

ICES WKARCT REPORT 2015

ICES ACOM COMMITTEE

ICES CM 2015\ACOM:30

Report of the Benchmark Workshop on Arctic Stocks (WKARCT)

26–30 January 2015

ICES Headquarters, Denmark



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International Council for
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Recommended format for purposes of citation:

ICES. 2015. Report of the Benchmark Workshop on Arctic Stocks (WKARCT), 26-30 January 2015, ICES Headquarters, Denmark. ICES CM 2015\ACOM:30. 126 pp.

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Executive Summary

The Benchmark Workshop on Arctic Stocks (WKARCT) was set up to develop benchmark assessments for Northeast Arctic Cod, Norwegian Coastal Cod, Barents Sea capelin and Northeast Arctic haddock. All these stocks are distributed in ICES Subareas I and II. The Workshop took place at ICES headquarters from 26-30 January 2015.

For Northeast Arctic cod, ages 3 to 9 from the Ecosystem Survey were added as tuning indices in the stock-assessment model. Given the addition of a fourth scientific survey, Russian cpue was dropped as a tuning index. The settings used in the XSA model were reviewed and some changes suggested for improving the model fit and the retrospective pattern. The standard error of F shrinkage was increased from 1.0 to 1.5 and population shrinkage was turned off. Other stock-assessment models should be run in parallel with XSA.

For Northeast Arctic haddock it was concluded that SAM should replace XSA as the main assessment model. For this stock, XSA has been shown to be very sensitive to the choice of settings, especially use or no use of population shrinkage. SAM is a statistically based and in general more appropriate model. The assessment made with SAM is fairly similar to that with XSA without population shrinkage, and gives almost a doubling of the SSB compared to the 2014 assessment which was made with XSA using population shrinkage. The difference is much less for the immature stock. One important reason for the discrepancy is that the strong 2004–2006 year classes now are moving past the age range used for tuning indices, and thus particularly sensitive to model settings. WKARCT decided to include catches-at-age up to 13+ in the stock assessment model given the recent prevalence of older haddock in the population.

Both for Northeast Arctic cod and haddock, the choices of biological models for recruitment, mortality, growth and maturation for use in long-term stochastic simulations were evaluated. No long-term simulations or evaluations of MSY reference points or harvest control rules were performed. For cod, more work is required to model cannibalism in an appropriate way, which is important in the population dynamics of this stock.

For Barents Sea capelin, the model approach, which includes multispecies elements (predation by cod), was generally endorsed. The basis for the existing reference point (B_{lim}) used in the target escapement management strategy for this stock is not in line with the ICES guidelines for determination of reference points. Further work on this is required, but first a consistent time-series for stock and recruitment for as long a period as possible has to be established.

For Norwegian Coastal Cod (NCC), the time-series of catch-at-age has been revised, using a new model for splitting cod catches between Norwegian Coastal Cod and Northeast Arctic Cod. This resulted in slightly lower NCC catches in the 1980s and 1990s, and higher catches in recent years, compared to the data series used previously. The trends-based assessment used at present has potential for improvement, but no suggestions were made. Better data are needed on the amount of recreational and tourist fisheries on this stock.

1 Introduction

The Benchmark Workshop on Arctic Stocks (WKARCT) chaired by Jeremy Collie (USA) and Bjarte Bogstad (Norway), with invited external experts Martin Dorn (USA) and Jonathan Deroba (USA) took place at ICES headquarters from 26–30 January 2015 to develop benchmark assessments for Northeast Arctic Cod, Norwegian Coastal Cod, Barents Sea capelin and Northeast Arctic haddock. All these stocks are distributed in ICES Subareas I and II. The objectives of the meeting were to evaluate the appropriateness of data and methods to determine stock status in relation to existing or proposed new biological reference points, and to investigate methods for short-term outlook taking agreed or proposed management plans into account. Where possible, knowledge of environmental drivers, including multispecies interactions, and ecosystem impacts, were required to be integrated in the methodology (see Annex 1). If no analytical assessment method could be agreed, then an alternative method, including if necessary following the ICES data-limited stock approach, was to be put forward. Finally, the meeting was an opportunity to develop recommendations for future improvement of the assessment methodology, aspects of the stock structure, biology and ecology of the stocks, and data collection.

As part of the benchmark process, a data compilation workshop was held in Murmansk, Russia 5–7 November 2014. Three WebEx meetings with the external experts were held (20 November 2014, 18 December 2014 and 15 January 2015).

Although stakeholders were invited to contribute in the benchmark process, there was no stakeholder participation. A full list of participants is provided in Annex 2. In addition, Margit Eero from DTU-Aqua provided a very valuable contribution on SAM model runs and settings for haddock after the meeting was finished.

The results of the workshop for each stock are given in Sections 2-5, and the external reviewers report is given in Section 6. Recommendations to other ICES Experts groups are available in Annex 3. Annexes 4-7 contain the “stock annex” of each stock, where data and methodology to be used for assessment of the stocks in the incoming years is described.

2 Cod (*Gadus morhua*) in Subareas I and II (Northeast Arctic)

2.1 Stock ID and substock structure

The North-East Arctic cod (*Gadus morhua*) is distributed in the Barents Sea and adjacent waters, mainly in waters above 0°C. The main spawning areas are along the Norwegian coast between 67°30' and 70°N. The 0-group cod drifts from the spawning grounds eastwards and northwards and during the international 0-group survey in August it is observed over wide areas in the Barents Sea.

Issues concerning separation of Northeast Arctic cod and Norwegian Coastal Cod are described in Section 3.1 on Coastal Cod.

Issue list

Stock	Northeast arctic cod (cod_arct)			
Benchmark year	January 2015			
Stock coordinator	Name: Yuri Kovalev	E-mail: Kovalev@pinro.ru		
Stock assessor	Name: Bjarte Bogstad	E-mail: Bjarte@imr.no		
Data contact	Name: Natalia Yaragina	E-mail: Yaragina@pinro.ru		
Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
(New) data to be Considered and/or quantified	Additional M - predator relations	Extending cannibalism time-series back to 1947	PINRO qualitative stomach content data 1947-present to be combined by PINRO/IMR quantitative stomach content data from 1984-present	
	Prey relations	Growth and maturity related to stock size and food abundance (not only capelin)	Prey abundance data available back to early 1980s	
	Ecosystem drivers	Temperature influence on recruitment and on stock distribution/food availability	Temperature data are available back to 1900	
	Other ecosystem parameters that may need to be explored?			
Tuning series	Combination of acoustic data Barents Sea and Lofoten surveys for use in tuning should be reviewed. How to take variable spatial coverage of stock by surveys into account?		Data available	
Discards/bycatch	Discards and bycatch in shrimp fishery not included in current time-series.	Time-series are available but should be quality checked		

Stock	Northeast arctic cod (cod_arct)			
Benchmark year	January 2015			
Stock coordinator	Name: Yuri Kovalev		E-mail:Kovalev@pinro.ru	
Stock assessor	Name: Bjarte Bogstad		E-mail: Bjarte@imr.no	
Data contact	Name: Natalia Yaragina		E-mail:Yaragina@pinro.ru	
Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
(New) data to be Considered and/or quantified	Additional M - predator relations	Extending cannibalism time-series back to 1947	PINRO qualitative stomach content data 1947-present to be combined by PINRO/IMR quantitative stomach content data from 1984-present	
	Prey relations	Growth and maturity related to stock size and food abundance (not only capelin)	Prey abundance data available back to early 1980s	
	Ecosystem drivers	Temperature influence on recruitment and on stock distribution/food availability	Temperature data are available back to 1900	
	Other ecosystem parameters that may need to be explored?			
Catch data	Inconsistency in catch figures used for cod-arct and cod-coas (sum does not match total catch). Time-series back to 1932/1913 should be considered for inclusion in assessment	Review of time-series		
Biological Parameters				
Ecosystem/mixed fisheries considerations	The influence a large cod stock with a large proportion of old and large fish has on the ecosystem should be considered.			

Stock	Northeast arctic cod (cod_arct)			
Benchmark year	January 2015			
Stock coordinator	Name: Yuri Kovalev	E-mail: Kovalev@pinro.ru		
Stock assessor	Name: Bjarte Bogstad	E-mail: Bjarte@imr.no		
Data contact	Name: Natalia Yaragina	E-mail: Yaragina@pinro.ru		
Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
(New) data to be Considered and/or quantified	Additional M - predator relations	Extending cannibalism time-series back to 1947	PINRO qualitative stomach content data 1947-present to be combined by PINRO/IMR quantitative stomach content data from 1984-present	
	Prey relations	Growth and maturity related to stock size and food abundance (not only capelin)	Prey abundance data available back to early 1980s	
	Ecosystem drivers	Temperature influence on recruitment and on stock distribution/food availability	Temperature data are available back to 1900	
	Other ecosystem parameters that may need to be explored?			
Assessment method	Several very strong generations passing through older part of the population. Such an event is unique and not observed in the period covered by surveys. Stock is at present assessed by XSA, with cannibalism included. Other stock methods such as statistical catch-at-age models and age-length structured models should be set up for this stock	Model assumptions regarding form of relationship between stock abundance and survey index needs to be verified.	Gadget model exists for this stock, will need help for setting up other alternative models	Expertise in stock assessment

Stock	Northeast arctic cod (cod_arct)			
Benchmark year	January 2015			
Stock coordinator	Name: Yuri Kovalev		E-mail:Kovalev@pinro.ru	
Stock assessor	Name: Bjarte Bogstad		E-mail: Bjarte@imr.no	
Data contact	Name: Natalia Yaragina		E-mail:Yaragina@pinro.ru	
Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
(New) data to be Considered and/or quantified	Additional M - predator relations	Extending cannibalism time-series back to 1947	PINRO qualitative stomach content data 1947-present to be combined by PINRO/IMR quantitative stomach content data from 1984-present	
	Prey relations	Growth and maturity related to stock size and food abundance (not only capelin)	Prey abundance data available back to early 1980s	
	Ecosystem drivers	Temperature influence on recruitment and on stock distribution/food availability	Temperature data are available back to 1900	
	Other ecosystem parameters that may need to be explored?			
Harvest control rule	To be evaluated in 2015 according to decision by managers	Long-term stochastic simulations where the underlying biological model is updated to take into account data from recent years.	Framework for stochastic simulations that can handle present harvest control rules is available (PROST)	Expertise in management strategy evaluations
Biological Reference Points	Need to be revised as longer time-series are now available			

2.2 Scorecard on data quality

The data on NEA cod biology (weights and maturity) are supposed to be of reasonably good quality and were not discussed during the benchmark.

New time-series for period 1946–1983 on young cod (ages 3–5) cannibalism values were presented to the group (WD7) and discussed. It was decided to include them in NEA cod assessment in order to reach consistency for recruitment time-series as cod recruitment since 1984 is estimated including data on cannibalism.

In WD18 the data on cod catches-at-age as well as all existing surveys were explored. Catch-at-age data are considered as having a relatively good quality and suitable for using in cohort models. Also based on this exploration the benchmark decided to keep the same scientific surveys and age ranges as used by AFWG previously. In addition it was decided to add to assessment model as new tuning data the Ecosystem survey (Table A.14 in AFWG 2014 report) indices for ages which showed a good internal consistency (3–9).

Assuming that four scientific surveys with age range up to 9 now is available for assessment it was considered to exclude commercial cpue, which is supposed to be fishery dependent source of information. It was done after testing of influence of such a change on assessment quality. The test runs demonstrate an increase of model stability after excluding commercial cpue and adding Ecosystem survey (section 2.5.3).

2.3 Multispecies and mixed fisheries issues

There are several multispecies issues for the cod stock. Predation by cod on cod, haddock and capelin is already implemented in the assessment, and in some periods cod growth has been considerably affected by prey abundance. Cannibalism is an important factor in the stock dynamics for this stock; and the implementation of this in the assessment model and in short- and long-term projections was discussed by WKARCT (section 2.5.4, 2.6 and 2.7). Mixed fisheries issues were not considered by WKARCT. Cod and haddock are to a large extent caught in a mixed fishery.

2.4 Ecosystem drivers

Inflow, sea temperature and ice conditions in the Barents Sea are important drivers for the Barents Sea ecosystem. These factors are known to affect both recruitment and distribution area for cod, with higher inflow and temperatures and less ice having a positive impact on this stock. Recent reviews of these effects have been made by Ottersen *et al.*, 2014 (recruitment) and Kjesbu *et al.*, 2014 (distribution and stock dynamics).

2.5 Stock Assessment

2.5.1 Catch – quality, misreporting, discards

Unreported catches have been added to the officially reported catches during the periods 1990–1994 and 2002–2008. For years after 2008 the official catches have been very close to independent estimates made by the Norwegian-Russian analysis group on estimation of total catches, and thus unreported catches have been set to zero. There have been some concerns of decreasing sampling from commercial fisheries during the last years. A time-series of discards for the period 1946–1998 (Table 3.29 AFWG 2014) is available. It was decided not to include it, because the methodology has not been evaluated. Also, the magnitude of discards of young fish (mainly age 3

and 4) is lower than that of cannibalism on the same age groups and could be considered as negligible compared to corresponding generation abundance (Section 2.5.3).

A revision of catch-at-age should be made following the update of Norwegian catch-at-age data for Norwegian Coastal Cod and Northeast Arctic cod (ref Coastal cod section). This will have a minor impact on the NEA cod time-series.

There is regular exchange of otoliths between Russian and Norwegian age readers, and age readings seem to be consistent between countries. Also old otoliths have been re-read and no significant difference was found between contemporary and historical age determinations.

2.5.2 Catch-at-age data are considered as having a relatively good quality and suitable for using in cohort models (WD18) Surveys

The survey and cpue series available for these stocks are:

- Joint winter survey (bottom trawl and acoustic);
- Lofoten survey on spawning cod (acoustic);
- Russian autumn survey (trawl);
- Ecosystem survey in August-September (trawl);
- Russian trawl cpue series.

The acoustic index from the winter survey has been combined with the Lofoten survey to one tuning series. The ecosystem survey has so far not been used as a tuning series in the assessment. A joint methodology for calculation of indices from this survey has not been agreed upon (WD 17). Two index series available for the Ecosystem survey were presented to the benchmark (Table A14 in AFWG-2014 report and WD 17).

Several of the surveys have suffered from incomplete spatial coverage in some years, due to ice conditions, lack of vessel time, and lack of access to another country's EEZ (WDs 16, 17). Attempts have been made to adjust for incomplete coverage.

The survey areas has been expanded during time as the distribution of cod has stretched further north- and eastwards, and this also may cause inconsistencies in the time-series. The area covered by the Joint winter survey was extended in 2014, and about 25% of the abundance of age 2 and older cod was found outside the old survey area (Mehl *et al.*, 2014). So far the indices from the pre-2014 survey area have been used in the assessment, and it is not obvious how to handle this in future.

Exploration of the internal survey consistency of all scientific surveys (WD 18) demonstrated a relatively good index quality for ages 3-8 and even for age 9 in some surveys. Based on this exploration WKARCT decided to keep the same scientific surveys and age ranges as used by AFWG previously. In addition it was decided to add to the assessment model, as new tuning data, one of the existing Ecosystem survey indices (ages 3-9 from Table A.14 in AFWG 2014 report) which showed a better internal consistency for ages 3 to 9. The methodology for calculating the index from this survey has not been agreed upon (WD 17). When the new agreed method for index calculation of the Ecosystem survey will be available, AFWG shall decide on replacement of the currently used index with a new one.

2.5.3 Cannibalism and natural mortality

Predation by cod on cod (cannibalism) is calculated based on annual quantitative cod stomach content data from 1984-present, and the mortality induced by cannibalism on age 1-6 cod is calculated assuming $M=0.2$ + cannibalism and using an iterative procedure with XSA. Including cannibalism has been found to improve the stock assessment. Cannibalism mainly affects the mortality on ages 1-4.

As quantitative stomach content data (i.e. data where the weight of the stomach content has been recorded) are not available for the period 1946-1983, the inclusion of cannibalism has caused an inconsistency in the time-series of recruitment for this stock. However, qualitative (i.e. frequency of occurrence in stomachs) data on cod cannibalism are available for the period 1947-1983 (WD7, Yaragina *et al.*, 2009). In WD7, a relationship between qualitative and quantitative data on cod cannibalism is established, and this is used to hindcast the cannibalism level for the period 1946-1983. This procedure resulted in considerably higher recruitment-at-age 3 for a number of years in the period 1946-1966.

It is suggested to include these estimates in the standard time-series for cod stock abundance, but the time-series with constant mortality ($M=0.2$) for all years and ages should also be presented by AFWG. Thus two sets of internally consistent time-series will be available for use in stock/recruitment models.

There are also indications that mortality on older ages may have decreased in recent years (WD1).

2.5.4 Weights, maturities, growth

Stock weight and maturity-at-age data are calculated as averages of Russian and Norwegian data. These data are collected from surveys in October-December and January-March, respectively, so using averages to represent figures valid for 1 January seems sensible. Catch weight at age are calculated based on samples from commercial fisheries.

2.5.5 Assessment model

2.5.5.1 XSA

Possible changes in the XSA assessment model could be a reduction of weight of F shrinkage in XSA and excluding p – shrinkage. In a situation of stock dynamics as observed now, when very abundant year classes are passing through the population, using the shrinkage procedure could groundlessly reduce such a generation's abundance.

All proposed changes were tested at the WKARCT. The test has shown that excluding commercial cpue and adding Ecosystem index substantially increasing the XSA retrospective stability (Figures 2.1 and 2.2).

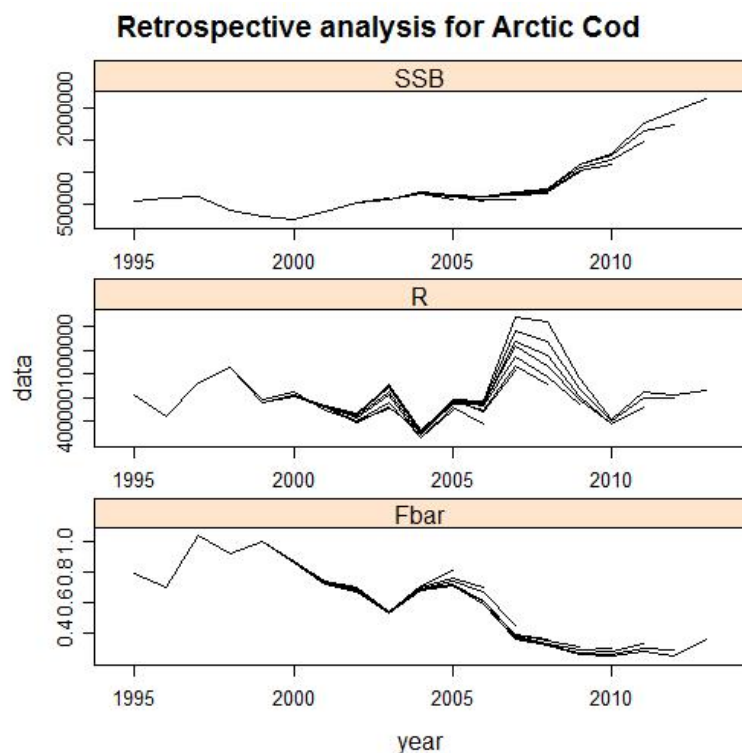


Figure 2.1. NEA cod SSB, R and F_{bar} retrospective patterns for final XSA run from AFWG 2014.

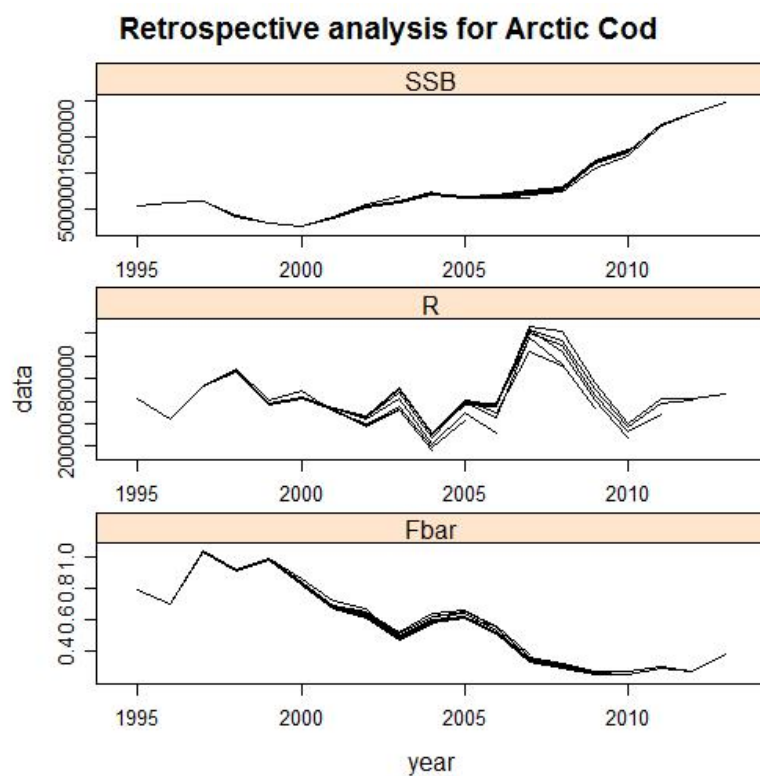


Figure 2.2. NEA cod SSB, R and F_{bar} retrospective patterns for new dataset proposed by the benchmark

The different combinations of possible changes in the XSA model configuration and their influence on assessment quality have been explored (Table 2.1). Two criteria were used to evaluate a model fit quality and stability. One is sum of squares of residuals of each survey (RSS) for most recent 10 years and for all surveys combined (S_RSS). Another was an average distance of each terminal parameter (SSB, F, R) in the retrospective run from the same parameter assessed using the whole time-series (R_RSS).

The best combination of these criteria was used to pick “the best” XSA model. Based on these XSA model runs WKARCT decided to exclude the Russian cpue index and include the Ecosystem survey (ages 3-9. F-shrinkage standard error was increased to 1.5 and P-shrinkage was turned off.

Table 2.1. Model fit for various XSA input data and model settings. [chosen combination in bold]

XSA configuration and some parameters values								
	p shr	yes	no	no	yes	no	no	No
	F shr s.e.	1.0	1.5	1.0	1.0	1.5	1.5	1.5
	Fl 09	+	+	+	-	-	-	-
	Fl 15	+	+	+	+	+	+	+
	Fl 16 (ages)	3-9	3-9	3-9	5-9	5-9	3-9	3-9
	Fl 18	+	+	+	+	+	+	+
	Fl 007	-	-	-	+	+	+	-
run name								
Fleet	AFWG 2014	new shr	no p shr	new sur set	2015 all new	2015 Acu 3-9	no Fleet 9 new shr	
S_RSS								
FLT09: RU-BTr-Com-All	2.9	2.5	2.7	-	-	-	-	
FLT15: BS-NoRu-Q1(BTr)	1.2	1.5	1.6	1.0	1.2	1.1	1.3	
FLT16: BS-NoRu-Q1(Aco)	2.5	3.2	3.3	-	-	2.2	2.5	
FLT16: ages 5-9	1.6	2.0	2.0	1.1	1.4	1.3	1.5	
FLT18: RU-BTr-Q4	3.6	4.9	5.2	2.6	3.4	3.2	3.5	
FLT007 Ecosystem survey	-	-	-	1.4	2.0	1.8	-	
Sum S_RSS	11.8	14.2	14.8	6.1	7.9	9.6	8.8	
Sum S_RSS (comparable)	6.4	8.4	8.8	4.7	6.0	5.7	6.3	
R_RSS for retro SSB, Recruitment-at-age 3 and F								
Retro RSS for SSB (10e3)	110	84	93	42	41	40	39	
Retro RSS for Recruitment	191	208	212	152	154	164	176	
Retro RSS for F	0.049	0.041	0.042	0.037	0.019	0.022	0.021	

2.5.5.2 TISVPA

The TISVPA (Triple Instantaneous Separable VPA) model (Vasilyev, 2006) model was presented as a possible alternative assessment method. TISVPA represents fishing mortality coefficients as a product of three parameters: $f(\text{year}) \cdot s(\text{age}) \cdot g(\text{cohort})$. The cohort-dependent parameters, which are estimated within the model, are intended to adapt traditional separable representation of fishing mortality to situations when several year classes may have peculiarities in their interaction with fishing fleets caused by different spatial distribution, higher attractiveness of more abundant schools to fishers, or for some other reasons.

The TISVPA model, applied to NEA cod data used by AFWG 2014, generally supports the results of the stock assessment made by means of the XSA model, except for a somewhat higher SSB estimate for 2013 - about 2.7 million tonnes - and somewhat lower estimates of recruits at age 3 in 2011–2013 (WD 19). Profiles of the components of the model objective function showed that all the sources of data, including catch-at-age and 4 “fleets”, contain more-or-less similar indications about the stock biomass in 2013, except for “fleet 16” which reveals a local optimum only by means of a robust measure of closeness of fit. Retrospective runs, similar to the XSA results, revealed some features of historical bias in the final years of assessment that may indicate possible changes in effective catchability of fishing fleets and surveys caused by presence of extremely abundant year classes in the stock.

WKARCT considers it to be important to continue to use models with different assumptions in NEA cod data exploration. Some properties of the TISVPA model, such as the possibility to strictly formulate the statistical meaning of the solution, not to consider as absolutely true the catch-at-age data, nor the data from surveys and fleet cpue, nor the assumption about stability of selection pattern, as well as its attention to robustness of the solution, could be valuable.

2.5.5.3 SAM

WKARCT recommended to also set up the SAM model for this stock (WD 10). The survey and catch data available are similar to those for haddock, so the haddock model would provide useful background for setting up the cod model. However, there are notable differences, for example in growth-rates and selection pattern. SAM has the ability to add e.g. discards to the landings, and then track these separately in the outputs. This same technique can be used to include predation data, but does then require an iterative procedure with ad hoc calculations of number eaten by age outside the SAM model, in the same way as is currently done in XSA with cannibalism (AFWG 2014). However, it should be possible to implement a model for cannibalism in SAM; this would have the advantage that uncertainty is included also for cannibalism.

2.6 Short-term projections

The methodology used for short-term prediction of weight, maturity, exploitation pattern, recruitment and natural mortality (WD5) generally seems to be adequate.

For the exploitation pattern, it was suggested to use an average for a longer period (5 years) than the 3-year average used at present. At present cannibalism mortality is predicted using a recent average (last 3 years average or last year's value if a strong trend in recent years is observed). It should be considered whether this could be improved using predictions of capelin abundance and abundance of large (predatory)

cod. When predicting growth and maturation, one should also consider whether large changes in prey abundance can be expected, such changes were experienced in the late 1980s and early 1990s and this strongly affected the accuracy of short-term predictions.

2.7 Appropriate Reference Points (MSY)

No recalculation of biological reference points was performed by WKARCT.

2.7.1 Limit and p_a reference points

The limit and precautionary approach reference points for this stock, adopted in 2003, are: $F_{lim}=0.74$, $F_{pa}=0.40$, $B_{lim}=220\ 000$ tonnes, $B_{pa}=460\ 000$ tonnes.

