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Stock Annex: Capelin (*Mallotus villosus*) in Subareas I and II (Northeast Arctic), excluding Division IIa west of 5°W (Barents Sea capelin)

Stock specific documentation of standard assessment procedures used by ICES.

Stock:	Capelin (*Mallotus villosus*) in Subareas I and II (Northeast Arctic), excluding Division IIa west of 5°W (Barents Sea capelin)
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Introduction

The present (2015) methodology for Barents Sea capelin was evaluated at WKARCT (ICES 2015). The previous evaluation was made the ICES benchmark workshop WKSHORT in Bergen 31 August–4 September 2009 (ICES 2009b). A significant development still ongoing at present (2015) is the development of the Bifrost model on an ADMB (non-commercial) software platform, which will allow for transparency, easy parameter estimation and uncertainty quantification.

Models used

Unlike most other stocks, the management of capelin is founded on one survey, which is considered to give an absolute measurement of the stock; no model to reconstruct the stock 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 simulation from the time of measurement (October 1) to the time of spawning (April 1 the following year). Bifrost is a model used to estimate parameters of the two main biological processes included in the simulations: maturation, predation by cod and natural mortality. The relation between the two models is shown in Figure 1.

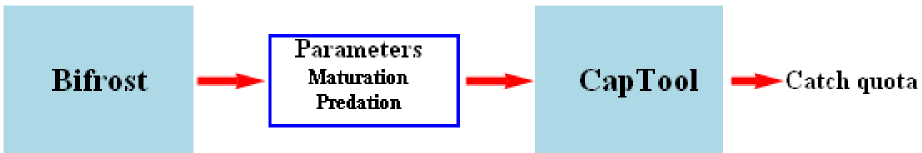

Figure 1. Relation between the models Bifrost and CapTool

CapTool is described in detail by Gjøsæter *et al.*, (2002) and Bifrost in detail in Tjelmeland (2005) and Anon. (2009b). This annex only describes the most important features of the models, but the data sources used and the procedure for running annual assessments are described in more detail.

The assessment of the Barents Sea capelin rests on a quantitative description of the essential parts of the population dynamics of the stock. Although the management of Barents Sea capelin is a strictly single species management, it rests on a multispecies model that includes predation by cod on capelin and as such is a step into an ecosystem based approach to management of the Barents Sea species.

A. General

A.1. Stock definition

Capelin in the Barents Sea spawn in March-April in shallow water off the north coasts of Norway and Russia (Gjøsæter, 1998). The juveniles are transported to the central and eastern parts of the Barents Sea where they grow up. The capelin mature and spawn 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 undertake an extensive feeding migration during 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 trawls. 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). 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 future, the part of the capelin catch delivered for meal and oil production will be associated to the international market for fishmeal and fishoil. The Russian part of the catch is delivered exclusively to human consumption.

A.3. Ecosystem aspects

A.3.1. Predators

The capelin play 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 (Bogstad and Mehl 1997, Gjøsæter *et al.*, 2009). Juvenile herring may feed intensively on capelin larvae (Hallfredsson and Pedersen, 2009), which may affect the capelin recruitment significantly (Hjermann *et al.*, 2010). Capelin 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 during the recent years, thereby increasing predation on mature and also on immature capelin.

At the moment only predation by immature cod on mature capelin in January-March is included in the models, this could be extended to include also predation at other times of the year and by mature cod also.

B. Data

B.1. Commercial catch

B.1.1 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 are operating by trawl and half by purse-seine. The Norwegian catch for a fishing season is calculated in numbers by age and length (1 cm length groups) and is also reported in tonnes by month.

The Russian catch is taken by trawl. The Russian catch in number and age by length and the division into tonnes by months are reported to the WG.

Intercatch has so far not been used for Barents Sea capelin.

B.1.1.1 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

Information about discarding is unavailable.

B.2. Biological data

Data from samples from commercial catches are used for converting commercial catch in tonnes to catch in numbers by age and length.

B.3. Surveys

Only 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 (Gjøsæter *et al.*, 1998). The abundance estimate from this survey is considered an absolute estimate of the stock.

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 2 (updated from Tjelmeland, 2002). 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 3 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 2006, 2008 and 2011 year classes, 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).

Although not completely new, drift ice overlapping the capelin distribution area has not been encountered frequently during the more than 40 years of September capelin surveys. The experience in 2014, where ice cover prevented full survey coverage, and the subsequent challenges with respect to stock assessment and management advice, calls for devising guidelines for how to deal with such scenarios. Since no direct evidence of either of the possibilities (presence or absence of capelin under the ice exists), auxiliary information must be considered.

