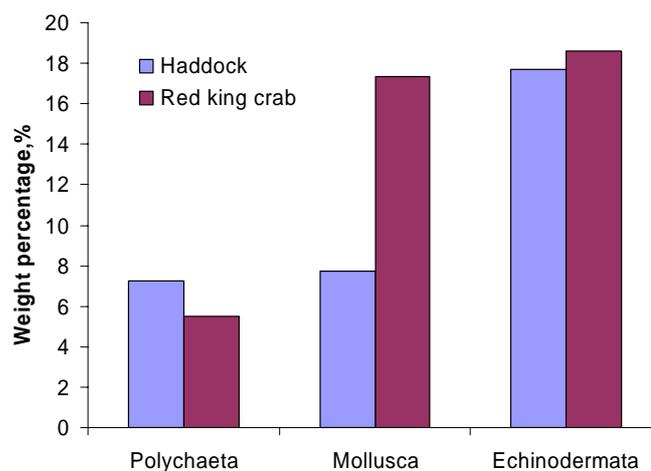


Fig. 6. Weight percentage of main benthic food items in the diets of red king crab and haddock in the coastal waters of the Kola Peninsula

The analysis made did not reveal any effect of the trophic competition from the side of the red king crab on the haddock feeding in the Russian part of the Barents Sea.

Conclusions

The research did not reveal any evident effect of the red king crab on the total biomass of benthos and biological diversity of the studied *M. sarsi* community in the Motovsky Bay. However, a selective consumption by the crab of some groups of bottom organisms led to a

considerable decrease in abundance of its food objects and to changes in the order of species domination within the community.

The red king crab predominantly consumes young scallops and almost do not affect the adult part of the population. Thereby, the red king crab having no considerable effect on the reproductive potential of the scallop population, nevertheless, can be a cause of its extra natural mortality due to elimination of juveniles.

It has been shown and documented highest registered Capelin eggs consumed by the crabs made up 0,03% of all capelin eggs laid in 2001. Thus, the negative effect of the king crab on the capelin recruitment can be considered as insignificant.

Such parameters as haddock catches, mean individual length in catches, feeding intensity, frequency of occurrence of plankton, worms, mollusks and echinoderms in the haddock stomachs were analyzed in the period from 1971 to 2002. The analysis made did not reveal any effect of the trophic competition from the side of the red king crab on the haddock feeding in the Russian part of the Barents Sea.

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THE INFLUENCE OF THE ENVIRONMENTAL FACTORS AND A NUTRITIVE BASE ON THE DISTRIBUTION AND BIOLOGICAL STATUS OF THE BARENTS SEA CAPELIN

by

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In the end of the 1950's – early 1960's the water temperature of the Barents Sea exceeded the norm, and capelin were widely distributed over the sea. However, the main area of feeding was in the north, where capelin fed on euphausiids, copepods and hyperiids. A peak of feeding was in July. In September-October, the fatness of capelin reached 19-21 %. In the capelin population, there was a big number of fish of older ages (4-5) that promoted a stable level of their reproduction. In the second half of the 1960's, the increase of capelin abundance was observed during the sufficient cooling of water masses. In connection with that the investigation of that species was widened, and the commercial exploitation of the capelin stock was initiated. In the 1970's, the catches of capelin amounted to 3.0 mill. t.

As a result of studying capelin food migrations, feeding behaviour and peculiarities as well as the growth, a quite clear picture of capelin feeding cycle was obtained. It was different for mature and immature fish under the different sea temperature. At present, the main attention is paid to studying the conditions of capelin nutritive base formation, peculiarities of its distribution depending on abundance and age structure of the population and feeding relationships between capelin and the other plankton-eaters, as well as the effect of the trophic factor on capelin population status.

The aim of the given paper is studying a long-term and seasonal dynamics of capelin feeding, a process of accumulation of fat and their influence on the maturation rate in the conditions, when the food supply is different in different areas of the central latitudinal zone of the Barents Sea.

Material and methods

To characterize feeding of capelin, the data on field and quantity-weight analysis (own and archive materials) for 1976-1978, 1982-1985, 1987, 1992, 2002-2003 (about 17 thou. stomachs) were used. Feeding potential of fish was estimated by the biomass of the copepod plankton (mg/m^3 of wet weight) for 1982-1985, 1987, 1992, 2002-2003. Those data were obtained by PINRO during the complex survey in the central latitudinal zone of the Barents Sea (Fig. 1) and the survey for 0-group pelagic fish. In total, about 600 samples were analyzed. Percentage by mass (m) (% of the stomach contents mass) and frequency of occurrence (f) (% of feeding fish) were used as feeding indices. Stomach fullness was visually determined using a five-point scale: 0, empty; 1, low fullness; 2, mean fullness; 3, full stomach; and 4, full stomach with walls stretched by food. An index of fullness was calculated as the stomach contents mass divided to the fish mass and multiplied by 10 000 (‰). Capelin fatness was determined by a standard method (Lazarevsky, 1955). The data on

capelin abundance were taken from the ICES (Anon., 2000, 2003), and the fish distribution was analyzed by the data from the fishery statistics and the trawl-acoustic surveys.

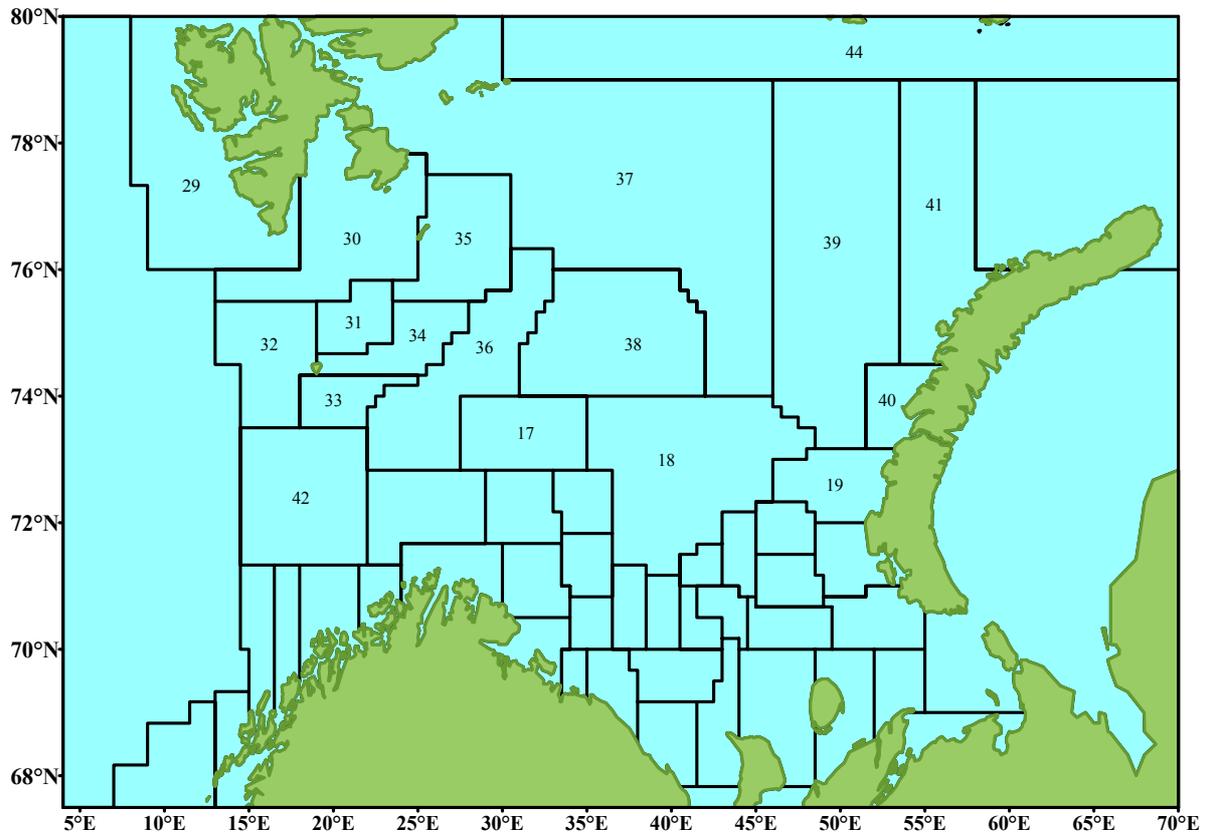


Fig. 1 Chart of the Barents Sea fishing area:

17-the Demidov Bank; 18-the Central Deep; 19-the Northern part of the Novaya Zemlya Shallows; 29-the West Spitsbergen; 30-the South Cape Deep; 31-the Spitsbergen Bank; 32-the Bear Island Bank Western slope; 33- the Bear Island Bank Southern slope; 34- the Bear Island Bank Eastern slope; 35- the Hopen Island area; 36-the Western Deep; 37-the Perseus Elevation; 38-the Central Elevation; 39- the Novaya Zemlya Bank; 40-the Sukhoy Nos area; 41-the Admiralteistvo Peninsula area; 42-the Kopytov area; 44- the Franz Josef Land area

Results

Formerly, estimating capelin food supply in 1972-1984, only the development of the North Atlantic species *Calanus finmarchicus* was taken into account. A role of the Arctic species was not estimated. However, a sufficient role of the arctic species in the formation of biomass in the high latitudes has been shown recently. *Calanus glacialis* is the most abundant species among them. Besides, during the discussed period the capelin population was changing that, probably, also influenced the distribution and conditions of capelin feeding.

A period of 1976-1978 is characterized by a high abundance of capelin and the presence of a great number of older fish (3+ and 4+) in the population. Their portion was high in the moderate and cold 1976-1977 (Fig.2). In those years, the capelin distribution was the widest. Their area reached 78-80°N in the north and the Novaya Zemlya in the east (Røttingen and

Dommasness, 1985). In the anomalous cold 1978, the feeding area of capelin reduced and shifted south and westwards. It was probably caused by the hydrological conditions, the decreased abundance of capelin and a drop of a portion of fish at the age of 3+ and 4+ in their population.

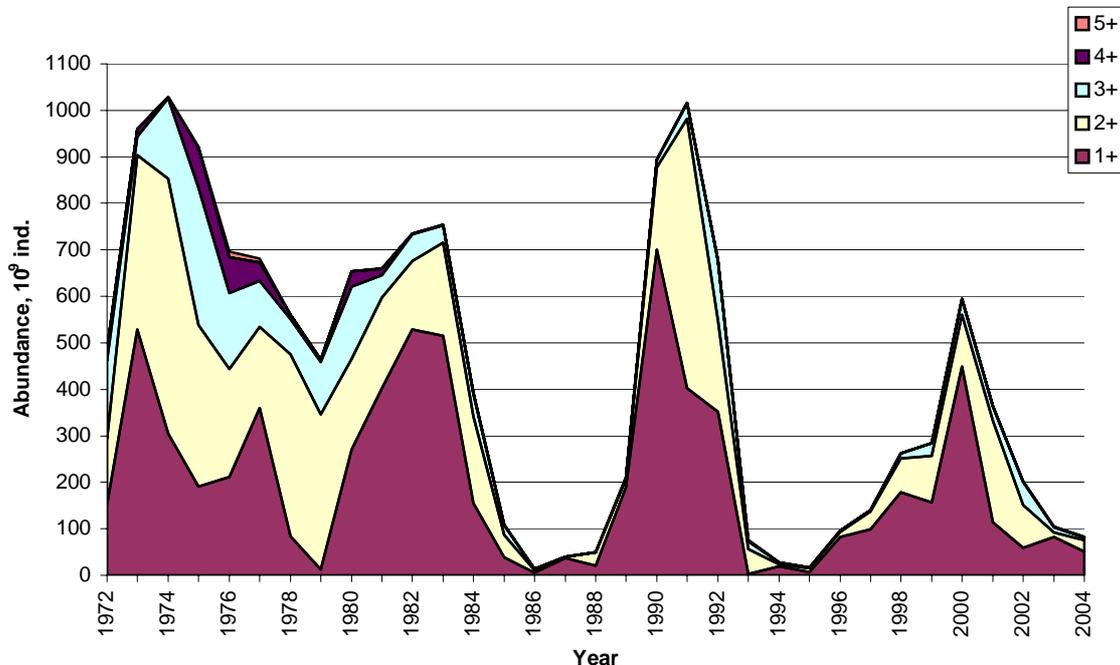


Fig 2. Dynamic of capelin abundance in the Barents Sea according to the TAS data

In the moderate 1976 capelin began to feed early. In that year, there was the high biomass due to the euphausiids (overwintering copepods) in the eastern and northeastern sea (Anon., 1991) that favoured the intensive feeding of the large capelin on them already in the first ten-day period of June. There, the consumption of copepods by the small fish (the mean length – 12 cm) was recorded (Fig.3a). In the early August, a part of capelin formed dense concentrations in the Hopen Island area, at 76°38' N, where the fish fed moderately on copepods and euphausiids. In the northeast, capelin predated on copepods in the end of August-the first half of September. Already in July, the level of capelin fatness (10.2%) was unusually high for summer. Fish fatness increased in August-September (11.3-11.7%).