2.7.2 Harvest control rules and MSY

Based on long-term simulations F_{MSY} was estimated as 0.40 by AFWG. MSY $B_{trigger}$ has been adopted by ICES at the level of 460 000 t. (B_{pa}), and is used as a trigger point in the HCR.

MSY and HCRs should be further investigated using long-term stochastic simulations, as previously described by Kovalev and Bogstad (2005) and by AFWG in 2005. WD6 describes a population model for use in evaluation of the harvest control rules for cod. The model includes stochastic stock–recruitment relationships and allows for density-dependence in growth and maturation. These models were generally considered suitable for evaluation of HCRs. The recruitment function and the handling of cannibalism needs more investigation. The main issues are: 1) Which recruitment time-series to use and modelling of cannibalism 2) Variations in recruitment over time (cyclic variation, autocorrelation), handling of uncertainty using a parametric on non-parametric (bootstrap) approach.

The modelling of growth, maturation and exploitation pattern seems adequate. For growth and maturation, runs should be made both with and without density-dependence, as data for the first part of the time-series (before about 1982) indicate marked density-dependence while this is not the case for the period 1982-present. Also, growth and maturation in future will depend on possible fishery induced evolution effects, which have been claimed for this stock by several authors (see WD14 for a literature summary on this).

In 2010, the Joint Norwegian-Russian Fisheries Commission decided that the harvest control rule used for Northeast Arctic cod should remain unchanged 'for five more years', i.e. until 2015. The current harvest control rule is given in the stock Annex.

2.8 Issues presented but not discussed/agreed by WKARCT

2.8.1 Stock–recruitment model with autocorrelated residuals (Jon Deroba)

During WKARCT, hockey stick and Beverton–Holt (BH) stock–recruit (SR) fits to estimates of spawning stock and recruitment from XSA fits for northeast Arctic (NEA) cod exhibited temporal trends in residuals, with more large positive residuals early in the time-series and negative residuals later in the time-series (Figure 2.3). Several options were considered to account for the temporal trends in residuals for use in the projection population model for NEA cod, including the use of a sinusoid in the recruitment process and autoregressive (AR) residuals. After some discussion,

the working group agreed that assuming that a systematic sinusoid would persist into the future was not well justified, and that including an AR process in recruitment would account for the evident residual pattern without as strong of a structural assumption as required for implementation of the sinusoid. Annex 8 evaluates Beverton–Holt SR fits with and without autocorrelated residuals.

2.8.2 Some comments on the harvest control rule for NEA cod.

WD 20 from Bulatov *et al.*, was presented to WKARCT. This WD provided suggestions for alternative harvest control rules that have not been communicated to ICES, are still under development by managers, as well as issues concerning the 2015 cod TAC. Those issues were not covered by WKARCT terms of reference (Annex 1). The abstract of WD 20 is included as Annex 9.

This WD was aimed to start discussion about possible changes to the NEA cod harvest control rule (HCR). It points out that the forecasts for the third prognostic year are characterized by much lower precision, but according to the present HCR they strongly influence the TAC. It was proposed to change the 3-year average for calculation of TAC to a 2-year average.

A new variant of the HCR was proposed that would increase F above 0.4 at levels of SSB greater than B_{pa} (WD 20). For illustrative purposes the estimated values of TAC according to this proposed HCR were presented. The estimates were based on abundance-at-age values obtained by TISVPA (see WD 19) and restricting the averaging period to 2 years. No evaluation of the long-term performance of proposed HCRs was conducted by WKARCT. The existence of a high correlation equal to 0.68 between recruitment and water temperature on the Kola section was also shown.

3 Cod (*Gadus morhua*) in Subareas I and II (Norwegian coastal waters cod)

3.1 Stock ID and substock structure

Coastal cod was recognized as different from the cod in the Barents Sea (NEA cod) at least 80 years ago (Rollefsen, 1933). Tagging experiments of cod inhabiting fjords indicate only short migrations (Jakobsen, 1987, Nøstvik and Pedersen, 1999, Skreslet, *et al.*, 1999). From these experiments very few tagged cod migrated into the Barents Sea (<1%). Some investigations based on genetics found large differences between NCC and North-East Arctic cod (NEAC) (Fevolden and Pogson, 1995, Fevolden and Pogson, 1997, Jørstad and Nævdal, 1989, Møller, 1969), while others did not find clear differences (Árnason and Pálsson, 1996, Mork, *et al.*, 1984, Artemjeva and Novikov, 1990). Investigations also indicate that NCC probably consists of several separate components/populations.

Ongoing studies on the genetic structure of cod along the entire Norwegian coast have revealed considerable genetic differences (WD 25 to WKARCT 2015). Two main clusters have been indicated, with a separation line somewhere between 63 and 66 degrees north. Within these clusters there are further genetic variations indicating a rather complex stock structure, and several regions may possibly be defined.

WKARCT does not have a sufficient basis for recommending any changes to the current assessment area. When these studies are published it will be useful to have this stock complex further evaluated by the ICES SIMWG.

3.2 Issue list

Stock	Coastal cod in Norwegian waters north of 62 N (cod_coas)			
Benchmark year	January 2015			
Stock coordinator	Name: Asgeir Aglen		E-mail: asgeir.aglen@imr.no	
Stock assessor	Name: Asgeir Aglen		E-mail: asgeir.aglen@imr.no	
Data contact	Name: Erik Berg		E-mail: erik.berg@imr.no	
Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
(New) data to be Considered and/or quantified	Additional M - predator relations		Time-series of cormorants, seals	
	Prey relations			
	Ecosystem drivers			
	Other ecosystem parameters that may need to be explored?			
Landings by age	Recalculate historic data consistent with NEA cod	Running ECA (also related to mixed-stocks)		
Tuning series	Uncertain otolith typing	Re-examine otolith typing (Up to 15000 otoliths to be re-read, may not be possible to get that done)		
Tourist and recreational fishing	Scarce data	Consider reports from new projects		
Biological Parameters	Maturity	Analysing commercial samples Q1	Historic data	
Ecosystem/mixed fisheries considerations	Fishing on mixed (sub)stocks	Examine samples from catches Re-analysing historic tagging data	Analysis by ECA	Expert on genetics
Assessment method	DLS procedure for substocks?			
Biological Reference Points	MSY	simulations	Sampling data/simulation results	

3.3 Scorecard on data quality

Not investigated.

3.4 Multispecies and mixed fisheries issues

Some fjord studies (Pedersen and Pope, 2003a and b, Mortensen 2007, Pedersen *et al.*, 2007) indicate that the main predators on young cod are larger cod, cormorants and saithe. Coastal cod predate on several commercial species. In stomach data from the coastal survey, haddock, herring and saithe were frequent in the northern areas, while Norway pout and shrimp were frequent in southern areas (Mortensen, 2007).

In the fisheries the catches of coastal cod are mixed with NEA cod, haddock and saithe. Commonly cod is the main target, particularly during spring. NEA cod tends to be the main target in the NEA cod spawning areas and the spawning migration routes.

3.5 Ecosystem drivers

Not investigated.

3.6 Stock Assessment

Catch-at-age

In 1998, a time-series of coastal cod numbers-at-age in catches inside the 12 nautical mile zone was published (Berg *et al.*, 1998). Reported catches of cod were separated into Norwegian coastal cod and North-east Arctic cod based on biological sampling. The method is based on otolith-typing (Rollefsen, 1932). The catches of Norwegian coastal cod (NCC) were calculated back to 1984 using available data on otolith typing. This has been updated annually and reported to AFWG. (Further details are described in the stock Annex of the AFWG report in 2014 and earlier years). An XSA assessment of coastal cod was introduced in 2001.

During this period (1984–2013) the catches have been between 22 000 and 75 000 t. Over the same period the assessment of NEAC subtracted a coastal cod quantity calculated as the sum of catches reported from area 6 and 7 in the whole year plus area 0 and 5 in autumn. These quantities are not identical with the quantity used in the coastal cod assessment.

Since about 2006 the XSA assessment (tuned by 1 survey series) has been considered relevant to historic trends only. Mortalities obtained from the survey data has been used for evaluating recent trends in F. Both the catch data and survey data are considered rather uncertain. The main challenge for estimating catch-at-age is that coastal cod is caught in a mixed coastal cod/NEA cod fishery. The main cod fisheries are in spring, during the spawning and spawning migration, where typically large catches of NEA cod contain highly variable fractions of coastal cod.

When analysing cod samples, the age readers assign each otolith to coastal cod or NEA cod according to the otolith structure. Recently the ECA-model (Hirst *et al.*, 2012) has been further developed to use this information to estimate catch-at-age for both stocks within the same model, also providing measures of uncertainty. The model also estimates numbers at length with measures of uncertainty. The user specifies the grouping of samples (number of area groups, gear groups and season groups). Based on the data within each group the model generates probability distributions based on bootstrapping and tabulates the mean values and the specified per-

centiles (like 5 and 95). An example of model outputs is shown in Figures 3.1 and 3.2. When doing the analysis on mixed samples of NEA cod and coastal cod in coastal areas, the area grouping and season grouping was considered more critical than the grouping on gears. For this purpose 6 coastal area groups were defined (Figure 3.3), 4 seasons and 3 gear groups (gillnet, bottom trawl and others). Others includes Danish seine, longline and handline. In years with less complete sampling 2 season groups were used. The analyses of NEA cod outside the coastal cod area are usually done with 3 area groups, 4 seasons and 5 gear groups.

A new time-series of catch-at-age produced by this model was presented to the WKARCT. The internal consistency was considered reasonable (Figure 3.4). The data were accepted as relevant information for describing the stock dynamics. The reasons for the differences between the old and new series (Figure 3.5) are not clear and need to be further explored.

Using the new catch in number series in an XSA tuned by the coastal survey gave poorer diagnostics than when using the old series. It is recommended not to use XSA tuned by the acoustic survey as a basis for a full analytic assessment. The converged period is relevant to the historic trends and stock dynamics. The converged part can also be used for “calibrating” survey mortalities for the purpose of estimating recent F_s from survey mortality, as described in stock Annex. Using the XSA for estimating the historic series of SSB should take account of the time-lag between spawning time and the time of the survey, where maturity and stock weights are observed.

The current time-series of recreational and tourist catches has been based on the assumption that annual recreational/tourist catch is proportional to the participation (effort) in this fishery (ICES 2010). It would be more realistic to assume that the recreational/tourist F is proportional to the participation (effort). In 2010 and later years 7000 tonnes of the Norwegian cod quota has been set aside to cover the catches taken in the recreational and tourist fisheries and to cover catches taken by young fishers (to motivate young people to become fishers).

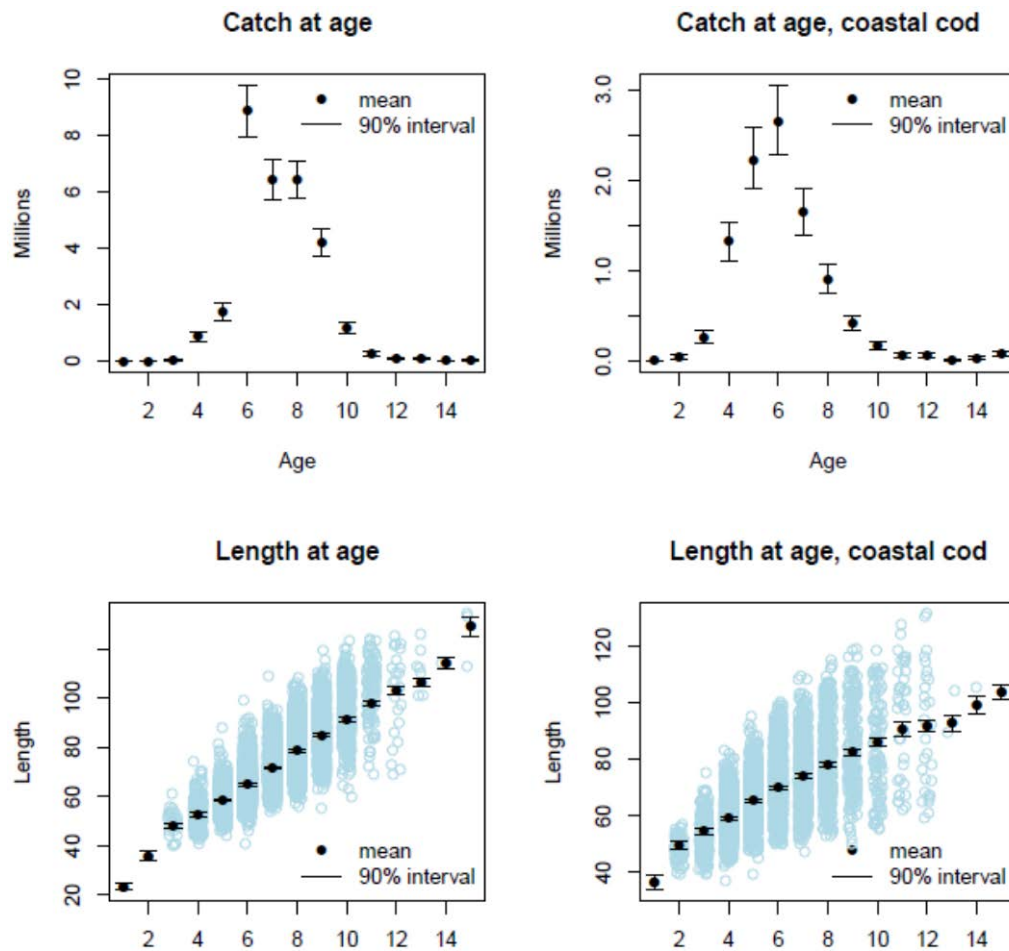


Figure 3.1. Example of ECA-output (year 2006). Left panels NEA cod. Right panels coastal cod.

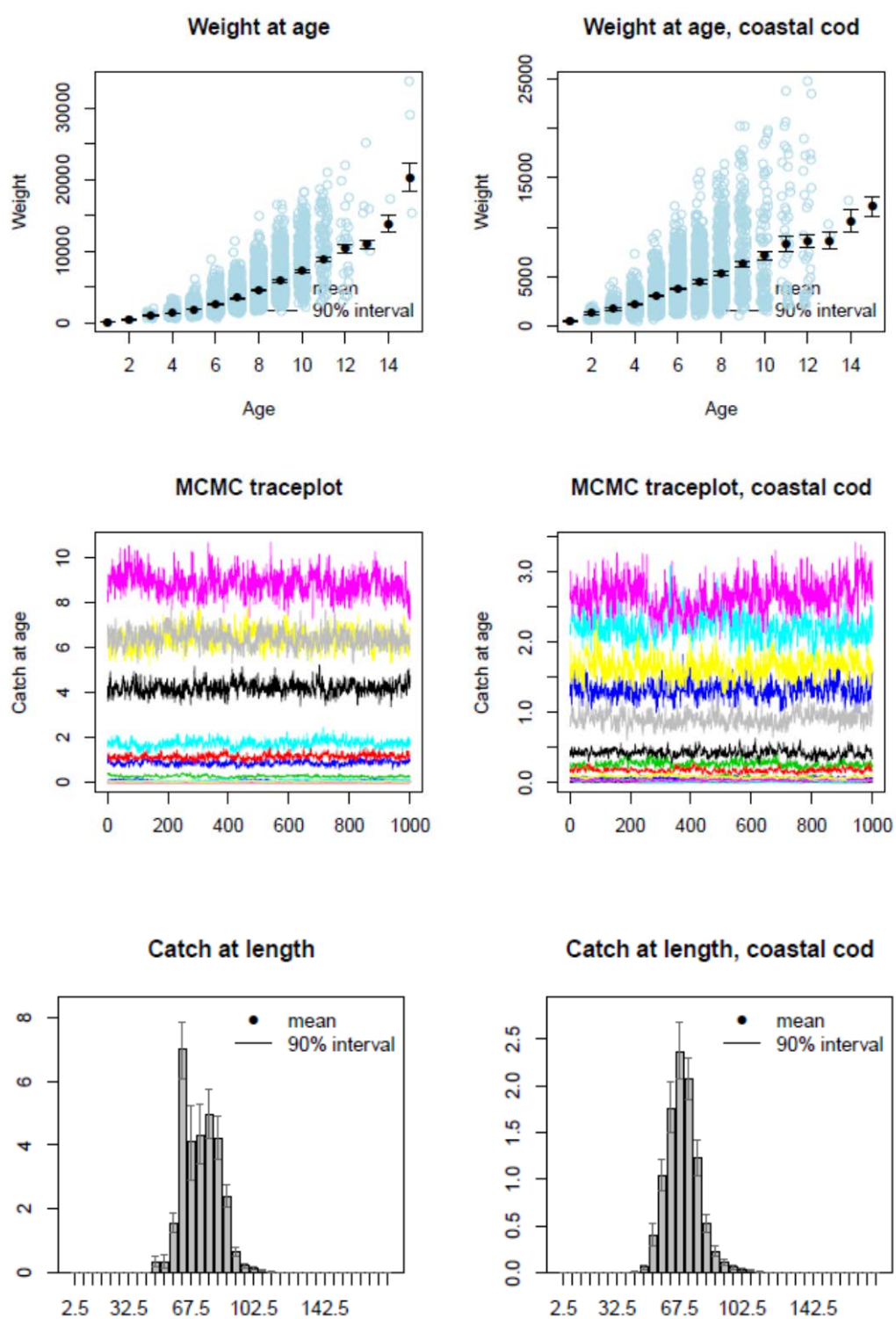


Figure 3.2. Example of ECA-output (year 2006). Left panels NEA cod. Right panels coastal cod.

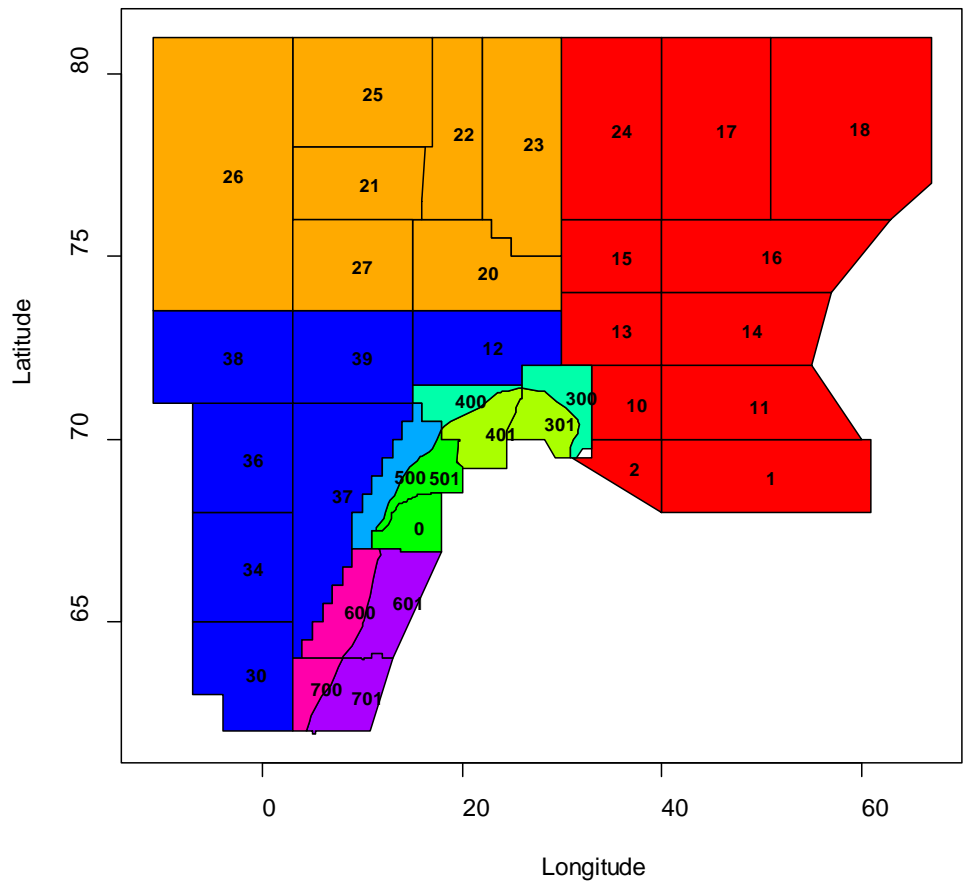


Figure 3.3. Norwegian statistical rectangles. The colors indicate area units used by the ECA-model for combining cod samples. Coastal cod are only estimated in coastal areas (0 and 300-701).

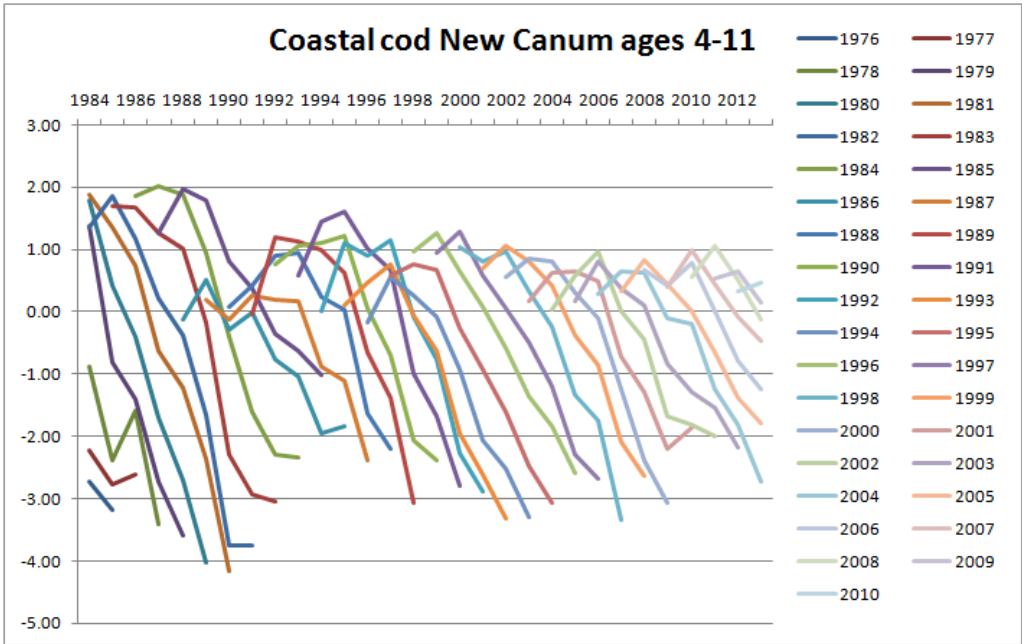


Figure 3.4. Log catch numbers-at-age by cohort (series names) and catch years (x-axis).

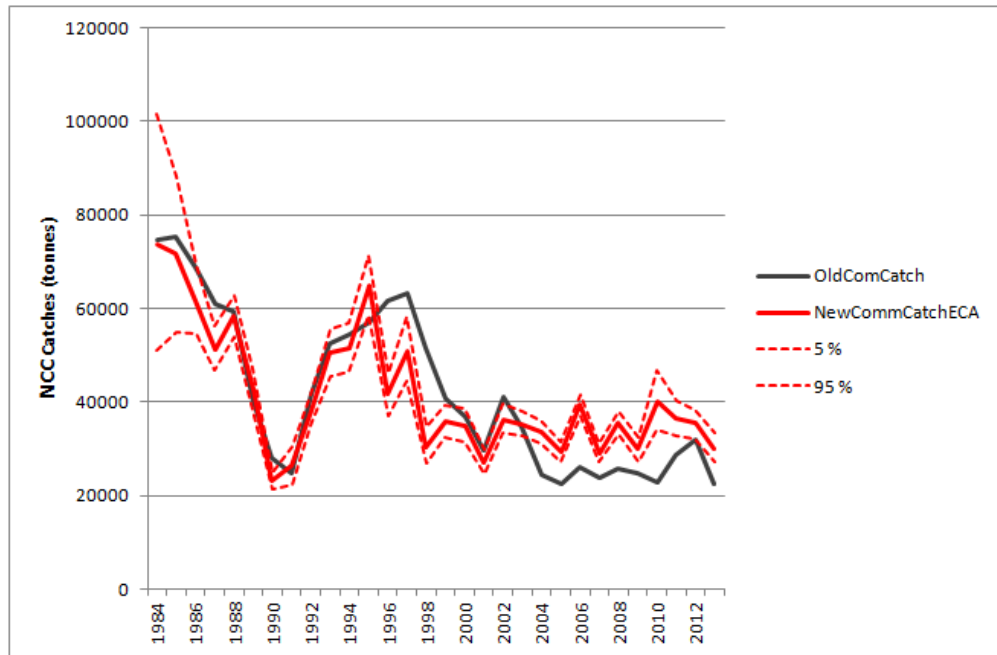


Figure 3.5. Catches (tonnes) of coastal cod from the ECA analysis, with confidence intervals, compared to the old time-series.

3.7 Short-term projections

The current rebuilding plan is relating to the annual survey results, and short-term stock projections are not strictly required.

3.8 Appropriate Reference Points (MSY)

Some biological reference points (candidates for B_{lim} , F_{max} , $F_{0.1}$) were explored during the rebuilding plan evaluation (ICES AFWG 2010 report). These values relate to the old catch dataseries and may not reflect the new series.

The rebuilding target in the rebuilding plan is defined by; in as two consecutive years having a survey index of $SSB > 60$ kt (the average survey SSB observed in 1995–1998). The reference for F -reductions in the plan is 15% steps relative to the F_{4-7} in 2009 (estimated to as 0.32 by ICES AFWG 2014).

3.9 Future Research and data requirements

-Limitations and potential splitting of the stock assessment area should be re-evaluated when more of the ongoing genetic studies are published.

-In the northern part of the stock area the acoustic survey contains a number of fixed bottom-trawl stations that could be used for a swept-area time-series for that region. Commercial cpue from the gillnet fishery during autumn (when the bycatch of NEA cod is lowest) could be considered.

-The differences between the old and new catch data (numbers and weights at age) should be further explored.

-Further information about the recreational and tourist fisheries is highly recommended.

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

4.1 Stock ID and substock structure

Capelin in the Barents Sea spawns 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. 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 dies after spawning (Christiansen *et al.*, 2008). The capelin undertakes extensive feeding migrations during summer into the northern and eastern parts of the Barents Sea. The stock is geographically separated from other capelin stocks, although there are some very small resident capelin stocks in fjords in Northern Norway (e.g. Balsfjord).