A pre-agreed procedure for adjusting for surveys with incomplete coverage should be developed. Two possibilities exist, area adjustment where the survey estimates are scaled up by the average (or recent) percentage of the stock in the unsurveyed area, and a time-series adjustment where the previous survey is projected forward based on recent average mortalities. Both procedures can be evaluated retrospectively, and prediction errors can be calculated. Therefore an inverse-variance weighting is feasible and would be preferable to reliance on a single approach.

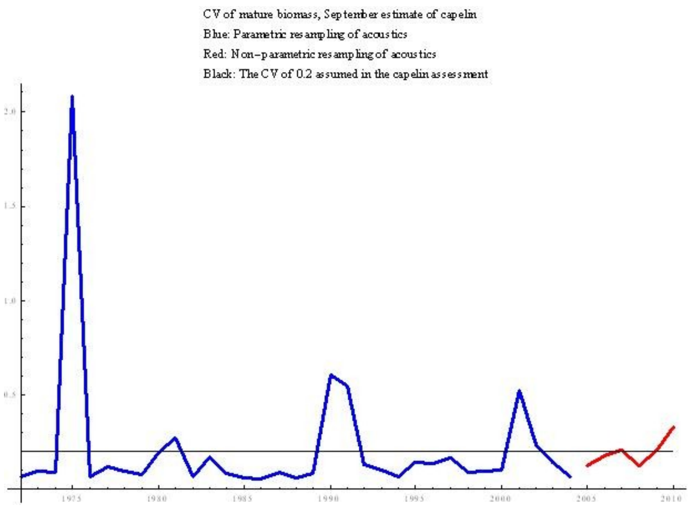

Figure 2. CV from resampling historic September surveys. The value 0.2 is shown as a horizontal black line.

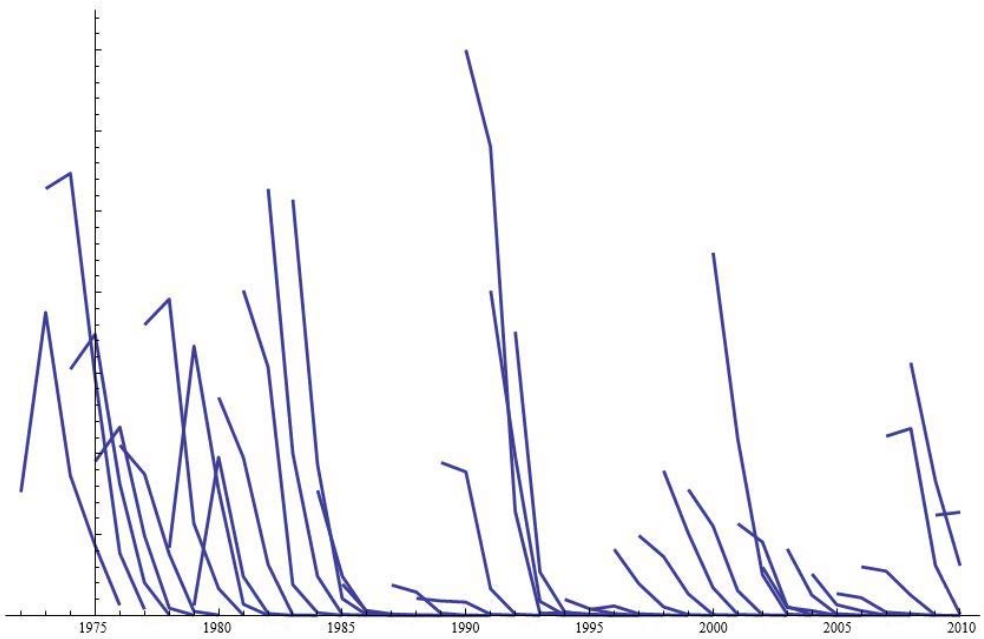

Figure 3. Development of year classes 1971–2009— Number-at-ages 1-4 (in billions) from the September survey.

B.4. Commercial cpue

Commercial cpue data are not relevant to this stock assessment.

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. Also temperature data are needed since the stomach evacuation rate, which is needed to calculate consumption, depends on the temperature.