In the cold 1977, regular feeding of capelin began in May-June in the fish migration area (the Demidov Bank), as well as in the wintering ones (the Central Deep). First, it was connected with euphausiids, then (June-July) - with the copepods also (Fig. 4). Fish aged 2+ - 3 were noticed to prefer those crustaceans in feeding. In August-September, the center of capelin feeding shifted to the areas with the arctic water masses – to the Hopen Island area (76-77°N) and the Perseus Elevation (76-78°N), as well as to the northeast. In some areas in the west and east, capelin also fed on euphausiids and, to a less extent, on hyperiids and *Sagitta*. By the end of July, the fatness of capelin made up 6 %. In August-September, a sudden increase of capelin fatness (to 11-15 %) happened, and, in October, they stopped to feed.

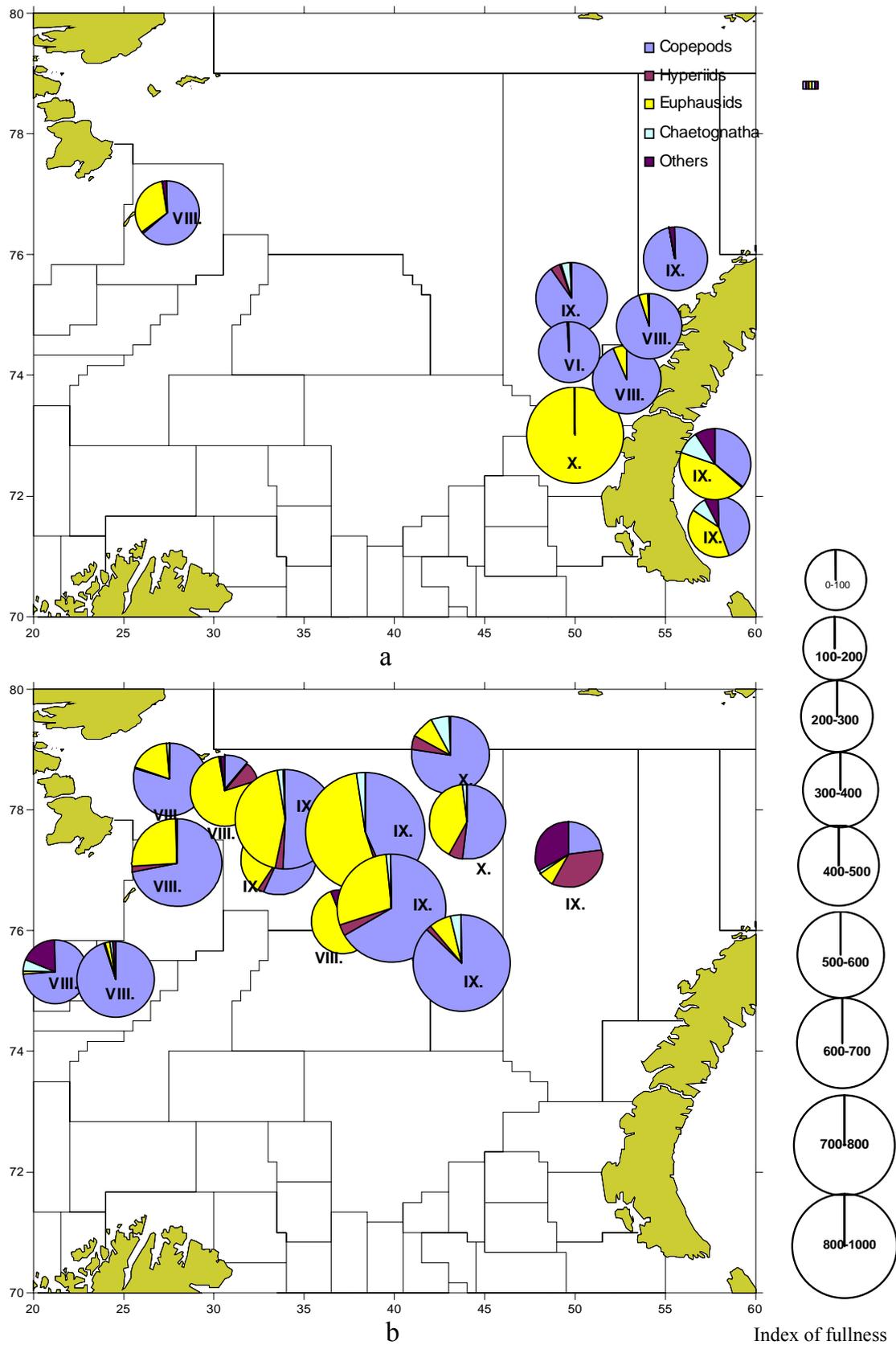


Fig. 3. Food composition (% by weight) and the intensity of consumption (Fullness $^{0}/_{000}$) in 1976 (a) and 1978 (b)

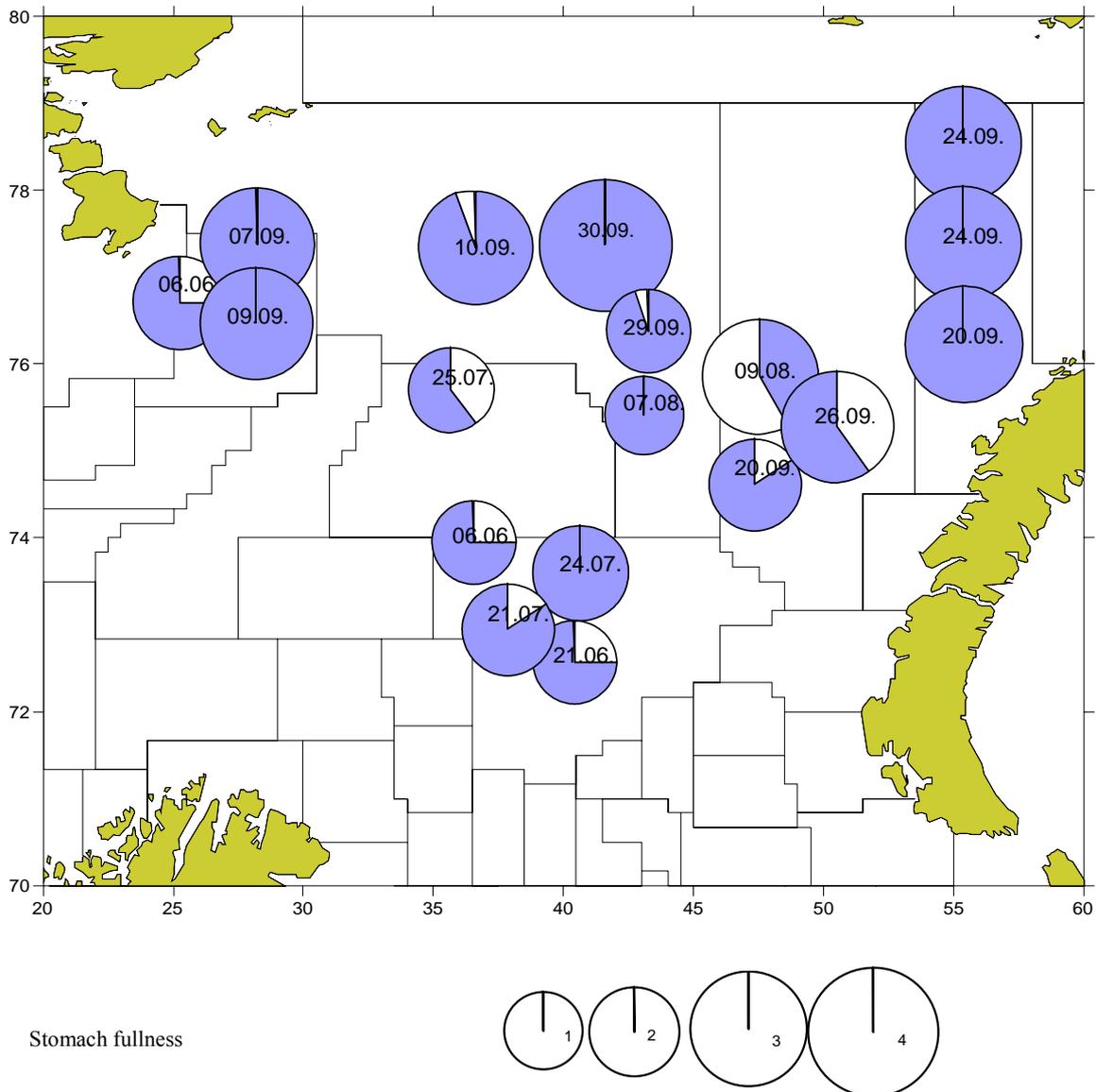


Fig. 4. Copepods frequency (%) in the food of 3+ years capelin in June-September 1977

The anomalous cold 1978 was characterized by the highest concentrations of the euphausiids in the northwest. Dense concentrations were also formed due to a wide distribution of coldwater *Th.raschii* alongside with the warm-water species (*Th.inermis*, *Th.longicaudata*). Rather poor, but prolonged (during the entire June) feeding of capelin was noticed on the ways of that fish migrations (the Western Deep), where capelin aggregations overlapped those ones of the euphausiids with a high density (100-1000 ind./1000 m³). In that period, the two-year-olds primarily fed on copepods and the diet of the three-year-olds was mixed with a prevalence of euphausiids. The main feeding of capelin from all the age groups started in August-the first half of the month in the Bear Island Bank, in the Hopen Island area (76-77°N) and the Perseus Elevation (76°N). In the second half of the month, the feeding went on in the same areas, but the capelin was gradually migrating to the north and northeast. In the capelin feeding, the age differentiation by the specific food composition (copepods predominated in the small fish diet and the euphausiids were preferred by larger capelin), which also varied

depending on the capelin feeding area, was observed well. In the late September-early October, in the northern borders of the capelin feeding area (77°35'-77°55' N), in the Perseus Elevation, capelin started feeding on hyperiids though the consumption of copepods (mainly, *Calanus finmarchicus*) and euphausiids (primarily *Th.inermis*) remained to be high and those species predominated in capelin diet by weight (Fig. 5). At that, capelin index of fullness was high. Practically, all the fish fed. On the Novaya Zemlya Bank, hyperiids were the main food object. As a result of intensive feeding, in August, capelin fatness was already 11 %, and, in September, it reached 16.7 %.