4.2 Issue list

Stock		Barents Sea capelin		
Stock coordinator	Name: Samuel Subbey	E-mail: Samuel.subbey@imr.no		
Stock assessor	Name: Dmitry Prozorkevitch	E-mail: dvp@pinro.ru		
Data contact	Name: Harald Gjørøster	E-mail: harald@imr.no		
Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
(New) data to be Considered and/or quantified	Additional M - predator relations	Expand the predation model to quarter 4	Available	Multispecies modelling
	Prey relations			
	Ecosystem drivers	Herring effect on capelin recruitment to be revisited with recent data	Available	
	Other ecosystem parameters that may need to be explored?			
Tuning series	Not relevant			
Discards	Not relevant			
Biological Parameters	Maturation model crucial in assessment – should be reviewed		Available	
Assessment method	Survey-based assessment (acoustic abundance estimate taken at face value). TAC determined by 6-month prediction from survey to spawning using multispecies model. Target escapement strategy used to determine TAC so that 95 % probability of SSB>Blim			Knowledge of target escapement strategies and management strategy evaluation. Good knowledge of parameter estimation techniques.

Stock		Barents Sea capelin		
Stock coordinator	Name: Samuel Subbey		E-mail: Samuel.subbey@imr.no	
Stock assessor	Name: Dmitry Prozorkevitch		E-mail: dvp@pinro.ru	
Data contact	Name: Harald Gjørøter		E-mail: harald@imr.no	
Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
(New) data to be Considered and/or quantified	Additional M - predator relations	Expand the predation model to quarter 4	Available	Multispecies modelling
	Prey relations			
	Ecosystem drivers	Herring effect on capelin recruitment to be revisited with recent data	Available	
	Other ecosystem parameters that may need to be explored?			
Biological Reference Points	Blim value should be reviewed, also one should consider whether this should depend on the expected recruitment conditions (ie the expected young herring abundance)	Should calculate how yield depends on choice of Blim (Bescapement)		

4.3 Scorecard on data quality

Not applicable in this context.

4.4 Multispecies and mixed fisheries issues

There are no mixed fisheries issues connected with this stock. Multispecies issues are addressed below.

4.5 Ecosystem drivers

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). Capelin are prey to several species of marine mammals, e.g. harp seals, humpback whales, minke whales, and seabirds, kittiwakes and guillemots. Capelin 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.

4.6 Stock Assessment

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 4.1 and the Bifrost simulation periods and data are outlined in Figure 4.2.

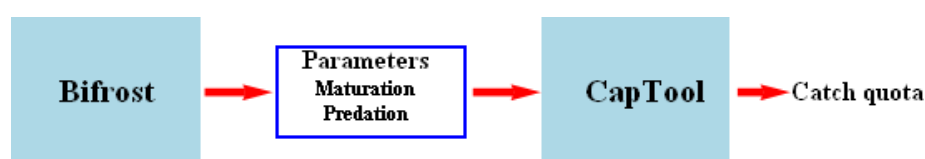


Figure 4.1. Relation between the models Bifrost and CapTool

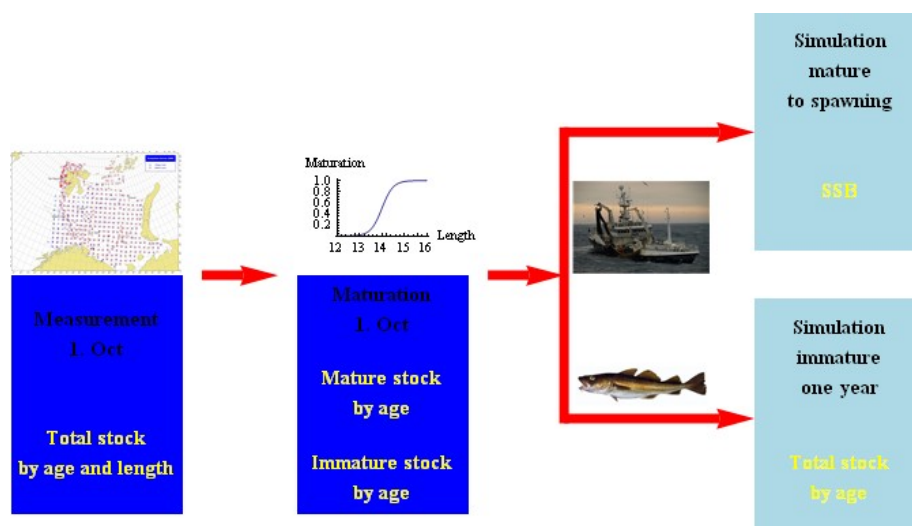


Figure 4.2. Overview of Bifrost simulations

In the current implementation, the surveyed stock is split into (length-based) mature and immature component, using a maturation submodel. This is the only stage of the assessment that length data are used. The model emphasis is on the mature component, which is expected to spawn in April of the following year. The population depletion is due to (i) natural mortality (ii) predation mortality, and (iii) commercial catch. Currently, there are 2 key assumptions in the Bifrost model implementation:

- The predation of cod on capelin in Q4 is included in the total capelin natural mortality for Q4 (October-December).
- Immature cod prey on mature capelin in Q1 (January – March). This mortality is modelled explicitly.

More detailed description of the models (CapTool and Bifrost) can be found in the Stock Annex.

4.6.1 Catch – quality, misreporting, discards

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 (1 cm length groups) 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.

Russian landings

The Russian catch is taken mainly by trawl. The Russian catch in number and age by length (1 cm length groups), and the division of catch in tonnes by month, are reported to the WG. From these data the catch in numbers and biomass by age and maturation group are transferred to CapCatch.

Discards

This is what we have in the advice given for 2015: 'All catches are assumed to be landed. The amount of bycatch in the pelagic fisheries is unknown, but is assumed to be low.

4.6.2 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.

4.6.3 Weights, maturities, growth

See stock Annex for detailed description.

4.6.4 Assessment model

Simulation

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 split the stock into an immature and a mature component on the basis of the length data and both components are summed over length, i.e. the length distribution is not kept during the subsequent simulation - it is only used for the maturation model.

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

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. Usually P_2 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.

Consumption by cod during January–March

The consumption of capelin by cod is given by:

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

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

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 parameters P_{10} , P_{13} and P_{17} are estimated based on stomach content data.

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 proportion of cod in the Svalbard area is inferred from autumn and winter demersal surveys, but the method should be revised.

4.7 Short-term projections

Short-term (1 October–1 April) probabilistic projections of the maturing capelin stock are conducted in order to give quota advice.

4.8 Appropriate Reference Points (MSY)

A B_{lim} (SSB $_{lim}$) management approach has been suggested for Barents Sea capelin stock (Gjøsæter *et al.*, 2002). In 2002, the Joint Russian-Norwegian Fishery Commission agreed to adopt a management strategy based on the rule that, with 95% probability, at least 200 kt of capelin should be allowed to spawn. Consequently, 200 kt has since been used as a B_{lim} for capelin.

The background to the current B_{lim} however, is that it was based on a single observation, when in 1989, a very low spawning-stock biomass resulted in high capelin recruitment. The 0-group in 1989 and age-1 capelin in 1990 were estimated at 862 and 700 billion individuals, respectively. The projected amount of spawners in 1989 based on the estimate of mature stock in autumn 1988 (200 kt) was considerably lower than 200 kt, the median in the projected distribution was in the order of 70–80 kt. A 200 kt B_{lim} was suggested by ICES to take account of uncertainty not included in the assessment.

The two main methods used by ICES in determining B_{lim} are either based on segmented regression or on an informed, logical decision. Neither method however, is applicable to capelin. This is because empirical data indicates that large recruitment may equally result from a low, as well as large capelin spawning stock. This is partly explainable by the fact that both juvenile herring and cod have strong influence on capelin recruitment. Juvenile herring (1+ year old) consume a considerable amount of capelin larvae in the Barents Sea in May–June, therefore affecting capelin recruitment. However, attempts to predict the juvenile herring population size have been unsuccessful for two reasons. First, the survey information has been highly divergent because juvenile herring exhibit uneven spatial distribution (and population densities) in the Barents Sea. An even more challenging task in predicting the juvenile herring population is the need to also predict at which age (3 or 4) the herring migration out of the Barents Sea might occur. High abundance of herring has been suggested to be a necessary but not sufficient factor for recruitment failure in the capelin stock (Hjermann *et al.*, 2010).

A limitation to the adoption of a standard B_{lim} -based HCR is that it is impossible to reconstruct the historical SSB time-series due to inconsistencies in survey, catch, and predation data, from 1972 to present. A modelling approach, e.g. to reconstruct his-

torical SSB time-series, has resulted in (unrealistic) vanishing SSB for some years. Also, the uncertainty in the modelled SSB for capelin is of a different kind than uncertainties in SSBs derived from a VPA-type population model.

The ICES recommendation that the capelin fishery only occurs on mature fish during the period from January to April has had the effect of protecting recruits from fishery. Furthermore, over the years, $B_{lim}=200$ kt as a threshold has resulted in stable capelin stock dynamics, and in guaranteeing recruitment success.

Gjøsæter *et al.*, (2015) investigated the performance of the current assessment and management procedure for capelin. The cod stock has been underestimated in recent years, and thus the predation by cod on capelin has been underestimated in the assessment. The probability of $SSB < B_{lim}$ has thus been higher than 5% in most of the years for which a non-zero TAC has been set. However, the spawning stock seems to have been sufficient to ensure adequate recruitment in years with good recruitment conditions, and this indicates that the current HCR is precautionary. Alternative HCRs involving different B_{lim} levels or risk levels could be investigated.

4.9 Future Research and data requirements

There are three principal areas of further research, which include addressing issues connected with (i) incomplete survey coverage (ii) stock assessment: Bifrost model assumptions and input data uncertainties, and (iii) reference points and HCRs.

4.9.1 Survey Coverage

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.

The capelin advice basis in 2014 adopted a projection approach in arriving at the quota advice, based on the following considerations. The meeting considered that the population dynamics of cod and capelin have been stable over the last three years (2010–2012), and that the mortalities for different capelin age groups were expected to be within the same range of mortalities as in the period 2010–2012. Considering uncertainty, it was determined that, a projection of the population size from 2013, taking into account the predation of cod on capelin and other mortalities offered a more plausible population trajectory. On the other hand, the final advice from ICES was based on corrections of the survey estimate based on the geographical distribution of capelin in recent years. The proportion of the mature capelin stock being in the ice covered area in 2014 was calculated assuming that this proportion was similar to that in the period 2011–2013, and the stock size was upscaled accordingly.

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. 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.

4.9.2 Stock Assessment

4.9.2.1 Cod predation on capelin

The assumptions and uncertainty connected to quantifying capelin mortality due to cod predation presents a major source of uncertainty in the current version of Bifrost. It has however been established (Bogstad and Gjørseter, 2001) that the predation in Q1 is both due to:

- Cod preying on immature capelin during the period January-April.
- Mature cod also consume capelin during this period (Q1).

These findings are both in contrast to what is currently assumed in the assessment, and have to be addressed.

4.9.2.2 Incorporating uncertainties in cod indices

The predation by cod is known to be a major source of capelin mortality. The current assessment tool, Bifrost, has a likelihood component to account for the consumption per cod (per age group). It has been suggested that in the uncertainty in capelin population projections might be improved by incorporating uncertainties in cod population statistics. There are two main challenges involved:

Barents Sea cod is assessed using a non-statistical assessment tool (XSA), which provides no estimates of population size uncertainties or confidence intervals

The cod population abundance used in capelin assessment for advising the quota for year $y+1$, are projected population numbers from the cod assessment in year y , projected to year $y+1$. The uncertainty associated with projecting the cod population abundance (just as in pt. 1) is not accounted for at present.

A possible approach is to use historical cod assessment results to obtain:

- 1) Estimates of the level and distribution in uncertainty (variances) across age groups
- 2) Estimates of population projection uncertainties based on an MCMC-type approach, where short-term cod projection trajectories are resampled to provide variance estimates of projection uncertainty.
- 3) Conditional uncertainties (across ages) by considering points 1 and 2.

Since the cod assessment is prone to annual updates, the conditional variances can, in themselves, be highly uncertain. However, not including uncertainty in cod estimates is untenable; see (Gjørseter *et al.*, 2015).

4.9.3 Reference Points and HCRs

An illustration of the complexity associated with the herring predation problem is given by Figure 4.3 below, where the link between capelin recruitment-at-age 0+, and number of herring individuals at age 1 and 2 is investigated (using data from ICES, 2014).

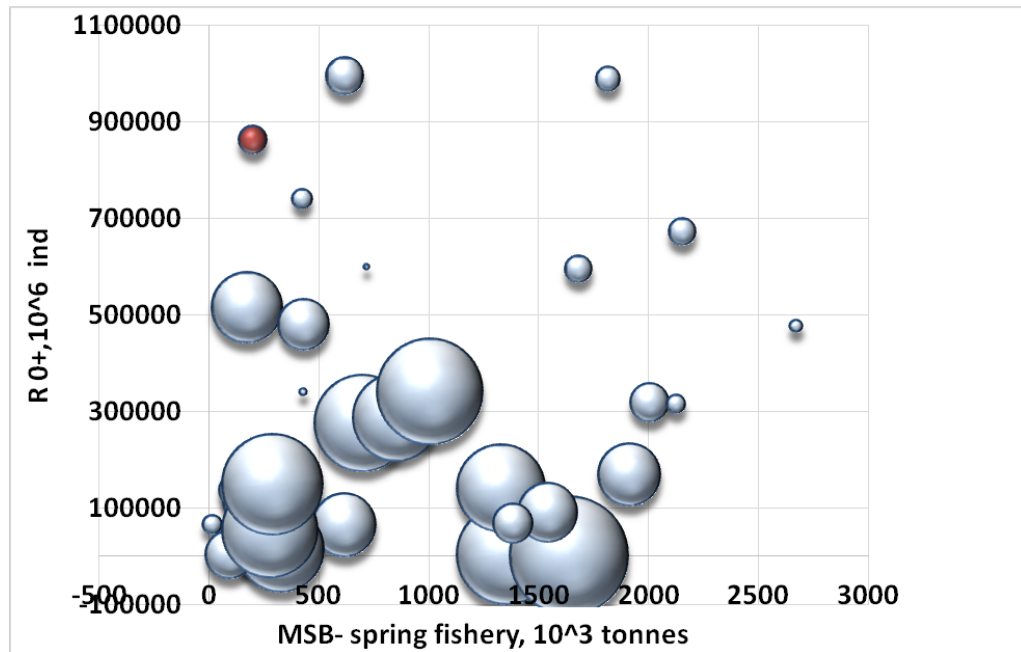


Figure 4.3. Relationship between mature stock biomass-spring fishery (1 Oct. Y, total landings from 1 Jan to 1 Apr.Y+1 are subtracted) and 0-group index (Y+1), covering the cohorts 1980–2013. The size of bubbles indicates the number of herring at age 1 and 2. Minimum diameter of bubble corresponds to 0.7 billion individuals of herring (1982), the maximum - 200.8 billion ind. (1993). The red point is the 1989 cohort which is the basis for the current B_{lim} .

Figure 4.3 shows the relationship between the mature stock biomass (MSB) and the index of recruitment-at-age 0 (next year). It can be argued (from Figure 4.3) that MSB less than 400 kt results, in general, in poor recruitment-at-age 0, thus suggesting that a MSB target of 400 kt may be a viable alternative to the current 200 kt SSB-based B_{lim} . This conclusion must be tempered with previous discussions about herring influence on capelin recruitment.

The MSB in Figure 4.3 is calculated by subtracting capelin landings in January-March in year Y+1 from the maturing stock biomass in year Y. Landings were also taken in autumn, but these are a mixture of immature and mature fish and were also partly taken before the survey, hence they are not subtracted. Furthermore, since the mortality rate from age 0 to age 1 can be high and variable, it is not clear whether age 0 or age 1 should be used to indicate recruitment in such analyses. Despite these caveats, the MSB approach warrants further research.

It is however our general conclusion that there is no basis for revision of the current target rule until the ecological issues (predation pressure) linking cod and herring to capelin recruitment are resolved. Any meaningful calculations of MSY would have to be conditioned on the level of the cod and herring stocks, and therefore calls for a multispecies approach (Tjelmeland, 2005). Candidate models for such exist (Bifrost, Gadget), but they would need further development to be used for this purpose.

5 Haddock (*Melanogrammus aeglefinus*) in Subareas I and II (Northeast Arctic)

5.1 Stock ID and substock structure

The North-East Arctic Haddock is distributed in the Barents Sea and adjacent waters, mainly in waters above 2°C. Tagging carried out in 1953–1964 showed that Northeast Arctic haddock inhabit the continental shelf of the Barents Sea, adjacent waters and the polar front. The main spawning grounds are located along the Norwegian coast and the area between 70°30' and 73°N along the continental slope, but spawning also occurs as far south as 62°N. Larvae are dispersed in the central and southern Barents Sea by warm currents. The 0-group haddock drifts from the spawning grounds eastwards and northwards and during the international 0-group survey in August it is observed over wide areas in the Barents Sea. Until maturity, haddock are mostly distributed in the southern Barents Sea, their nursery area. Having matured, haddock migrate to the Norwegian Sea.

There are a number of signs indicating that NEA haddock have different life-history traits outside the survey area. Spawning occurs as far south as 62°N and possibly as far north as 74°N. Observations at the 0-group survey find two peaks in the length distributions of 0-group haddock. Korsbrekke (2001) compared population parameters as observed in a survey off Lofoten islands and in Vesterålen with observations made in the annual bottom-trawl survey (winter) in the Barents Sea. The results showed differences in growth and maturation and a comparison of estimated abundance indices showed a different pattern off Lofoten relative to year-class strength. This may have shown up as “catchability” issues in the stock assessment. One example is the 1996 year class being estimated as very weak in the surveys, but showing up as a moderate year class in the catches. Tagging experiments (Erik Berg, not published) show that haddock migrate west and south, and don't always return to the Barents Sea after spawning. This can also explain the poor coverage of the oldest ages in the surveys. It is recommended that the Joint Barents Sea survey (NoRu-Q1) is extended southwards along the Norwegian coast to improve the coverage of the older ages.

5.2 Issue list

NEA haddock stock is annually assessed by AFWG using standard procedures accepted by ICES. Data and methods used in the assessment in AFWG are based on catch-at-age analysis and details are described in the Stock Annex. In recent AFWG meetings some issues were found that needed additional investigations requiring a benchmark. Issues considered in this benchmark relate to:

- 1) Norway has started to test out the assessment model SAM (Stockassessment.org) and presented model results (WKARCT WD3, 4, 12). SAM is a statistical catch-at-age model that is used for many ICES stocks. Model estimates of SSB and F for the haddock stock are different from estimates from XSA, especially for the end of the period. The reason for these discrepancies will be investigated in the benchmark meeting.

Model assumptions. XSA model estimates are sensitive to model settings. The main issue was how the settings (assumptions) can reflect the stock and fishing mortality dynamics.

Northeast arctic haddock (had_arct)				
Stock				
Benchmark year	January 2015			
Stock coordinator	Name: Alexey Russkikh		E-mail:russkikh@pinro.ru	
Stock assessor	Name: Gjert Dingsør		E-mail: gjerted@imr.no	
Data contact	Name: Alexey Russkikh		E-mail:russkikh@pinro.ru	
Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
(New) data to be Considered and/or quantified	Additional M - predator relations	Extending time-series of predation by cod on haddock back to 1947	PINRO qualitative stomach content data 1947-present to be combined by PINRO/IMR quantitative stomach content data from 1984-present	
	Prey relations	Growth and maturity related to stock size and food abundance	Prey abundance data available back to early 1980s	
	Ecosystem drivers	Temperature influence on recruitment and on stock distribution/food availability	Temperature data are available back to 1900	
	Other ecosystem parameters that may need to be explored?			
Tuning series	How to take variable spatial coverage of stock by surveys into account?		Data available	
	The time-series from the Joint Ecosystem Survey should be revised using standard swept-area estimation methods		Data available	
Discards/bycatch	Discards not included in current time-series.	Anecdotal information available?		

Northeast arctic haddock (had_arct)				
Stock				
Benchmark year	January 2015			
Stock coordinator	Name: Alexey Russkikh		E-mail:russkikh@pinro.ru	
Stock assessor	Name: Gjert Dingsør		E-mail: gjerted@imr.no	
Data contact	Name: Alexey Russkikh		E-mail:russkikh@pinro.ru	
Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
Catch data		Will check effect of changes in software used to calculate Norwegian catch-at-age, but this is not likely to have a large effect on the assessment		
Biological Parameters				
Ecosystem/mixed fisheries considerations	The influence a large haddock stock with a large proportion of old and large fish has on the ecosystem should be considered. Cod and haddock fisheries are mixed, and there has been concern from the fishers in recent years about the relationship between cod and haddock quota as the cod/haddock quota ratio has changed considerably in the past two years. Present harvest control rules are single-species.			

Northeast arctic haddock (had_arct)				
Stock				
Benchmark year	January 2015			
Stock coordinator	Name: Alexey Russkikh	E-mail: russkikh@pinro.ru		
Stock assessor	Name: Gjert Dingsør	E-mail: gjerted@imr.no		
Data contact	Name: Alexey Russkikh	E-mail: russkikh@pinro.ru		
Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
Assessment method	Several very strong generations passing through older part of the population. Such an event is unique and not observed in the period covered by surveys. Stock is at present assessed by XSA, with predation by cod on haddock included. Other stock methods such as statistical catch-at-age models (e.g. SAM) and possibly also age-length structured models should be set up for this stock	Model assumptions regarding form of relationship between stock abundance and survey index needs to be verified.	SAM model is being set up for this stock. Will need help for setting up other alternative models	Expertise in stock assessment
Harvest control rule	To be evaluated in 2015 according to decision by managers	Long-term stochastic simulations where the underlying biological model is updated to take into account data from recent years.	Framework for stochastic simulations that can handle present harvest control rules is available (PROST)	Expertise in management strategy evaluations
Biological Reference Points	Need to be revised as longer time-series are now available			

5.3 Scorecard on data quality

The data on NEA haddock biology (weights and maturity) are supposed to be of a reasonably good quality and were not discussed during the benchmark.

5.4 Multispecies and mixed fisheries issues

Cod is the main predator on haddock, and predation by cod on young haddock is included in the assessment as an additional mortality. This is found to improve the assessment. Predation by cod removes on average about the same biomass as the fishery, but predation mainly takes place on ages 1–3, while the fishery starts at age 3.

Haddock mainly prey on benthic organisms. It is not known whether the current very high stock level for haddock, which is likely to persist for some more years, could significantly influence the food availability. The demersal fisheries in the Barents Sea are highly mixed, and haddock is fished together with cod (particularly), but also together with saithe. About 75% of the catch is taken by trawl and the rest by other gears such as longline and gillnet. The ratio between cod and haddock quota and exploitation rate, as well as the size composition and geographical distribution of those stocks, affect the way the fishery is carried out and also influence unreported landings and discards.

No mixed fisheries model has been set up for this area.

5.5 Ecosystem drivers

The strength of a haddock year class is generally determined by autumn of its first year of life. Water temperature strongly affects the abundance of 0-group haddock (Dingsør *et al.*, 2007) and if it is cold, the probability of strong year classes is very low. The mechanisms behind the temperature effect are not fully understood and several factors are likely to be important. Temperature probably influences the growth and maturity of the adult population, as well as the growth and survival of eggs and larvae, either directly through metabolism or indirectly through the abundance of available prey. The North Atlantic current and the Norwegian coastal current are also important for transport of the eggs and larvae, and observed temperature effects may be caused by increased inflow of Atlantic water into the Barents Sea. Like other haddock stocks, NEA haddock stock dynamics are strongly influenced by single, strong year classes occurring infrequently (typically once or twice every decade). However, in the 2000s NEA haddock produced three consecutive strong year classes (2004–2006). This has never been seen before and the reasons are not known. A possible driver is matching of Atlantic water inflow and increasing biomass of zooplankton (Skern-Mauritzen *et al.*, 2014). The Barents Sea temperatures have increased in the last several decades. This has led to an increase in area of suitable or preferred habitat, which may again have increased the carrying capacity of haddock in the Barents Sea. This hypothesis was investigated by (Landa *et al.*, 2014).

5.6 Stock Assessment

5.6.1 Catch – quality, misreporting, discards

Commercial landings data allocated to ages 1–14 from 1950 to 2013 were available at the WKARCT 2015 meeting.

Data for these landings came from the ICES database with landings reported by 13 countries including sampled information from Norway, Russia, and Germany. High-

est landings were reported for the Russian and Norwegian trawl and longline fisheries.

Catch in numbers-at-age and weights-at-age were compiled by port sampling program for Norway and by data from fishing vessels for Russia, and applied to the remaining landings by area.

Details about how the landings data were derived and processed are described in the stock annex.

5.6.2 Surveys

An annual Russian bottom-trawl survey has been conducted since 1983 (mostly in October-December), covering the ice-free part of the Barents Sea. The aim of conducting this survey is to investigate all size/age groups of haddock. In 1984, acoustic methods started to be implemented during surveys of fish stocks. In 1995 a new acoustic assessment method was applied for the first time, which allowed the differentiation and registration of echo intensities from fish of different length.

There were two survey abundance indices at age from that survey available at WKARCT 2015:

- 1) trawl indices, calculated as relative numbers per hour trawling (RU-BTr-Q4) for the period 1983–2009 (ages 0–9). Based on an internal consistency test, the RU-BTr-Q4 index is used in tuning for ages 3–7.

absolute numbers (in thousands) computed from the acoustics estimated by new method (RU-Aco-Q4) for the period 1995–2013 (ages 0–10). The indices (RU-Aco-Q4) were not used for tuning due to a strong “year effect” observed in years with incomplete area coverage. This index needs further adjusting before it can be used for tuning, but it is useful as additional information about stock dynamics.

The Norwegian winter (February) survey (from 2000; Joint Barents Sea survey) started in 1981 and covers the ice-free part of the Barents Sea. Two abundance indices at age from that survey were available at WKARCT:

- 1) swept-area estimates from bottom trawl NoRu-BTr-Q1 for the period 1981–2014 (ages 1–10);

swept-area estimates from acoustic NoRu-Aco-Q1 for the period 1981–2014 (ages 1–10).

During the meeting it was decided to use both of them for tuning: NoRu-BTr-Q1 for (ages 3–8) and NoRu-Aco-Q1 for ages 3–7.

A joint ecosystem survey in August–September was started in 2004 and a new bottom-trawl index, based on this survey, is now available. This survey covers a larger portion of the distribution area of haddock. The new index Eco-NoRu-Btr-Q3 was accepted during the WKBENCH 2011 for applying in NEA haddock assessment. During the meeting it was decided to use Eco-NoRu-Btr-Q3 for period 2004–2013, ages 3–8. The methodology for calculating the index from this survey has not been agreed upon (WD 17). When the new agreed method for index calculation of Ecosystem survey will be available AFWG shall decide on replacement of the current conventional index with a new one.

WKARCT continued the practice of using indices for all surveys only for the period 1990 onwards.

The data from surveys in the first quarter are shifted to 31 December of the previous year and ages are shifted 1 year back accordingly. This is done in order to use most recent survey indices in the annual assessment, carried out in spring.

No commercial cpue indices are used (see stock annex).

5.6.3 Weights, maturities, growth

Details about how the biological data were derived and processed are described in the NEA haddock stock annex.

5.6.4 Assessment models

The XSA model has been used for the assessment for Northeast Arctic haddock many years. The alternative model SAM was tested during WKARCT.

