

Barents Sea capelin Stock Annex

Introduction

The present (2009) methodology for Barents Sea capelin, which has remained the same since 2003 was evaluated during the ICES benchmark workshop WKSHORT in Bergen 31 August - 4 September 2009 (ICES 2009b). Although the method was endorsed, the written documentation provided by the Stock Annex made at the meeting was not accepted, as it was found incomplete. The present document is a rewrite of the WKSHORT Stock Annex, where the essential elements in the methodology are made clearer, and model assumptions are motivated.

The 2003 methodology was established in an era with less demand for rigid documentation at the level where people completely unfamiliar with either the ecosystem or the essential methodological elements shall be able to understand and repeat the analyses. After 2003, modelling work has concentrated on bringing the management of capelin more firmly into an ecosystem context, and developing methodology for long-term simulations needed to test harvest control rules, with little or no emphasis on documenting the 2003 methodology.

A comprehensive Stock Annex is needed not only for a full ICES endorsement and for meeting the demands on transparency of ICES methodology, but is also needed for facilitating technology transfer in PINRO and IMR. The present version of the underlying model Bifrost provides for consumption of capelin by cod the year around. However, in the context of the present Stock Annex, only consumption during January-March is modelled, in compliance with the management methodology applied since 2003.

■ Models used

Unlike most other stocks, the management of capelin is founded on one survey, which is considered giving an absolute measurement of the stock, no model to reconstruct history is needed. Also, the precautionary approach is implemented by carrying out simulations with uncertainty, so a precautionary reference point is not needed, only a limit reference point. The Barents Sea capelin assessment is based on the use of two different models. CapTool is an Excel spreadsheet from which the catch quota corresponding to the harvest control rule is calculated using stochastic prognostic simulation from the time of measurement (October 1) to the time of spawning (April 1 the following year). Bifrost is a model which is used to estimate parameters in the two main biological processes behind the simulations: maturation and predation by cod. The relation between the two models is shown in figure 1.

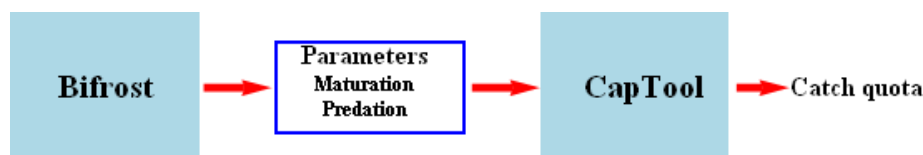


Figure 1. Relation between the models Bifrost and CapTool

Unlike most other stocks, for which the entire population dynamics is represented by one subjectively chosen parameter (M), the assessment of the Barents Sea capelin rests on a quantitative description of the essential parts of the population dynamics of the stock. Therefore, the Stock Annex gets somewhat more involved in the model description part than most other stocks. Even though the management of Barents Sea capelin is a strictly single species management, it rests on a multispecies model and as such is a small step into an ecosystem based approach to management of the Barents Sea species.

More details about the scientific background concerning estimation issues and the process leading up to the present Stock Annex may be found at the web site www.assessment.imr.no

A. General

■ A.1. Stock definition

Capelin in the Barents Sea spawn in March-April in shallow water off the northern coasts of Norway and Russia (Gjøsæter 1998). The juveniles are transported to the central and eastern parts of the Barents Sea where they grow. The capelin matures and spawns at age 3-5. In recent years, the number spawning at age 5 has been negligible, but during the 1970s spawning capelin of age 5 or even age 6 was not uncommon. The capelin die after spawning (Christiansen et al 2008). The capelin undertakes extensive feeding migration during the summer into the northern and eastern parts of the Barents Sea.

■ A.2. Fishery

Some fishing for Barents Sea capelin has taken place for centuries. The fishery intensified during the early 1960s, when a Norwegian purse seine fishery started (Gjøsæter 1998). It soon became a large-scale fishery, and was followed by a Russian fishery conducted mainly with pelagic trawl. The fishery took place from January to March on schools of prespawning capelin on or close to the spawning grounds. In the 1970s and early 1980s a fishery also took place on the feeding grounds in the central and northern Barents Sea during August to October. In recent years, this summer and autumn fishery has been banned (ICES, 2009a). The winter fishery has also been banned during periods when the capelin stock was at a low level. This has happened three times, in the mid 1980s, in the mid 1990s and in the early 2000s. During each of these periods the fishery was stopped for 5 years.

In recent years, the fishery has changed from being mostly an industrial fishery to being mostly for human consumption. This is partly because of low TACs, but also because new markets for frozen capelin for human consumption have developed. In the present fishing period a substantial part of the catch has been delivered for meal and oil production, driven by demands from the aquaculture industry. In the future, the part of the capelin catch delivered for meal and oil production will be associated to the international market for fish meal and fish oil. The Russian part of the catch is delivered exclusively to human consumption.

■ A.3. Ecosystem aspects

■ A.3.1. Predators

The capelin plays a key role in the marine ecosystem and is by far the most important pelagic fish stock in the Barents Sea. They are the main diet of Northeast arctic cod (Mehl and Yaragina, 1992, Gjøsæter et al 2009). Juvenile herring may feed intensively on capelin larvae (Hallfredsson and Pedersen, 2009). They are prey to several species of marine mammals, e.g. harp seals, humpback whales, minke whales, and seabirds, kittiwakes and guillemots. They are also important food for several other commercial species (Dolgov 2002).

The main impact on capelin from predators is the consumption by cod, which has expanded its area northwards the latest year, thereby increasing the predation also on immature capelin. Harp seals may also have a significant impact on capelin. There are less data, however, to evaluate the impact of harp seals on capelin.

B. Data

■ B.1. Commercial catch

■ B.1.1 Landings

□ *B.1.1.1 Norwegian landings*

Most of the Norwegian catch is taken by purse seiners, constituting about half of the vessels in numbers and taking about 75% of the catch. The rest of the catch is taken by smaller coastal vessels, about half of which operating by trawl and half by purse seine. The Norwegian catch in numbers by age and length (larger and smaller than 14 cm) and by ICES areas is calculated by the program FangstFisk using an Excel file of catch in tonnes by month and geographical location from the Directorate of Fisheries and a file of biological samples from the fishery in the format SPD. The result is stored on Excel files lo<4-digit year>.xls, from which the catch in numbers and biomass by age and maturation group (divided at 14 cm) are transferred to the Excel file CapCatch, which is used by Bifrost.

□ *B.1.1.2 Russian landings*

The Russian catch is taken by trawl. The Russian catch in number and age by length and the division in tonnes on months are reported to the WG. From these data the catch in numbers and biomass by age and maturation group are transferred to CapCatch.

□ *B.1.1.3 Use of catch data in the assessment*

The catch data influence the population dynamics parameters transferred from Bifrost to CapTool, but not the current assessment.

Formally, the historic simulation during January-March is made for an age-disaggregated stock. However, the predation mortality is assumed equal for all age groups and the food abundance for cod is expressed as biomass of capelin. Thus, the age distribution of the catch does not influence the estimated predation parameters. Uncertainty in catch is not taken into account.

The uncertainty in catch in tonnes by month connected to registration of catch and biological sampling is not known, but considered to be small and the uncertainty in the catch will then have a small influence on the uncertainty in the estimated predation parameters.

In the fishery some capelin may be killed in the catch operation. The magnitude of this is not known, but considered to be larger in the trawl fishery than in the purse seine fishery.

■ B.1.2 Discards

Discarding is considered negligible for this stock

■ B.2. Biological data

No biological data are used other than those used for converting commercial catch in tonnes to catch in numbers by age and length and the data used in the September survey to calculate the number of capelin by age and length.