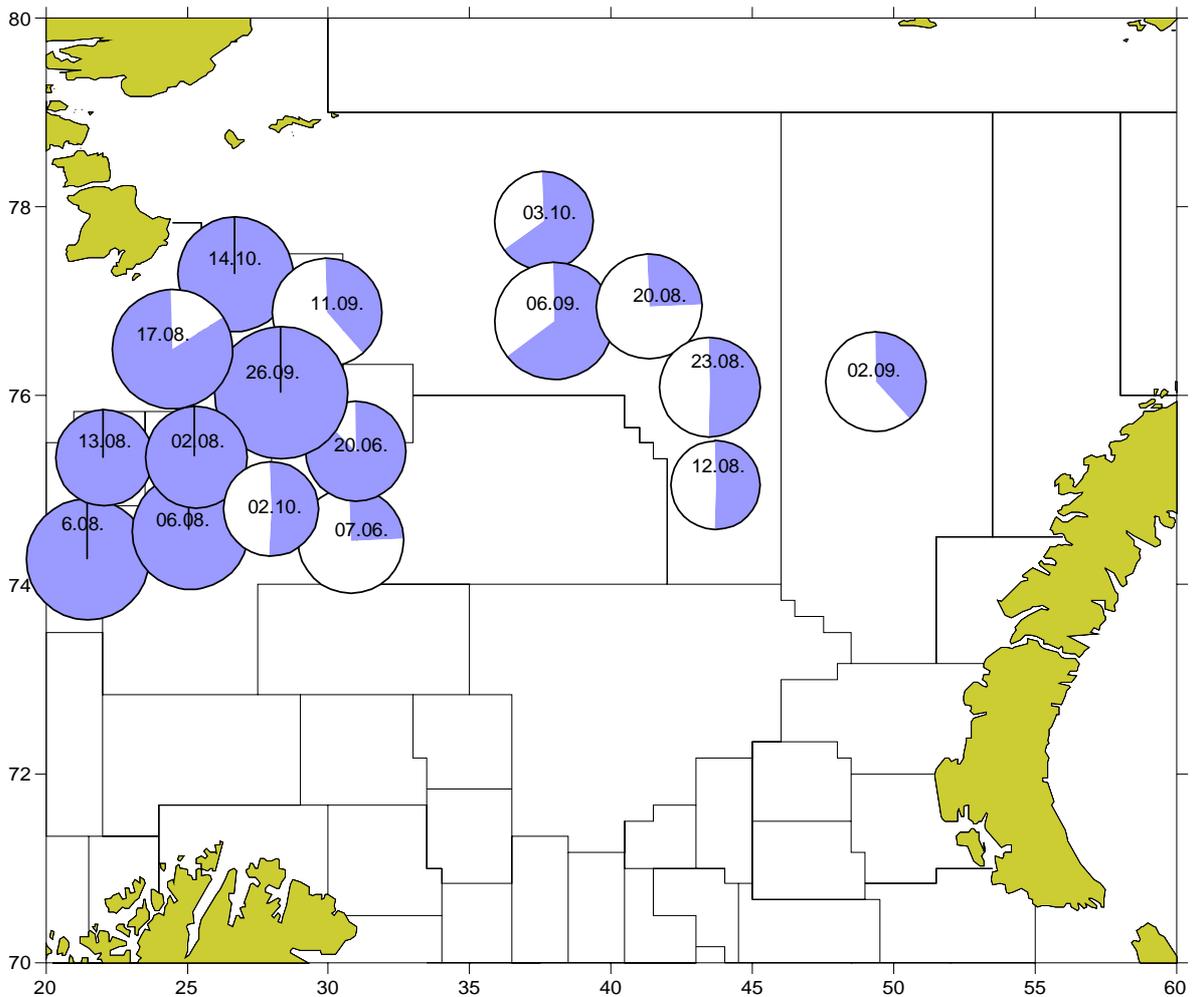


Fig. 5. Copepods frequency (%) in the food of 3+ years capelin in June-October 1978 (see legend Fig. 4)

The second group of years (1982-1987 and 1992) differs sufficiently from the previous one. At that time, capelin stock changed its status from stable (1982-1984) to collapse (1985-1987) and then it was recovered in 1992 (Fig. 2). Besides, at that period, a portion of older fish reduced much in the population compared to 1976-1978, and since 1984 fish aged 2 and 3 predominated. In 1982-1987 and 1992, unlike the previous years, the data on the food supply were available in the majority of cases, that permitted to analyze a role of this factor in feeding and dynamics of capelin fatness.

In June of warm 1983, all over the Barents Sea, the reproduction of copepods was mainly completed. In the western areas, nauplia and young copepodites from the North Atlantic species *Calanus finmarchicus* predominated. The Arctic species were also in plankton in the north, among which *C. glacialis* predominated. In the second half of July, in the central part, the spawning of *Calanoida* was in progress only at 77°N. The Arctic species predominated among older copepodites in the north, and *C. finmarchicus* prevailed in the southern areas. In the northeastern part of the sea the copepods kept high abundance till the end of July. The abundance of young copepods continued to be high in the northeastern sea to the end of July. On the Novaya Zemlya Bank, the individuals of *C. finmarchicus* at Stages I-II predominated. *C. glacialis* prevailed in the Sukhoy Nos area and was represented by copepodites at Stages III-V.

In July, in the layer 0-50 m, the total biomass of plankton did not exceed 100-200 mg/m³, and only in the northern areas, to the east of Spitsbergen, the biomass was not higher than 500 mg/m³. The contribution of each species was different (Table 1).

Table 1. Copepods biomass in 0-50 m layer in the central latitudinal zone of Barents Sea July-August 1983 (mg/m³)

Fishing area	<i>C. finmarchicus</i>		<i>C. glacialis</i>		<i>C. hyperboreus</i>	
	July	August	July	August	July	August
Western Spitsbergen	56	135	47	6	29	0
South Cape Deep	174	33	159	7	10	12
Spitsbergen Bank	33	47	434	3	2	1
Eastern slope of the Bear Island Bank	-	6	-	0	-	0
Hopen Island area	41	94	172	17	6	2
Western Deep	13	17	0	0	0	6
Perseus Elevation	72	56	91	149	50	1
Central Elevation	28	48	5	1	0	1
Novaya Zemlya Bank	28	-	33	-	11	-
Sukhoy Nos area	7	-	75	-	44	-
Admiralteistvo Peninsula area	3	-	15	-	6	-

Plankton mass maturation and sinking to the depth took place in August. The copepods were consumed, probably, in that period. In the Arctic waters, the biomasses in the upper layer were low and formed owing to *C. finmarchicus*. Only on the Perseus Elevation, they reached maximum (150 mg/m³) due to *C. glacialis*.

In autumn-winter 1982/1983, in the northwest, the aggregations of euphausiids were also scattered, obviously, because of the intensive consumption of them by capelin in summer 1982 (further).

Since the rates of plankton development differed in the different water masses, the feeding of capelin in 1983 was irregular. In July, in the western areas, feeding of the large capelin predated on young *Themisto* and copepods (*C. finmarchicus* at Stage V and *M. longa*) was the most intensive. However, obviously, there was a small amount of food. Capelin fed more intensively in the end of July, in the Central Elevation (Fig. 6), where the diet by weight mainly consisted of euphausiids and copepods (predominantly cold-water species *C. glacialis*, *C. hyperboreus* and *P. minutus*). In August, capelin concentrations remained to be stable due

to the mass passing into feeding on copepods. In that period, higher biomass in the low water layers was caused by mature *C. finmarchicus* and plenty of the Arctic species. The latter ones (*C. hyperboreus*, predominantly), as well as warm-water species of euphausiids (*Th. inermis*, *Th. longicaudata*) and chaetognaths (*Sagitta spp.*) predominated in capelin diet. In accordance with the seasonal order of the development of copepods and euphausiids, capelin fed the most intensively in the Central Elevation (August), the Perseus Elevation (August-September), in the Hopen Island area (September) and on the Novaya Zemlya Bank (August) (Fig. 6). Due to the intensive feeding, capelin reached high fatness in the first days of September already. In September and October of that year, fatness indices were equal to 10.8 and 10.7%, respectively.

A character of the capelin food supply formation in the warm 1992 was close to that one in 1983. The main feature of capelin feeding was irregularity connected with many factors: a character of their distribution, spatial differences in the plankton species composition and biomass, and the level of plankton consumption. In 1992, there was a food competition from the side of the polar cod, the abundance of which increased almost in six times as compared to 1990. The food competition between those fish species was the largest on the Novaya Zemlya Bank, where the polar cod had advantages in food consumption. A limitation of capelin diet influenced their fatness. In September 1992, that index was only 5.7 %, and in October – 6.6 %, that was much lower than for the same period of 1983 under the favourable feeding conditions for capelin.

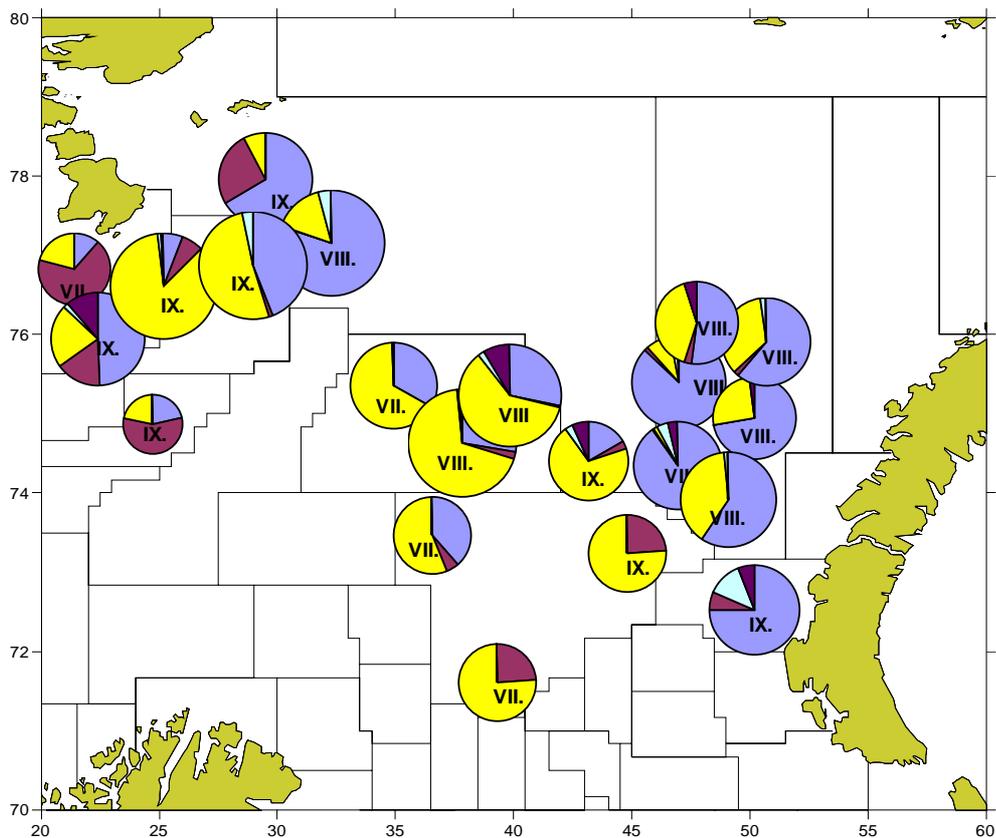


Fig. 6. Food composition (% by weight) and the intensity of consumption (Fullness ‰) by capelin in 1983 (see legend Fig. 3)

A situation with the formation of capelin food supply in the moderate years (1982, 1984 and 1985) was quite different. In 1982, under a big value of the capelin stock and the lowered portion of fish older age groups (Fig. 2), capelin had the northwestern distribution. *C. finmarchicus* predominated in the plankton composition there. In the end of August, a considerable part of crustaceans, predominantly in the south of the area, reached Stages IV-V, but in higher latitudes, nauplia and copepodites at Stages I-III were found. In the Arctic waters, the aggregations of *C. glacialis*, a portion of which was the highest in the area of the Hopen Island area and in the South Cape Deep (25-45 % of the large copepod total abundance) were registered. Large amounts of *C. hyperboreus* were also observed there. In August, the biomass formed mainly due to older stages of *C. finmarchicus*, *C. glacialis* and *C. hyperboreus*. There mean values equaled to 227 mg/m³ in the area of 72-75°N and to 203 mg/m³ at 76-78°N. A great food potential in those areas had been existing for a long time that conditioned capelin stay in most those areas till October-November. In the northwest, the aggregations of the euphausiids were quite poor.