XSA is a semi-deterministic model that ignores observation noise and gives point estimates. Catches are assumed known and without errors, which is a very strong and incorrect assumption. XSA is sensitive to subjective settings, e.g. population shrinkage (P-shrinkage), which can cause large differences in the results. It was therefore considered appropriate to consider alternative model approaches and a short meeting was held in AFWG 2013 with Anders Nielsen, responsible for developing the SAM model, on the potential for using the SAM model for several NEA stocks. SAM is a statistical assessment model that acknowledges observation noise; the error structure is part of the model description. Estimation of uncertainties is an integrated part of the model (WD#4).

A comparative analysis was made for the two models XSA (with different settings) and SAM. For XSA the settings used previously were taken as a starting point. For SAM, a number of trial runs with different settings were made. The final settings are given in Table 5.1 and results of runs with alternative settings are shown in Table 5.2.

Model settings for recruitment between Beverton–Holt vs. Ricker show little differences in AIC (i). BH recruitment model is used in the final settings. Some correlation for the log F-processes (ii) gives the best result. Both symmetrical correlation and correlation between neighbouring age classes are allowed in the final settings. Separate calculation of F for age class 9 and onwards gave only more parameters to be estimated (iii). In coming years the cohorts in age class above 9 could be measured more precisely because of the strong Year classes 2004:2006. To set equal the variance for age class 6:13 (iv) may interfere with that future scenario. The model settings for log N RW VARIANCES are therefore kept as in configuration (e.g. Variance grouping of age class 6:8 and age class 9:13+). In table 4 the observation variances for the two indices “BS-NoRu-Q1 Aco” and “BS-NoRu-Q1 Btr” are both grouped into age classes 3:4 and 5:7. The two indices “BS-NoRu-Q1 Aco” and “BS-NoRu-Q1 Btr” are acoustic and bottom-trawl indices from the same survey. The variance for age class 3:4 is calculated to be half of the variance for age class 5:7 for “BS-NoRu-Q1 Aco”. At present the calculation of variances for age class 3:4 and age class 5:7 for “BS-NoRu-Q1 Btr” are more equal (v) and could be grouped into a single group (age class 3:7). The differences in variance results for the two series could be due to some vertical distributions of the stock. Further studies should be accomplished if this grouping of age class 3:7 should be applied in the model, for “BS-NoRu-Q1 Btr”.

Table 5.1. SAM configurations.

```

# Min Age (should not be modified unless data are modified accordingly)
3
# Max Age (should not be modified unless data are modified accordingly)
13
# Max Age considered a plus group (0=No, 1=Yes)
1
# The following matrix describes the coupling
# of fishing mortality STATES
# Rows represent fleets.
# Columns represent ages.
#3      4      5      6      7      8      9      10     11     12     13
#flat F from age 9
1       2       3       4       5       6       7       7       7       7       7
0       0       0       0       0       0       0       0       0       0       0
0       0       0       0       0       0       0       0       0       0       0
0       0       0       0       0       0       0       0       0       0       0
0       0       0       0       0       0       0       0       0       0       0
# Use correlated random walks for the fishing mortalities
# ( 0 = independent, 1 = symmetrical correlation estimated, 2=AR(1)-correlation estimated)
2
# Coupling of catchability PARAMETERS
0       0       0       0       0       0       0       0       0       0       0
1       1       2       2       2       0       0       0       0       0       0
3       3       4       4       4       0       0       0       0       0       0
5       5       6       6       6       7       0       0       0       0       0
8       8       9       9       9       10      0       0       0       0       0
# Coupling of power law model EXPONENTS (if used)
0       0       0       0       0       0       0       0       0       0       0
1       1       2       2       2       0       0       0       0       0       0
3       3       4       4       4       0       0       0       0       0       0
5       5       6       6       6       7       0       0       0       0       0
8       8       9       9       9       10      0       0       0       0       0
# Coupling of fishing mortality RW VARIANCES
1       2       2       2       2       2       2       2       2       2       2

```


0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0

Coupling of log N RW VARIANCES

1	2	3	4	4	4	5	5	5	5	5
---	---	---	---	---	---	---	---	---	---	---

Coupling of OBSERVATION VARIANCES

1	2	2	2	2	2	3	3	3	3	3
4	4	5	5	5	0	0	0	0	0	0
6	6	7	7	7	0	0	0	0	0	0
8	8	9	9	9	10	0	0	0	0	0
11	11	12	13	13	14	0	0	0	0	0

Stock recruitment model code (0=RW, 1=Ricker, 2=BH, ... more in time)

2

Years in which catch data are to be scaled by an estimated parameter

0

first the number of years

Then the actual years

Then the model config lines years cols ages

Define Fbar range

4 7

Table 5.2 Some candidate model settings in SAM configuration

			# of parameters	
			Negative log likelihood	AIC
Table 4 configuration gave:			878.84	44
Alternative settings				
Recruitment	RW		883.58	42
	Ricker (i)		878.93	44
F correlation	No correlation		922.53	43
	log F-processes correlated in time (ii)		878.84	44
Fishing mortalities				
	Varying F (e.g. is $F_9 \neq F_{10}...$) (iii)		880.21	44
log N RW VARIANCES				
	(age class 6:13, grouped variance) (iv)		878.98	43
Observation variances				
	Age3-7 "BS-NoRu-Q1 Btr" Obs			
	(age class 3:7, grouped variance) (v)		879.01	43

Stock dynamics

Figure 5.1 shows the differences in SSB estimates. Results of SAM and XSA without P-shrinkage are similar. However, XSA estimates strongly depended on assumptions about shrinkage, the effect of not using P-shrinkage is that SSB is almost doubled, while the effect on immature haddock biomass estimates is much smaller. As it has been reflected in the previous benchmark report the XSA model for haddock is sensitive to choice of model parameter values.



Figure 5.1 Results of assessment of NEA haddock - SSB, Recruits and F by different models (XSA with different settings and SAM with confidence intervals)

Retrospective patterns

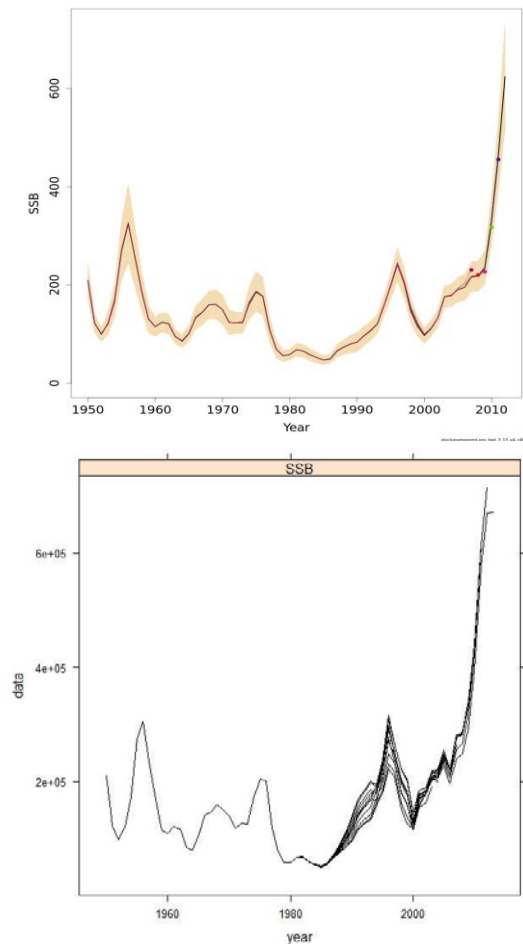


Figure 5.2 Retrospective assessment of SSB by SAM (left) and XSA (without P-shrinkage).

The SAM model shows a better retrospective picture than XSA.

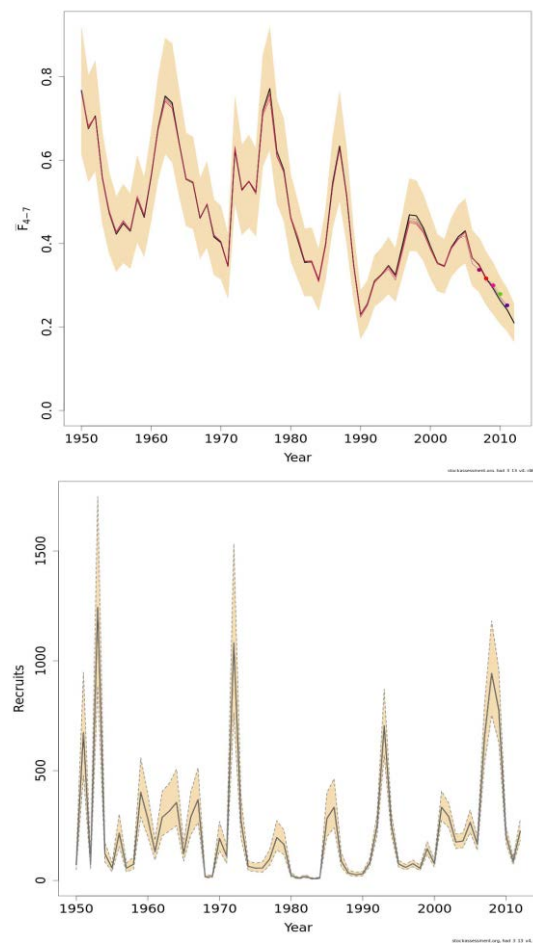


Figure 5.3 Retrospective assessment of F_{4-7} and Recruits estimated with SAM.

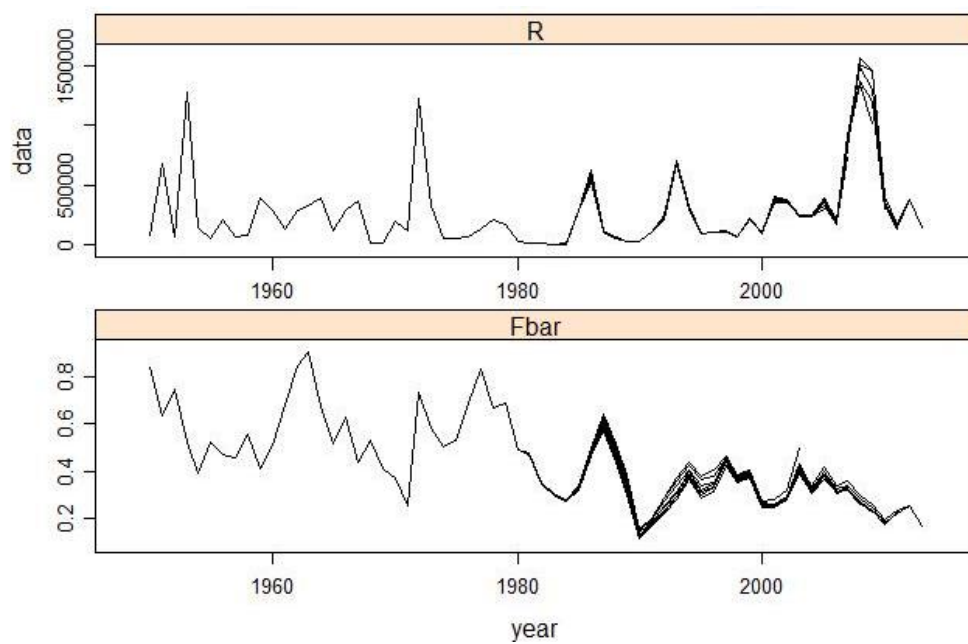


Figure 5.4 Retrospective assessment of Recruitment (R) and Fully-recruited fishing mortality (F_{bar}) estimated with XSA (without p-shrinkage).

Catchability and stock size

Based on results of exploratory runs at the 2011 benchmark, it was found that there is reason to assume q depends on stock size for all ages. The last age in the surveys data is 8, so the XSA parameter “Catchability independent of stock size for ages ≥ 9 ” was chosen, which is equivalent to using a power model in SAM for all the ages 3–8. During WKARCT this assumption was again tested and it was decided to keep it.

Shrinkage (XSA only)

The main differences between various XSA estimates are related to use of shrinkage to the population mean (P-shrinkage). This assumption particularly affects the abundance of older fish (age 9 and older) for which there are no tuning data. With the present very high stock abundance of older fish it is not logical to use shrinkage and shrink the abundance of these strong year classes (2004–2006) towards the size of previous year classes of average strength.

The difference in stock estimation with and without P-shrinkage is shown in Figure 5.5

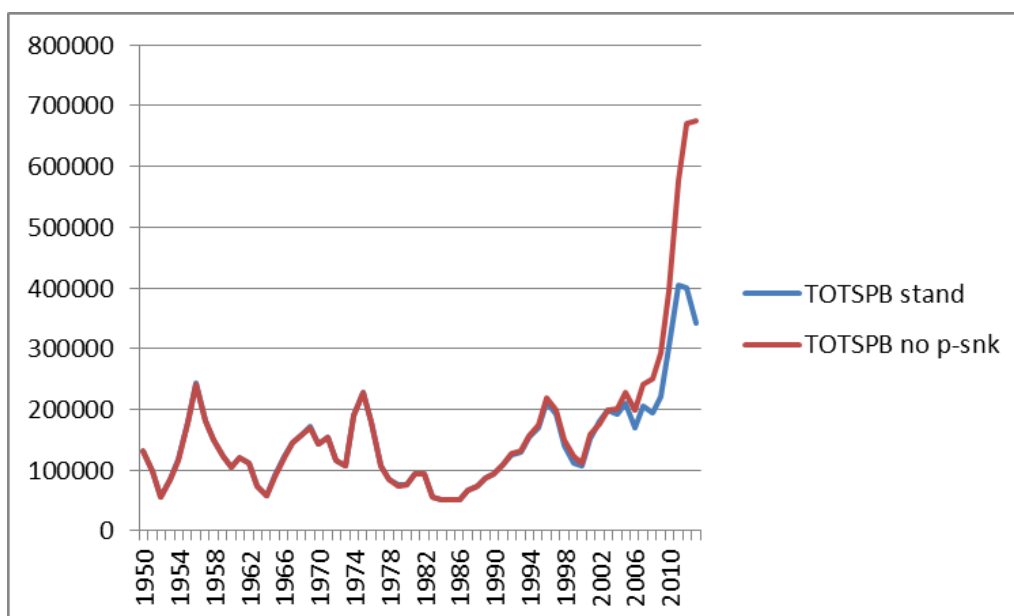


Figure 5.5 Dynamics of SSB using XSA with and without p-shrinkage. The main differences occurred for oldest ages, which are very abundant (Figure 5.6).

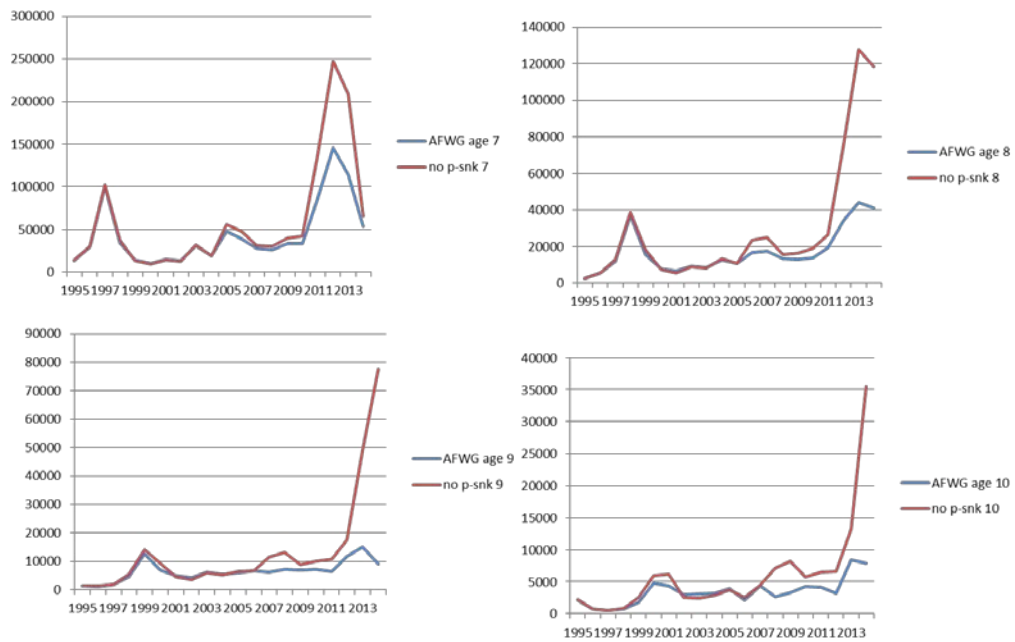


Figure 5.6 Differences in stock numbers estimates with AFWG XSA settings (blue) and with XSA without P-shrinkage (red)

Tapered time weighting (XSA only)

Different time window sizes and taper values were tested during the 2011 benchmark. Based on an analysis of retrospective patterns and XSA diagnostics it was decided to retain the AFWG settings for these parameters (20 years and power 3).

Plus group and age range

AFWG have used age 11+ group for most recent years. During the benchmark meeting, the 12+, 13+ and 14+ group was tested instead. No improvement of the retrospective pattern was observed. However, it is important to be able to track those year classes as long as possible, and also XSA may be sensitive to the choice of plus group. It was decided to change the plus group in future to 13+ in update assessments. However, one should keep the 14+ time-series of catch-at-age and weight at age updated.

In coming years more indices with a reasonable precision level will likely become available for age classes 9 and older because the cohorts 2004-2006 are still strong. Then it should be considered whether the age range for tuning indices should be expanded upwards, and accordingly the assumptions about the age ranges for fixed F and variance grouping should be re-evaluated. Such an analysis can be done by the working group based on objective criteria of the type given in table 5.1, without having a new benchmark meeting.

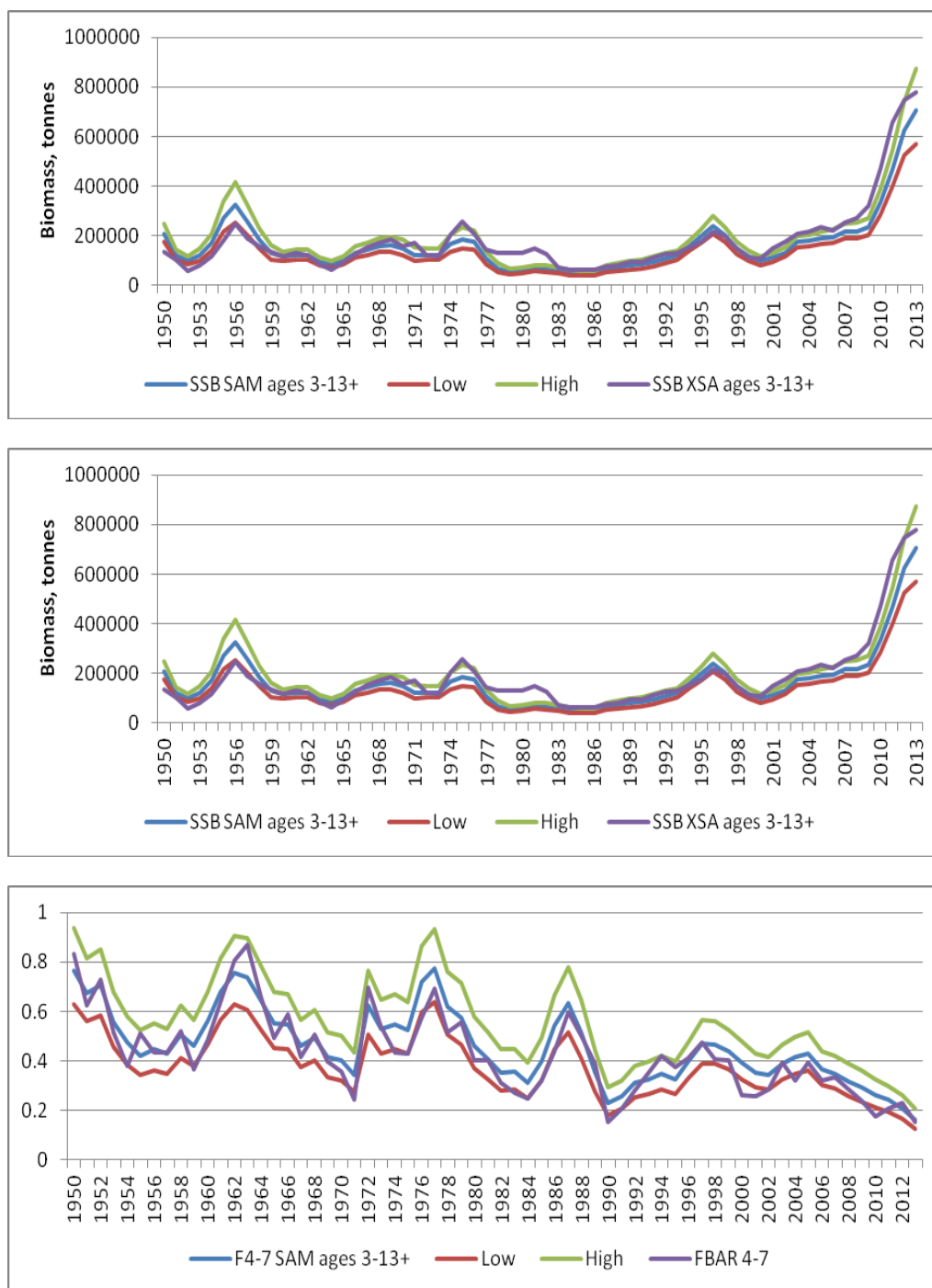


Figure 5.7. Northeast Arctic haddock. Results of XSA and SAM runs with new proposed XSA model settings.

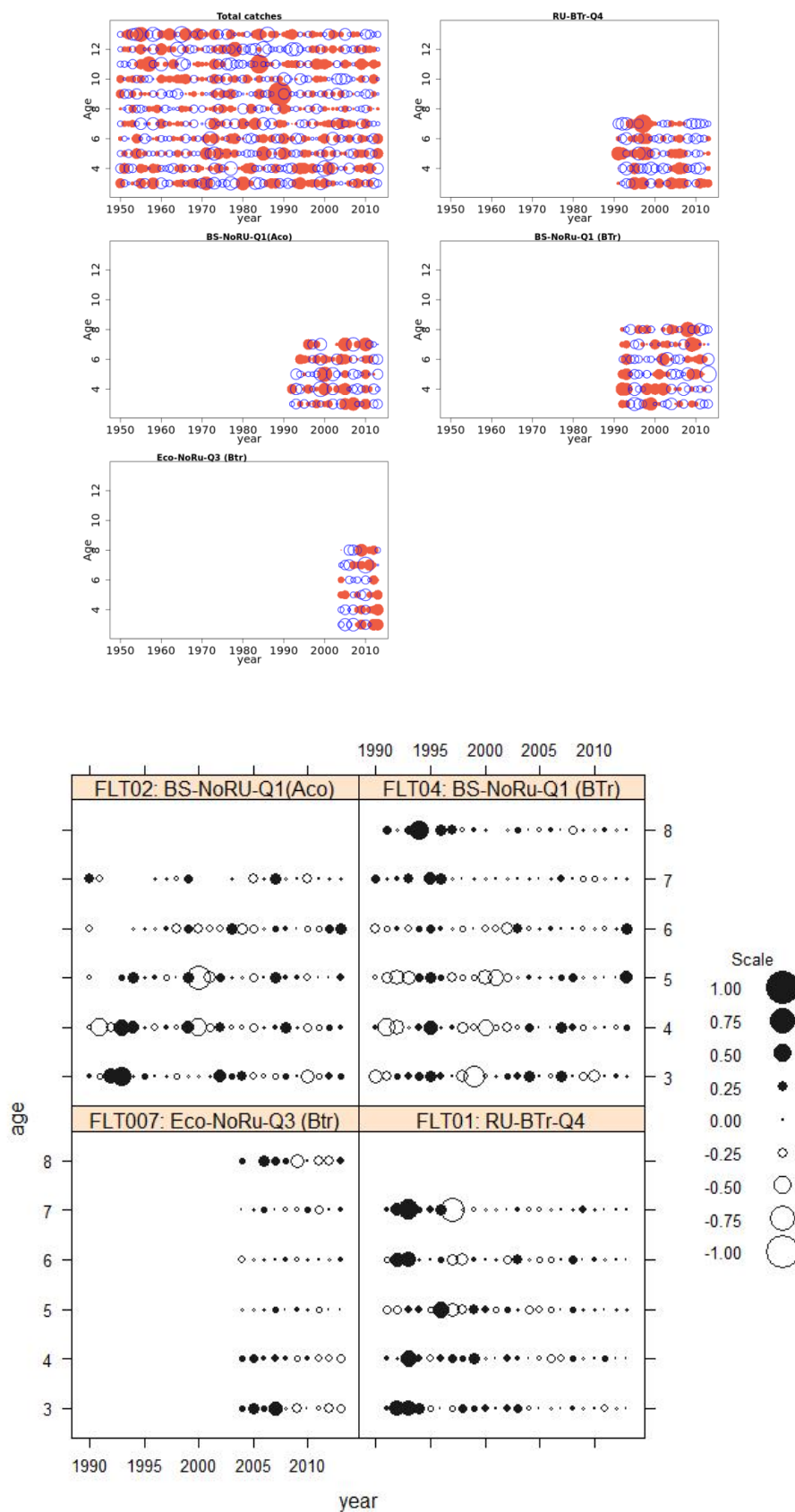


Figure 5.8. Northeast Arctic haddock. Residuals from SAM (top) and XSA (with P-shrinkage).

5.7 Short-term projections

The methodology used for short-term prediction of weight, maturity, exploitation pattern, recruitment and natural mortality (WD9 and Stock annex) generally seems to be adequate. However, the stock annex procedures for short-term prediction were not followed for all quantities at AFWG 2014 and some clarification about the need for permanent changes in the procedures is needed. Forecasts were not performed during the benchmark.

5.8 Appropriate Reference Points (MSY)

5.8.1 Limit and p_a reference points

The biomass reference points for this stock are: $B_{lim}=50\,000$ tonnes (equal to B_{loss}), $B_{pa}=80\,000$ tonnes. No new data points with low SSB values have been included since then, and it seems reasonable to keep these values. Possible values of a breakpoint are so high that they are not considered to be candidates for B_{MSY} trigger. F_{lim} and F_{pa} were re-estimated in 2014 to 0.77 and 0.47, respectively. No work was done on revising biological reference points during the meeting. MSY reference points should be reviewed based on updated long-term stochastic simulations, this will be investigated at AFWG 2015.

5.8.2 Harvest control rules and MSY

The current HCR was evaluated in 2006/2007 and found to be precautionary. Stochastic long-term simulations were used, with a biological model that included density-dependent growth and maturation. Two kinds of uncertainty were included: assessment uncertainty and uncertainty in the stock–recruitment relationship. The F_{MSY} was accepted as 0.35.

The stock–recruitment relationship for the 1953–2010 year classes is shown in Figure 5.9. A stochastic stock–recruitment relationship was fit, assuming a hockey-stick curve. The method used is described by Skagen and Aglen (2002) and is the same as used in previous studies for this stock and also for Northeast Arctic cod by Kovalev and Bogstad (2005).