■ B.3. Surveys

One survey is used in the assessment of the Barents Sea capelin stock: a joint Russian-Norwegian trawl-acoustic survey in September, which started in 1972 and is conducted annually. The abundance estimate from this survey is considered an absolute estimate of the stock. Figure B.1 shows the tracks of the 2007 and 2010 surveys. Each nautical mile of Sa data (for the Russian vessel in the east, each 5 nmi) is represented by a filled circle, the radius of which being proportional to the Sa value, with a maximum of 500. The colour denotes the time referred to the start of the survey, with violet at the start and red at the end.

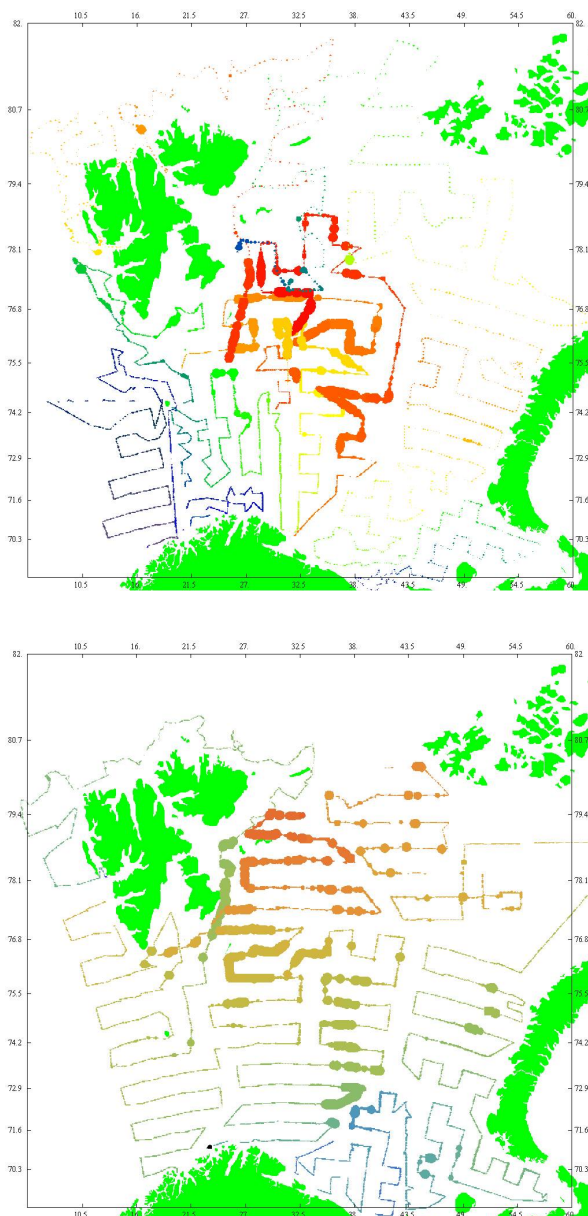


Figure B.1. Survey tracks in 2007 (upper panel) and 2010 (lower panel). Explanations in the text.

Synopticity can be an issue at this survey, where a large area is covered by several vessels that for practical reasons not always can work simultaneously. This is evidently a problem in the 2007 survey, and much less of a problem in the 2010 survey. Migration during the survey will introduce an uncertainty in the estimate that cannot be accounted for. This seems to have been a problem in 2007, as vessels recording nearby registrations at different time encountered different densities of capelin.

In designing the surveys, the 2010 survey might be the model survey, and designs as that of 2007 should be avoided. However, this may be difficult to achieve in practice, as the survey from 2003 has been a multipurpose survey also covering 0-group fish, demersal fish and benthos.

Figure B.2 shows the Sa values by depth for one Norwegian vessel in 2001 and one Norwegian vessel in 2008. Sa values are coloured white and the position of trawl stations are coloured yellow. 0-group stations where the trawling is in different depths during one trawl haul are marked with two yellow dots, one at the surface and one at 40 m. In 2008 the capelin survey was a part of a multipurpose survey also covering 0-group fish and demersal fish. Trawl stations directed at capelin registrations are substantially fewer in 2008 than in 2001. Even if the identification of capelin may not have been seriously hampered, the representativity of trawl stations for the most abundant parts of the capelin distribution certainly has.

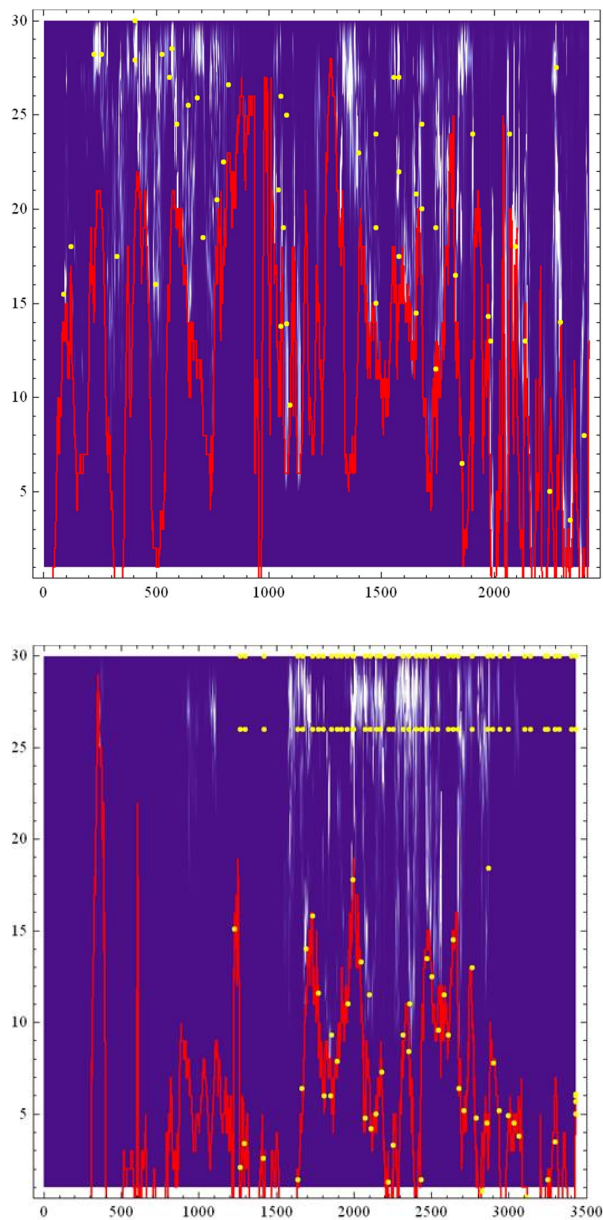


Figure B.2. Sa values (white) by depth and trawl stations (yellow) in 2001 and 2008. Further explanations in the text.

Figure B.2 serves as a demonstration of how trawling for obtaining biological samples representative for the main acoustic densities of the capelin can be sacrificed when the survey shall deliver data for many purposes. Care must be exercised by the cruise leader that enough directed trawl samples for capelin are obtained.