B.6. Summary of data

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

Type	Origin	Year range	Biological division	Used by
Catch-at-age in numbers	Commercial catch Biological samples	1972 - present	Age 1 - 5 Season/Month Maturation stage (immature and mature split at 14 cm)	Bifrost
Stock size* October 1	Survey	1972 - present	Age 1 - 5 Length Weight by length	Bifrost CapTool
Stock size* replicates October 1	Survey	1972 - present	Age 1 - 5 Length Weight by length	Bifrost
Cod abundance Assessment year + 1	Arctic Fisheries WG assessment	Assessment year + 1	. Age 1 – 13+ Number, weight and maturity-at-age Assumed CV on number-at-age	CapTool
Cod abundance Historic	Arctic Fisheries WG assessment	1946 - present	Age 1 – 13+ Number, weight and maturity-at-age Assumed CV on number-at-age	Bifrost
Cod geographical distribution	Survey data*	1981-present	Age 1-10+	Bifrost
Stomach content data from the field	Biological samples from research vessels	1984 - present	Prey in individual cod stomachs	Bifrost

***Considered an absolute estimate of the stock**

**** Remains to be updated**

The consumption per cod data used in Bifrost to estimate parameters in the predation function are calculated exogenously 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 exogenously 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).

C. Assessment methodology

The models used and the basic assumptions are listed in Table 2.

Table 2. Models and assumptions used in the Barents Sea capelin assessment

Model	Usage	Submodel	Parameters
Bifrost	Estimation of maturation and predation parameters	Maturation	Sigmoidal function of length – 2 parameters estimated
		Predation per cod	Type II relation to capelin biomass. Maximum consumption and prey biomass at half maximum consumption – 2 parameters - estimated
		Natural mortality	Annual values - estimated
CapTool	Calculation of catch according to HCR	Maturation	Replicate values from Bifrost (usually 1000)
		Predation per cod	Replicate values from Bifrost (usually 1000)
		Natural mortality	Replicate values from Bifrost (usually 1000), year range from which to select values based on expert decision

C.1 Model formulations

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

C.1.1 Maturation

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

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

where P2 is the length at 50% maturation and P1 is the increase in maturation by length at P2. l is the length in cm. Usually P2 is close to 14 cm and in many calculations outside Bifrost a knife-edge split between immature and mature capelin is made at 14 cm.

The number of immature cod by age residing in the Svalbard area, and 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.

C.2. Simulation

The simulation of capelin in Bifrost is shown in Figure 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. The maturation model is applied to these data 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.

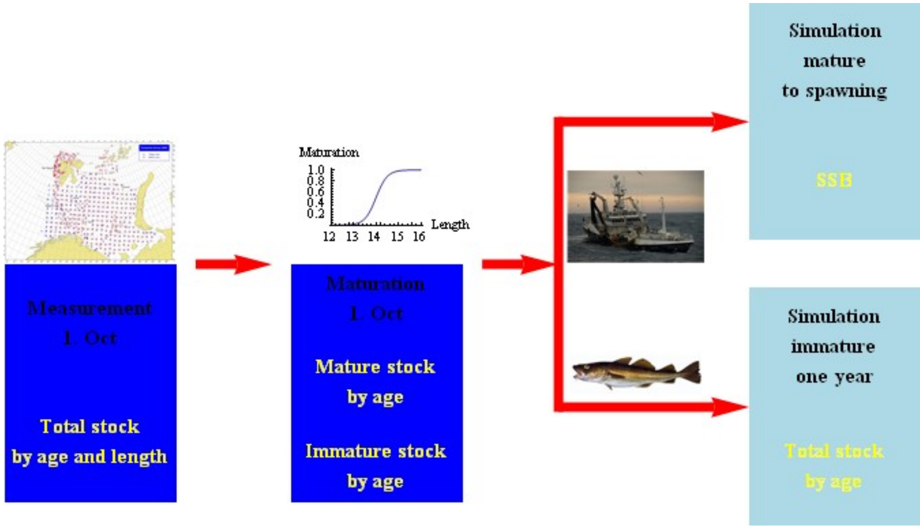

Figure 4. Overview of Bifrost simulation.

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

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

During the period January-March the consumption of capelin by cod is particularly intense, as is the fishery.

The catch statistics used by Bifrost are given by 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 P3 is a constant parameter that is estimated along with the parameters in the maturation function.