In the mid-June 1982, in the Hopen Island area (at 75°45' N), 3-4 year old fish traditionally fed on euphausiids. In August, in the northwest, the main concentrations of capelin overlapped the increased biomass of zooplankton. In the middle of the month, their percentage in the diet of 3-4 year capelin abruptly increased. Copepods predominated in September as well, however, the change of food was not synchronized in time, and, in that area, the condition factor was low (Fig. 7).

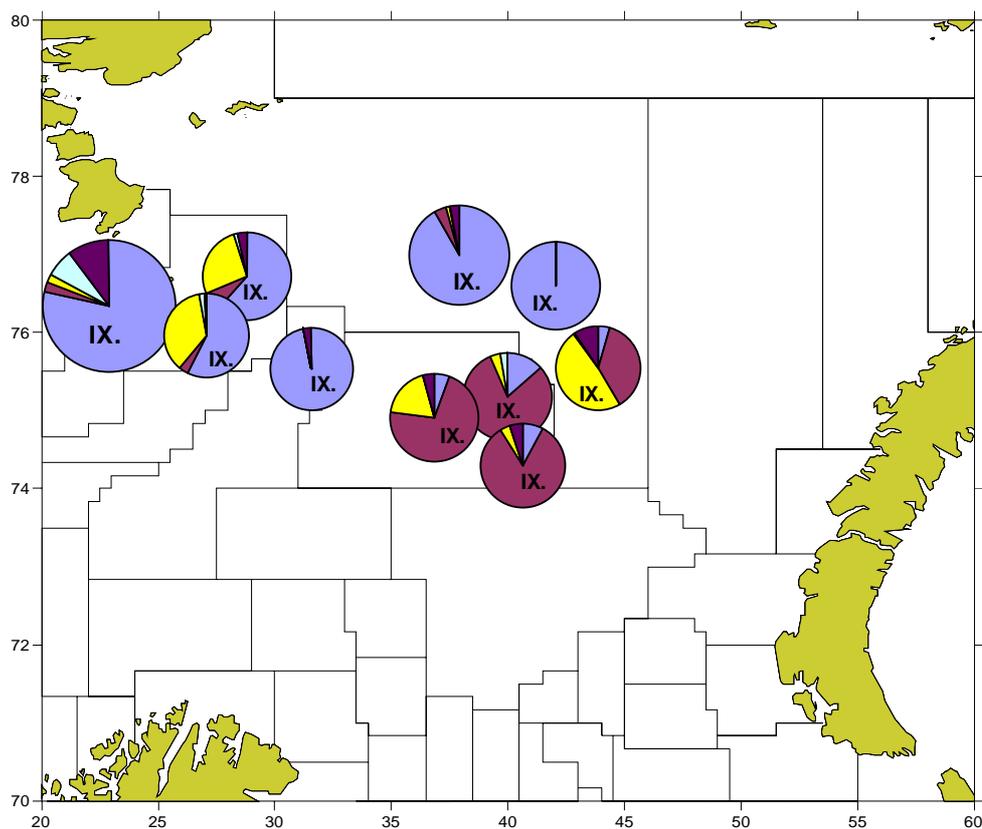


Fig. 7. Food composition (% by weight) and the intensity of consumption (Fullness ‰) by capelin in 1982 (see legend Fig. 3)

In the Perseus Elevation (76°55' N), the feeding of capelin on copepods began in August, but was not intensive. In September, in the northern areas, *C. finmarchicus* and *C. hyperboreus* at Stages IV-V predominated in diet. At that, in the early September, small-sized capelin (the average size – 11.5 cm), which reached the northern borders, fed on crustaceans there. The role of *C. hyperboreus* in the feeding of large fish was especially great in the end of the month. In the south of the feeding area, their diet was mixed (Fig. 7). The capelin aggregations were distributed for a long time in the Central Elevation, where fish at age of 2-5 fed intensively on the mixed food in August. The shortest period of the intensive feeding of capelin on copepods (September-October) was in the cold waters of the South Cape Deep with a maximum in the first half of September. Since the feeding of capelin in 1982 was irregular, fish reached a high fatness (more than 10 %) in the first-second ten-day periods of September in the Perseus Elevation and in the end of September in the South Cape Deep.

The environmental conditions had the main influence on the feeding in 1985. The lowered heat content of waters in the west (right up to July) caused the slow development of plankton. However, the intensive warming up of waters in August favoured the quick maturation of plankton and their sinking to the bottom. In that year, the euphausiid community also appeared to be poor, probably, owing to the consumption of copepods in the previous years. Since zooplankton biomass on the migration ways of capelin was very low in July-August, fish almost did not feed. In August, despite feeding on euphausiids (the Western Deep, the Hopen Island area) the capelin index of fullness was very low (it does not exceed 7-25 ‰). In September, in the surface layers, plankton was also scanty. Compared to warm and normal years, when the intensive feeding of capelin began already in July-August, in 1985, a peak of capelin feeding was in September, when the main part of the food plankton was near the bottom (the fullness index increased up to 142-275 ‰). In that year, the euphausiids were not prevailing in the diet due to their low abundance in the northwest.

The area of the capelin feeding on copepods was very wide. At that, in the South Cape Deep, the Hopen Island area and in the Central Elevation, the intensive consumption of those copepods began in early September and stopped in early October (Fig. 8). Feeding of capelin in the Perseus Elevation lasted to October. In 1985, capelin feeding was characterized by the consumption of mainly copepods of the older copepodite stages in the lower layers and the lack of vertical migrations. A portion of *C. glacialis* in the capelin diet was the highest (58 % by quantity or 65 % by weight), and, as a whole, the Arctic species dominated. The consumption of euphausiids (primarily, of grown up juveniles) was mainly recorded in the northwest, in September. The disturbance of a seasonal rhythm of capelin feeding caused the lowered accumulation of fat supply. As a result of the poor feeding in August, in September, the fatness had been low (5.7 %), and only in October the index increased to 8.2 %.

In the cold 1987, at the low abundance of capelin and predomination of the two year old fish in the population, the formation of feeding concentrations was late, and, in the end of August, the capelin were yet in the Norwegian Channel. On the Demidov Bank, there were small and larger capelin migrating for feeding to the northwestern areas. Their feeding was moderate and the food was diverse. In addition to *C. finmarchicus* and *Th. inermis* composing the basis of capelin feeding, the Arctic species *M. longa* and *C. glacialis* were found in the small numbers. The main feeding of capelin took place in the areas with the increased concentration of copepods and euphausiids, in September. The index of capelin stomach fullness was high, in the most areas, the diet was dominated by euphausiids (55-95 % by the frequency of

occurrence) and, only in some parts, the increased number of copepods was registered. In some areas, capelin fed quite intensively in the beginning of October, when their small concentrations moved forward to the Perseus Elevation. There, capelin started consuming mainly hyperiids, whereas in the west the feeding was the same. The late beginning and early termination of feeding in 1987, as well as the predomination of young individuals in the population and the limited feeding area could lead to the low fatness of fish.

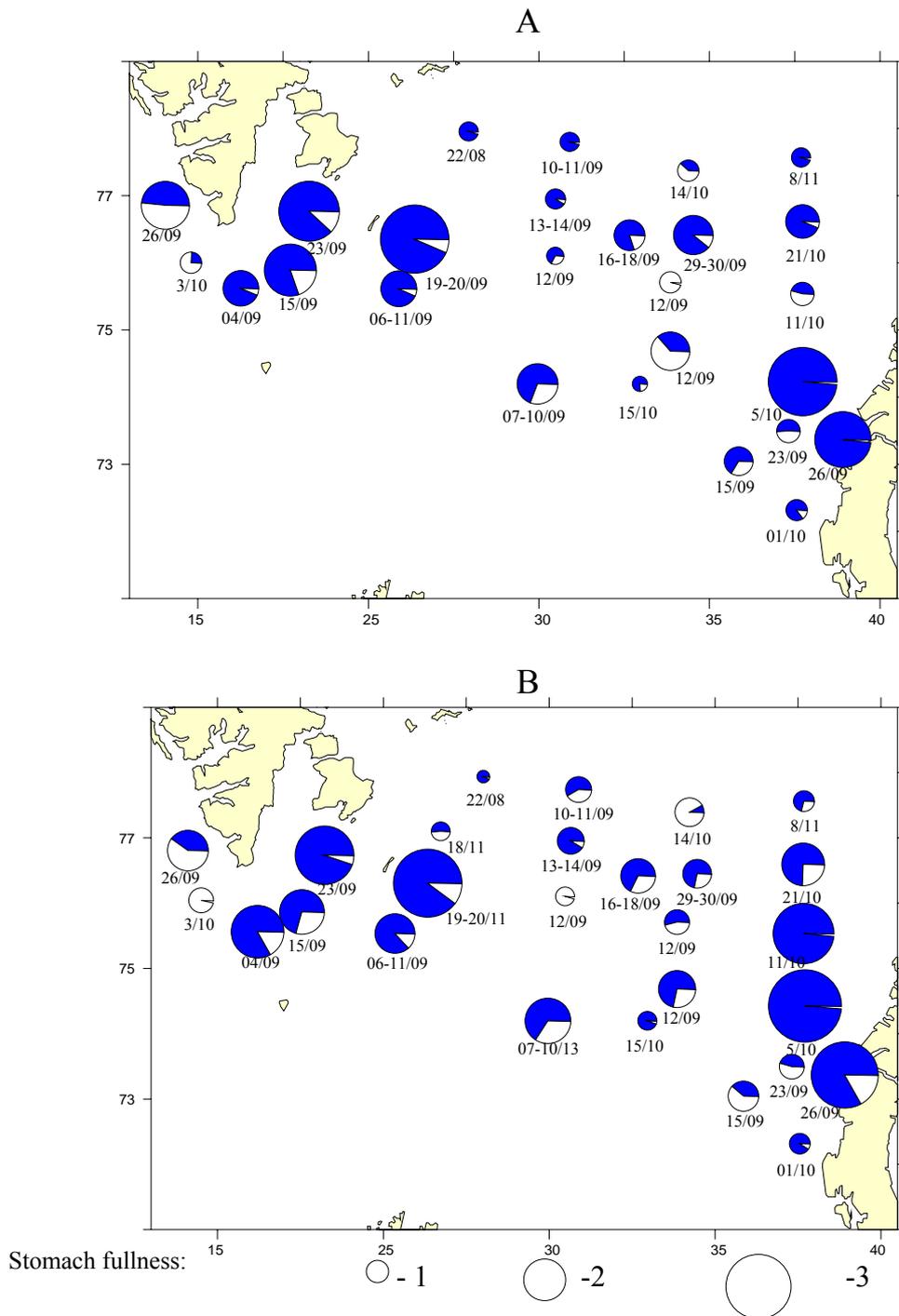


Fig. 8. Significance (blue sector frequency) of copepods in the 2+ years capelin (A) and 3+ years capelin (B) feeding in autumn 1985

Peculiarities of capelin feeding have been recently studied taking the warm 2002 and 2003 as the examples. In that period, with a relatively low stock size and a sufficient percentage of young fish in the population, the feeding area of capelin was small. In 2002, young fish distributed further to the south with the border in the north along 78°N. Mature capelin were distributed further to the north, but the main concentrations of fish from all the age groups were located in the Perseus and Central Elevations. In 2003, their distribution was further to the south and not so wide. The main concentrations were in the area of the Hopen Island area, the Perseus Elevation and the Central Deep reaching 78°30' N in the north.