■ **Survey uncertainty**

The survey uncertainty is a part of the input to CapTool. It would be natural to base the survey uncertainty on the actual survey that has been conducted, so that a poor survey with bad coverage and inadequate sampling resulting in a large uncertainty yielded a more cautious capelin quota. This has not been implemented yet. Instead, a fixed survey CV of 0.2 is used based on the historic replicates for all years, as shown in figure B.3

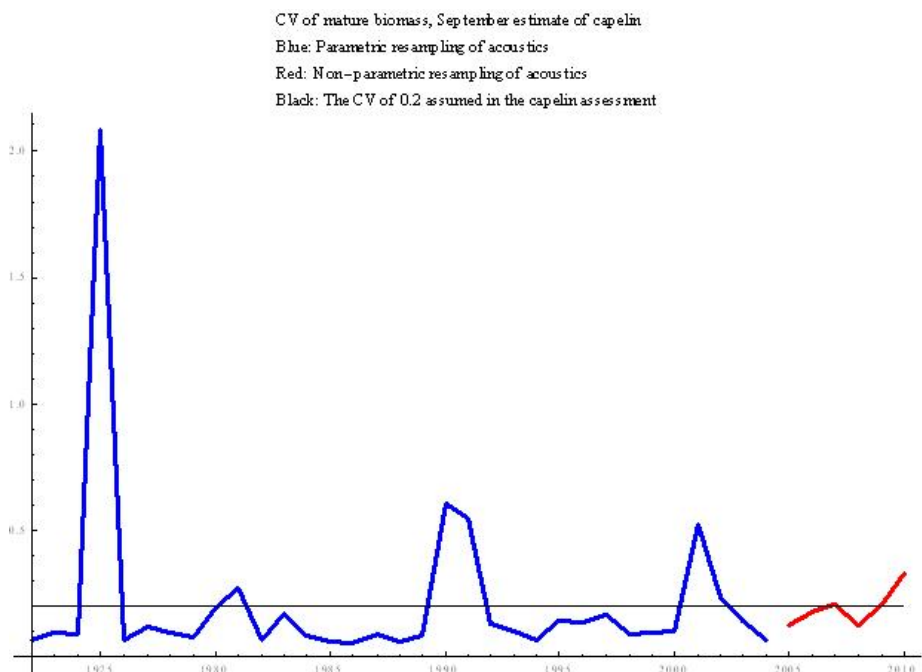


Figure B.3. CV from resampling historic September surveys. The value 0.2 is shown as a horizontal black line.

The CV is in most years somewhat below 0.2. The reason for the large spikes is not known.

Area coverage may be an issue, especially during the 1970s where the surveys were primarily directed towards the adult capelin. Figure B.4 shows the development of the year classes 1971-2009, starting from age 1. Most of the year classes prior to 1980 show an increase in abundance from age 1 to age 2. There is an increase in abundance from age 1 to age 2 also for the 2007 year class, which is worrying since the area coverage in later years is considered adequate. However, the observed increase is not highly unlikely in view of the assumed CV on the estimates (0.2).

When recruitment relations are estimated in Bifrost, the number of 1 year old capelin is adjusted so that the cohort matches the observed number of 2 year old capelin when natural mortality on immature capelin is accounted for. This is done in order to avoid the problems of underestimation of the 1-group encountered in earlier years.

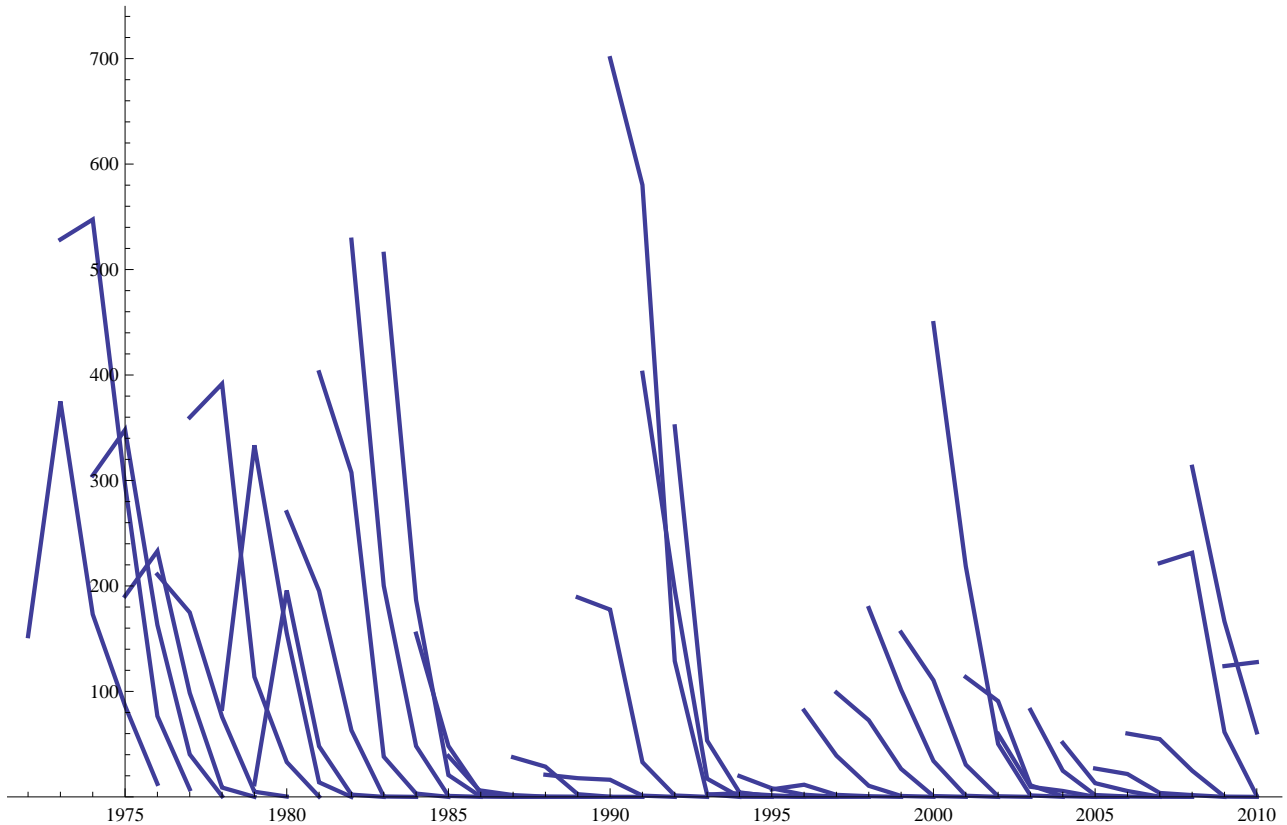


Figure B.4. Development of year classes 1971-2009, number at age 1-4 in billions from the September survey.

■ B.3.1. Calculation of capelin abundance from survey data

Based on past experience the available vessels are allocated to areas in such a way that the whole area in which capelin is expected to occur is covered with a spacing between survey tracks of preferably no less than 30 nmi. The mean S_a value in each WMO (1 by 2 degrees) square is calculated and a length distribution representative for the square is calculated by manually selecting trawl stations within or close to the square that are considered representative for the capelin in the square.

The total number of fish in one WMO square is calculated as

$$S_a \text{ areaSize } 10^7$$

$$5.0 \frac{\sum_i n(i)^{1.91}}{\sum_i n(i)}$$

where:

S_a	Mean S_a values from all transects through the square
$n(i)$	Number of fish in each length group i from biological samples in the square or in the vicinity of the square. Care must be taken that the biological samples are representative for the capelin that contributed most to the S_a value.
areaSize	The size of the area in nautical miles squared

The total number of fish is multiplied with the relative length distribution to yield the total length distribution within the square. It is worth noting that the length dependence of the backscattering ability is used only to calculate the total number of fish. It does not affect the calculated length distribution, which only depends on the observed relative length distribution from the samples.

It has usually been taken for granted that it will be possible to find trawl stations in or in the vicinity of a square that are representative of the fish in the square, since trawling as a rule was conducted to identify the registrations. After the multipurpose survey started in 2003 this is no longer as obvious, as the large number of stations in predefined locations have led to a severe decrease in trawl stations on acoustic registrations.

□ **B.3.1.1. Checklist for capelin abundance estimation**

Task	Comment
Plot integrator values Determine if necessary to reduce size of some squares	Applies near border of distribution
Verify that representative samples are used in each square	If insufficient directed trawls, apply the following rule : Use 0 – group stations if more than 50 kg capelin. Use bottom trawl stations if more than 10 kg capelin

■ **B.4. Commercial CPUE**

Commercial CPUE data are not relevant for this stock

■ **B.5. Other data used in the assessment**

In addition to capelin data, the modelling of consumption of capelin by cod requires data for the cod stock, abundance data, maturation data, weight data and stomach content data. Parameters in the function for capelin consumption by cod are estimated by constructing a likelihood with modelled consumption as expectation values and consumption calculated exogeneously directly from the stomach content data using laboratory data of the evacuation rate as observation values. Since the evacuation rate depends on the temperature, data in the vicinity of trawl stations where stomachs are samples are needed. Finally, the consumption per cod is scaled with cod abundance data taken from the February bottom trawl survey, in order to correct for a possibly geographically skewed sampling of cod stomachs with respect to the geographical distribution of the cod stock.

