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Report of the Working Group on Inter-benchmark Protocol on Northeast Arctic Cod (2017)

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Executive summary

The ICES inter-benchmark protocol for Northeast Arctic cod (IBPArcticCod) was held at ICES headquarters on the 4th-6th of April 2017. The meeting was chaired by Daniel Howell from Norway, with 12 participants from 5 nations. Reviewers were Noel Cadigan from MUN-MI, Canada and Jan Horbowy from the National Marine Fisheries Research Institute, Po-land.

The meeting was to address issues arising from the improved age structure in the Northeast Arctic (NEA) cod stock, which had been posing challenges to the annual assessment. Two large year classes in 2004 and 2005 are currently forming an important part of the stock and catches, especially when considered in terms of biomass. Specifically, issues around maturation, natural mortality on the larger fish, data quality and age range and assessment method were considered. This report is structured around the terms of reference covering these points.

The meeting decided that although there was a concern that natural mortality may be declining on the larger fish, due to a lack of predators to consume the current large biomass of such fish, there was no clear evidence to support a reduction of M within the model. Indeed, within the SAM model, such a reduction resulted in a worse fit to data. Natural mortality on the younger fish in the assessment already includes cannibalism mortality, so this is already tracking the rise in biomass of large fish. Therefore natural mortality was left unchanged. The current method for estimating maturation was presented, and the meeting concluded that this was robust to the changing age structure, and therefore this was not altered.

The number of fish at ages 10 and older are increasing and form a significant proportion of the current catches, but were previously included in a single plus group within the assessment surveys. Data on older fish is available in the surveys, up to 15+ in some, but not all, surveys. The meeting concluded that it was valuable to include data on the older fish in the assessments, and that not doing so would lead to serious errors in the assessments. However given the changing nature of the age structure as the large year classes age, the meeting felt that setting prescriptive age ranges for each survey was inappropriate, and the decision on which age ranges to use in any given year should be left to the AFWG. The meeting also recommended that the age ranges in the catch should be extended from 3-13+ to 3-15+. Although this change made little difference to the current assessment, it should make the assessment more robust to further increases in the age structure.

A new method for computing one survey (the winter survey, listed as fleet 15 in the assessment) using the new "STOX" program has been adopted in Norway, and this method will be available for the corresponding acoustic survey (fleet 16) by 2018. Although a presented WD (WD 9) showed relatively little change from the old method, there was no data evaluation meeting as part of the inter-benchmark. It is likely that Norway will aim to use this method for all surveys in the near future. The meeting recommended that the new method be provisionally accepted, but go for a further ICES review.

Four models were presented at the meeting: the existing XSA assessment, the existing auxiliary TISVPA model, and XSAM and SAM (both Statistical Catch at Age models). It was felt that TISVPA was not suitable for the assessment model for such a data rich stock, but that as a smoothed model it should continue to be run as an auxiliary model to provide a contrast in cases of difficulties with the assessment model. The XSA model

was felt to be too sensitive to the changes in age structure, and had a history of requiring ad-hoc adjustments to function. Consequently the meeting recommended not continuing the XSA assessment model, although the model should be run as an auxiliary model for a few years in parallel with the new assessment model. Both XSAM and SAM seemed able to provide assessments for this data rich stock, however the XSAM model presented at the start of the short, three day, and meeting did not do a good job of modelling reported catches. Given the limited time available, the meeting therefore recommended that the SAM model be adopted as the assessment model, and recommended that support and training in this be provided to the WG. The results from the model were similar to XSA, and near identical for the early part of the time series. The meeting therefore concluded that no changes were required to the reference points, and that the agreed HCR remained precautionary.

1 Introduction

Benchmark ToRs

IBPArcticCod–An Inter-benchmark Protocol on Northeast Arctic cod

2016/2/ACOM30 **An Inter-benchmark process (IBP) on Northeast Arctic cod** (IBPArcticCod), chaired by Daniel Howell*, Norway, and attended by invited external experts Jan Horbowy, Poland, and Noel Cadigan, Canada, will be established and work by correspondence in February–March 2017 and meet at ICES Headquarters for a 3 day Inter-Benchmark meeting 4–6 April 2017 to address ToRs a) to e). In addition, IBPArcticCod will meet by correspondence in April–May 2017 to address ToR f).

a) Evaluate the appropriateness of data and methods to determine stock status and investigate methods for short-term outlook taking agreed management plan into account for Northeast Arctic cod (cod-arct). The evaluation shall include consideration of:

i. Life-history data (natural mortality and maturity ogives);

ii. Fishery-dependent and fishery-independent data (quality and age range);

iii. Assessment method and issues (XSA, SAM, stock size dependent catchability, other settings);

b) Agree and document the preferred method for evaluating stock status and providing short-term forecast and update the stock annex as appropriate. Where appropriate, Knowledge of environmental drivers, including multispecies interactions, and potentially ecosystem impacts should be integrated in the methodology;

c) Re-examine and update if appropriate MSY and PA reference points according to ICES guidelines; also taking the results from WKNEAMP2 into account;

d) Develop recommendations for future work to improve of the assessment and data collection and processing;

e) Produce working documents to be reviewed during correspondence work in February–March 2017, produce working documents to be reviewed during the Benchmark meeting at least 7 days prior to the meeting;

f) Re-evaluate whether the Joint Russian–Norwegian Fisheries Commission management plan remains precautionary taking into account the new agreed analytical assessment method and potential new biological reference points. To the largest extent possible, the evaluation should follow the guidelines provided by the “Workshop on Guidelines for Management Strategy Evaluations” (WKGMSE, ICES CM 2013 ACOM 39), including the guidelines for reporting provided in Section 6 of the WKGMSE report. The agreed ACOM criteria for considering management plans as precautionary should also be taken into account in the evaluation;

g) Conduct correspondence work on data evaluation and hold Web conference preparatory meetings during February 2017. Stakeholders are invited to contribute data (including data from non- traditional sources) and to contribute to data preparation and evaluation of data quality.

IBPArcticCod cod will report by 15 May 2017 for the attention of ACOM.

Supporting information

Priority: The activities of this Group will improve Northeast Arctic (NEA) cod stock assessment.

Scientific justification	The cod stock has a high abundance of old fish and the XSA assessment model is sensitive to this. The estimated fishing mortalities for the strong year classes 2004–2005 are unexpectedly high for 2015 with the SPALY assessment. This may indicate that the abundance of these year classes was underestimated in the 2016 assessment. In the assessment of NEA cod, data from fish older than age 9 has not previously been included in the tuning series. This was due to lack of consistency in the data for the oldest age classes resulting from the extremely small sample sizes at these ages. However, the large 2004 and 2005 year classes are now aging beyond the age range currently used in tuning. These year classes represent a significant portion of the stock and catch, and excluding data on these from the tuning fleets in the assessment would not be advisable. At the same time, the high abundance of these year classes, combined with the moderate fishing mortality they have experienced during their life, means that the number of sampled fish at age 10 and 11 is now much higher than in recent years. During the 2016 assessment it was therefore decided to investigate the age range used for the tuning fleets, in order to include more information about the strength of the 2004 and 2005 year classes. However, ADGANW and ACOM leadership did not accept the changes proposed by AFWG "as there were too many unresolved issued with the new model" and it was decided that ICES should conduct an Inter-benchmark (IBP) process to work through the spring of 2017 to review the assessment for this stock.
Resource requirements	Two external reviewers (one SAM expert) and work from WG members.
Participants	The Group is expected to be attended by 10–15 members and guests.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to advisory committees	ACOM
Linkages to other committees or groups	AFWG
Linkages to other organizations	None.

2 Description of the benchmark process

A physical meeting was held between the 4th–6th April 2017, and was preceded by a number of webex meetings to ensure that work was on track for the benchmark. All work was focussed around the issues raised by the increasing age range of the stock (as highlighted in the ToRs, section 2). The solutions identified in this report focus almost exclusively on this topic. Other issues, such as the merits of different age-structured modelling techniques (e.g. XSAM and SAM) have been left for the next full benchmark. The aim here was to identify where changes were required in order for the assessment to deal with the changing age structure.

3 Cod (Gadus morhua) in subareas 1 and 2 (Northeast Arctic)

3.1 Stock ID and sub-stock 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 the AFWG report 2016, Section 2.2.1 on Coastal Cod.

3.2 ToR a(i) Life-history data

Natural Mortality

For many years, M on NEA cod has been assumed to be M=0.2+cannibalism. Following the increased biomass in recent years, the biomass removal corresponding to M=0.2 has increased correspondingly (WD1). These removal estimates are in recent years considerably higher than estimates of food consumption by predators (mainly marine mammals). If predation is an important source of natural mortality, it could be plausible that natural mortality has decreased in recent years.

The age-dependence of the average natural mortality (M=0.2+cannibalism) in the recent period (1995–2015) is consistent with the shape of the size–dependence of M indicated by Lorenzen (1996) for temperate and polar stocks with a growth curve such as that for NEA cod. The curve for 'polar' stocks levels out at around M=0.10 for older ages. Based on this, scenarios were run investigating reduced mortality at older ages, using the following values: M=0.17 for age 7, M=0.14 for age 8 and M=0.11 for ages 9 and older. A fixed M value for age 9 and older was used as there is not information available which can be used to investigate whether mortality in the recent period increases again for older fish as claimed e.g. by Tretyak (1984). In addition the SAM model shows a very slightly worse fit to the data with the proposed alternate values of M. We conclude that there may well be improvements to be made in modelling M for this stock, but at this meeting there was no strong case for making such a change. We note that by including cannibalism the assessment already includes higher M on the younger ages.

Recommendation: Retain current mortality model (M=0.2 plus modelled cannibalism).

Maturation

Data on maturity at age are one of the basic components for spawning stock bio-mass (SSB) estimates. There have been substantial changes observed in maturity at age of NEA cod over large historical period (since 1946) showing an acceleration in maturity rates especially in the 1980s. They are thought to be connected both with compensatory density-dependence mechanisms and genetic changes in individuals (Heino *et al*., 2002; Jørgensen *et al*., 2007; Kovalev and Yaragina 2009; Eikeset *et al*., 2013; Kuparinen *et al*., 2014) resulted from strong fishing pressure.

Recent maturity-at-age data has been received from actual observations done mainly during scientific surveys conducted by Norway and Russia since 1983. Historical data (1946–1982) has been reconstructed using two different methods. Norwegian data has been calculated using the Gulland (1964) method taking into account information on age at first spawning from otoliths (ICES CM 2001/ACFM:19). Russian proportions of mature cod at age were based on visual inspection of gonads in the pre-spawning season (November–February). Both data series, obtained by different methods, shown the same long-term trends (ICES 2003).

Decline in maturity at age during the most recent years seems to be connected with dynamics of the stock size such as very high SSB values. These conditions may influence cod migration pattern and stock availability for different surveys. However, it should be investigated further.

Method of maturity-at-age estimations has not been changed since the last 2016 assessment; it is most probably able to handle the changes in the maturation rate. The same data and procedure of calculations (see Stock annex of 2016 AFWG) are to be basis for the stock estimations in the nearest future. This is not to say that the maturation ages remain unchanged, rather than the existing method is able to handle these changes.

Recommendation: Do not change current method of computing maturation.

3.3 ToR a(ii) Fisheries-dependent and Fisheries-independent data

The data set used at the IBP meeting was mostly the same as that used by AFWG in 2016. However, some extensions and corrections were made, and the impacts of these changes examined during the meeting:

Catch at age: The age range was extended from 3-13+ to 3-15+ and catch number at age was updated accordingly. Weight in stock and catch and maturity at age used for 13+ previously were used both for age 13, 14 and 15+.

The tuning age range was extended upwards for all surveys, see table below.

The Norwegian winter survey bottom trawl (FLT15) was updated back to 1994, see below

A minor error in last data year for the ecosystem survey (FLT 007) was corrected, some age groups were shifted one year

The same values were used for cannibalism mortality in all models as those used in the final (ACOM) assessment for 2016.

Age range in catch data

Catch-at-age data were analysed (WD 7). It could be concluded that catch-at-age data are suitable for using in the VPA and other cohort models, as cohorts can be followed well and there are clear signals of changes in level of overall mortality. Catch-at-age data have for many years been used until age 13+ but now there are two abundant generations at the stock which become close to plus group and it was decided to increase age range for catch data until age 15+. The data for additional ages are available in AFWG 1999 report and in the Intercatch data base. Catch in numbers at age up to 15+ was made available during the IBP meeting and weight at age data will be reconstructed up to age 15+ before AFWG 2017.

Recommendation: Use catch data up to age 15+, and structure the assessment model accordingly.

Age range in survey data

Comparison of cohort abundance data in adjacent age groups demonstrates good consistency from age 3 to age 11 or even 12 for some surveys. It was observed that when an abundant year class enter the oldest age group of the survey r2 of the relationship between corresponding age groups of this survey might increase considerably. In the younger age groups (ages 0-2) survey index consistency is quite high (r2 = 0.42–0.72), but still is considerably lower than for older ages (r2 = 0.71–0.92).

XSA name	Name	Season	Age range (2016 range as used by ACOM in brackets)	Years
FLT15	Joint bottom trawl survey	Feb–Mar	3–11 (3–8)	1980–2015
FLT16	Joint acoustic survey+ Lofoten acoustic	Feb–Mar	3–11 (3–9)	1984–2015
FLT18	Russian bottom trawl surv.	Oct–Dec	3–12 (3–9)	1982–2015
FLT007	Joint Ecosystem survey	Aug–Sept	3-12 (3-9)	2004–2015

Recommendation: Use survey data up to age 15+, where available and considered reliable. Since the viable age range for each dataset will vary as the age structure of the stock varies, the choice of which age range to use for each dataset in a given year shall be made at the AFWG.

Recommendation: Update weight at age in stock and catch and maturity ogive for ages 13+ before AFWG 2017.

New method for winter survey

The new method for calculating bottom trawl indices is described in Mehl *et al*. (2017). Revisions of the acoustic indices from this survey will be available before AFWG 2018. Then the time series for weight at age and maturity at age will be revised accordingly.

Recommendation: Provisionally adopt the new method for this survey only. Monitor its performance and send the new method for review at a full benchmark or bespoke ICES review.

3.4 Assessment method and issues

3.4.1 TISVPA

The characteristic feature of the TISVPA consists in intentional implementation of principles of robust statistics in procedures of estimation of model parameters which helps it to operate with strongly noisy data. Among them: robust loss functions, possibility to ensure unbiased solution, independence of estimated selection pattern upon user's choice about its overall shape, implementation of different options concerning mutual validity of assumptions about quality of catch-at-age data and stability of selection pattern, possibility to exclude influence of year-to-year survey catchability variations caused by difference in survey conditions, etc.

The model also includes an "enhanced" separable representation of fishing mortality as a product of three parameters: f(year)*s(age)*g(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 fishermen, or by some other reasons.

The model was first presented and tested at the ICES Working Group on Methods of Fish Stock Assessments (WGMG 2006) and was used for data exploration and stock assessment for several ICES stocks, including North-East Atlantic mackerel, blue whiting, Norwegian spring spawning herring. To NEA cod TISVPA was first applied at AFWG in 1998. Later at benchmark group for arctic stocks (WKARCT) in 2015 and at AFWG in 2015 and 2016.

At AFWG in 2015 and 2016 TISVPA showed significantly higher SSB estimates for final years in comparison to the results of XSA. At AFWG in 2016 the reason for this discrepancy was found to be a deficit of information about older ages in tuning data for XSA. When the age range of tuning data was enlarged the results of XSA became much closer to the results of TISVPA.

However, such an enlargement of age range could introduce some instability due to lower quality of tuning data for elder ages. In WD4 for IBPArcticCod it was shown that such an enlargement did not produce, at least from point of view of TIS-VPA, a significant number of new outliers, estimated in spirit of so called "X–84 rule" proposed by P. Huber. Exclusion of the detected outliers almost did not change the TISVPA-derived estimates (see figure 3.4.1.1)

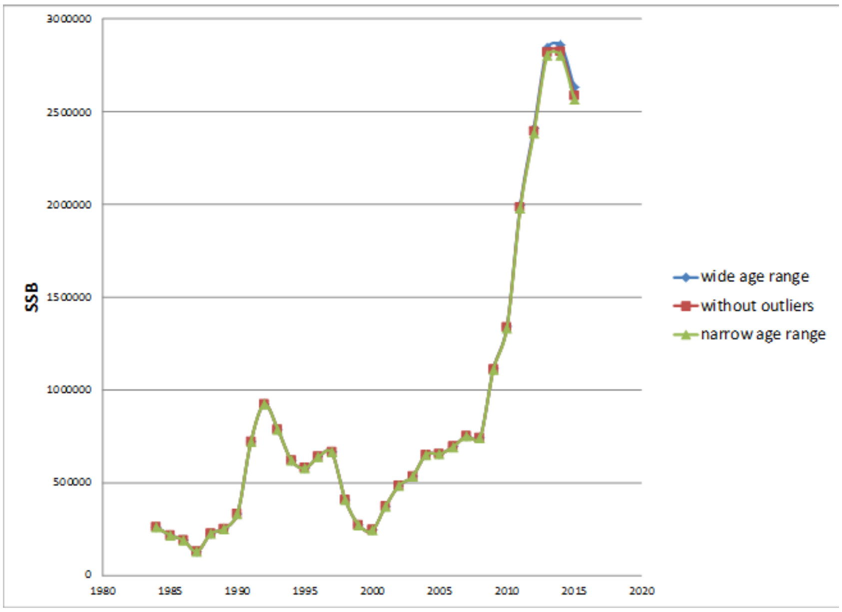

Figure 3.4.1.1. TISVPA-derived estimates of SSB for "narrow" and "wide" age ranges of tuning data, as well as for "wide" age range with excluded outliers.

At IBPArcticCod it was decided to further enlarge the age range of surveys data and some other changes were also made in the other input data. The results of the TIS-VPA retrospective runs for these data are presented in figure 3.4.1.2.

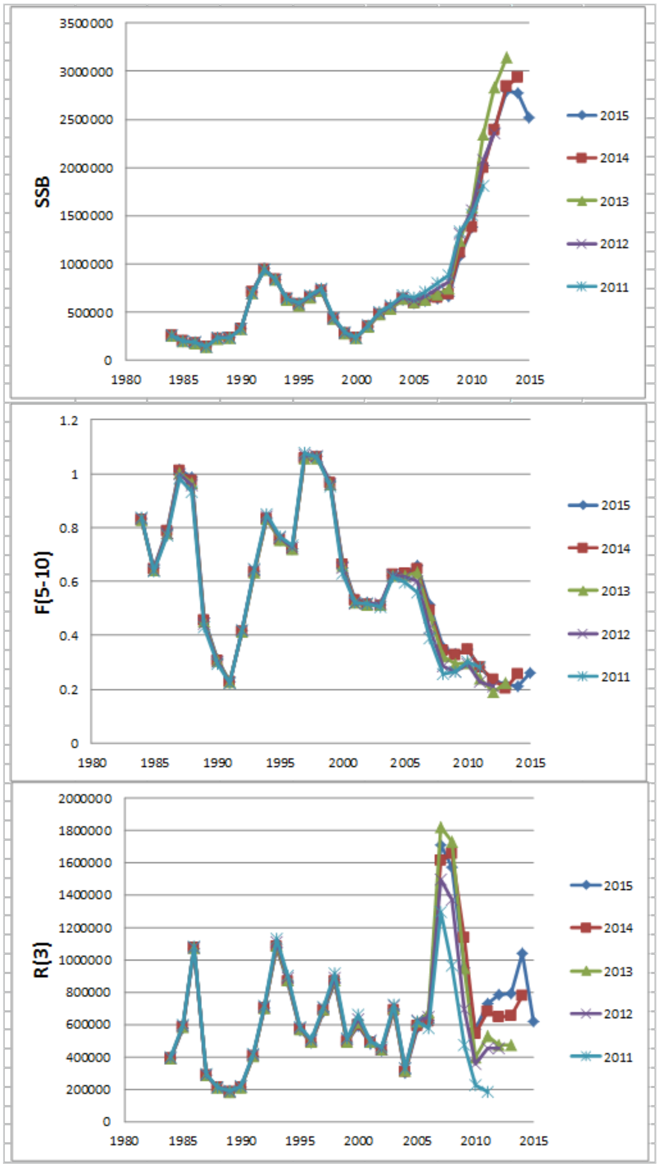

Figure 3.4.1.2. TISVPA retrospective runs.

It is needed to mention that in the TISVPA runs the so-called "back-shifted" data for surveys were used in order to use the same data as XSA did, while TISVPA is able also to use survey data in the (terminal+1) year (as SAM can). Runs with not back-shifted data were not done because of lack of time at the meeting.

Generally, the TISVPA model, mostly aimed at robustness dealing with poor quality data, for data of good quality, such as for Arctic cod, produced less stable retrospective pattern in comparison to SAM which is more flexible to adapt to existing data provided that they are of good quality.

Recommendation: This model has proved valuable as an auxiliary model, giving a less flexible model to compare against the assessment model. The IBP therefore recommends that this continue to be run as an auxiliary model.

3.4.2 XSA

A VPA model with XSA tuning was used by AFWG for NEA cod assessment as the main method for many years. Since AFWG 2011 this model started to demonstrate a systematic pattern where the previous assessment of stock biomasses were lower for terminal years than estimates received in following years of assessment (WD 8). In order to solve this problem AFWG changed model parameters several times. During the last benchmark (WKARCT 2015) it seemed that the "retrospective problem" disappeared but during the AFWG 2016 it appeared again. All variants of exploratory runs made during this meeting with different XSA model parameters and survey age ranges did not help to solve it. One of the most problematic issue for the model is interpretation of relationships between survey indexes and stock abundance. This has been especially problematic important for two year classes 2004 and 2005, the most abundant ones in current stock history. As these year classes have aged, and had high survivorship, many of the assumptions about age ranges built into the assessment model have required frequent revision. As a model that begins with the oldest ages and works back-wards, the VPA/XSA model is sensitive to the choice of plus group. Some of the surveys fit better if we assume linear relationship while others prefer to have a power model for catchability, and the overall model outcome is sensitive to these choices. The most reliable estimates were produced using power model for all ages, although such a model also has a bad retrospective.

So far, such an instability in assessment makes it difficult to use the model in management. It was decided that the XSA model now probably is not an appropriate meth-od for NEA cod. It is necessary to get more data on dynamics of abundant year classes and to do more study on the form of relationships between survey indices and stock abundance before the XSA may be used as a main method again. It should be noted that the increasing age range that is proving problematic for NEA cod is likely to occur in many stocks following a rebuilding process, and therefore any VPA-based methodology should be examined carefully in such instances.

3.4.3 XSAM

The XSAM model is a state space model building on the time series model introduced by Gudmundsson 1994. Compared to Gudmundssons original formulation it includes a generalization of the process model for fishing mortality and a focuses on the formulation of the observation models. The main objective for establishing the XSAM framework was to enable using prior knowledge about quality of the input data as it can utilize information from sampling distribution (variances and covariance) of input data in addition to the more typical approach of using only point estimates as input. The alternative is to estimate the error structures by fitting the model to point estimates. If prior information about observation errors is available it can be utilized to improve the estimates and reduce bias in inference as data points attain more appropriate weights when fitting the model (Aanes 2016a). The XSAM model was reviewed for assessing Norwegian Spring Spawning (NSS) herring at the benchmark working group WKPELA in 2016 (ICES 2016a) and is documented in Aanes 2016a and 2016b. It is currently adopted by WGWIDE for assessment of NSS herring (ICES 2016b).

Prior to this working group the framework was extended to utilize plus groups from abundance indices and to estimate predation mortality due to cannibalism based on consumption data.

Prior knowledge about quality of the input data (e.g. sampling errors) is currently only available for parts of the input data for a restricted number of years which restricts the possibility of utilizing known error structures somewhat. That aside, the results from implementing this model on the cod data generally produces estimates that are similar to the estimates obtained by XSA or the SAM model with comparable settings concerning observations model (e.g. density dependent vs independent catchability and age of plus group) and results and diagnostics was partly considered by the Working Group. The results are shown in WD 6.

The results obtained by estimating predation mortality based on consumption data was not considered by the working group.

This framework will be further developed by the Norwegian Computing Center and the Institute of Marine Research through the REDUS project.

3.4.4 SAM

SAM is a State-space Assessment Model and as such it contains two parts. A process part and an observation part.

The process part describes the dynamic development of the states, which are the log-transformed stock sizes at age and the log-transformed fishing mortalities at age. The increments of the log-transformed stock size at age 3 (recruitment) is assumed normally distributed with zero mean and a separate variance parameter. The increments of log-transformed stock sizes at all other ages (ages 4-15+) are assumed normally distributed with mean predicted by the stock equation and a common variance parameter. The increments of log-transformed fishing mortalities at age are assumed to follow a zero mean multivariate normal distribution with an AR(1) covariance structure across ages. It is further assumed that the two last ages (14 and 15+) have the same fishing mortality.

The observation part describes the distribution of the observations conditioned on the process part. The catch-at-age observations are assumed independent log-normally distributed with common variance parameter for all ages (3–15+) and mean as predicted by the logarithm of the catch equation. For each of the four survey fleets (FLT15:NorBarTrSur, FLT16:NorBarLofAcSur, FLT18:RusSweptArea, and FLT007:Ecosystem) it is assumed that the yearly observation vector follow a multivariate log–normal distribution with mean vector proportional to the stock sizes at the time of the survey and an irregular grid AR(1) covariance structure. The irregular grid AR(1) correlation structure is similar to a regular AR(1) structure, but the correlation distances between neighboring age–groups are described by different a model parameters. Each survey fleet has a separate variance parameter, and separate correlation distance parameters. It is assumed that the last two ages within each survey fleet has common catchabilities, and that the last 4, 3, 6, and 4 ages respectively have the same correlation distances.

Key model diagnostics of SAM:

The SAM model is validated by standard model diagnostics. Observation residuals, process residuals, leave out runs, and retrospective runs.

Observation residuals can be difficult to compute in state-space models. The standard practice of calculating the residuals (as `observed' minus `predicted' divided by an estimate of the standard deviation) is strictly only valid for models with purely independent observations. It is not valid for state-space models, where an underlying unobserved process is introducing a correlation structure distribution of the observations. The problem is that the resulting residuals will not become independent. To get independent residuals the so-called `one-observation-ahead' residuals are computed.

The residual for the n'th observation is computed by using the first n-1 observations to predict the n'th. Details can be found in Thygesen *et al*. (2017).

The process residuals are a special thing for state-space models. Intuitively it is the standardized increments of the process equations. Details can be found in Thygesen *et. al*. (2017).

Leave out runs are conducted by comparing results from four runs where one of the surveys fleets are omitted in each run.

Retrospective runs are conducted by comparing runs where last year's data is successively omitted five times from catches and all surveys

3.4.5 Model comparison

The graph below shows the overall stock trends predicted by the four different models. As can be seen, there are only rather small differences between the models. To an extent this is to be expected given the rich data available for this stock, the issue prompting the benchmark was the need for frequent revisions to the XSA model rather than a lack of data to tune the model. The models do diverge at the end of the time series, where there is disagreement about the size of the recent biomass peak, however all of the models capture the same trends.

The benchmark considered that in principle the XSAM model was a viable tool for this stock. However, the model initially presented did not fit well to the recent catches. Although this was something that could be rectified, given the short time available this model was not considered further as a candidate assessment model at this time. The developers of this model are encouraged to develop it and present it for discussion at future AFWGs. TISVPA was considered to be overly smoothed for such a data-rich stock, it was developed aimed at more data-poor situations. However, that smoothing does make it a valuable auxiliary model to help understand the behaviour of the main assessment model in years where unexpected model behaviour is observed. Although a properly specified XSA model seems able to provide assessments for this stock, the need to frequently revise the specification as the age structure of the stock changes poses challenges to the assessment process. Therefore it was not recommended to continue with the XSA assessment model. The SAM model was able to capture the dynamics in the stock, and this model was therefore selected as the most appropriate assessment model. The detailed description and diagnostics of the SAM model for NEA cod are given in WD 10.

The method currently in use for calculating cannibalism is an iterative loop that sits outside the assessment model, and calls that model several times. As such, the current formulation is model-independent, and can be directly implemented for SAM. However, it would seem preferable to develop a method for including the cannibalism routines directly within SAM.

Recommendation: SAM should be run as the assessment model.

Recommendation: Support in the SAM model should be provided in the early years of the SAM assessment model, and training to enable the WG members to take full ownership of the model.

Recommendation: Methods of streamlining the current cannibalism procedure should be developed and taken into use.

Recommendation: XSA should be run as an auxiliary model for the first few years of the SAM model.

Recommendation: The SAM model be used to produce consumption estimates of haddock for use in the haddock model.

Recommendation: Investigating use of age 3 indices also for FLT15 and 16 (can be done now because of no back shifting).

Figure 3.4.5.1. Comparison of different model estimates of NEA cod population parameters – total and spawning stock biomass, recruitment at age 3 and average fishing mortality for ages 5-10

3.5 Short term projections

Bjarte

The short term prediction approach for NEA cod was adopted during the last benchmark (WKARCT 2015) and were not considered in detail during this meeting. There is a problem in one of sub-models used in the hybrid method (prediction of cod recruitment) as it uses SSB as one of the predictors and assumes a linear relationship between R and SSB. Such an assumption may not be treated as reliable in current stock status and this part of the model should be reconsidered before the next AFWG.

The short-term prediction has been based on numbers at age 4 and older from the start of the intermediate year taken from the assessment model. The number at age 3 in the intermediate year and the two following years has been taken from the hybrid recruitment method as described in the stock annex. Weight at age in the stock and maturity at age in the intermediate year are taken from observations. Recent average values have been used to predict weight at age in the stock and in the catch, maturity at age, natural mortality and exploitation pattern. The fishing mortality in the intermediate year has been set to the same value as in the last data year.

Few changes are needed in this when moving to SAM. When using SAM with shifted survey data, the model can be run through the intermediate year. The fishing mortality in the intermediate year could be assumed to be the same as in the assessment year, provided that this does not deviate strongly from the TAC (catches have in recent years been quite close to the TAC).

The age range in the predictions should be the same as in the assessment model. For the oldest age groups (11+), data on weight at age in stock and catch have been noisy and closer analysis is needed to decide which period the averages for weight in stock and weight in catch in the prediction should be based on. This may also be the case for the exploitation pattern.

3.6 Appropriate reference points (ToRs c and f)

TorR c required that reference points be re-examined and updated if necessary. ToR f required re-evaluating whether the Joint Norwegian-Russian Fisheries Commission management plan remains precautionary.

Although the assessment model has changed, the stock assessment prior to the early 2000s is unchanged. There is only slight disagreement on the stock biomass since then, mostly as a result of slightly different recruitment estimates. Consequently the reference points are not materially affected by the change in assessment model, and the performance of the management plan tested and agreed in 2016 should not be impacted by this change.

Recommendation: No changes required to reference points or management plan

3.7 Future research and data requirements

The AFWG will doubtless identify research requirements for this stock, we note here only those issues arising from the work conducted at this inter-benchmark meeting.

Continue to monitor model performance as the stock age structure evolves.

Continue to evaluate M on the older fish

Implementation of cannibalism in forward simulation models taking uncertainty into account.

4 Conclusions

The focus of the IBP was to assess what changes were required to adapt the assessment model to the increasing age structure in the stock resulting from a decade and more or moderate fishing pressure. In this respect the IBP concludes that:

- The new method for computing the Norwegian winter survey be provisionally adopted, and the method go to an ICES review
- There is no evidence to support changing the current natural mortality model (M=0.2 plus modelled cannibalism)
- The current method for modelling maturity is able to handle the changes in maturation age and should be retained
- The catch data should be extended to 15+, and that AFWG should ex-tend the age data in the surveys as required as the age structure of the stock changes up to a maximum of 15+
- The AFWG should run SAM as the assessment model, with TISVPA (and possibly XSA) as auxiliary models
- Support and training in SAM should be provided to enable the WG members to take full ownership of the SAM model
- Inclusion of cod cannibalism in SAM should initially implemented following the current XSA iterative procedure during the next AFWG, but should be fully integrated into the SAM model at a later stage

5 External reviewers' report

The reviewers confirm that the outcomes of the benchmark (i.e., the stocks annex) are appropriate to provide scientific advice.

This is stock with a good deal of survey and catch information. As is often the case, not all surveys indicate the same trends in the stock – some have increased recently more than others. In particular, the Russian survey (Fleet 18) does not indicate the same increase in stock size as the Norwegian winter bottom trawl and acoustic surveys.

The range of ages in the stock has been expanding and this has caused some problems with the age range used in the stock assessment. One of the basic goals of the Inter-Benchmark meeting was to investigate if and how information on stock dynamics at older ages (biological, survey, and fishery data) may be included into the analytical stock assessment. Following the benchmark meeting in 2015, the last true age used in the assessment was age 12 (ages 13 and older were considered as a plus group). At that meeting the XSA method was used as primary assessment tool for the stock, and TISVPA was the secondary model. However, strong year classes of cod from 2004–2005 led to marked numbers of cod observed in catches and surveys at older ages. It was considered by the Arctic WG desirable to include this information into the assessment and the group included it at its meeting in 2016. However, the ADG considered that such inclusion should be preceded by an inter-benchmark meeting, where effects of a wider age range in the assessment could be tested.

At this inter-benchmark meeting, four assessment models were presented and tested to different extents as assessment tools for cod: XSA, TISVPA, and two new models - SAM and XSAM.

5.1 Issues

There are some reasons to think that natural mortality rates may have decreased recently, because of the size of the stock relative to the predators. During the inter-benchmark process some effort was undertaken to analyse possible changes in natural mortality at adult ages (expected decline) and its effects on assessments. Models were fit with an alternative assumption about M decreasing in recent years. Analyses with XSA and TISVPA showed only small effects of possible changes in M on the assessments. For the SAM assessment the fit of the model with declining M was worse than in case of constant M model. Thus, the group concluded that M should be kept as in previous assessments (constant at 0.2 for older ages including cannibalism at younger of younger ages). However, possible changes in natural mortality should be investigated in the future, especially at the next full benchmark meeting.

Assessment experts were asked about cod condition information, and they responded that recently condition seems good compared to historic values.

Some of the weights at age produced by StoX seemed a little off and need further examination.

The range of survey ages to include for parameter estimation of assessment models was considered in depth. Checks of internal consistency of tuning data showed high internal consistency (high correlations between survey numbers at a given age and survey numbers of the same generations one year later). Some age classes (i.e. older ages) provide less precise stock size indices than others. Some assessment models have the capability to have different variance parameters for different survey age classes, and this is another way to account for the different precision of survey indices.

Some of the same age information is used to estimate survey abundance at age for Norwegian bottom trawl and acoustic surveys. There is partial overlap in the age information. However, the area expansion weights are different so in the end the age compositions of the two surveys are not the same. It is not clear how deal with the partial overlap in age information, and the current approach of treating the bottom trawl and acoustic indices separately (i.e. assume independent) in assessment models seems adequate.

Two state-space models were considered by the review group: SAM and XSAM. Important differences in the models were:

1) SAM included process error in the cohort population dynamics model, while XSAM did not.
2) SAM and XSAM used different stochastic models for fishing mortality.
3) For the implementations presented at the benchmark meeting, XSAM utilized variance estimates for Norwegian survey indices and Norwegian catch statistics. SAM did not (although the software has these capabilities).
4) XSAM did not estimate correlations in survey indices (but it has these capabilities) whereas SAM did.

These model formulation differences resulted in some differences in assessment model results. A concern for the benchmark was recent differences in total observed versus predicted catch weights from XSAM. This model under-estimated total catches and the confidence intervals for total catch did not cover the reported landings. This seemed implausible to the review group. Therefore, the specific formulation and implementation of XSAM was not considered appropriate for the benchmark; however, the reviewers appreciated the XSAM initiative, particularly the focus on including information about tuning index measurement error when fitting a stock assessment model.

XSA diagnostics seemed to suggest that there were density dependent relationships between stock size and survey indices, particularly in winter surveys. This was much less evident in SAM diagnostics. The generating mechanisms for such density dependence were consider in some detail; however, it was not clear why the effects seem different between XSA and SAM.

The XSA analysis was run with catchability dependent on year class strength for all ages and low shrinkage. Default options were used for most other settings. The analysis was performed using FLR, which produces less extensive diagnostics than the Lowestoft XSA software. It was suggested to use the Lowestoft XSA at least in some runs to inspect diagnostics more carefully than FLR allows. Such runs were performed at last the benchmark meeting. The suggestion from reviewers was to inspect future assessments with catchability independent of year-class strength for some older ages and to check the sensitivity of the XSA assessment and its diagnostics to such assumptions.

The SAM run with updated data did not provide evidence for density dependence catchability for most survey indices; however, there was some evidence of density dependence in index catchability for the Russian survey. For that survey the predicted survey indices using density dependence differed appreciably in some years and ages; however, there did not seem to be a substantial improvement in fit overall and there was a reduction in fit to recent indices. Hence, the reviewers concluded that using density dependent index catchability in SAM was not a useful improvement.

The motivation for the density dependence model modification may partially be related to other assessment model problems, such as some historical catch misreporting and more recently an expansion of the spatial distribution of the stock outside of the range of some surveys, and consequently the potential for a change in survey catch ability. It is not clear how adding a density dependent parameter can fix such assessment model problems, and it may be that even if the proposed density dependence approach could be successful in fixing problems, the parameters values required for this purpose may change over time. That is, the density dependence parameter may be stationary. This may be why including density dependence in SAM did not seem to provide improved fit to indices overall.

There was some suggestion that the catchability of the winter surveys for younger ages may have changed recently, because of a redistribution of fish partially outside the survey area. Hence, there may have been a change in survey index catchability at these ages.

The SAM model residual diagnostics involved evaluating the predictive performance of the model, by predicting the n'th observation using the first n-1 observations. It was not clear how this was done, because it was not obvious how stock assessment data (i.e. different surveys and ages) could be uniquely ordered. A more complete description of model fit could involve: 1) examining observed versus predicted values (survey and catches), 2) examining the differences, scaled by standard errors, even though these differences are correlated, and 3) examining the uncorrelated predictive residuals to check if there are features in the common raw residuals that we should not worry about.

TISVPA allows for year class effects in fishing mortalities in addition to age and year effects. The model was designed to be robust, especially for data of poor quality. However the quality of Arctic cod data is good and this is not a stock that is a good candidate for TISVPA because there are likely to be better modelling approaches. Retrospective patterns for the TISVPA model were worse than e.g. the pattern of SAM model.

5.2 Recommendations

The spatial coverage of surveys relative the perceived stock distribution (from fishery information and other) should be described. This may involve time blocks that could characterize periods in which the stock spatial distribution has changed. Such a description could be used as the basis to model a controlled changed in index catch ability. By controlled we mean for a restricted range of surveys, ages, and years. This may require a customized assessment model for this stock.

Survey catchability (q) estimates should be routinely reported. There is a stock assessment philosophy that survey catchability at older ages should be aggregated unless there are good reasons to do otherwise.

Assessment experts indicated that there was some “prior” information about unaccounted catches. This could be used in an assessment model using a censored catch model (e.g. Hammond and Trenkel, 2005; Cadigan, 2016). This seems easier to do in a model formulation that treats separately the two sources of information on commercial catches (i.e. landings statistics, and sampling for length and age compositions). This should be the objective of an integrated state-space stock assessment model. The current strategy of modelling the derived statistics (i.e. catch numbers at age) makes the inclusion of sampling variability more complex.

A cohort strength model applied to survey indices at pre-exploitation ages to get an overall survey recruitment signal would have been useful to compare to the model estimates.

Include index and catch values of zero. This will continue to be an issue as the age range of the assessment may increase in the future. There are several published ways to do this, including the censored approach of Cadigan (2016). Replacing zeros with small values is not a good idea in general because assessment models that assume lognormal errors may be highly sensitive to the rather arbitrary values used to replace zeros.

Stock assessment model review meetings involve much examination of model diagnostics. It would be useful if a standard set of diagnostics could be agreed on before the review meeting. For example, in IBP ARCTIC COD 2017 the stock assessors could not agree on what diagnostics to examine and compare for different models, and the assessors may not have been capable of producing the diagnostics even if there was agreement on what to look at. It would be useful to have additional guidance on this difficult issue. Although this was beyond the scope of IBP ARCTIC COD 2017, it could be a useful objective for a future 'methods' study group.

TISVPA be a secondary assessment model as in former years, as a check on what the SAM model estimates. If there are very large differences then this indicates a high sensitivity to some model assumption that should be further investigated, perhaps in a benchmark process.

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Annex 1: List of participants

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Annex 2: Agenda

Tuesday 4th April 2017

10.00-12.00 Welcome and Introductions

- ToR D: recommendations for future improvements. Introduce this here, and then this should be borne in mind as we work, noting down things as the arise, and we will re-visit this on Thursday
- ToR A: Introduce the topics
    i. ToR A.1 Life history (maturity and mortality)
    ii. ToR A.2 Data (This splits into changes to the overall data series and changes to extend the age range)
    iii. ToR A.3 Assessment methods and issues, present work on SAM, XSAM and XSA

13.00-18.00

- Continue with ToR A, suggest additional exploratory runs to be made over-night

Wednesday 5th April 2017

09.00-12.00

- Work on ToR A, present results of additional runs

13.00-18.00

- Work on ToR A
- Hopefully have time for ToR B. Agree and update methods and stock annex

Thursday 6th April 2017

09.00-12.00

- Continue ToR B if required
- ToR C re-examine and if necessary update reference points (note: this stock does not use MSY reference points in management)

13.00-18.00

- ToR D, recommendations for improvements.
- Work on ToR F, check if the HCR remains precautionary (potentially conclude this work by correspondence)

18.00

- Close, earlier if required due to participant travel

Annex 3: List of stock annexes

Stock ID	Stock name	Last updated	Link
Cod.27.1-2_SA	Cod (*Gadus morhua*) in subareas 1 and 2 (Northeast Arctic)	10 mai 2017	cod.27.1-2_SA

Annex 4: Recommendations

There are no recommendations from this benchmark that extend beyond the work of the AFWG.

Annex 5: Working documents

WD 1: Bogstad, B. M. and consumption

WD 2: Kovalev, Y., Prozorkevich, D. & Chertyrkin, A. BESS index 2016

WD 3: Bogstad, B. Additional diagnostics

WD 4: Vasilyev, D. Testing of the input data for NEA cod stock assessment for outliers

WD 5: Yaragina, N. Maturity ogives of the Northeast Arctic cod

WD 6: Aanes, S. Assessment of NEA cod using XSAM

WD 7: Kovalev, Y., & Chetyrkin, A. Evaluation of the NEA cod assessment quality

WD 8: Kovalev, Y. NEA cod XSA assessment PREHISTORY.

WD 9: Mehl, S., Aglen, A. & Johsen, E. StoX revision of the swept area abundance indices 1994-2016

WD 10: Nielsen. A. Note on SAM setup for NEA cod

WD 11: Aglen, A. Extended age range winter survey

WD 12: Johannesen, E. & Mehl, S. StoX estimates cod BESS

Natural mortality of Northeast Arctic cod – time for revision

WD1, NEA Cod IBP April 2017

Bjarte Bogstad, IMR, Bergen, Norway

Background

Natural mortality is a key variable in stock assessments. Estimates of recruitment and biomass from catch-based assessments inflate substantially as input M values are increased, and fishing mortality estimates are consequently reduced for a given catch. Incorrect M values are also a problem if the assessment model estimates of abundance are being treated as absolute, for example to compute total food consumption by the stock.

For NEA cod, it has for many years been assumed that M=0.2+predation by cod on cod (cannibalism) for prey age 1-6 and predator age 1-11+. Calculation of cannibalism is described in the AFWG report. The 0.2 value is the traditional gadoid M value used by ICES and has been unchanged since the 1970s. Hereafter we use MSVPA terminology and denote 0.2 as M1, thus M=M1+M2 where M2 is cannibalism mortality.

In recent years the abundance of large cod (> 60cm/6 years, say) in the Barents Sea has increased considerably. There is a limited abundance of predators on such large fish in this area. The fishing mortality in recent years has been so much lower than before that the relative impact of the natural mortality on the survival of older fish has increased considerably. The strong cod year classes 2004-2005 are still abundant in surveys and catches and lowered natural mortality could be one of the reasons for that.

In 1995-2007 total stock biomass (TSB, age 3+) varied between 1.1 and 1.9 million tonnes and F varied between 0.53 and 1.03 in 1995-2006. After a transition period in 2007-2009 with rapidly increasing stock size TSB has been between 3 and 4 million tonnes since 2009 and F has been between 0.25 and 0.40 since 2007.

As predation is likely to be a major source of natural mortality, it could thus be considered whether the natural mortality on older age groups would be expected to be different in these two periods. Fig. 1 shows the biomass removed by a natural mortality (M1) of 0.2 (denoted as MOB – M-Output-Biomass) for cod, for age groups 3+ and 7+, respectively. This is compared to the consumption by the two most important piscivorous marine mammals in the Barents Sea; harp seals and minke whales. The method of calculating biomass removal (MOB) is given in Bogstad et al. (2000), while the consumption by harp seals and minke whales are taken from Nilssen et al. (2000) and Folkow et al. (2000). Cannibalism is not included in the MOB figures as this is taken care of by assuming M=M1+M2=0.2+predation by cod for cod age 1-6. It should also be noted that a considerable proportion of the cod eaten by marine mammals may be age 1 and 2 fish, which is not included in the removal-by-M plot in Fig. 1. Although there are other predators and not all mortality is due to predation, the figures still indicate that M may have decreased considerably in recent years, as there is probably not predation capability to remove the amount of cod indicated by the figure. More recent estimates of the consumption of cod by marine mammals (Mauritzen et al. in prep) seem to be of the same order of magnitude as the estimates by Nilssen et al. and Folkow et al. The only non-mammal predator on large cod in the area is Greenland shark, for which there is no stock estimate, but the biomass of this species is believed to be relatively low compared to seals and whales.

