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# Basis for stock assessment and management advice

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## ICES working procedures and form of advice

For most stocks of any commercial interest in the ICES area, ICES is asked for annual advice on fisheries management (catch levels). The normal working procedure is that each fisheries laboratory reports its research regarding each stock to the relevant ICES working group. In many cases this is reported through a stock co-ordinator appointed by the working group. In addition each member country reports (to ICES) the annual official landing statistics by species and ICES area. Most working groups meet annually for about 5-10 days. Here the research is critically reviewed and combined to give a best assessment of the state of the stock and the potential harvest in both short term and long term. The working group compiles a report where the analyses are documented in detail and an advice for management is suggested. This report forms the basis for the final advice, which is formulated by the ICES Advisory Committee on Fishery Management (ACFM). In this committee each member country has one representative. The main tasks of ACFM are;

- -Critical review of the working group report
- -Formulate an advice in accordance with the established ICES Form of Advice
- -Assure that the advice properly relates to objectives formulated by the management agencies and that items raised in requests from management agencies are covered.

The ICES Form of Advice defines the general objectives for the advice, and specifies the type of biological reference points related to these objectives. This is, therefore, an important basis both for the fisheries scientists formulating the advice and for the managers receiving the advice. This Form of Advice applies to all stocks and it is designed to give consistent advice between stocks.

The main objective is to have the stocks within safe biological limits. In recent years the Form of Advice has been revised for the purpose of giving advice in accordance with the Precautionary Approach. In that context it has become particularly important to focus on uncertainties in the assessments, and safe biological limits are now defined in terms of probabilities. As a result, new reference points have been defined as criteria for evaluating stocks and fisheries in relation to the Precautionary Approach. The conceptual basis for those are given in the present Form of Advice (ICES 1999a):

*In order for stocks and fisheries exploiting them to be within safe biological limits, there should be a high probability that 1) the spawning stock biomass is above the threshold where recruitment is impaired, and 2) the fishing mortality is below that which will drive the spawning stock to the biomass threshold which must be avoided. The biomass threshold is defined as* $\boldsymbol{B}_{lim}$ *($_{lim}$ stands for limit) and the fishing mortality threshold as* $\boldsymbol{F}_{lim}$*. In order to have a high probability to avoid the thresholds, management action must be taken before the thresholds are approached. The precision with which the thresholds and current status of the stocks are known, and the risk which is tolerable, are important factors in determining the distance away from the threshold that management action is required. The greater the precision of the assessment, the smaller the distance between limit and precautionary reference points. If the assessment is less reliable, the distance will be greater. ICES has defined* $\boldsymbol{B}_{pa}$ *($_{pa}$ stands for precautionary approach) as the biomass below which action should be taken and* $\boldsymbol{F}_{pa}$ *as the fishing mortality above which management action should be taken. The distance between the limit and the precautionary approach reference points is also related to the degree of risk that fishery management agencies are willing to accept. Therefore, although ICES sees its responsibility to identify limit reference points, it will suggest precautionary reference points. The adoption of precautionary reference points requires discussion with fishery management agencies.*

ICES considers its main responsibility to give advice relating to these precautionary reference points. Therefore, the ICES advice does not usually attempt to define optimum management targets, but rather defines the limits of responsible management. In cases when the management agencies have defined clear objectives, ICES evaluates whether those are in agreement with the Precautionary Approach, and the advice is formulated in relation to those objectives.

**Basis for stock assessment**

To develop advice for fish stock management, a sufficient body of reliable information is necessary, and also the instrument of its analysis, first of all - theoretical models that would more or less entirely and adequately describe the processes occurred in marine ecosystem, such as species distribution, spawning, wintering and feeding migrations, response to fishery, links with climatic conditions and ecological interrelations between the species. Fairly many theoretical models applied in fisheries management are presently available. Single-species models, for instance, the VPA (Baranov, 1918, 1960; Beverton and Holt, 1957; Gulland, 1965) were the first to be developed and used in practice. Complex multi-species models have been developed during recent decades (Andersen and Ursin, 1977; Tjelmeland and Bogstad, 1998; Stefanson and Palsson, 1997).