Cod weight at age and maturation at age are taken from the Arctic Fisheries WG assessment. When Bifrost is run, number of cod at age have been calculated exogeneously using the catch at age data and terminal F-values from the Arctic Fisheries WG assessment. In these calculations, Pope's approximation is used. When CapTool is run, the number at age of cod is taken directly from the latest Arctic Fisheries WG assessment.

■ **B.6. Summary of data**

Table B.1 shows a summary of the data used in the Barents Sea capelin assessment

Table B.1. Summary of data used in the Barents Sea capelin assessment

Type	Origin	Name of file	Year range	Biological division	Used by
Catch at age in numbers	Commercial catch Biological samples	CapCatch.xls	1972 – present	Age 1 – 5 Season Maturation, divided at 14 cm	Bifrost
Stock size * October 1	Survey	CapTab.xls	1972 – present	Age 1 – 5 Length Weight by length	Bifrost CapTool
Stock size replicates October 1	Survey	bootstrapSexAgeLength – AcousticBiology < year >	1972 – present	Age 1 – 5 Length Weight by length	Bifrost
Cod abundance Assessment year + 1	Arctic Fisheries WG assessment	CapTool.xls	Assessment year + 1	Age 1 – 13	CapTool
Cod abundance Historic	Calculation in MakeVPA.nb		1946 – present	Age 1 – 13	Bifrost
Consumption of capelin per cod	Calculations in StomachData. nb	consumptionPerCod < year > < length group >	1984 – present	Age 1 – 10	Bifrost

*Considered an absolute estimate of the stock

■ Summary of data used to calculate consumption of capelin per cod

The consumption per cod data used in Bifrost to estimate parameters in the predation function are calculated exogeneously using stomach content data from the field, stomach content data from an evacuation rate experiment (dos Santos and Jobling 1992), temperature data from stations in the vicinity of trawl stations where stomachs are sampled and cod distribution data from the demersal survey in February. Replicates of the evacuation rate parameters are calculated exogeneously using a model without the stomach content immediately after a meal as a variable, since this quantity is not known in the field (Temming and Andersen 1994). Table B.2 shows an overview of the data used for calculating consumption per cod replicates.

Table B.2. Summary of data used to calculate consumption per cod replicates.

Type	Origin	Name of file	Year range	Biological division	Used by
Stomach content data from the laboratory experiment	Laboratory data University of Tromsø	Evacjsmj.csv			StomachData.nb
Stomach content data from the field	Biological samples from research vessels	nydump	1984 – present	Prey in individual cod stomachs	StomachData.nb
Temperature data	CTD stations from research vessels taken from the IMR tindor data base	tindorCTD < year >	1986 – present	Depth	StomachData.nb
Geographical distribution of cod	February demersal survey	allEstimateArea: DemersalWinter	1984 – 1987 *	Area, age, maturation	StomachData.nb

* Remains to be updated

C. Assessment methodology

The models used and the basic assumptions are listed in Table C.1

Table C.1. Models and assumptions used in the Barents Sea capelin assessment

Model	Usage	Assumptions	
FangstFisk	Calculation of catch statistics for use in Bifrost		
BEAM	Calculation of abundance, September survey		
Bifrost	Estimation of maturation and predation parameters	Maturation	Sigmoidal function of length Estimated
		Predation by cod	Type II relationship to capelin biomass Estimated maximum consumption and prey biomass at half maximum consumption Only immature cod preys on capelin during January – March Max predation is a power function of weight, exponent from literature
CapTool	Calculation of limit catch according to HCR	Maturation	Identical to Bifrost Parameters from Bifrost
		Predation by cod	Identical to Bifrost Parameters from Bifrost

■ Model formulations

The mathematical formulations are essentially the same in Bifrost and CapTool.

■ C.1.1.1. Maturation

The proportion maturing (as of October 1) of capelin is modelled as a function of length using the logistic function:

$$m(l | P_1, P_2) = \frac{1}{1 + e^{4 P_1 (P_2 - l)}}$$

where P_2 is the length at 50% maturation and P_1 is the increase in maturation by length at P_2 . l is the length in cm.

Figure C.1 shows the estimated replicate values of the parameters in the maturation function. In 24 % of the replicates P_1 have been estimated to values larger than 2, i.e. approximate cut – off maturation. The mean of the P_2 is 13.816.

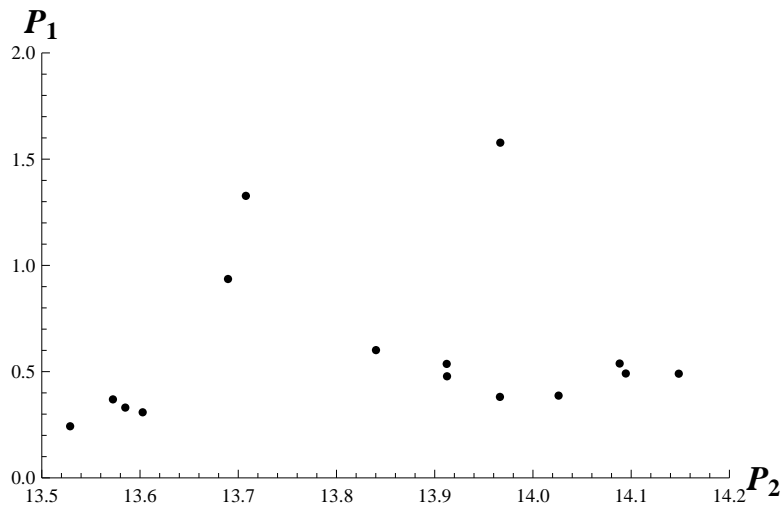


Figure C.1. Estimated replicates of the parameters in the maturation function.

■ C.1.2. Consumption by cod during January-March

The consumption of capelin by cod is given by:

$$\text{consumption} = P_{17} \frac{\text{capelinBiomass}^{P_{13}}}{P_{10}^{P_{13}} + \text{capelinBiomass}^{P_{13}}} \text{predationAbility}$$

$$\text{predationAbility} = \sum \text{Suit}(i) N(i) W(i)^{0.801}$$

consumption is the consumption of capelin by cod in million tonnes per month and capelinBiomass is the capelin biomass in million tonnes. The suitability of capelin as food for cod is assumed not to be dependent on capelin age. This assumption would be violated if the spatial and temporal migration pattern of young mature capelin differed from that of older mature capelin. Suit(i) is the suitability of capelin as food for cod of age i. N(i) is the number of immature cod at age i in billions and W(i) is the weight at age i of cod in kg. The exponent 0.801 is taken from the literature (Jobling 1988).

The number of immature cod by age residing in the Svalbard area thus not preying on capelin during January-March is subtracted before the calculations are carried out. The fraction of cod in the Svalbard area is inferred from autumn demersal surveys. It has not been updated since 2004, however. Data on cod area distribution from the autumn (ecosystem) survey are now available and will be used for updating the area distribution before the 2011 capelin assessment. P_{10} and P_{17} are parameters to be estimated from the data.

Figure C.3 shows consumption as function of capelinBiomass for unit predationAbility for the estimated parameter replicates.

The suitability of capelin as food for cod is dependent on cod age. The stomach content data show that the youngest cod do not eat much capelin, and the oldest cod tend to have a lesser portion of capelin in their diet than cod of intermediate ages. Figure C.2 shows the assumed suitability by age.