In 2002, in the end of August-early September, *C. finmarchicus* and *C. glacialis* at the early stages (I-III) predominated in zooplankton in the areas having recently become free from the ice and along the ice edge. In 2003, the similar situation (the availability of eggs, nauplia and young copepodites) in the areas further to the south in the Perseus Elevation was observed in the middle of September, but *C. finmarchicus* predominated there. Specially should be mentioned a big abundance of this Atlantic species at Stage V on the Novaya Zemlya Bank.

In 2002, the biomass fluctuated at the level of 50-200 mg/m³, on the average, in the north, and they reached 300-750 mg/m³ in the northernmost areas. In 2003, the biomass was lower and amounted to 100-300 mg/m³ in the main areas of capelin feeding at 76-77°N. Thus, the feeding conditions of capelin in autumn of 2002 were more favourable.

In 2002-2003, capelin began to feed in July-August, but the peak of feeding was in September, although in 2003, in some areas, capelin continued to feed in October-November as well (Figs. 9,10). In 2002, the capelin distribution depended more on the copepod plankton because of the wide distribution and prolonged production of *C. finmarchicus* and *C. glacialis*, especially in the northern areas (78-80°N). In that year, the intensive consumption of copepods was registered in the Perseus Elevation, under a big importance of older copepodites in the capelin diet. It is important to notice that the individuals of older age groups of *Calanus* selected by capelin did not predominate in the plankton (Fig. 11) that can be explained by insufficient taking *Calanus* by the Juday net. Macroplankton organisms (the boreal species of euphausiids *Thysanoessa inermis* primarily) were also important in the distribution of capelin concentrations.

Capelin reached the highest fatness in 2002 in the northern areas of the Perseus Elevation (10.4-13.6 %) and on the Novaya Zemlya Bank (8.1-10.8 %). In 2003, the capelin fatness was somewhat lower, but the increased values (7.6-8.1 %) were also registered when the large individuals appeared at the northern borders of the feeding area on the Perseus Elevation. The latter fact is connected with the consumption of the Arctic species of copepods, which are characterized by a high content of lipids.

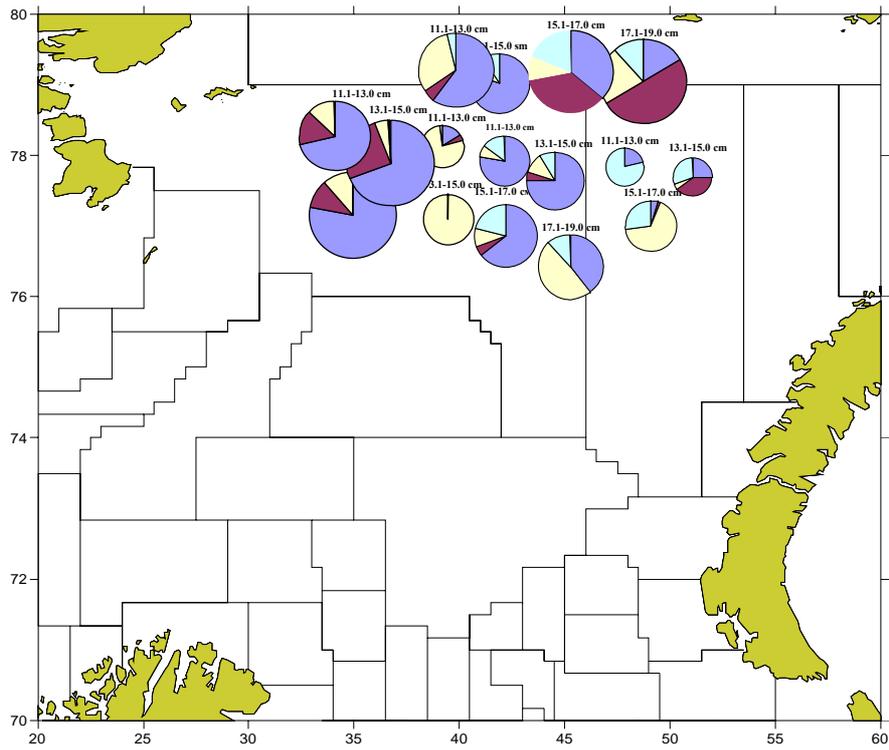


Fig. 9. Food composition (%) and the intensity of consumption (Fullness ‰) by different length capelin in 2002 (see legend Fig. 3)

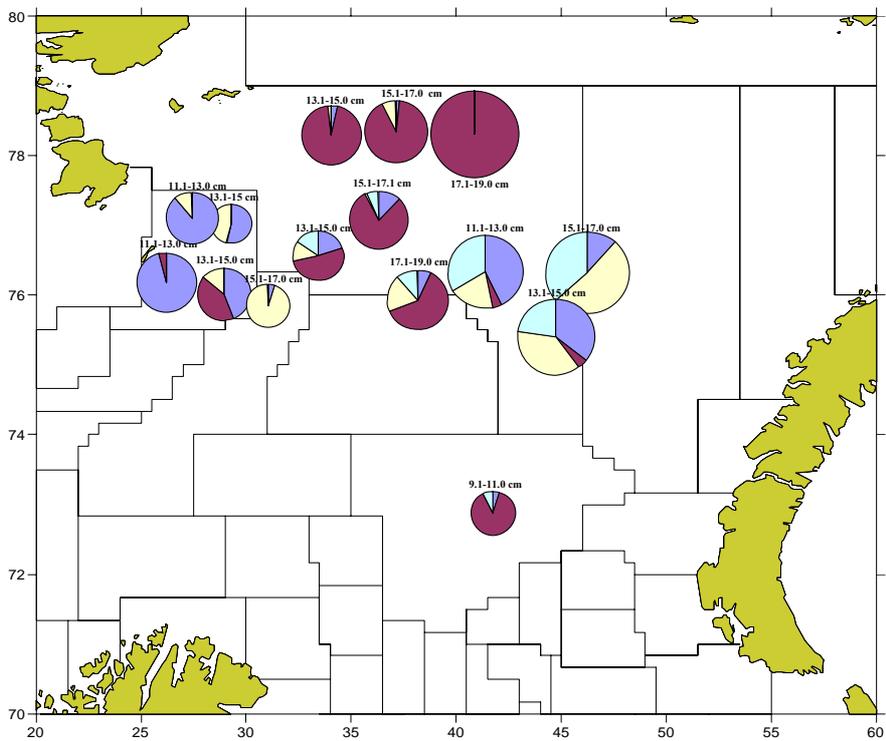


Fig. 10. Food composition (%) and the intensity of consumption (Fullness ‰) by different length capelin in 2003 (see legend Fig.3)

In accordance with the dependence of a maturation rate of capelin on their fatness level (Oganesyan and Dvinin, 1988), in 2002 a mass maturation of the second- and third-year females characterized by a high fatness was registered mainly in the Perseus Elevation, whereas males were immature with the little exception there (Table 2). In 2003, a portion of mature individuals in the mentioned age groups of capelin was lower.

Table 2. Abundance of mature capelin (%) and fatness of different length capelin in September 2002-2003

Fishery area	Date	Length group, cm	Fatness, %	Mature capelin, %					
				2+		3+		4+	
				female	male	female	male	female	male
2002									
Perseus Elevation									
78°50'N43°01'E	09.09.02	14.0-17.5	13.6	100	-	100	-	75	-
78°30'N44°52'E	10.09.02	12.0-16.0	10.7	100	-	100	-	-	-
77°35'N34°15'E	12.09.02	11.5-15.5	10.4	100	100	100	100	100	100
76°15'N45°15'E	16.09.02	14.5-18.1	8.7	-	-	96	40	-	-
Novaya Zemlya Bank									
77°25'N47°15'E	14.09.02	13.1-18.2	10.8	-	-	-	92	-	-
76°55'N49°45'E	15.09.02	14.0-17.6	8.1	-	25	100	27	-	-
77°15'N50°45'E	15.09.02	13.1-17.2	10.4	-	-	100	100	-	-
2003									
Perseus Elevation									
76°18'N 37°01'E	18.09.03	9.9-13.7	5.2	13	0	-	-	-	-
76°48'N 43°34'E	21.09.03	12.0-16.5	7.6	100	-	100	-	100	-
77°10'N 38°12'E	22.09.03	14.6-17.5	7.1	-	-	100	0	83	14
77°55'N 30°35'E	23.09.03	14.5-17.0	6.6	100	-	100	0	100	0
76°40'N 32°48'E	27.09.03	13.0-15.7	8.1	100	0	100	100	100	-
Hope Island area									
77°39'N 26°37'E	25.09.03	14.0-17.0	6.3	100	0	80	0	33	0
77°02'N 29°02'E	27.09.03	12.2-14.3	6.0	64	-	67	-	-	-
76°39'N 28°59'E	29.09.03	12.8-16.0	6.8	92	-	85	-	100	-

Conclusions

Thus, an effectiveness of capelin feeding depends on hydrological conditions, abundance of their population, age composition of fish and a character of their distribution. The abiotic conditions indirectly influencing the specific composition of zooplankton communities have a great influence on the distribution and the development of zooplankters that determines the periods and duration of the fish feeding. The accessibility of food organisms and their abundance changing as a result of the biotic press are of decisive importance. The lack of food is felt to the utmost in the abnormally warm years (1983 and 1992), especially in the western areas, when the upper layers were very much depleted in connection with the intensive development and sinking of copepods. In the moderate years, under the slowed development of the copepod plankton and later spawning of the euphausiids, fish of all ages are better supplied with food, especially in the northern areas, where the most part of plankton consists of copepodites of older stages of *C. finamrchicus* and the cold-water species, *C. glacialis*, first of all (1982). More distinct dependence on the mentioned factors is expressed in the

abnormally cold and cold years, but in this case the abundance of capelin and the availability of fish of older ages in their population are of a big importance. In the abnormally cold year of 1978, capelin were characterized by a wide distribution that was accompanied by their intensive feeding all over a vast area from August to early October. At that, the euphausiids forming the abundant concentrations, when the aggregations of ecologically different species (*Th. inermis*, *Th. longicaudata*, *Th. raschii*) overlapped, played greater role in the capelin feeding. In 1987, under the minimal abundance of capelin, their food migration was late, and the feeding area was very narrow. As a result, capelin poorly used food resources of the northern areas. The main feeding period of capelin on copepods (as well as on the euphausiids) shifted to September and was very short-term.

A condition favouring the prolonged feeding and the achievement of a high level of fatness and mass maturation by capelin is their migration to the north, where a high food potential is kept for a long time in the zone of the floating ice due to the continuing reproduction of copepods there. Such a possibility is realized under the presence of fish from older age groups migrating for a long distance in the capelin population; this appears to be both in the warm and cold years.