The most important processes are reflected in the models with the appropriate equations in use:

- growth of marine organisms;
- maturation;
- fluctuations in recruitment;
- consumption of certain species by others;
- natural mortality;
- fishery.

Estimation of modelling parameters requires a large number of various reliable data. The data are collected by regular systematic, sometimes routine work performed by technicians and other specialists.

**Data sources and assessment methods for Northeast Arctic cod**

This section describes the types of data required for the models applied presently within the frames of ICES for stock assessment and for development of management advice. Uncertainties are discussed both regarding data and assessment methods. These are summarised in Tables 1 and 2.

Fisheries statistics

Fishery for the Northeast Arctic cod is known to be carried out by vessels from many countries. A major role in the fishery was played by Norway, Russia (previously the USSR), Great Britain and Germany. Cod catches taken in the period 1946-1997 varied considerably around the mean level, i.e. 700 thousand tonnes. Maximum catch (1343 thousand tonnes) was taken in 1956 and minimum one (212 thousand tonnes) - in 1990.

The stock size is calculated by annual catch (in number) of fish at age (year class). To obtain these values, the data on catch (tonnes) from appropriate departments of fisheries are used. Catch statistics is pooled by the data from fisheries organizations which are obliged to report back to the regulatory bodies. However, the statistics is not always complete, with the catch size, fishing areas and exceeding of quota allocated for catch being sometimes misrepresented (Table 2). Thus, by the data from the ICES Arctic Fisheries Working Group, the catches unreported in 1990-1994 varied from 25 to 130 thousand tonnes, with the maximum in 1992; the catch taken by the countries having no quota made up from 10 to 60 thousand tonnes during the same years (ICES, 1994, 1995, 1996). Few information is usually available about discards. The discards reported for 1946-1990 are believed to have decreased much (Nakken, 1994) owing to some modifications in mesh size and to a number of other management measures.

To recalculate catch weight into the number of fish by age, data on length, weight and age composition are required. To that end, specialists of scientific institutions perform mass measurements of fish (both at the sea and onshore when landing), collect age samples and read age. It should be noted that high variation in growth is typical of the Northeast Arctic cod. Range in value from maximum and minimum mean weight varies from 0.49 kg in cod at age 3 to 3.49 kg in specimens at age 9; standard deviations of mean weight increase from 0.1 kg to 0.65 kg for the same age groups, respectively (Ozhigin et al., 1997). Variability in growth is caused by a combined influence of a number of factors, the major of which are water temperature, feeding conditions and population density (Dementyeva and Mankevich, 1965; Ponomarenko et al., 1985; Nakken and Raknes, 1987; Jørgensen, 1992; Nilssen et al., 1994).

Precise estimation of stock biomass requires actual data on fish weight for the entire study period. However, only the data from 1983 are presently available for the ICES Working Group (Table 2).

Another important challenge is age reading. Earlier, cod were aged by scales, further - by otoliths (Rollefsen, 1933; Mankevich, 1966). The co-operation between age readers (exchange of samples and specialists on a regular basis) has been developed since 1992. However, the Norwegian and Russian methods for age reading have similarities and differences, which can have significant consequences. Thus, the yearly catch calculations using only Russian data on age determination have resulted in a difference in catch from 30 to 80 thousand tonnes, compared to those done when using both the Russian and Norwegian data (Yaragina et al., 1998).

Stock surveys

Instrumental survey for fish stocks is an integral part of research during which a large body of information on stocks, including fish abundance and on other parameters of the stock, is accumulated.

Hence, some words about a history of the surveys conducted in the Barents Sea. Quantitative assessment of cod and haddock at age O+ and 2+ with a small-meshed bottom trawl has been initiated by PINRO since 1946 and since 1978 - abundance and biomass of demersal fish in the Barents and Norwegian Seas were assessed during these surveys (Shevelev et al., 1996; Lepesevich and Shevelev, 1997). The attempts to estimate the recruitment of cod and haddock using acoustic methods were first undertaken by IMR in 1970 (Jakobsen et al., 1997). Full-scale acoustic survey has been performed by IMR since 1981, and since 1987 by PINRO. A number of other surveys (Table 3) are also carried out in the Barents Sea and adjacent areas and their basic aim is to assess abundance of recruitment at different stages of life cycle. This task remains one of the most difficult aspects of mathematical modelling.