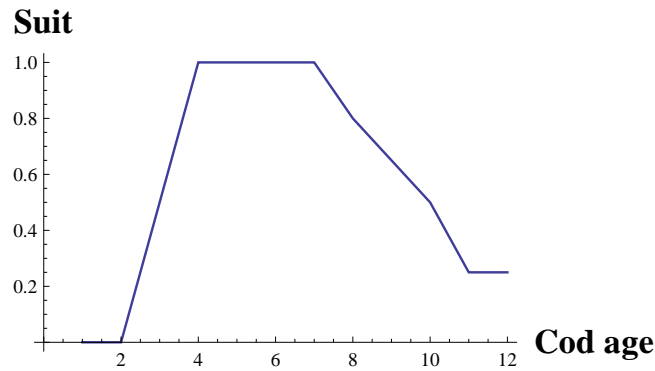


Figure C.2. Suitability of capelin as food for cod by cod age used in Bifrost.

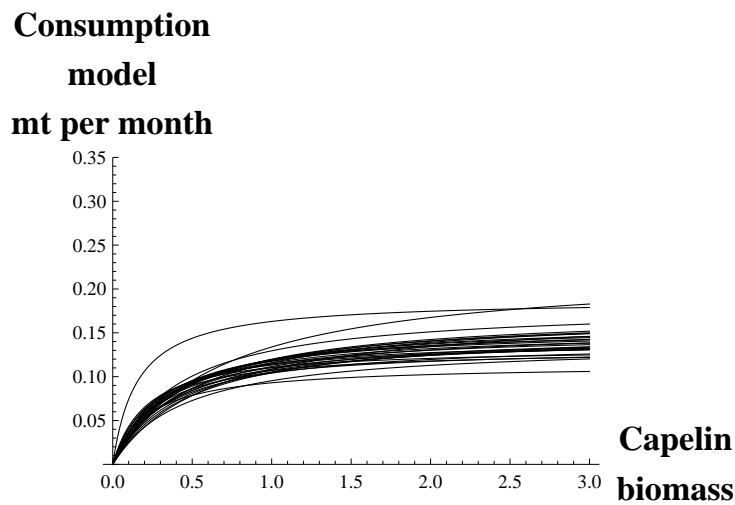


Figure C.3. Replicates of consumption per month as function of capelin biomass for unit predation ability.

■ **C.1.3. Simulation**

The simulation of capelin in Bifrost is shown in figure C.4. Events are shown in blue boxes and processes in light blue boxes. The model results from each event or process are shown in yellow letters. The yearly simulation period starts October 1, when the stock is initialized as number by age and length from the measurement obtained by the September survey. On these data the maturation model is applied to split the stock into an immature and a mature component on the basis of the length distribution, and both components are summed over length, i.e. the length distribution is not kept during the subsequent simulation - it is used only for the maturation model.

Then the mature component is projected to spawning at 1 April and the immature component to the time of next measurement at 1 October.

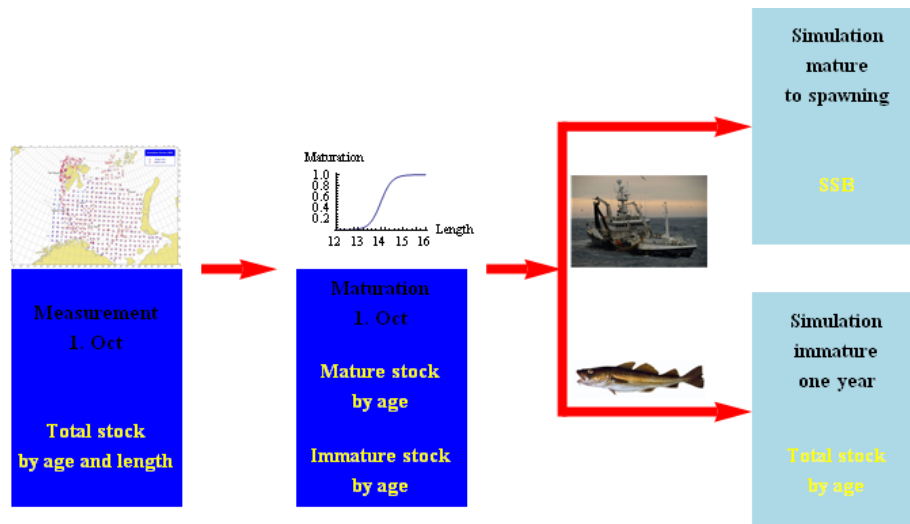


Figure C.4. Overview of Bifrost simulation.

The simulation of both mature and immature capelin from time of measurement 1 October is performed using Pope's model for the catch and a natural mortality by month, which is constant during the 12 month simulation period :

$$Cap_{i+1} = (Cap_i e^{-0.5 P_3} - C_i) e^{-0.5 P_3}$$

During the period January – February the consumption of capelin by cod is particularly intense, as is the fishery. The catch statistics used by Bifrost is given on season only (e.g. January – March), and a constant subdivision of the season is applied to give the catch by month.

The natural mortality for immature capelin P_3 is a constant parameter that is estimated along with the parameters in the maturation function.

■ C2. The Bifrost model framework and estimation of parameters

Bifrost is written in Mathematica. Accompanying the Bifrost notebook are several notebooks that are used for data handling and other tasks outside of the Bifrost simulations. Table C.2 gives an overview of the notebooks used. The overview is limited to tasks relevant for the estimation of parameters to be used in CapTool.

Table C.2. Overview of Mathematica notebooks used in Bifrost simulation and estimation

Bifrost	Main notebook
StomachData	Stomach content data handling, calculation of consumption per cod
Temperature	Handling of temperature data
STUVData	Handling of biological data of cod
EstablishingDataForMigration	Calculation of cod distribution
MakeVPA	VPA for cod, based on terminal Fs from the WG
SeaStar	Prognostic simulation of herring
BootstrapCapelin	Calculation of September data replicates

C2.1 Estimation of parameters

■ **C2.1.1 Historic replicates of estimated parameters - uncertainty in input data**

How the uncertainty in the input data affect the uncertainty in the estimated parameters is evaluated by repeated estimation of parameters, each time drawing input data at random from a distribution constructed from the actual measured values. The collection of these replicates of parameters is then transferred to CapTool. Table C.3 shows how the uncertainties in the individual input data sources are treated.

Table C.3. Overview of Mathematica notebooks used in Bifrost simulation and estimation

September data	Data are drawn according to the uncertainty used in CapTool (CV of 0.2)	
Consumption per cod	Stomach content data	No uncertainty for the measured data or for the division of unidentified food
	Evacuation rate parameters	Estimated repeatedly by resampling laboratory data
	Temperature	Drawn from a normal distribution with uncertainty taken from an analysis of using temperature stations not in the immediate vicinity of the trawl stations
	Cod distribution	No uncertainty applied
Cod assessment entities	No uncertainty applied	

□ **C2.1.2 Estimation of maturation parameters**

Figure C.5 gives an overview of the estimation of the maturation parameters.

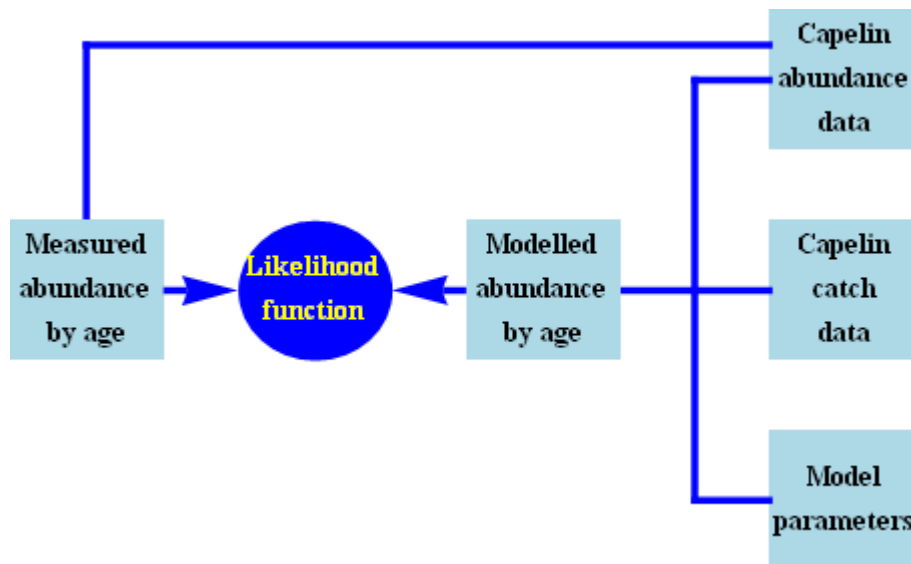


Figure C.5. The estimation of maturation parameters in Bifrost.