C.2.1 Parameter estimation

C.2.1.1 Estimation of maturation parameters and annual mortalities

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

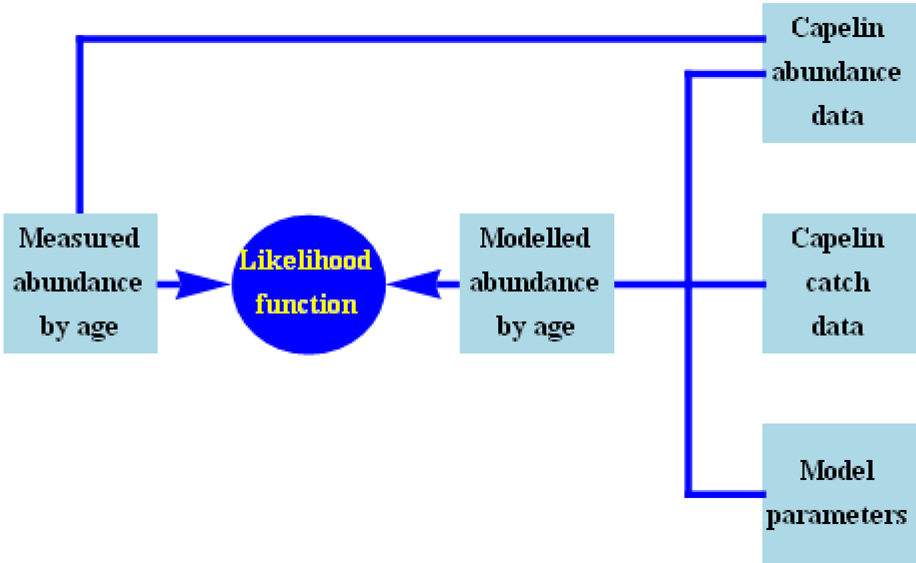

Figure 5. Estimation of maturation parameters in Bifrost.

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 (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 (calculated by cohort, comparing the September survey in two consecutive years) was fairly small. All three parameters P1, P2 and P3 are estimated simultaneously. Only the 9 first September-September 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 measurements of number-at-age, given that the simulated values are the expectation values, follow a gamma probability density distribution, and the CV of the distribution is estimated along with the other parameters.

After the maturation parameters are estimated based on the 9 first periods, these are assumed to be fixed and another estimation of annual mortalities is performed. These mortalities are used in CapTool for the period October-December, scaled to monthly values.

C3.2 Estimation of predation parameters

The main idea behind estimating parameters in the model for consumption is to calculate the consumption by year during January-March outside 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.

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

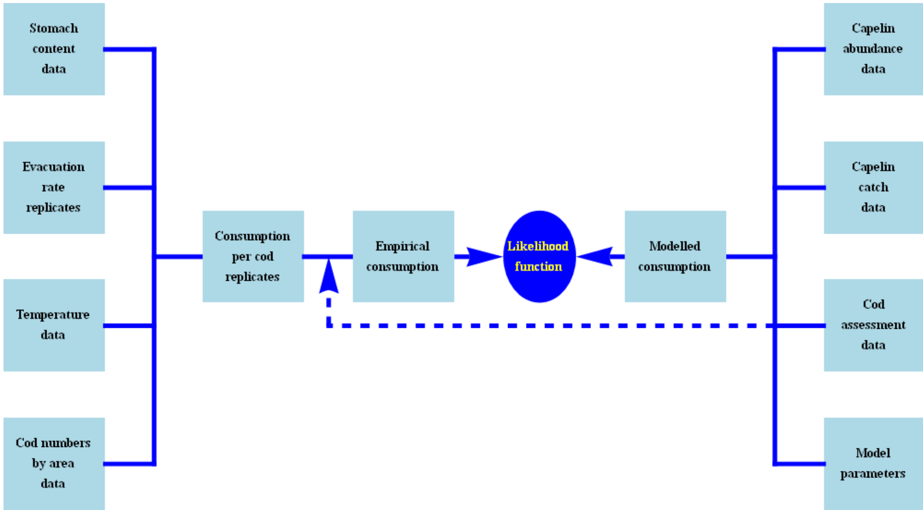

Figure 6. Estimation of predation parameters in Bifrost.

The estimation of parameters in Bifrost is based on maximum likelihood.

C.4. The CapTool spreadsheet for short-term probabilistic projections

C.4.1 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.

C.4.2 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 (usually 30 000) and calculates the number of trajectories that leads to a SSB at April 1 of less than 200 000 tonnes.

Updates needed annually in CapTool:

Capelin survey estimate, cod assessment, Svalbard component (to be revisited)

Updates needed less often:

Catch distribution by month, Choice of year range for M in autumn, (for these two historical values years have to be checked in order to choose from a representative range of years), replicate file updates when new estimates available.