Fluctuations in abundance of the Northeast Arctic cod inhabiting the Barents Sea, within the margin of its area, are known to be rather significant. By the data from the VPA calculations, the abundance of rich year classes exceeds that of the poor ones by 16 times (for comparison: the 1970 year class at age 3 amounted to 1818 million individuals and 112 million - from the 1966 year class) (ICES, 1999b).

Analysis and processing of survey data allows to obtain abundance indices of fish at different age, both relative (catch per hour, logarithmic indices, etc.) and absolute. Besides predicting recruitment, these data are also used to tune the VPA and estimate the total mortality of different year classes in order to define a regime of stock exploitation.

The survey areas are chosen to cover the sites of fish distribution. However, this is not always achieved in each specific survey. The area of cod distribution is known to be linked with those where the Atlantic and coastal waters are distributed. In connection with the variations in oceanographic conditions a distribution of cod can vary from year to year. Abundant year classes are usually distributed over a vaster area, compared to the poor ones. This variability may be illustrated by the charts showing the distribution of O-group cod during 1987 and 1992. It is therefore necessary sometimes to correct the areas to be surveyed. Thus, the Norwegian winter survey area was extended in 1993 (Jakobsen et al. 1997). Serious problems with the surveys occurred during 1996-1998 that had disrupted the time series. In 1996, due to some financial difficulties PINRO could not carry out the survey in the ICES Division IIb; no survey was conducted in Subarea I in 1997. A part of this area was further covered by a grid of stations, however, not during traditional period of time, but in February-March 1998. In 1997-1998, only the Norwegian economic zone was covered by the Norwegian trawl-acoustic surveys, as far as the Russian authorities did not allow to conduct the survey in the Russian economic zone, where a considerable proportion of cod stock is distributed in February-March. Therefore, the ICES Working Group had to make interpolations, that resulted in essential uncertainty in the stock estimates.

Monitoring of the stock biological status

Data on fish maturity, usually used to calculate the spawning stock, are the supplementary data necessary for a development of advice. One of the main criteria for stock management is the spawning stock biomass. Actual data on cod maturity are available only from 1982; earlier, fixed values, i.e. knife-edge ogive (all fish at age below 8 were assumed to be immature and those at or above 8 - mature), were used. However, a period of cod maturity is known to be prolonged, with rather essential variations in the maturity rate being observed during a 50-year period of observations. The maturity rate has increased during that period (Ponomarenko and Yaragina, 1994; Jørgensen, 1990). Besides, the spawning stock value is not always precise and flexible parameter of cod reproductive potential (Marshall et al., 1998). Others, more precise parameters, are necessary to be found.

In connection with a development of multispecies approach to modelling, it was necessary to have a detailed database on fish feeding. It was developed owing to joint efforts of scientists from IMR and PINRO (Mehl and Yaragina, 1992) and it is one of the examples of successful co-operation between the scientists of both countries. Based on it, the abundance of young cod (and of other marine organisms) consumed by the cod itself is being calculated, and the stock recruitment corrected. Cannibalism grows when the abundance of major food objects (capelin, young herring) is low. The cannibalism was especially high in 1994-1997, when the biomass of juveniles consumed by the cod itself attained 230-520 thousand tonnes, compared to 10-45 thousand tonnes in the mid-80-ies (Korzhev and Tretyak, 1989; Bogstad et al., 1994; ICES, 1999b) (Figure 1).

The considered stock inhabits the margin of its area, no other cod stock is distributed so far northward. Therefore, natural fluctuations in the abundance of cod, its food objects, competitors and predators, are rather significant in the Barents Sea ecosystem. Large-scale mixed species fisheries in the area surveyed is a major factor of population dynamics. To manage the stocks it is necessary to have objective, complete fisheries statistics and reliable data on catch composition. In addition it is important to have regular monitoring of stock size and population biological parameters, as well as monitoring of oceanographic conditions, food supply and feeding of fish. Theoretical models of commercial communities should also be improved.