Scenario for natural mortality

On this background it seems desirable to explore assessments with scenarios for M1 using ranges of values of M1 lower than those presently used, and age dependence of M1, that are likely to encompass the true values and for which there is evidence to help bound the plausible ranges. One approach to indicate the level of natural mortality is to use the body weight-natural mortality relationship suggested by Lorenzen (1996), an approach used e. g. by WKIRISH2. Here, we use average weight at age in the stock from 1995-2016, a period with relatively stable growth rates, and average M values for 1995-2015. Lorenzen assumes the natural mortality to be a power function of weight : $M_W = M_u W^b$, where W is weight and u and b parameters. He gives one set of parameters for temperate ecosystems and one for polar ecosystems. Fig. 2 shows M as function of age for the two parameter sets using the mean weight and mortality at age described above. Both curves correspond relatively well to the average age-dependence for M for age 2 onwards, with the 'polar' curve somewhat below the M values actually used and the 'temperate' curve somewhat above.

Based on the curves in Figure 2, a lower bound of M of 0.11 ('polar' curve') may be appropriate. From Figure 1 we suggest as a first approximation to assume lower M1 values from 2009 onwards, with 2007-2008 as transition years from the usual M1 value of 0.2 to be used until 2008. Considering the age dependence, we suggest using some smooth curve taking the approach outlined by Lorenzen (1996) to give age-specific values. We suggest to use a fixed M value for older fish (e.g. age 9 and older), as we do not have information which can be used to investigate whether mortality in the recent period increases again for older fish as claimed e .g. by Tretyak (1984). Such information from earlier periods with high abundance of old fish (1940-1950s) may not be relevant at present partly because mean age at first maturation was much higher then (about 9 years compared to about 7 years at present).

A reasonable scenario would then be to assume that

1: M decreases linearly from age 6 to 9 and is constant for ages 9 and older

2: M at age 9 decreases linearly from 0.2 in 2006 to 0.11 in 2009

This gives the M matrix shown in Table 1. M values before 1995 would affect reference points, but not the assessment of current stock size.

Relating survey data to natural mortality

The issue of handling changes in M in assessments has been addressed by several authors. For the Gulf of St. Lawrence cod, a variable M has been used in assessments (see e.g. Chouinard 2005). Sinclair (2001) suggested a way of estimating based on regressions of Z vs. fishing intensity and adding a time-class variable. It should be noted that the situation for that stock was opposite that for NEA cod – low stock levels and a suspicion that M could increase in such cases. Also fishing was very close to zero for that stock for several years, allowing for estimation of natural mortality without the usual confounding with fishing mortality.

A similar approach was tried for NEA cod, assuming full recruitment to fisheries and surveys at age 8 and using the Russian autumn survey and the combined Barents Sea/Lofoten acoustic surveys (FLT18 and FLT16). The ecosystem survey has a too short time series and the Barents Sea winter survey has too low coverage of older age groups to use the Sinclair approach. Preliminary analyses did not indicate any clear pattern in residuals over time, but this could be further investigated at IBP.

Several factors may make it difficult to identify such a pattern: In addition to the usual confounding of F and M and the accuracy of catch reporting, survey catchability may have changed over the period due to increased distribution area. Also increased proportion of older fish in the 8+ group may affect overall catchability of 8+ as gear catchability in the survey may be size-dependent also for large fish. Further, if catchability is stock size dependent, using Z values derived directly from survey estimates would not be an appropriate approach to estimate Z.

It should also be noted that several years of precise observations would be needed to detect a change from M=0.2 to around 0.1. However, a reduction from M=0.2 to M=0.1 would over a period of 7 years amount to a 50% increase of the cohort abundance at the end of the period!

Further investigations on this issue are needed.

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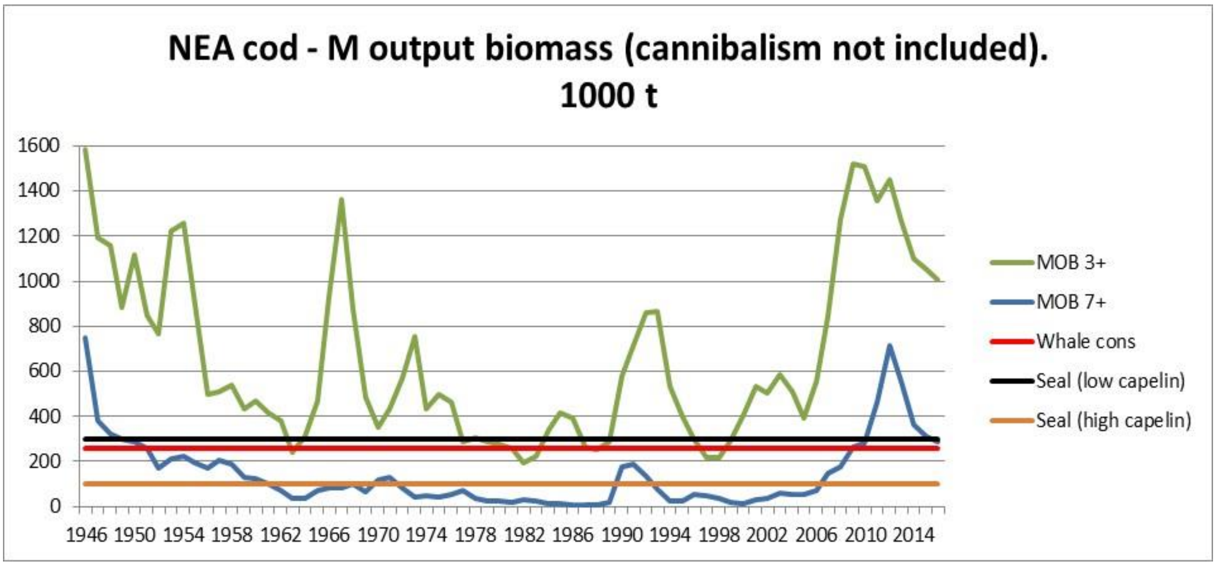

Figure 1. Biomass removed by M (MOB) for Northeast Arctic cod compared to calculated consumption by minke whales and harp seals.

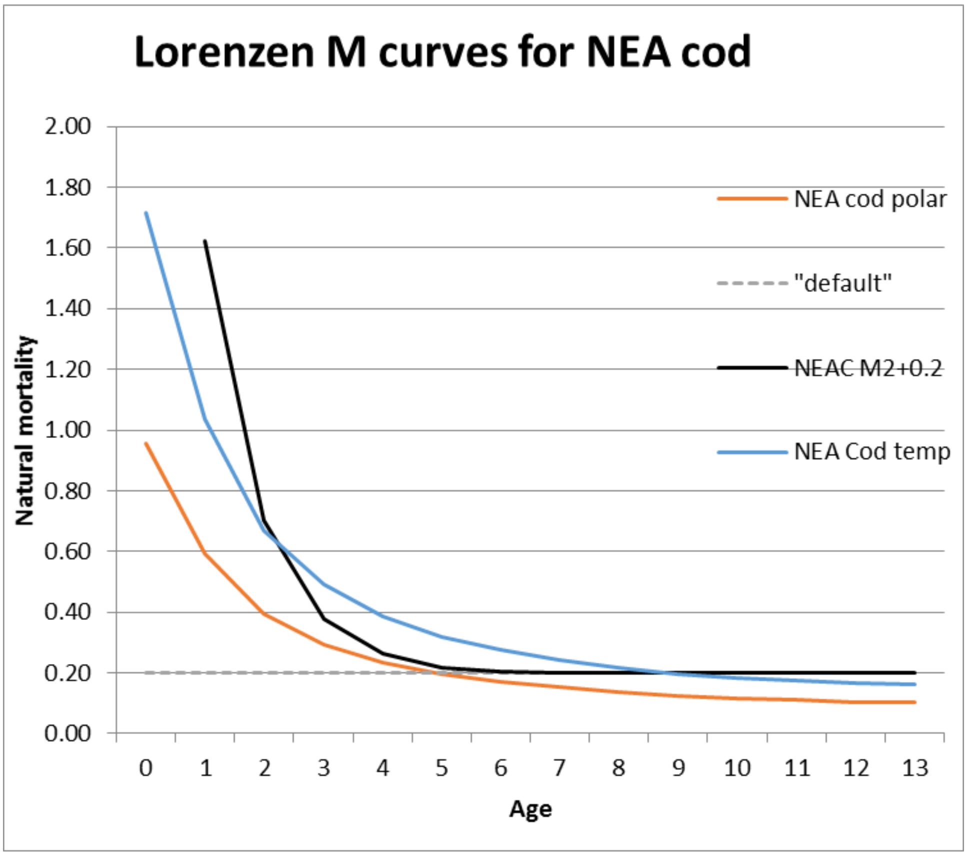

Figure 2. Lorenzen M curves for NEA cod, based on average weight in stock for 1995-2016 and mortalities for 1995-2015.

New M1 matrix (cannibalism will come in addition)										
Year/age	3	4	5	6	7	8	9	10	11	12	13+
1996	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
1997	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
1998	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
1999	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2000	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2001	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2002	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2003	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2004	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2005	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2006	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2007	0.2	0.2	0.2	0.2	0.19	0.18	0.17	0.17	0.17	0.17	0.17
2008	0.2	0.2	0.2	0.2	0.18	0.16	0.14	0.14	0.14	0.14	0.14
2009	0.2	0.2	0.2	0.2	0.17	0.14	0.11	0.11	0.11	0.11	0.11
2010	0.2	0.2	0.2	0.2	0.17	0.14	0.11	0.11	0.11	0.11	0.11
2011	0.2	0.2	0.2	0.2	0.17	0.14	0.11	0.11	0.11	0.11	0.11
2012	0.2	0.2	0.2	0.2	0.17	0.14	0.11	0.11	0.11	0.11	0.11
2013	0.2	0.2	0.2	0.2	0.17	0.14	0.11	0.11	0.11	0.11	0.11
2014	0.2	0.2	0.2	0.2	0.17	0.14	0.11	0.11	0.11	0.11	0.11
2015	0.2	0.2	0.2	0.2	0.17	0.14	0.11	0.11	0.11	0.11	0.11

Table 1. Suggested M matrix for use in scenarios.

WD 2, IBP Arctic Cosd 2017

BESS index 2016.

Y. Kovalev, D. Prozorkevich and A. Chetyrkin, PINRO, Russia

The 14th joint Barents Sea autumn ecosystem survey (BESS) was carried out during the period from 17th August to 5th October 2016. Research vessel tracks and bottom trawl stations during the BESS 2016 were mainly the same as in previous years, however due to independent from scientists` reasons the large survey area was not covered by bottom trawls.

The Norwegian vessels did not carry out bottom trawls in the Loop hole in the Barents Sea, outside the economic zones because of the absence of the permission from Russian authorities. Russian vessel also did not cover some part of REEZ because the area has been closed due to Russian navy training (Fig.1). However, relatively small numbers of cod is usually allocated during the BESS in areas not covered in the 2016 survey.

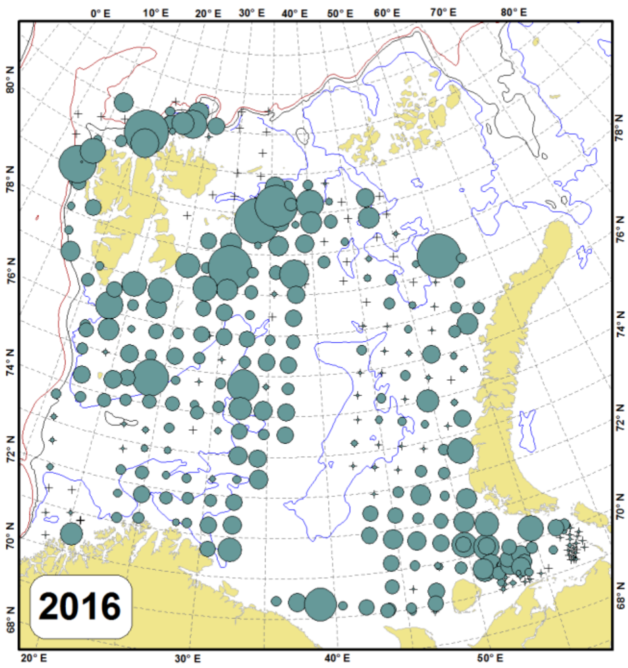

Figure 1. Total distribution of Northeast Arctic cod (kilograms per square nautical mile) at stations of the 2016 BESS. The areas without bottom trawling is clearly seen.

The basic sampling methodology and stock index calculation in 2016 was the same as in the previous years (http://www.imr.no/filarkiv/2012/11/5_6_1_demersal_fish_species.pdf/nb-no, ICES AFWG-2014 WD02). The detail information about the BESS is available on the website (http://www.imr.no/tokt/okosystemtokt_i_barentshavet/nn-no).

In August-September 2016 the main concentrations of cod were distributed on edges of the feeding areas. (Fig. 2). The calculation method by BIOFOX program has interpolated boundary data inside “holes”. It works well if fish distribution is uniform. However, results will be very critical if the “holes” are near the maximum fish concentration places or survey area margin.

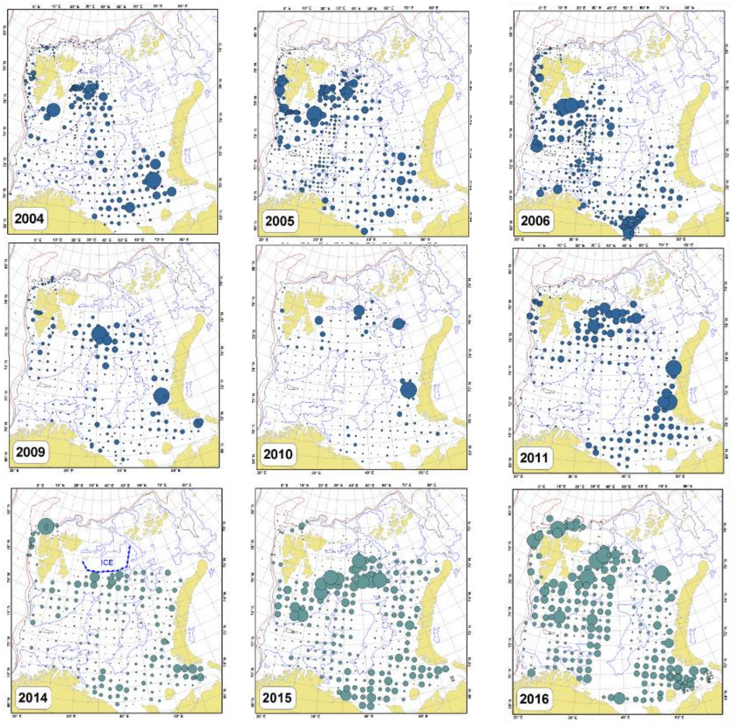

Figure 2. Distribution of Northeast Arctic cod in 2004-2016 (the BESS data).

The work goal was to find out how the data from not covered areas (Fig. 3) can affect to the total assessment. For this purpose, the trawl catch data from 2004-2015 surveys have been completely removed from database inside 24 WMO (World Meteorological Organization) squares (Fig. 3). This way to simulated coverage in 2016. “New” survey indexes were calculated by standard methods with data interpolation and filling emptiness (Table 2).

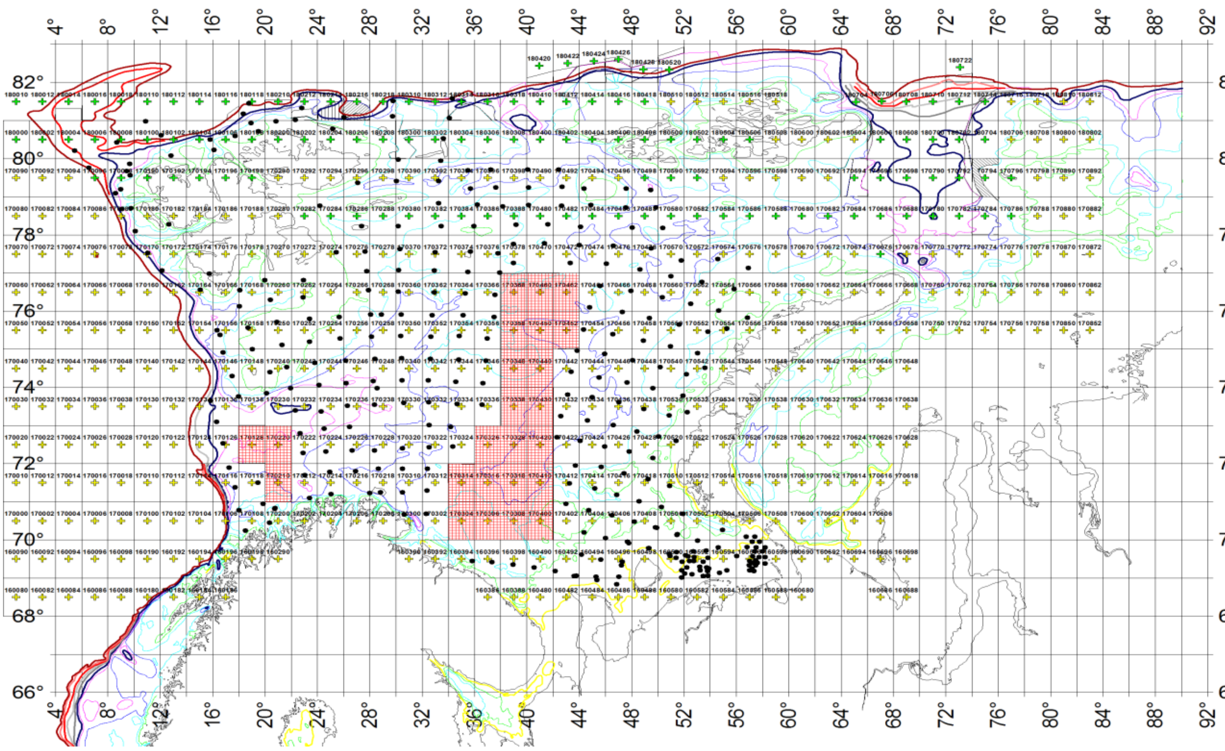

Figure 3. WMO squares (red) uncovered in the BESS 2016 and removed from the database 2004-2015 before simulation.

Table 1. Indexes calculated with all data available (thousands).

Age\ Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016 (only RUS age)
0+ (bot)	543044	180169	276036	101048	483444	903274	652598	2082961	1412741	2281839	2445196	350928	1144583
1	330631	440711	479015	333324	130942	569715	310259	509808	1454272	914192	308152	725316	362090
2	329740	146597	509664	505358	372612	93520	84155	160004	255853	658992	155120	153989	351027
3	147721	216599	186105	586192	652619	202337	56811	123648	229092	249106	190016	174411	62982
4	421529	55799	205591	159152	483428	280640	177044	101527	146407	183591	108592	225164	84850
5	150215	100856	59855	79075	132269	289625	397182	240167	69962	125688	93910	141294	111010
6	79762	27998	69755	24568	51067	101694	424933	300390	150769	63154	52809	72569	91726
7	40211	15645	17641	26920	12816	31883	142730	178433	165156	118220	30410	48560	49199
8	10089	5653	8090	5968	17453	12662	38534	32276	84514	130197	50180	26240	30245
9	2211	1172	2558	2164	3284	7277	10550	7693	12699	53848	36338	35256	14828
10	503	464	650	932	850	2569	6784	1850	4352	9141	12073	26634	13870
11	128	120	248	146	229	815	1589	1336	1550	3315	3426	7865	6033
12	65	0	44	206	202	283	310	594	1429	1521	1025	1697	2130
13	0	50		0	109	167	205	280	428	445	837	149	263
14	135			34	0	0	107		143	329	267	811	592
15					0	0			75	164	205	0	350
16					80	55					61	95	

Table 2. "New" indexes calculated with trawl catch inside 24 WMO squares removed from the database in 2004-2015 (thousands).

Age\ Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
0+ (bot)	575393	180357	252468	101075	475257	864364	638523	2004769	1619825	2211348	2790869	350190
1	347508	399441	532191	312359	137165	616006	332267	524113	1360868	881793	304163	728972
2	343410	130635	576122	486611	376344	99718	80820	165018	245414	622473	152804	150800
3	168207	196855	194171	567351	645715	218197	55387	126663	226297	220955	185083	169925
4	423379	53414	211747	150408	484131	294859	172293	107817	144573	176198	109960	228893
5	143221	99651	60326	78403	132093	281952	395986	246716	73723	124295	93386	139892
6	75651	27147	70614	24196	50480	98755	425422	305507	153518	58792	55312	75505
7	40613	15688	16414	26567	13103	31262	137227	184902	167375	120471	27889	49561
8	10373	5513	8070	5543	17126	12407	39067	31874	86669	128302	49465	27071
9	1971	1235	2469	1987	2971	7712	10275	7725	13505	50750	35521	36394
10	462	338	715	880	878	2707	6900	1882	4448	8655	12008	27496
11	102	107	199	83	153	1037	1858	1597	1500	2950	3620	8159
12	0		52	240	230	285	351	524	1240	1433	725	1612
13	0				73	260	346	179	400	455	968	151
14	199						234		79	64	197	629
15									92	106	220	
16											73	72

“New” index as well as original data (Table 1) shows good correlation between year-classes in most of all years (Table 3). In accordance with a high correlation between the same age-groups in original and “New” index the effect of absence data in area not covered by BESS survey in 2016 should not influence on population dynamics considerably (Table 4).

Table 3. Coefficient of determination between year-classes numbers in original and “New” indexes.

Year	2004/ 2005	2005/ 2006	2006/ 2007	2007/ 2008	2008/ 2009	2009/ 2010	2010/ 2011	2011/ 2012	2012/ 2013	2013/ 2014	2014/ 2015
R^2 original	0,79	0,80	0,95	0,94	0,75	0,38	0,83	0,98	0,95	0,87	0,92
R^2 “New”	0,81	0,83	0,95	0,94	0,73	0,39	0,82	0,98	0,98	0,86	0,91

Table 4. Coefficient of determination between same age-groups in original and “New” indexes.

Age	0+(bot)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
R^2	0,99	1,00	0,99	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,96	0,84

“New” index had been compared with the original one and the deviations between them were calculated (in percentages of original index data; see table 5). High values of deviations are typical for older ages (11+), as well as for early years (2004-2006).

Table 5. Deviations between original and "New" BESS index.

Age\Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Maximum deviation (%)	Standard deviation (%)
0+(bot)	6,0	0,1	-8,5	0,0	-1,7	-4,3	-2,2	-3,8	14,7	-3,1	14,1	-0,2	14,7	6,8
1	5,1	-9,4	11,1	-6,3	4,8	8,1	7,1	2,8	-6,4	-3,5	-1,3	0,5	11,1	6,2
2	4,1	-10,9	13,0	-3,7	1,0	6,6	-4,0	3,1	-4,1	-5,5	-1,5	-2,1	13,0	6,1
3	**13,9**	**-9,1**	**4,3**	**-3,2**	**-1,1**	**7,8**	**-2,5**	**2,4**	**-1,2**	**-11,3**	**-2,6**	**-2,6**	**13,9**	**6,6**
4	**0,4**	**-4,3**	**3,0**	**-5,5**	**0,1**	**5,1**	**-2,7**	**6,2**	**-1,3**	**-4,0**	**1,3**	**1,7**	**6,2**	**3,5**
5	**-4,7**	**-1,2**	**0,8**	**-0,8**	**-0,1**	**-2,6**	**-0,3**	**2,7**	**5,4**	**-1,1**	**-0,6**	**-1,0**	**5,4**	**2,4**
6	**-5,2**	**-3,0**	**1,2**	**-1,5**	**-1,1**	**-2,9**	**0,1**	**1,7**	**1,8**	**-6,9**	**4,7**	**4,0**	**6,9**	**3,4**
7	**1,0**	**0,3**	**-7,0**	**-1,3**	**2,2**	**-1,9**	**-3,9**	**3,6**	**1,3**	**1,9**	**-8,3**	**2,1**	**8,3**	**3,6**
8	**2,8**	**-2,5**	**-0,2**	**-7,1**	**-1,9**	**-2,0**	**1,4**	**-1,2**	**2,6**	**-1,5**	**-1,4**	**3,2**	**7,1**	**2,8**
9	**-10,9**	**5,3**	**-3,5**	**-8,2**	**-9,5**	**6,0**	**-2,6**	**0,4**	**6,3**	**-5,8**	**-2,2**	**3,2**	**10,9**	**5,8**
10	**-8,2**	**-27,2**	**10,1**	**-5,7**	**3,2**	**5,4**	**1,7**	**1,7**	**2,2**	**-5,3**	**-0,5**	**3,2**	**27,2**	**9,1**
11	**-20,3**	**-10,9**	**-19,7**	**-43,0**	**-33,1**	**27,3**	**16,9**	**19,6**	**-3,2**	**-11,0**	**5,7**	**3,7**	**43,0**	**20,5**
12			19,8	16,6	13,8	0,8	13,4	-11,7	-13,2	-5,8	-29,3	-5,0	29,3	15,1
13					-32,6	55,8	68,9	-36,1	-6,5	2,1	15,7	1,8	68,9	35,2
14	47,6						120		-44,9	-80,4	-26,1	-22,5	119,8	66,2
15									22,6	-35,4	7,5		35,4	24,6
16											19,7	-24,5	24,5	22,1

** age groups used in XSA tuning are highlighted as bold*

The standard and maximum (in absolute value) deviations by ages have been calculated. They have similar dynamics (Fig. 4). The dynamics of deviations for neighboring ages by years could be similar (Fig. 5). Nevertheless, the deviations for other ages may have a different dynamic (Fig. 6). It allows assuming that overall error in stock assessment (total biomass) done using “New” index should be less than errors observed for particular age.

It should be mentioned, that the highest errors are observed for oldest ages, which have low abundances, and represent a small part of the total biomass. In addition, we could see that in period while abundance of age group increasing an error in its survey index caused by not full coverage is decreasing. See, for instance, that the errors for age 11 became smaller in period 2012-2015 when the abundance of this age group increased considerably.

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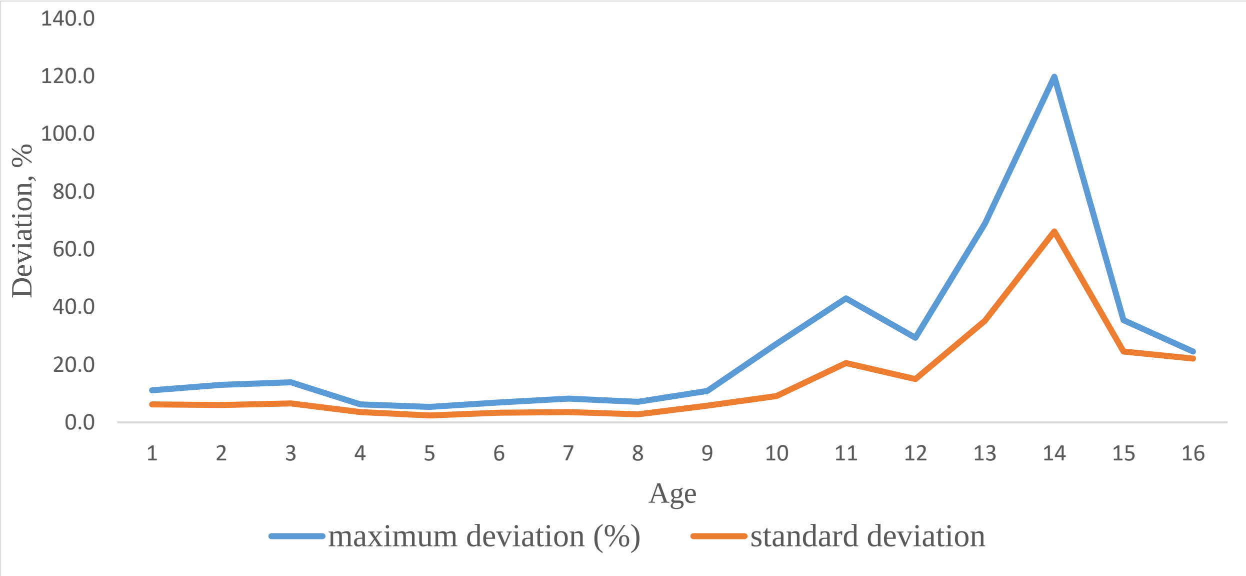

Figure 4. Maximum and standard deviations between original and "New" BESS index

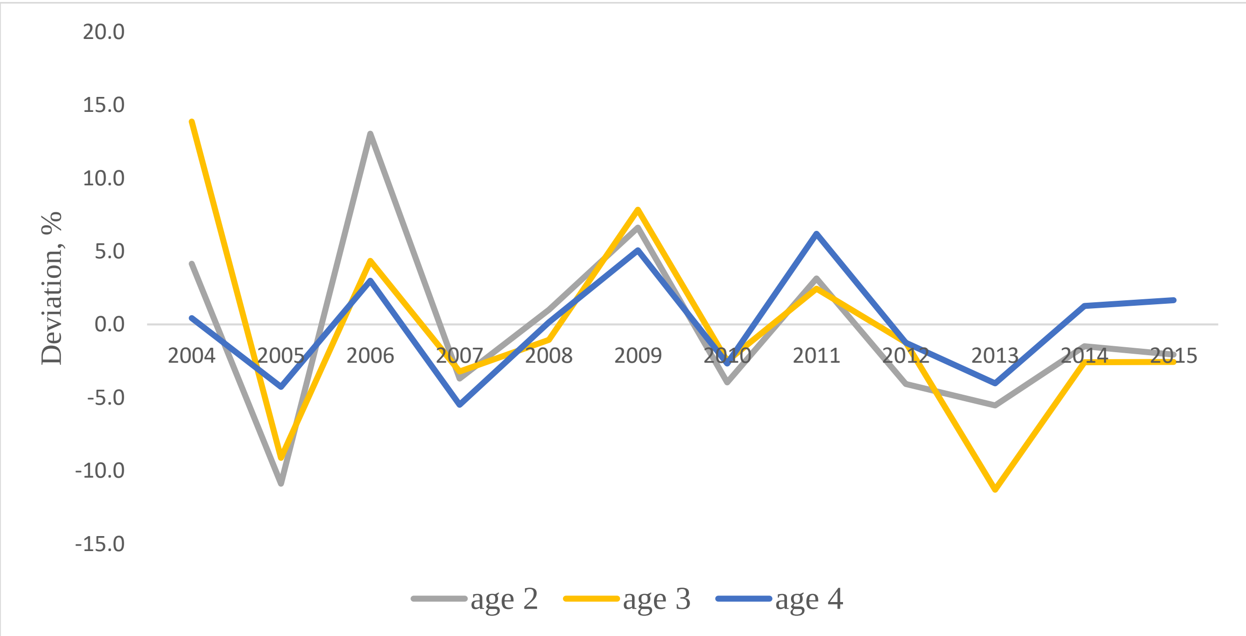

Figure 5. Deviations between original and "New" BESS index in 2-4 ages

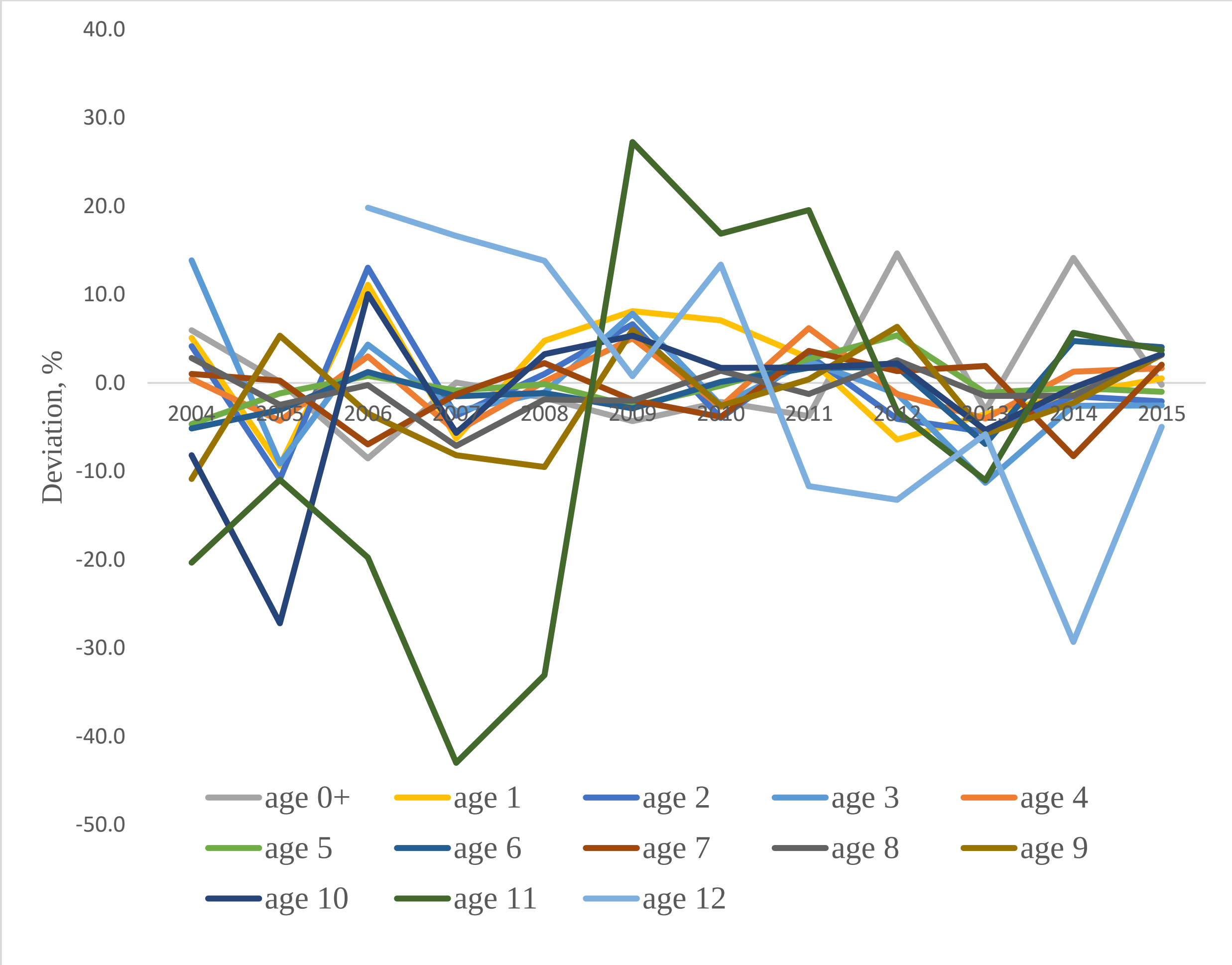

Figure 6. Deviations between original and "New" BESS index in 0+-12 ages

So, possible effect of data absence in the area not covered by the BESS survey in 2016 should not influence on assessment considerably. Taking into account that Russian bottom survey was not done in 2016 and that Joint February survey also had problems with data coverage, we considered that the 2016 BESS index should be used in XSA model tuning in 2017 assessment.

Additional diagnostics and considerations concerning NEA cod assessment

WD3 to NEA cod IBP 2017

Bjarte Bogstad, IMR, Bergen, Norway

In 2016, ADGANW and later ACOM rejected the AFWG 2016 cod assessment, choosing instead to use SPALY settings for the XSA run (ie not increasing the age range in the tuning series FLT15, FLT16 and FLT 007 from 3-8, 3-9 and 3-9 to 3-10, 3-11 and 3-11 respectively, as AFWG did). As we know this had considerable effect on the assessment and advice. In the time between AFWG 2016 and ADGANW/ACOM 2016, a number of additional diagnostics for the NEA cod assessment were made. This Working Document shows these diagnostics and also raises some concerns about the tuning series and assumptions used in the assessment. The two assessments are denoted AFWG 2016 and ACOM 2016.

Additional diagnostics

Fig 1-2 shows a comparison between VPA SSB and Lofoten biomass, in Fig 1 Lofoten biomass is shown on another axis (ie scaled by 2 compared to SSB), while Fig 2 shows Lofoten biomass on the same scale as SSB. Fig 3-5 compares assessments and Lofoten estimate by number for ages 10+, 11+ and 12+. Fig.6 shows TSB compared to the sum of 3+ biomasses in the Lofoten survey and the Joint Winter survey (bottom trawl and acoustic), using all survey indices as absolute values. It seems quite clear that the ACOM 2016 assessment is an underestimate for SSB (in particular for age 10+ cod) in relation to the Lofoten estimate, while the AFWG 2016 estimate fits much better to the Lofoten estimate. When comparing surveys and assessments for the total stock (Fig. 6), the picture is less clear. Is there any information available (e.g. likely range of catchability) on how the absolute value of the Lofoten estimate is likely to be related to the abundance in the area covered?

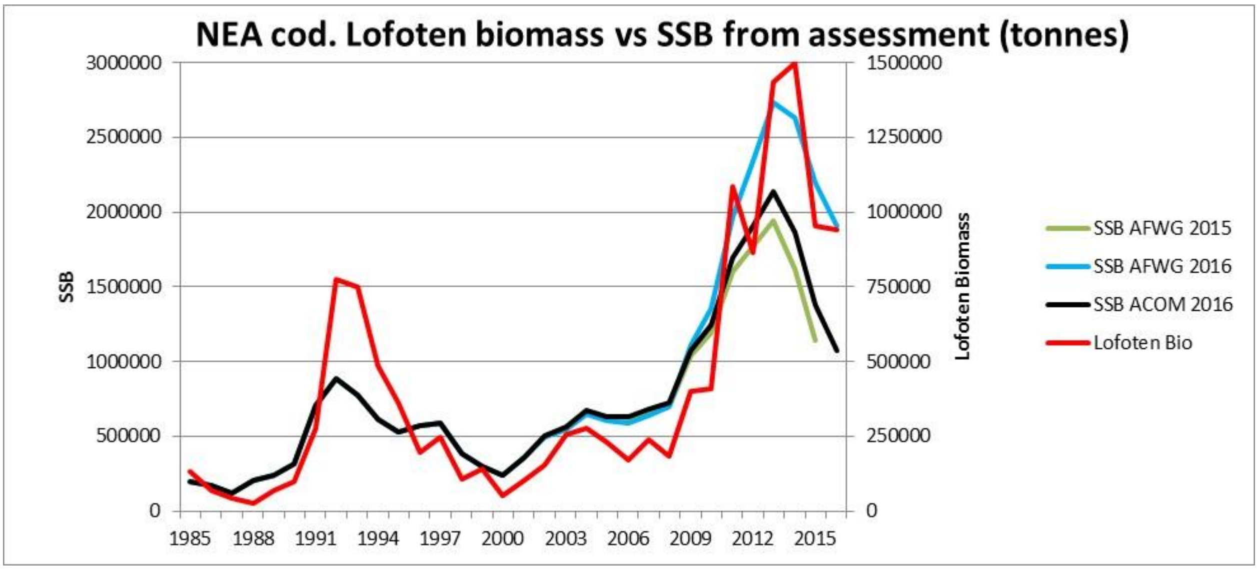

Fig 1. Lofoten survey compared to SSB, using a different scale for the Lofoten survey.

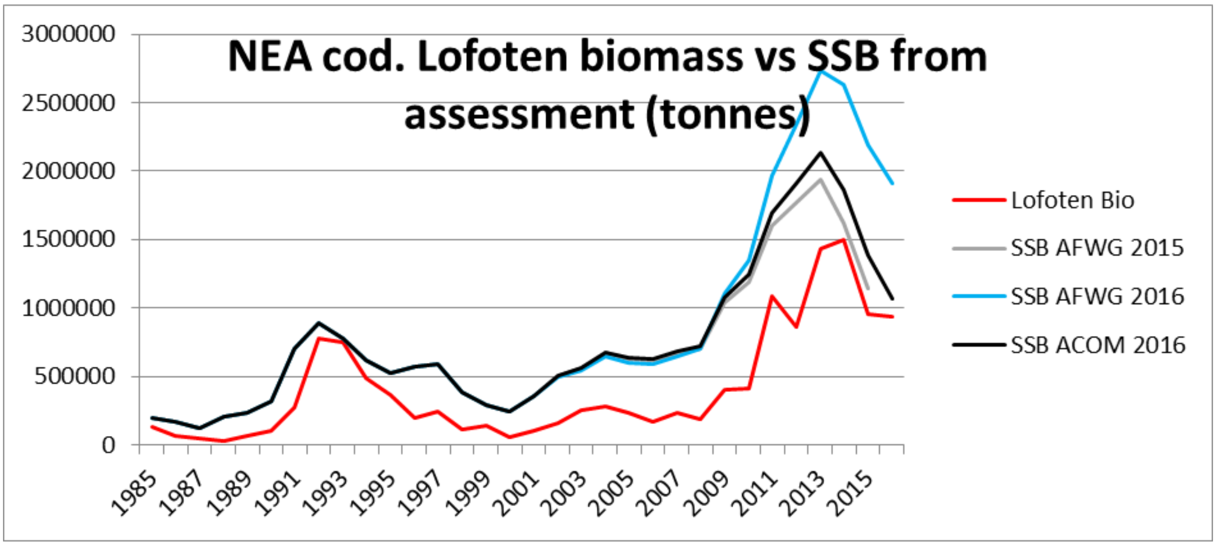

Fig 2. Lofoten survey compared to SSB, using the same scale for both.

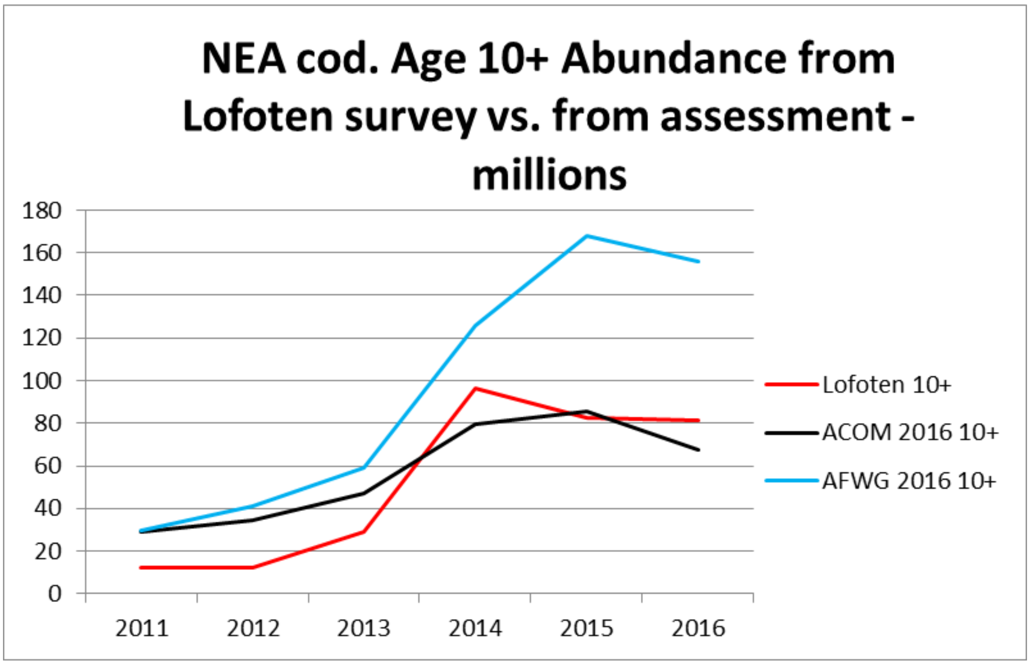

Fig 3. Number of age 10+ cod in the Lofoten survey vs. in the assessment in recent years.

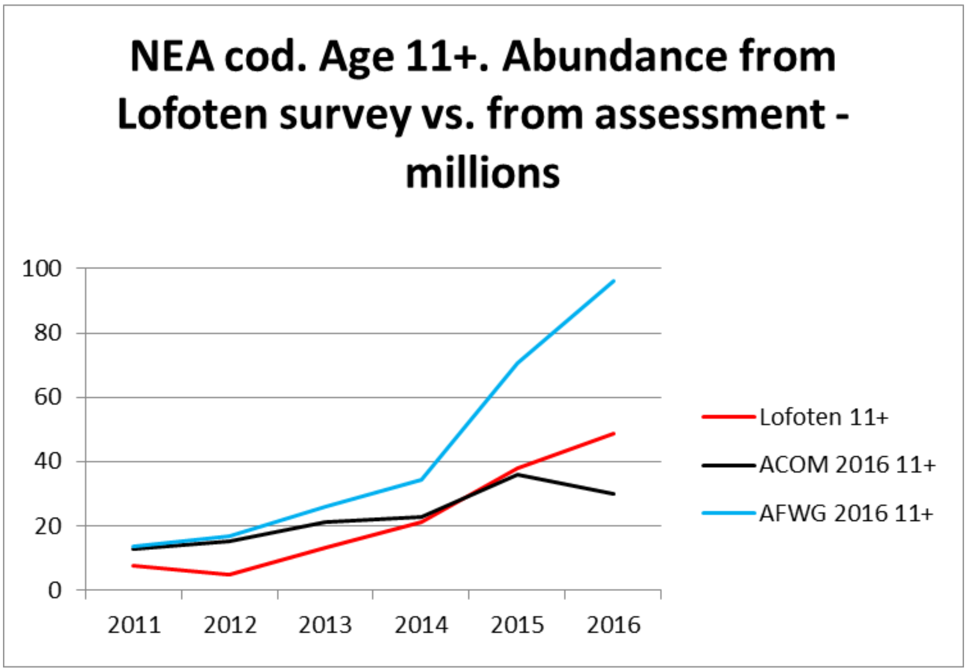

Fig 4. Number of age 11+ cod in the Lofoten survey vs. in the assessment in recent years.