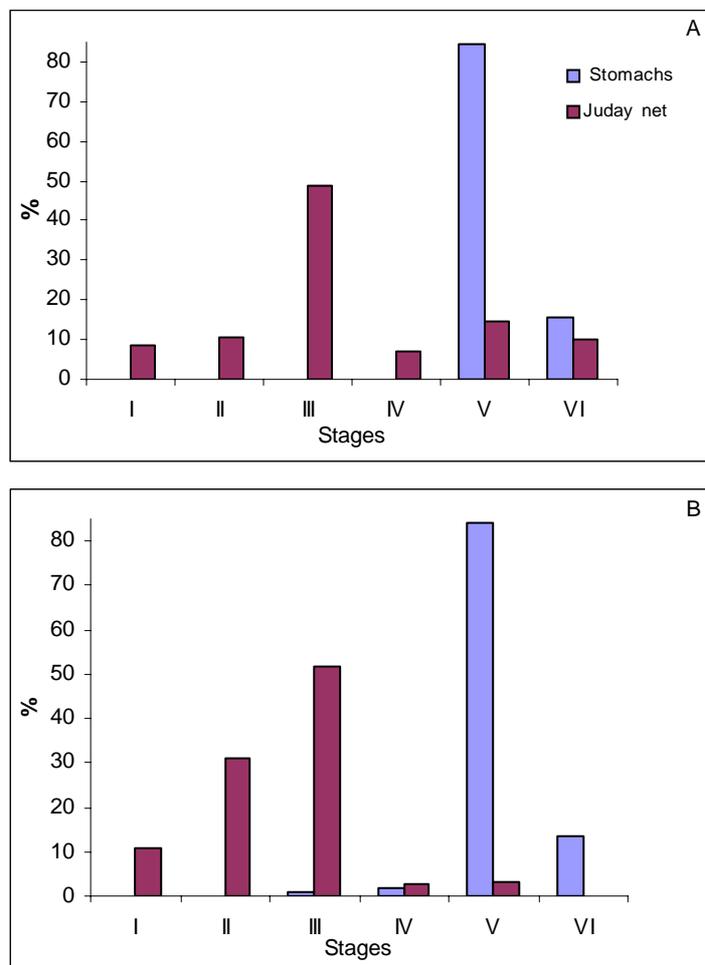


Fig. 11. Stage composition of *C. glacialis* in capelin stomachs and Juday net catches in the Franz Josef Land area (A) and Perseus Elevation (B) in September 2002

PREDICTION OF CAPELIN GROWTH FOR USE IN CAPTOOL

by

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Background

Since 1999, a 1-year prognosis of capelin has also been made during the assessment, using CapTool. The prognosis gives the abundance of 1+ capelin during the survey in year $y+1$, based on the survey of 1+ capelin in year y , as well as the 0-group survey in year y . The temperature and the cod stock abundance are also taken into account in this prediction. Since capelin is a key species in the ecosystem, e.g. as food for cod (*Gadus morhua*) and other predators, such a 1-year prediction is important for predicting the development of other important stocks in the ecosystem. It also gives some indication of whether the stock will be large enough to support a fishery in year $y+2$. An evaluation of the prediction methodology is given in Gjørseter et al. (this symposium).

A key element in the 1-year predictions is the growth. In this poster, we make regressions in order to improve the 1-year predictions for capelin length growth, which are used in CapTool.

Results of regressions

$$L_{y+1,1} = 0.36L_{y,0} + 8.10 \quad (r^2=0.20, p < 0.05)$$

$$L_{y+1,2} = 0.49LI_{y,1} - 0.26Cap_{y,1+} + 9.29 \quad (r^2=0.66, p < 0.05)$$

$$L_{y+1,3} = 1.37 LI_{y,2} - 1.39 \quad (r^2=0.34, p < 0.05)$$

- $LI_{y,a}$: Mean length (cm) of immature capelin of age a in year y , from capelin survey
- $L_{y+1,a+1}$: Mean length (cm) of (all) capelin of age $a+1$ in year $y+1$, from the capelin survey
- $L_{y,0}$: Mean length (cm) of 0-group capelin, as observed during the 0-group survey in year y
- Cap_y : Biomass (million tonnes) of capelin (1+) in year y

The following variables were tested, but found not to improve the models:

- Kola temperature January-September or August-September.
- Plankton abundance by size fraction or total, from autumn survey.

Conclusions

- Length of age 1-3 capelin depends on length of age 0-2 capelin the year before.
- Growth from age 1 to 2 seems to be density-dependent.
- For growth from year y to $y+1$, no relationship was found to temperature or plankton abundance in year y .
- The equations given will be implemented in CapTool.

Further work

- Break the data (temperature, plankton etc. down by area/water mass.
- Check correlation with ambient temperature and with inflow of water to the Barents Sea.

LONG-TERM PROJECTION OF WATER TEMPERATURE TO BE USED IN THE ADVANCE ASSESSMENT OF THE BARENTS SEA PRODUCTIVITY

by

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Water temperature is one of the main characteristics of seawaters. It is widely used for estimation of heat content in water masses, dynamic processes, intensity of interaction between the ocean and atmosphere and other physical phenomena. Water temperature is of crucial importance for marine ecosystems. Therefore, study of its spatial and temporal variability and development of projection methods with different time in advance is an important scientific and practical problem.

The effect of variability in the heat content of the Barents Sea water masses on the ecosystem manifests itself at all trophic levels. In years with low water temperature in the upper 50-m layer in April-June in the southwestern Barents Sea 64% of cod yearclasses at the age of 0-group were poor and only 36% of the yearclasses were of average strength. In cold years rich yearclasses never appeared. Rich yearclasses of cod at the stage of pelagic juveniles formed only in years with high (58%) and average (42%) water temperature (Figure 1 and 2).

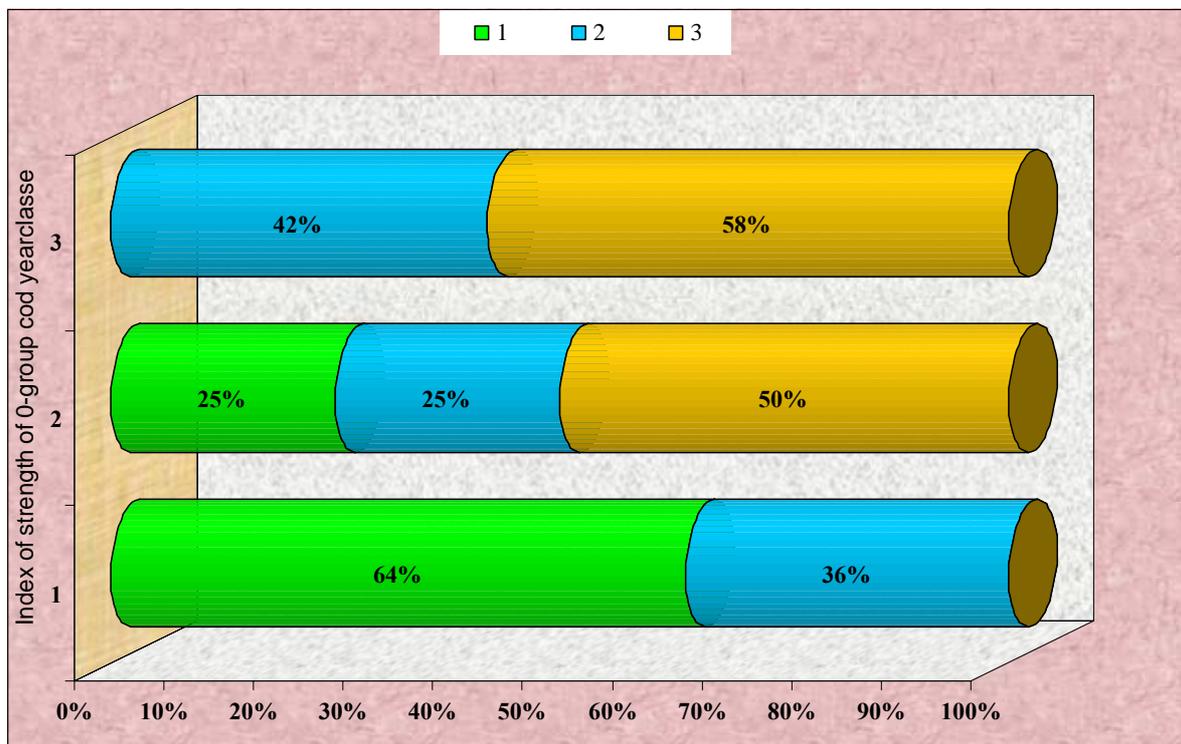


Figure 1. Frequency of occurrence of 0-group cod yearclasses of different strength at low (1), average (2) and high (3) water temperature in the Barents Sea

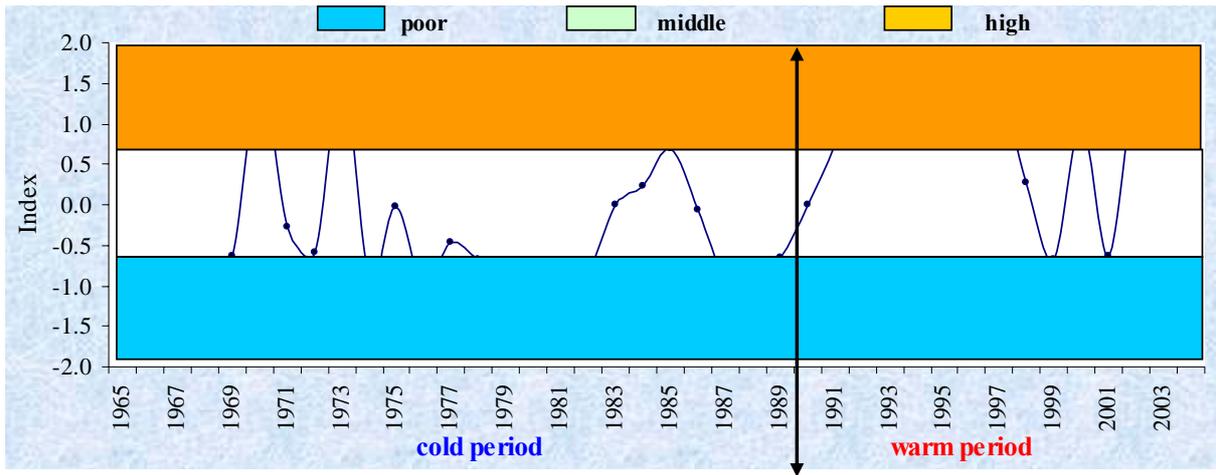


Figure 2. Variation in abundance index of 0-group cod

Year-to-year temperature variability in the Barents Sea correlates well with biomass dynamics of the main demersal species such as cod and haddock. Over a long period of water temperature decrease in 1960-80's, their total biomass also reduced (Figure 3). Under overall rise of water temperature in the Barents Sea, cod and haddock biomass was observed to increase. These examples demonstrate the importance of long-term temperature prognoses as they are taken into account in the advance assessment of expected changes in the Barents Sea ecosystem including recruitment and fishable stocks of the main fish species.