D. Short-term projection

CapTool is used for short-term projections. The current September estimate and latest cod assessment and short-term prediction are entered manually into CapTool on separate pages. By trial and error a total catch rounded to the nearest 10 000 tonnes for January-March is set so that the harvest rule is satisfied. Figure 7 shows the simulation output from the assessment in autumn 2013 while Figure 8 shows the risk level as a function of the quota.

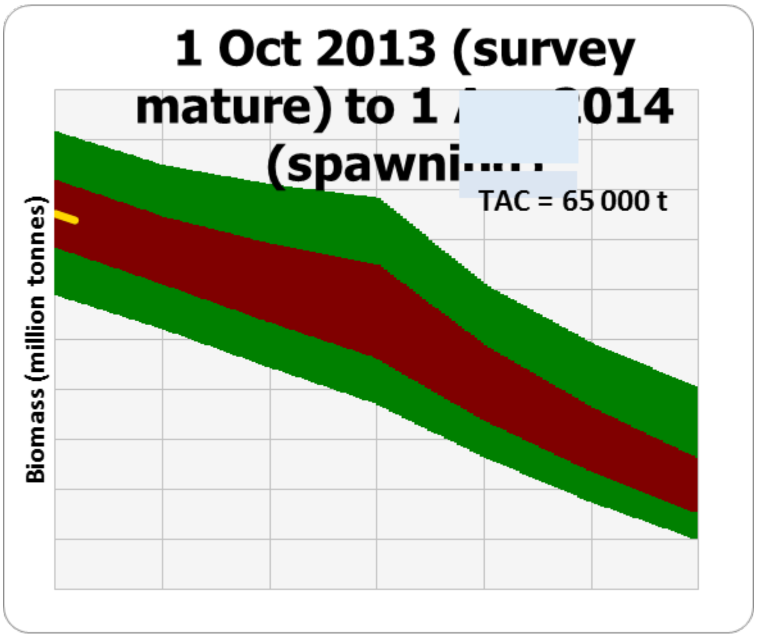

Figure 7. Simulation output from CapTool, from the autumn 2013 assessment

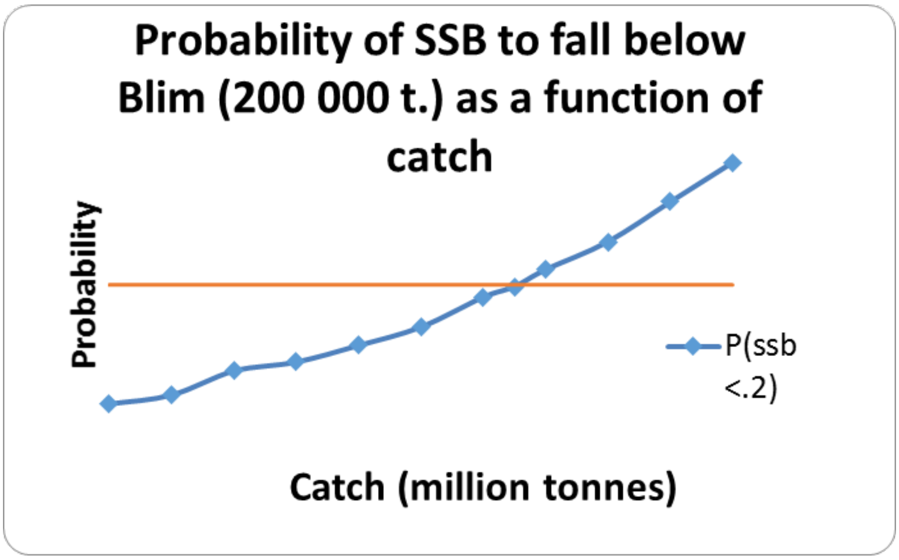

Figure 8. Risk level as a function of the quota, from the assessment of autumn 2013.

E Medium term projections

Not used for this stock

F Long-term projections

Stochastic long-term simulations for capelin in order to investigate maximum long-term yield for this stocks have been performed by Tjelmeland (2005) using the Bifrost model. Since cod and herring may have considerable impact on the capelin stock through species interactions, these simulations were made for a range of fishing mortalities (harvest control rules) for cod and herring. This work should be updated.

G Biological reference points

G.1 B_{lim}

Originally, in an attempt to build on first principles, the researcher group conducting the assessment proposed using the SSB in 1989 as B_{lim}. 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 was slightly smaller than 100 kt. A 200 kt B_{lim} was suggested by ICES to take account of uncertainty not included in the assessment.

The B_{lim} value should be updated according to ICES guidelines for reference points, following the establishment of a new time-series for spawning stock and recruitment. No other reference points are at present used for this stock.

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