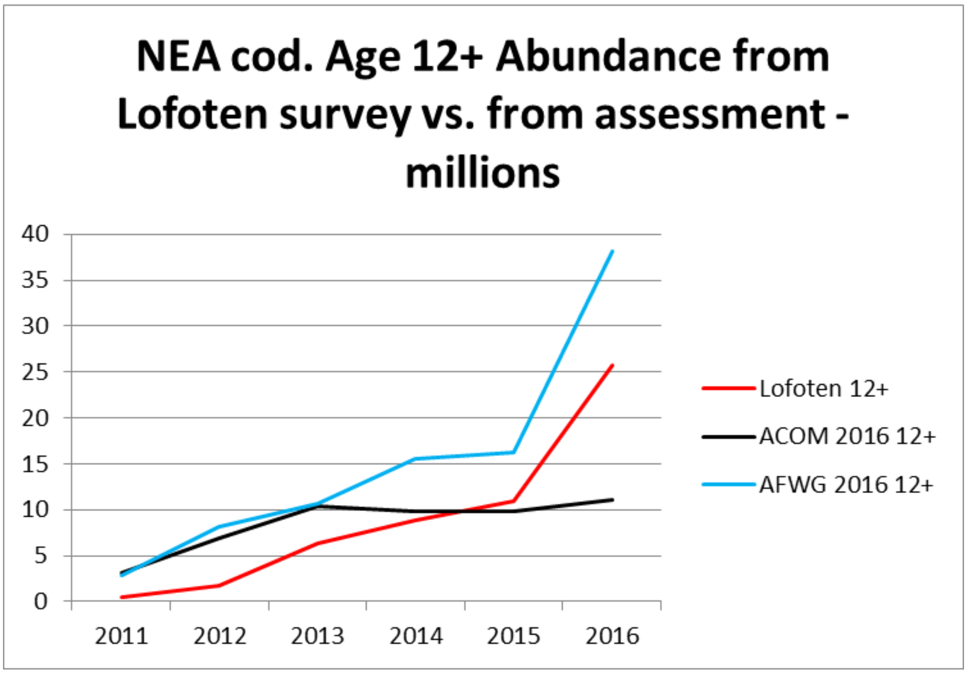

Fig 5. Number of age 12+ cod in the Lofoten survey vs. in the assessment in recent years.

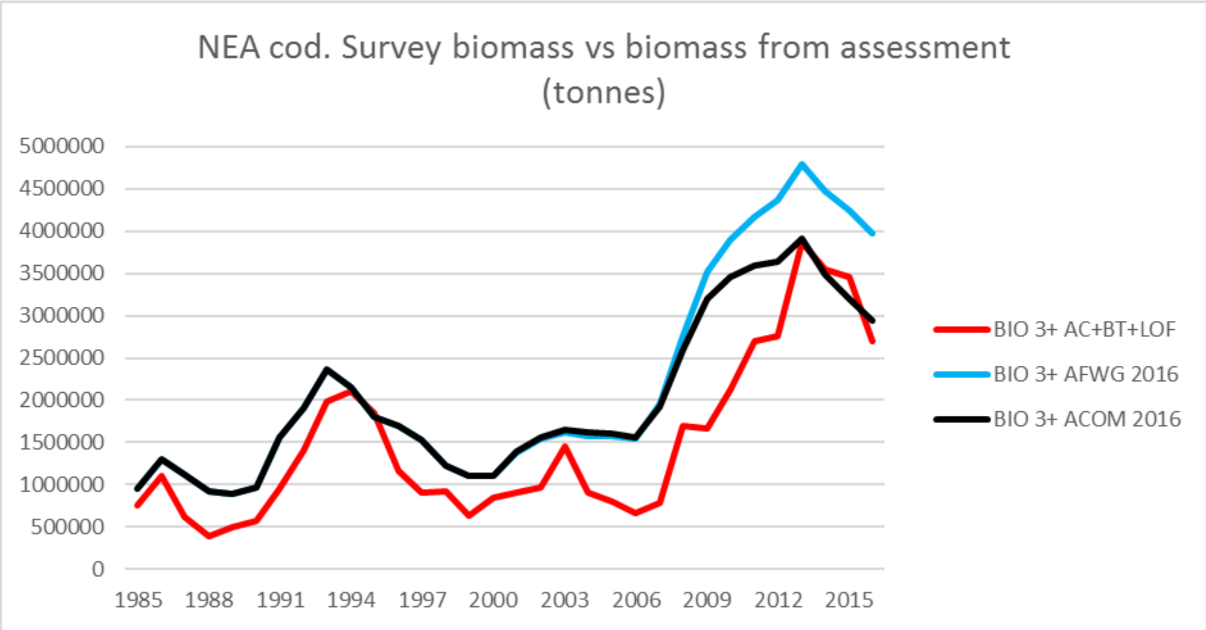

Fig 6. Total stock biomass (TSB) from VPA) vs. sum of 3+ biomass Lofoten (LOF)+winter bottom trawl (BT) + winter acoustic (AC).

Catchability considerations

For the BT survey (FLT 15), in particular for ages 7-9 (ie ages 6-8 in the tuning after shifting), one would expect the catchability to change considerably in recent years due to large changes in maturity ogives (Fig. 7) Thus, this survey is likely to have covered a larger proportion of these age groups than previously, remember that the quantity (1-Ogive (age)) is an indication of the proportion of the age group covered by the winter survey. For age groups 7-9 in 2015 (2006-2008 cohorts) this survey (FLT 15) gives the highest estimate of survivors (Table 3.14) and thus increases the stock estimate. This is seen both for the ACOM and AFWG assessment. The other surveys used in the tuning are not likely to be affected by changes in maturity ogives in a similar way, as they cover both mature and immature fish. Also note that the length-dependent effective fishing width correction factor is constant for cod above 62 cm, while most likely this continues to increase also above 62 cm. If size at age for ages 6 and older changes over time, this will affect the indices by age in a way that the current length-dependent effective fishing width correction factor does not account for.

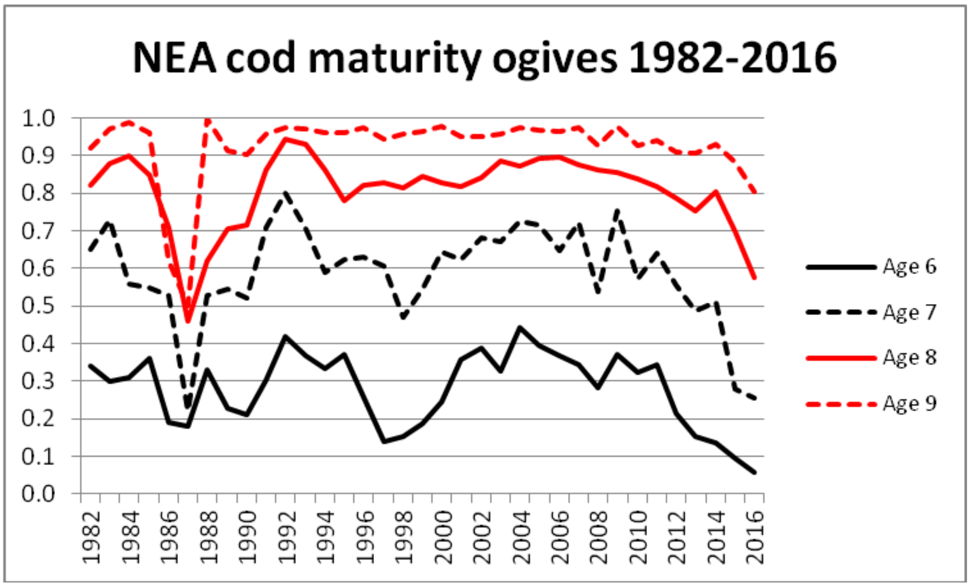

Fig. 7. Maturity ogives for age 6-9 NEA cod.

Issues concerning tuning age range

When extending the tuning age range AFWG should have discussed in more detail which indices to include before starting the calculations, both related to length of time series, internal consistency of data, CV of index and validity of the assumption of coverage of a constant proportion of the age group (see also above concerning ogives and FLT15). Also, data from the Russian autumn survey (FLT 18) are now given for age 0-9 and 10+, 10+ in this survey should be split up (e.g. in ages 10, 11 and 12+) so that increasing the tuning age range can be investigated also for this stock.

CPUE and F comparison

Fig 3.8 shows the development of Russian commercial trawl CPUE by area and also Norwegian trawl CPUE up to 2007. The trend in CPUE may fit better with the ACOM assessment, note the strong decrease in area I from 2014 to 2015. Although one should always be skeptical about using CPUE in assessments, it would be very interesting to also see updated figures for CPUE in the Norwegian trawl fishery. Anecdotal information received by IMR points to a considerable decrease in CPUE in Norwegian trawl fisheries the last two-three years. I do not have the necessary data used in fig 3.7 (Russian and Norwegian effort) to combine that with development in F, but may be PINRO can help with that?

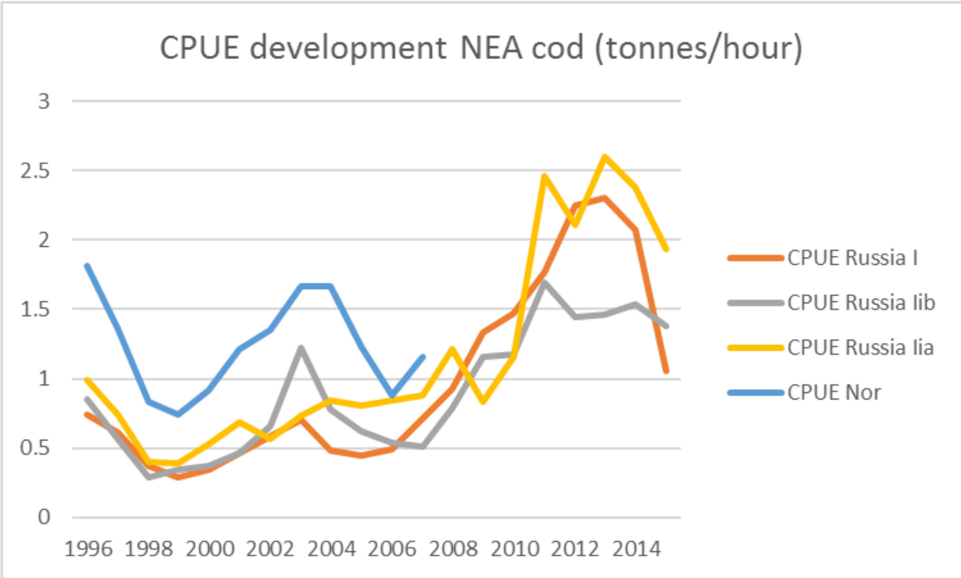

Fig. 8. Russian CPUE vs fishing mortality (ages 5-10).

Testing of the input data for NEA cod stock assessment for outliers

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During the 2016 assessment it was decided to enlarge the age range used for the tuning fleets, in order to include more information about the strength of the 2004 and 2005 year classes as follows (see the Table below taken from (AFWG 2016), previous age range is given in brackets):

:

XSA name	Name	Place	Season	Age	Years
Fleet 15	Joint bottom trawl survey	Barents Sea	Feb-Mar	3-10 (3-8)	1981-2016
Fleet 16	Joint acoustic survey	Barents Sea+Lofoten	Feb-Mar	3-11 (3-9)	1985-2016
Fleet 18	Russian bottom trawl surv.	Total area	Oct-Dec	3-9 (3-9)	1994-2015
Fleet 007	Ecosystem surv.	Total area	Aug-Sep	3-11 (3-9)	1994-2015

For fleet 18, data to extend the tuning age range were not available at the time of the meeting.

One of the main objections to such an innovation could be that the data for oldest age groups are much more noisy what can cause instability of the results.

The purpose of this WD was to test: these data for older age groups must be considered as “extremely” noisy, i.e. “outliers”, what can create problems in assessment, or they are still within the “properties” of the other data.

To determine the outliers in the data the so called “X-84 rule” by P.Huber (Hampel et al., 1986) was used. According to this rule all data point with residuals higher than 5.2 absolute median deviations are to be excluded.

Naturally, since we work with residuals, the outliers are model-dependent: for different models the conclusions can be different.

For the TISVPA run based on the data from (AFWG 2016) the data points of the surveys which can be treated as outliers from point of view of “X-84-rule”, age given in tables 1-4. Used data points are marked by grey; used but looking like outliers – by red.

Year\Age	3	4	5	6	7	8	9	10	11	12	13
2004											
2005											
2006											
2007											
2008											
2009											
2010											
2011											
2012											
2013											
2014											
2015											

Table 1. Fleet 007.

Year\Age	3	4	5	6	7	8	9	10	11	12	13
1984											
1985											
1986											
1987											
1988											
1989											
1990											
1991											
1992											
1993											
1994											
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2011											
2012											
2013											
2014											
2015											

Table 2. Fleet 015.

Year\Age	3	4	5	6	7	8	9	10	11	12	13
1984											
1985											
1986											
1987											
1988											
1989											
1990											
1991											
1992											
1993											
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2010											
2011											
2012											
2013											
2014											
2015											

Table 3. Fleet 016

Year\Age	3	4	5	6	7	8	9	10	11	12	13
1984											
1985											
1986											
1987											
1988											
1989											
1990											
1991											
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2015											

Table 4. Fleet 018

As it can be seen, for fleet 007 only 2 points at age 11 looks like outliers; for fleets 015 and 016 no outliers are found in newly added age groups, but 1 outlier is found at age 7 for fleet 015 and 2 for fleet 016 at ages 7 and 9. For fleet 018 outliers are found at age 9 but the data for this age group were used previously.

In order to outline a possible influence of the revealed outliers on the result of the assessment an additional TISVPA run was made using tuning data with excluded points looking like outliers. Results in terms of SSB are compared in figure 1. For comparison the TISVPA-derived results for “narrow are range” of fleets data (that is as before 2016) are also given.

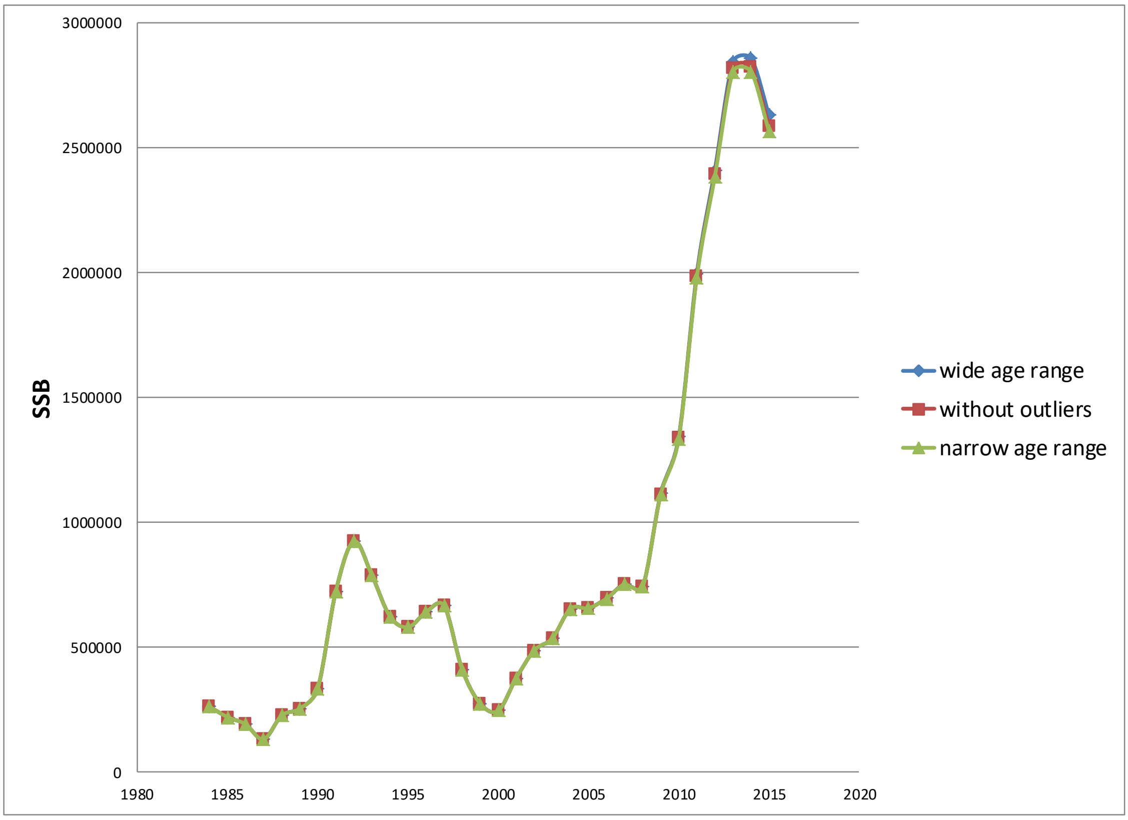

Figure 1. TISVPA-derived estimates of SSB for “narrow” and “wide” age ranges of tuning data, as well as for “wide” age range with excluded outliers.

As it can be seen, from point of view of TISVPA there is no much difference between cases. At least it can be said that the “widening” of the age range did not introduce into the assessment “a lot of new outliers” and almost does not change the result taken from TISVPA.

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Maturity ogives of the Northeast Arctic cod

WD 5, to IBPArcticCod–An Inter-benchmark Protocol on Northeast Arctic cod (IBP) 2017 ToR A.1 Life history (maturity)

Natalia Yaragina, PINRO, Murmansk, Russia

Stock assessments and spawning stock biomass (SSB) estimates in particular, are based on maturity ogives data (or maturity at age or portion of mature specimens at age/length).

History

Survey period

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

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

where

$M_{rus,a-1}$: Maturity 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

$M_{nbar,a}$: Maturity 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

$M_{lof,a}$: Maturity at age a in the Lofoten survey in year y

Pre-survey period

Concerning historical period, two approaches were in use for NEA cod stock assessments in terms of maturity ogives data. At first, a knife-edge maturity ogive was used for historical (1946-1982). These data assumed that all cod younger than 8 years were immature while all cod 8 years and older were mature (Figure 1). However, this approach did not fully satisfy scientists and some attempts to use variable values were undertaken (Jakobsen, 1993; Nilssen et al., 1994; Nakken, 1994). The second approach was connected with variable by ages and years maturity data calculated for the whole period.

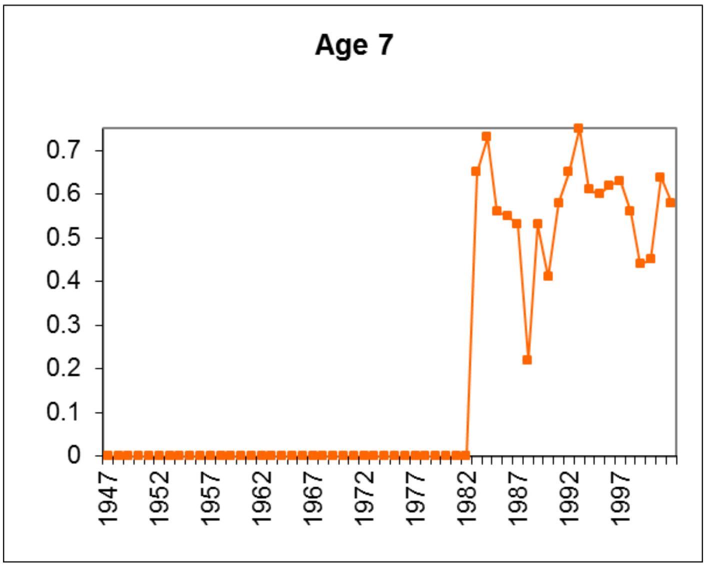

Fig.1. NEA cod. Maturity ogives for cod at age 7 used before 2001

Big work has been done by IMR and PINRO for compiling and summarizing data on maturity of NEA cod from historical sources. Since 2001, the reconstructed historical data has been used in stock assessment (Figure 2).

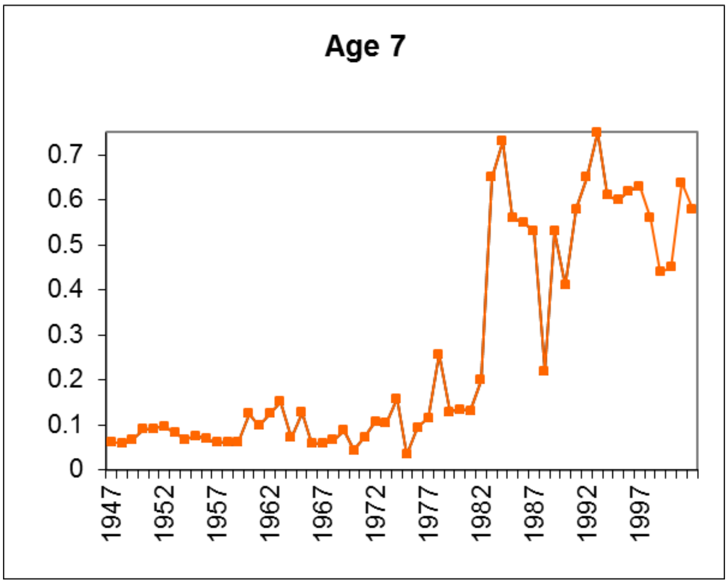

Fig.2. NEA cod. Maturity ogives for cod at age 7 used after 2001

Methods

For the survey period, observation data on maturity at age/length are available.

For the historical period, the Russian proportions mature cod at age based on visual inspection of gonad maturity in the pre-spawning season (November-February) were available from 1959. As for Norwegian data, the Gulland (1964) method was used to construct maturity ogives for individual cohorts taking into account information on age at first spawning from otoliths (ICES CM 2001/ACFM:19); the data were available from 1946 (Norwegian sampling in the Lofoten spawning fishery).

Examination of the Norwegian and Russian data, obtained by different methods, suggests that the long-term trends were the same in both time series (ICES 2003) (Figure 3).

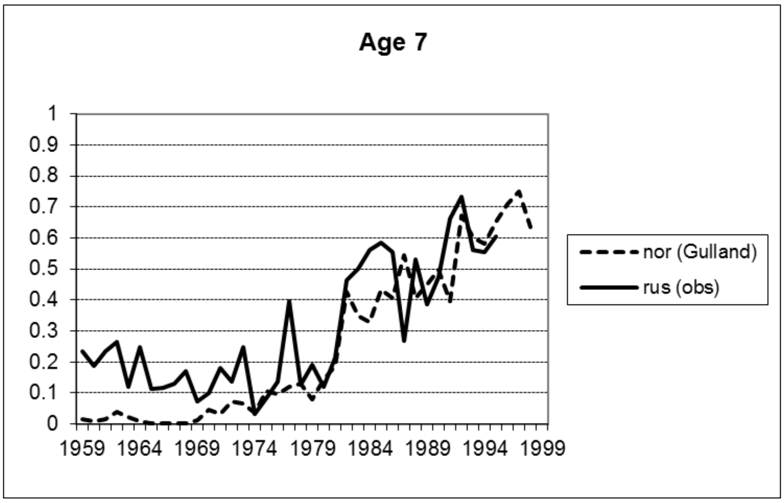

Fig.3. NEA cod. Norwegian (nor, Gulland) and Russian (rus, obs) data on maturity ogives for cod at age 7

Summary

There have been substantial changes observed in maturity at age of NEA cod over large historical period (since 1946). They are thought to be connected both with compensatory density-dependence mechanisms and genetic changes in individuals (Heino et al 2002; Jørgensen et al. 2007; Kovalev and Yaragina 2009; Eikeset et al 2013; Kuparinen et al 2014). Since marine systems are very changeable it is difficult to disentangle genetic and environmental effects, however.

Changes depended on population density are most likely to be reversible. Upon fishery management directed to a decrease in fishing mortality and an increase in biomass/ density of the stocks they tend to respond by the decrease of growth and sexual maturation. This effect can be seen on NEA cod data in recent years (Figure 4). Genetic traits, however, took much more years to evolve back to pre-harvest levels (Enberg et at 2009; Swain et al 2007).

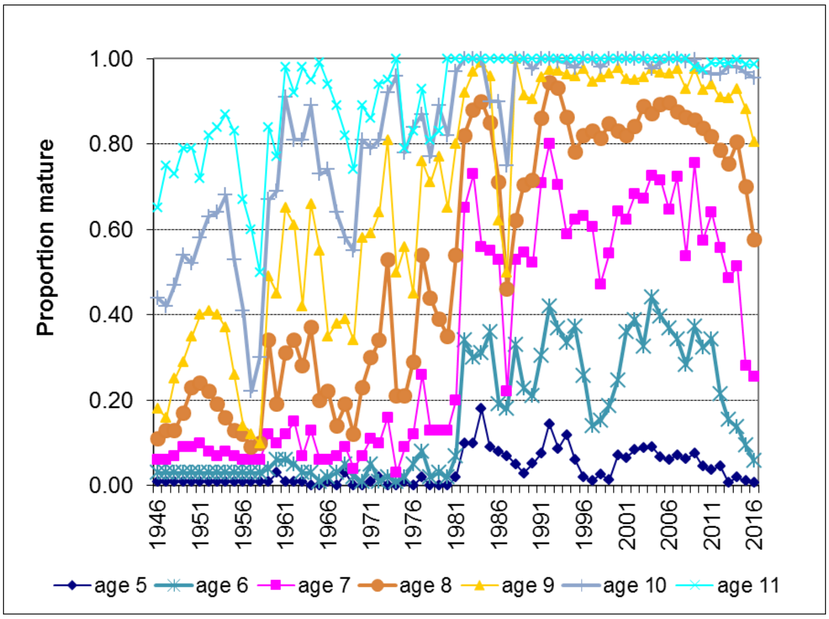

Fig.4. NEA cod. Maturity ogives used at AFWG 2016

There are also some untouched problems in maturity at age schedule of NEA cod (e.g. skip spawning). The phenomenon is well documented (Skjæraasen et al. 2009, 2012; Yaragina 2010); it closely linked to individual female energy reserve. However, at the moment, it should be stated that more work is needed to have full and reliable picture of the phenomenon for the whole time range and possibly some strong stimulus to change this time series.

So, methodology of maturity-at-age estimations has not been changed since the last assessment. The same data and procedure of calculations is supposed to be used at this IBP as described in Stock annex of AFWG (2016).

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Assessment of NEA cod using XSAM

By

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Objectives

- Evaluate whether XSAM can be used for assessing the cod stock
- Evaluate the effect of using old fish in survey time series and to introduce them as plus groups. More specifically we look at 3-9, 3-9+ and 3-11
- Evaluate the effect of density dependent versus density independent catchability
- Evaluate the effect of backshifting surveys in the assessment year
- Evaluate the effect of estimation predation mortality due to cannibalism.
- Evaluate the sampling variability in input data and if it can be utilized when fitting the model to data. Restricted to Norwegian catch at age and the Norwegian bottom trawl index.

Introduction

The XSAM models is described in Aanes 2016a and 2016b. The framework was established partly due to a generalization of models for fishing mortality and partly to enable better utilization qualities of input data. The approach was tested and evaluated for NSS herring during the benchmark working group WKPELA and is currently the model used for assessing NSS herring (ICES 2016). In summary the model for fishing mortality includes a modest generalization of the structural time series model for fishing mortality described in Gudmundsson 1994. This model includes mechanisms with a thorough justification that is believed to control the process of fishing mortality. The modification in XSAM is essentially moving from Random Walks to AR(1) models. It should be recognized that this model includes several other well-known models for F as special cases (e.g. separable models, TS model as Nielsen and Berg 2014). Although increasing the number of parameters going from random walks to AR(1) models imply increasing the number of parameters to be estimated, it is often found that this change results in an improved fit of the model. It could be noted that the nature of a stationary AR process forces any values of predicted fishing mortalities within reasonable compared to the RW which not is stationary by definition.

The other aspect concerning utilizing errors structures. Aanes 2016 showed it is difficult to estimate complex error structures in data and that if prior information about sampling errors is available it can be utilized to improve the estimates and reduce bias in inference

The model may include different formulations of recruitment, either recruitment can be modelled as a latent process or the numbers of recruits can be treated as fixed parameters to be estimated. Aanes 2016 found that formulating recruitment as a simple process corresponding to mean recruitment with a constant variance practically resulted in the same estimates as considering the recruited numbers as parameters to be estimated, but the process version improved the speed of convergence. Therefore, to not interfere the estimates with the recruitment process, this procedure is kept here.

First it is shown that the model provides very similar estimates of the key parameters SSB and average F as found by AFWG (ICES 2016) using the same data and the same settings concerning catchability assumptions for the surveys. After that, units on estimates of biomasses are not presented in this document to not interfere the process of identifying adequate model setup for assessing the stock which should be independent of the actual biomass estimates.

Methods

The model and estimation is described in detail in Aanes 2016. The request resulted in the necessity of implementing two new features.

Using plus groups in surveys

Omitting the time index for simplicity:

For $A^{*+} < A^{+}$

$$I_{A^{*+}} = q_{A^{*+}} N'_{A^{*+}} = q_{A^{*+}} \sum_{a=A^{*+}}^{A^{+}} N'_a$$

Where N'_a is the abundance at the time of the survey which is $N'_a = N_a e^{-\delta Z_a}$, where δ is the fraction of the year past at the time of the survey.

Density dependent catchability:

$$I_a = q_a (N_a)^{\beta_a}$$

Note that this can be rewritten as

$$I_a = q_a (N_a)^{\beta_a} = q_a (N_a)^{\beta_a} \frac{N_a}{N_a} = q_a (N_a)^{\beta_a - 1} N_a$$

such that the catchability can be interpreted as $q_a (N_a)^{\beta_a - 1}$

Predation mortality

The available data on predation are estimates of average numbers at age a eaten by individuals of age a^* in year y season $K(a, a^*, y, s)$. Then the total consumption within season s is

$$C_2(a, y, s) = \sum_{a^*=1}^{A} K(a, a^*, y, s) N^*(a^*, y, s)$$

where $N^*(a^*, y, s)$ are the numbers at age in the population overlapping the prey population. In AFWG

$$N^*(a, y, 1) = N_{a,y} e^{\left(-\frac{Z_{a,y}}{4}\right)} \left(1 - p_{a,y}^{(mat)}\right)$$

$$N^*(a,y,2) = N_{a,y}e^{\left(-\frac{3Z_{a,y}}{4}\right)}$$

The total consumption is then found by summarizing over the seasons

$$C_2(a,y) = \sum_s C_2(a,y,s)$$

Approach 1

This approach follows the same method as AFWG, i.e. adding the consumption to the catch at age and iterating until convergence (ICES 2016). Fishing mortality (including M2) will be modelled as a TS process. The F process will be confounded with the predation process since predation is added to the catches. Similarly, observation errors will be confounded with «predation data». Therefore this approach may offer some challenges in interpreting estimates of error and process.

Approach 2

Model the predation mortality according to a multivariate AR(1) model

$$log(\mathbf{M}_{2y}) = \boldsymbol{\alpha}_M + \boldsymbol{\beta} log(\mathbf{M}_{2y-1}) + \boldsymbol{\varepsilon}_{My-1}$$

Where $\boldsymbol{\varepsilon}_M \sim MVN(\mathbf{0}, \boldsymbol{\Sigma}_M)$

Using 'pseudo' observations

$$C_2(a,y) = \frac{M_{2a,y}}{Z_{a,y}}(1 - e^{-Z_{a,y}})N_{a,y}e^{\varepsilon_{a,y}}$$

Where $Z_{a,y} = M_{a,y} + M_{2a,y} + F_{a,y}$

Data

In addition to estimates of catch at age, the following abundance indices are considered

Table 1. Abundance indices

NAME	Source	NAME	PLACE	SEASON	AGE	YEARS
Fleet 15	Table A3	Joint bottom-trawl survey	Barents Sea	Feb-Mar	1-12+	1981–2016
Fleet 16	Table A13 (Tables A2+A4)	Joint acoustic survey	Barents Sea+Lofoten	Feb-Mar	1-13+	1985–2016
Fleet 18	Table A10	Russian bottom-trawl surv.	Total area	Oct-Dec	0-10+	1994–2015
Fleet 007	Table A14	Ecosystem surv.	Total area	Aug-Sep	1-13+	1994–2015

Table 2. Data sets used in this document. All data sets includes catch at age ages 1-13+ unless otherwise stated. All data sets are restricted to the year range 1984-2016.

NAME	Description
D_{3-9}	All survey data restricted to ages 3-9
$D_{BS,3-9}$	As D_{3-9}, but ages and years in data from Fleet 15 and 16 have been backshifted with one year.
D_{3-9+}	As D_{3-9}, but the age 9 is a plus-group
$D_{BS,3-9+}$	As $D_{BS,3-9}$, but the age 9 is a plus-group
D_{3-11}	All survey data restricted to ages 3-11, except Fleet 18 which contains ages 3-9
$D_{BS,3-11}$	As D_{3-11}, but ages and years in data from Fleet 15 and 16 have been backshifted with one year.

Error structures in input data

Analysis of error structures in input data is available for the Norwegian catch at age and the joint winter survey. The method used for estimating Norwegian catch at age is described in Hirst et al (2012) and is implemented in the ECA software used at IMR for estimation of catch at age for cod. Similarly, estimation of abundance indices based on analysis of sample data is implemented in the StoX software at IMR with methods presented at WGIPS 2015 (e.g. ICES, 2015b). Common to the approaches are that they provide sampling distributions of the estimates such that standard errors and covariance structures are available.

Examples of key features for the estimates of Norwegian catch at age and abundance indices from the joint winter trawl survey are shown in Figure 1. The precision in the catch data, measured by its Relative Standard Error (standard error by mean, RSE) is typically around 10% for the most abundant ages (4-8) in the catch, whereas it increases to more than 30% for less abundant ages in the catch. Low precision for the catch data, particularly for young and old ages suggest that fishing mortality cannot be expected to be estimated precisely.

The precision in abundance indices from the trawl survey is somewhat lower (RSE~10-15% for the most abundant ages in the survey), and less abundant ages has lower precision than the more abundant ages for the catch estimates.

The inevitable cluster sampling for most surveys for fish along with length stratified sampling of ages (for other species) for both survey and catch generally result in a complex correlation structure where a positive correlation often is found for neighboring ages (c.f. Hrafnkelsson and Stefánsson 2004, Aanes and Vølstad 2015 and Aanes 2016). This is also the case for the data from the trawl survey and the correlation structures for estimates of catch at age and abundance at age are shown in Figure 1.

The implication of the positive correlation is that the amount of information in the estimates is reduced as neighboring ages effectively contain the same information about the abundances, resulting in a reduction of effective sample size for the survey.

The sampling variances fit very well to the power function $\hat{\sigma}^2 = \alpha\hat{\mu}^{\beta}$ which is related to Taylors spatial power law. Sampling variances obviously depend on sample sizes and in Aanes 2016 it is described how this function can be related to sample sizes as it effects the α's. However, if the sample sizes and sampling design is constant it can be argued that α is constant over time such that the relationship holds. The function fits the data very well with a remarkably stable value for β which is around 1.5. This has been found for a range of data sets although the value of β appear to vary across species (see Aanes 2016). Assuming that the value of β holds for the sample data sets not analyzed here, this will be used to specify the error structure of the input data.

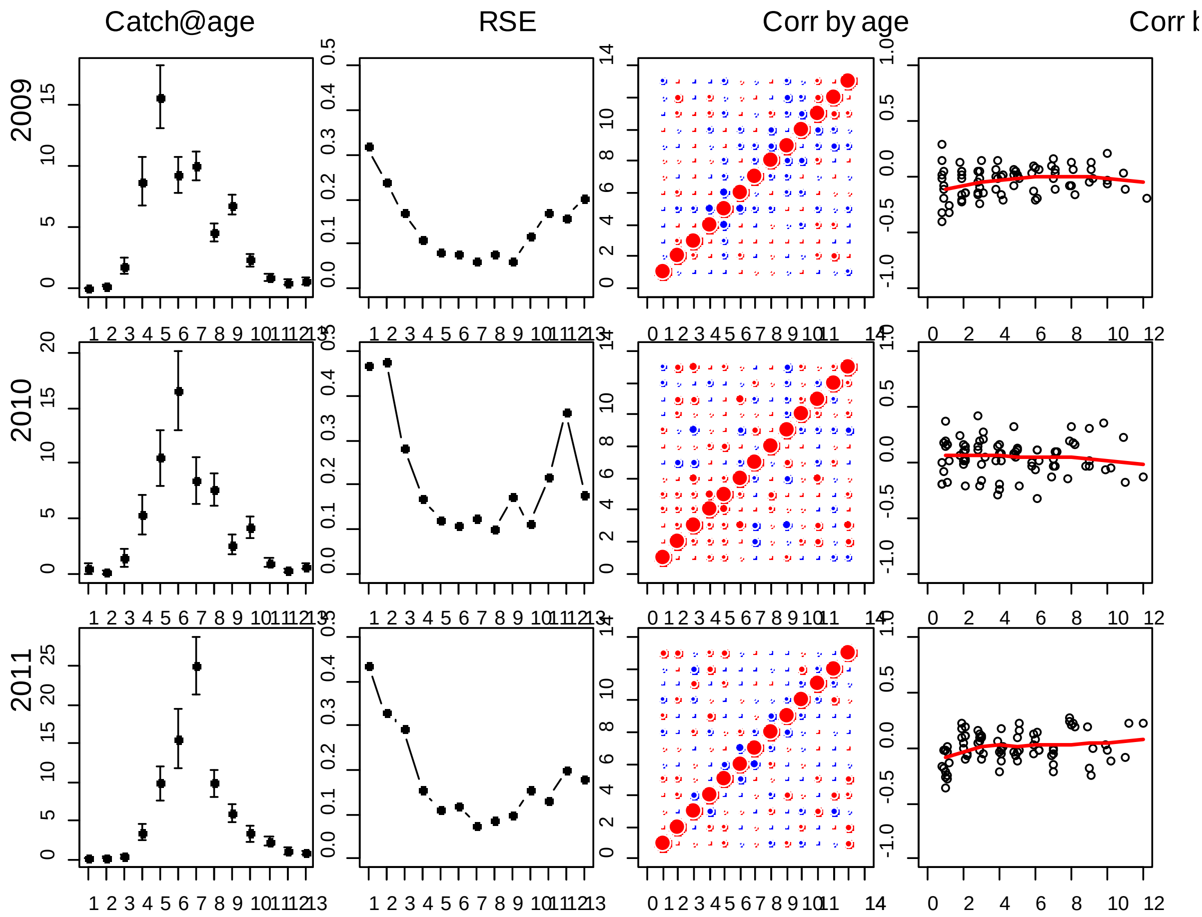


Figure 1. Summary of estimates of Norwegian catch at age in 2009-2011 for NEA cod. Numbers at age (1. column) with 95% confidence intervals, relative standard error at age (2. column), correlation of abundance estimates by age (3. column), and correlation by distance in age (4. column). Estimates of catch at age are based on ECA.

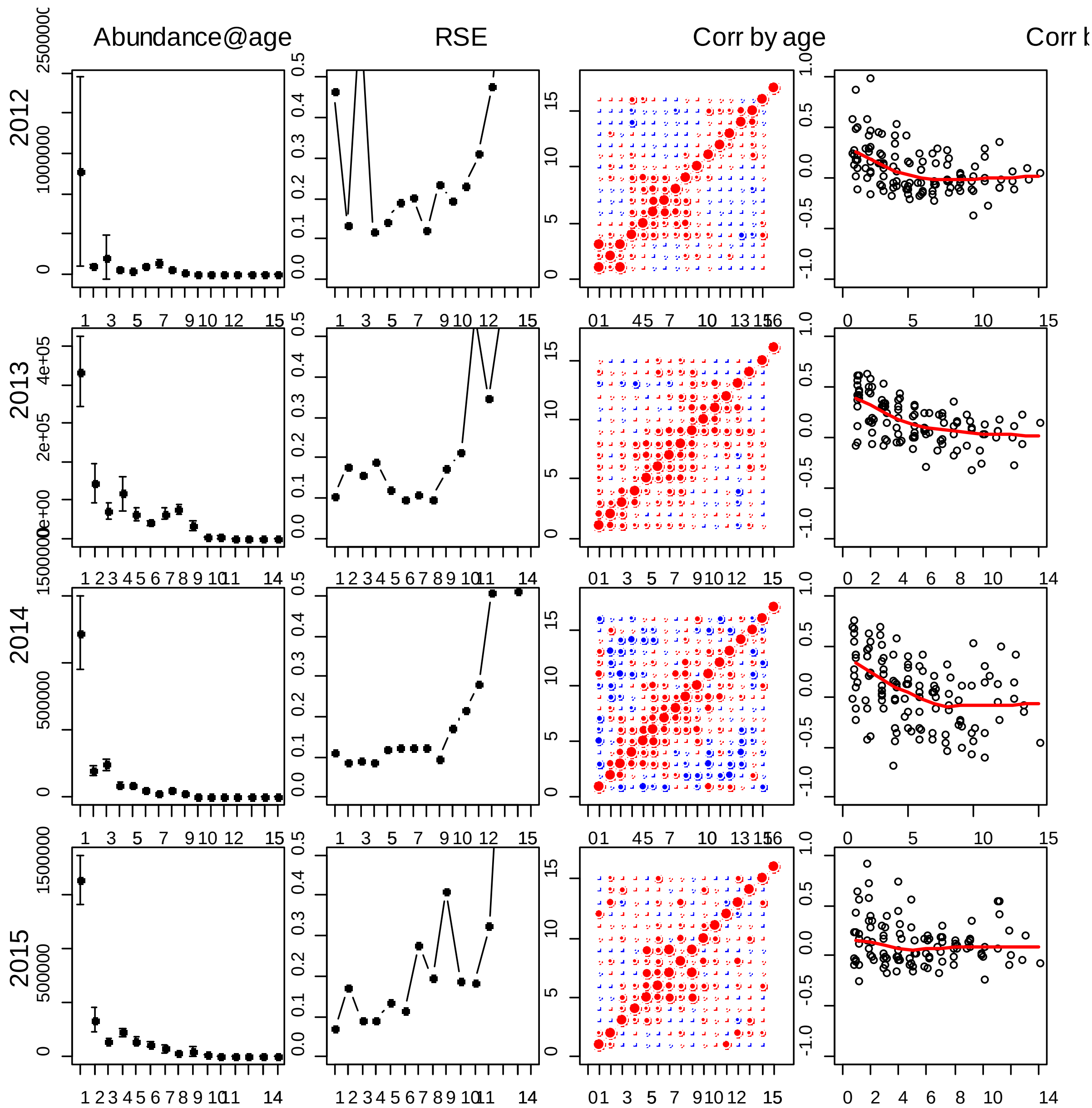


Figure 2. Summary of estimates of abundance indices at age from FLT15 in 2012-2015 Numbers at age (1. column) with 95% confidence intervals, relative standard error at age (2. column), correlation of abundance estimates by age (3. column), and correlation by distance in age (4. column). Estimates of abundance at age are based on StoX.

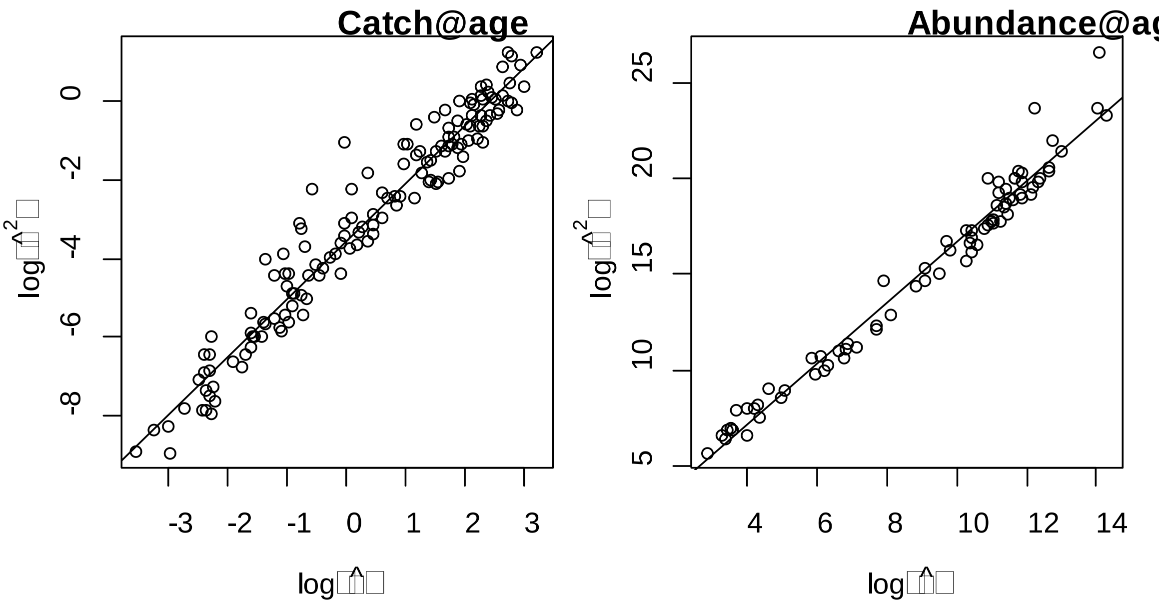


Figure 3. Estimated variance versus mean value for Norwegian catch at age for 2001-2011 and Abundance at age from FLT15 for the years 2012-2016.