**Summary of uncertainties relating to assessment methods and management advice**

In the scientific community there has been a lot of discussions and analyses relating to the problems with the assessment of Northeast Arctic cod in recent years (Pennington 1999). Besides the methodological problems of properly treating the large variability in cannibalism, growth and maturity (Table 1), there also seem to be problems related to some of the data from surveys and landings. The variation between neighbouring years ("random noise") does not appear to be particularly large, but there could be biases that changes over longer periods. It seems to be a common understanding that an important part of the problem is that the surveys and the landings show different time trends or periodic cycles. This could be caused by changes in the part of the mortality not explained by landings and cannibalism (other predators and/or misreported catch). It could also be caused by changes in survey methodology and/ or the availability of the stock to the survey method. It is likely that there has been a general increase in the overall "survey catchability" due to changes in survey methodology. In the late 80-ies and early 90-ies improved acoustic equipment and equipment for monitoring trawl performance were introduced, and the investigated areas increased. For some of the survey time series the ratio between survey estimates and the estimates based on landings at age analysis (VPA) show periodic changes which are negatively correlated with the size of the capelin stock (Figure 2). This indicates that some biological processes might be involved (mortality and/or fish availability to the survey method). Until the underlying mechanisms are fully understood, it is difficult to take such patterns fully into account in the assessment.

The reference points, defined in the first section of this document, are strongly related to the stock –recruitment relationship. Figure 3 shows the scatter-plot of corresponding values of recruitment and parent stock for Northeast Arctic cod. As can be seen the "biomass threshold where recruitment is impaired" ($B_{lim}$) is not very obvious. It has been set at 112 000 tonnes, the lowest biomass observed. By a standard calculation procedure, data on stock, recruitment and fishing mortality have been used to obtain the value of 0.7 for $F_{lim}$ ("the F which will drive the spawning stock to $B_{lim}$"). The obtained values of $B_{lim}$ and $F_{lim}$ are regarded to be rather uncertain, both due to the large scatter of the observations and due to the uncertainties mentioned regarding historic values of natural mortality, weight at age, maturity and spawning potential. It is worth noticing that the average recruitment close to $B_{lim}$ is somewhat lower than at higher biomass.

The proposed value of $F_{pa} = 0.42$ is obtained by setting a safety margin towards $F_{lim}$ corresponding to the estimated uncertainty of $F_{lim}$.

The proposed value of $B_{pa}$ (500 000 tonnes) is equal to the value of the formerly used MBAL (Minimum Biological Acceptable Level). When the stock is below this value action should be taken to prevent further decline towards $B_{lim}$. In this case with large uncertainty both for the assessment and for the estimate of $B_{lim}$ it is important to have that large "buffer" between $B_{pa}$ and $B_{lim}$.

It might be argued that in view of the stock history, the proposed reference points appear to be rather restrictive, since the stock still exists after long periods with a spawning stock below $B_{pa}$ and a fishing mortality above $F_{pa}$ (Figure 4). It should be noticed that the spawning stock showed a steady decreasing trend, only interrupted by some temporary peaks, over the period 1946-1987. This means that the stock did not sustain the high fishing mortality, and the risk of a severe collapse would have increased if not action had been taken in the late 80-ies.

Another weakness of the reference points in general is that in many respects they reflect average conditions over the time series. In theory, changes in environmental conditions like food availability, predator abundance and temperature could alter the reference points. At the present state of the art the ability to predict such conditions and the knowledge on how they influence the reference points are too poor to contribute to any improvement of the advice on management.

For the short term advice the uncertainty of the assessment is much more critical than the uncertainty of the reference points. Therefore, the research needs to focus on improving the assessment. As indicated above an improved statistical and biological understanding of the data is important for an improved assessment. A new assessment model has been developed for the purpose of making progress in that respect.