The estimation of the maturation parameters relies on projecting the immature part of the population one year, from after the estimate in September until the new estimate in September the following year. The basis for the likelihood function is the projected immature stock, which is the total stock next year since the mature capelin dies after spawning, which is compared to the measured total stock.

The projected immature stock depends not only on the maturation parameters, but also on the monthly natural mortality of immature capelin, which is a parameter in the model.

The trawl-acoustic estimation of Barents Sea capelin started in 1972. Past modelling experience has shown that during the first decade the population dynamics of the capelin remained fairly stable, i.e. the variation in natural mortality from year to year was fairly small. All three parameters P_1 , P_2 and P_3 are estimated simultaneously. Only the 9 first periods are used, i.e. 1972-1973, -----, 1980-1981. It is assumed that length at maturity is constant across age groups. The age groups 2-3 and 3-4 years are used in the likelihood.

It is assumed that the measurement of number at age given that the simulated values are the expectation values follow the gamma distribution, and the CV of the distribution is estimated along with the other parameters.

□ **C2.1.3 Estimation of predation parameters**

The maturation parameters must have been estimated before the predation parameters are being estimated.

The main idea behind estimating parameters in the model for consumption is to calculate the consumption by year during January-March outside of the modelled (referred to here as "empirical consumption") and adjust parameters so that the consumption calculated by the model is as close to the empirical consumption as possible. The estimation is done with standard minimizing software that is part of Mathematica.

Figure C.6 gives an overview of the estimation of the predation parameters.

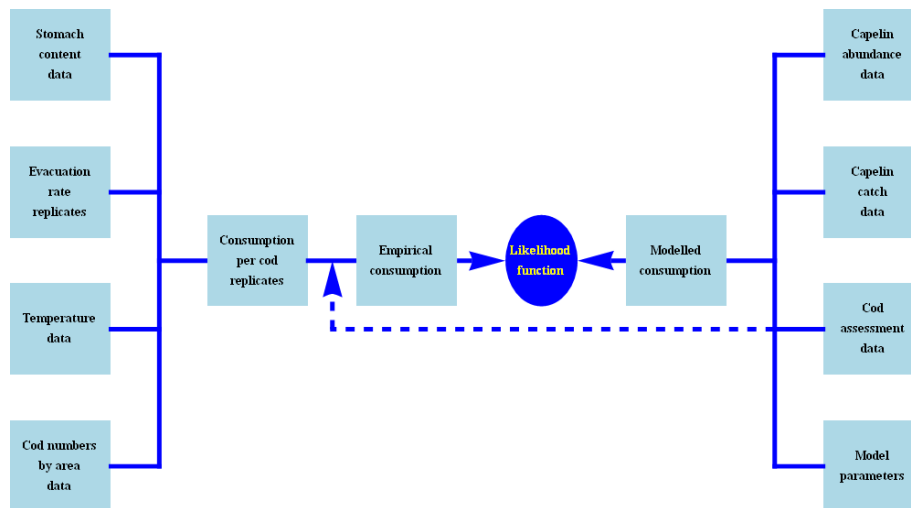


Figure C.6. The estimation of predation parameters in Bifrost.

C2.1.1.1 Calculation of empirical consumption

The calculation of the empirical consumption is based on an assumption of equilibrium: during the period of calculation (which in this case is January-March) the food eaten equals the food evacuated from the cod stomachs. The total amount of food evacuated is calculated as the average of the food evacuated per time unit for each stomach times the duration of the period. The evacuation rate is given by Bogstad and Mehl (1997):

$$R = \frac{\ln(2) e^{\gamma T} W^\delta S^\xi}{\alpha S_0^\beta}$$

where:

- α : evacuation rate halftime
- β : dependence on initial meal size
- γ : dependence on ambient temperature
- δ : dependence on predator body weight in grams
- ξ : shape parameter
- S: stomach content of prey
- S_0 : initial meal size in grams
- T: ambient temperature
- R: consumption in grams per hour

The initial stomach content S_0 is not known in the field, so β is set to zero. The other parameters are estimated repeatedly by resampling the laboratory data from an experiment at the University in Tromsø (dos Santos and Jobling 1992). This approach is the same as the approach recommended by Temming and Andersen (1994). The file of estimated evacuation rate parameters is kept on a separate input file, see figure C.6

The consumption per cod in grams per hour is then calculated as:

$$C_a = \frac{\sum_i N_{i,a} \bar{R}_{i,a}}{\sum_i N_{i,a}}$$

where

- C_a : consumption of capelin per hour by preying cod of age a
- $N_{i,a}$: the number of preying cod of age a in area i
- $\bar{R}_{i,a}$: the mean consumption of capelin by preying cod in area i, calculated as $\frac{1}{n} \sum_{j=1}^n R_{i,a,j}$ where the summation

extends over stomachs of cod of age a in area i and n is the number of sampled stomachs of preying cod of age a in the area.

Weighting with geographical distribution from survey

The empirical consumption is the consumption per cod times the number of cod preying on capelin. It is possible that the geographical distribution of stomach content samples does not equal the geographical distribution of cod preying on capelin. For that reason, the consumption per cod calculated from stomach samples is weighted by the number of cod preying on capelin in sub-areas of the Barents Sea. The area division chosen is the Multspec areas, which were used in connection with the Multspec model (Tjelmeland and Bogstad 1998), which was used with management of capelin before Bifrost.

Figure C.7 shows the Multspec areas.

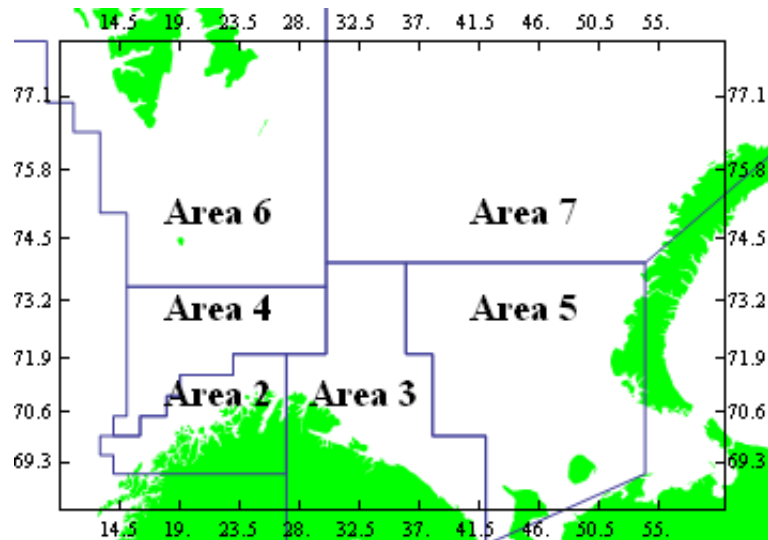


Figure C.7. Multispec areas

Handling of temperature

A temperature must be connected to each cod stomach, preferably being indicative of the ambient temperature since time of last ingestion. There are gradients in temperature - the depth gradient usually being especially strong - which would lead to possibly large inaccuracies using one temperature for a large spatio-temporal area. Unfortunately, the temperature during trawling has not been collected and stored with the stomach content data. As a rule, a CTD station is taken a short time after each trawl station.