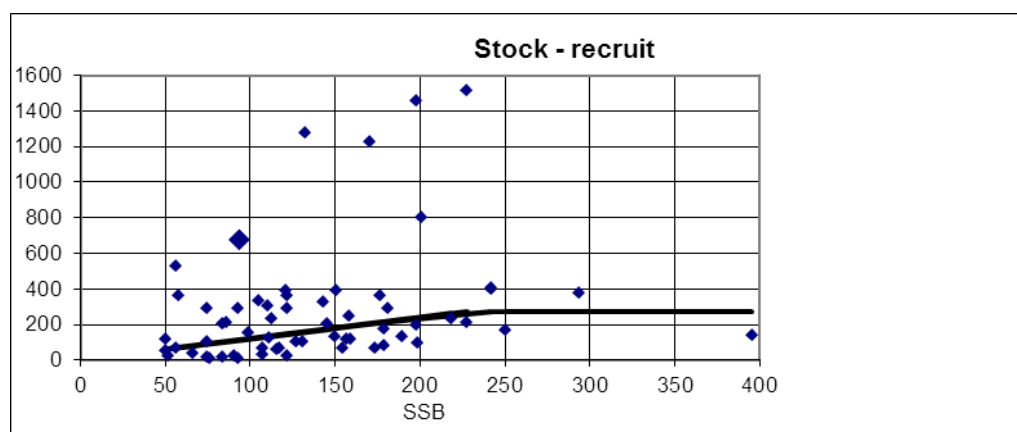


Figure 5.9. Northeast Arctic haddock. The stock–recruitment relationship for the 1953–2010 year classes. A segmented regression (hockey-stick) stock–recruitment relationship with lognormal error distribution was fit to the data:

$$R = \text{Min}(\alpha, \alpha * \text{SSB} / \beta) * e^{\epsilon}$$

where $\varepsilon = N(0, \sigma)$. The fit was done using Solver in Excel spreadsheets described by Skagen and Aglen (2002). A constraint on the sum of the difference between modelled and observed recruitments being zero was applied. The following parameter values were estimated: $\alpha = 289$ (million), $\beta = 229$ (thousand tonnes), $\sigma = 1.09$.

Criteria for fit and diagnostic plots

Skagen and Aglen (2002) suggested 3 quality criteria for stochastic stock–recruitment functions:

- 2) Independence between residuals and SSB;
- 3) Probability coverage;
- 4) The recruitment estimates should be unbiased.

Criteria 2) is a control that the distribution assumed for the residuals is adequate, while 3) may be used as an additional constraint when finding the parameters of the stock–recruitment function.

Assuming that each of the historic residuals is equally likely, the rank of each of them, divided by the number of observed residuals, gives the empirical cumulated probability of the historical residuals. On the other hand, according to the model that is assumed for the residuals in the prediction, there corresponds a cumulated probability for the value of each observed residual. Each of these model probabilities should be close to the empirical cumulated probability of the same historic residual. The Kolmogorov goodness-of-fit test is based on this reasoning, and the Kolmogorov test statistic can be derived directly from the pairs of modelled and observed values.

This seems to be an appropriate stock–recruitment relationship, but when evaluating the harvest control rule, other relationships should also be tried:

- Beverton–Holt S/R relationship (Ricker does not seem to be appropriate).
- Hockey-stick type model with breakpoint e.g. at lowest observed SSB (50 000 tonnes), remember that the correlation between R and SSB is very weak.
- Including autoregressive term(s) in the recruitment model

The approach taken in 2007 by assuming a fixed periodicity in recruitment and modelling strong year classes separately does not seem to be appropriate. MSY and HCRs should be investigated using long-term stochastic simulations, as previously done by AFWG. WD11 describes population models for use in evaluation of the harvest control rules for these stocks. Both models include stochastic stock–recruitment relationships and allow for density-dependence in growth and maturation. The model was generally considered suitable for evaluation of HCRs, although the actual parameter values need to be re-estimated following the adoption of a new assessment model. A stock–recruitment function with lognormally distributed error was found adequate for modelling the uncertainty in recruitment. Simulations should be run both for high and medium values of predation mortality induced by cod. The modelling of growth, maturation and exploitation pattern seems adequate.

In 2010, the Joint Norwegian-Russian Fisheries Commission decided that the harvest control rule used for Northeast Arctic haddock should remain unchanged 'for five more years', i.e. until 2015. The current harvest control rule is given in the stock Annex.

5.9 Future Research and data requirements

Compared to 2014 assessment the following changes are proposed:

For stock assessment at the next AFWG, the SAM model can be applied as the main model and XSA, with revised settings, will be used as additional model.

6 External reviewer report

The external experts have been requested to report on: (1) the issues raised by the reviewers throughout the process (i.e. during the preparatory work before the workshop and during the workshop) (2) a statement confirming that the outcomes of the benchmark (i.e. the stocks annex) are appropriate to provide scientific advice; (3) recommendations for future work.

We commend this group on the amount of work and preparation they did for this meeting. Likewise, we were impressed by the critical thinking and considerations of predator–prey interactions, natural mortality rates, and possible environmental effects. We encourage continued research in these areas.

6.1 Issues raised

6.1.1 Coastal cod

An XSA model is used to evaluate historical fishing mortalities for coastal cod, but the XSA model is not considered reliable for providing scientific advice on recent trends. In theory, information available for the stock should be adequate for a stock assessment, but a simpler assessment may be required than has been attempted in the past. There is an adequately long time-series of catch-at-age data (29 years) and a dedicated survey extending for greater than 15 years. Management of the stock is based on an empirical approach using survey trends. The current management approach could be expected to result improvement in the status of the stock, if the required reductions in fishing mortality are implemented according to the plan.

6.1.2 Northeast Arctic cod

Winter trawl/acoustic surveys are used to provide two indices of abundance. Both indices use age composition estimates from the bottom-trawl samples. These samples may not be representative of acoustic backscatter, and there are issues regarding double use of data. The acoustic estimates are combined with a winter acoustic survey in the Lofoten area. All of these manipulations are perhaps needed in order to create indices for use in XSA, but an improved approach would maintain the distinctness of each survey and sampling method, and bring the model to data. This would only be possible in an integrated approach.

The methods for calculating the ecosystem survey were not presented, but were included in assessment, with some awkward discussion about future calculation and inclusion. This situation should be avoided in future. Only data for which the methods are pre-agreed and presented at benchmark should be considered.

With respect to the assessment model, we caution that the possibility of accepting spurious relationships among variables can be quite high. For example, the stock assessment for NEA cod included a non-linear relationship between survey indices and stock abundance, largely justified by a couple very high observations of recent indices. The justification for this non-linearity has degraded through time. Similarly, the population projection model for NEA cod included density-dependent maturity, but evidence of this density-dependence has diminished. It is likely that other relationships, like those suggested for projecting cannibalism in the NEA cod population model, could degrade through time.

We commend the group for thinking about ecosystem interactions, but recommend caution in how such interactions are considered and modelled. The cannibalism hind-casting method may be inappropriate. For example, the frequency of occurrence is not necessarily linearly related to M (despite the regression fit). Additional numbers-at-age 3 are added to account for assumed cannibalism with no independent estimate of abundance (e.g. survey abundance). The reviewers asked to examine more carefully the relationship between M_2 and the predictor variable (FO). It was decided to estimate the recruitment time-series with and without hind-casting cannibalism.

The use of Eq 7 (WD 6) could lead to spurious correlation because M_2 and N_3 are not measured independently. N_3 depends on the level of M_2 that is assumed. Therefore one would expect a positive relationship because the two values are structurally related. Since M_2 is a per capita mortality rate, in theory it should decline with increasing prey abundance.

In several instances (e.g. hindcasting method of cannibalism in NEA cod, model for projecting cannibalism in NEA cod), regression equations were extrapolated to predict quantities of interest. The reasonable fit of the regression equations was used to justify that they would also be reasonable for prediction, but this is not necessarily true. More evaluation of the predictive capability of modelling efforts should be done before application in stock assessments.

More attention should also be paid to uncertainty. For example, the models of cannibalism, hindcasting, and stock-recruit are all highly uncertain, but suggestions and decisions were often based on the point estimate fits. Reliance on point estimates can lead to overly optimistic projections and false sense of precision. Stock assessment model estimates were also often treated as error-free data, which can lead to spurious relationships. Care should be taken.

6.1.3 Northeast Arctic haddock

An evaluation of the stock-recruit relationship is necessary to estimate B_{lim} . There is no obvious curvature in stock-recruit relationship. The segmented regression gives a very high inflection point but this not likely to be a robust result. B_{lim} is based on the lowest observed stock size, in keeping with ICES (2002).

6.1.4 Barents Sea Capelin

Survey coverage was an issue in 2014 due to ice coverage, and it was necessary to develop a method very quickly to make harvest recommendations. A pre-agreed approach is needed.

Better logic and justification is required for choosing B_{lim} . A scientific rationale is needed for setting B_{lim} that is consistent with ICES guidelines, to the extent possible.

6.2 Are the outcomes of the benchmark appropriate to providing management advice?

6.2.1 Coastal cod

A revised catch-at-age time-series was developed. The external experts agreed that the new estimates were based on appropriate analytical methods, and could be used in future stock assessments.

6.2.2 Northeast Arctic cod

A revised XSA for Northeast Arctic cod was evaluated during the benchmark review. The evaluation of various XSA settings was careful and thorough and model output was carefully examined. The XSA is adequate to provide scientific advice for this stock.

6.2.3 Northeast Arctic haddock

The SAM model gave comparable results to the previous XSA model. We recommend it as the preferred model for stock assessment moving forward because it can better accommodate the likely stock development in future with reductions in fishing mortalities and larger numbers of fish in the older age classes and in the plus group. The XSA model should be retained for comparison to SAM model.

6.2.4 Barents Sea Capelin

No changes were proposed for the capelin assessment methodology. The Bifrost code for projecting cod abundance from survey to the period of the fishery is being converted to a different programming language and revisions are anticipated once that conversion is complete.

We were asked to comment on a method for accounting for survey with incomplete coverage due to ice. The method used in 2014 is appropriate, but improvements should be considered as described below.

6.3 Recommendations for future work

6.3.1 Coastal cod

Explore reasons for differences between old and new catch series. Explore possibility that new catch series is in fact better, but problem could be survey (sampling multiple stocks; time varying q).

Improved sampling of recreational fisheries is needed. The recreational fishery for coastal cod is an important component of the total mortality for coastal cod, but sampling to estimate recreational fishery removals could benefit from greater attention. While sampling recreational fisheries is difficult, the difficulties are not insurmountable, and successful sampling programs have been developed in other parts of the world.

Alternative abundance indices should be considered. Several approaches were discussed: 1) an area-swept bottom-trawl index developed from bottom trawls conducted during the acoustic survey, 2) fishery CPUE indices, i.e. from the reference fishery, 3) and an index derived from the estimated abundance in the stock assessment for NE Arctic cod and percent composition of coastal cod on shared spawning grounds.

Evidence of different subpopulations of coastal cod should be evaluated. Specifically the possibility of splitting the assessment and management into northern and southern components should be evaluated.

Given uncertainties in catch data, alternative assessment methodologies should be considered. Possibilities include various data-moderate assessment methods, and integrated statistical models. SAM also allows estimation of “catch inflation factors” that might be a modelling solution in the short-term absence of recreational catch.

6.3.2 Northeast Arctic cod

Continue research and consider direct inclusion of the temperature effect on recruitment in projections. Recruitment variability should be modelled with a first-order autocorrelation function to account for the quasi cyclic recruitment variation (strings of high and low years).

Consideration of newer integrated statistical approaches is strongly recommended for assessing NE Arctic cod. Some initial work has been done for a SAM implementation. SAM has many attractive features and we encourage its future development. Nevertheless, there are other age-structured modelling tools available such as ASAP, Stock Synthesis, or stock-specific models developed in ADMB.

A stock-specific model would likely be necessary to appropriately model cod cannibalism and make use of the consumption data available. Clever tricks to incorporate cannibalism in existing models is not an ideal approach. Before identifying a preferred modelling approach, an inventory should be taken of biological, fishery, and survey characteristics of NE Arctic cod that are considered important to model, and a modelling framework should be selected that would allow those features to be modelled correctly.

There is a need for a more biologically based model to estimate cannibalism as a function of the abundance of young and old cod and capelin abundance.

In the cod population model (WD 6) it would be preferable to model the growth increments of cod in relation to density as opposed to weight at age. Note that weight at age increments are used in the cod projection model (WD5).

The calculation of mortality due to cannibalism should begin with a more realistic level of natural mortality. The base M presumably accounts for some cannibalism, and so should be reduced a bit when cannibalism is added. In addition, the base M is not likely to be the same for all ages. One possibility is to use a descending natural mortality curve similar to a Lorenzen curve to establish the baseline natural mortality, but other alternatives should be evaluated to ensure the results are robust.

Do research on adjusting indices for variable spatial coverage of surveys.

If XSA continues to be used as the assessment model for NE Arctic cod, we encourage simulation testing of when XSA options like P-shrinkage and F-shrinkage are appropriate/inappropriate to use.

Catchability is assumed to be a non-linear function of abundance, but this assumption is not well justified and should be revisited. If non-linear catchability continues to be considered, we recommend gear work to explore this issue directly.

6.3.3 Northeast Arctic haddock

Do research on adjusting indices for variable spatial coverage of surveys.

With the switch to a SAM model, expert support should be provided to the stock leads as needed. The use of SAM is becoming ubiquitous in ICES, yet most participants in WKARCT were not comfortable with the model. A broad outreach and education program for SAM is recommended. There is a need for manuals for using SAM.

Calculate and compare biomass indices for all surveys and compare to equivalent stock assessment output. This should be done for all surveys as a routinely although the surveys are disaggregated into age-specific indices. The scale of the biomass indi-

ces should be compared to the scale of the stock assessment and inconsistencies noted.

Measure the 1st-order autocorrelation of the recruitment residuals for use in the population model.

Rather than depending on species-specific estimation of reference points, it may be better to acknowledge that in some (most) cases the quantity and contrast in the stock–recruit data are insufficient to calculate reference points. In such cases, stock–recruitment meta-analyses may be used as priors or may inform robust reference point selection.

6.3.4 Barents Sea Capelin

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. 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.

Recommend a formal methodology be developed for incorporating uncertainty into forward projections. For example, the method for incorporating uncertainty in cod population abundance is ad hoc and not transparent.

Continue work on herring-capelin interactions and how this might affect assessment, management, and reference points.

Population models that track cohorts could be used more than they are at present (see WD 15). The present assessment method assumes an absolute estimate of biomass from the acoustic survey, without taking into account survivorship from prior years.

The forecasting of capelin SSB could be framed as a filtering problem, in that there are prior estimates of biomass that are updated with acoustic surveys. This could be handled with a state-space approach.

7 References and Working Documents

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7.2 Working documents

WD1: Bogstad, B. Natural mortality of cod and haddock related to predator consumption of these species

WD2: Dingsør, G. E. Haddock in the Norwegian coastal survey

WD3: Dingsør, G. E. Has the Northeast arctic haddock stock been underestimated in recent years?

WD4: Dingsør, G. E. Statistical catch-at-age model SAM applied to Northeast Arctic haddock

WD5: Bogstad, B., Kovalev, Yu. A., Yaragina, N. A., and Aglen, A. Northeast Arctic cod prediction input

WD6: Kovalev Yu. A., Bogstad, B. Update of the population model for NEA cod

WD7: Yaragina, N. A., Kovalev, Yu. A., and Chetyrkin, A. Hindcasting cod cannibalism back to 1947

WD8: Gjøsæter, H., and Bogstad, B. Capelin stock–recruit modelling

WD9: Russkikh, A. and Bogstad, B.: NEA haddock prediction input

WD10: Bogstad, B. and Howell, D.: SAM model applied on NEA cod - an outline

WD11: Russkikh, A. and Bogstad, B. Northeast Arctic haddock - population model for MSY/HCR simulations and update of reference points

WD12: Fotland, Å. Statistical catch-at-age model SAM age span 3:13+ applied on NEA haddock

WD13: Gjøsæter, H. Historical distribution of Barents Sea capelin during September

WD14: Yaragina, N. A. Short literature review on fishery-induced evolution in cod

WD15: Prozorkevitch, D. V. Cohort method for capelin stock assessment.

WD16: Sokolov, A., Kovalev, Yu. A., Russkikh, A., and Yaragina, N. A. Russian Autumn trawl-acoustic survey of bottom fish in the Barents Sea and adjacent waters

WD17: Dingsør, G. E. Bottom-trawl indices from ecosystem survey – design based

WD18: Kovalev, Yu. A., and Chetyrkin, A. Evaluation of the NEA cod assessment quality

WD19: Vasilyev, D. NEA cod stock assessment by means of TISVPA

WD20: Bulatov, O., Borisov, V., and Vasilyev, D. Some comments on the harvest control rule for Northeast Arctic cod.

(no WD21-24)

WD25: Johansen, T., Westgaard, J. I., and Aglen, A. The Northeast Arctic cod (NEAC) and coastal cod in Barents Sea and coastal waters: identification of stock structure

WD26: Russkikh, A. Differences XSA run p-shrinkage in and out

Annex 1. 2015 WKARCT Terms of Reference

2014/2/ACOM:31 A **Benchmark Workshop on Arctic Stocks** (WKARCT), chaired by External Chair Jeremy Collie, USA and ICES Chair Bjarte Bogstad, Norway, and attended by three invited external experts Martin Dorn, USA, Jeremy Collie, USA, and Jonathan Deroba, USA, will be established and work by correspondence and during meeting 4–6 November 2014 in Murmansk, Russia for data compilation and at ICES Headquarters for a 5 day Benchmark meeting 26–30 January 2015 back to back with WKICE to:

- a) Evaluate the appropriateness of data and methods to determine stock status and investigate methods for short-term outlook taking agreed or proposed management plans into account for the stocks listed in the text table below. The evaluation shall include consideration of:
 - i. Stock identity and migration issues;
 - ii. Life-history data;
 - iii. Fishery-dependent and fishery-independent data;
 - iv. Further inclusion of environmental drivers, multispecies information, and ecosystem impacts for stock dynamics in the assessments and outlook
- b) Agree and document the preferred method for evaluating stock status and (where applicable) short-term forecast and update the stock annex as appropriate. Knowledge of environmental drivers, including multispecies interactions, and ecosystem impacts should be integrated in the methodology

If no analytical assessment method can be agreed, then an alternative method (the former method, or following the ICES data-limited stock approach) should be put forward;

- c) Evaluate the possible implications for biological reference points, when new standard analyses methods are proposed. Propose new MSY reference points taking into account the WKFRAME2, results and the introduction to the ICES advice (section 1.2), and WKMSYREF3.
- d) Develop recommendations for future improving of the assessment methodology and data collection;
- e) As part of the evaluation:
 - i) Conduct correspondence work on data compilation and hold a WebEx meeting on 29 October. Stakeholders are invited to contribute data (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality. As part of the data compilation work consider the quality of data including discard and estimates of mis-reporting of landings;
 - ii) Following the DC correspondence work, produce working documents to be reviewed during the Benchmark meeting at least 7 days prior to the meeting

Stocks	Stock leader
cod-arct	Yuri Kovalev
cod-coas	Asgeir Aglen
cap-bars	Samuel Subbey
Had-arct	Alexey Russkikh

The Benchmark Workshop will report by 1 March 2015 for the attention of ACOM.

Annex 2. List of participants

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Annex 3. Recommendations for future work from WKARCT

See recommendations from externals in section 6

North East Arctic cod:

WKARCT recommended to also set up the SAM model for the NEA cod stock.

Coastal cod:

Limitations and potential splitting of the stock assessment area should be re-evaluated by SIMWG when more of the ongoing genetic studies are published.

-In the northern part of the stock area the acoustic survey contains a number of fixed bottom-trawl stations that could be used for a swept-area time-series for that region. Commercial cpue from the gillnet fishery during autumn (when the bycatch of NEA cod is lowest) could be considered.

-The differences between the old and new catch data (numbers and weights at age) should be further explored.

-Further information about the recreational and tourist fisheries is highly recommended.

Capelin:

There are three principal areas of further research, which include addressing issues connected with (i) incomplete survey coverage (ii) stock assessment: Bifrost model assumptions and input data uncertainties, and (iii) reference points and HCRs.

North East Arctic haddock:

It is recommended that the Joint Barents Sea survey (NoRu-Q1) is extended southwards along the Norwegian coast to improve the coverage of the older ages.

Annex 4. Stock annex Cod (*Gadus morhua*) in Subareas I and II (Northeast Arctic)

Stock specific documentation of standard assessment procedures used by ICES.

Stock:	Cod (<i>Gadus morhua</i>) in Subareas I and II (Northeast Arctic)
Working Group:	Arctic Fisheries Working Group (AFWG)
Date:	30 January 2015
Revised by:	WKARCT, Yuri Kovalev (stock coordinator)

A. General

A.1 Stock definition

The North-East Arctic cod (*Gadus morhua*) is distributed in the Barents Sea and adjacent waters, mainly in waters above 0°C. The main spawning areas are along the Norwegian coast between 67°30' and 70°N. The 0-group cod drifts from the spawning grounds eastwards and northwards and during the international 0-group survey in August it is observed over wide areas in the Barents Sea.

A.2 Fishery

The fishery for North-east Arctic cod is conducted both by an international trawler fleet operating in offshore waters and by vessels using gillnets, longlines, handlines and Danish seine operating both offshore and in the coastal areas. 60-80% of the annual landings are from trawlers. Catch quotas were introduced in the trawl fishery in 1978 and for the fisheries with conventional gears in 1989. In addition to quotas the fisheries are regulated by mesh size limitations including sorting grids, a minimum catching size, a maximum bycatch of undersized fish, maximum bycatch of non-target species, closure of areas with high densities of juveniles and by seasonal and area restrictions. Since January 1997 sorting grids have been mandatory for the trawl fisheries in most of the Barents Sea and Svalbard area. Discarding is prohibited. The minimum catching size of cod is 44 cm, and the maximum proportion of undersize fish allowed is 15% by number for cod, haddock and saithe combined. The fisheries are controlled by inspections at sea, requirement of reporting to catch control points when entering and leaving the EEZs and by inspections when landing the fish for all fishing vessels. Keeping a detailed fishing logbook on board is mandatory for most vessels, and large parts of the fleet report to the authorities on a daily basis. There is some evidence that the present catch control and reporting systems are not sufficient to prevent discarding and underreporting of catches, but it has considerably improved compared with historical period.

A.3 Ecosystem aspects

Considerable effort has been devoted to investigate multispecies interactions in the Northeast Arctic. Some of these investigations have reached the stage where quantitative results are available for use in assessments. Growth of cod depends on availability of prey such as capelin (*Mallotus villosus*), and variability of cod growth has had major impacts on the cod fishery. Cod are able to compensate only partially for low capelin abundance, by switching to other prey species. This may lead to periods of

high cannibalism on young cod, and may result in impacts on other prey species which are greater than those estimated for periods when capelin is abundant. In a situation with low capelin abundance, juvenile herring (*Clupea harengus*) experience increased predation mortality by cod. The timing of cod spawning migrations is influenced by the presence of spawning herring in the relevant area. The interaction between capelin and herring is illustrated by the recruitment failure of capelin coinciding with years of high abundance of young herring in the Barents Sea. Herring predation on capelin larvae is believed to be partially responsible for the recruitment failure of capelin when young herring are abundant in the Barents Sea.

The composition and distribution of species in the Barents Sea depend considerably on the position of the polar front which separates warm and salty Atlantic waters from colder and fresher waters of arctic origin. Variation in the recruitment of some species including cod and capelin has been associated with the changes in the influx of Atlantic waters to the large areas of the Barents Sea shelf.

The annual consumption of herring, capelin and cod by marine mammals (mainly harp seals and minke whales) has been estimated to be in the order of 1.5–2.0 million tonnes (Bogstad *et al.*, 2000; See also Table 1.9 ICES 2014).

However, estimates of total annual food consumption of Barents Sea harp seals are in the range of about 3.3–5 million tonnes (depending on choice of input parameters, Nilssen *et al.*, 2000). The applied model used different values for the field metabolic rate of the seals (corresponding to two or three times their predicted basal metabolic rate) and under two scenarios: with an abundant capelin stock and with a very low capelin stock.

If capelin was abundant the total harp seal consumption was estimated to be about 3.3 million tons (using lowest field metabolic rate). The estimated consumption of various commercially important species was as follows (in tonnes): capelin approximately 800 000, polar cod (*Boreogadus saida*) 600 000, herring 200 000 and Atlantic cod 100 000.

A low capelin stock in the Barents Sea (as it was in 1993–1996) led to switches in seal diet composition, with estimated increased consumption of polar cod (870 000 tonnes), other codfish (mainly Atlantic cod; 360 000 tonnes), and herring (390 000 tonnes).

B. Data

B.1 Commercial catch

Norway

Norwegian commercial catch in tonnes by quarter, area and gear are derived from the sales notes statistics of The Directorate of Fisheries. Data from about 20 subareas are aggregated on 6 main areas for the gears gillnet, longline, handline, purse-seine, Danish seine, bottom trawl, shrimp trawl and trap. For bottom trawl the quarterly area distribution of the catches is adjusted by logbook data from The Directorate of Fisheries and the total bottom-trawl catch by quarter and area is adjusted so that the total annual catch for all gears is the same as the official total catch reported to ICES.

No discards are reported or accounted for, but there are several reports of discards.

The sampling strategy is to have age and length samples from all major gears in each main area and quarter. The main sampling program is sampling the landings. Additional samples from catches are obtained from the IMR reference fleet (fishing vessels contracted for sampling), and the coast guard.

The ECA software (Hirst *et al.*, 2012) has been developed to utilize all sampling information to estimate catch-at-age for areas (I, IIa and IIb), quarters and gears (bottom trawl, gillnet, Danish seine and longline/handline). This software also handles the splitting of catches into NEA cod and Coastal cod.

Russia

Russian commercial catch in tonnes by quarter and area are derived from the All-Russian Institute of fishery and oceanography (Moscow) statistics department. Data from each fishing vessel are aggregated on three ICES subdivisions (I, IIa and IIb). Russian fishery by passive gears was almost stopped by the end of the 1940s. At present the bottom-trawl fishery constitutes more than 95% of the cod catch.

The sampling strategy was to conduct mass measurements and collect age samples directly at sea, onboard of both research and commercial vessels to have age and length distributions from each area and quarter. Data on length distribution of cod in catches were collected in areas of cod fishery all the year-round by a "standard" fishery trawl (since 2011 the mesh size is 130 mm for the entire Barents Sea, previously it was 125 mm in the Russian Economic zone and Svalbard area and 135 mm in the Norwegian Economic zone) and summarized by three ICES Subareas (I, IIa and IIb). Previously the PINRO area divisions were used, which differed from the ICES subdivisions.