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Table 1. Uncertainties related to cod assessment methods

| Method | Uncertainties |
|---|---|
| Using the analytical mathematical methods (VPA) adopted within the framework of ICES | Methodological problems:<br>- XSA tuning method is very sensitive to choosing the age at which the catchability (q) depends on year-class abundance<br>- natural mortality coefficient varies by age groups (Tretyak, 1984) and is not constant (M=0,2) |
| Using the elements of multispecies modeling to estimate cod cannibalism | Methods of calculating rations have not been completely agreed and are at the stage of elaboration.<br>There are problems of including cannibalism in the standard VPA calculations |
| Using long-term/running means for short- and long-term forecasts | There no adopted models of forecasting recruitment, growth, maturation, temperature, abundance of food organisms, cannibalism included in standard VPA calculations |

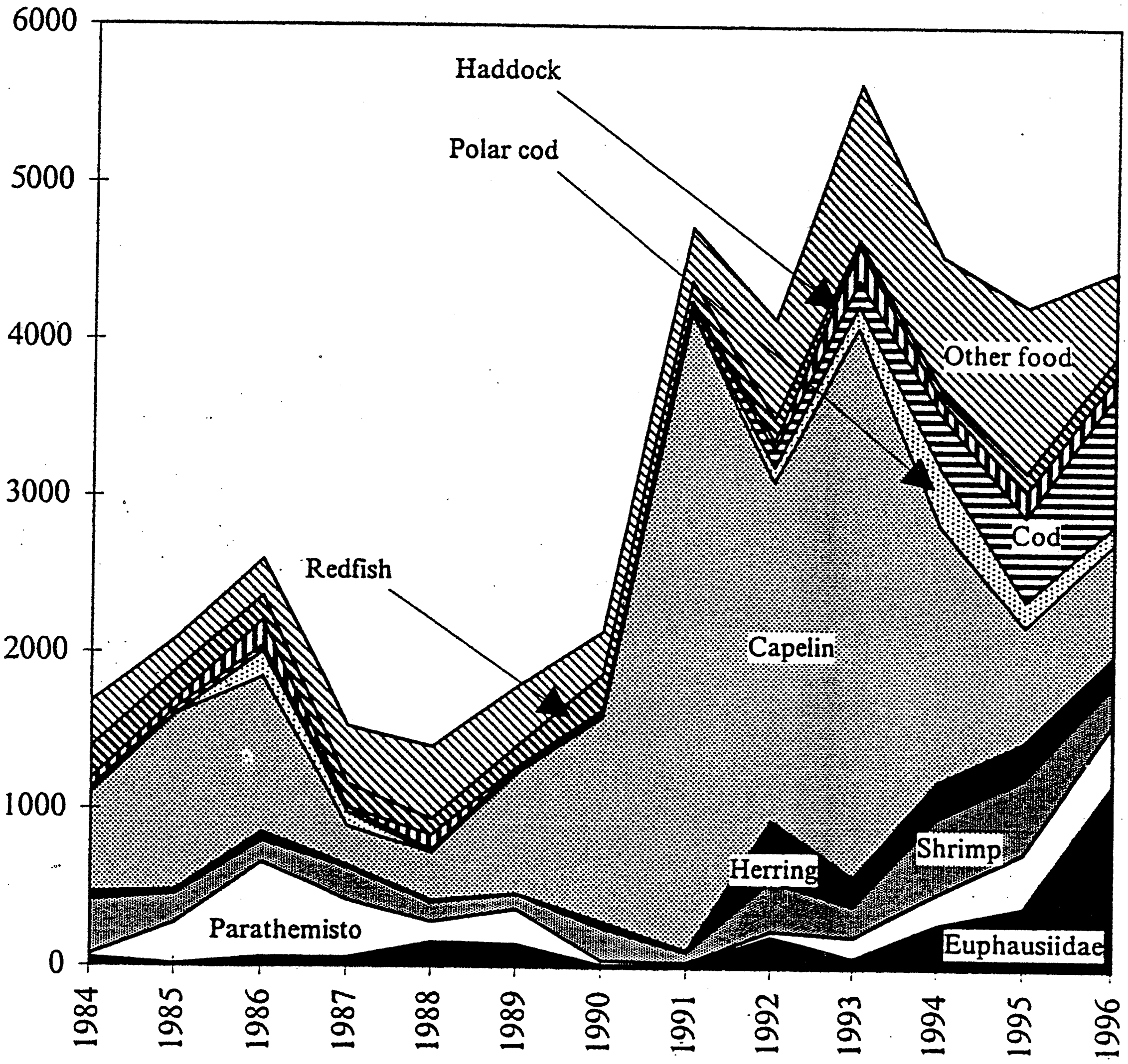
Table 2. Uncertainties related to the data used to assess the cod stock