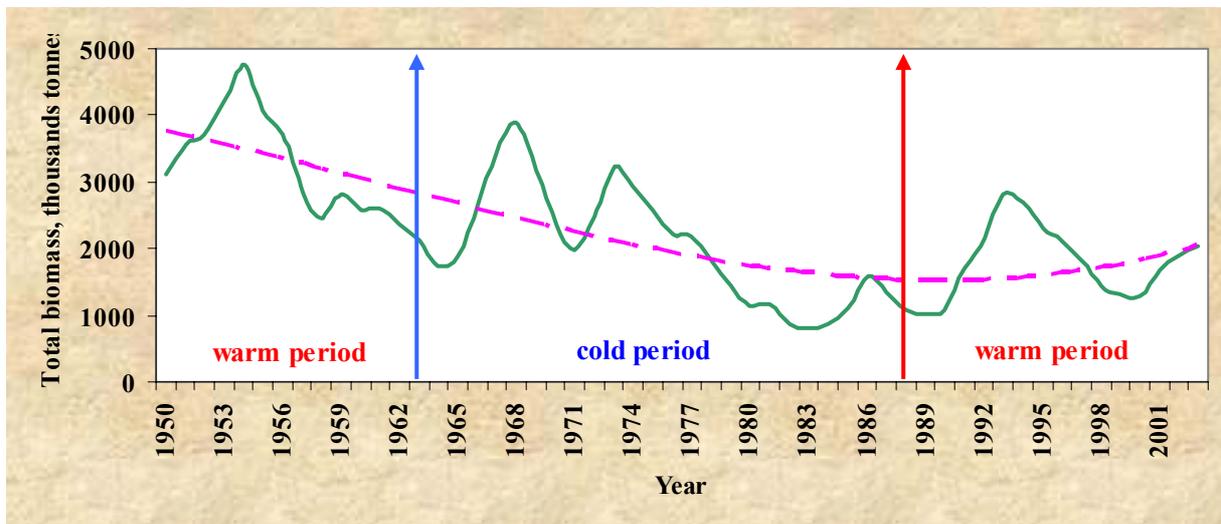


Figure 3. Year-to-year variability in total biomass of cod and haddock in the Barents Sea

Water temperature temporal variability in the Barents Sea has a complicated structure. The spectrum of year-to-year fluctuations in water temperature is rather wide, from short-term 2-3-year fluctuations to a trend component, which can be a part of the long-term cycle. The polycyclic nature of water temperature fluctuations is determined by numerous cause-and-effect relationships between oceanographic, meteorological and heliogeophysical conditions. Due to various reasons it is not always feasible to formalize and use such relationships in the long-term prediction of water temperature with the accuracy required for practical purposes.

Therefore, at present, the major task when developing new methods of the long-term water temperature prognoses in the Barents Sea is to take into account frequency structure of its fluctuations and instability in time of amplitudes and phases of cyclic components. In the present study, the cyclic components were identified in water temperature fluctuations within the 0-200 m layer of the Kola Section using periodogram analysis, spectral analysis, integer and non-integer harmonics identification and wavelet analysis. All the methods used showed almost the same ensemble of year-to-year fluctuations in water temperature. Its main components were a trend and cyclic components with average periods of 14-18, 8-10, 5 and 2-3 years (Figure 4). In 1951-2000, their contribution to the variance accounted for 18, 18, 34, 10 and 15%, respectively. The rest of power was due to noise effects.

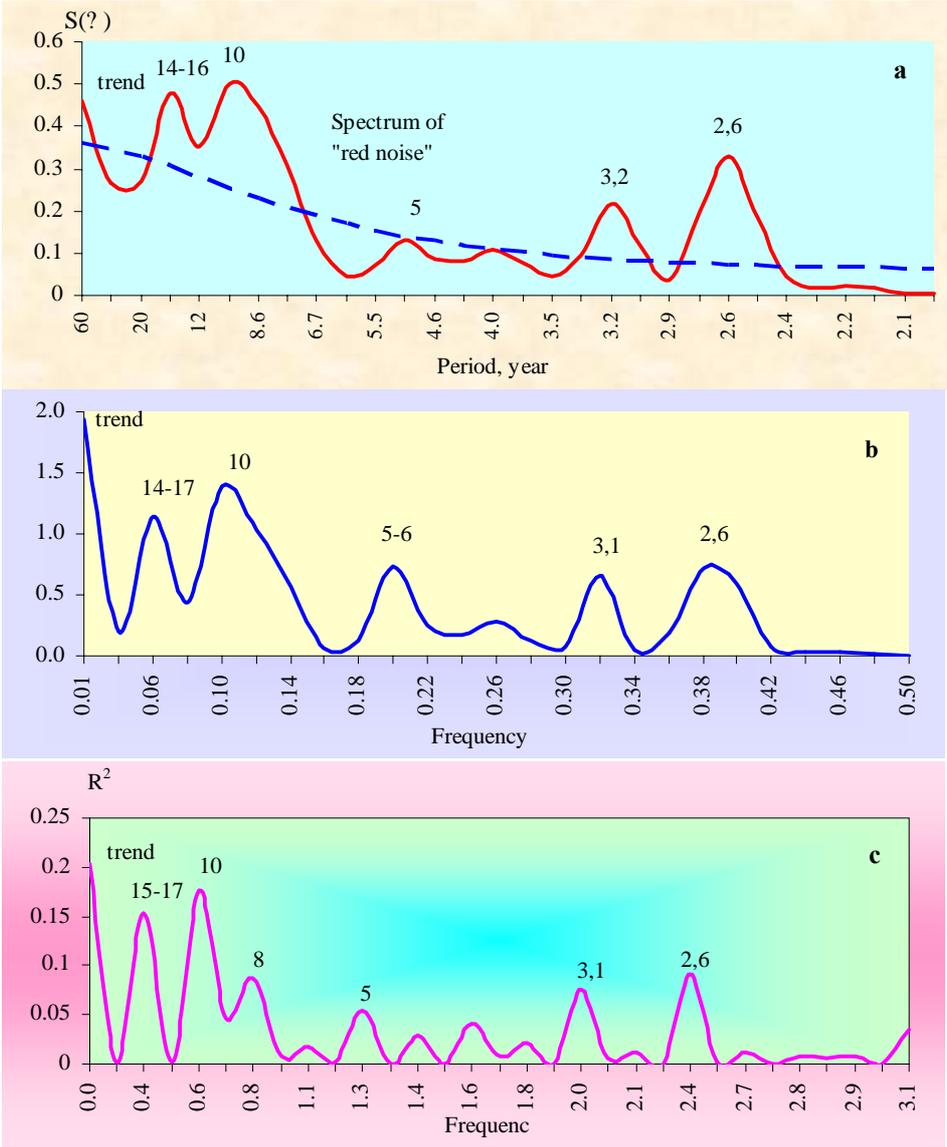


Figure 4. The spectrum (a), periodogram (b) and harmonicogram (c) of mean annual water temperature fluctuations in the 0-200 m layer in the Kola Section based on data of 1900-2000 (above the peaks – period in years; in the top panel a dashed line shows “red noise” spectrum; in the bottom panel a dashed line indicates threshold significance level of coefficient of determination)

A great problem is that year-to-year temperature fluctuations in the Kola Section are non-stationary. If this feature is ignored in methods being developed for temperature projections, errors will be inevitable in the future. Non-stationary frequency structure of water temperature fluctuations makes itself evident in the fact that in the second half of the XX century compared to its first half the period of low-frequency components increased from 12-15 and 8 years to 14-18 and 8-10 years, correspondingly. Amplitude instability of some cycles was also revealed. In 1951-2000, spectral power of the trend decreased while contribution of high-frequency fluctuations increased compared to the prior 50-year period (Figure 5).

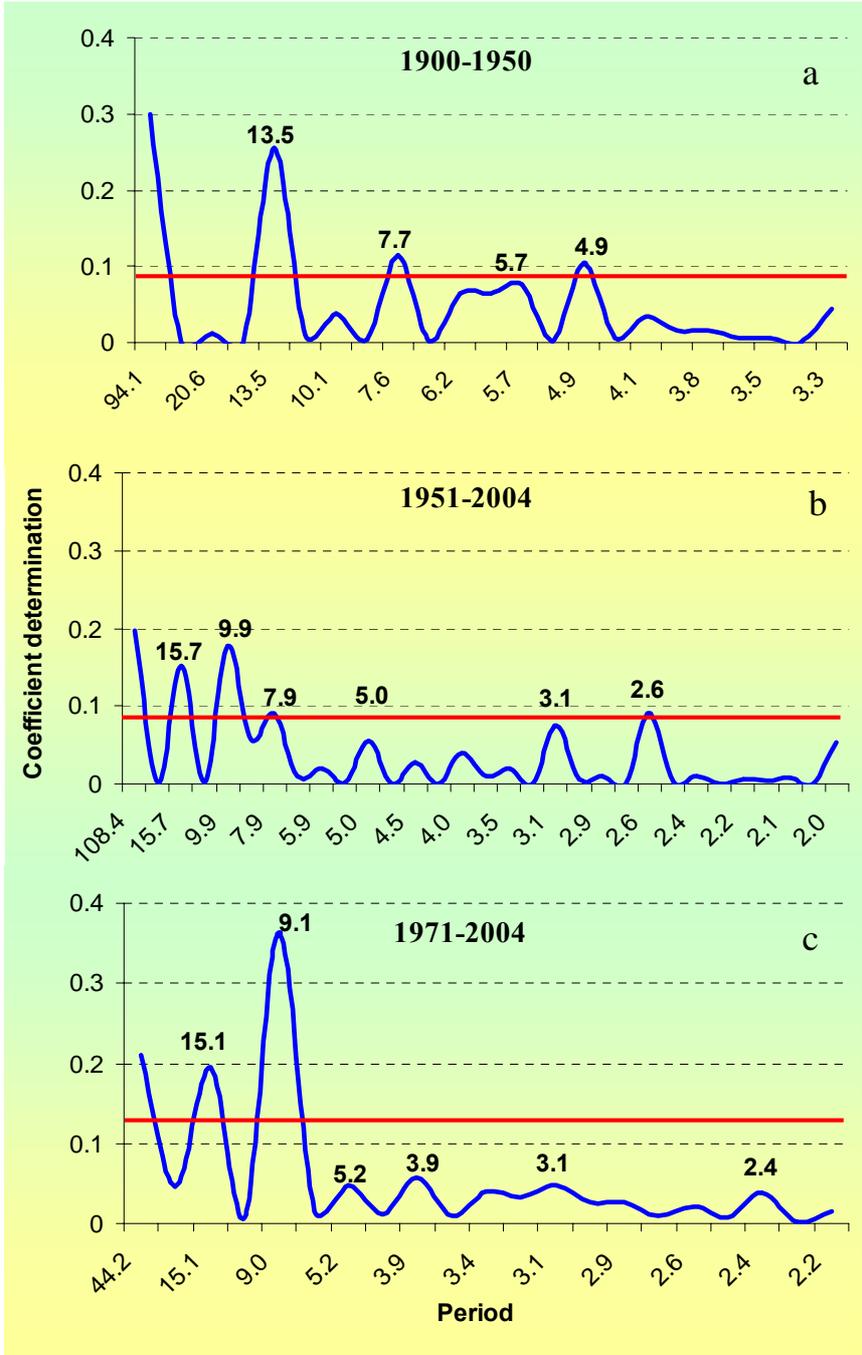


Figure 5. Periodograms of water temperature in the Kola Section in the 0-200 m layer for the periods 1900-1950 (a), 1951-2004(b) and 1971-2004 (c)

Analysis of water temperature fluctuations in 0-200 m layer of the Kola Section since 1971 until the present showed that variance of the short-term quasi-cycles decreased greatly again, while proportion of low-frequency components increased (Figure 5). The up-to-date pattern of water temperature fluctuations in the Kola Section was used for temperature projection by extrapolation of trend, 14-16 and 8-10-year quasi-cycle components. Such projections are proved to be correct in about 90% instances (Figure 6).