Table 3. Estimated parameters of the power function $\hat{\sigma}^2 = \alpha\hat{\mu}^{\beta}$ and R^2.

Data	Age range	Year range	$\hat{\beta}$	R^2
Norwegian Catch at age	1–13	2001–2011	1.48 (0.03)	0.94
Winter survey	1–15	2012–2016	1.58 (0.03)	0.97

Setting up the model

A summary of the likelihood components and parameters is given in Table 4 below and further details on the model and parameters are given in Aanes 2016a and 2016b. As in all modelling exercises for models with a certain degree of complexity, also this model offers a high number of choices to be made to find an adequate configuration to specific stock in question and the data at hand. A summary for XSAM is made here: First an initial run is made where the number of parameters is kept to a reasonable minimum. Here this is achieved using density independent catchabilities and setting all observational variances to iid within each data source. The model for fishing mortality is set similar to Gudmundsson (1994) (i.e. separable model with noise where selectivity evolves according to a multivariate RW and effort according to RW). Some of the variances in the various processes can be difficult to identify and separate. In particular if some variances are very small this may result in convergence problems: To constrain the variances to allowable values, it the log of the variances that are actually estimated. If the variances are very small, the log value becomes a large negative number which are unstable and may result in convergence problems while the actual value is just small (or close to 0). It may therefore be necessary to put additional constraints on these parameters. For the cod data I found it necessary to constrain the variance on the noise of the separable model and it was set to e^{-5}. The other variance parameters can be estimated can be estimated without additional constraints.

Inspecting the residuals after the initial run it is apparent that the residuals for catch at age ages 1-3 are rather big indicating that either the variance in F is different for these ages or a different variance should be used for these data than for the older ages. To test the cases one run was made by assuming different variance in F for ages 1-3 and 4-13+ keeping the observation error constant to keeping the variance in F constant and assuming different observation variance in the catches for ages 1-3 and 4-13+. The two runs resulted in the practically the same fit, except for the dynamics in F at lower ages implying that the two are confounded and cannot be separated. Supported by analyses of the empirical data (Figure 1) it was decided to assume different observation variances in catch at age for ages 1-3 and 4-13+. This will be referred to as Error-Type 1.

Table 4. Summary of likelihood components. In addition to the parameters in the table, the model depend on the following parameters: initial values of abundance and selectivity in fishing mortality.

Component	Variable	Description	Fixed parameters	Likelihood component
Fishing mortality F	$\{\log F_{a,t}\}_{\substack{a=a_{min},\dots,A_m,\\ t=1,\dots,T}}$	Random	σ_1^2	l_F
F: Selectivity	$\{U_{a,t}\}_{\substack{a=a_{min},\dots,a_m-1,\\ t=1,\dots,T}}$	Random	$\{\alpha_{aU}\}_{a=a_{min},\dots,a_m-1}$, β_U, and σ_2^2	l_s
F: Realized effort	$\{V_t\}_{t=1,\dots,T}$	Random	σ_3^2	l_v
F: effort	$\{Y_t\}_{t=1,\dots,T}$	Random	α_Y, β_Y, σ_4^2	l_y
Recruitment	$\{R_t\}_{t=1,\dots,T}$	Random	μ_R and σ_R^2	l_R
Catch at age	$\{C_{a,t}\}_{\substack{a=a_{min},\dots,A,\\ t=1,\dots,T}}$	Observation	Optionally elements in $\mathbf{\Sigma}_t^c$	l_C
Abundance indices	$\{I_{a,t}^f\}_{\substack{a=a_{min}^f,\dots,A^f,\\ t=1,\dots,T}}$	Observation	$\{q_a^f\}_{a=a_{min},\dots,a_m^f}$ Optionally elements in $\mathbf{\Sigma}_t^f$	$\{l_I^f\}_{f=1,\dots,n_f}$

Utilizing error structures

Some choices that may be made concerning observational variance

1. If no idea about the errors: Assume log normal iid errors for each data source (i.e. estimate one variance for each). Error in assumption -> biased estimates (see Aanes 2016).
2. If all $\boldsymbol{\Sigma}$'s are truly known and if no other error than sampling error. Set all $\boldsymbol{\Sigma}$'s as known. Completely controls the weighting of data (and uncertainty)

Intermediate solutions may be:

3. If other sources of uncertainty:
   a. Consider to use $h_i\boldsymbol{\Sigma}_i$ where h_i is a scaling factor of $\boldsymbol{\Sigma}_i$ which is estimated. Controls the internal weighting of data points.

b. If the h_i's not are significantly different reduce the numbers of parameters by setting $h_i = h$. Controls the internal weighting of data points as well as weights between input data.

4. If the variance-mean relationship is known
   a. If β in $\hat{\sigma}^2 = \alpha\hat{\mu}^{\beta}$ is known it can be shown that this is the same as $\boldsymbol{\Sigma}_i$ being known up to a scaling constant and the above approach can be used.

Analysis of survey sample data is currently only available for the Norwegian part of catch at age and for FLT15 for a limited number of years which means that we are forced to estimate or make assumptions about the error structures. Relying on the estimated β in $\hat{\sigma}^2 = \alpha\hat{\mu}^{\beta}$ to hold we can inform the observational variance according to point 4 above. This will be tested and will be referred to as Error-Type 2 in the remainder of this document.

Although the empirical data suggest some positive correlations for FLT15, this has not been used in the results in this document. The effects of positive correlations is to reduce the effective sample size and to 'down-weight' the data. Due to the limited data, it could be attempted to model the correlation structure, but it is questionable whether such models can estimate complex error structures (see Aanes 2016 for details and simulation studies). It has not been further considered in this document.

Diagnostics

AIC
As diagnostics AIC is used for a given set of data to provide a measure of relative quality of each model (recall that this measure is not meaningful if the comparing model fits with different data inputs)

Residuals
The residuals considered here are the one step prediction errors which are the basis for the likelihood function. These residuals may be serially correlated and reflects the unexplained part of the model (cf Harvey chapter 5). In such cases, the residuals must be interpreted with care and tests for misspecification based on e.g. qq-plots of standardized residuals may be questioned due to potential dependence.

Likelihood weights
The weight given to the input data is defined by the inverse of their covariance matrices. If the input data are not internally correlated the weights are defined by the inverse of the variances.

Predicted biomasses
The total reported catch weight is not a part of the likelihood since the models predicted total catch is a function of catch at age which is a part of the likelihood. It is however informative to compare the models predicted total catch. With similar arguments we also consider the predicted biomass given by each survey for the ages included in the model. These measures may provide additional insight to understand the estimates, particularly when there are conflicting signals in the different data sources.

Likelihood profiles

For a given range of key parameters, the likelihood profiles for both the marginal likelihood (which is the one that is optimized) as well as likelihood components for the various data input and effect on key parameters provides useful information regarding the overall fit, relative weighting of data and which parameter which is most influential for the key parameters.

Results

First the model is fitted to the data reported as the final XSA run in AFWG (ICES 2016) using the same settings concerning density dependent catchability (density dependent for ages below 10, and independent for older ages) and the same data (including the backshift of age and year for Fleets 15 and 16) but starting at age 3. Qualitatively this gives the same residuals as in AFWG for the abundance indices although the scaling of the bubbles are more exaggerated here (Figures Initial run). The largest weights are given to the catch at age (Figures initial run). Due to the positive residuals for catch at age in the most recent years the model predicts catches that are lower than the reported catches, although the overall difference is small. Figure 4 also includes the biomasses predicted by the model versus the observed biomasses. Note how the abundances from FLT15 in 2015 and 2016 is higher than predicted by the model.

After the initial run the model is set up as described in 'Setting up the model' and the Error-Type 1 is defined.

Catchability

Using AIC as selection criteria to determine whether one should apply density dependent or independent catchability all considered data sets gives the same result: Using density dependent catchability for all ages gives the lowest AIC value (Table 5 below) despite the increased numbers of parameters. The AFWG choice of choosing density independent catchability for ages above 9 results in lower AIC values than choosing all density independent, but higher than choosing all density dependent (not shown) and is not considered in the remainder of this document.

Diagnostics are shown for the set of models and data in Figures :

- Case 1: Initial run (see above).
- Case 2: D_{3-11}, density dependent catchability Error-Type 1
- Case 3: D_{BS3-11}, density dependent catchability Error-Type 1, using backshift for FLT15 and 16
- Case 4: D_{3-9+}, density dependent catchability Error-Type 1
- Case 5: D_{3-11}, density dependent catchability Error-Type 2

Residuals

Residuals from all model fits are qualitatively similar in terms of signs and size of the residuals.

Error structure

Over the range of considered data sets, using informed covariance matrices according to Error Type 2 gives the lowest AIC with one exception. It is difficult to make any conclusions based on visual inspection of residuals and qq-plots. Retrospective plots appear somewhat less variable (Figure Diagnostics Case 5)

Table 5. AIC values model fits to the data sets comparing density independent and dependent catchability for the two error types Type 1 (different observation variances in catch at age for ages 1-3 and 4-13+) and Type 2 (Setting covariance matrix proportional to covariances modelled using the fitted power function and estimating the proportionality constant)

Data	Density dependent catchability	Error-Type	#parameters	AIC
D_{3-9}	No	Type 1	65	1706.5
	Yes	Type 1	93	1636.3
	No	Type 2	64	1663.2
	Yes	Type 2	92	1624.4

Data	Density dependent catchability	Error-Type	#parameters	AIC
D_{3-9+}	No	Type 1	65	1699.9
	Yes	Type 1	93	1620.9
	No	Type 2	64	1657.5
	Yes	Type 2	92	1619.1

Data	Density dependent catchability	Error-Type	#parameters	AIC
D_{3-11}	No	Type 1	71	1863.2
	Yes	Type 1	105	1795.8
	No	Type 2	70	1882.1
	Yes	Type 2	104	1826.2

Data	Density dependent catchability	Error-Type	#parameters	AIC
$D_{BS,3-9}$	No	Type 1	65	1586.3
	Yes	Type 1	93	1490.1
	No	Type 2	64	1555.3
	Yes	Type 2	92	1475.8

Data	Density dependent catchability	Error-Type	#parameters	AIC
$D_{BS,3-9+}$	No	Type 1	65	1620.1
	Yes	Type 1	93	1527.7
	No	Type 2	64	1577.7
	Yes	Type 2	92	1503.8

Data	Density dependent catchability	Error-Type	#parameters	AIC
	No	Type 1	71	1742.3

$D_{BS,3-11}$	Yes	Type 1	105	1629.8
	No	Type 2	70	1705.7
	Yes	Type 2	104	1615.4

Effect of backshift

The general effect is to increase estimate of SSB in assessment year (see Figure 4). This is probably because FLT15 observes higher abundances than predicted by the model. When backshifting this adds strength to the increase one year backwards in time and thus the entire estimate is lifted. No notable differences can be seen by inspecting residuals

Effect of catchability model

The general effect by using density independent catchability is to result in lower biomasses in the peak period from 2010 and onwards (Figure X). However, other diagnostics including biomass diagnostics improves. Also provides more stable retrospective estimates (not shown).

Effect of plus-group

It was explored to use survey indices with a plusgroup for ages 9 and older while keeping catch at age to 1-13+. Although difficult to conclude from residuals, the biomass diagnostics showed much poorer correspondence than using the age span 3-11 for the abundance indices.

Likelihood profiles

For D_{3-11}, density dependent catchability and Error-Type1 the log-likelihood along with selected components is profiled over values of variances for catch at age, FLT15 and FLT007.

Effect of estimating predation mortality

Some exploratory runs were made by the time series model for predation mortality. The error in the 'pseudo-observations' were assumed to be iid and was estimated very large. Estimates of M2 followed the main overall trends, but with very low precision, and appear much smoother than the estimates obtained by AFWG. The residuals were heavily serially correlated. The approach was not followed further as it require more time to model this adequately.

Using the AFWG approach works well numerically, but it is noted that the general feature is to lower the estimates of SSB and increase estimates of F compared to not accounting for predation (Figure 5). This effect was smallest for Error-Type 2 (Figure 5). Diagnostics for this have not been properly evaluated in this document.

Conclusions

- The estimates of SSB and F are data driven, and the largest effects are how the observation models are formulated in terms of density dependent versus density dependent catchability. When these formulations are in accordance with AFWG 2016 which uses XSA, the model yields very similar estimates.

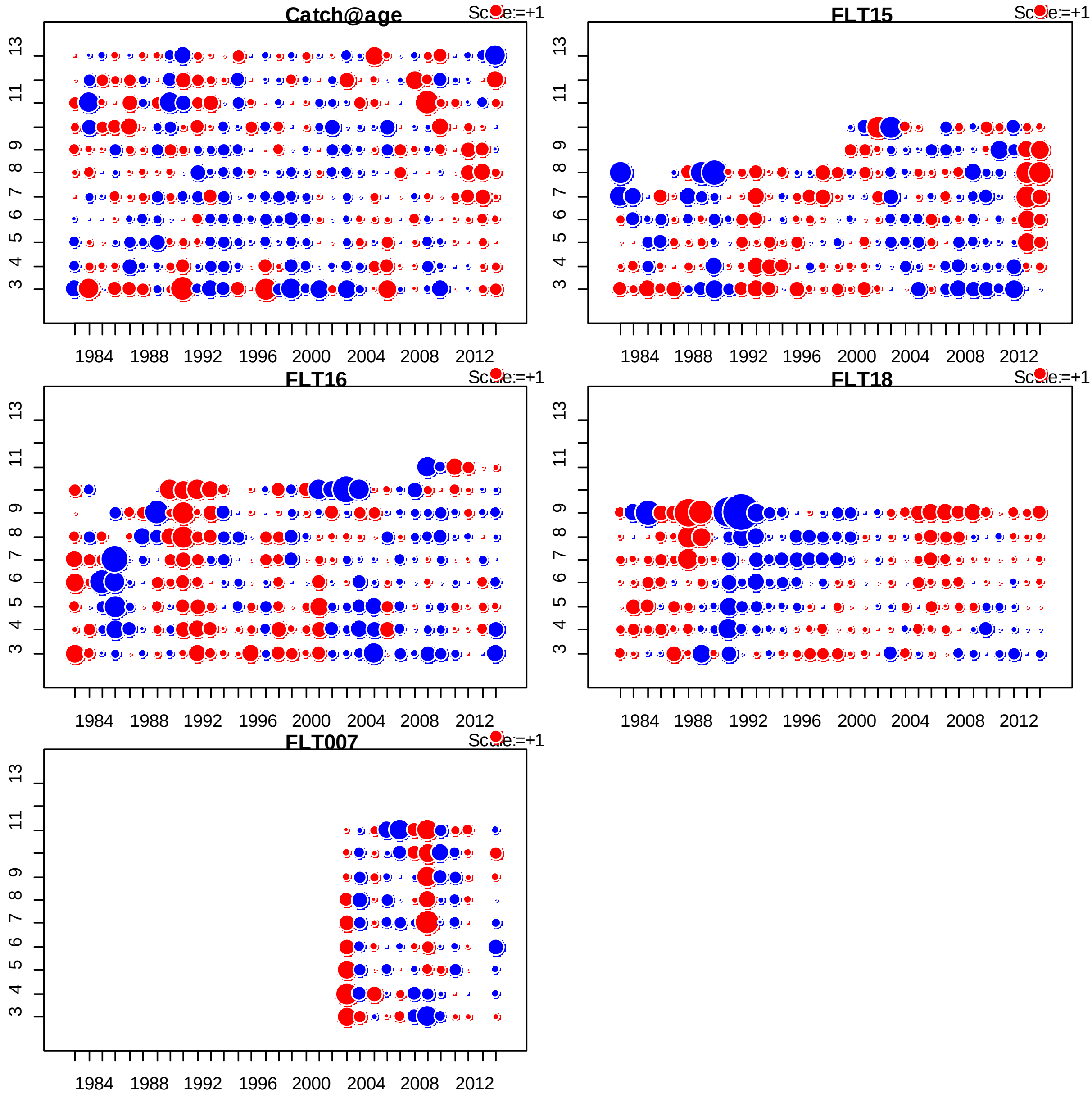
- Diagnostics suggest using density dependent catchabilities for all age groups used in the survey and estimates appear more stable (by retrospective plots and when including predation data)
- AIC indicates that error structures could be informed by using empirical estimates, and estimates appear more stable. However, these estimates are based on a limited dataset not covering all data sets used.
- Residuals by first step-prediction errors are qualitatively similar for all fits making it difficult to use these to choose between models. They are however informative in scrutinizing the signals in the data

References

To come

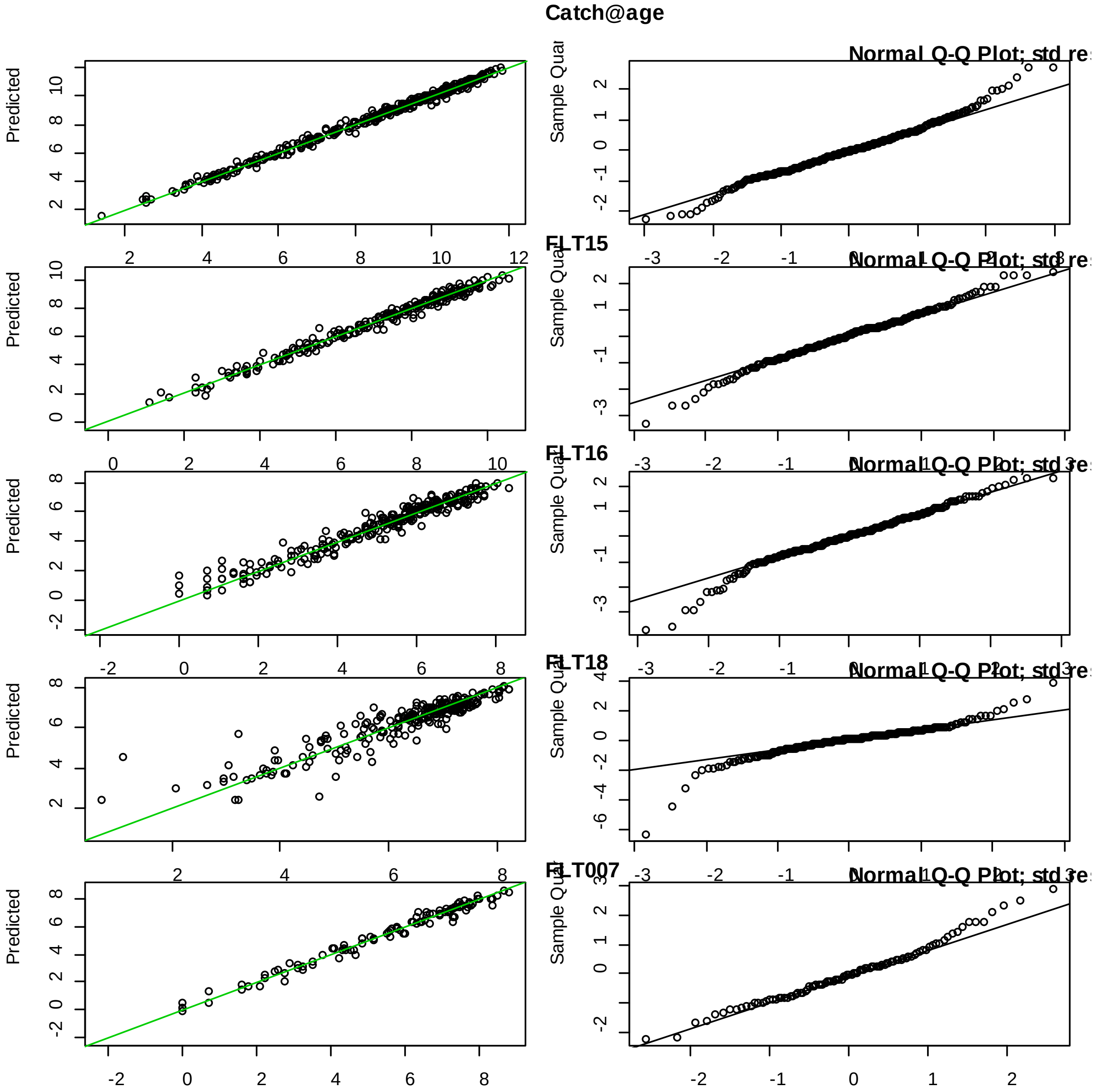
Figures

Diagnostics case 1

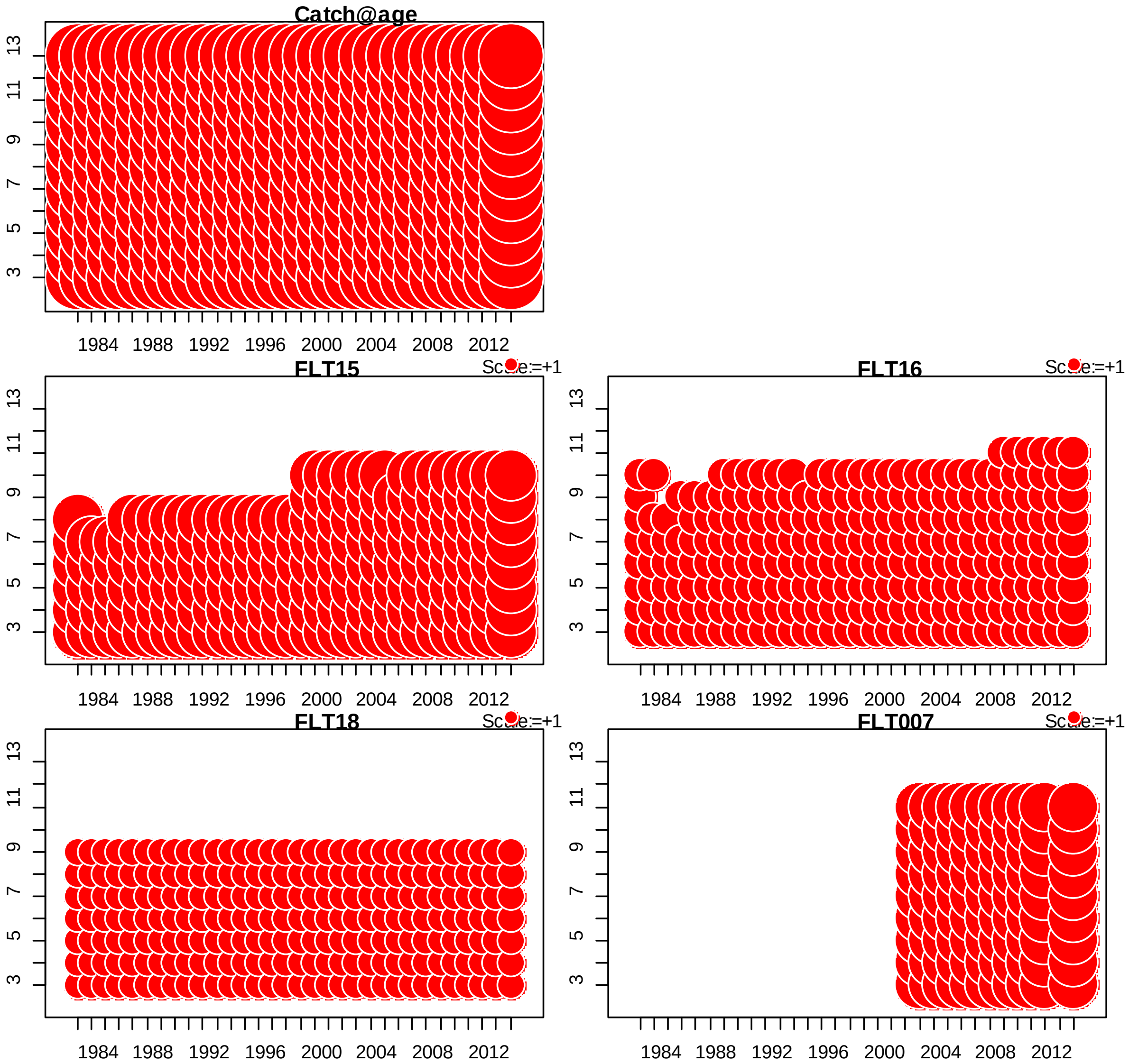


Residuals

Diagnostics case 1

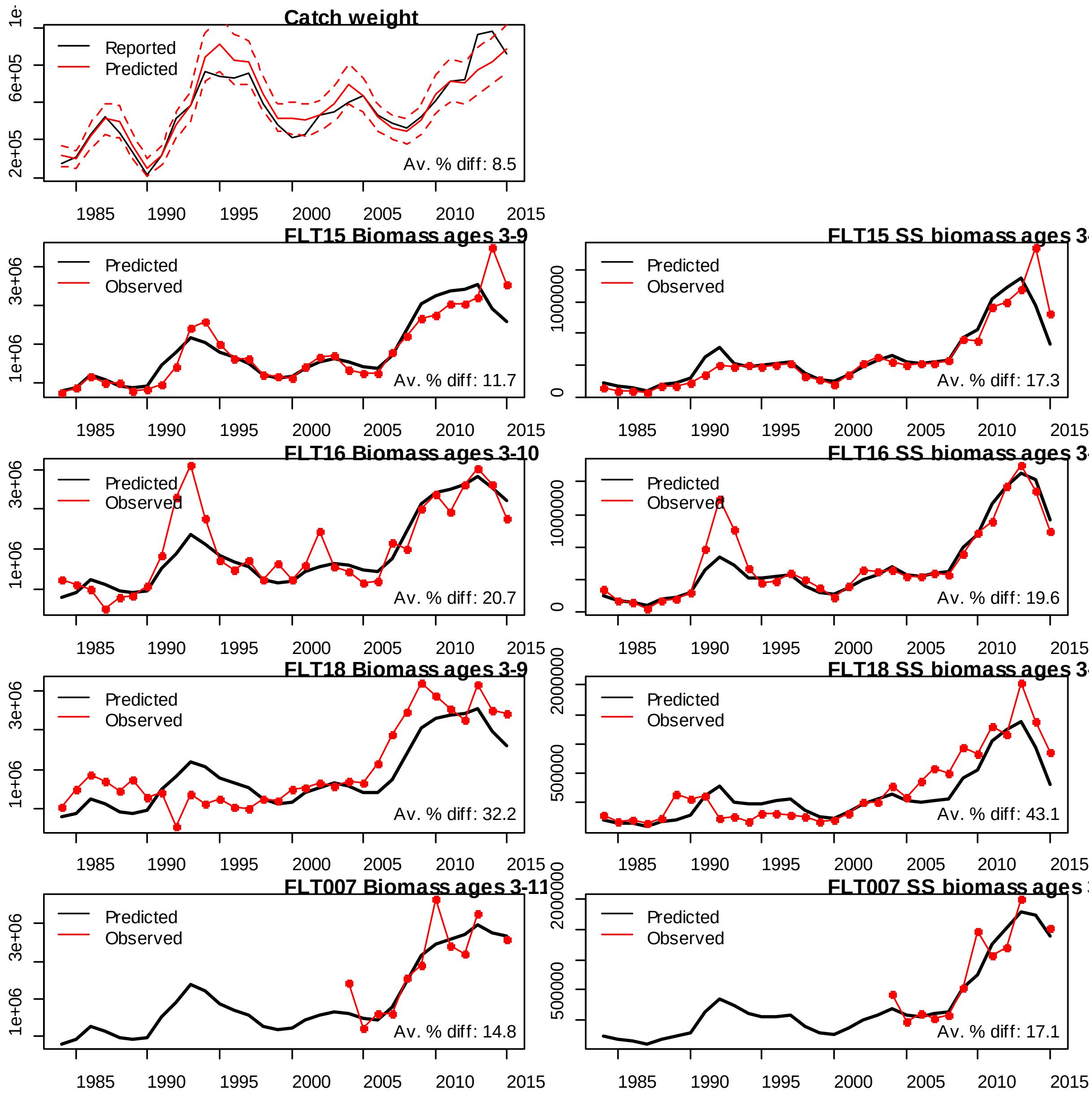


Diagnostics case 1

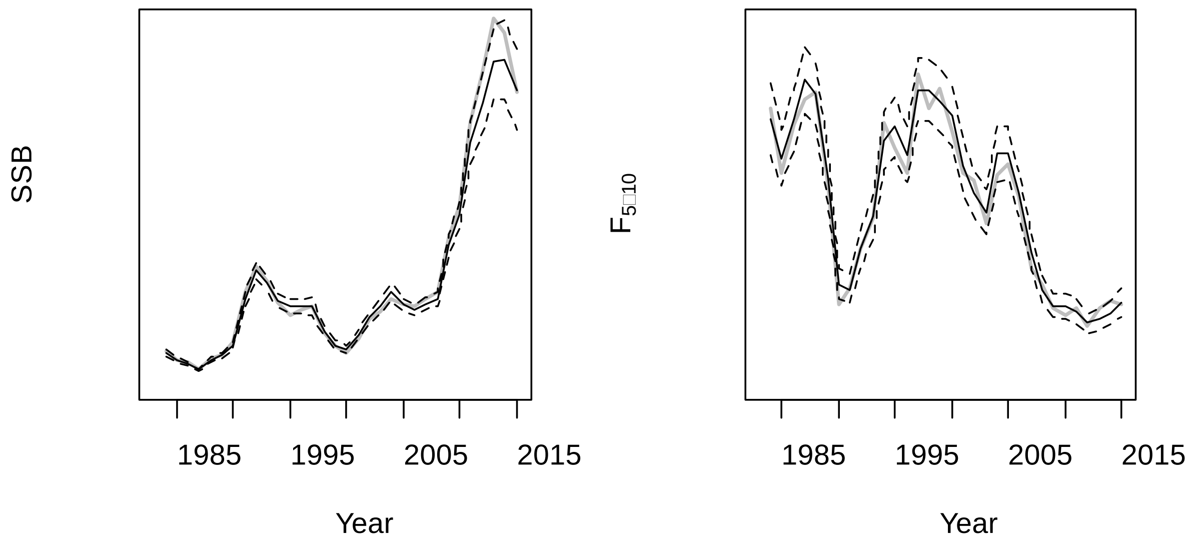


Weights: inverse of observation variances

Diagnostics case 1



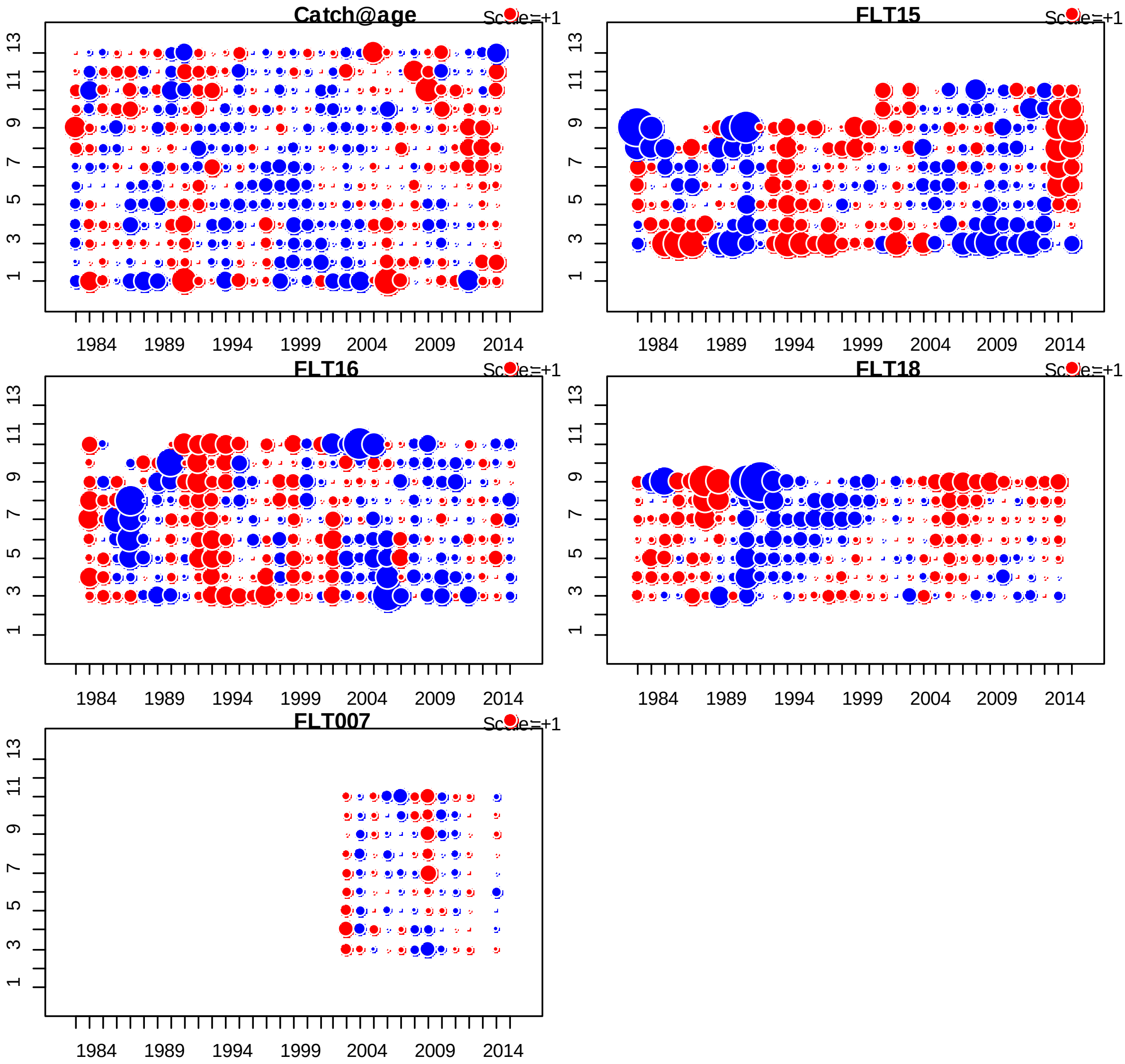
Diagnostics case 1



Gray: AFWG 2016

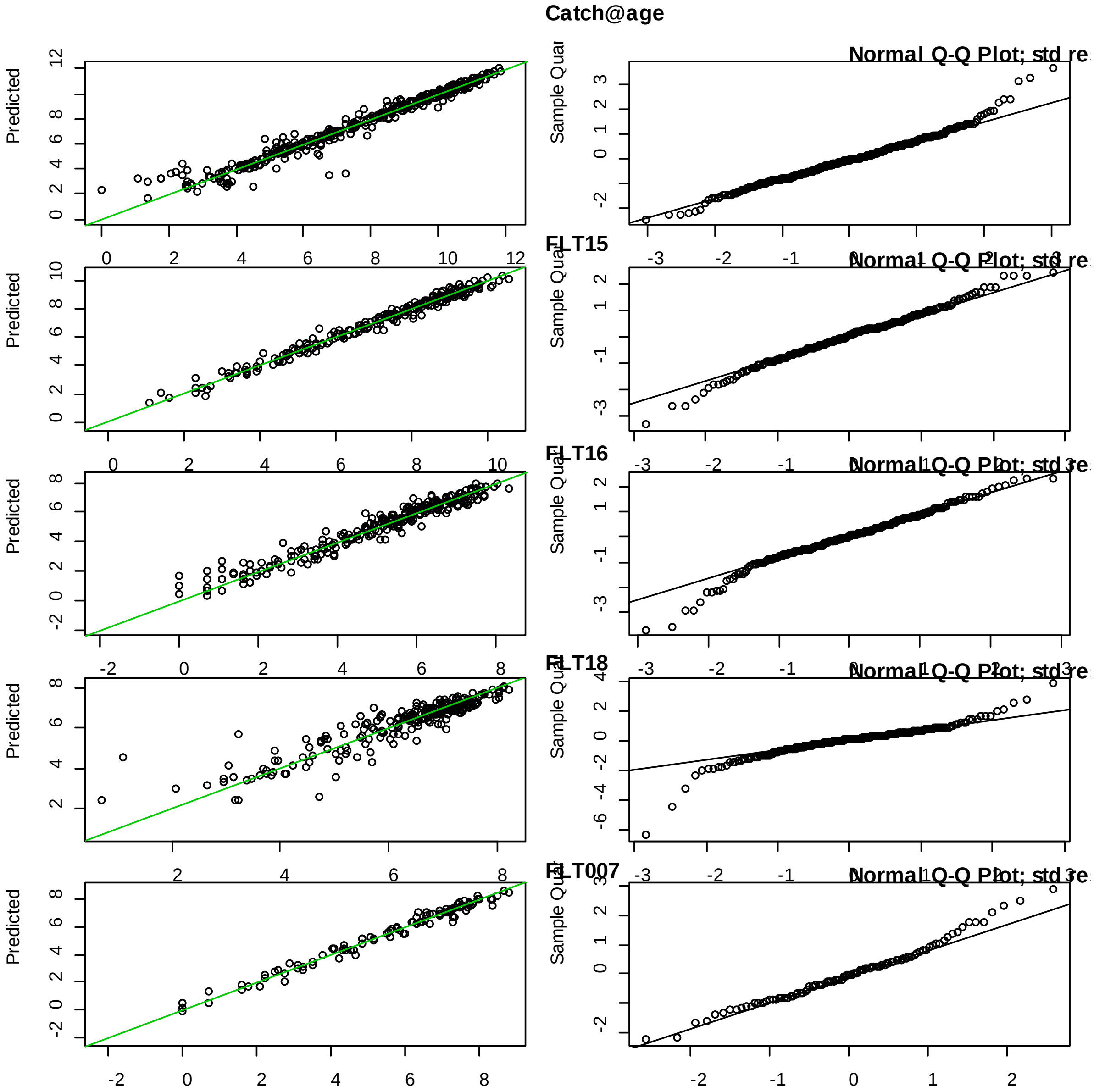
Black: XSAM

Diagnostics case 2

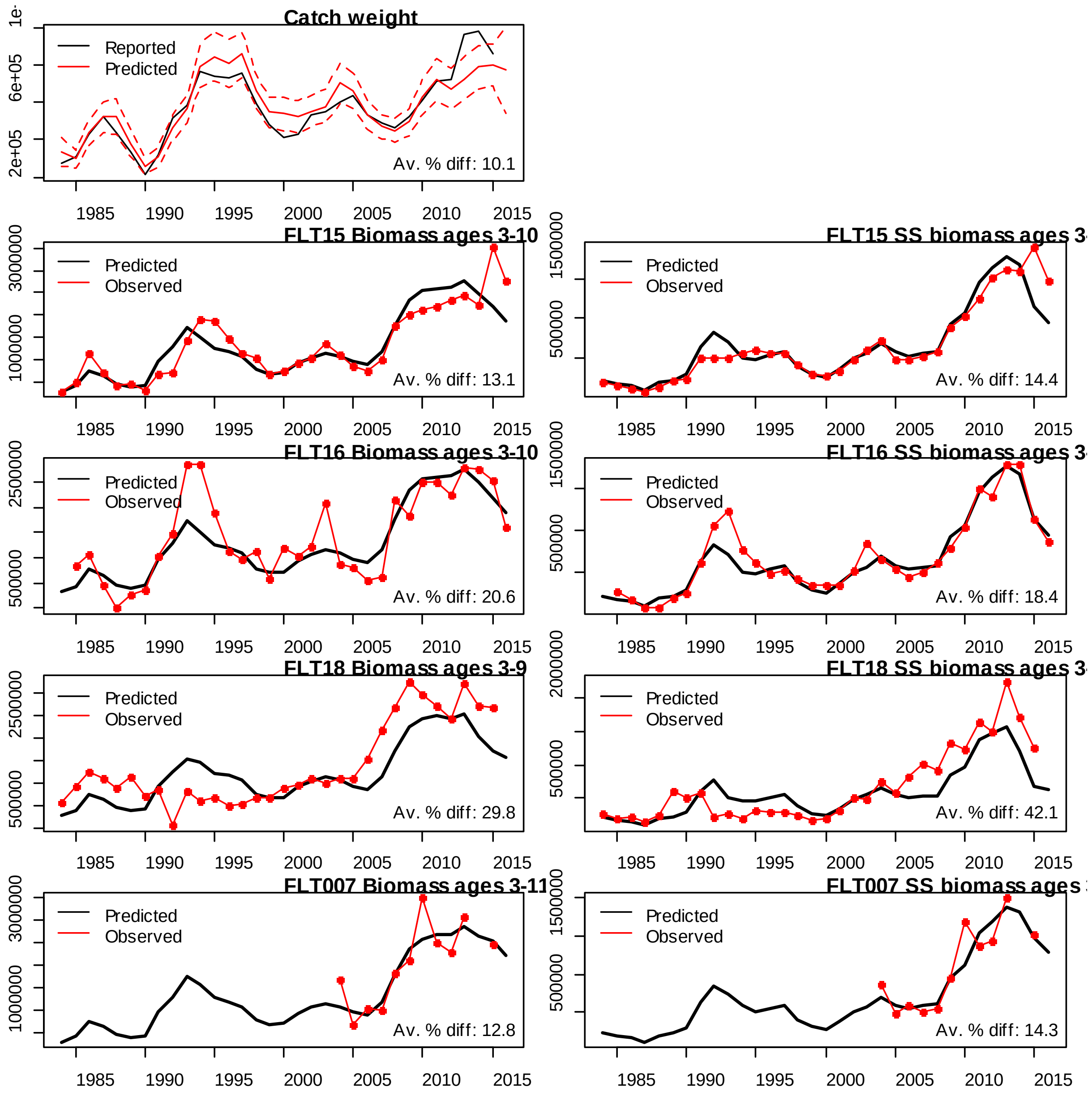


Residuals

Diagnostics case 2

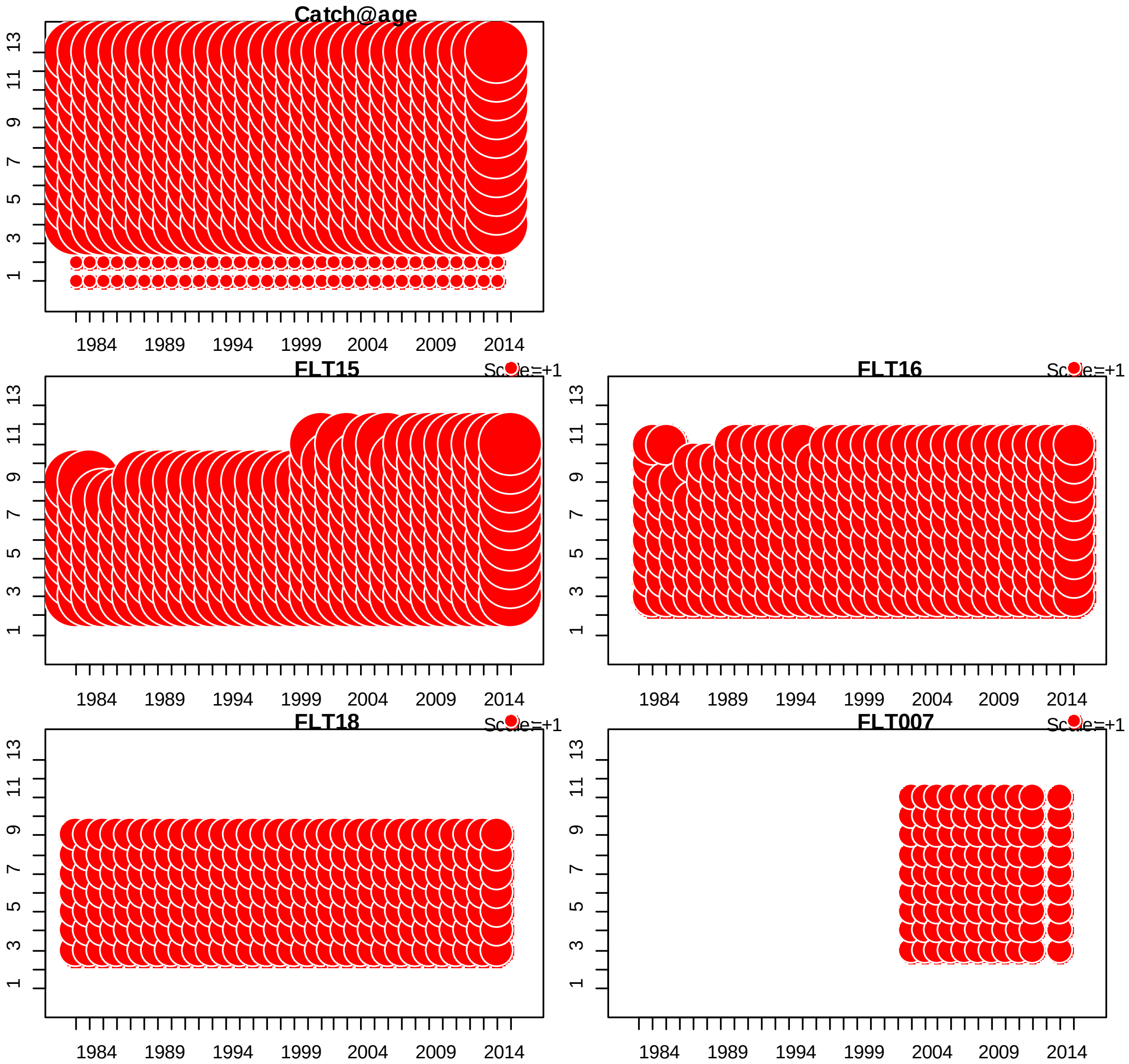


Diagnostics case 2



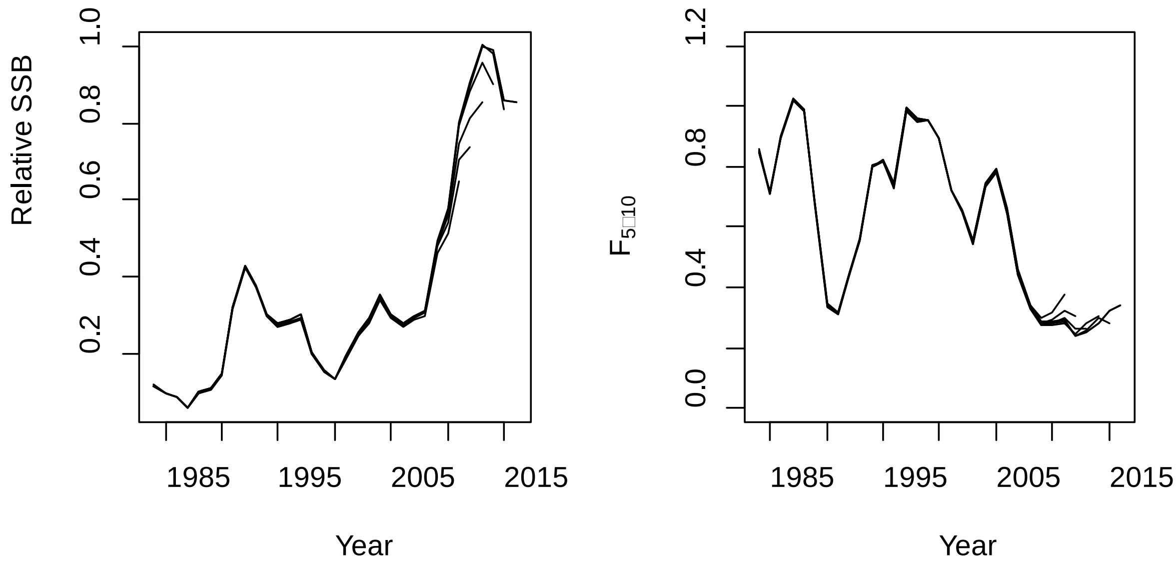
Predicted biomasses

Diagnostics case 2



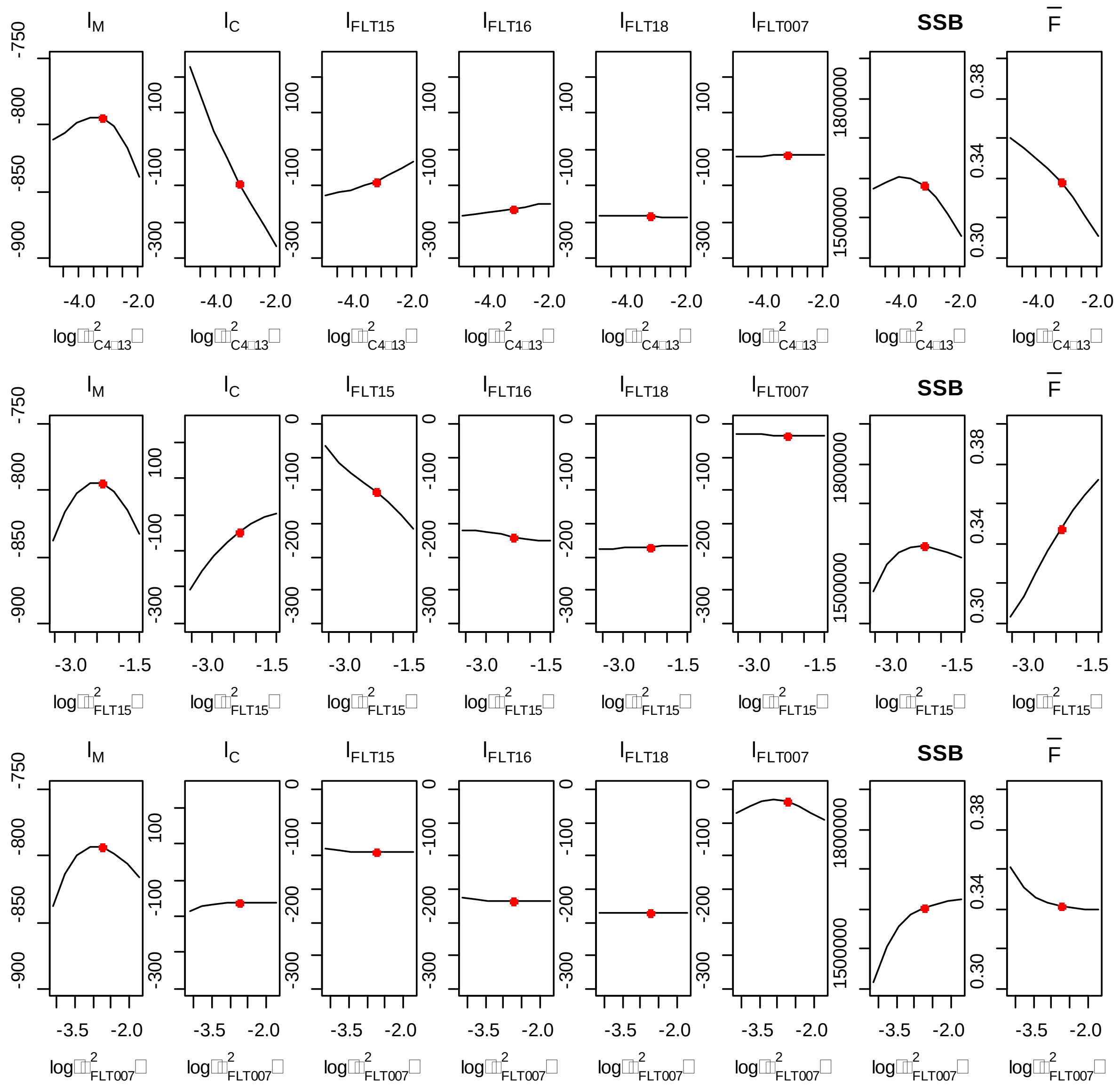
Weights: inverse of observation variances