In order to find the most appropriate temperature for a given trawl station, first a CTD station in the close spatio-temporal vicinity is sought. If none is found, the search box is increased. If still no CTD station is found, a neighbouring year is tried and the temperature from the CTD station is scaled with the changes in the temperature in the Kola section. The uncertainty connected to not finding a CTD station at the first attempt is evaluated by investigating all CTD data using the same algorithm around all CTD stations in the material. The procedure is described more fully in the separate document "Temperature in Bifrost.pdf".

C2.1.1.2 The likelihood function

The file of consumption per cod replicates is an input file to Bifrost (see figure C.6) and read during initialisation. The total consumption is calculated during the estimation process by multiplying consumption per cod with the number of preying cod from the cod assessment (Arctic Fisheries WG) and the duration of the preying period January-March. The modelled consumption is also summed over January-March before the log-likelihood is evaluated.

It is assumed that the exogeneously calculated consumption follows a gamma distribution when the expectation values are represented by the simulated consumption. The CV of the distribution is estimated along with the parameters in the consumption function.

■ C2.1.3 Likelihood estimation and parsimonious models

The estimation of parameters in Bifrost is based on maximum likelihood throughout. The parameters do then have a justification in that they represent a model for which the likelihood of the observed data is the highest possible. Also, using a likelihood is a powerful tool in seeking models that give the best balance between simplicity and overfitting. The models should be as simple as possible, yet capture the essentials of the population dynamics. The small-sample Akaike Information Criterion (AIC, Burnham and Anderson 2002) is used, defined as:

$$AIC_c = -2 \log(L(\hat{\theta})) + K \left(\frac{n}{n - K - 1} \right)$$

where L is the likelihood, evaluated at the estimated values of the parameters – $\hat{\theta}$ – and n is the number of data points and K the number of parameters.

The model with the lowest AIC is the most parsimonious model and to be preferred. This is a model where the parameters represent a biological reality, avoiding superfluous model fit due to overparameterization. Two alternatives to the chosen models were tested: a cut-off maturation function as opposed to the chosen sigmoid maturation, and a three-parameter consumption model enabling a type III feeding relationship. The sigmoid maturation was in itself not an improvement. It had a better fit in terms of a lower log-likelihood, but a higher AIC value. However the fit to the consumption data was significantly (in terms of AIC) worse using a cutoff maturation than using the sigmoid maturation. Using a three-parameter consumption model gave a modest better fit, but an increased AIC.

■ **C3. The CapTool spreadsheet for short term probabilistic projections**

■ **C3.1 The harvesting rule**

The harvesting rule adopted by the Norwegian-Russian Fishery Commission is that there shall be a maximum probability of 5% for the SSB at April 1 to be smaller than 200 000 tonnes. This rule was originally devised by the then ACFM.

■ **C3.1 CapTool**

The total Bifrost methodology is quite involved and a simpler tool is needed with the yearly assessment of capelin following the September survey, when only probabilistic projections from October 1 to April 1 the following year are needed. This is done in an Excel spreadsheet - CapTool - with the @RISK simulation module implemented. The Bifrost model formulations are programmed into CapTool and the replicates of the estimated parameters are copied to a separate page in CapTool. The CapTool spreadsheet, which is self-explanatory, carries out a large number of trajectories and calculates the number of trajectories that leads to a SSB at April 1 of less than 200 000 tonnes.

D. Short term projection

CapTool is used for short term projections. The current September estimate and latest cod assessment are entered manually into CapTool on separate pages. By trial and error a total catch rounded to the nearest 10 000 t for January-March is set so that the harvest rule is satisfied. Figure D.1 shows the simulation output from the assessment the autumn 2010.

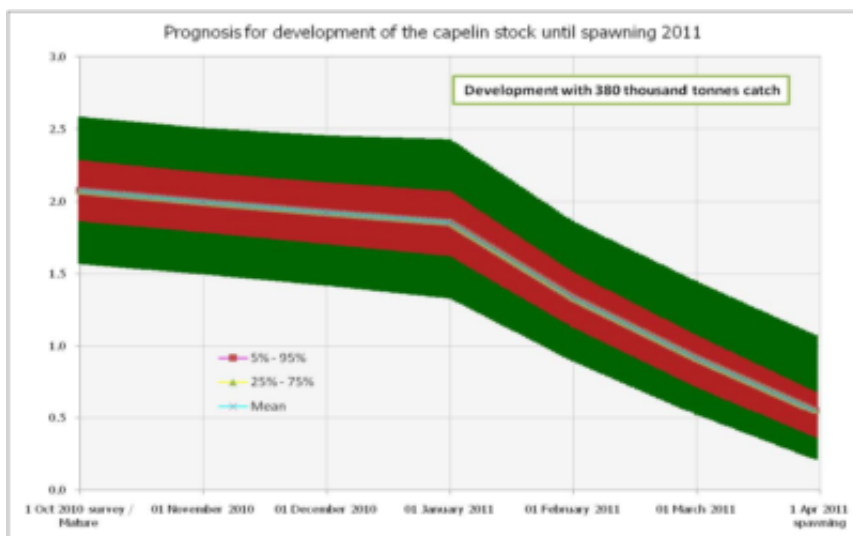


Figure D.1. Simulation output from CapTool, from the assessment of the autumn 2010

E. Medium term projections

Not relevant

F. Long term projections

Not relevant

G. Biological reference points

G.1. Blim

Blim for Barents Sea capelin is set to 200 000 tonnes by ICES. Originally, in an attempt to build on first principles, the researcher group conducting the assessment proposed using the SSB in 1989 as Blim. In that year, an extremely abundant year class originated from a small SSB, which however was adequate for taking full advantage of the good recruitment conditions in that year. SSB in 1989 is slightly smaller than 100 000 tonnes.

G.2. B_{MSY} (Experimental)

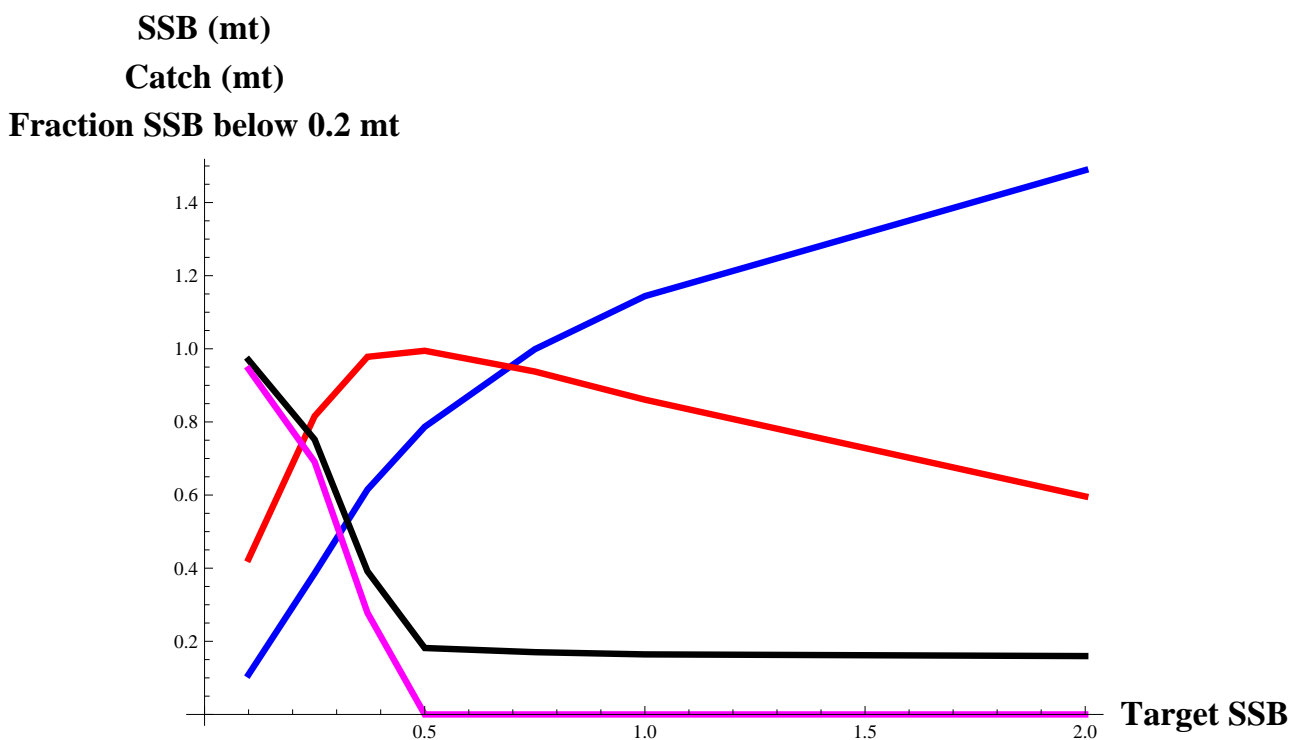
An alternative to the present rule could be to use a target SSB that maximizes the long term expected yield. Such an MSY-based harvest rule must be tested with long term simulations, and thus it is crucial to build a recruitment relation as realistic as possible. In addition, models for weight at age, maturation at age and natural mortality on immature capelin must be built. Finally, assumptions on the cod stock and the covariates to the recruitment function must be made.