| Routine activities | Uncertainties |
|---|---|
| Fisheries statistics<br><br>National and international systems of collecting statistical data on fishing<br><br>National systems of control over the observance of fishing regulations | It is impossible to control fishing activities of each vessel<br><br>Illegal catch (including International waters)<br><br>Unreported catch (from unknown areas and in unknown size)<br><br>Undersized fish discards are unknown<br><br>By-catch size in other fisheries is unknown |
| Monitoring of stock biological parameters<br><br>Systems of collecting fisheries and biological data on age composition, length and weight of fish caught | Applying actual data on fish weight since 1983 and fixed values for 1946-1982<br><br>Differences in methods and results of cod age reading by IMR and PINRO<br><br>Using actual data on ogives of fish maturation since 1982 and fixed values (knife-edge curve) for 1946-1981<br><br>Using actual data on cod feeding since 1984. The lack of data for previous (1946-1983) |
| Stock surveys<br><br>Carrying out annual instrumental stock surveys to estimate abundance and collect biological data | Heterogenity of survey time series as a result of:<br>- change of survey techniques<br>- acoustic problems<br>- incomplete coverage of fish distribution areas due to climatic changes, as well as political and financial problems |

Table 3. List of surveys used in cod stock assessment

| Name | Place | Season | Years | Indices |
|---|---|---|---|---|
| International 0-group survey | Barents sea and adjacent waters | August | 1966-1998 | Abundance indices |
| Russian trawl young fish survey | Barents sea and adjacent waters | Autumn-Winter | 1949-1980 | Numbers per hour trawling |
| Russian bottom trawl | Barents sea and adjacent waters | October-December | 1981-1998 | Numbers per hour trawling |
| Russian acoustic | Barents sea and adjacent waters | October-December | 1985-1998 | Stock numbers by age in millions |
| Norwegian bottom trawl | Svalbard | September-October | 1983-1998 | Abundance indices (millions) |
| Norwegian bottom trawl | Barents sea | January-March | 1981-1999 | Abundance indices (millions) |
| Norwegian acoustic | Barents sea | January-March | 1981-1999 | Stock numbers by age in millions |
| Norwegian acoustic on the spawning grounds | Lofoten | March-April | 1984-1999 | Stock numbers by age in millions |
| Russian ichthyoplankton | Norwegian and Barents sea | April- July | 1959-1993 | Numbers per net |
| Norwegian bottom trawl | Barents sea and adjacent waters | August-September | 1990-1998 | Abundance indices (millions) |