Diagnostics case 2



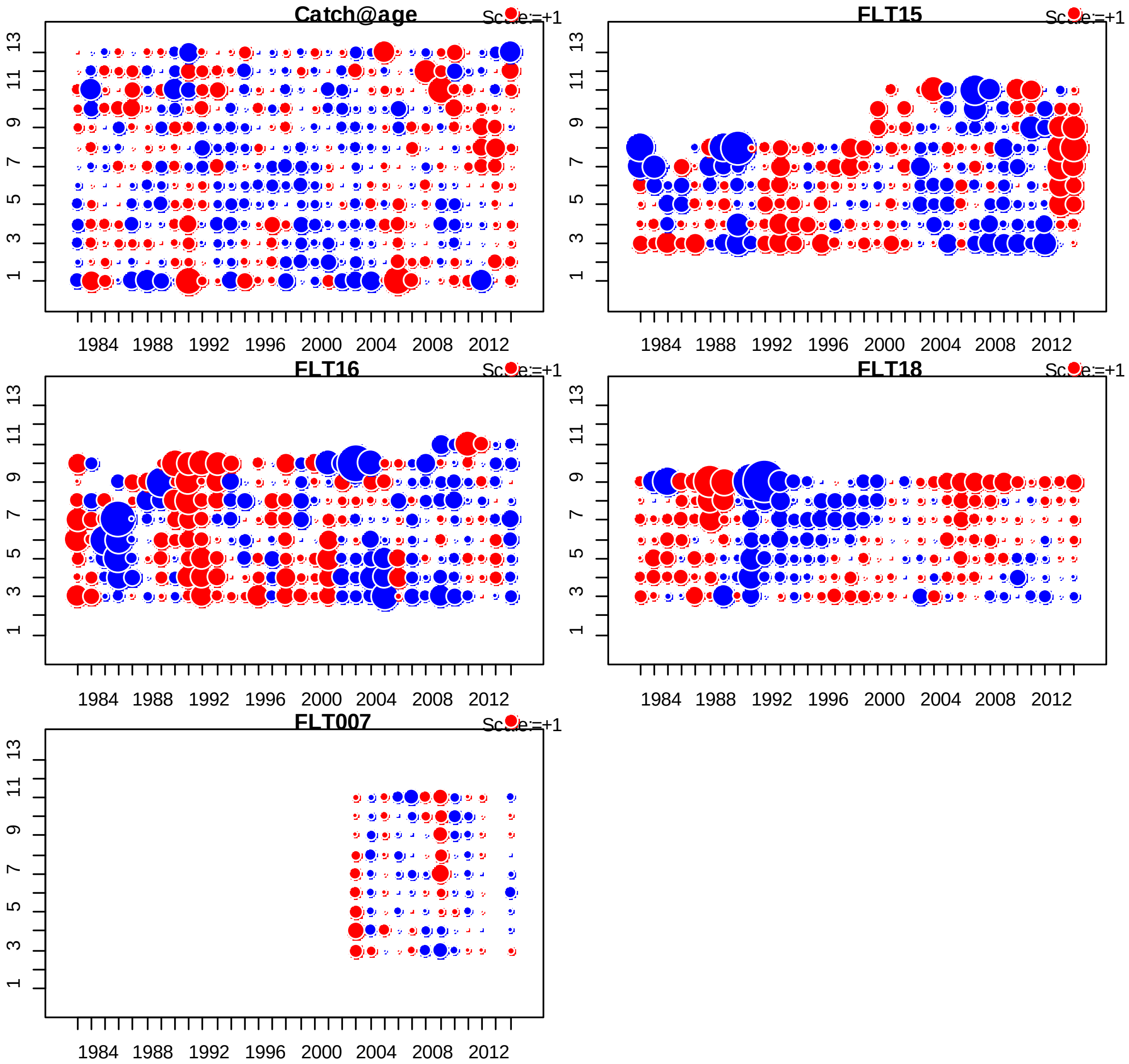
Retrospective plots

Diagnostics case 2

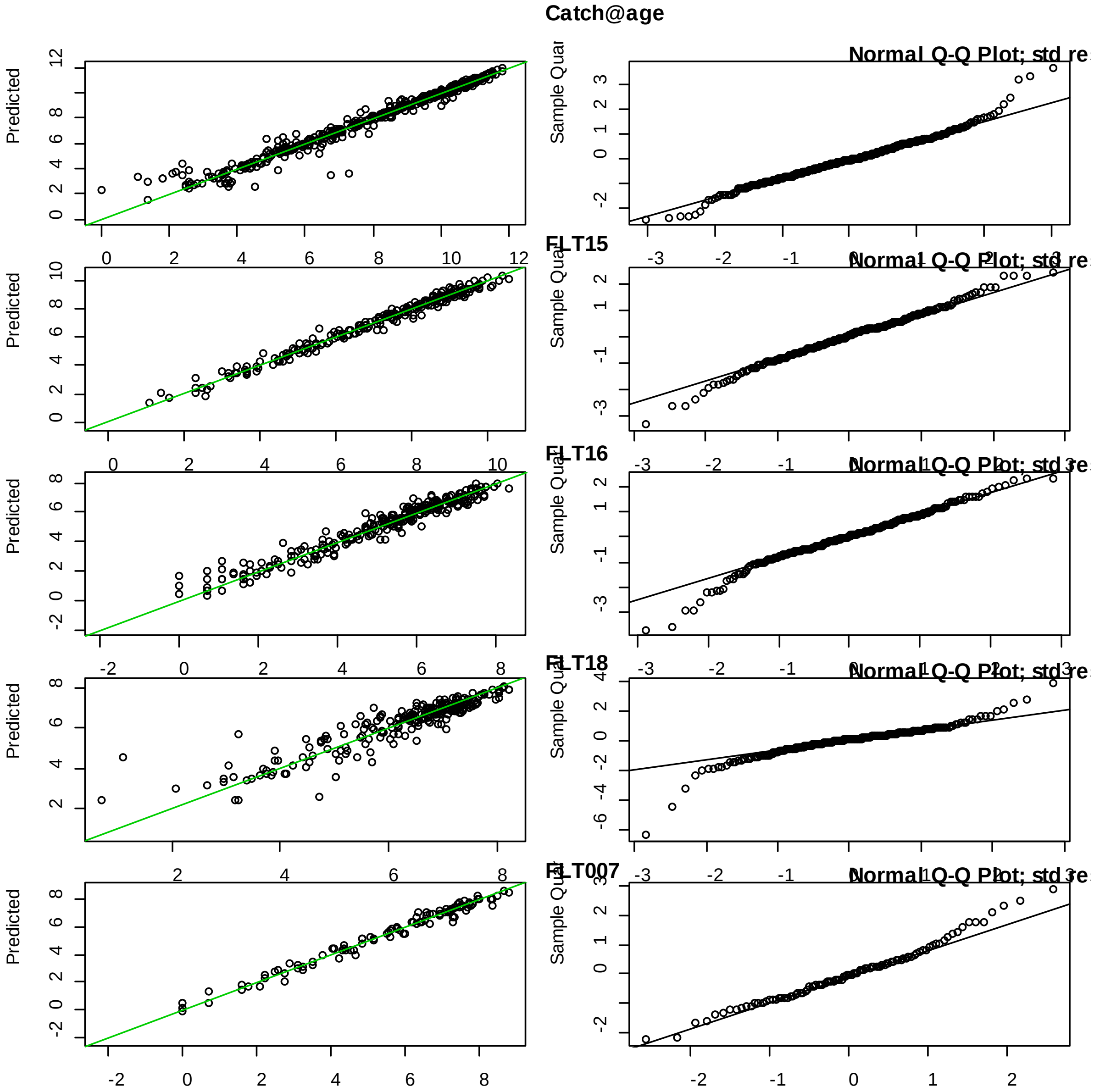


Profiles of marginal log-likelihood l_M, the catch component l_C, FLT15, FLT 16, FLT18 and FLT007 components, point estimate of SSB and average F (ages 5-10) in 2016 over variance in catch data σ_C^2 (top row), abundance indices from FLT15 σ_{FLT15}^2 (middle row) and abundance indices from FLT007 σ_{FLT007}^2 (bottom row). The red dots indicate the value of the respective variances for which the log-likelihood is maximized.

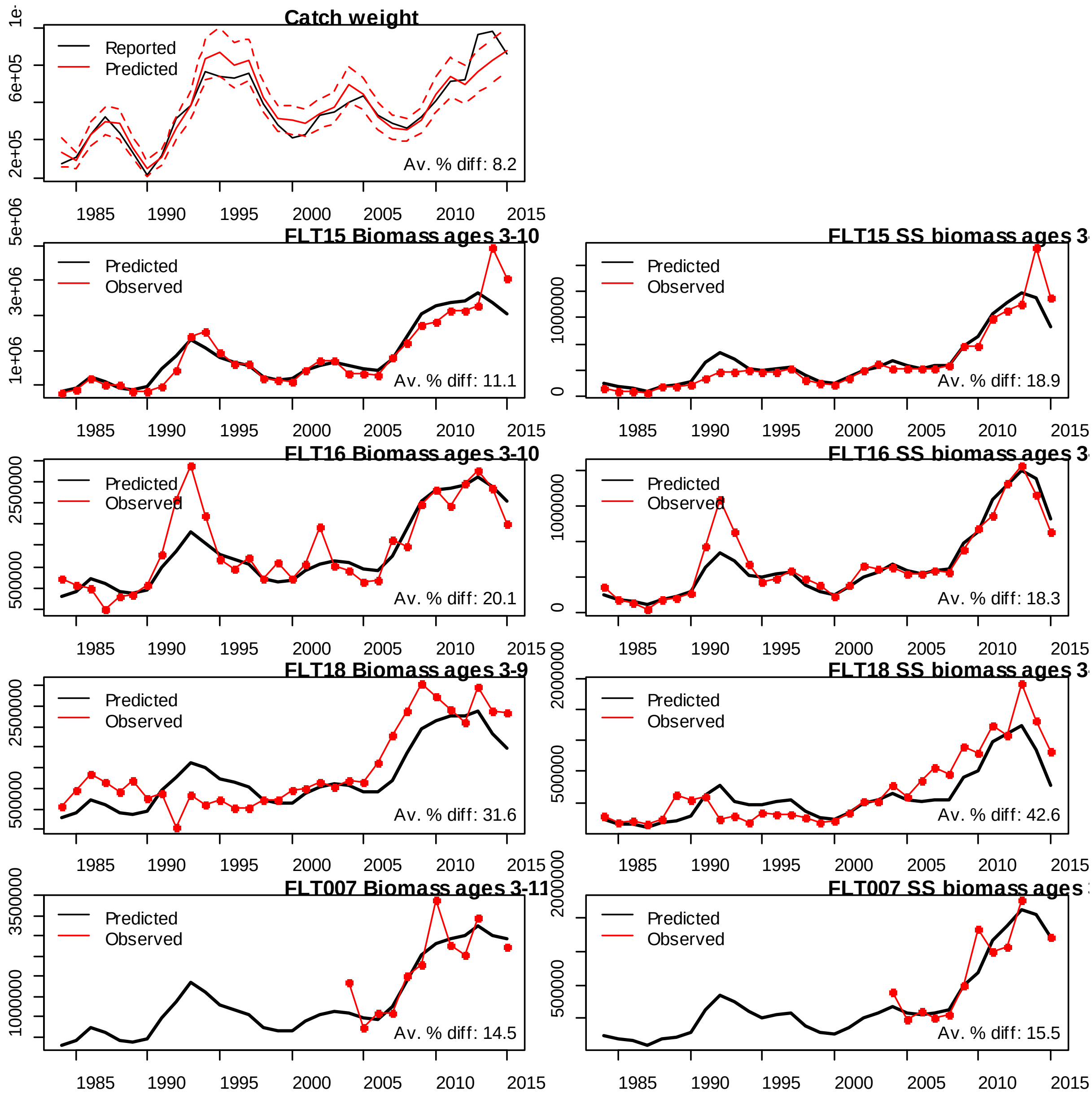
Diagnostics case 3

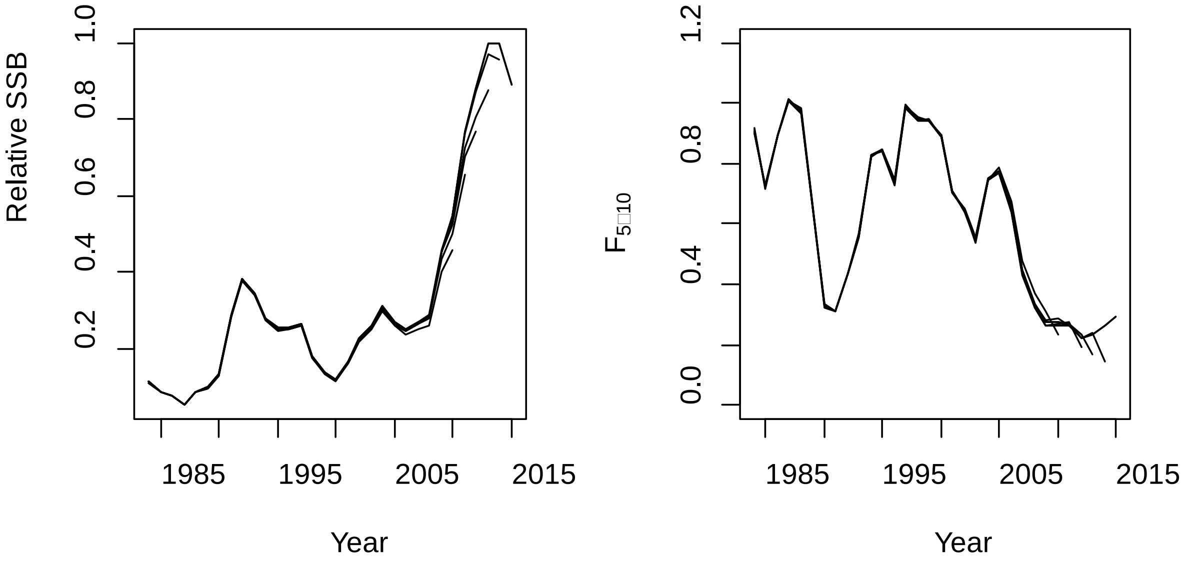


Diagnostics case 3

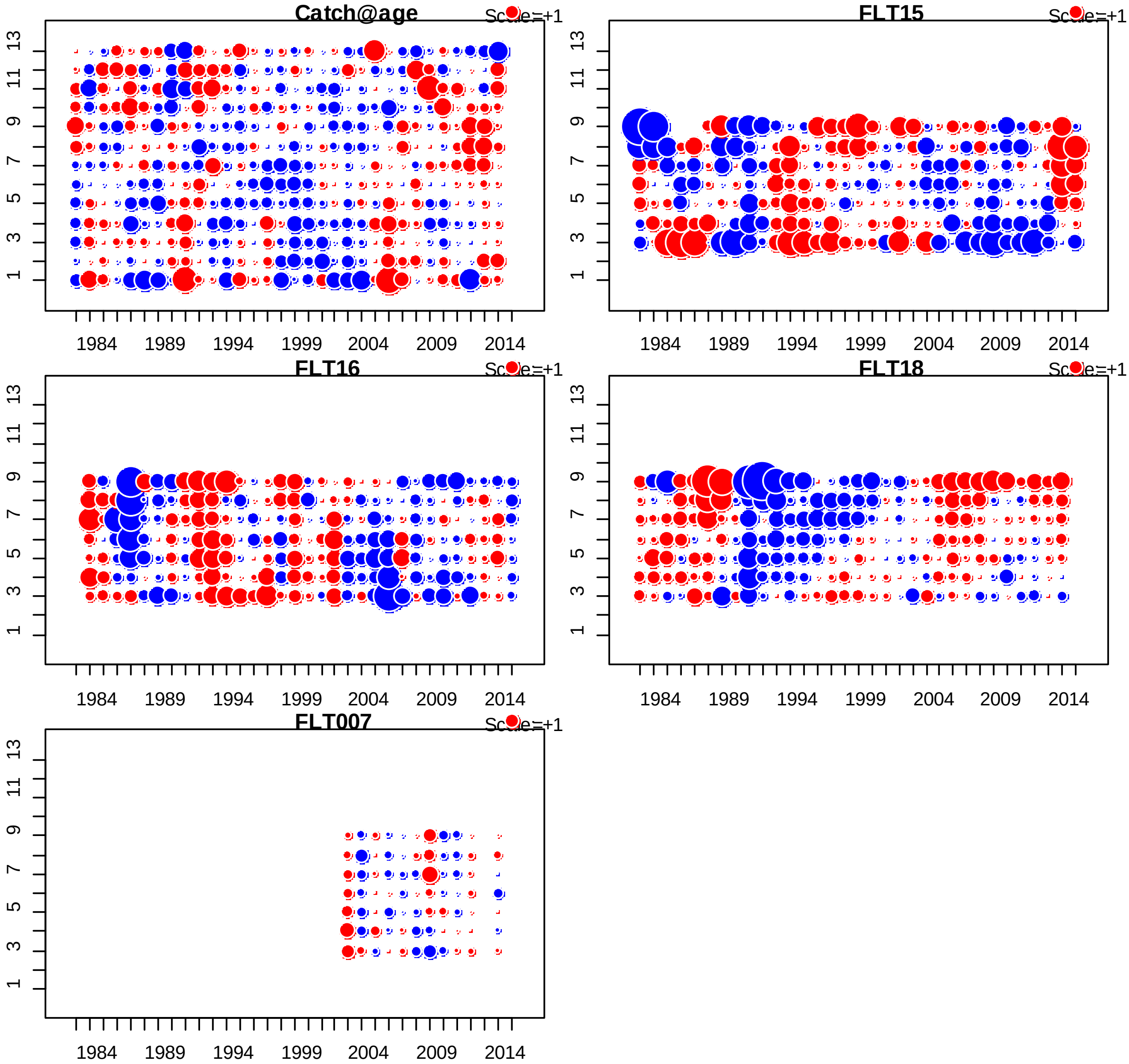


Diagnostics case 3

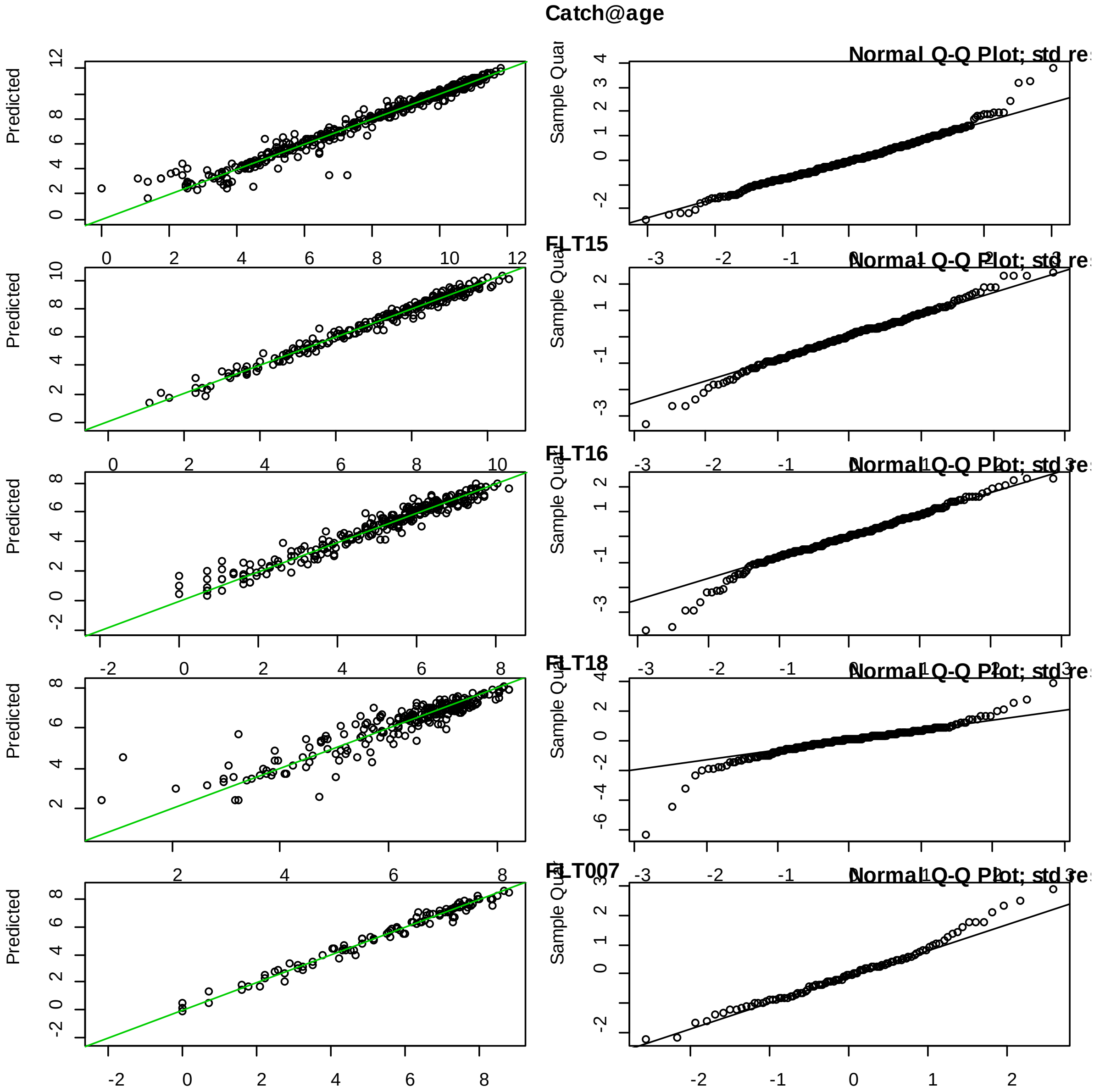



Relative SSB
0.2
0.4
0.6
0.8
1.0
1985
1995
2005
2015
Year
F_{5-10}
0.0
0.4
0.8
1.2
1985
1995
2005
2015
Year

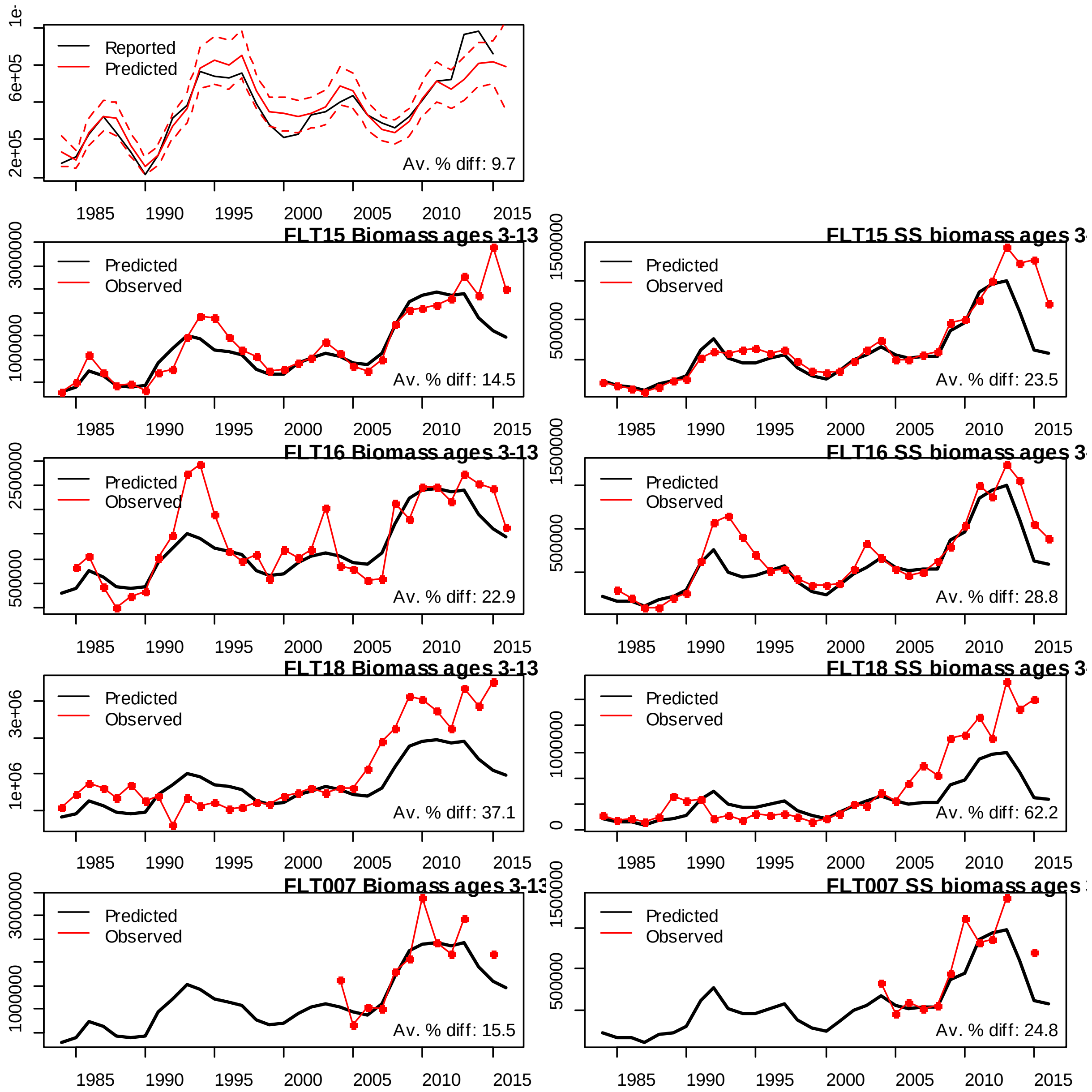
Diagnostics case 4



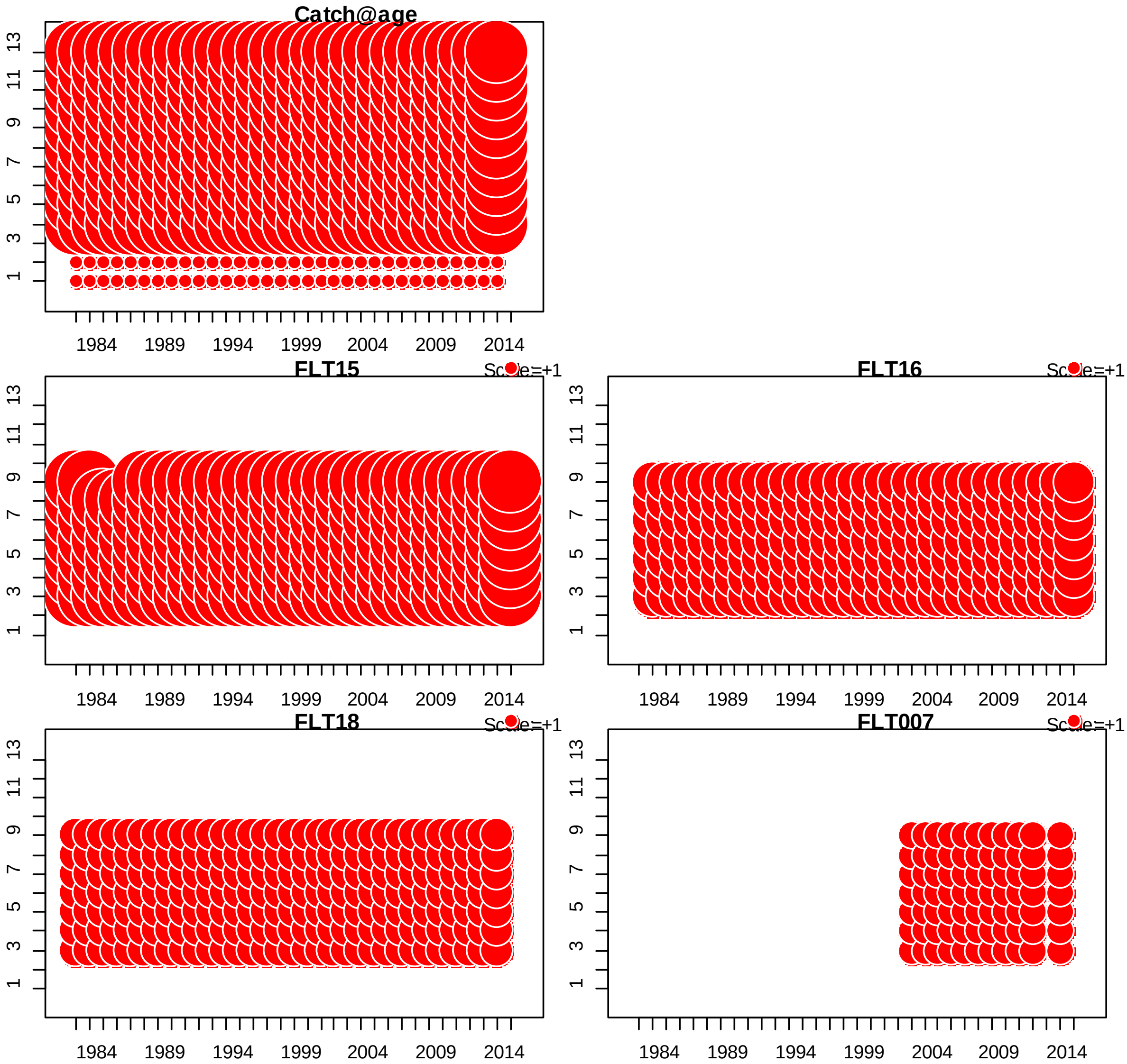
Diagnostics case 4



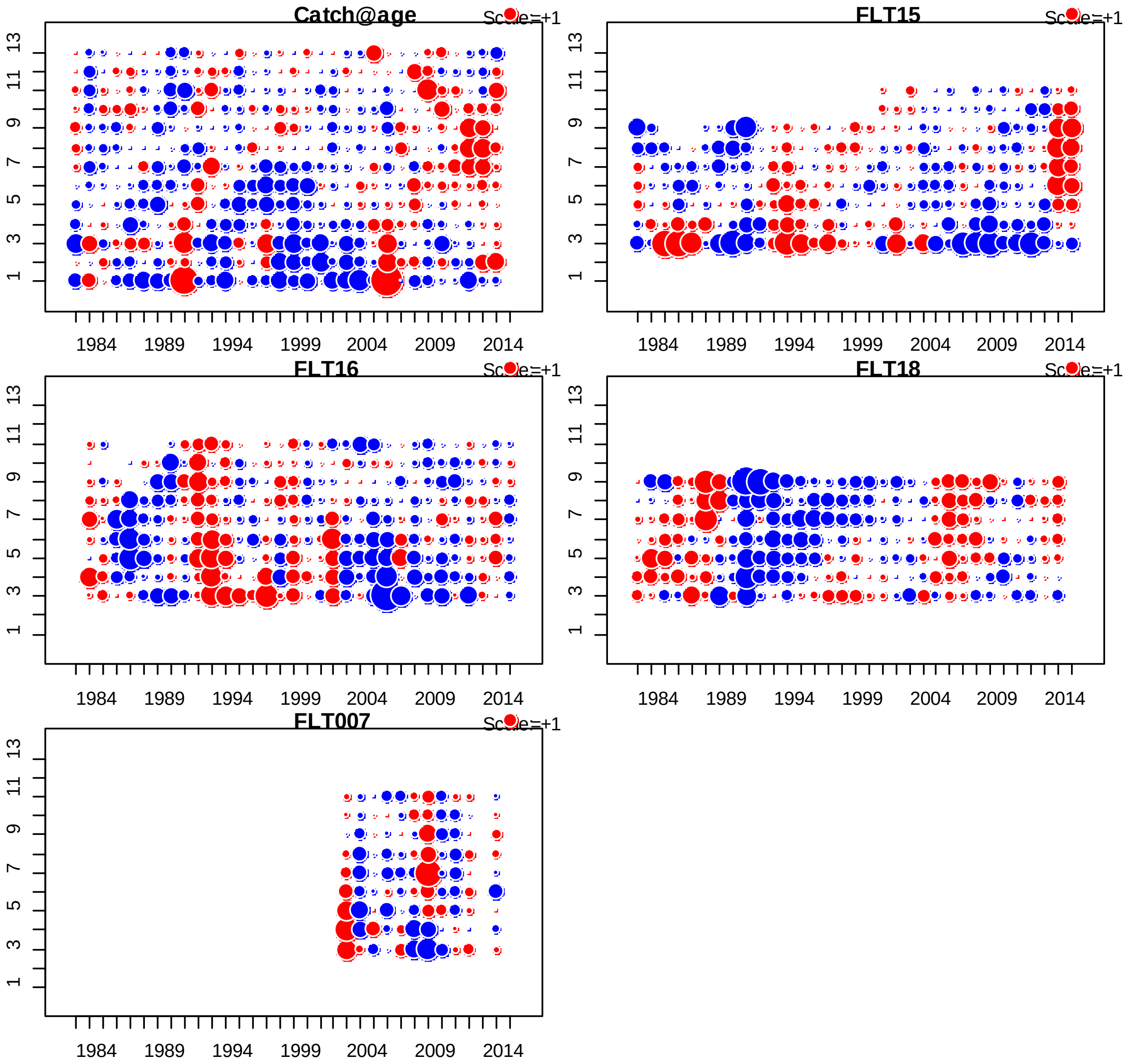
Diagnostics case 4



Diagnostics case 4



Diagnostics case 5



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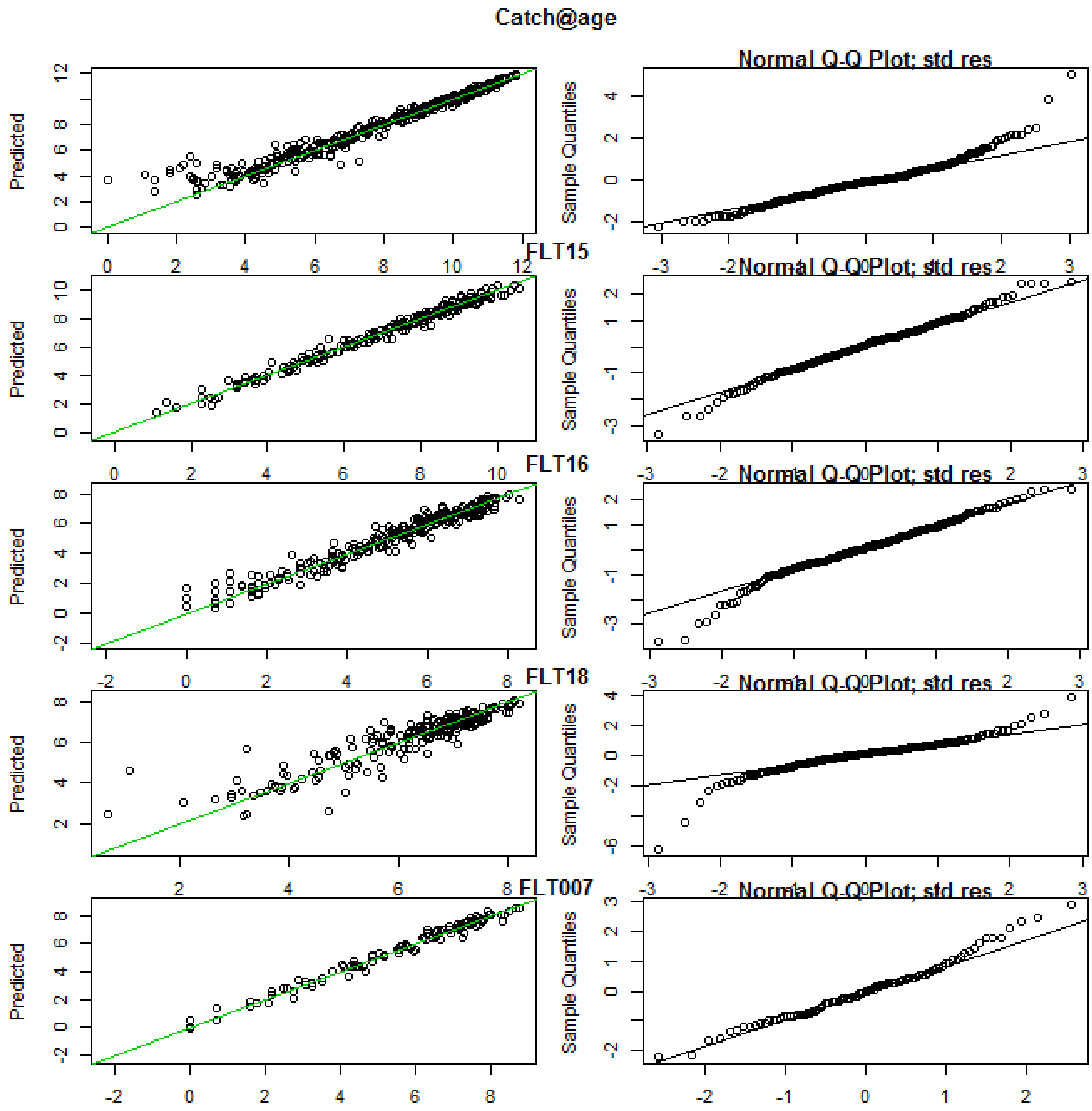