Figure G.1 shows the mean long term yield, the mean long term SSB, the fraction of years where $SSB < 0.2$ million tonnes and the fraction of years in which there was a fishery where $SSB < 0.2$ million tonnes but excluding years with zero catch. In the upper figure assessment uncertainty is not applied and in the lower figure assessment uncertainty is applied. Table G.1 shows the assumptions used.

Table G.1. Assumptions used during long term simulations

Simulation time	600 years from 1972
Assessment uncertainty	CV of 0.2 (as in CapTool)

Recruitment functions	1219 recruitment functions have been fitted to the historic (simulated) SSB and recruit (as 1 year old capelin matched to observed 2 year old capelin) data with herring, 0 – group herring, 0 – group cod, temperature (several variants based on the Kola section data, AO index and capelin biomass as covariates. The 30 best according to the AIC are selected and one is drawn at random each year using Akaike weights.
Weight at age	Regressions on historic data using temperature and capelin biomass by age as covariates
Proportion mature at age	Regressions on historic data using temperature and capelin biomass as covariates
Herring	Cyclic since 1991
Temperature	Cyclic all historic
Natural mortality of immature capelin	Cyclic all historic
Cod stock	Constant at the 2009 level



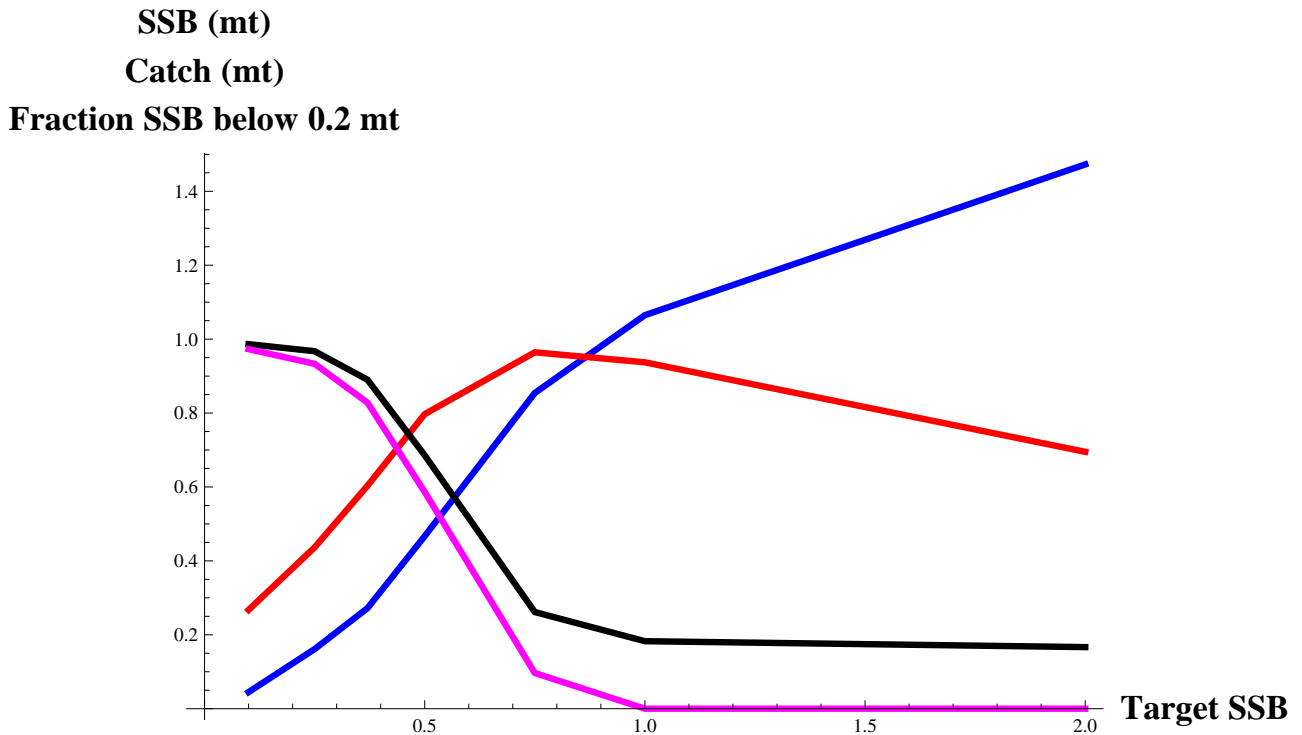


Figure G.1. Long term simulation entities as function of target SSB. The red line is mean long term catch, the blue line is long term mean SSB, the black line is fraction of years of SSB < 0.2 million tonnes and the magenta line is fraction of years of SSB < 0.2 million tonnes, excluding years with zero capelin catch. The upper figure shows results from simulations without applying assessment uncertainty, the lower figure shows results from simulations when assessment uncertainty is implemented.

The target SSB is about 0.5 million tonnes when assessment uncertainty is not applied, and around 0.75 million tonnes when the assessment uncertainty is applied. These values are in the range of the realised SSBs prior to spawning using the present harvest rule, which therefore can be concluded to be nearly optimal and in compliance with MSY. The mean SSB increases from below 0.1 million tonnes to 1.5 million tonnes when the target SSB is increased from 0.1 to 2.0 million tonnes. This quantity is of management relevance, since the post-spawning capelin is an input to the ecosystem. Even if the target SSB is much increased, the fraction of years where the SSB is less than 200 000 tonnes does not drop much below 0.2. Because of the strong natural fluctuations it is not possible to realise a goal of maximum 5% of SSBs below 0.2 million tonnes. This goal is realised however for those years in which there has been catch for target SSBs slightly larger than the optimal value.

It should be noted that stakeholders challenge the present harvest rule on two different issues. Some stakeholders claim that

the post-spawning dead capelin benefits the ecosystem and that this should be taken into account in management. Other stakeholders would want to fish more often to not too frequently lose contact with well-paying markets, possibly at the expense of very large catches when capelin is abundant. It is possible that these two views could be reconciled to some extent. Also, one should investigate whether the precautionary element could be based on first principles rather than the present ad hoc settings. Such first principles might be the danger of extinction or near-extinction, defined as recruitments lower than the lowest observed 3 years in a row. Thus, modifying the harvest rule is a complicated process, which should involve stakeholders.

Note that the present simulations have been done with cod preying on capelin only during January-March and the cod stock has been kept constant during simulations. A revised harvest rule should preferably be built on a model where cod preys on capelin the year around, and on a dynamic cod stock during simulations.

H. Other issues

None

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