Age sampling was carried out by two ways: without any selection (otoliths were taken from any fish caught in one trawl, usually from 100–300 sp.) or using a stratified by length sampling method (i.e. approximately 10–15 sp. per each 10-cm length group). The last method has been used since 1988.

All fish taken for age-reading were measured and weighted individually.

Catch-at-age are reported to ICES AFWG by subdivision (I, IIa and IIb) and quarter (before 1984 – by subdivision and year). Data on length distribution of cod in catches, as well as age-length keys, are formed for each quarter and area. In the case when a catch is present in the area/quarter but a length frequency is absent, a length frequency for the corresponding quarter, summarized for the whole sea is used. If there is no data on length composition of cod in catches per a quarter within the whole sea, a frequency summarized for the whole year and whole sea is used. Gaps in age-length distributions in subdivisions are filled in with data from the corresponding quarter, summarized for the whole sea. Remaining gaps are filled in with information from the age-length key formed for the long-term period (1984–1997) for each quarter and for the whole sea (Kovalev and Yaragina, 1999). Before 1984, calculation of catch-in-numbers in subdivisions was based on the age-length keys for the whole year and length distribution in catches.

Germany and Spain

Catch-at-age is reported to the WG by ICES subdivision (I, IIa and IIb) and quarter, according to national sampling. Missing quarters/subdivisions are filled in by use of Russian or Norwegian sampling data.

Other nations

Total annual catch in tonnes is reported by ICES subdivisions. All catches by other nations are taken by trawl. The age composition from the sampled trawl fleets is therefore applied to the catches by other nations.

The text table below shows which country supplied which kind of data for 2013:

Country	Kind of data				
	Caton (catch in weight)	Canum (catch-at-age in numbers)	Weca (weight at age in the catch)	Matprop (proportion mature by age)	Length composition in catch
Norway	x	x	x	x	x
Russia	x	x	x	x	x
Germany	x	x	x		
UK	x				
France ¹	x				
Spain	x				
Portugal	x	x	x		
Poland	x				
Ireland ¹	x				
Greenland ¹	x				
Faroe Islands ¹	x				
Iceland ¹	x				
	x				

¹ As reported to Norwegian and Russian authorities

Since 2008 the catch data has been handled by Intercatch. Earlier the nations that sample the catches, provided the catch-at-age data and mean weights at age on Excel spreadsheet files, and the national catches were combined in Excel spreadsheet files. Historic data should be found in the national laboratories and with the stock co-ordinator.

For 1983 and later years mean weight at age in the catch is calculated as the weighted average for the sampled catches. For the earlier period (1946–1982) mean weight at age in catches is set equal to mean weight at age in the stock (ICES 2001).

Since 2008 the catch data has been handled by Intercatch.

B.2 Biological

For 1983 and later years weight at age in the stock and maturity-at-age is calculated as weighted averages from Russian and Norwegian surveys during the winter season. Stock weights at age a (W_a) at the start of year y are calculated as follows:

$$W_{a,y} = 0.5W_{rus,a-1,y-1} + \left(\frac{N_{nbar,a,y}W_{nbar,a,y} + N_{lof,a,y}W_{lof,a,y}}{N_{nbar,a,y} + N_{lof,a,y}} \right)$$

where

$W_{rus,a-1}$: Weight at age $a-1$ in the Russian survey in year $y-1$

$N_{nbar,a}$: Abundance at age a in the Norwegian Barents Sea acoustic survey in year y

$W_{nbar,a}$: Weight at age a in the Norwegian Barents Sea acoustic survey in year y

$N_{lof,a}$: Abundance at age a in the Lofoten survey in year y

W_{lofa} : Weight at age a in the Lofoten survey in year y

Maturity-at-age is estimated from the same surveys by the same formulae, replacing weight by proportion mature.

For age groups 12 and older, the stock weights are set equal to the catch weights, since most of these fish are taken during the spawning fisheries, and in most years considerably more fish from these ages are sampled from the catches than from the surveys.

For the earlier period (1946–1982) the maturity-at-age and weight at age in the stock is based on Russian sampling in late autumn (both from fisheries and from surveys) and Norwegian sampling in the Lofoten spawning fishery. These data were introduced and described in the 2001 assessment report (ICES 2001).

Natural mortality (M) is assumed to be equal to 0.2 plus cannibalism mortality for ages 1–6.

The method used for calculation of the prey consumption by cod described by Bogstad and Mehl (1997) is used to calculate the consumption of cod by cod for use in XSA. The consumption is calculated based on cod stomach content data taken from the joint PINRO-IMR stomach content database (methods described in Mehl and Yaragina, 1992). On average about 9000 cod stomachs from the Barents Sea have been analysed annually in the period 1984–2013.

These data are used to calculate the per capita consumption of cod by cod for each half-year (by prey age groups 0–6 and predator age groups 1–11+). It was assumed that the mature part of the cod stock is found outside the Barents Sea for three months during the first half of the year. Thus, consumption by cod in the spawning period was omitted from the calculations.

The number of cod predators at age is taken from the VPA, and thus an iterative procedure has to be applied. All occurrences of intra-cohort predation were removed from the dataset as these could possibly cause problems with convergence. The following procedure realized in FLR script was followed: As a starting point the number of cod consumed by cod was estimated from the stock estimates assessed with zero consumption and the per capita estimates of consumption of cod by cod. Then the number consumed was added to the catches used for tuning. The resulting stock then leads to new estimates of consumption. This procedure was repeated until the consumed numbers for the latest year differed less than 0.001% from the previous iteration.

Since 2015 hindcasted data on cod cannibalism for the historical period (1946–1983) are also available. These have been applied to make the VPA time-series with cannibalism consistent (Yaragina *et al.*, WD7 WKARCT 2015). A time-series which does not include cannibalism is also presented in the AFWG report.

Both the proportion of natural mortality before spawning (M_{prop}) and the proportion of fishing mortality before spawning (F_{prop}) are set to 0. The peak spawning in the Lofoten area occurs most years in late March-early April.

B.3 Surveys

Russia

Russian surveys of cod in the southern Barents Sea started in the late 1940s as trawl surveys of young demersal fish. Since 1957 such surveys have been conducted over

the whole feeding area including the Bear Island - Spitsbergen area (Baranenkov, 1964; Trambachev, 1981), both young and adult cod have been surveyed simultaneously. In 1984, acoustic methods started to be implemented during surveys of fish stocks (Zaferman, Serebrov, 1984; Lepesevich, Shevelev, 1997; Lepesevich *et al.*, 1999). In 1995 a new acoustic assessment method was applied for the first time, which allowed the differentiation and registration of echo intensities from fish of different length (Shevelev *et al.*, 1998). Methods of calculations of survey indices also changed, e.g. due to the necessity to derive length-based indices for the FLEKSIBEST model (Bogstad *et al.*, 1999; Gusev and Yaragina, 2000).

Survey duration has been reduced from 5–6 months (September–February) in 1946–1981 to 2–2.5 months (October–December) since 1982. The aim of conducting a survey is to investigate both the commercial size cod as well as the young cod and to receive reliable data to compose annual maturity ogives. The survey covers the main areas where juveniles settle down as well as the commercial fishery takes place, including cod at age 0+ - 10+ years. A total of more than 400 trawl hauls are conducted during the survey (mainly bottom-trawl hauls, a few pelagic trawl hauls).

There are two survey abundance indices at age: 1) absolute numbers (in thousands) computed from the acoustics and 2) trawl swept-area indices, calculated as absolute numbers registered in survey standard area (Golovanov *et al.*, 2006, 2007).

Ages 3-9 are used in the XSA-tuning.

Joint Russian–Norwegian winter (February) survey

The survey started in 1981 and covers the ice-free part of the Barents Sea. Both swept-area estimates from bottom-trawl and acoustic estimates are produced. The swept-area estimates are used in the tuning for ages 3–8, and the acoustic estimate are added to the Norwegian acoustic survey in Lofoten and used for tuning for ages 3–9. The survey is described in Jakobsen *et al.*, (1997) and Mehl *et al.*, (2013, 2014).

Norwegian Lofoten survey

Acoustic estimates from the Lofoten survey extends back to 1984. The survey is described by Korsbrekke (1997).

Joint Russian–Norwegian Ecosystem survey (August–September)

This survey started in 2004, but is a continuation and integration of previous surveys conducted at this time of year (0-group survey, capelin survey, various bottom-trawl investigations). The survey methodology and results are described in annual survey reports (Prokhorova 2013). Unfortunately, there is at present no agreed method for calculating bottom-trawl indices from this survey (Dingsør, WD17, WKARCT 2015 vs. ICES AFWG 2014 Table A14). Agreeing on a common methodology has very high priority.

Commercial cpue

Russia

A cpue series based on PST vessel type (stern trawler, 2000 HP) was used in the assessment before 2015, but has now been excluded from the assessment.

Information from each fishing trawler was daily transferred to PINRO, including data on each haul (timing, location, gear and catch by species). Yearly catch of cod by the PST trawlers as well as number of hours trawling was summarized and cpue

index (catch on tons per hour fishing) was calculated. The effort (hours trawling) was scaled to the whole Russian catch. The cpue indices were split on age groups by age data from the trawl fishery.

C. Estimation of historical stock development

Model used: XSA

Software used: FLR / Lowestoft VPA suite

Model Options chosen:

Tapered time weighting applied, power = 3 over 20 years

Catchability independent of stock size for ages >9

Catchability independent of age for ages > 10

Survivor estimates shrunk towards the mean F of the final 5 years or the 2 oldest ages

S.E. of the mean to which the estimate are shrunk = 1.500

Minimum standard error for population estimates derived from each fleet = 0.300

Prior weighting not applied

Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1946–last data year	3–13+	Yes
Canum	Catch-at-age in numbers	1946–last data year	3–13+	Yes
Weca	Weight at age in the commercial catch	1982–last data year	3–13+	Yes, set equal to west for 1946–1981
West	Weight at age of the spawning stock at spawning time.	1946–last data year	3–13+	Yes
Mprop	Proportion of natural mortality before spawning	1946–last data year	3–13+	No, set to 0 for all ages in all years
Fprop	Proportion of fishing mortality before spawning	1946–last data year	3–13+	No, set to 0 for all ages in all years
Matprop	Proportion mature at age	1946–last data year	3–13+	Yes
Natmor	Natural mortality	1946–last data year	3–13+	No, values 0.2 for all ages in all years

Additional natural mortality caused by cannibalism	1946–last data year	3–6	Yes, annual est. of cannibalism from 1984, for period 1946- 1983 set to hindcasted values since 2015 WG (WD7 WKARCT 2015)
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Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1	Joint Barents Sea survey, February	1981–last data year	3–8
Tuning fleet 2	Joint Barents Sea Acoustic, February+ Lofoten Acoustic survey in March	1985–last data year	3–9
Tuning fleet 3	Russian bottom-trawl survey, November	1984–last data year	3–9
Tuning fleet 4	Barents Sea ecosystem survey, September	2004–last data year	3–9

XSA settings

Type of setting	Settings of 2015 benchmark	Used this year (why changed)
Time-series weighting	Tapered time weighting power = 3 over 20 years	The same
Recruitment regression model (catchability analysis)	Catchability independent of stock size for ages >9 Regression type = C Min. 5 points used Survivor estimates are NOT shrunk to the population mean Catchability independent of age for ages >10	The same
Terminal population estimation	Survivor estimates shrunk towards the mean F of the final 5 years or the 2 oldest ages. S.E. of the mean to which the estimate are shrunk = 1.5 Minimum standard error for population estimates derived from each fleet = 0.3	The same
Prior fleet weighting	Prior weighting not applied	The same

D. Short-term projection

Model used: Age structured

Software used: FLR script prediction with management option table

Initial stock size: Taken from the XSA for age 4 and older. The recruitment-at-age 3 for the initial stock and the following 2 years are estimated from survey data and environmental data using the “hybrid model” described in section 1.4.5 in AFWG 2014 (ICES CM 2014/ACOM:05)

Natural mortality: average of the three last years or set equal to the values estimated for the terminal year if there is a strong trend during the most recent years.

Maturity: average of the three last years

F and M before spawning: Set to 0 for all ages in all years

Weight at age in the stock: Predicted by applying 3-year average of annual increments by cohort on last year's observation.

Weight at age in the catch: Predicted by applying 10-year average annual increments by cohort on last year's observation.

Exploitation pattern: Average of the recent years taking into account stability of the pattern. 5 years average as default.

Intermediate year assumptions: Normally F status quo is used. If this corresponds to a catch which deviates considerably from the agreed TAC, one should consider other approaches.

Stock recruitment model used: None

Procedures used for splitting projected catches: Not relevant

E. Medium-term projections

Not used.

F. Long-term projections

MSY and HCRs should be investigated using long-term stochastic simulations, as previously done by Kovalev and Bogstad (2005) and by ICES AFWG. Kovalev and Bogstad (2015) provided an update of the population model by Kovalev and Bogstad (2005). The model includes stochastic stock-recruitment relationships and allows for density-dependence in growth and maturation. These models were generally considered suitable for evaluation of HCRs. The recruitment function and the handling of cannibalism need more investigation. The main issues are: 1) Which recruitment time-series to use and modelling of cannibalism 2) Variations in recruitment over time (autocorrelation), handling of uncertainty using a parametric approach.

The modelling of growth, maturation and exploitation pattern seems adequate. For growth and maturation, runs should be made both with and without density-dependence, as data for the first part of the time-series (before about 1982) indicate marked density-dependence while this is not the case for the period 1982-present. Also, growth and maturation in future will depend on possible fishery induced evolution effects, which have been claimed for this stock by several authors (see Yaragina, 2015 for a literature summary on this).

This section of the Stock Annex is to be updated when long-term simulations have been carried out, with reference to the actual document giving results.

G. Biological reference points

Introduced 1998: $B_{lim}=112\ 000\ t$, $B_{pa}=500\ 000\ t$, $F_{lim}=0.70$, $F_{pa}=0.42$

Adopted in 2003: $B_{lim}=220\ 000\ t$, $B_{pa}=460\ 000\ t$, $F_{lim}=0.74$, $F_{pa}=0.40$

F_{MSY} is estimated at level of 0.40.

$MSY\ B_{trigger}$ is at the level of 460 000 t (B_{pa}), and used as a trigger point in HCR.

This section of the Stock Annex is to be updated when long-term simulations have been carried out, with reference to the actual document giving results.

H. Other issues

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Annex 5. Stock annex Cod (*Gadus morhua*) in Subareas I and II (Norwegian coastal waters cod)

Stock specific documentation of standard assessment procedures used by ICES.

Stock:	Cod (<i>Gadus morhua</i>) in Subareas I and II (Norwegian coastal waters cod)
Working Group:	Arctic Fisheries Working Group
Date:	30.01.15
Author	WKARCT, Asgeir Aglen (stock coordinator)

A General

A.1. Stock definition

Cod in the Barents Sea, the Norwegian Sea and in the coastal areas living under variable environmental conditions form groups with some peculiarities in geographical distribution, migration pattern, growth, maturation rates, genetics features, etc. The degree of intermingling of different groups is uncertain (Borisov *et al.*, 1999).

Both types of cod (the Norwegian Coastal cod and the North-East Arctic cod) can be found together on spawning grounds during spawning period as well as in catches all the year-round both inshore and offshore in variable proportions.

The assessment area for Norwegian Coastal cod (NCC) is the Norwegian statistical rectangles 0, 3, 4, 5, 6 and 7. The catch reporting separates catches inside and outside the 12 nautical mile limit. In the map in Figure A2.1 each statistical rectangle is split along the 12-mile limit so that area 300+301 is area 3, 400+401 is 4 etc.

Spawning areas are located in fjords as well as offshore along the coast. The spawning season extends from March to late June, with peak spawning early April. The 0 and 1-group of NCC inhabit shallow water both in fjords and in coastal areas and are hardly found in deeper trawling areas until reaching about 25 cm. Afterwards they gradually move towards deeper water. NCC starts on average to mature at age 4–6 and migrates towards spawning grounds in early winter. The majority of the biomass (about 75%) is located in the northern part of the area (North of 67°N).

Tagging experiments of cod inhabiting fjords indicate only short migrations (Jakobsen 1987, Nøstvik and Pedersen 1999, Skreslet, *et al.*, 1999). From these experiments very few tagged cod migrated into the Barents Sea (<1%). Some investigations based on genetics found large differences between NCC and North-East Arctic cod (NEAC) (Fevolden and Pogson 1995, Fevolden and Pogson, 1997; Jørstad and Nævdal, 1989, Møller 1969), while others did not find clear differences (Árnason and Pálsson, 1996, Mork, *et al.*, 1984, Artemjeva and Novikov, 1990). Investigations also indicate that NCC probably consists of several separate populations.

Ongoing studies on the genetic structure of cod along the entire Norwegian coast have revealed considerable genetic differences (WD 25 to WKARCT 2015). Two main clusters have been indicated, with a separation line somewhere between 63 and 66 degrees north. Within these clusters there are further genetic variations indicating a rather complex stock structure, and several regions may possibly be defined.

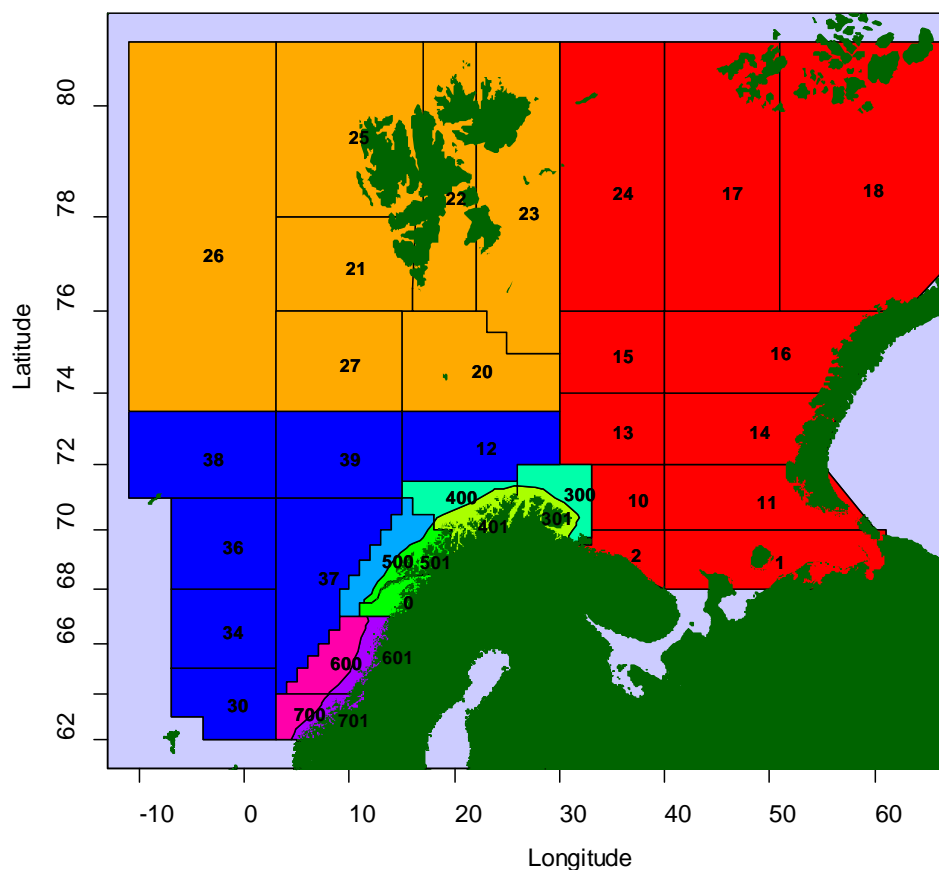


Figure A2.1. Norwegian statistical rectangles areas 3-7 are here split along the 12 nmile limit (300 and 301, 400 and 401, etc.).

A.2. Commercial Fishery

Coastal cod is mainly fished by coastal vessels using traditional fishing gears like gillnet, longline, handline and Danish seine, but some is also fished by trawlers and larger longliners fishing at the coastal banks. The fishery is dominated by gillnet (50%), while longline/handline account for about 20%, Danish seine 20% and Trawl 10% of the total catch. There was a shift around 1995 in the portion caught by the different gears. Before 1995 the portion taken by longline and handline was higher, while the portion taken by Danish seine was lower. Norwegian vessels take all the reported catch. However, trawlers from other countries probably take a small amount of NCC when fishing near the Norwegian coast fishing for North-East Arctic cod and North-East Arctic haddock.

When setting the annual cod quota an expected catch of coastal cod is added to the Norwegian TAC for North-east Arctic cod, giving a total combined TAC to distribute on fishing vessels. In 2010 and later years 7000 tonnes of the Norwegian cod quota has been set aside to cover the catches taken in the recreational and tourist fisheries and to cover catches taken by young fishers (to motivate young people to become fishers).

Cod catches are not identified to stock at landing, and therefore no landings are counted against a separate coastal cod quota. When the fishing year is finished the catches of coastal cod are estimated from otolith sampling. All regulations for North-east Arctic cod also apply to coastal cod. These include minimum catch size, minimum mesh size, maximum bycatch of undersized fish, and closure of areas having high densities of juveniles. In addition, trawl fishing for cod is not allowed inside the 6-n.mile, and since the mid-1990s the fjords in Finnmark and northern Troms (areas 03 and 04) have been closed for fishing with Danish seine. Since 2000 the large long-liners have been given restrictions and are now only allowed to fish outside the 4 nautical mile. Since 2004 additional restrictions on coastal fisheries have been introduced to reduce catches of coastal cod. In these new regulations “fjord-lines” are drawn along the coast to close the fjords for direct cod fishing with vessels larger than 15 meters. A box closed for all fishing gears except handline and fishing rod is defined in the Henningsvær-Svolvær area. This is an area where spawning concentrations of coastal cod are usually observed and where the catches of coastal cod have been high. Since the coastal cod is fished under a combined coastal cod/North-east arctic cod quota, these regulations are supposed to turn parts of the traditional coastal fishery over from catching coastal cod in the fjords to catch more cod outside the fjords where the proportion of Northeast Arctic cod is higher. Further restrictions were introduced in 2007 by not allowing pelagic gillnet fishing for cod and by reducing the allowed bycatch of cod when fishing for other species inside fjord lines from 25% to 5%, and outside fjord-lines from 25% to 20%. Since 2009 a fjord area near Ålesund has been closed in the spawning season for fishing with all gears except handline and fishing rod.

Recreational and tourist fishing

Recreational and tourist fishing occurs all along the coast. The total amount of coastal cod taken in these fisheries is considered to be rather large. In 2010 and later years 7000 t of the Norwegian cod quota has been set aside to cover the catches taken in the recreational and tourist fisheries and to cover catches taken by young fishers (to motivate young people to become fishers).

The time-series for this fishery is considered highly uncertain (Hallenstvedt and Wulf, 2004, WD 17 AFWG 2010). It shows a rather constant catch over the time-series. WKARCT propose to assume a constant fishing mortality as an alternative approach to illustrating the effect of these fisheries.

A.3. Ecosystem aspects

Not investigated

B. Data

B.1 Commercial catch

In 1996, a time-series of coastal cod numbers-at-age in catches inside the 12 nautical mile zone was presented to AFWG. Reported catches of cod were separated into Norwegian coastal cod and North-east Arctic cod based on biological sampling (Berg, *et al.*, 1998) The method is based on otolith-typing (Rollefsen, 1933). The catches of Norwegian coastal cod (NCC) were calculated back to 1984 using available data on otolith typing. This has been updated annually and reported to AFWG. During this period (1984–2013) the catches have been between 22 000 and 75 000 t. Further details are described in the stock Annex of the AFWG report in 2014 and earlier years.

At the meeting of WKARCT 2015 a new time-series of catch-at-age and weight at age was presented. The main reasons for recalculating the series were:

- The Norwegian catches used in the historical NEAC-assessment and the CC-assessment for the years 1984-2012 do not add up to the total Norwegian annual catch;
- Improving NEAC/CC split by using the ECA-model (Hirst *et al.*, 2012), utilizing both otolith typing and length/age-differences, and providing uncertainty estimates;
- Including coastal cod at coastal banks outside 12 nautical mile.

At WKARCT 2015 the data were accepted as relevant information for describing the stock dynamics. The reasons for the differences between the old and new series are not clear and need to be further explored.

Norway accounts for all NCC landings. The text table below shows which kind of data are collected:

Kind of data					
Country	Caton (catch in weight)	Canum (catch-at-age in numbers)	Weca (weight at age in the catch)	Matprop (proportion mature by age)	Length composition in catch
Norway	X	X	X	X	X

B.2. Biological

Weight at age in the stock is obtained from the Norwegian coastal survey in from 1995 onwards. From 1984 to 1994 weight at age in stock is taken from weight at age in the catch because no survey data from this period are available. The mean values are weighted by biomass in the respective areas. A fixed natural mortality of 0.2 is used in the assessment. Some fjord studies (Pedersen and Pope, 2003a and b, Mortensen 2007, Pedersen *et al.*, 2007) indicate that the main predators on young cod are larger cod, cormorants and saithe. There are no estimates of annual predation mortality for the stock complex.

Both the proportion of natural mortality before spawning (M_{prop}) and the proportion of fishing mortality before spawning (F_{prop}) are set to 0.

B.3. Survey

Since 1995 a Norwegian trawl-acoustic survey (Norwegian coastal survey) specially designed for coastal cod has been conducted annually in September (prior to 2003) and in October-November (28 days). The survey covers the fjords and coastal areas from the Varangerfjord close to the Russian border and southwards to 62°N. The aim of conducting an acoustic survey targeting Norwegian coastal cod has been to support the stock assessment with fishery-independent data of the abundance of both the commercial size cod as well as the youngest prerecruit coastal cod. The survey therefore covers the main areas where the commercial fishery takes place, normally dominated by 4–7 year old fish.

The 0- and 1 year-old coastal cod, mainly inhabiting shallow water (0–50 m) near the coast and in the fjords, are also represented in the survey, although highly variable from year to year. However, the 0-group cod caught in the survey is impossible to

classify to NCC or NEAC by the otoliths since the first winter zone is used in this separation. A total number of about 150 trawl hauls are conducted during the survey.

The survey abundance indices at age are total numbers (in thousands) computed from the acoustics.

Ages 2–8 are used in the XSA-tuning.

B.4. Commercial cpue

No commercial cpue are available for this stock.

B.5. Other relevant data

A number of bottom-trawl tows are made during the coastal survey, and since 2003 the survey has aimed for towing at the same fixed positions each year. This might be used to calculate a bottom-trawl index.

C. Historical stock development

Using the new coastal cod catch in number series in an XSA tuned by the coastal survey gave poorer diagnostics than when using the old series. It is recommended not to use XSA tuned by the acoustic survey as a basis for a full analytic assessment. The converged period is relevant to the historic trends and stock dynamics. The converged part can also be used for “calibrating” survey mortalities for the purpose of estimating recent F_s from survey mortality, as described in the Stock Annex since 2010 (see below). Using the XSA for estimating the historic series of SSB should take account of the time-lag between spawning time and the time of the survey, where maturity and stock weights are observed. The maturity based on commercial sampling presented at the 2012 AFWG should be updated and considered for use.