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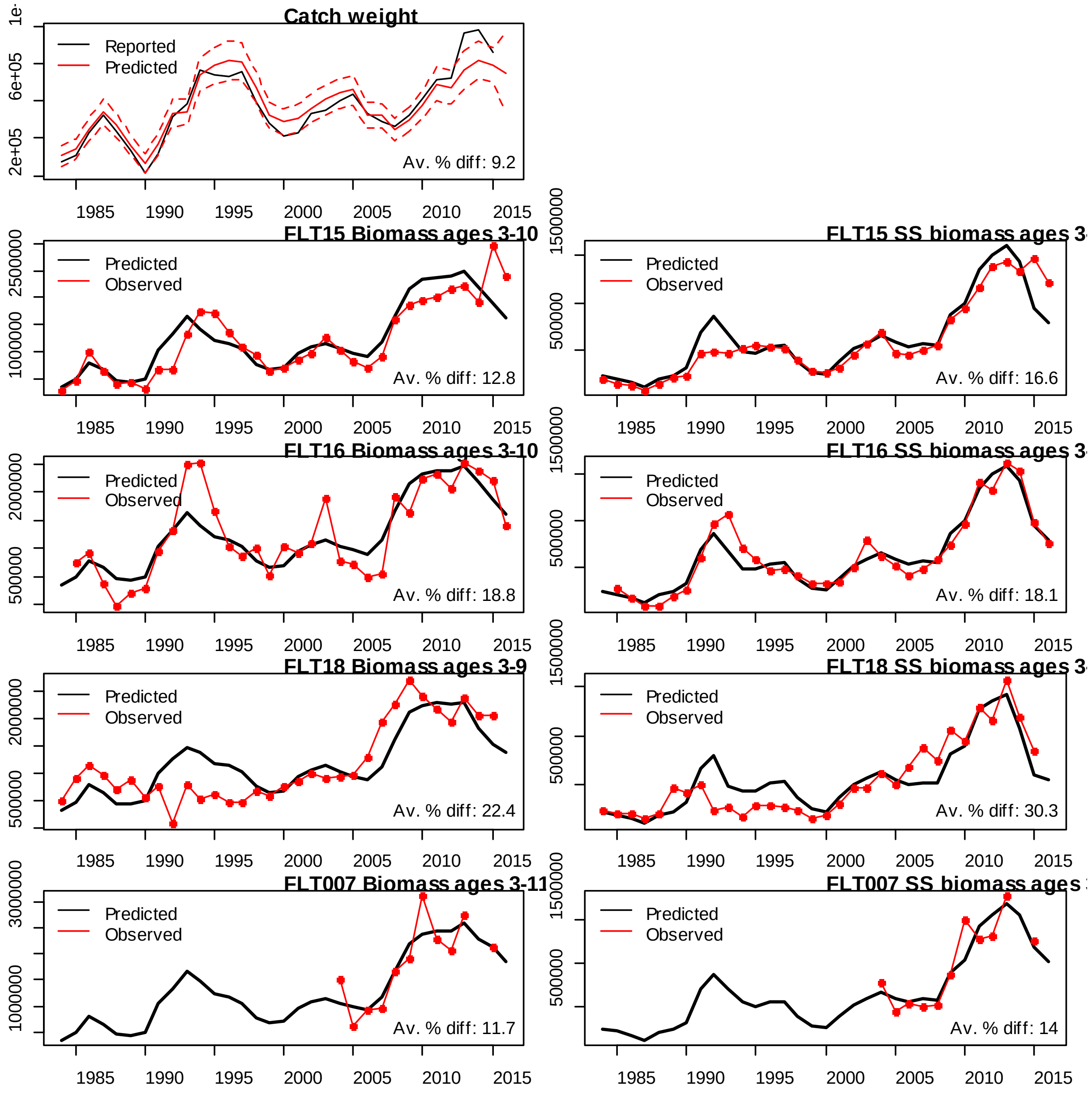
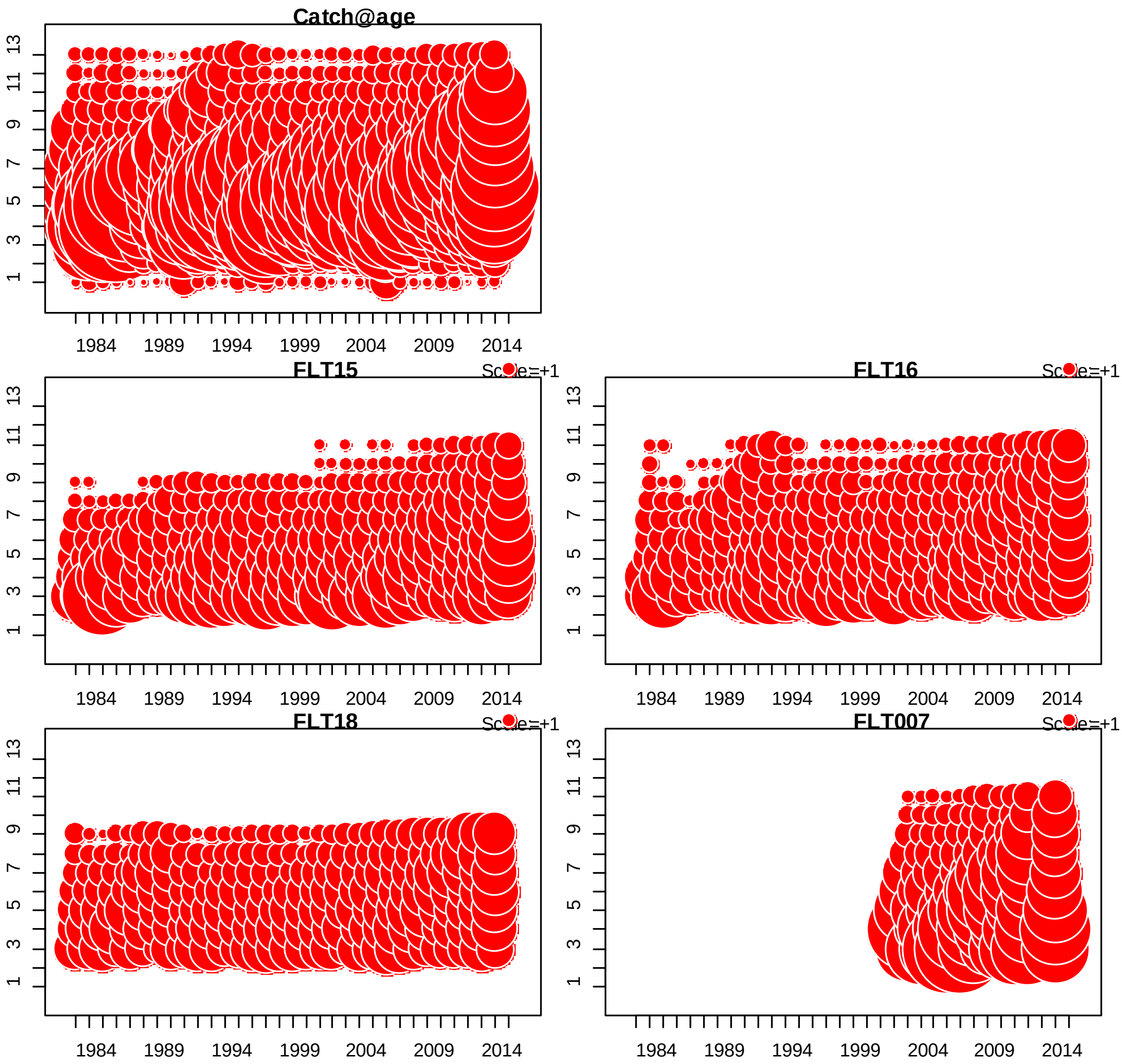
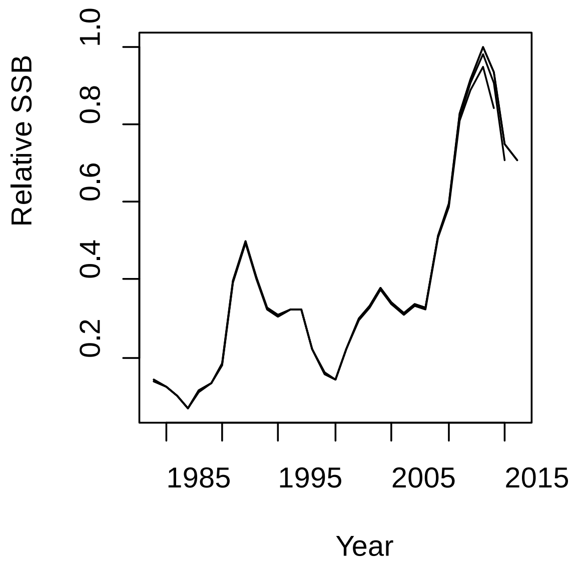
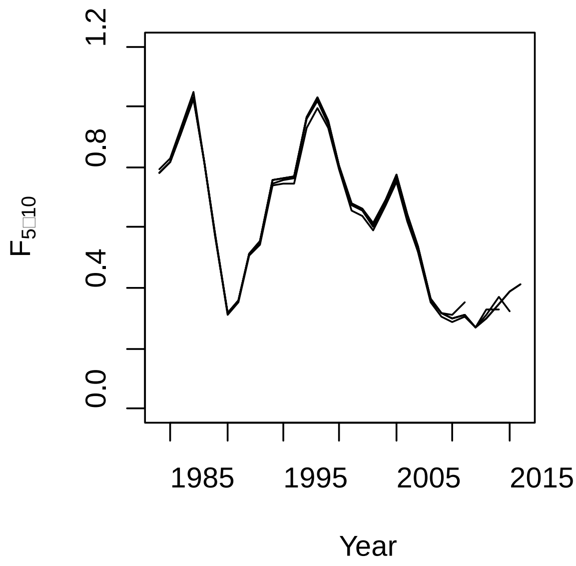


Diagnostics case 5



Diagnostics case 5





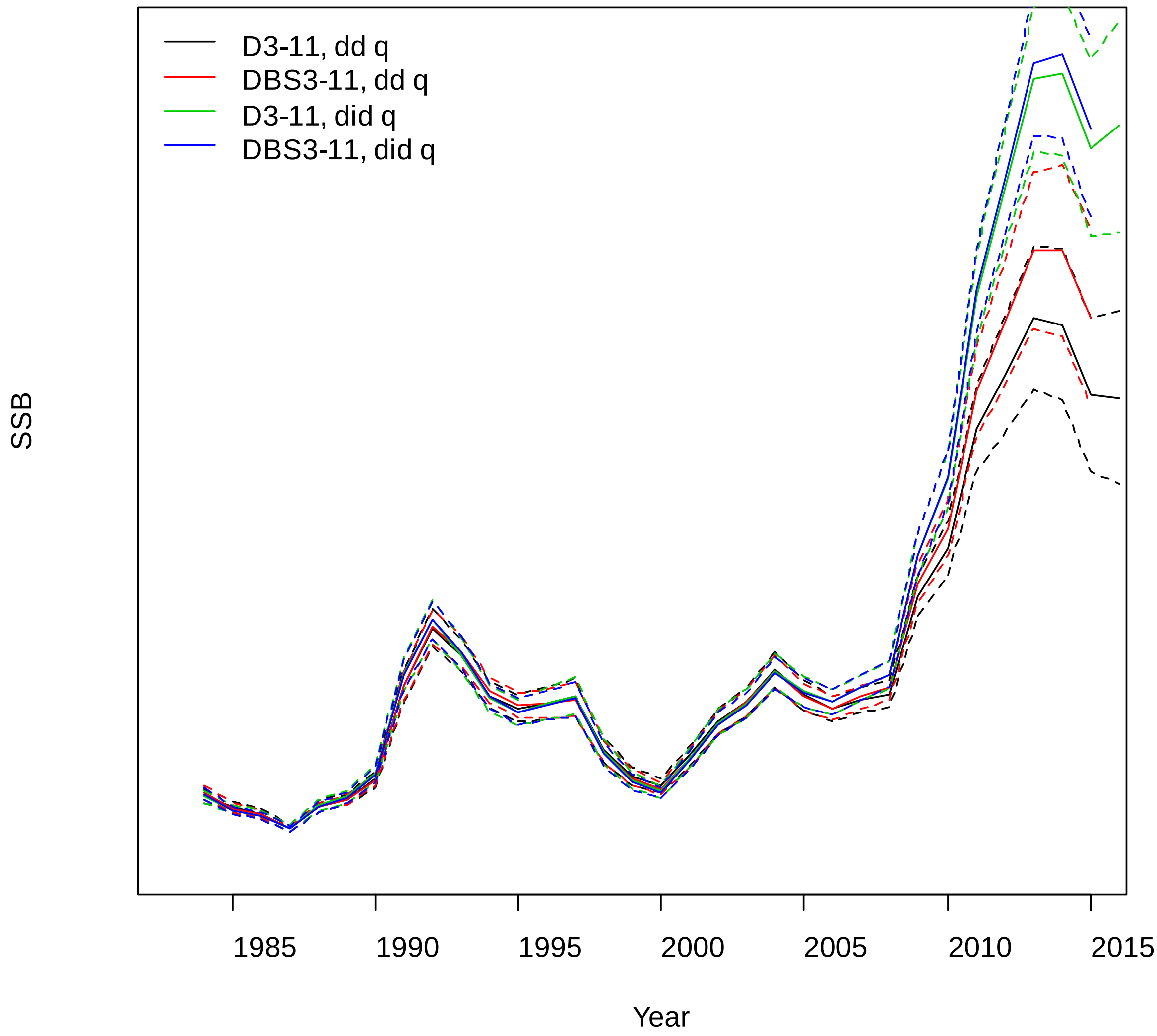


Figure 4. Estimates of SSB using data set D_{3-11} with density dependent catchability (D3-11, ddq), D_{BS3-11} with density dependent catchability (DBS3-11, ddq) and the same using density independent catchability.

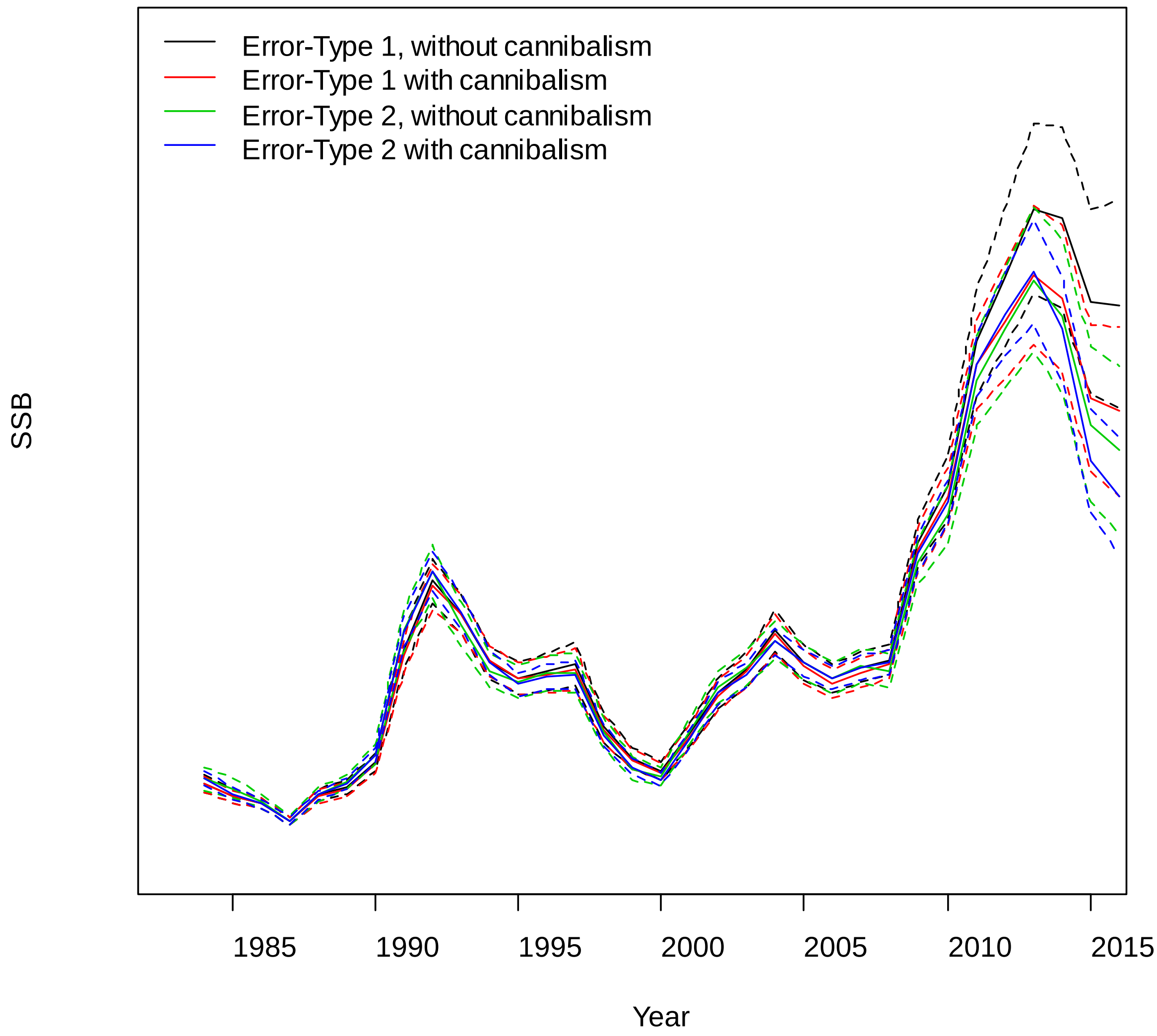


Figure 5. Effect on estimates of SSB by estimating predation mortality for the different error models. All estimates are obtained by data set D_{3-11} using density dependent catchability.

Inter-benchmark on Northeast Arctic Cod (IBPArcticCod 2017)

Working Document No. 7

(Copenhagen, 04-06 April 2017)

Evaluation of the NEA cod assessment quality

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Introduction

North-East Arctic cod stock is currently assessed by the AFWG using the VPA model with XSA tuning. This model used for many years and several times was compared with alternative methods like ADAPT, ISVPA, Gadget and others. So on results often were very close and WG always stay on using XSA.
Our main objective was to explore quality of the assessment through analysis of model parameters and input data in order to check current model parameters. At this document we mainly explore internal survey consistency especially paying attention to oldest ages as some survey now were extended in age range. XSA were tried with extended age range. Therefore, corresponding parameter "***Catchability independent of size"*** were studied. Most other parameters were not checked as they were extensively studied in similar WD presented on previous benchmark (WD18 to WKARCT 2015).

Material and methods

The input data used by AFWG for NEA cod assessment (XSA and SVPA runs) in 2016 were used for run of the NEA cod assessment using different alternative model settings and data sets. Some errors in survey data were corrected and fleet15 was taken as an updated data set (WD 6).
All calculations done using FLR.
R version 2.8.1 and FLR for version 2.8.1 (with addition libraries which are available on web site:
FLCore 2.2, **FLAssess** 1.99-102, **FLEDA** 2.0, **FLXSA** 1.99-100).

Survey and catch-at-age data were explored using following criteria:

- visual analysis of dynamic of each generation in data;
- coefficient of determination between data series (f. e.: analysis of internal consistency if it is a data from the same source but from different ages).

The following criteria have been used to decide on a better model fit for XSA parameter choice:

- standard XSA diagnostic values;
- visual analysis of retrospective graphs (SSB, R, fishing mortality data);

Results

Exploration of catch-at-age data

At the beginning of the work the graphs of population dynamics over generations were studied (fig. 1, 2). Catch-at-age data were log transformed and divided on the figures into several age groups to improve the visibility. The 2 periods (1946-1983 and 1984-2015) and 2 groups by ages (younger apart from the older; age 3-4 and 5-13) were chosen.

Rich and poor generations could be followed on these graphs. It is observed that catches in the younger age groups increase with age, due to an increase in their availability to the fishery by increasing the length / age (selectivity). In the older ages the noise in the observed data most often is higher.

A higher level of noise in catch-at-age data is observed in the beginning time series (1946-54) and in the beginning of 1990^s. A significant increase in total mortality of cod from the 1940^s to the 1960^s is seen on figures 1-2. By the early 1960^s the numbers of older fish were significantly lower compared with the 1940^s years. Later period is characterized by a significant reduction in overall mortality in the middle of 1990s and in the most recent years. In other years of all period the total mortality rate is relatively large. Last 7 years show very different pattern in comparison with all investigation period. The catch-at-age were not decrease with age increasing even for older age groups.

On the next step the catch-at-age data was investigated for internal consistency (fig.3, table 2, 3). The data only since 1984 were considered to check for consistency. There are some rich generations well seen in catches over several years and ages. R^2 of dependence between the different generation numbers in the adjacent age groups are quite high and vary in the range of 0.52-0.94.

Data for ages 13 and older, and the question of the plus group were not considered. It was decided to keep the plus group as currently used by AFWG – 13+.
It could be concluded that catch-at-age data are suitable for using in the VPA model, as there are clear signals of generations abundance and changes in level of overall mortality.

Exploration of surveys indexes

There are 5 surveys indexes available for NEA cod:

XSA name	Name	Season	Age	Years
Fleet 09 (FLT09)	Russian commercial trawl CPUE	All year	9-13+	1985-2015
Fleet 15 (FLT15)	Joint bottom trawl survey	Feb-Mar	0-14+	1980-2015
Fleet 16 (FLT16)	Joint acoustic survey+Lofoten acoustic	Feb-Mar	0-12+	1984-2015
Fleet 18 (FLT18)	Russian bottom trawl surv.	Oct-Dec	0-13+	1982-2015
Fleet 007 (FLT007)	Joint Ecosystem survey	Aug-Sept	0-13+	2004-2015

The graphs of population dynamics on each of the surveys were analyzed. The indexes checked for internal consistency.

The results of surveys investigation:

Fleet 09 (table 4)

Age indices obtained from the Russian commercial fleet have a good consistency between the ages (r2 in the range of 0.74 – 0.92) (fig. 6). Dynamic of numbers (fig. 5) shows continuous growth of indices in recent years. During last benchmark, it was decided not to use this index in the model and we did not try to include it in tuning.

Fleet 15 (table 5)

Comparison of survey index values shows high variation of year class strength (fig. 7). The number of young cod in each generation generally increased with age until the early 1990s and decreased for later period. Apparent reason for this is the modifications in the methodology of survey index calculation. It appears that catchability coefficients for the younger groups were not applied until 1994. However, this difference in index calculation method should not have impact abundance estimates significantly since the VPA used index only from age 3 where observed effect is much lower. On the other hand, for ages 0-2 the data collected after 1994 could be used in tuning also. Trends in overall mortality shows its increases in early 1980-s and late 1990-s. Z for most recent years is on lowest observed level. In 2014 the effect of the year has been clearly traced.

This parameter for total mortality decreasing in the early 1990s and in the most recent years demonstrates similarity with catch-at-age data (fig. 7). The maximum value of total mortality observed in the middle of the 1980^{s} and late 1990^{s}.

Comparison of generations abundance data in adjacent age groups (fig. 8) demonstrates good consistency since age 3 to age 11. Some extremely rich generations can cause significant deviation of the trend line (e.g. 1983 generation in ages 1-2 and 2-3 and 2004-2006 in ages 7-8-9-10). In the younger age groups (ages 0-2) survey indexes consistency is quite high (r2 = 0.42-0.72), but still is considerably lower than for older ages (r2 = 0.71-0.92). It decided to use in tuning the data for ages 3-11 from the entire period of survey.

Fleet 16 (table 6)

Survey indexes demonstrate mortality decrease in 1990-92 and during most recent years (fig. 9). In general index for this survey demonstrates more noise than for the previous one. The distinct year-effects (decrease/increase in catchability) observed in 1987, 1999 , 2007 and 2014 (fig. 9). As in the previous survey the values for each generation were increasing for younger ages up to 1994 year. After 1994 trends are reversed. Apparently, it is also associated with changes in index calculation method.

The analysis of internal survey data consistency showed a significant decrease for the younger ages (age 0-2 r2 = 0.19-0.44) as compared to the trawl estimates of the same survey (fig. 10). For other ages there were better agreement, especially for ages from 6 to 11 age (r2 = 0.83-0.95). High degree of correlation explained by strong influence of abundant 1983 , 2004 and 2005 generations.

Following the analysis the decision was made to use ages 3-11 from this survey in the first XSA run on account of good internal consistency.

RU-BTr-Q4 – Fleet 18 (table 7)

The graphs of the Russian trawl survey indexes dynamic demonstrate high level of noise up to the early 1990s especially in the older age groups (fig. 11). It is evident that trawl catchability coefficients for the younger ages are not quite adequate. Number of older age groups can exceed the number of younger ones, so the coefficients of catchability for the younger age groups are rather low. Z in recent years has a continuous tendency to decrease.

Internal consistency of data between neighboring ages is low for ages 0-1 (r2 = 0.01-0.03) (fig. 12), but since age 2 the coefficient of determination shows a significant increase (r2 = 0.50-0.91). The influence of generations of 1983 , 2004 and 2005 on regression is also high but lower than for previous surveys (except for ages 7-8, 8-9, 9-10 consistency). Age groups 0-2 indexes are not suitable for using in the XSA.

Therefore, ages 3-12 from this survey selected for the first XSA run, as they demonstrate high enough internal consistency.

EcoNoRu-Q3 – Fleet 007 (table 8)

Some noise observed in data of the ecosystem survey indexes dynamics (fig. 13). It appears that catchability coefficients increase as age of cod increases (abundance of a generation in an older age can exceed abundance of the same generation in the younger age). This effect can be explained by year effect (overestimation in 2010). A significant decrease in total mortality in the period 2006-2010 and in the last 4 years is observed (fig. 13).

Internal survey consistency is quite a high for most of the age groups (r2=0.42-0.88) but very low for ages 4-5 (R^2=0.23) (fig. 14). This observation for ages 4-5 is hard to explain.

Ages 3-12 demonstrate good internal consistency for most ages, so they selected for first XSA run.

XSA runs and model configuration

The following survey data selected for the first XSA run:

XSA name	Name	Season	Age	Years
Fleet 15 (FLT15)	Joint bottom trawl survey	Feb-Mar	0-11	1980-2015
Fleet 16 (FLT16)	Joint acoustic survey+Lofoten acoustic	Feb-Mar	0-11	1984-2015
Fleet 18 (FLT18)	Russian bottom trawl surv.	Oct-Dec	0-12	1982-2015
Fleet 007 (FLT007)	Joint Ecosystem survey	Aug-Sept	0-12	2004-2015

The following XSA parameters from ACOM-2016 remained unchanged and were not tested:

Regression type = C
Minimum of 5 points used for regression
Prior weighting not applied
Minimum standard error for population estimates derived from each fleet = 0.3

The first exploratory XSA run (**All_ages**) with a new set of fleets was carried out in FLR program using default settings. The only difference between the ACOM-2016 run and this run were:

- some errors in data has been fixed;
- Fleet 15 was updated with new index numbers
- all indices were taken with the expanded age ranges chosen by us above.

Other XSA parameters (same as ACOM-2016) are:

Tapered time weighting applied
Power = 3 over 20 years
Catchability independent of 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 estimates are shrunk = 1.0
Prior weighting not applied
F shrinkage s.e. = 1.5
P shrinkage – not used

All these parameters were tested on benchmark in 2015 and described in WD18 attached to that group results. We decided to leave most of them the same as on ACOM-2016 due to not significant impact on the result or because of the incorrect application of another parameter value. Nevertheless, several runs of the model were made in order to check how it behaves if we use it with a full linear (**All_ages_linear**) or power (**All_ages_power**) function.

First XSA run was compared with SALY run (the same as ACOM 2016 , but with updated Fleet 15 indices) and other runs were compared with All_ages run.

All_ages

This run shows extremely big values of residuals in ages 11 for all Fleets, and in age 12 for Fleet 18.
Retrospective graphs of All_ages run demonstrate the same stable assessment in comparison to SALY run (Fig.17, 18).

All_ages_power

Parameters "catchability independent of size for ages" and "catchability independent of age for ages" in this run were set >12 to attain full power relationship model. Power relationship for all ages leads to decreasing of residual values for all fleets in compare with All_ages run. But in retrospective patter there are some worsening in last years (18, 19).

References

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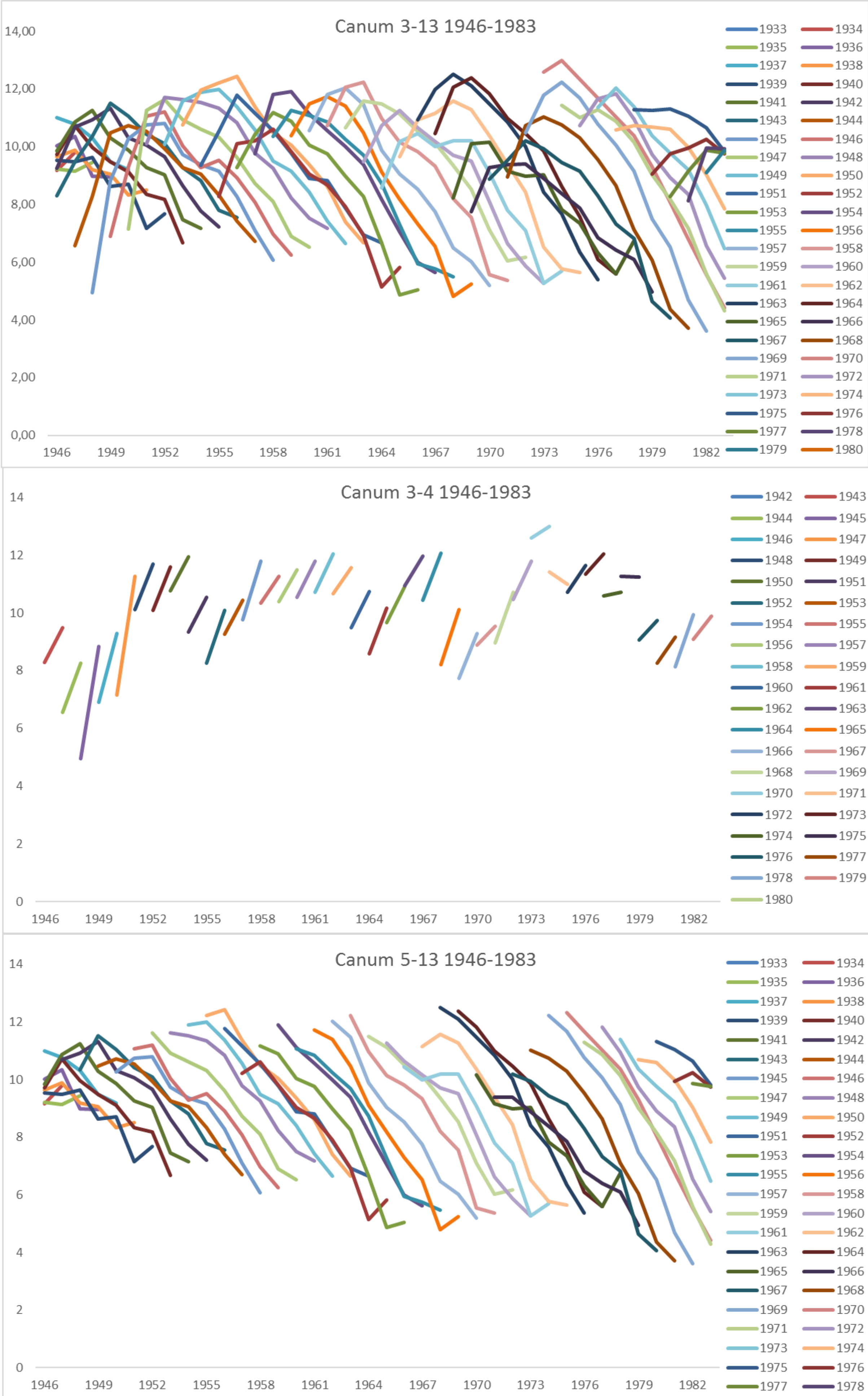


Fig. 1. Catch-at-age numbers dynamic in Log (ages 3-13, years 1946-1983)

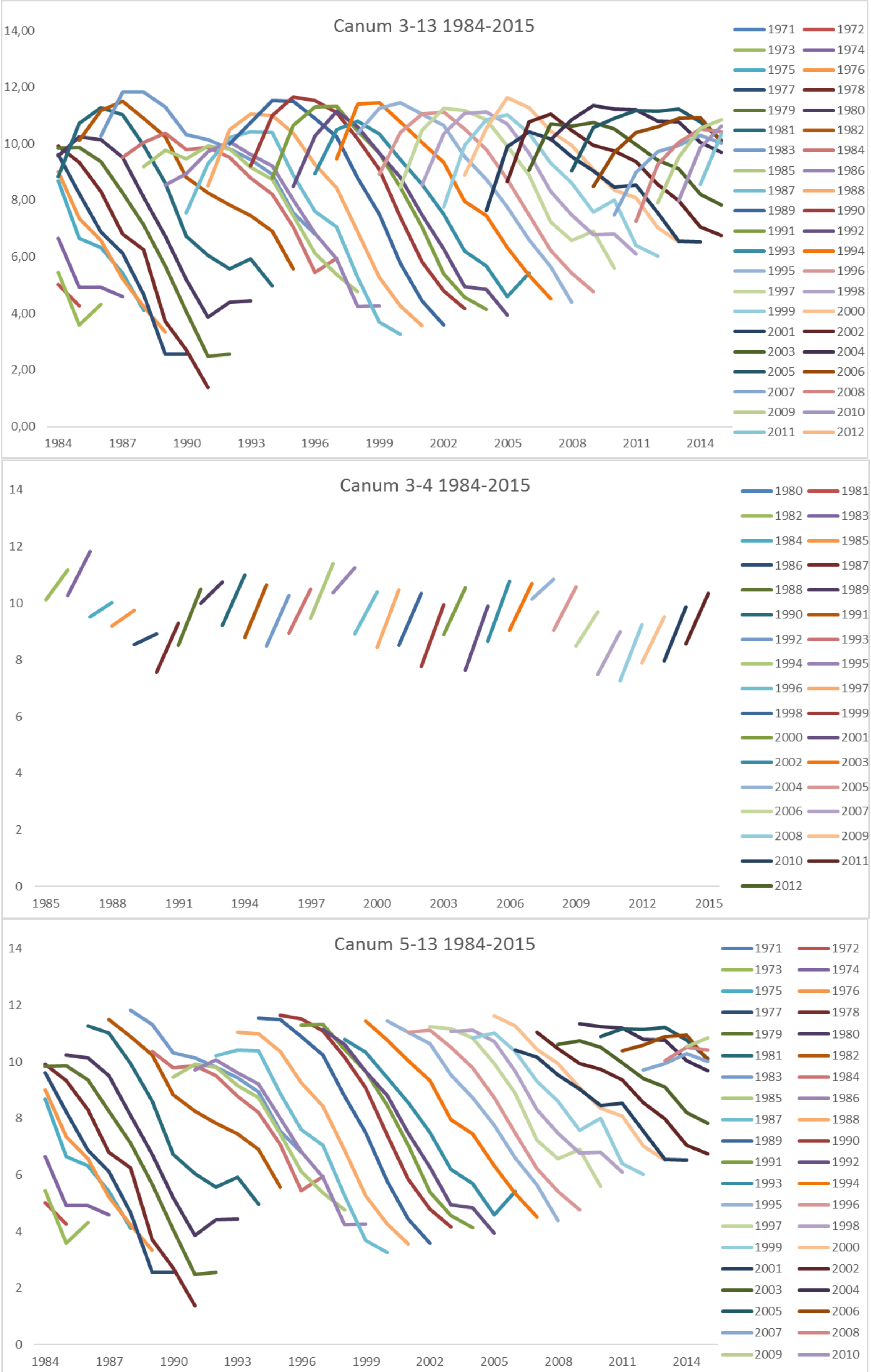


Fig. 2. Catch-at-age numbers dynamic in Log (ages 3-13, years 1984-2015)

Fig.3 Catch-at-age numbers for NEA cod generations taken at the corresponding years and ages (numbers on the figures – years of generations origin).

Table 4. FLT09 RU-BTr-Com-All indices

	Age 9	Age 10	Age 11	Age 12	Age 13
1985	291	77	30	6	0
1986	87	59	22	3	1
1987	127	95	37	11	2
1988	442	215	53	12	3
1989	140	47	11	0	0
1990	204	49	14	2	0
1991	791	71	16	4	1
1992	3852	689	62	10	0
1993	2019	1778	68	13	2
1994	1237	595	167	40	5
1995	684	345	146	21	1
1996	364	164	34	10	0
1997	488	99	34	10	0
1998	559	88	34	13	1
1999	882	171	0	0	0
2000	742	185	25	1	0
2001	235	95	35	7	0
2002	336	61	18	1	0
2003	319	83	19	9	1
2004	710	262	56	12	0
2005	588	203	57	9	1
2006	1182	183	102	20	0
2007	554	244	83	23	4
2008	1741	556	175	36	9
2009	1075	529	147	34	0
2010	1533	627	222	83	13
2011	2740	990	526	182	22
2012	4118	1389	608	308	72
2013	14838	3215	887	248	78
2014	20151	5227	940	249	35
2015	11703	5830	1124	241	38

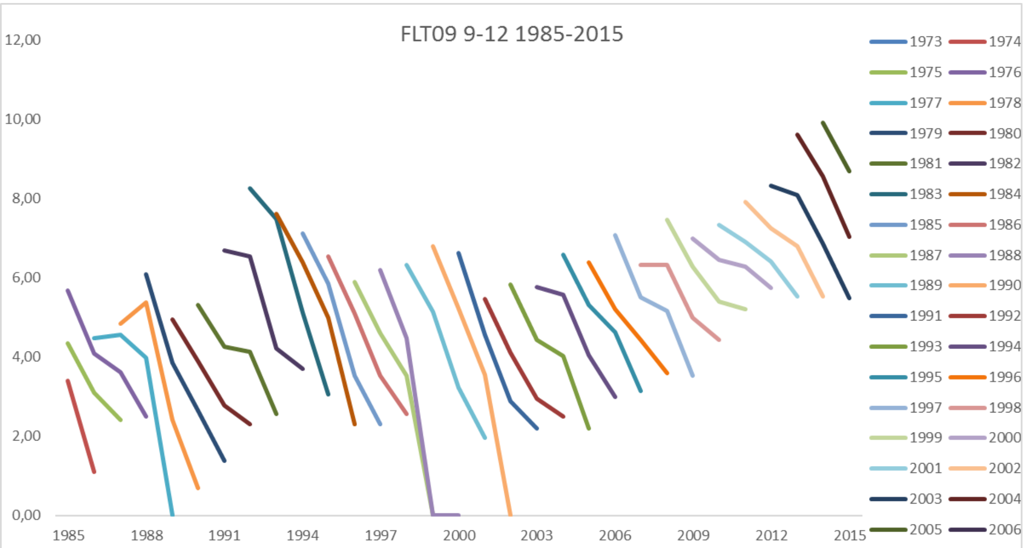


Fig. 5. FLT09 Ru-Btr-Com-All dynamic of numbers in Log scale (years 1985-2015)

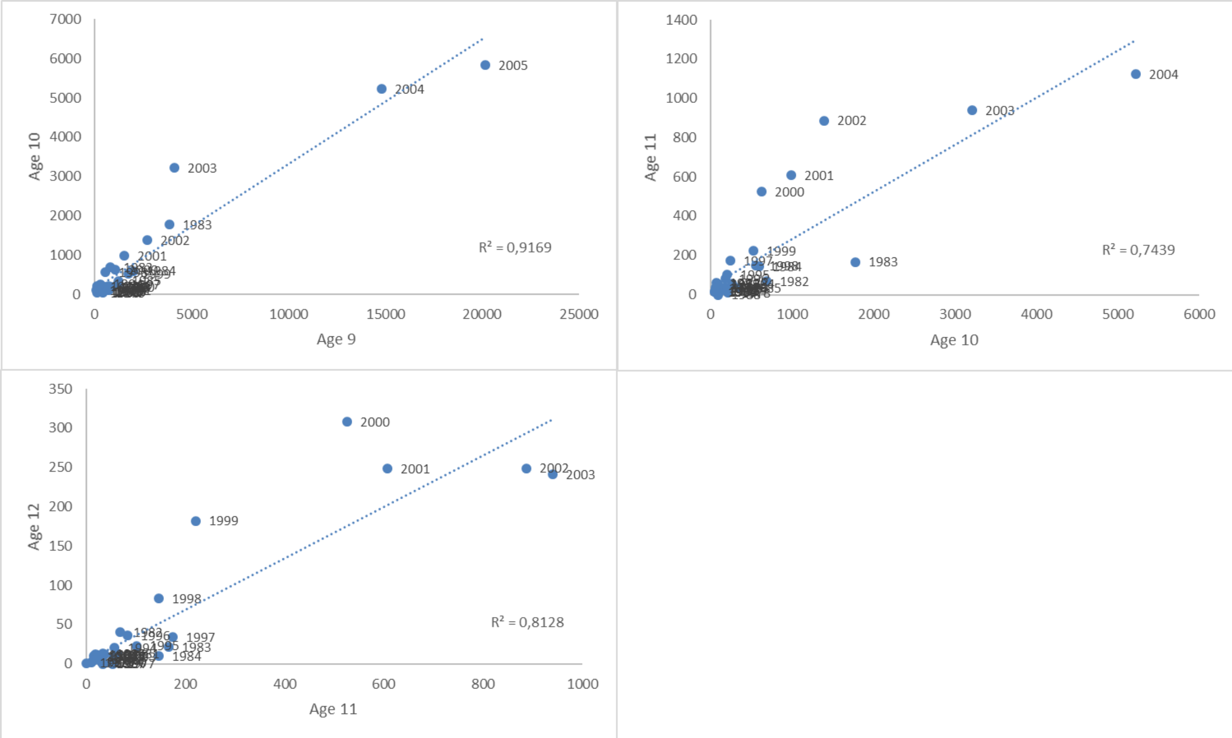


Fig. 6. FLT09 RU-BTr-Com-All internal consistency

Table 5. FLT15 BS-NoRu-Q1(BTr) indices

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14+
1980	460	3430	1640	2330	4000	3840	480	100	30	NA	NA	NA	NA	NA	NA
1981	80	290	2830	2770	2360	1550	1600	140	20	NA	NA	NA	NA	NA	NA
1982	15290	1340	2495	5234	4333	1696	582	321	97	NA	NA	NA	NA	NA	NA
1983	275504	37911	9749	2828	2144	1174	407	40	8	NA	NA	NA	NA	NA	NA
1984	4949	66004	16679	12598	1992	767	334	21	7	NA	NA	NA	NA	NA	NA
1985	66579	39961	80500	14393	6414	830	191	34	4	NA	NA	NA	NA	NA	NA
1986	3072	44498	24038	39115	5435	1570	200	45	3	NA	NA	NA	NA	NA	NA
1987	321	7283	14803	8049	17331	2048	358	53	3	NA	NA	NA	NA	NA	NA
1988	824	1562	4636	7586	3779	9019	982	94	10	NA	NA	NA	NA	NA	NA
1989	20717	5672	2835	3487	3459	2056	2723	161	38	NA	NA	NA	NA	NA	NA
1990	46045	22014	4585	3367	2565	2149	1215	1267	61	NA	NA	NA	NA	NA	NA
1991	12656	57092	15826	5771	1782	1283	767	429	272	NA	NA	NA	NA	NA	NA
1992	53448	42040	27389	14013	7248	1583	624	389	223	NA	NA	NA	NA	NA	NA
1993	104450	54550	29680	30760	15260	4680	813	259	132	55	52	11	5	0	0
1994	534380	54020	28040	24210	25230	7710	1790	233	113	55	59	19	0	0	0
1995	590830	77860	16400	11670	14070	11120	2480	279	37	16	8	8	5	2	0
1996	512280	141370	31540	6920	7500	6070	2680	495	63	68	46	0	0	0	0
1997	251210	49250	35520	16740	3170	2640	1750	826	79	52	65	0	35	0	4
1998	47970	35360	18960	18190	6130	1280	683	519	98	27	2	3	2	0	0
1999	12820	24280	24750	13000	11200	2700	473	182	123	36	10	3	2	0	0
2000	71580	7760	18200	19450	8160	3800	958	119	45	19	4	0	0	0	1
2001	3420	41620	11800	13770	10860	4650	1450	219	34	19	5	0	0	0	2
2002	302140	6120	38080	12540	9520	6660	1790	472	102	16	4	0	2	2	0
2003	32130	23630	6550	18610	5360	4320	3090	692	166	29	8	1	1	0	0
2004	84680	21640	24480	5480	10270	2240	1640	380	88	30	4	2	3	4	0
2005	67690	28380	11560	11400	2810	4330	1400	519	134	22	21	8	0	0	0
2006	58420	36990	36580	12730	6890	1370	2360	685	220	40	31	8	0	0	0
2007	6900	10330	19250	30000	11560	4080	1800	829	186	35	2	2	1	0	0
2008	38940	3550	12430	19610	21800	5820	1750	844	527	50	18	3	3	0	0
2009	103150	9650	3700	11490	15550	14450	3980	1120	370	164	57	5	2	3	2
2010	61530	22560	8540	5070	12990	13800	10310	1670	434	117	79	20	17	4	2
2011	142970	12460	25890	7030	3640	9390	13630	4960	938	233	87	60	47	2	5
2012	43910	14720	7030	11980	6400	4100	6500	7620	3360	221	283	41	35	6	3
2013	49980	14880	18060	8510	6790	4780	3260	4690	3170	936	101	97	15	4	7
2014	129500	19680	12540	17020	13570	9980	7120	2740	5280	1700	286	72	10	7	4
2015	21190	23350	5270	11270	15150	10900	6670	2580	1280	1500	652	99	50	17	14

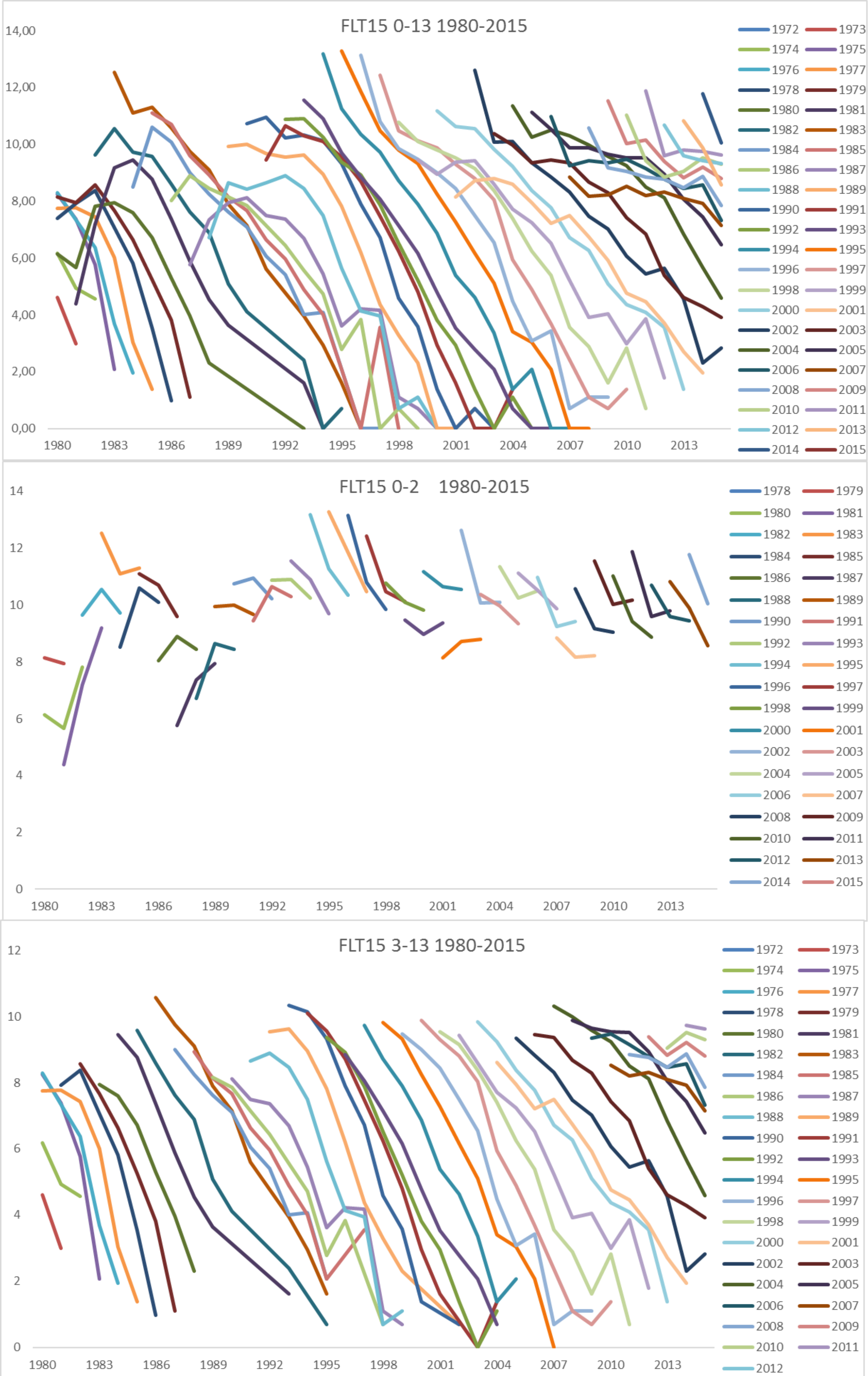


Fig. 7. FLT15 BS-NoRu-Q1(BTr) dynamic of numbers in Log scale (years 1980-2015)