Figure 1. **Biomass of preys consumed by cod in 1984-1996**



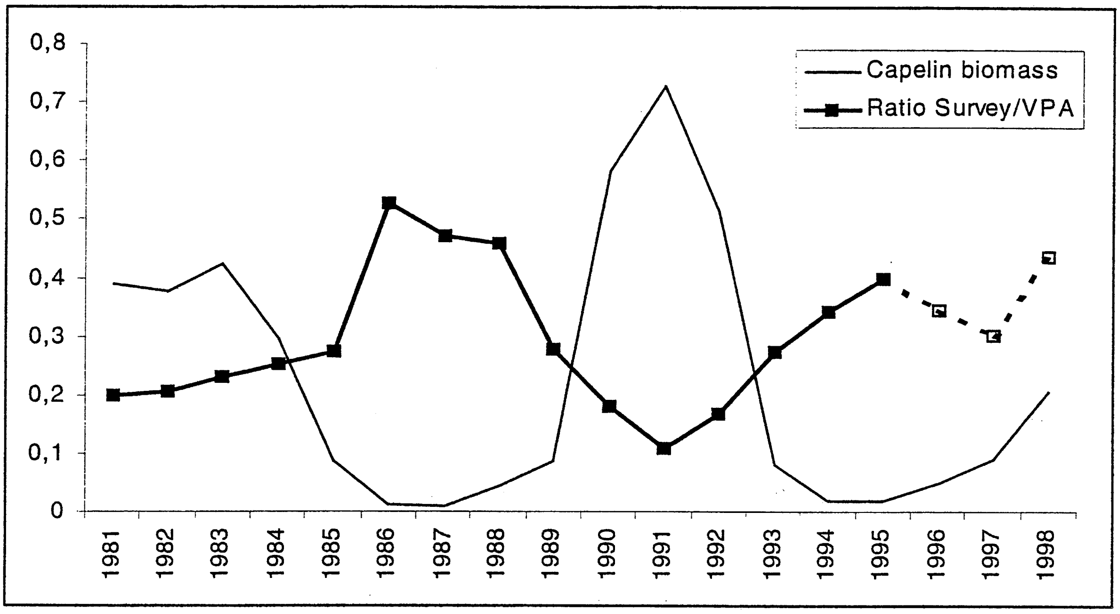



Figure 2. The ratio between survey estimates and VPA estimates of Northeast Arctic cod (number of fish at age 3 and older), compared to the biomass of capelin (as estimated in the autumn capelin survey, unit 10 mill. Tonnes). The survey estimates of cod are from the Norwegian bottom trawl survey during winter.

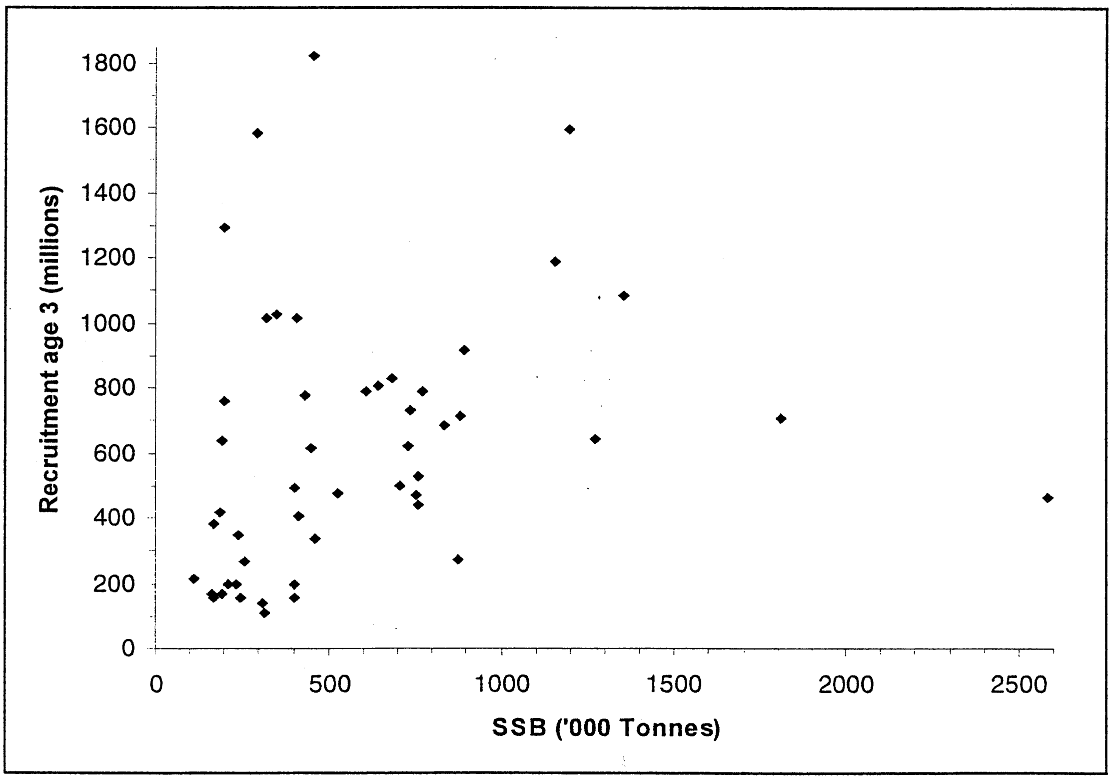



Figure 3. Corresponding values of recruitment and parent stock for Northeast Arctic cod for the year classes 1943-1994.