Current approach

Since about 2006 the XSA assessment (tuned by 1 survey series) has been considered relevant to historic trends only. The 2010 AFWG was asked to evaluate a rebuilding plan for coastal cod, which then created a need for a more robust analytical assessment. In addition, a new time-series on catch-at-age in the recreational fishery was presented and added to the canum for commercial catches. It is recommended to continue that procedure.

An estimate of F in the latest survey year (F_{term}) is obtained from surveys by calibrating survey Z_s to the F_s in the converged part of a trial XSA. These estimates are used for deciding on a best estimate of (F_{term}) that is further used as terminal F in a traditional VPA. Selection at age in the terminal year and F_{old} for earlier years is taken from the trial XSA. The traditional VPA is then taken as the final assessment.

Further details on the procedure:

- 1) Run a trial XSA (IFAP / Lowestoft VPA suite) with updated catch-at-age and survey data with the following model options chosen:
 - a) Tapered time weighting applied, power = 3 over 20 years
 - b) Catchability independent of stock size for all ages
 - c) Catchability independent of age for ages ≥ 8
 - d) Survivor estimates shrunk towards the mean F of the final 2 years or the 4 oldest ages

- e) S.E. of the mean to which the estimate are shrunk = 1.0
- f) Minimum standard error for population estimates derived from each fleet = 0.300
- g) Prior weighting not applied
- h) Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1984–last data year	2–10+	Yes
Canum	Catch-at-age in numbers	1984–last data year	2–10+	Yes
Weca	Weight at age in the commercial catch	1984–last data year	2–10+	Yes
West	Weight at age of the spawning stock at spawning time. (shifted to January the following year)	1984–last data year	2–10+	Yes, but for the period 1984-1994 set equal to the average of 1995-2000
Mprop	Proportion of natural mortality before spawning	1984–last data year	2–10+	No, set to 0 for all ages in all years
Fprop	Proportion of fishing mortality before spawning	1984–last data year	2–10+	No, set to 0 for all ages in all years
Matprop	Proportion mature at age	1984–last data year	2–10+	Yes, observed from catch sampling March-April
Natmor	Natural mortality	1984–last data year	2–10+	No, set to 0.2 for all ages in all years
Tuning fleet	Norwegian coastal survey	1995–last data year	2–8	

1) Estimate annual $F(4-7)$ from survey Z at age

- a) Survey Z at age a in year y is calculated as $Z_{a,y} = -\text{Log}(U_{a+1,y+1} / U_{a,y})$ where U is the survey index (observed late in the year). If both catchability and natural mortality is stable between years, those factors will only influence the scaling of the “survey mortality” while the trends observed would be driven by F . Within years the Z -values have been averaged over various age groups, and the 4–9 average have shown the highest correlation with the $F(4-7)$ in the converged years of the trial XSA (1995–2005 in the 2010 assessment. 1995–2006 in the 2011 and 2012 assessment). The annual values of $Z(4-9)$ is then fitted by a linear regression to the $F(4-7)$ in the converged part of the VPA, and the regression parameters are used to convert $Z(4-9)$ to $F(4-7)$ for the terminal year.
- b) Average F at age for the 3 latest years in the trial XSA is then scaled to this survey based $F(4-7)$ and further used as terminal F at age in a standard VPA

(“user-defined VPA” in the Lowestoft version of the program). The historical Fs for the oldest true age group are also taken from the trial XSA.

2) The procedure is repeated for total catch including recreational fisheries

The current time-series of recreational and tourist catches has a rather weak basis and shows nearly constant catches over time. As long as no further information is available, a fixed recreational F (fixed effort assumption) or a recreational F scaled to indicators of effort could be used as alternative scenarios to illustrate the effect of these rather unknown catches.

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Annex 6. 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 (<i>Mallotus villosus</i>) in Subareas I and II (Northeast Arctic), excluding Division IIa west of 5°W (Barents Sea capelin)
Working Group:	Arctic Fisheries Working Group
Date:	January 2015
Revised by	WKARCT, Samuel Subbey (stock coordinator)

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.

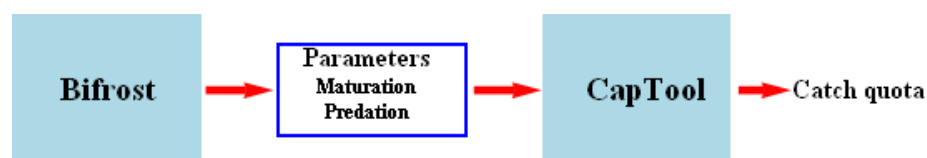


Figure 1. Relation between the models Bifrost and CapTool

CapTool is described in detail by Gjørseter *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.

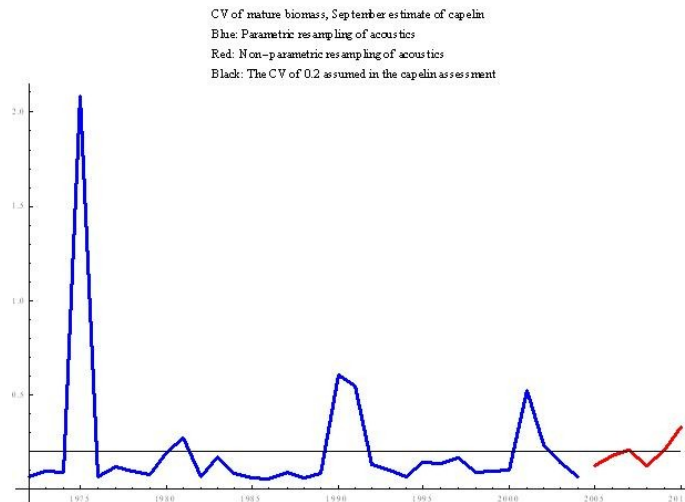


Figure 2. CV from resampling historic September surveys. The value 0.2 is shown as a horizontal black line.

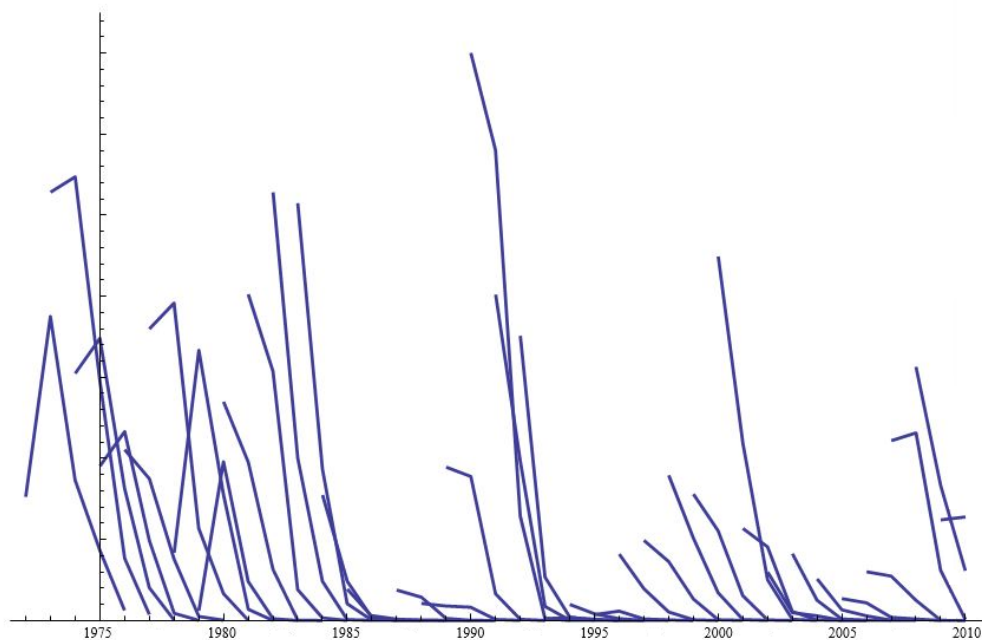


Figure 3. Development of year classes 1971–2009— Number-at-ages 1-4 (in billions) from the September survey.

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:

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

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. Usually P_2 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.

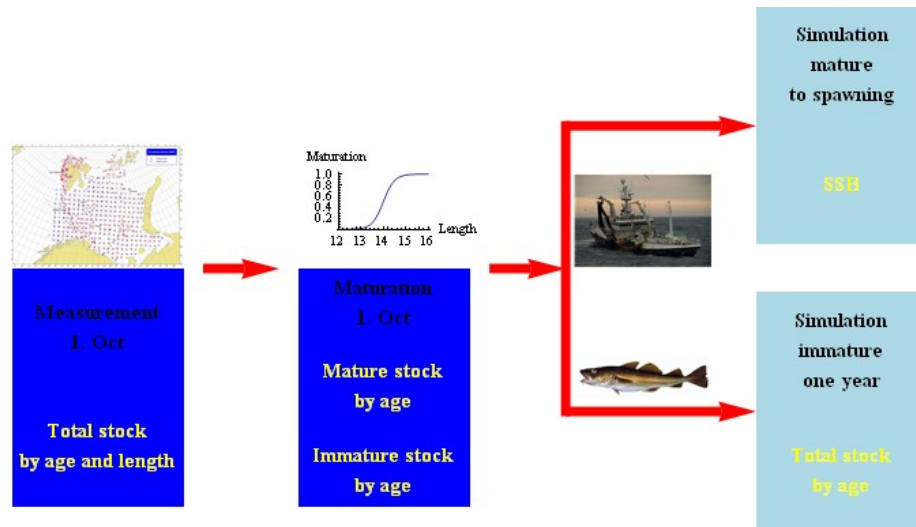


Figure 4. Overview of Bifrost simulation.

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 P_3 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.

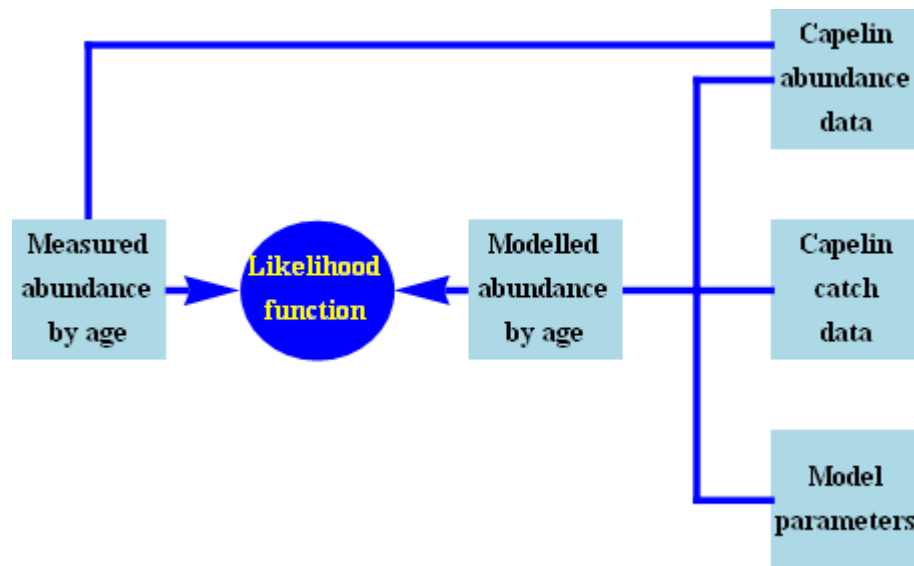


Figure 5. Estimation of maturation parameters in Bifrost.

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 P_1 , P_2 and P_3 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.

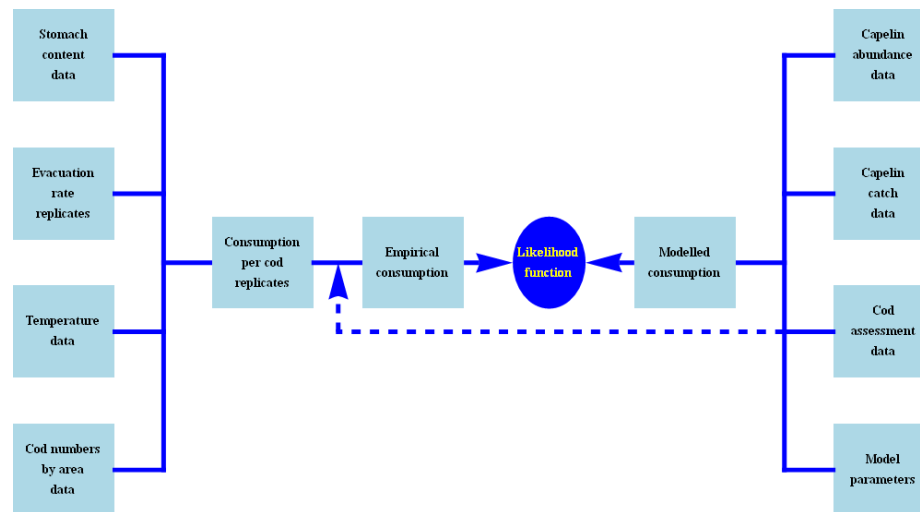


Figure 6. Estimation of predation parameters in Bifrost.

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.

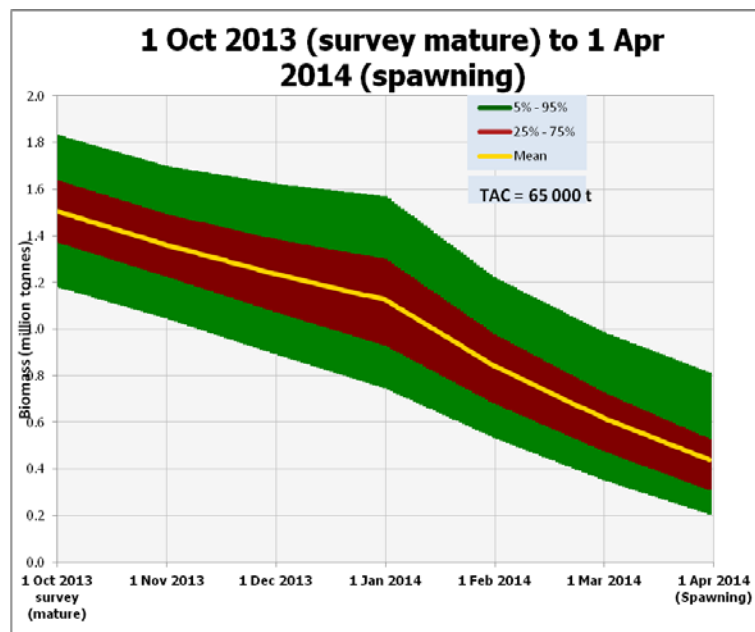


Figure 7. Simulation output from CapTool, from the autumn 2013 assessment

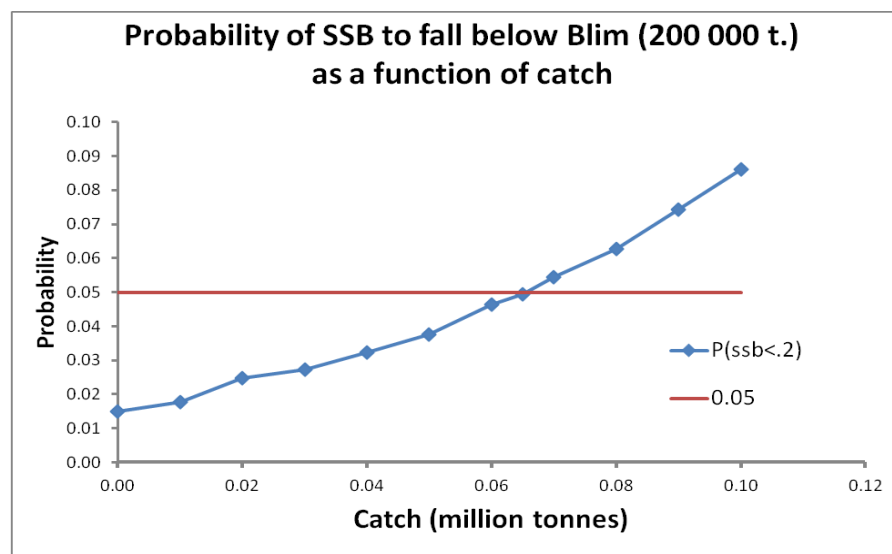


Figure 8. Risk level as a function of the quota, from the assessment of autumn 2013.

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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Annex 7. Stock annex Haddock (*Melanogrammus aeglefinus*) in Subareas I and II (Northeast Arctic)

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Haddock (<i>Melanogrammus aeglefinus</i>) in Subareas I and II (Northeast Arctic)
Working Group:	Arctic Fisheries Working Group
Date:	18.02.2015
Revised by:	WKARCT 2015 / AFWG 2015, Alexey Russkikh (stock coordinator), Gjert Endre Dingsør, Bjarte Bogstad

A. General

A.1. Stock definition

The North-East Arctic Haddock (*Melanogrammus aeglefinus*) is distributed in the Barents Sea and adjacent waters, mainly in waters above 2°C. Tagging carried out in 1953–1964 showed that Northeast Arctic haddock inhabits the continental shelf of the Barents Sea, adjacent waters and polar front. The main spawning grounds are located along the Norwegian coast and area between 70°30' and 73°N along the continental slope, but spawning also occurs as far south as 62°N. Larvae are dispersed in the central and southern Barents Sea by warm currents. The 0-group haddock drifts from the spawning grounds eastwards and northwards and during the international 0-group survey in August it is observed over wide areas in the Barents Sea. Until maturity, haddock are mostly distributed in the southern Barents Sea being their nursery area. Having matured, haddock migrate to the Norwegian Sea.

A.2. Fishery

Haddock are harvested throughout the year; in years when the commercial stock is low, they are mostly caught as bycatch in cod trawl fishery; when the commercial stock abundance and biomass are high, haddock are harvested during their target fishery. On average approximately 75% of the catch is taken by trawl while 25% of the catch is with conventional gears, mostly longline, which are used almost exclusively by Norway. Part of the longline catches are from a directed fishery.

The fishery is restricted by national quotas. In the Norwegian fishery the quotas are set separately for trawl and other gears. The fishery is also regulated by a minimum landing size, a minimum mesh size in trawls and Danish seine, a maximum bycatch of undersized fish, closure of areas with high density/catches of juveniles and other seasonal and areal restrictions.

In recent years Norway and Russia have accounted for more than 90% of the landings. Each country fishing for haddock and engaged in the stock assessment provides catch statistics annually (see section B.1). Summary sheets in the AFWG Report indicate total yield of haddock by Subareas I, IIa and IIb, as well as catch by each country by years. Catch information by fishing gear used by Norway in the haddock fishery is used internally when making estimations at AFWG meeting. Catch quotas were in-

troduced in the trawl fishery in 1978 and for the fisheries with conventional gears in 1989. Since January 1997 sorting grids have been mandatory for the trawl fisheries in most of the Barents Sea and Svalbard area. Discarding is prohibited.

From 01.01.2011, the minimum catching size of haddock is 40 cm in the Russian Economic zone, the Norwegian Economic zone, and the Svalbard area. It is allowed that up to 15% (by number) of the fish is below the minimum catching size of (this is counted for cod, haddock and saithe combined), larger proportions of undersized fish lead to closure of areas. The minimum mesh size in trawl codends is 130 mm. The fisheries are controlled by inspections at sea, requirement of reporting to catch control points when entering and leaving the EEZs and by inspections when landing the fish for all fishing vessels. Keeping a detailed fishing logbook on board is mandatory for most vessels, and large parts of the fleet report to the authorities on a daily basis. There is some evidence that the present catch control and reporting systems are insufficient to prevent discarding and underreporting of catches. However, since 2005 Port State Control (PSC) has been implemented, which should prevent IUU catches in the Barents Sea.

The historical high catch level of 320 000 tonnes in 1973 divides the time-series into two periods. In the first period, highs were close to 200 000 tonnes around 1956, 1961 and 1968, and lows were between 75 000 and 100 000 tonnes in 1959, 1964 and 1971. The second period showed a steady decline from the peak in 1973 down to the historically low level of 17 300 tonnes in 1984. Afterwards, landings increased to 151 000 tonnes before declining to 26 000 tonnes in 1990. A new increase peaked in 1996 at 174 000 tonnes. Three strong year classes (2004–2006) have caused peak catches in the recent years. The highest catch (315 000 t) was in 2012. The exploitation rate of haddock has been variable (F between 0.2 and 0.5 in the last 20 years).

The highest fishing mortalities for haddock have occurred at intermediate stock levels and show little relationship with the exploitation rate of cod, despite haddock being primarily a bycatch in the cod fishery. The exception is the 1990s when more restrictive quota regulations resulted in a similar pattern in the exploitation rate for both species. It might be expected that good year classes of haddock would attract more directed trawl fishing, but this is not reflected in the fishing mortalities.

Since 2007, estimates of unreported catches (IUU catches) of haddock have been added to reported landings for the years 2002 and onwards. In 2007–2008, two assessments were presented, based on Norwegian and Russian estimates of IUU catches, respectively. The basis for the Norwegian IUU estimates ($N - IUU$) is the annual ratio between cod and haddock in the international reported landings from Sub - area I and Division II b in 2002–2008. These ratios are assumed to be representative of the ratios in the IUU catches. The ratio is applied to the estimated IUU catches of cod in order to get the estimate for haddock. The estimates are similar to those made by the Norwegian Directorate of Fisheries for 2005–2008. The Russian estimates of IUU haddock are obtained by applying the same ratio, but using the Russian estimate of IUU catches of cod in 2002–2007. Both approaches show an increase from 2002 to 2005 followed by a decline. In 2010 the Working Group decided to set the IUU estimate for haddock in 2009 to 0. During the benchmark meeting in 2011, as in recent AFWG, it was decided to use Norwegian estimates for the period 2002–2008, because from 2009 onwards IUU catches equal Zero and only small differences exist in final estimates using both values of IUU.

A.3. Ecosystem aspects

The composition and distribution of species in the Barents Sea depend considerably on the position of the polar front which separates warm and salty Atlantic waters from colder and fresher waters of arctic origin. Variation in the recruitment of haddock has been associated with the changes in the influx of Atlantic waters to the large areas of the Barents Sea shelf.

Independently from age and season, haddock vary their diet and will prey on plankton or benthic organisms. During the spawning migration of capelin (*Mallotus villosus*) haddock prey on capelin and their eggs on the spawning grounds. When the capelin abundance is low or when their areas do not overlap, haddock can compensate by eating other fish species (e.g. young herring) or euphausiids and benthic organisms. Haddock growth rate depends on the population abundance, stock status of main prey species and water temperature.

Water temperature at the first and second years of the haddock life cycle is a fairly reliable indicator of year-class strength. If mean annual water temperature in the bottom layer during the first two years of haddock life does not exceed 3.75°C (Kola-section), the probability that strong year classes will appear is very low even under favourable effects of other factors. A steep rise or fall of the water temperature shows a marked effect on abundance of year classes (Landa *et al.*, 2014).

Nevertheless, water temperature is not always a decisive factor in the formation of year-class abundance. Strength of year classes is also determined to a great extent by size and structure of the spawning stock. Under favourable environmental conditions, strong year classes are mainly observed in years when the spawning stock is dominated by individuals from older age groups with abundance at a fairly high level.

Annual consumption of haddock by marine mammals, mostly seals and whales, depends on stock status of capelin as their main prey. In years when the capelin stock is large the importance of haddock in the diet of marine mammals is minimal, while under the capelin stock reduction a considerable increase in consumption by marine mammals of all the other abundant gadoid species including haddock is observed (Korzhev and Dolgov, 1999; Bogstad *et al.*, 2000).

The appearance of strong haddock year classes usually leads to a substantial increase in natural mortality of juveniles as a result of cod predation.

B. Data

B.1. Commercial catch

Norway

Norwegian commercial catch in tonnes by quarter, area and gear are derived from the sales notes statistics of The Directorate of Fisheries. Data from about 20 subareas are aggregated on 6 main areas for the gears gillnet, longline, handline, purse-seine, Danish seine, bottom trawl, shrimp trawl and trap. For the bottom trawl, the quarterly area distribution of the catches is adjusted by logbook data from The Directorate of Fisheries and the total bottom-trawl catch by quarter and area is adjusted so that the total annual catch for all gears is the same as the official total catch reported to ICES. No discards are reported or accounted for.

The sampling strategy is to have age and length samples from all major gears in each main area and quarter. The main sampling program is sampling the landings. Additional samples from catches are obtained from the coast guard, from observers and from crew members reporting, according to an agreed sampling procedure (reference fleet).

The ECA software (Hirst *et al.*, 2012) has been developed to utilize all sampling information to estimate catch-at-age for areas (I, IIa, and IIb), quarters and gears (bottom trawl, gillnet, Danish seine and longline/handline). This method replaced the traditional method in 2006, and the time-series of Norwegian catch-at-age (early 80's and onward) was updated based on the modelling approach. The old method involved allocating unsampled catches to sampled catches based on judgements on "distance criteria's" (in area, time and sometimes gear) and the use of ALK's to fill holes in the sampling frame.

Russia

Russian commercial catch in tonnes by season and area are derived from the Russian Federal Research Institute of Marine Fisheries and Oceanography (VNIRO, Moscow) statistics department. Data from each fishing vessel are aggregated on three ICES Subdivisions (I, IIa, and IIb). Russian fishery by passive gears was almost stopped by the end of the 1940s. Until late 1990's, relative weight (percentage) of haddock taken by bottom trawls in the total Russian yield exceeded 99%. Only in recent years an upward trend in a proportion of Russian longline fishery for haddock was observed to be up to 5% on the average and longline catches were taken into account for estimation catch-at-age matrix.

The sampling strategy was to conduct mass measurements and collect age samples directly at sea, onboard both research and commercial vessels to have age and length distributions from each area and season. Data on length distribution of haddock in catches are collected in areas of cod and haddock fishery all the year-round by a "standard" fishery trawl and summarized by three ICES Subareas (I, IIa, and IIb).

Age sampling was carried out in two ways: without any selection (otoliths were taken from any fish caught in one trawl, usually from 100–300 specimen or using a stratified by length sampling method (i.e. approximately 10–15 specimen per each 10 cm length group). The last method has been used since 1988.

All fish taken for age-reading were measured and weighed individually.

Data on length distribution of haddock catches, as well as age-length keys, are formed for each ICES Subarea, each fishing gear (trawl and longline) for the whole year. Catches-at-age are reported to ICES AFWG by subdivision (I, IIa, and IIb) for the whole year. In the case of lack of data by ICES Subareas, information on size-age composition of catches from other areas is used.

Germany

Catches-at-age were reported to the WG by ICES Subdivision (I, IIa, and IIb) according to national sampling. Missing subdivisions were filled in by use of Russian or Norwegian sampling data.

Other nations

Total annual catch in tonnes is reported by ICES Subdivisions or by Russian and Norwegian authorities directly to WG. All catches by other nations are taken by

trawl. The age composition from the sampled trawl fleets is therefore applied to the catches by other nations.