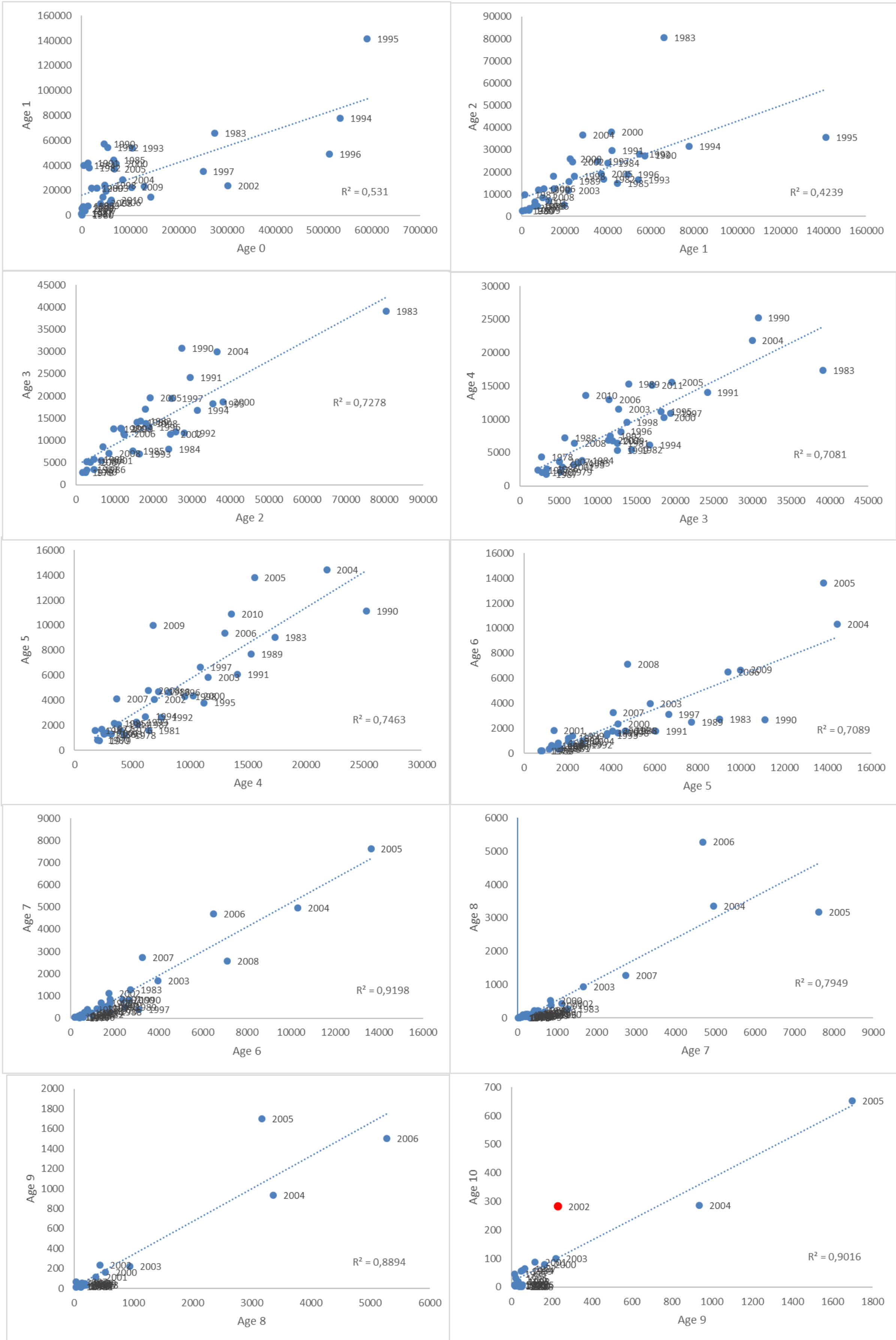


Fig. 8. FLT15 BS-NoRu-Q1(BTr) internal consistency

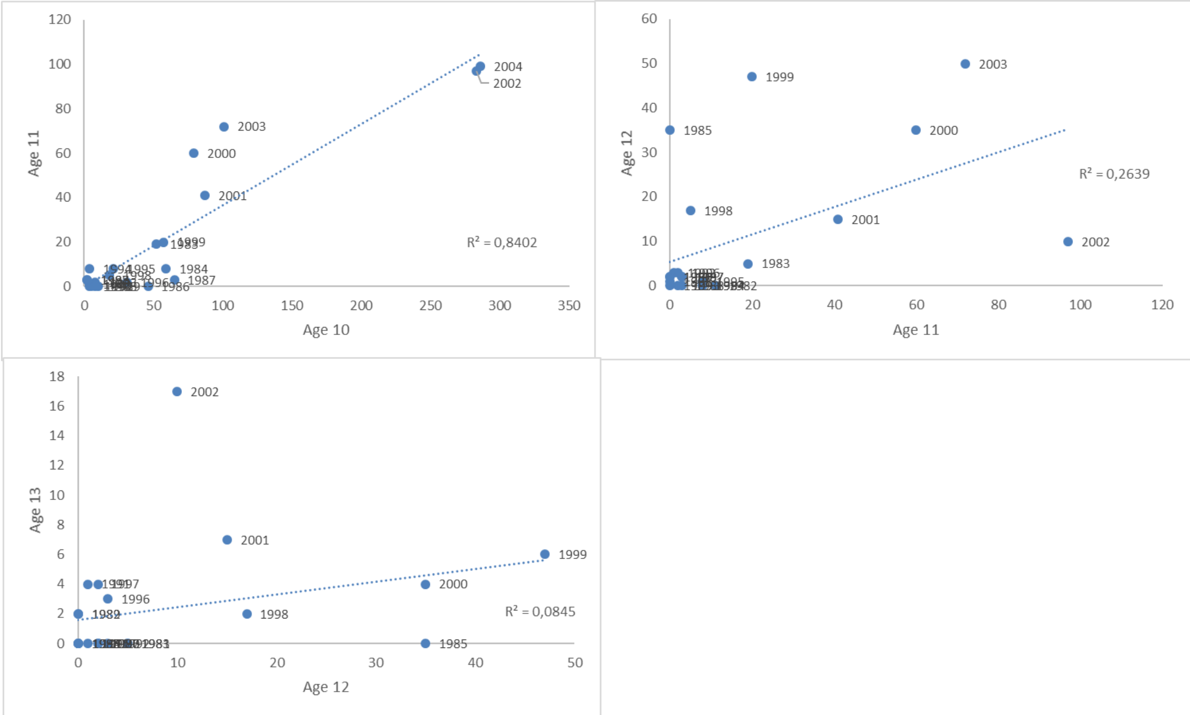


Fig. 8 (continue). FLT15 BS-NoRu-Q1(BTr) internal consistency

Table 6. FLT16 Bs-NoRu-Q1(Aco) indices

	0	1	2	3	4	5	6	7	8	9	10	11	12+
1984	691	4463	1530	1416	204	151	157	33	13	10	5	NA	NA
1985	3536	2439	4996	1343	684	116	77	31	3	0	4	NA	NA
1986	16	341	628	2049	502	174	14	30	7	0	0	NA	NA
1987	20	263	504	355	578	109	40	3	0	1	0	NA	NA
1988	75	80	170	344	214	670	166	32	5	2	0	NA	NA
1989	811	249	148	206	262	269	668	73	6	3	0	NA	NA
1990	1810	2195	502	346	293	339	367	500	37	2	2	NA	NA
1991	2414	5621	1765	658	215	184	284	254	824	43	17	NA	NA
1992	10740	4947	3572	1911	1131	354	255	252	277	442	49	NA	NA
1993	8583	5772	3498	4045	2175	895	225	119	94	39	180	NA	NA
1994	26192	2929	1662	1598	2166	1040	290	44	43	30	26	NA	NA
1995	23960	3398	929	705	872	891	446	65	11	4	9	NA	NA
1996	16235	4305	1883	517	497	422	499	205	22	5	0	NA	NA
1997	34013	6329	4277	1826	424	338	340	247	49	7	2	NA	NA
1998	3583	3043	1500	964	454	122	112	187	92	10	2	NA	NA
1999	1541	2214	2452	1589	1457	493	129	69	52	12	6	NA	NA
2000	6299	639	1382	1716	816	573	198	24	8	6	3	NA	NA
2001	182	2155	693	1122	1043	661	345	95	12	5	6	NA	NA
2002	16939	615	3034	1144	1315	1445	643	212	38	5	1	NA	NA
2003	1577	1052	336	928	327	451	468	222	88	22	2	NA	NA
2004	4653	1196	1239	337	661	299	432	172	75	18	1	NA	NA
2005	5446	2166	798	591	157	381	169	155	88	24	3	NA	NA
2006	1250	617	803	371	318	130	427	138	75	33	8	NA	NA
2007	688	976	2102	3061	1410	754	246	329	58	28	17	NA	NA
2008	3215	306	1826	1783	1405	495	401	133	260	37	17	NA	NA
2009	4854	594	347	1219	1759	1949	709	375	111	88	17	NA	NA
2010	3893	1248	471	291	824	1587	2843	656	226	61	78	5	6
2011	9506	727	1339	527	381	828	2244	1547	309	108	48	20	8
2012	4706	1108	641	850	710	575	1194	2249	1756	209	126	49	33
2013	6301	1391	2200	1178	918	679	529	1354	1751	977	142	66	40
2014	11410	1270	949	1542	1193	996	965	362	1112	663	300	68	52
2015	1429	1207	410	583	969	646	587	339	341	481	292	170	113

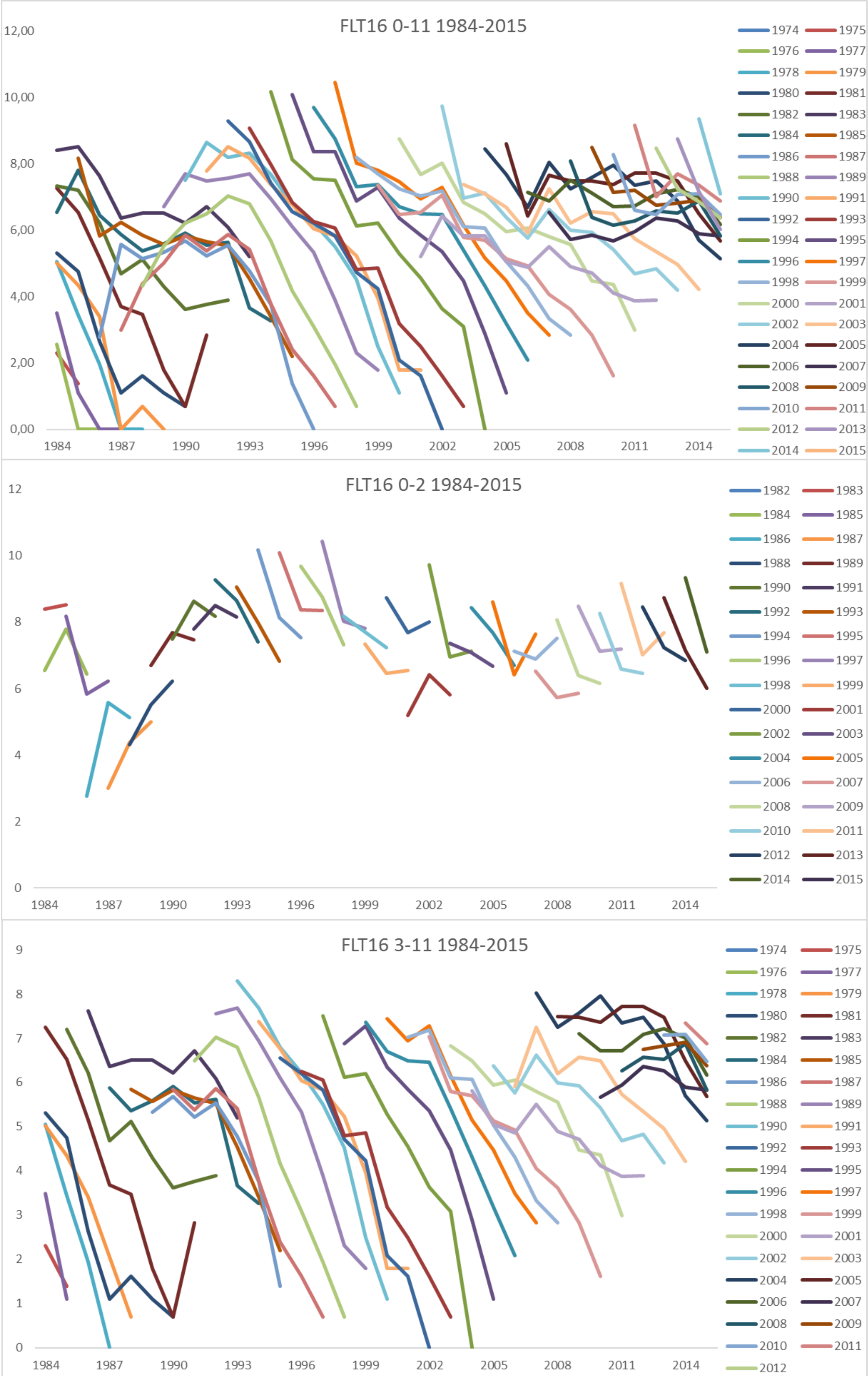


Fig. 9. FLT16 BS-NoRu-Q1(Aco) dynamics of values in Log scale (1984-2015)

Fig. 10. FLT16 Bs-NoRu-Q1(Aco) internal consistency

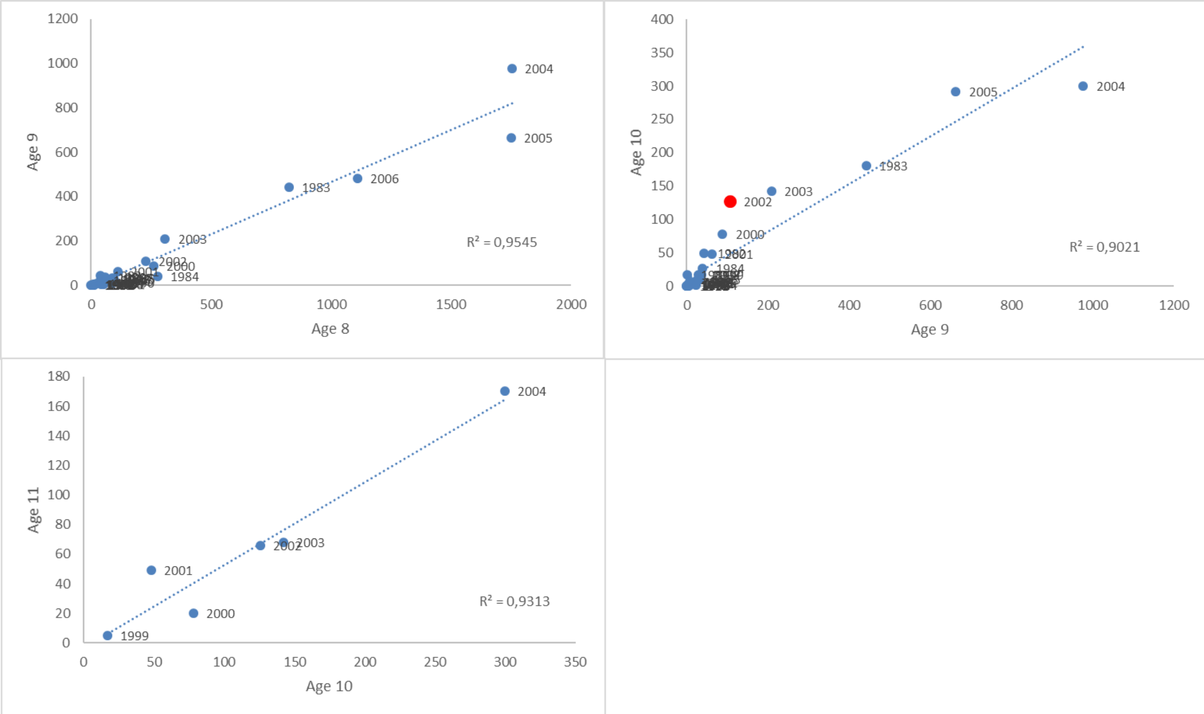
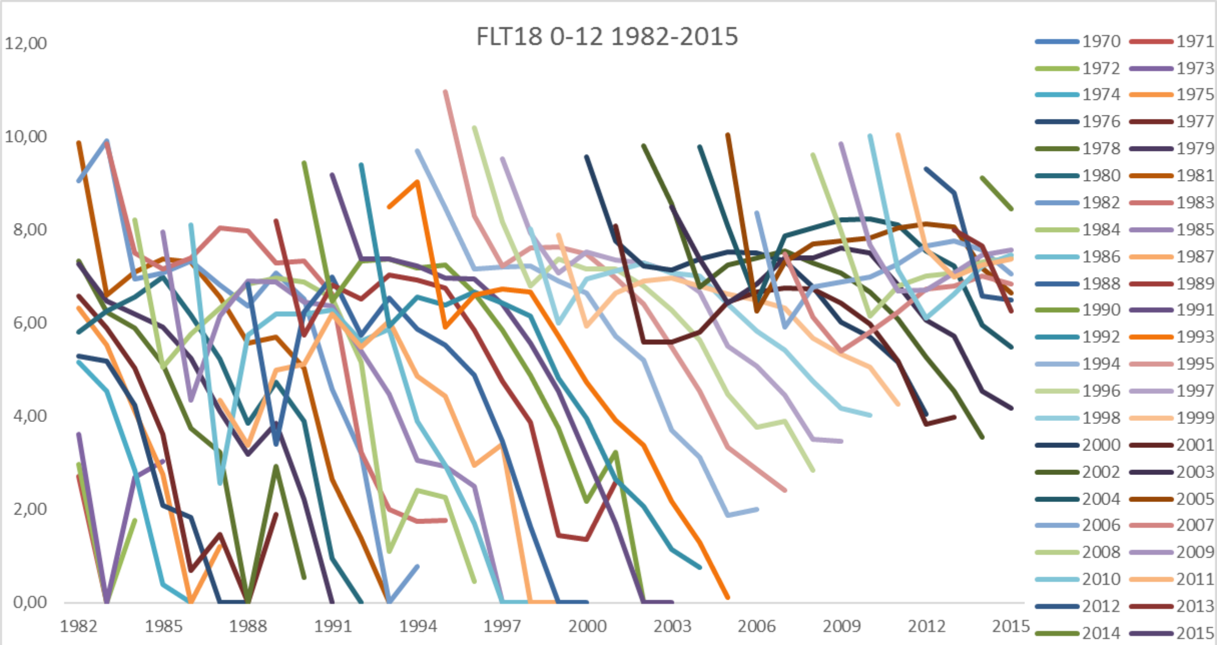
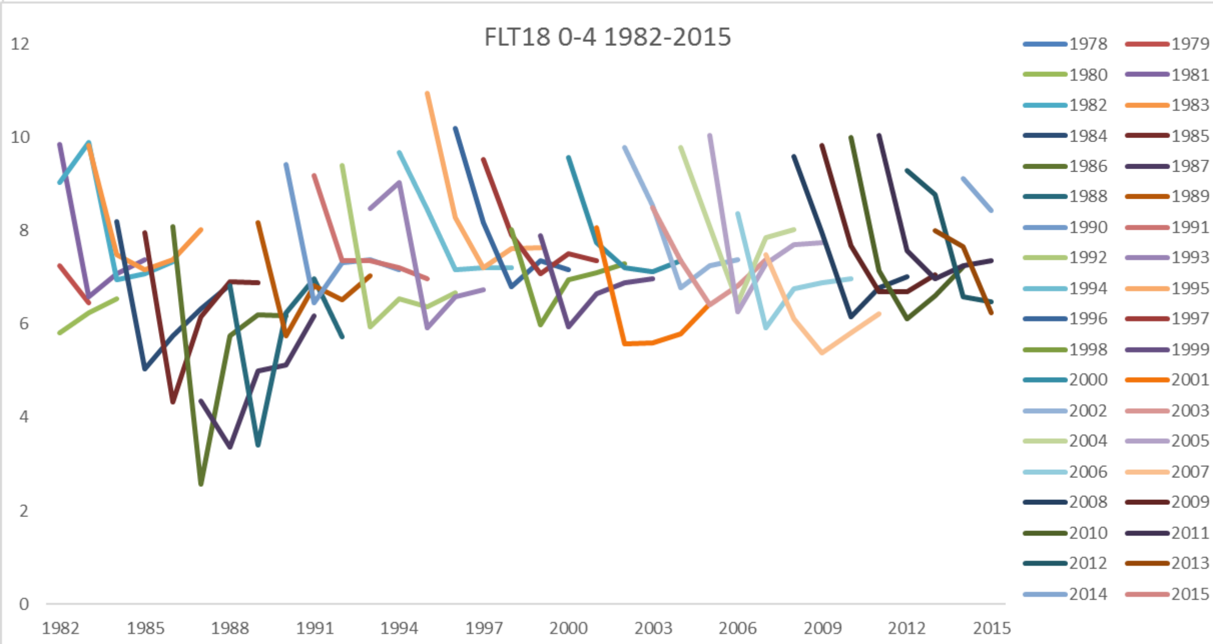


Fig. 10 (continue). FLT16 Bs-NoRu-Q1(Aco) internal consistency

Table 7. FLT18 RU-BTr-Q4 indices

	0	1	2	3	4	5	6	7	8	9	10	11	12	13+
1982	8493	19053	332	1413	1525	721	198	551	174	37	19	15	1	0
1983	18722	20034	732	520	642	506	358	179	252	94	0	0	0	0
1984	3633	1805	1044	1189	700	489	357	154	69	61	17	15	6	2
1985	2846	156	1290	1188	1592	1068	365	165	37	8	16	1	21	0
1986	3299	76	317	1622	1532	1493	481	189	42	2	6	0	0	0
1987	77	13	469	557	3076	900	701	184	60	25	4	1	3	0
1988	925	29	313	993	938	2879	583	260	47	24	1	0	0	0
1989	3558	30	147	490	978	1062	1454	1167	299	112	47	18	7	5
1990	12484	311	510	167	487	627	972	1538	673	153	49	9	2	0
1991	9740	640	911	1077	484	532	583	685	747	98	14	3	0	0
1992	12048	1577	1511	675	308	239	273	218	175	25	25	4	0	0
1993	4848	380	1586	1604	1135	681	416	354	87	3	7	1	1	0
1994	16066	8332	699	1363	1309	1019	354	128	49	21	11	6	2	0
1995	57035	4719	369	589	1065	1395	849	251	83	19	18	9	6	0
1996	26603	3965	1285	733	784	1035	773	348	132	19	5	12	2	0
1997	13714	3539	1353	1342	835	613	602	348	116	32	30	0	0	0
1998	3048	2768	896	2028	1363	788	470	259	130	48	5	0	1	0
1999	2669	401	1184	1587	2072	980	301	123	94	42	4	0	0	0
2000	14365	377	1036	1839	1286	1786	773	114	52	23	9	4	0	0
2001	3216	2338	773	1224	1557	1290	1061	304	50	14	5	25	13	0
2002	17979	267	1356	980	1473	1473	896	600	182	29	8	1	1	0
2003	4895	5175	268	1246	1057	1166	1203	535	241	40	9	3	0	1
2004	17704	1584	875	329	1576	880	1111	776	279	93	23	4	2	0
2005	22980	3239	617	1408	631	1832	744	605	244	88	28	6	1	0
2006	4274	524	632	927	1613	777	1801	662	342	161	43	17	7	0
2007	1775	370	1486	2579	1617	1903	846	1525	553	226	86	49	11	7
2008	14686	452	863	2203	3088	1635	1472	830	863	291	115	33	17	2
2009	18777	2878	219	974	2317	3687	2016	1175	620	413	205	65	32	9
2010	22104	2149	470	334	1070	2505	3715	1817	789	395	299	156	55	20
2011	22961	1259	800	882	508	1432	3065	3300	917	439	176	175	70	35
2012	10960	1962	451	815	1114	839	2122	3358	1878	432	195	46	57	19
2013	2971	6540	1076	747	1174	1177	884	2349	3132	1367	306	92	54	45
2014	9097	2110	721	1399	1368	1725	1483	1111	1929	1297	383	93	35	20
2015	5729	4654	515	657	1583	1742	1932	1610	925	1158	761	242	65	49


FLT18 0-12 1982-2015
12,00
10,00
8,00
6,00
4,00
2,00
0,00
1982 1985 1988 1991 1994 1997 2000 2003 2006 2009 2012 2015
1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015


FLT18 0-4 1982-2015
12
10
8
6
4
2
0
1982 1985 1988 1991 1994 1997 2000 2003 2006 2009 2012 2015
1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015

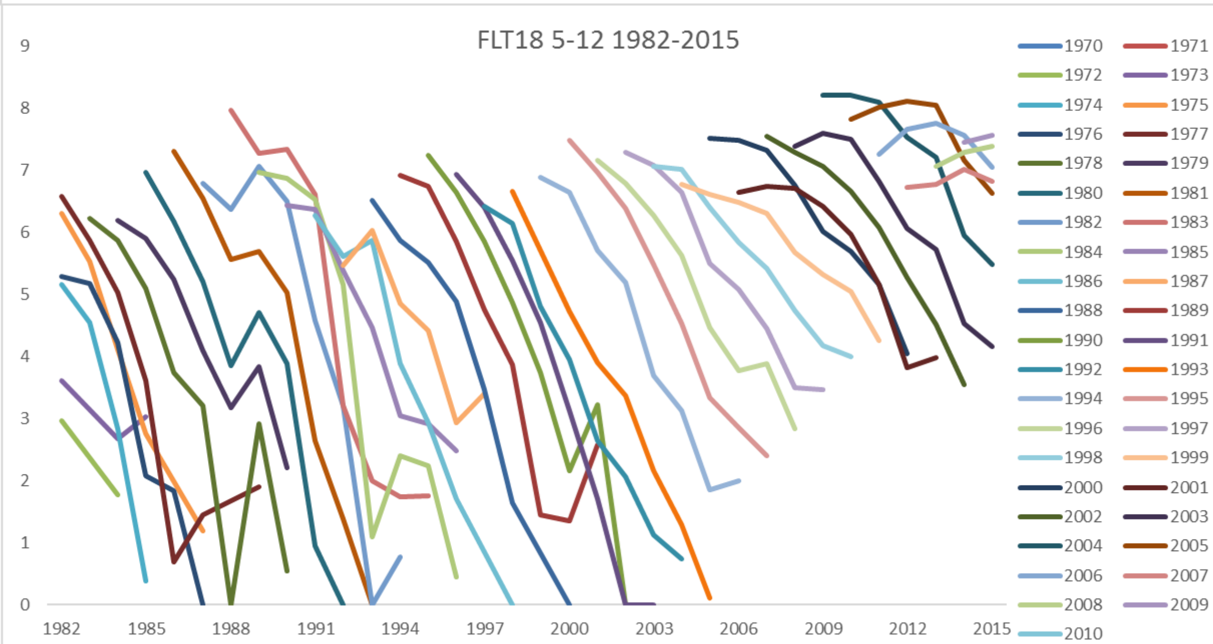

FLT18 5-12 1982-2015
9
8
7
6
5
4
3
2
1
0
1982 1985 1988 1991 1994 1997 2000 2003 2006 2009 2012 2015
1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

Fig. 11. FLT18 RU-BTr-Q4 dynamics of values in Log scale (1982-2015)

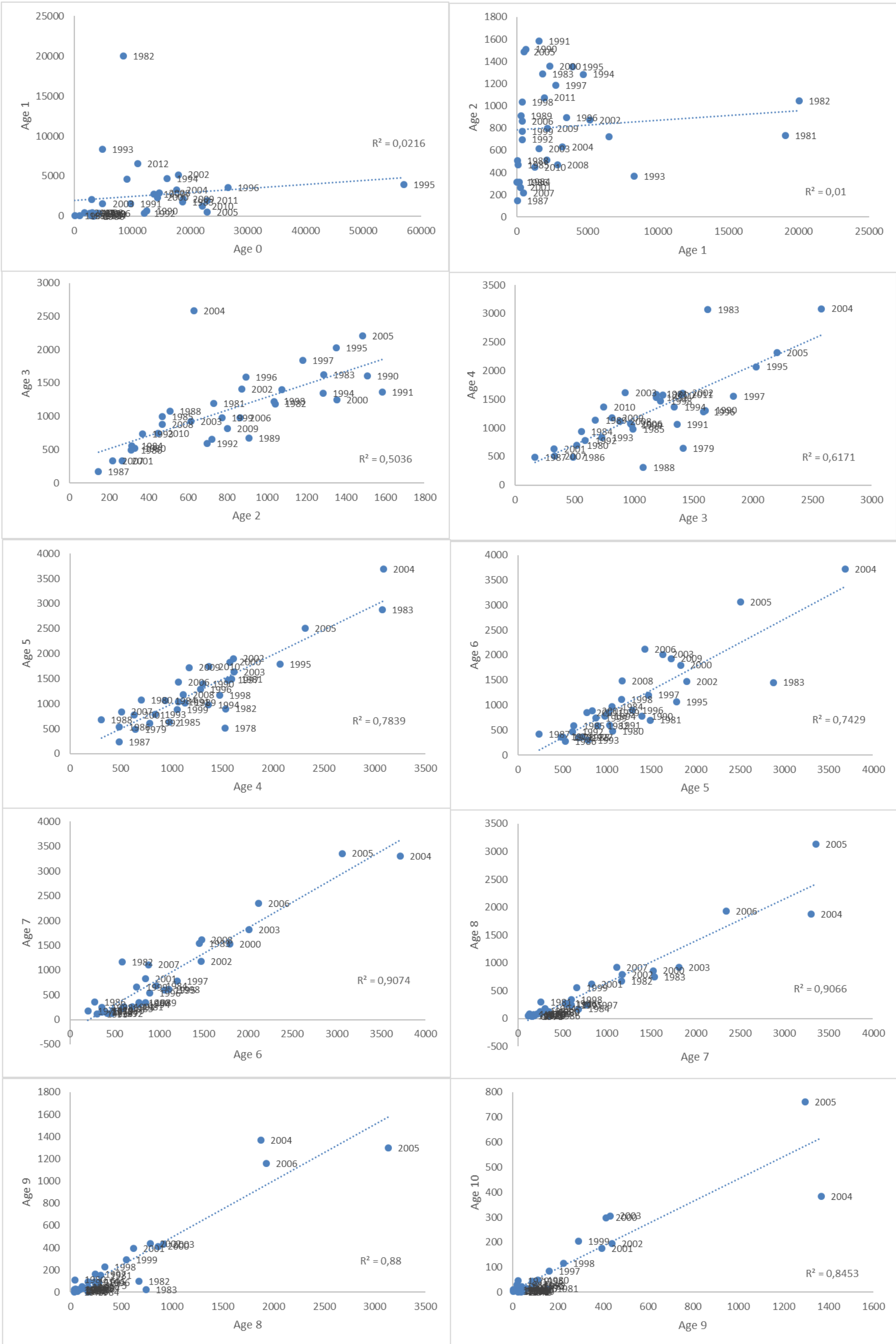


Fig. 12. FLT18 RU-BTr-Q4 internal consistency

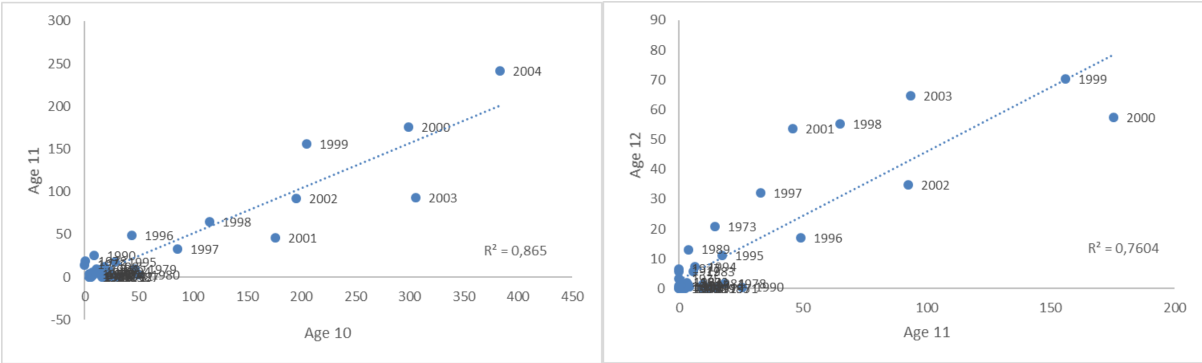


Fig. 12 (continue). FLT18 RU-BTr-Q4 internal consistency

Table 8. FLT007 Eco-NoRu-Q3 indices

	0	1	2	3	4	5	6	7	8	9	10	11	12	13+
2004	5430	3306	3297	1477	4215	1502	798	402	101	22	5	1	1	1
2005	1802	4407	1466	2166	558	1009	280	156	57	12	5	1	0	1
2006	2760	4790	5097	1861	2056	599	698	176	81	26	6	2	0	0
2007	1010	3333	5054	5862	1592	791	246	269	60	22	9	1	2	0
2008	4834	1309	3726	6526	4834	1323	511	128	175	33	9	2	2	2
2009	9033	5697	935	2023	2806	2896	1017	319	127	73	26	8	3	2
2010	6526	3103	842	568	1770	3972	4249	1427	385	105	68	16	3	3
2011	20830	5098	1600	1236	1015	2402	3004	1784	323	77	18	13	6	3
2012	14127	14543	2559	2291	1464	700	1508	1652	845	127	44	16	14	6
2013	22818	9142	6590	2491	1836	1257	632	1182	1302	538	91	33	15	9
2014	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2015	3509	7253	1540	1744	2252	1413	726	486	262	353	266	79	17	10

Fig. 13. FLT007 EcoNoRu-Q3 dynamics of values in Log scale (2004-2015)

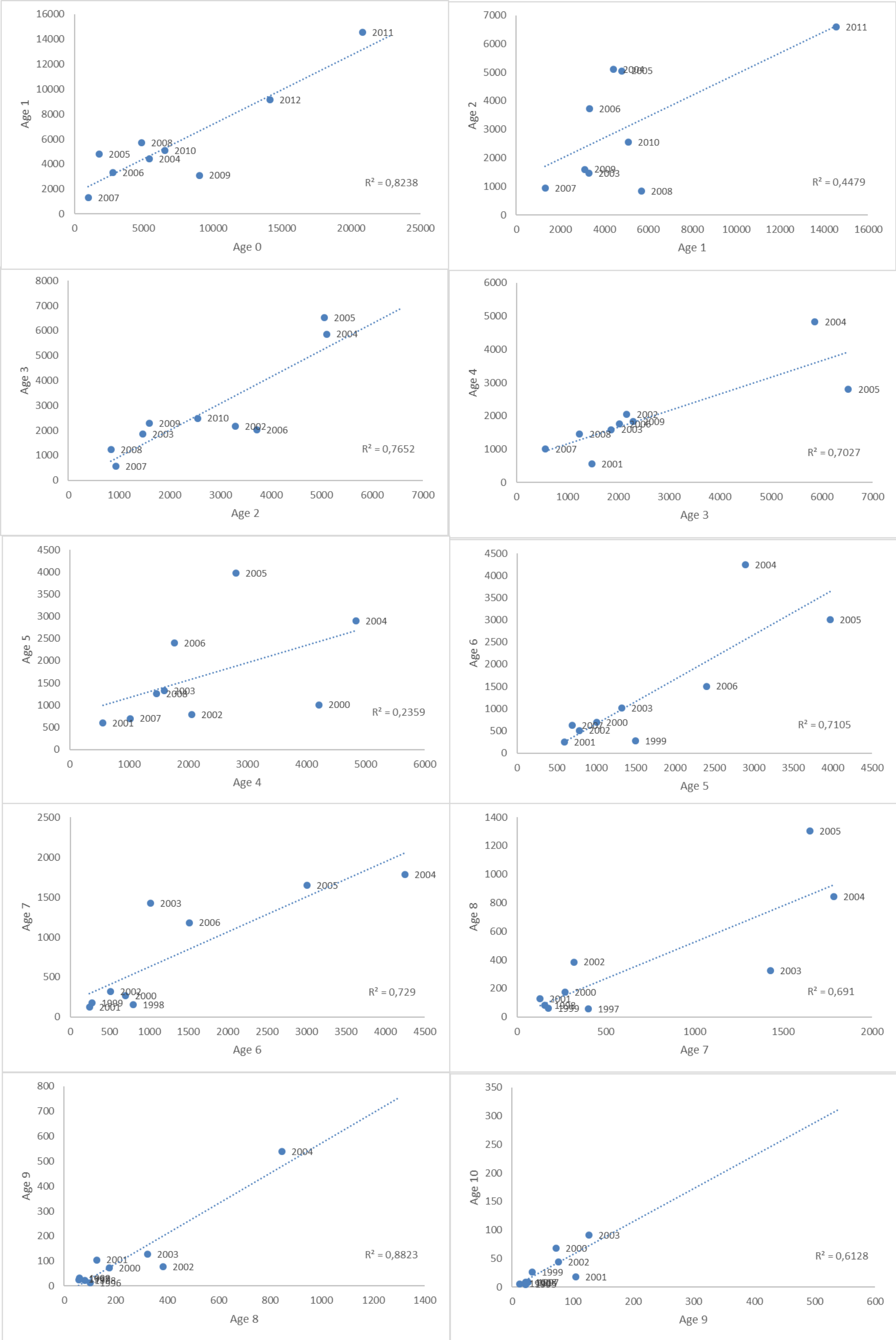


Fig. 14. FLT007 Eco-NoRu-Q3 internal consistency

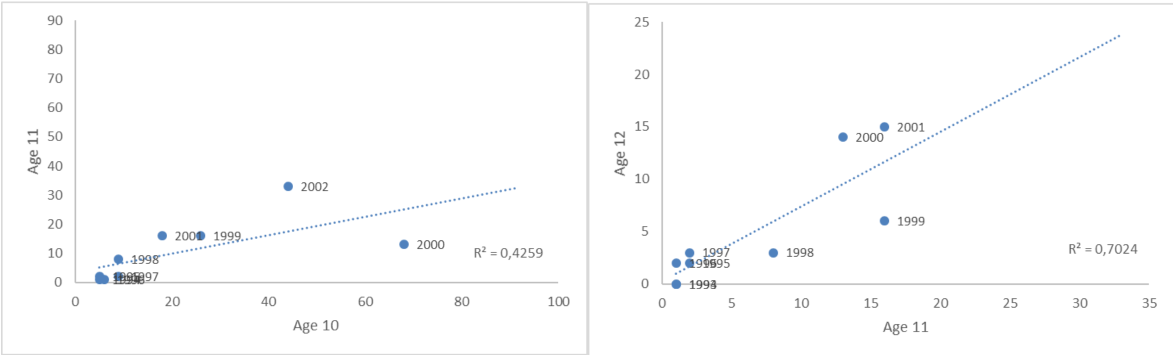


Fig. 14 (continue). FLT007 Eco-NoRu-Q3 internal consistency

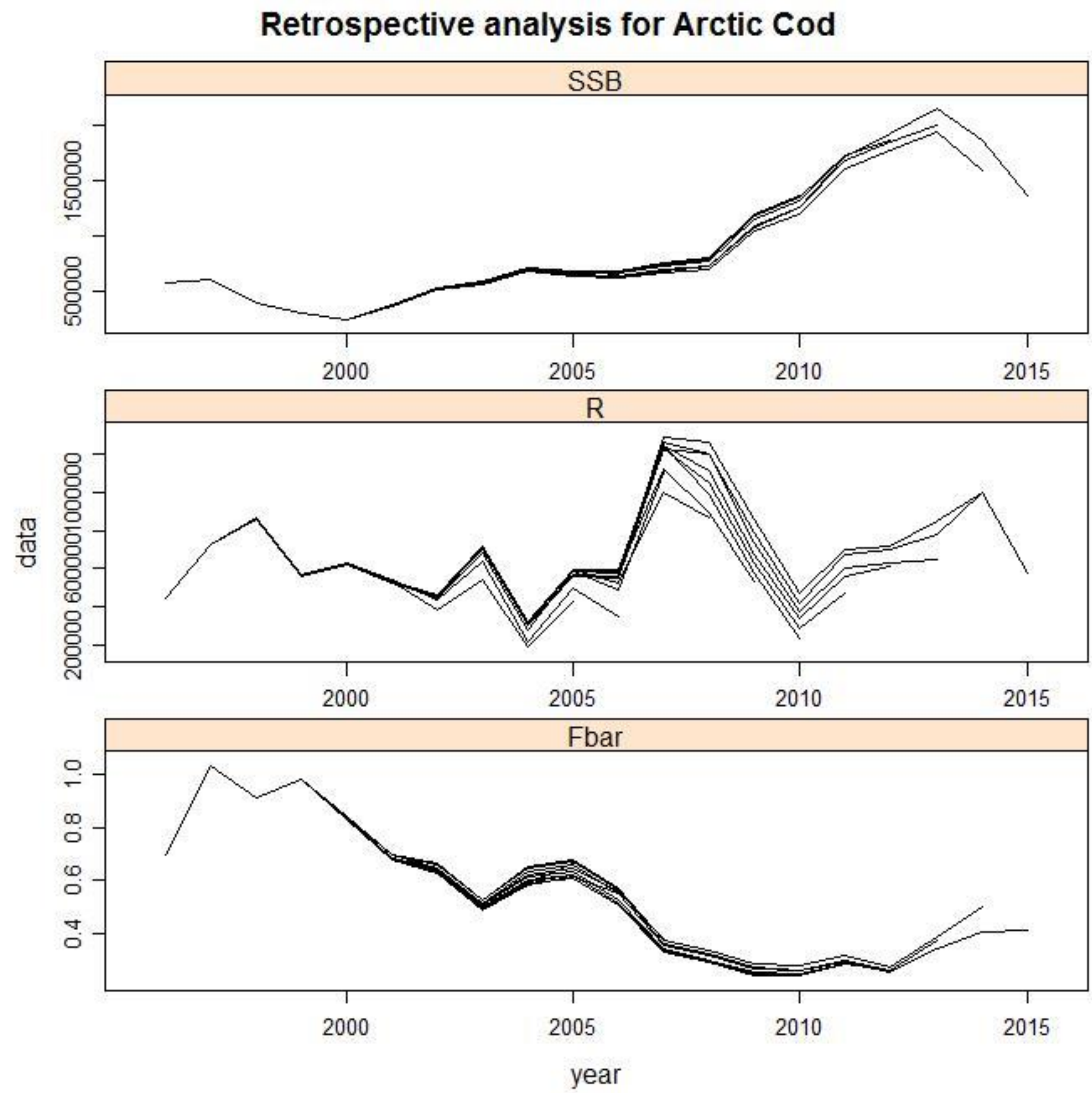


Fig. 17. Retrospective graph SALY run.