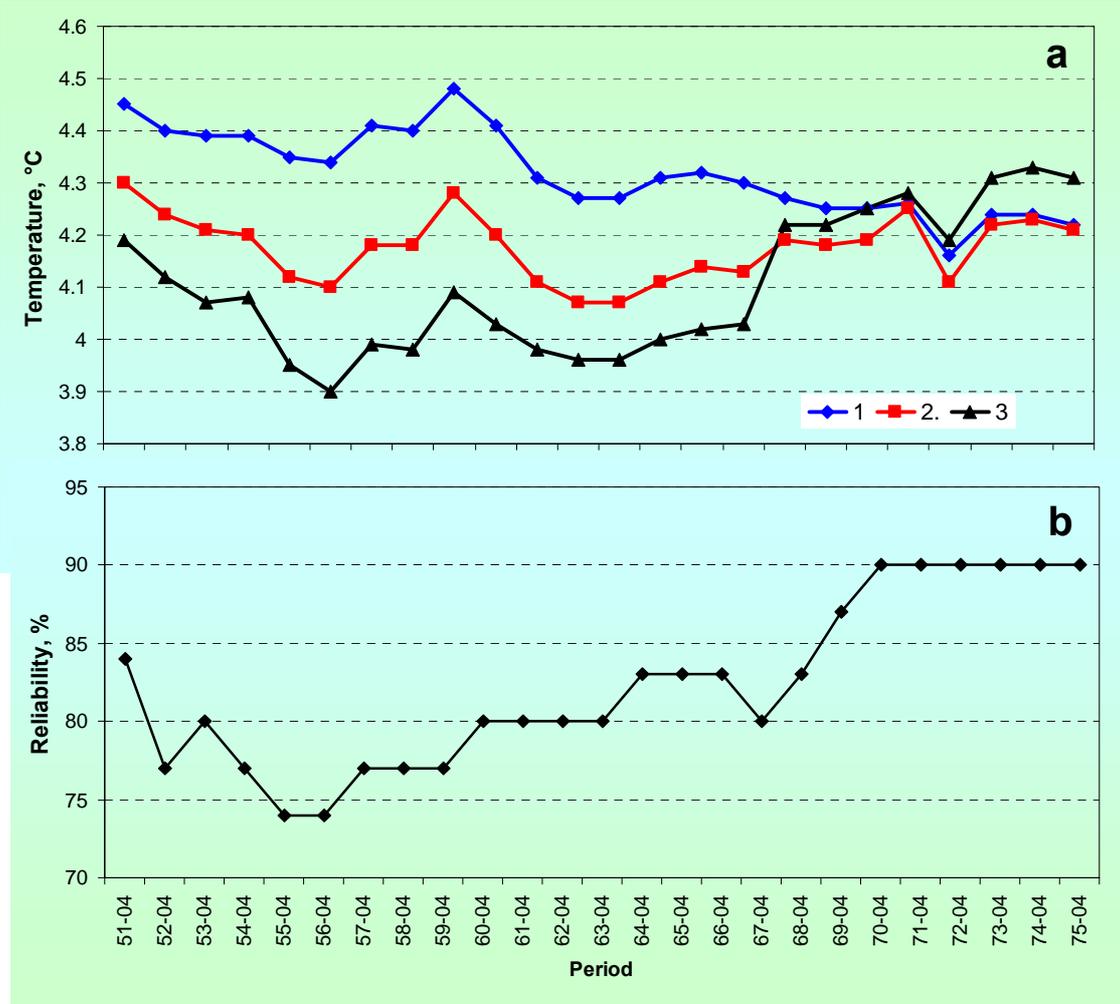


Figure 6. Projections of water temperature in the Kola Section in 0-200 m layer (a) for 2005 (1), 2006 (2) and 2007 (3) based on time series of different length and their reliability (b)

One more method of the water temperature prediction was also based on extrapolation of its cyclic components, which were identified based on data of 1941-2000 using a method of bandpass filtering. For each of them in the time interval, within which the cyclic recurrence appeared not less than 2 times, the Non-Integer technique was used to select those harmonics, which in sum described its variability to a closest possible approximation (no less than 95%). To arrive at more reliable results, one more way of analytical description of variability of the identified components was applied. With the least-squares method, polynomial functions approximating their last cycle were selected. This permitted us to minimize the frequency and amplitude instability in each cyclic component (Figure 7).

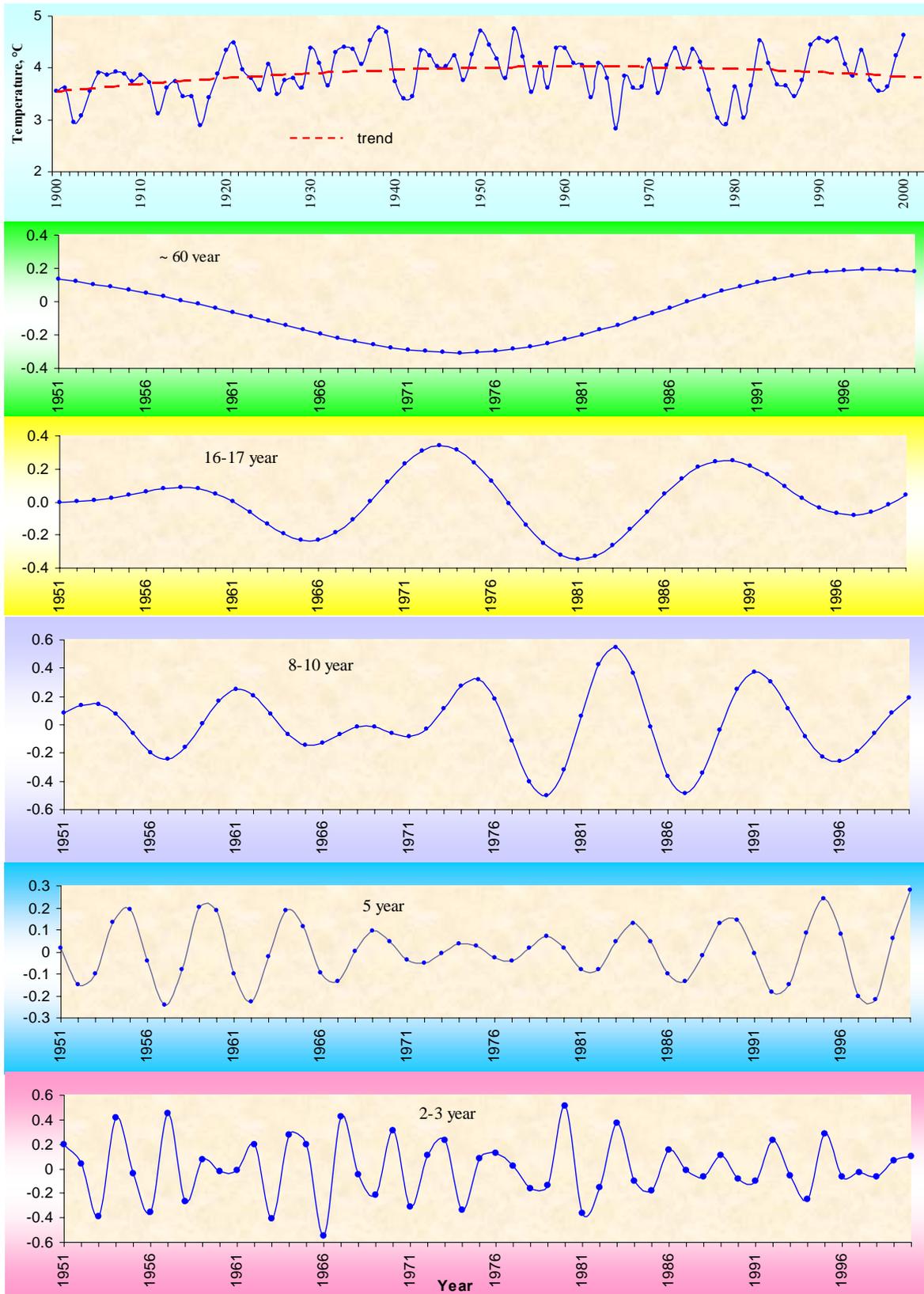


Figure 7. Cyclic components of water temperature variability in 0-200 m layer in the Kola Section

Water temperature was projected in several steps. Using the obtained analytic formula of the trend component based on data over the whole period of observations (1900-2000), its values were calculated for two years ahead. Having excluded the trend from the initial time series within the interval from 1951 to 2000 and using the method of sequential bandpass filtering, values of the main cyclic components were estimated and differentiated. Then, each estimate was extrapolated two steps forward with the use of the selected approximating polynomial functions and a set of non-integer harmonics. Estimates of all the components were summed up with regard to the sign that gave two projected estimates of water temperature. Each of the projected estimates was obtained for one and two-year periods in advance. Mean value of the two projected estimates in each of the above periods served as prognosis of water temperature in the 0-200 m layer in the Kola Section (Figure 8).

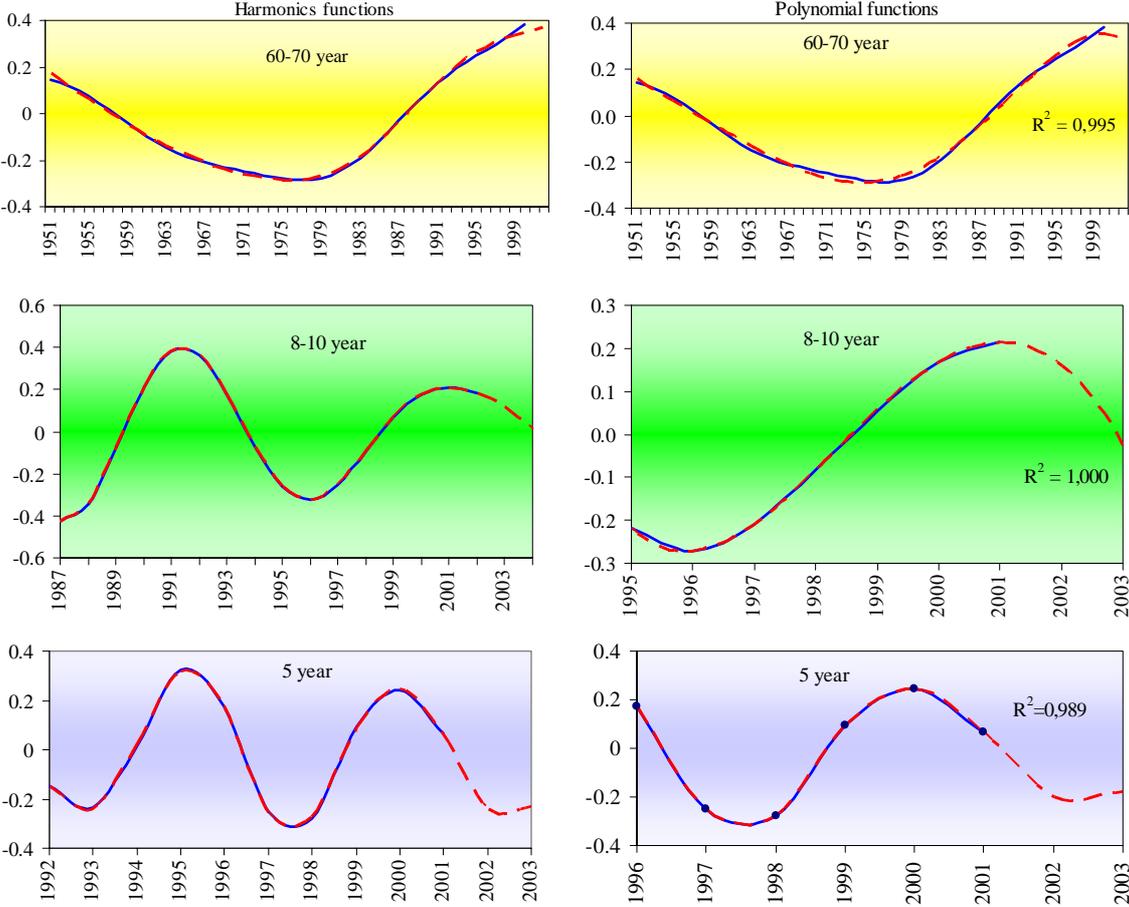


Figure 8. Approximation examples of cyclic components in the Kola Section water temperature in 0-200 m layer by the two methods and projection two years in advance

The method used was examined for quality based on independent data (2001-2004). All projected water temperature values did not exceed the standard deviation, in other words, were proved to come true. Efficiency of the method made up 75%.

According to the prediction made using the aforementioned methods, it is expected that in the nearest future water temperature in the Barents Sea will remain above long-term mean.

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REPORT