The table below shows which country supplied which kind of data:

Kind of data					
Country	Caton (catch in weight)	Canum (catch-at-age in numbers)	Weca (weight at age in the catch)	Matprop (proportion mature by age)	Length composition in catch
Norway	X	X	X	X	X
Russia	X	X	X	X	X
Germany	X	X	X		X
UK	X				
France	X				
Spain	X				
Portugal	X				
Ireland	X				
Greenland	X				
Faroe Islands	X				
Iceland	X				
Poland	X				
Belarus	X				

The combined catch data were previously estimated by the SALLOC program (Patterson, 1998). The national data from 2009 and onwards are available in Intercatch (ICES database); earlier data should be found in the national laboratories and with the stock coordinator.

For 1983 and later years, mean weight at age in the catch is calculated as the weighted average for the sampled catches. For the earlier period (1946–1982) mean weight at age in catches is set equal to mean weight at age in the catch for period 1983–2009.

The resulting files can be found on ICES (SharePoint) and with the stock coordinator as ASCII files in the Lowestoft format.

B.2. Biological

Weights and length-at-age in the stock and proportion of mature fish to ages 1–11 are derived from Russian surveys in autumn (mostly October–December) and Norwegian surveys in January–March for the period from 1983 and onwards. In 2006 the AFWG, based on WKHAD06 investigations, decided to smooth raw data of stock weight-at-age and maturity-at-age using models in order to remove some of the sampling variability of the estimates. On benchmarks in 2011 and 2015 this practice was continued.

Mean length-at-age is calculated from the bottom-trawl surveys. A von Bertalanffy function is fitted to the data:

$$L = L_{\infty} - L_{\infty} \cdot e^{(-K_Y(A-A_0))}$$

with L and A being the length and age variables. L_{∞} and A_0 are constants, estimated on the entire time-series, while K_Y depends on year class. Weight-at-age is then fitted with:

$$W = \alpha \cdot L^{\beta}$$

where α and β are constants and L are smoothed lengths.

Norwegian maturity data are smoothed by fitting a logistic function using both age, A , and length, L , as explanatory variables:

$$\log\left(\frac{m}{1-m}\right) = I + \alpha A + \beta L$$

Russian maturity data are smoothed by fitting a logistic function using age, A , and year class dependent age at 50% maturity, $A_{50\%}$, as explanatory variables:

$$Mat = \frac{1}{1 + e^{(-\alpha \cdot (A - A_{50\%}))}}$$

Estimates were produced separately for the Russian autumn survey and the joint winter survey and were later combined using an arithmetic average. These averages are assumed to give representative values for the beginning of the year.

Norwegian lengths-at-age are used to estimate mean weights-at-age and maturity-at-age for the period 1980–1982.

The combined data on weight-at-age in stock and proportion of mature fish by age group for the period (1950–1979) are set equal to mean values for period 1980–2010 from the benchmark in 2011.

Natural mortality used in the assessment is estimated as 0.2 + mortality from predation by cod. The method used for calculation of the prey consumption by cod described by Bogstad and Mehl (1997) is used to calculate the consumption of haddock by cod. The consumption is calculated based on cod stomach content data taken from the joint PINRO-IMR stomach content database (methods described in Mehl and Yaragina, 1992). On average about 9000 cod stomachs from the Barents Sea have been analysed annually in the period 1984–2013.

The estimated consumption of NEA haddock by NEA cod is incorporated into the XSA analysis on first step by constructing catch-at-age matrix, adding estimated numbers of haddock eaten by cod to the catches for the ages 1–6, for years where such data are available (1984–present). The fishing mortality estimated by the XSA is split into the mortality caused by the fishing fleet (F) and the mortality caused by the cod's predation ($M2$) according to the ratio of fleet catch and predation "catch". The new natural mortality dataset were then prepared by adding 0.2 ($M1$) to the predation mortality. This new M matrix is used in the final XSA. Natural mortality for period without observations (1950–1983) is replaced by mean values for period 1984–2010.

In the SAM model the extra mortality caused by cod predation is added using the method suggested by A. Nielsen; i.e. add predation to the landings, and then track these separately in the outputs. The landing fraction is then defined as $Catch/(Catch+Predation)$.

Both the proportion of natural mortality before spawning (M_{prop}) and the proportion of fishing mortality before spawning (F_{prop}) are set to 0. The peak spawning occurs most years in the middle of April.

B.3. Surveys

Russian surveys of cod and haddock in the southern Barents Sea started in the late 1940s as trawl surveys of young demersal fish. Since 1957 such surveys have been conducted over the whole feeding area including the Bear Island-Spitsbergen area (Baranenkova, 1964; Trambachev, 1981); both young and adult haddock have been surveyed simultaneously. Duration of the survey has declined from 5-6 months (September-February) in 1946–1981 to 2-2.5 months (October-December) since 1982. The aim of the survey is to investigate both the commercial size haddock as well as the young haddock. The survey covers the main areas where juveniles settle to the bottom, as well as the area where the commercial fishery takes place. A total number of more than 400 trawl hauls are conducted during the survey (mainly bottom trawl, a few pelagic trawls). In 1984, acoustic methods started to be implemented during surveys of fish stocks (Zaferman and Serebrov, 1984; Lepesevich and Shevelev, 1997; Lepesevich *et al.*, 1999). From 1995 onwards there has been a substantial change in the method for calculating acoustic indices, which allowed the differentiation and registration of echo intensities from fish of different length (Shevelev *et al.*, 1998).

There are two Russian survey abundance indices at age available: 1) absolute numbers (in thousands) computed from the acoustics estimated by the new method (RU-Aco-Q4) for the period 1995–2009 (ages 0-10); 2) trawl index, calculated as relative numbers per hour trawling (RU-BTr-Q4) for the period 1983–2013 (ages 0-9).

The indices (RU-Aco-Q4) were not used for tuning the XSA due to a strong “year effect” observed in years with incomplete area coverage. This index needs further adjusting before it can be used for tuning.

The Norwegian winter (February) survey (from 2000 - Joint Barents Sea survey) started in 1981 and covers the ice-free part of the Barents Sea. Both swept-area estimates from bottom-trawl and acoustic estimates are produced. The survey is described in Jakobsen *et al.*, (1997) and Mehl *et al.*, (2013, 2014).

Before 2000 this survey was made without participation from Russian vessels, while in the three latest surveys Russian vessels have covered important parts of the Russian zone. The indices for 1997 and 1998, when the Russian EEZ was not covered, have been adjusted as reported previously (Mehl, 1999). The number of fish (age group by age group) in the Russian EEZ in 1997 and 1998 was interpolated assuming a linear development in the proportion found in the Russian EEZ from 1996 to 1999. These estimates were then added to the numbers of fish found in the Norwegian EEZ and the Svalbard area in 1997 and 1998.

It should be noted that the survey conducted in 1993 and later years covered a larger area compared to previous years (Jakobsen *et al.*, 1997). Other changes in the survey methodology through time are described by Jakobsen *et al.*, 1997. Note that the change from 35 to 22 mm mesh size in the codend in 1994 has not been corrected for in the time-series. This mainly affects the age 1 indices. There are two abundance indices at age from that survey available for stock assessment:

- 1) swept-area estimates from bottom trawl (NoRu-BTr-Q1) for the period 1981-2014 (ages 1-10);

- 2) swept-area estimates from acoustic (NoRu-Aco-Q1) for the period 1981-2014 (ages 1-10).

Bottom-trawl estimates from the joint Norwegian-Russian ecosystem survey in August-September started in 2004. This survey covers a larger portion of the distribution area of haddock. The index (Eco-NoRu-Btr-Q3) for the period 2004–2013 and ages 1-8 was available for AFWG 2014. This time-series was accepted as a new tuning fleet in XSA during the benchmark in 2011. The survey methodology and results are described in annual survey reports (Prokhorova, 2013). Unfortunately, there is at present no agreed method for calculating bottom-trawl indices from this survey (Dingsør, WD17, WKARCT 2015 vs. ICES AFWG 2014 Table A14). Agreeing on a common methodology has very high priority.

Based on the test made during WKBENCH 2011 (ICES 2011a) and previous AFWG work it is decided to use only tuning indices for the period 1990 and onwards.

B.4. Commercial cpue

Russia

No Russian data are used in the stock assessment.

Norway

Historical time-series of observations onboard Norwegian trawlers were earlier used for tuning of older age groups in VPA. The basis was catch per unit of effort (cpue) in Norwegian statistical areas 03, 04 and 05 embracing coastal banks north of Lofoten, on which approximately 70% of Norwegian haddock catch was taken. However, the proportion of haddock taken as bycatch is pretty high and thus it is difficult to estimate their actual catch per unit of effort. Since 2002, cpue indices have not been used in XSA tuning.

B.5. Other relevant data

Not used.

C. Assessment: data and method

Model used: XSA (Darby and Flatman, 1994), SAM (State-space assessment model) (<https://www.stockassessment.org>; Nielsen and Berg, 2014). Software used: for XSA–FLR suite (and VPA95 suite), for SAM – AD Model Builder (ADMB) and R.

The 2015 Benchmark Assessment (WKARCT, ICES 2015) recommended to expand the age range from 3-11+ to 3-13+ (WKARCT WD 4 and WD 12).

Input data types and characteristics used in both models:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1950 – last data year		Yes
Canum	Catch-at-age in numbers	1950 – last data year	3 – 13+	Yes
Weca	Weight at age in the commercial catch	1950 – last data year	3 – 13+	Yes, constant -> 1982
West	Weight at age of the spawning stock at spawning time.	1950 – last data year	3 – 13+	Yes, constant -> 1982
Mprop	Proportion of natural mortality before spawning	1950 – last data year	3 – 13+	No – set to 0 for all ages in all years
Fprop	Proportion of fishing mortality before spawning	1950 – last data year	3 – 13+	No – set to 0 for all ages in all years
Matprop	Proportion mature at age	1950 – last data year	3 – 13+	Yes, constant -> 1981
Natmor (SAM)	Natural mortality	1950 – last data year	3 – 13+	No – set to 0.2 for all ages in 1984-2013; 1984-2010 average used for the years 1950-1983
Natmor (XSA)	Natural mortality	1950 – last data year	3 – 13+	Includes annual est. of predation by cod from 1984, set to 1984-2010 average for the years 1950-1983
Landing Fraction	consumption	1984 – last data year	3-6	=C/(C+predation)

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1	RU-BTr-Q4	1991 – last data year	3-7
Tuning fleet 2	BS-NoRU-Q1(Aco)	1992 – last data year	3-7
Tuning fleet 3	BS-NoRu-Q1 (BTr)	1992 – last data year	3-8
Tuning fleet 4	Eco-NoRu-Q3 (Btr)	2004 – last data year	3-8

The input data used for SAM are the same as for XSA. Although it is not required, winter survey tuning indices are backshifted as it is done for XSA. The extra mortality caused by cod predation is added using the method suggested by A. Nielsen; i.e. add predation to the landings, and then track these separately in the outputs. The landing fraction is then defined as $\text{Catch}/(\text{Catch}+\text{Predation})$. The model fit for haddock is best when the individual log F-processes are allowed to develop correlated in time, and the correlation is set to reflect the intuition that neighbouring age classes should have more similar fishing mortalities. This correlation structure is commonly named AR(1) (Nielsen and Berg 2014). The survey catchabilities are represented by power models, choosing linear models inflates the stock estimates far beyond any reasonable stock sizes. The recruitment model is represented by the Beverton–Holt equation. The configuration is given below.

Model Options chosen for SAM (Model.cfg).

```
# Min Age (should not be modified unless data are modified accordingly)
3

# Max Age (should not be modified unless data are modified accordingly)
13

# Max Age considered a plus group (0=No, 1=Yes)
1

# The following matrix describes the coupling
# of fishing mortality STATES
# Rows represent fleets.
# Columns represent ages.
#3      4      5      6      7      8      9      10     11     12     13
#flat F from age 9
1       2       3       4       5       6       7       7       7       7       7
0       0       0       0       0       0       0       0       0       0       0
0       0       0       0       0       0       0       0       0       0       0
0       0       0       0       0       0       0       0       0       0       0
0       0       0       0       0       0       0       0       0       0       0

# Use correlated random walks for the fishing mortalities
# ( 0 = independent, 1 = symmetrical correlation estimated, 2=AR(1)-correlation estimated)
2

# Coupling of catchability PARAMETERS
0       0       0       0       0       0       0       0       0       0       0
1       1       2       2       2       0       0       0       0       0       0
3       3       4       4       4       0       0       0       0       0       0
5       5       6       6       6       7       0       0       0       0       0
```

8	8	9	9	9	10	0	0	0	0	0
---	---	---	---	---	----	---	---	---	---	---

Coupling of power law model EXPONENTS (if used)

0	0	0	0	0	0	0	0	0	0	0
1	1	2	2	2	0	0	0	0	0	0
3	3	4	4	4	0	0	0	0	0	0
5	5	6	6	6	7	0	0	0	0	0
8	8	9	9	9	10	0	0	0	0	0

Coupling of fishing mortality RW VARIANCES

1	2	2	2	2	2	2	2	2	2	2
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0

Coupling of log N RW VARIANCES

1	2	3	4	4	4	5	5	5	5	5
---	---	---	---	---	---	---	---	---	---	---

Coupling of OBSERVATION VARIANCES

1	2	2	2	2	2	3	3	3	3	3
4	4	5	5	5	0	0	0	0	0	0
6	6	7	7	7	0	0	0	0	0	0
8	8	9	9	9	10	0	0	0	0	0
11	11	12	13	13	14	0	0	0	0	0

Stock recruitment model code (0=RW, 1=Ricker, 2=BH, ... more in time)

2

Years in which catch data are to be scaled by an estimated parameter

0

first the number of years

Then the actual years

Them the model config lines years cols ages

Define Fbar range

4	7
---	---

Model options chosen For XSA:

Tapered time weighting applied, power = 3 over 20 years

Catchability independent of stock size for ages > 8

Catchability independent of age for ages > 8

Survivor estimates shrunk towards the mean F of the final 5 years or the 3 oldest ages

S.E. of the mean to which the estimate are shrunk = 1.500¹

Shrinkage to the population mean (p-shrinkage) not applied due to the strong effect of highly abundant yearclasses

Minimum standard error for population estimates derived from each fleet = 0.300

Prior weighting not applied

D. Short-Term Projection

Model used: Age structured

Software used: R and FLR suite, MFDP with management option table and yield-per-recruit routines.

Initial stock size: Estimated by model as abundance of individuals that survives the terminal year for age 3 and older.

Recruitment-at-age 3 for the start year and the 2 consecutive years is estimated from survey data in RCT3 using the tuning series as input.

F and M before spawning: assumed equal to 0 for all ages in all years.

Maturity: for current year smoothed actual data combined by Russian and Norwegian surveys are used; for subsequent years – using the fitted parameters and last year maturity as input.

Weight at age in the stock: for current year smoothed actual data combined by Russian and Norwegian surveys are used, for two years ahead, using the fitted parameters and last year lengths as input.

The Norwegian and Russian weight-at-age and maturity-at-age are then combined as arithmetic averages.

Weight at age in the catch show strong patterns related to periods of good recruitment. The Working Group decided to, for the time being, to use similar trends in weight at age, maturity-at-age and natural mortality as has been observed in previous periods following good recruitment. Attempts should be made to relate natural mortality to cod and capelin stock size. As for the exploitation pattern, this should be looked at again when the settings of the SAM model are finalized.

Intermediate year assumptions: Normally F status quo is used. If this corresponds to a catch which deviates considerably from the agreed TAC, one should consider other approaches.

Stock recruitment model used: Not required for short-term projection.

Procedures used for splitting projected catches: Not relevant.

E. Medium-Term Projections

Not required in assessment.

¹ During the benchmark in 2011 (ICES 2011) it was decided that the AFWG 2011 should evaluate different options for this value and make the final decision on the appropriate value. The AFWG 2011 decided to change this setting from 0.5 to 1.5.

F. Long-Term Projections

MSY and HCRs have previously been investigated using long-term stochastic simulations by ICES AFWG. Russkikh and Bogstad (2015) describes population models for use in evaluation of the harvest control rules for these stocks. Both models include stochastic stock–recruitment relationships and allow for density-dependence in growth and maturation. The model was generally considered suitable for evaluation of HCRs, although the actual parameter values need to be re-estimated following the adoption of a new assessment model. A stock–recruitment function with lognormally distributed error was found to be adequate for modelling the uncertainty in recruitment. Simulations should be run both for high and medium values of predation mortality induced by cod. The modelling of growth, maturation and exploitation pattern seems adequate. **This section of the Stock Annex is to be updated when long-term simulations have been carried out, with reference to the actual document giving results.**

G. Biological Reference Points

Based on the analysis of the stock recruitment plot it was proposed to keep $B_{lim}=50\,000$ t and $B_{pa}=80\,000$ t with the rationale that B_{lim} is equal to B_{loss} , and $B_{pa}=B_{lim}*\exp(1.645*\sigma)$, where $\sigma=0.3$. This gives a 95% probability of maintaining SSB above B_{lim} taking into account the uncertainty in the assessments and stock dynamics. For BMSY trigger was proposed equal B_{pa} , $B_{trigger}$ was then selected as a biomass that is encountered with low probability if FMSY is implemented, as recommended by WKFRAME2 (ICES CM 2011b). There is no standard method of estimating F_{lim} nor F_{pa} , and ACOM accepted to use geometric mean recruitment (146 million) and B_{lim} as basis for the F_{lim} estimate. F_{lim} is then based on the slope of line from origin at SSB=0 to the geometric mean recruitment (146 million) and SSB= B_{lim} . The SPR value of this slope gives the F_{lim} value on SPR curve; $F_{lim}=0.77$ (found using Pasoft). Using the same approach as for B_{pa} ; $F_{pa}=F_{lim}*\exp(-1.645*\sigma)=0.47$. $F_{MSY}=0.35$ has been estimated by long-term stochastic simulation (WD 16, AFWG 2011).

	Type	Value	Technical basis
MSY	MSY $B_{trigger}$	80 000 t	$B_{trigger}=B_{pa}$
Approach	FMSY	0.35	Stochastic long-term simulations
	B_{lim}	50 000 t	B_{loss}
Precautionary	B_{pa}	80 000 t	$B_{lim}*\exp(1.645*\sigma)$, where $\sigma=0.3$
Approach	F_{lim}	0.77	SSB= B_{lim} , SPR value of slope of line from origin at SSB=0 to geometric mean recruitment
	F_{pa}	0.47	$F_{lim}*\exp(-1.645*\sigma)$, where $\sigma=0.3$

H. Other Issues

H.1 Harvest control rule

The harvest control rule (HCR) was evaluated by ICES in 2007 (ICES CM 2007/ACFM:16) and found to be in agreement with the precautionary approach. The agreed HCR for haddock with the last modifications is as follows (Protocol of the 40th Session of The Joint Norwegian Russian Fishery Commission, 14 October 2011:

- TAC for the next year will be set at level corresponding to F_{MSY} .
- The TAC should not be changed by more than +/- 25% compared with the previous year TAC.

- *If the spawning stock falls below B_{pa} , the procedure for establishing TAC should be based on a fishing mortality that is linearly reduced from F_{MSY} at B_{pa} to $F=0$ at SSB equal to zero. At SSB-levels below B_{pa} in any of the operational years (current year and a year ahead) there should be no limitations on the year-to-year variations in TAC.*

As mentioned above F_{lim} and F_{pa} were revised in 2011. The new values of $F_{lim}=0.77$ and $F_{pa}=0.47$ are higher than the previous values (0.49 and 0.35, respectively). In the 2012 meeting of the Norwegian Russian Fishery Commission the proposals of ICES were accepted and the current HCR management is based on F_{MSY} instead F_{pa} . This corresponds to the goal of the management strategy for this stock and should provide maximum sustainable yield.

At the 39th Session of The Joint Norwegian Russian Fishery Commission in 2010 it was agreed that this HCR should be left unchanged for 5 years and then re-evaluated.

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Annex 8. Stock–recruitment model with autocorrelated residuals

Methods

The spawning stock and recruit estimates were taken from the ‘final’ northeast Arctic cod (NEA) cod XSA assessment, as agreed to on January 29, 2015. The units of spawning stock and recruitment are equal to that in the XSA model. The settings of the XSA model from which the stock and recruit estimates were taken are: p shrinkage off, f shrinkage s.e. is 1.5, the Russian commercial bottom-trawl CPE series was not used, the acoustic Norwegian/Russian quarter 1 survey used ages 3–9, and the ecosystem survey was included. Since recruitment is measured at age-3, the stock and recruit estimates were appropriately lagged three years, such that the stock in year y produced the recruits in year $y+3$. Life history characteristics necessary for estimates of unfished biomass, and subsequently steepness, equalled the values used for 2013 in the XSA stock assessment (Table A8.1). Selectivity was inferred by rescaling the F at age in 2013 to have a maximum of 1.0.

A Beverton–Holt (BH) stock–recruit (SR) model with and without autocorrelated (AR) residuals was fit to the SR data. The BH model without AR residuals was:

$$R_{y+3} = \frac{\alpha S}{(\beta + S)} e^{\epsilon_y}; \epsilon_y \sim \text{normal}\left(-\frac{\sigma^2}{2}, \sigma^2\right).$$

The mean of the residuals equals $-\frac{\sigma^2}{2}$ so that the recruit estimates are mean unbiased (i.e. this is a lognormal bias correction; without this the recruit estimates would be median unbiased).

The BH model with AR residuals was:

$$R_{y+3} = \frac{\alpha S}{(\beta + S)} e^{\epsilon_y};$$

$$\text{where } \epsilon_y = \rho \epsilon_{y-1} + \omega_y; \omega_y \sim \text{normal}\left(-\frac{\sigma_\omega^2}{2}, \sigma_\omega^2\right).$$

Additional details of the framework used to estimate the SR models is provided in the accompanying technical documentation and the program is publicly available for download at: <http://nft.nefsc.noaa.gov/>. Download is Stock Recruitment Fitting Model (SRFIT v7.0.1).

Results

The model with AR residuals provided a better fit than the model with uncorrelated residuals (Table A8.2). The difference in reference points and parameters of interest are summarized in Table A8.2.

The results of these fits could be used in projection models for NEA cod and for the estimation of biological reference points.

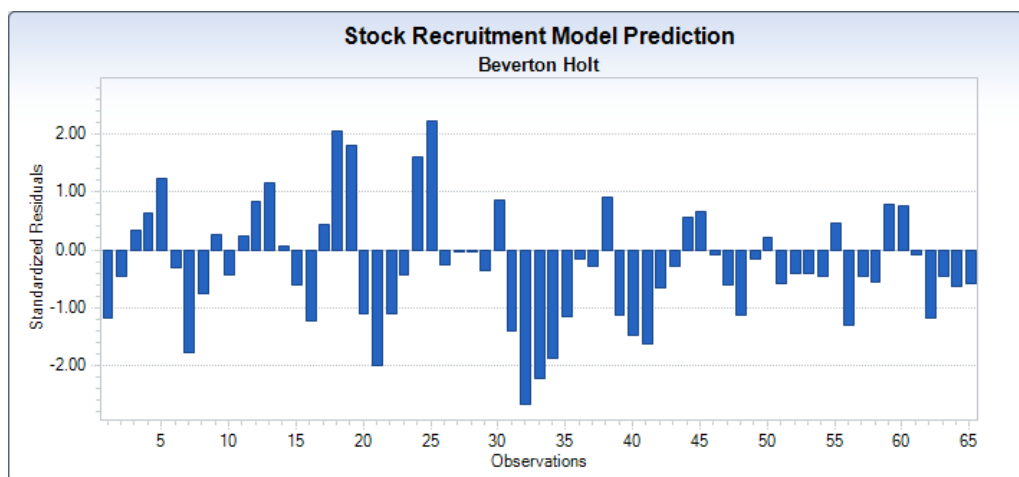







Figure A8.1. Standardized residuals of BH fit to stock and recruitment estimates of NEA cod assuming uncorrelated, lognormal, iid, residuals. Note larger and greater frequency of positive residuals early and generally negative residuals later in the time-series.

Table A8.1. Life-history and fishery characteristics used to calculate unfished spawning stock and steepness.

Age	M1	M2	Total M	F	Select	Mature	CatchWt	StockWt
3	0.200	0.316	0.516	0.007	0.01	0.00	0.71	0.26
4	0.200	0.049	0.249	0.047	0.09	0.00	1.17	0.59
5	0.200	0.038	0.238	0.135	0.25	0.01	1.67	1.15
6	0.200	0.011	0.211	0.244	0.46	0.15	2.36	2.02
7	0.200	0.000	0.200	0.367	0.69	0.49	3.19	2.86
8	0.200	0.000	0.200	0.423	0.80	0.75	4.22	4.05
9	0.200	0.000	0.200	0.466	0.88	0.91	5.58	5.63
10	0.200	0.000	0.200	0.423	0.79	0.98	7.31	8.15
11	0.200	0.000	0.200	0.532	1.00	0.99	9.08	10.38
12	0.200	0.000	0.200	0.509	0.96	1.00	11.28	13.25
13	0.200	0.000	0.200	0.509	0.96	1.00	13.33	14.31

Table A8.2. Parameters of the Beverton–Holt stock–recruitment estimated with Uncorrelated or first-order autocorrelated (AR) residuals.

	Uncorrelated	AR
Neg LL	911	903
bias corrected AIC	1829	1814
MSY	930520	758650
Fmsy	0.28	0.32
SSBmsy	3644100	2560900
alpha	1135300	910200
beta	270560	170830
unfished SSB	13940000	11222000
unfished R	1113700	896550
steepness	0.93	0.94
 	0.57	-
 	-	0.50
	-	0.49

Annex 9. Some comments on Harvest Control Rules for NEA Cod

WD 20 from Bulatov *et al.*, was aimed to start discussion about possible changes to NEA cod harvest control rule (HCR). It was outlined that the forecasts for the 3-rd prognostic year are characterized by much lower precision, but according to acting HCR they strongly influence the TAC. It was proposed to change the 3-year average for calculation of TAC to 2-year average.

It was also shown that only in recent years characterized by very high SSB values the stock was fished with $F < 0.4$, while in most previous years F was much higher and it did not cause any real damage to stock. This may support the idea standing behind the changes to HCR proposed by Norway and Russia with the aim to better utilize the stock potentialities in years of high SSB and retain precautionary features of acting HCR for the cases of moderate and low SSB. For illustrative purposes the estimated values of TAC according to Norwegian and Russian proposals to HCR were presented. The estimates were based on abundance-at-age values obtained by TIS-VPA, assuming the input parameters (see WD 19). It was shown that if to restrict the averaging period by 2 years of forecast the values of TAC for 2015 will be 1 150 000 tonnes based on Norwegian proposal to HCR, and equal to 1 072 000 tonnes for Russian proposal to HCR. The proposed changes to HCR should be discussed in nearest future with Russian and Norwegian fishers.

The existence of high correlation equal to 0.68 between recruitment and water temperature on Kola section was also shown.