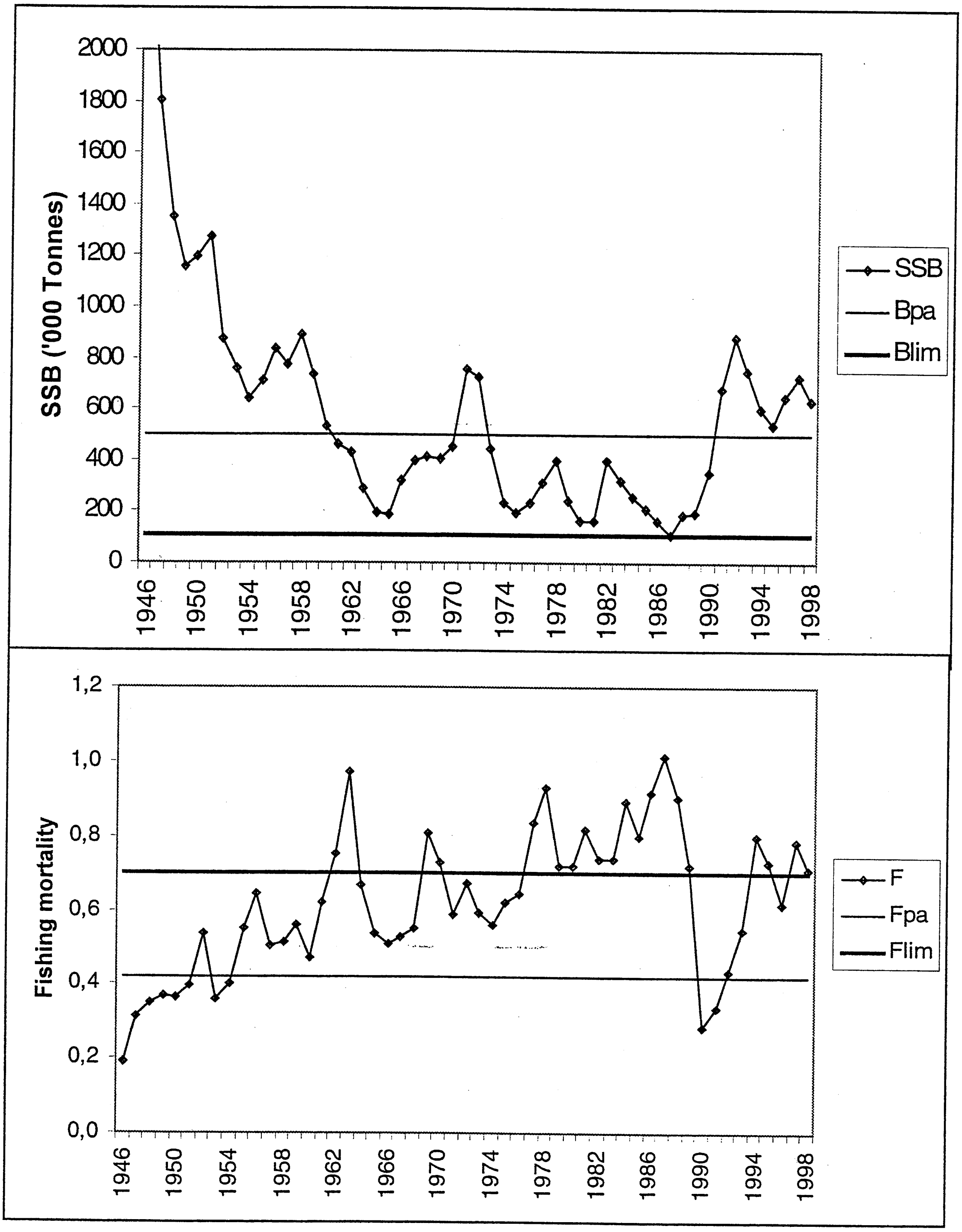



Figure 4. Historical development of spawning stock (upper panel) and fishing mortality (average for age groups 5-10, lower panel) compared with the proposed reference points (straight lines).