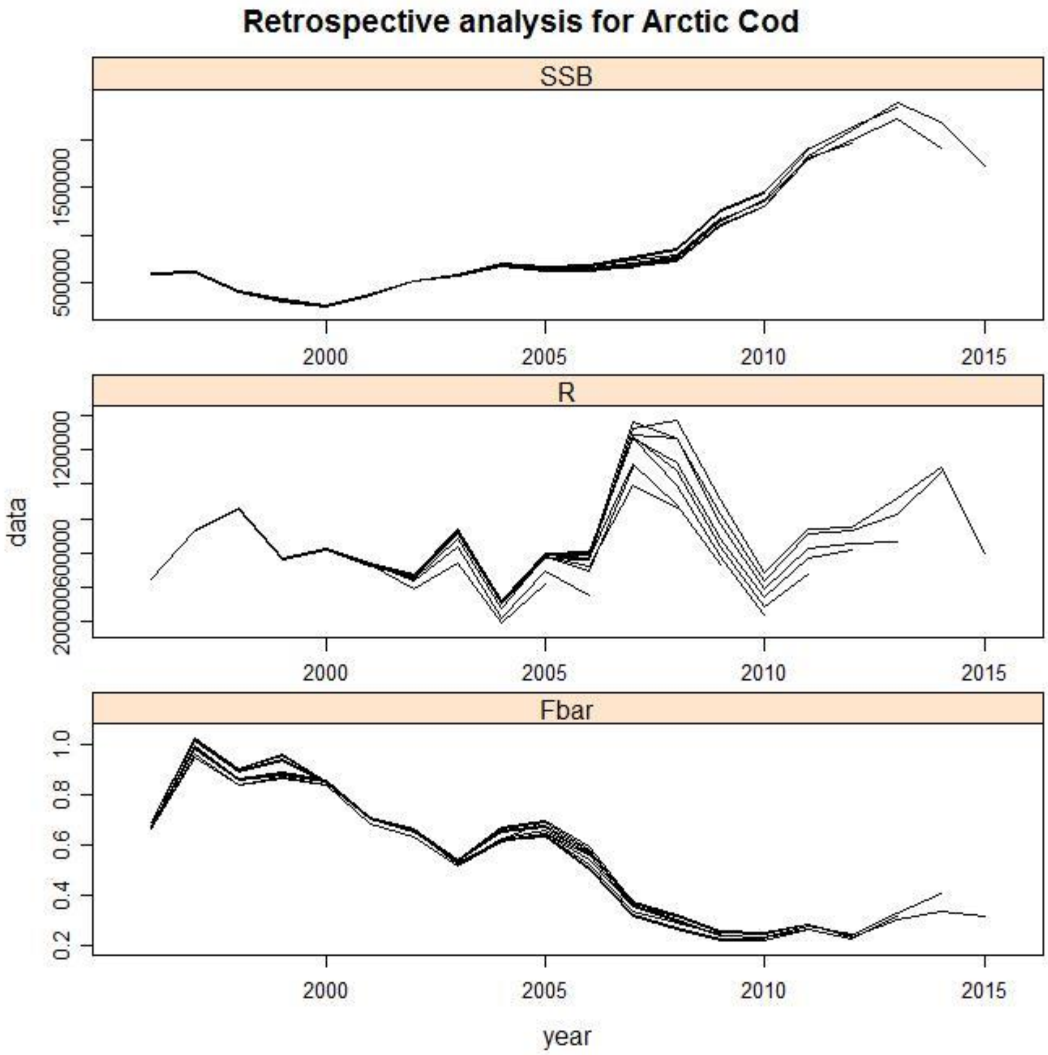


Fig. 18. Retrospective graph All_ages run.

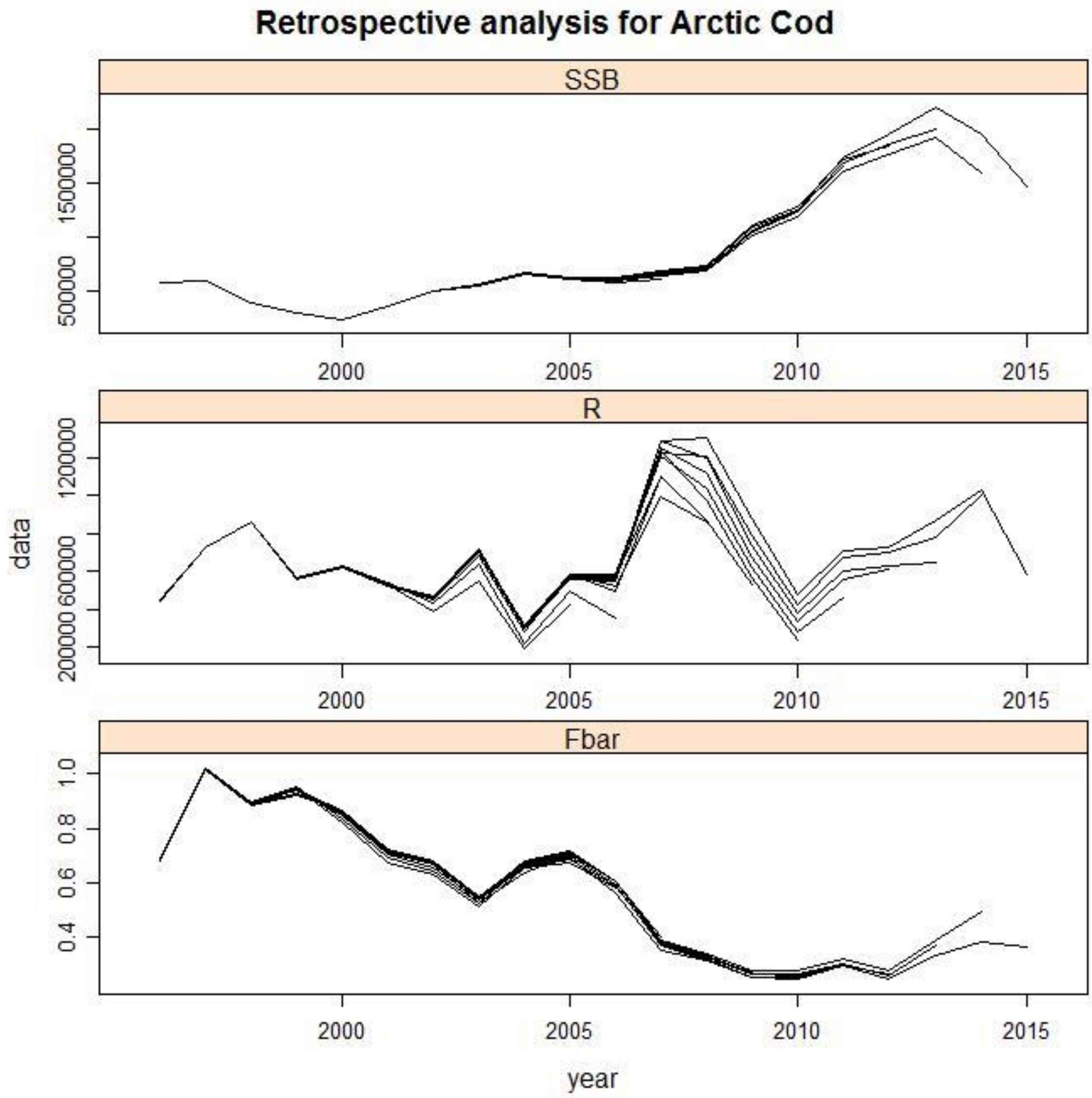


Fig. 19. Retrospective graph All_ages_power run.

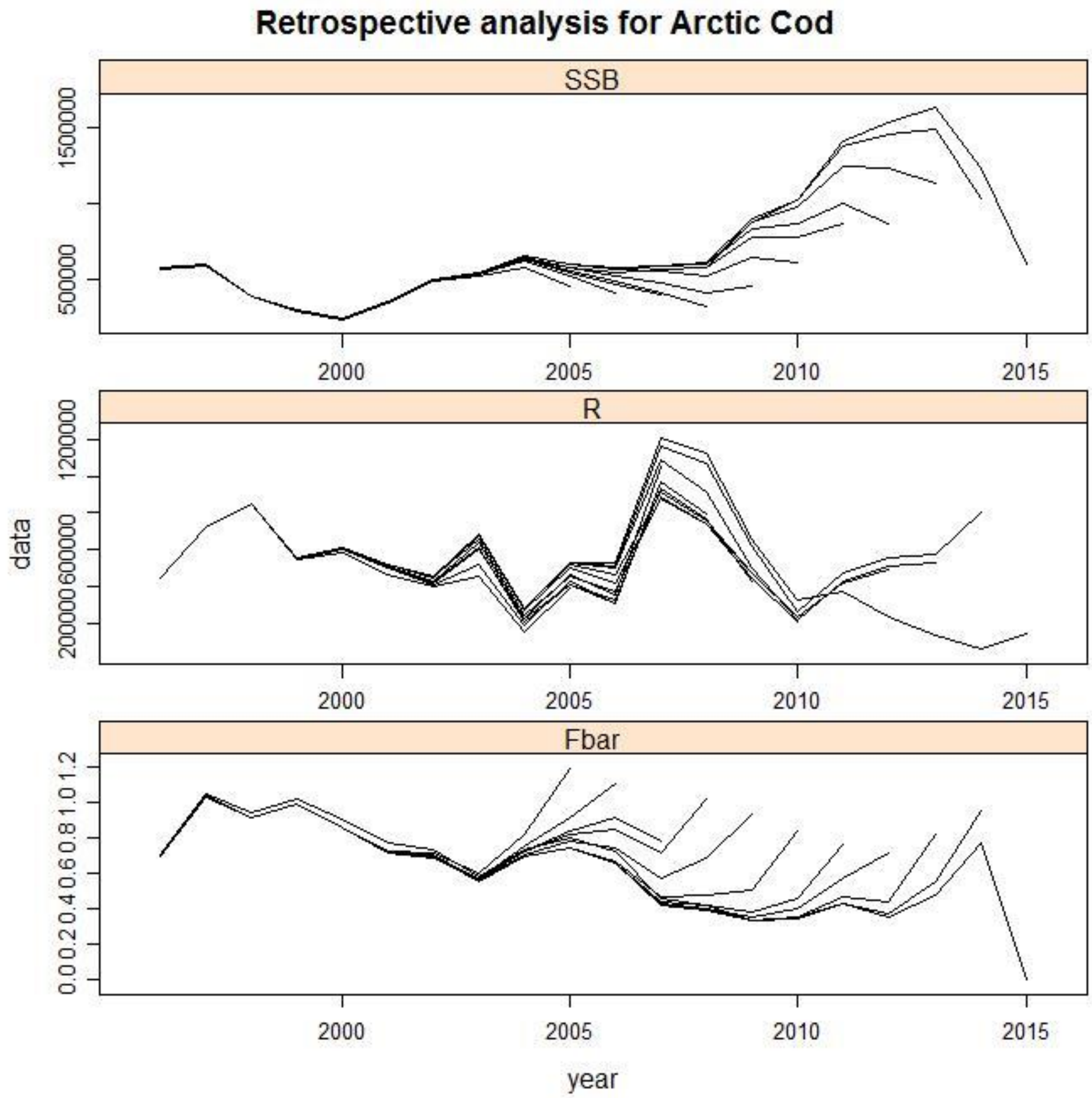


Fig. 20. Retrospective graph All_ages_linear run.

NEA cod XSA assessment PREHISTORY

Yury Kovalev

This document is just collection of copies of pieces from AFWG reports with some small comments (highlighted in cyan). It should demonstrate what kind of changes we did with XSA parameter "**Catchability dependent of stock size for ages less than**" and sometimes with other parameters in order to improve the assessment quality. A key text from reports highlighted in yellow.

Catchability dependent on stock size for ages < 6 VPA-95 since 1999 (and earlier)

AFWG-2010

- **XSA settings**

The output tables from the tuning include ages 1 and 2, just to show the year class abundance at age 1 and 2 created by the cannibalism numbers (Section 3.4.3). These age groups are not included in the tuning, however.

Some of the survey indices have been multiplied by a factor 10. This was done to keep the dynamics of the surveys even for very low indices, because XSA adds 1.0 to the indices before the logarithm is taken.

XSA was run using default settings with the following exceptions:

Tapered time weighting power 3 over 10 years

Catchability dependent of stock size for ages less than 6 (AFWG-2000)

F of the final 5 years and the 2 oldest age groups used in F shrinkage

Standard error of the mean to which estimates are shrunk set to 1.0

These settings are identical to those used by last years' Working Group. Since the assessments in August 2000, few changes in model settings and data choices have been made.

Lowestoft VPA Version 3.1						
19/04/2010 16:43						
Extended Survivors Analysis						
Arctic Cod (run: XSAASA01/X01)						
CPUE data from file fleet						
Catch data for 26 years. 1984 to 2009. Ages 1 to 13.						
Fleet, First, Last, First, Last, Alpha, Beta						
, year, year, age , age						
FLT09: Russian trawl, 1985, 2009, 9, 11, .000, 1.000						
FLT15: NorBarTrSur r, 1984, 2009, 3, 8, .990, 1.000						
FLT16: NorBarLofAcSu, 1984, 2009, 3, 9, .990, 1.000						
FLT18: RusSweptArea , 1984, 2009, 3, 9, .900, 1.000						
Time series weights :						
Tapered time weighting applied						
Power = 3 over 10 years						
Catchability analysis :						
Catchability dependent on stock size for ages < 6						
Regression type = C						
Minimum of 5 points used for regression						
Survivor estimates shrunk to the population mean for ages < 6						
Catchability independent of age for ages >= 10						
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 estimates are shrunk = 1.000						
Minimum standard error for population						
estimates derived from each fleet = .300						
Prior weighting not applied						
Tuning had not converged after 30 iterations						

AFWG-2011

XSA settings (Figure 3.2a, Table 3.13a)

The output tables from the tuning include ages 1 and 2, just to show the year class abundance at age 1 and 2 created by the cannibalism numbers (Section 3.4.2). These age groups are not included in the tuning, however.

Some of the survey indices have been multiplied by a factor 10. This was done to keep the dynamics of the surveys even for very low indices, because XSA adds 1.0 to the indices before the logarithm is taken.

XSA was run using default settings with the following exceptions:

Tapered time weighting power 3 over 10 years

Catchability dependent of stock size for ages less than 7

F of the final 5 years and the 2 oldest age groups used in F shrinkage

Standard error of the mean to which estimates are shrunk set to 1.0

These settings are identical to those used by last years' Working Group except "Catchability dependent of stock size" parameter. Since the assessments in August 2000, few changes in model settings and data choices have been made but in this year some corrections were needed.

As a result of the successful management of the stock in recent years, the survivorship to older ages is now higher than has been seen for many years. As a result the stock is moving into a state where some previous model settings may need to be re-examined. In particular, the previous strategy of including stock size dependent catchability (ssdq) for age 3-5 and not older ages may no longer be valid.

In several surveys (Fleet 15 and Fleet 16) the WG has identified that the most recent results for age 6 fish appear as outliers when compared to the existing linear (non-ssdq) catchability (Figure 3.2a, red line). Figure 3.2a also presents a comparison of including ssdq for age 6 (black line). As can be seen the power model (i.e. with ssdq) is a good fit to all data, including the most recent point. This indicates that the new points are not outliers, but rather that the previous linear catchability is no longer appropriate, suggesting that the ssdq should be extended to age 6 within XSA.

Table 3.13a shows that the conflict between surveys becomes weaker (the survey residuals in the terminal year becomes smaller) if a power model is used also for age 6. The sum of squares measure of misfit for each survey and each parameter set demonstrate that SSQ is visibly lower for case where power model for age 6 is used than linear. These indicate that moving to ssdq for age 6 gives a large benefit in model fit, whereas the gains for including this for older ages is much less clear cut.

Figure 3.2a also demonstrates that the effects of a misfit between model and reality are magnified if the most recent year's data is the extreme point in the data series, as is the case here. Furthermore the effects of a model misfit in a large year class (as here) will have a large effect on the modeled stock size. It is therefore important that the modification to use ssdq for age 6 be implemented this year, rather than waiting for a benchmark meeting. Without this change the stock assessment for the current year (and resulting short term projections) are likely to be seriously flawed.

The WG has therefore concluded that the stock size dependent catchability (ssdq) should be extended from ages 3-5 to ages 3-6 with immediate effect. The WG also recommends that the development of the high survivorship yearclasses be monitored, and that the issue is examined in depth at the next benchmark meeting. Several more years of data will be available by the benchmark, facilitating this analysis.

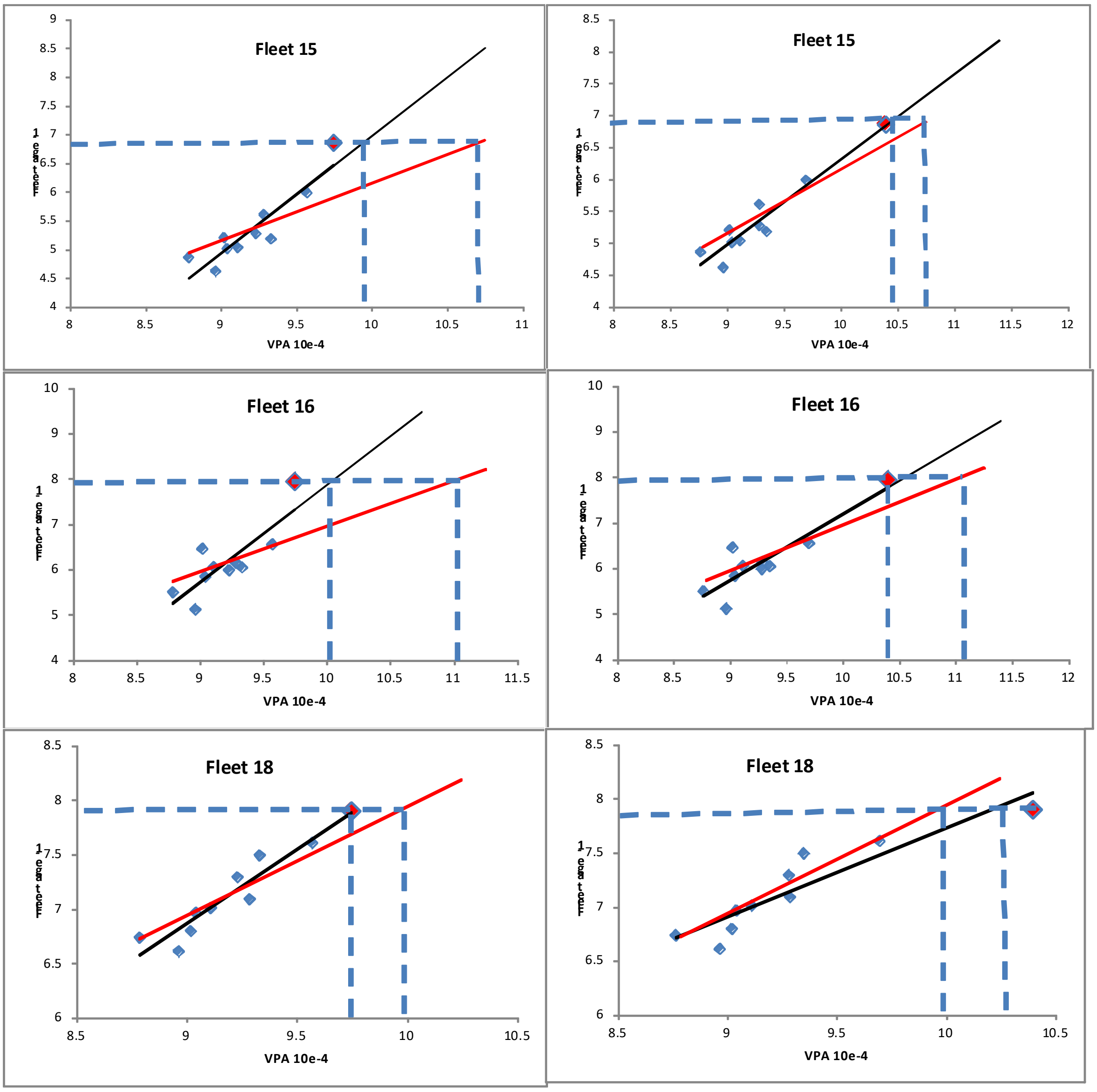


Figure 3.2a. **Northeast arctic cod**. Linear (red) and power (black) fits for age 6 for three surveys, Fleet 15, 16 and 18 (log scale). The power law corresponds to having stock-size dependent catchability (ssdq) for that age class. The most recent data point is shown in red on all three graphs. Left plots correspond to XSA where age 6 fitted to power model, right – linear model.

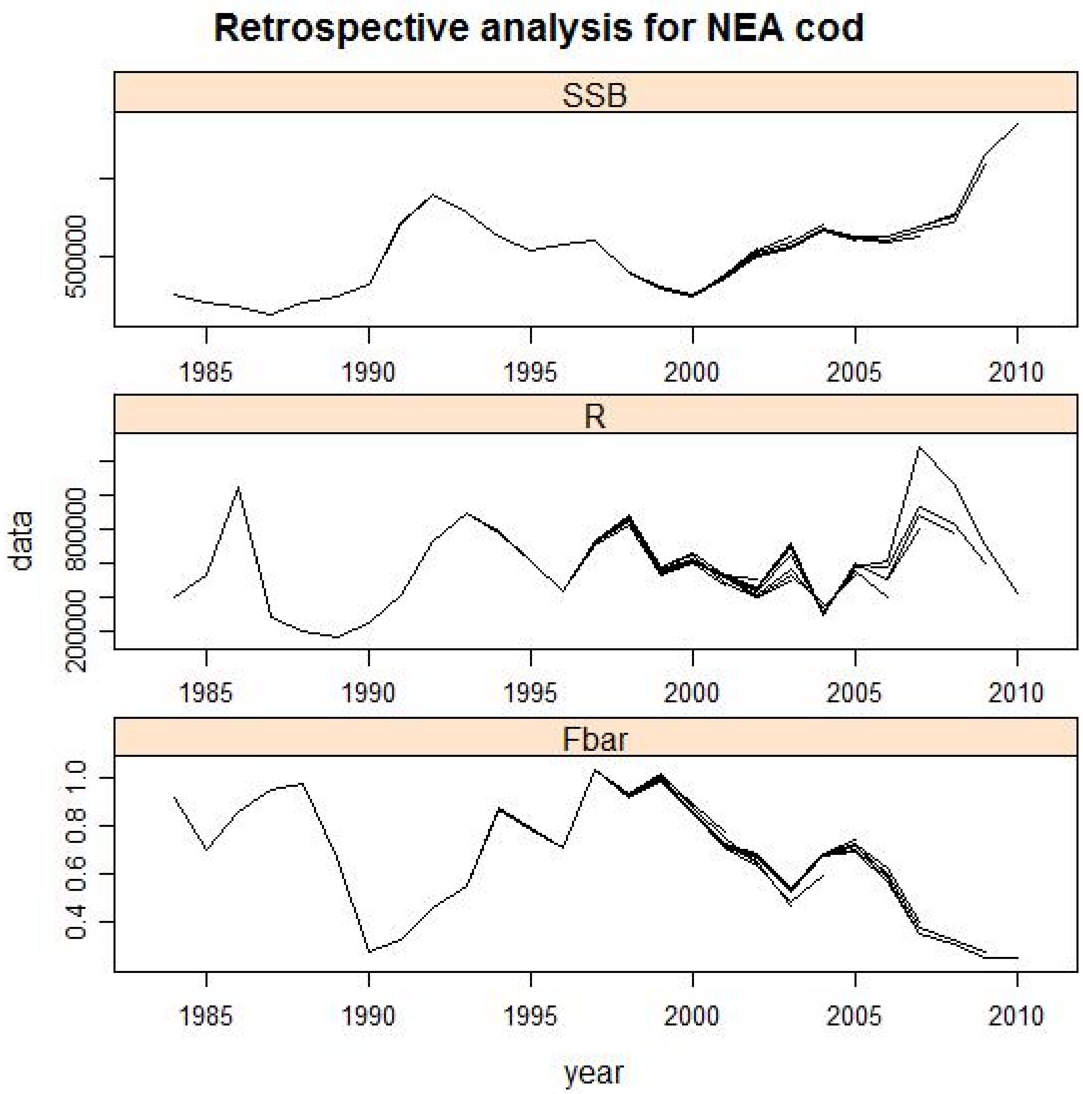


Figure 3.4. Northeast Arctic cod. Retrospective plots with catchability dependent on stock size for ages < 7.

AFWG-2012

XSA settings (Figures 3.2a-b, Table 3.14)

The output tables from the tuning include ages 1 and 2, just to show the year class abundance at age 1 and 2 created by the cannibalism numbers (Section 3.4.2). These age groups are not included in the tuning, however.

Survey indices for Fleet 15 and 16 have been multiplied by a factor 10. This was done to keep the dynamics of the surveys even for very low indices, because XSA adds 1.0 to the indices before the logarithm is taken.

The comprehensive evaluation of XSA settings has been done intersessionally (WD 11). It was demonstrated that the model is quite robust to changes in the currently used values of parameters. The only parameter needs a special attention is "Catchability dependent on stock size for ages".

XSA was run using default settings with the following exceptions:

Tapered time weighting power 3 over 10 years

Catchability dependent of stock size for ages less than 7

F of the final 5 years and the 2 oldest age groups used in F shrinkage

Standard error of the mean to which estimates are shrunk set to 1.0

These settings are identical to those used by last years' Working Group.

The WG at 2011 has concluded that the stock size dependent catchability (ssdq) should be extended from ages 3-5 to ages 3-6 (ICES 2011) and also recommended that the development of the high survivorship year classes be monitored, and that the issue is examined in depth at the next benchmark meeting

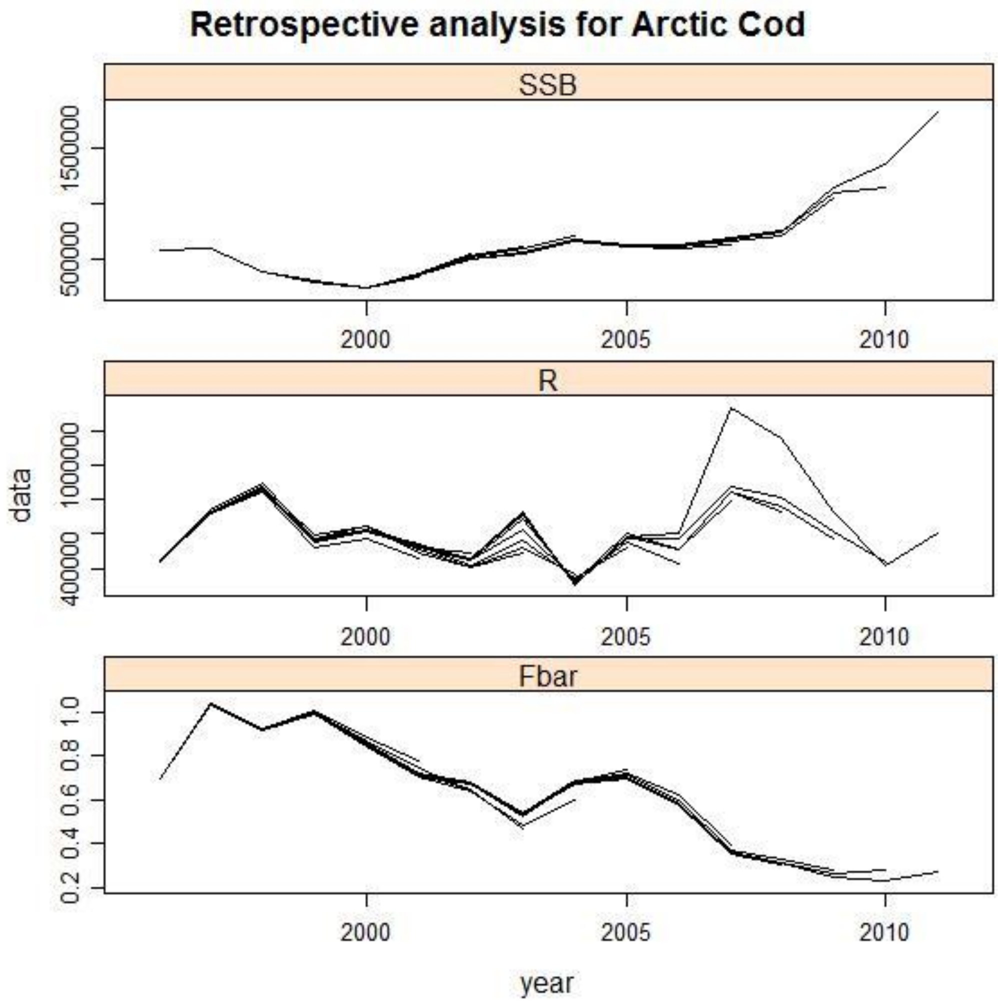


Figure 3.4. Northeast Arctic cod. Retrospective plots with catchability dependent on stock size for ages < 7.

AFWG-2013

XSA settings (Figures 3.2a-d, Table 3.14, 3.31)

The output tables from the tuning include ages 1 and 2, just to show the year class abundance at age 1 and 2 created by the cannibalism numbers (Section 3.4.2). These age groups are not included in the tuning, however.

Survey indices for Fleet 15 and 16 have been multiplied by a factor 10. This was done to keep the dynamics of the surveys even for very low indices, because XSA adds 1.0 to the indices before the logarithm is taken.

An analysis of XSA diagnostics with the same model parameters as last year's assessment shows a substantial discrepancy between different surveys in the terminal year (Fig. 3.2a), especially seen for most abundant yearclasses (2004-2006) at ages 6-8. The discrepancy between surveys and VPA estimates have also greatly increased compared to the previous year, and survey residuals have become much higher than in the previous assessment (ICES C. M. 2012/ACOM:05).

The most plausible explanation for such a behavior of the XSA model is following: It is known that large cohorts of gadoids (including cod) have an impact on VPA-survey relationship during XSA tuning, requiring a stock-size dependent catchability (q) to ensure valid tuning. The NEA cod had large yearclasses in 2004, 2005, and 2006. In the previous two assessments (ICES C. M. 2011/ACOM:05, ICES C. M. 2012/ACOM:05) such stock-size dependent catchability was present up to age 6 to account for this. However these cohorts are now giving large stock sizes in 2012 at ages 7 and 8, which is beyond the age range previously given a stock-size dependent catchability.

The XSA documentation (Darby and Flatman, 1994) recommends setting stock-size dependent catchability for ages where the tuning procedure produces a slope to a power-law based stock size dependent catchability which is significantly different from one (based on diagnostic t-statistics). The t – criteria in the XSA diagnostic are shown in Table 3.31. These are more than 1.6 (the level at which they may be considered statistically significant) for Fleet 15 (for age 7), Fleet 16 (ages 7 and 8) and Fleet 18 (ages 7-9). Based on these criteria, and a number of exploratory runs, it was decided to use a stock size dependent catchability for ages 7 and 8 in the final run.

A second change to the model configuration was made to increase the number of years in time window (from 10 to 20). The time window had previously been limited to avoid changes in survey design and coverage in the early 1990s. As the time series of consistent survey results increases, the number of years including in the tuning should also increase, and the increase in the window is justifiable in its own right. Furthermore the increase in the number of years with stock-size dependent catchability increases the model flexibility, which in turn requires an increase in tuning data in order to avoid model over parameterization. The increased size of the tuning dataset also increases the resilience of the tuning to noise in individual data points, and hence increases the stability of assessment from year to year. The Norwegian bottom trawl and acoustic survey have been run in essentially same way since 1994 (Section 3.2.2), and thus 20 years is the length of the time period with consistent surveys (1994-2013 is 20 years, in the VPA runs these are shifted to the end of the previous year, i. e. 1993-2012).

As a consequence of these changes in the XSA model the discrepancies between surveys in the terminal year (Table 3.14) as well as between all surveys and VPA, were markedly decreased (Fig. 3.2b). The retrospective pattern was also improved by these changes in XSA model parameters (see figures 3.2c and 3.2d – final run retro).

The age range for stock-size dependent catchability needs a special attention during next benchmark. The XSA documentation implies that this parameter should be re-considered each year as large cohorts move through the population. XSA model sensitivity to parameter "Catchability dependent on stock size for ages" should to be considered by ICES method study group (WGMG) – errors resulting from both erroneous inclusion and exclusion should be investigated. Although other assessment models than XSA may be more flexible in the range of assumptions made (e.g. different assumptions on proportionality between surveys and stock abundance for different surveys), the choice made about proportionality will likely affect the result considerably also for such models.

Final XSA was run using the following settings:

Tapered time weighting power 3 over 20 years

Catchability dependent of stock size for ages less than 9

F of the final 5 years and the 2 oldest age groups used in F shrinkage

Standard error of the mean to which estimates are shrunk set to 1.0

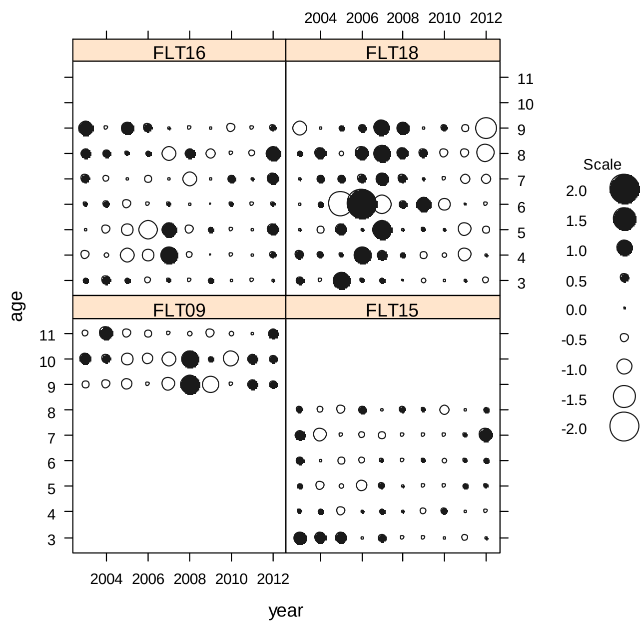


Figure 3.2a. Log catchability residuals by fleets for the tuning data used in XSA with SALY model parameters.

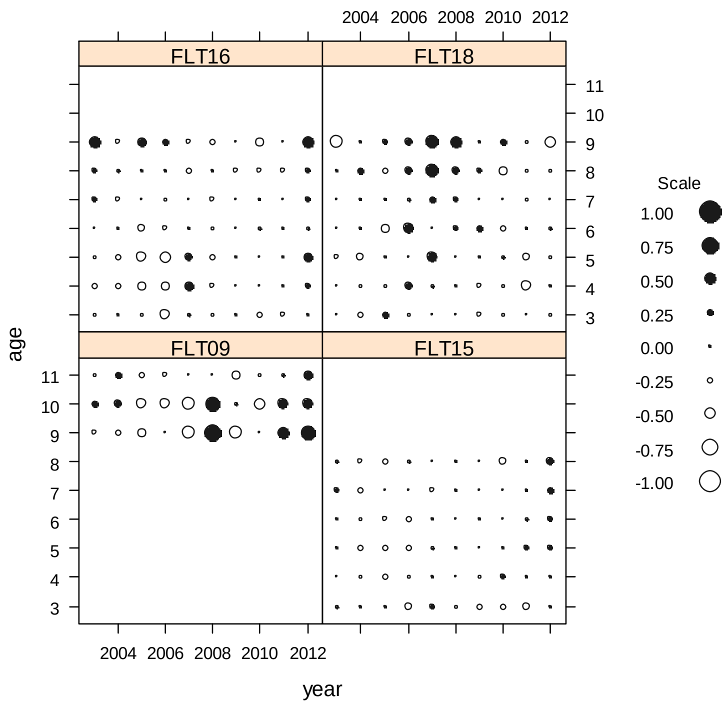


Figure 3.2b. Log catchability residuals by fleets for the tuning data used in final XSA run (with changed settings: assumed q – dependent from yearclass strength for ages 3-8 and tuning window increased to 20 years).

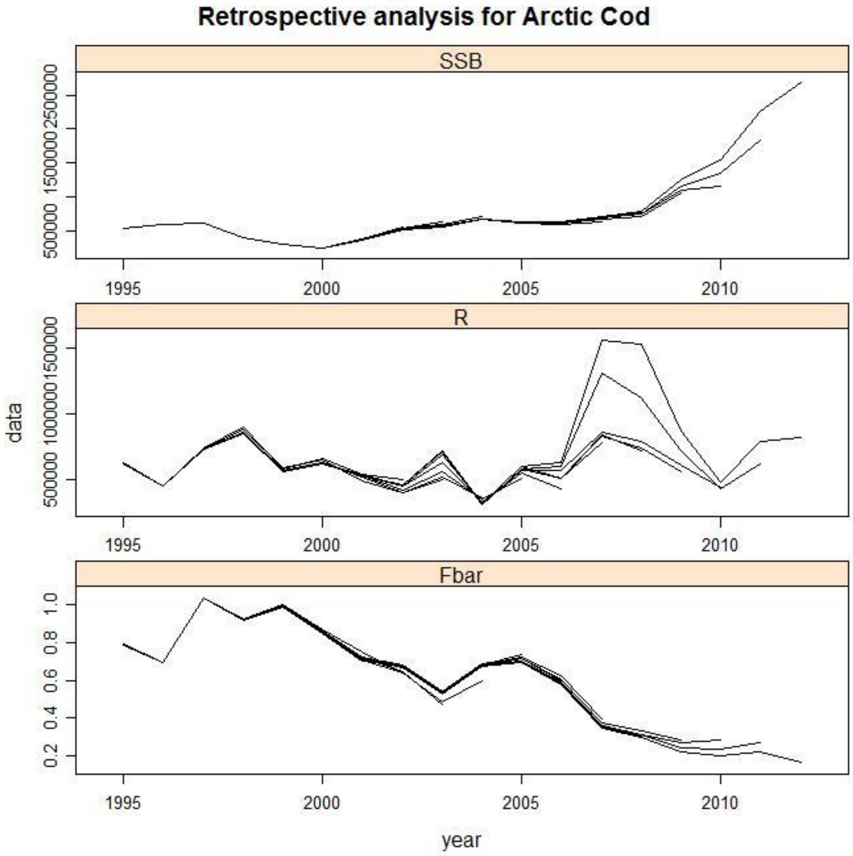


Figure 3.2c. NEA cod SSB, R and Fbar retrospective patterns for XSA model with all parameters same as last year settings.

catchability dependent on stock size for ages < 7.

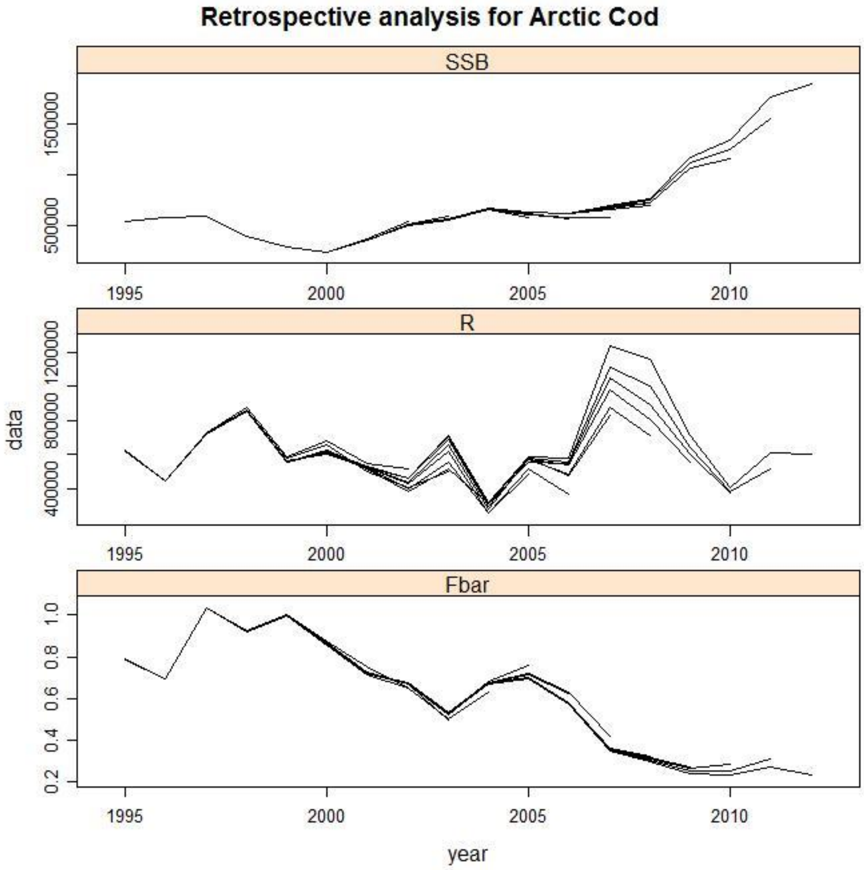


Figure 3.2d. NEA cod SSB, R and Fbar retrospective patterns for final XSA run settings.

Catchability dependent of stock size for ages less than 9

AFWG-2014

XSA settings (Figures 3.2a-b, Table 3.14)

The output tables from the tuning include ages 1 and 2, just to show the year class abundance at age 1 and 2 created by the cannibalism numbers (Section 3.4.2). These age groups are not included in the tuning, however.

Survey indices for Fleet 15 and 16 have been multiplied by a factor 10. This was done to keep the dynamics of the surveys even for very low indices, because XSA adds 1.0 to the indices before the logarithm is taken.

An analysis of XSA diagnostics with the same model parameters as last year's assessment shows a big revision of the strength of the 2004 and 2005 year classes (Fig. 3.2c-d). It leads to substantial increase of SSB and total stock for most recent years compare to last year assessment. Such an effect of very abundant generations on stock assessment have been observed in all previous assessments since these generations appeared in the stock (ICES C. M. 2011/ACOM:05, ICES C. M. 2012/ACOM:05, ICES C. M. 2013/ACOM:05). The discrepancy between surveys and VPA estimates have also increased compared to the previous year, and survey residuals (Fig. 3.2a) are higher than in the previous assessment (ICES C. M. 2013/ACOM:05).

The most plausible explanation for such a behavior of the XSA model is following: It is known that large cohorts of gadoids (including cod) have an impact on VPA-survey relationship during XSA tuning, requiring a stock-size dependent catchability (q) to ensure valid tuning. For NEA cod the year classes 2004, 2005, and 2006 are large. In the 2011 and 2012 assessments (ICES C. M. 2011/ACOM:05, ICES C. M. 2012/ACOM:05) such stock-size dependent catchability was applied up to age 6 to account for this. At later assessments it has been further taken into account by applying stock-size dependent at older ages (7 and 8) as these strong year classes have grown older (ICES C. M. 2013/ACOM:05) In 2013 the 2004 year class is at age 9 and interpretation of its indexes also as having stock size dependent *q* improved the XSA diagnostics (see text table below).

Sum of squares for each survey index residuals					
	Fleet				number of XSA model parameters
	9	15	16	18	
SPALY XSA model	3.5	2.3	5.5	5.2	53
power relationship for age 9 XSA model	3.2	1.9	4.5	3.6	57
% difference	7.5	15.2	18.1	30.3	

The XSA documentation (Darby and Flatman, 1994) recommends setting stock-size dependent catchability for ages where the tuning procedure produces a slope to a power-law based stock size dependent catchability which is significantly different from one (based on diagnostic t-statistics). The t – criteria in the XSA diagnostic are shown in Table 3.14. These are more than 1.6 (the level at which they may be considered statistically significant) for age 9 for all tuning fleets except Fleet 18. Based on these criteria, and a number of exploratory runs, it was decided to use a stock size dependent catchability for age 9 in the final run. It is similar to the decision made by last AFWG for the same yearclasses at ages 7 and 8. The age range for stock-size dependent catchability needs a special attention during next benchmark. The XSA documentation implies that this parameter should be re-considered each year as large cohorts move through the population. XSA model sensitivity to parameter "Catchability dependent on stock size for ages" should to be considered at the upcoming benchmark meeting – errors resulting from both erroneous inclusion and exclusion should be investigated. Although other assessment models than XSA may be more flexible in the range of assumptions made (e.g. different assumptions on proportionality between surveys and stock abundance for different surveys), the choice made about proportionality will likely affect the result considerably also for such models.

The next benchmark should also evaluate the assumed natural mortality (=0.2) which has strong influence on the assessment results when F is low. In the current situation the retrospective pattern improves when assuming a lower M. An explanation of why a lower M in recent years may be likely is given in Section 1.4.1.

The final XSA was run using the following settings:

Tapered time weighting power 3 over 20 years (changed from 10 years in 2013 – but this is not updated in stock annex)

Catchability dependent of stock size for ages less than 10

Catchability independent of age for ages >=11 (in stock annex this is set to 10, but the vpa95 program does not allow to use same value for "Catchability independent of age for ages>=" as "Catchability dependent on stock size for ages<" – this is, however, possible in FLR version)

F of the final 5 years and the 2 oldest age groups used in F shrinkage

Standard error of the mean to which estimates are shrunk set to 1.0

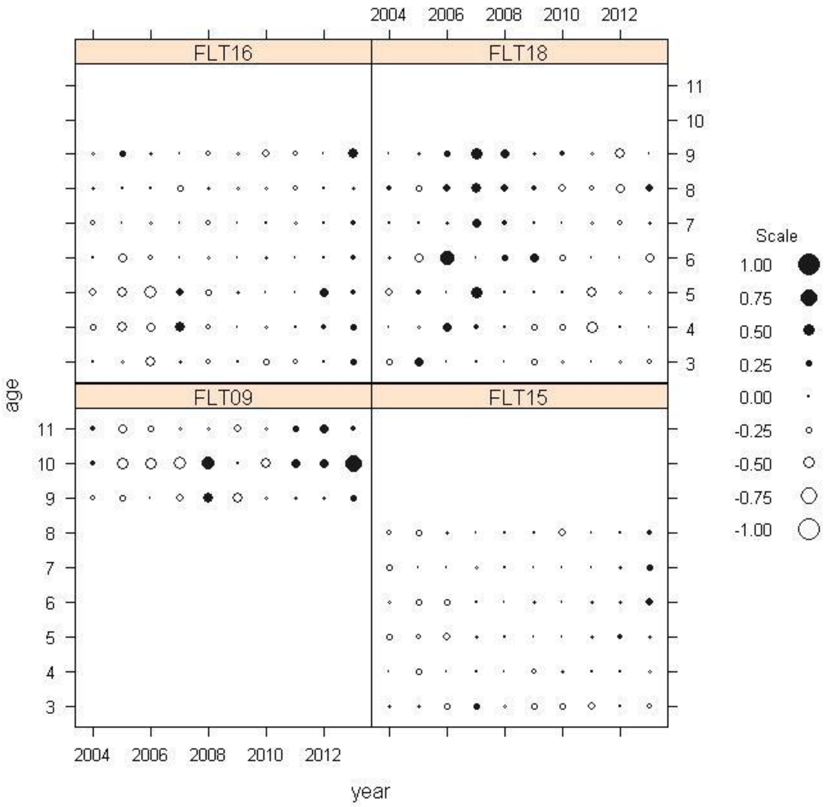


Figure 3.2a. Log catchability residuals by fleets for the tuning data used in final XSA run.

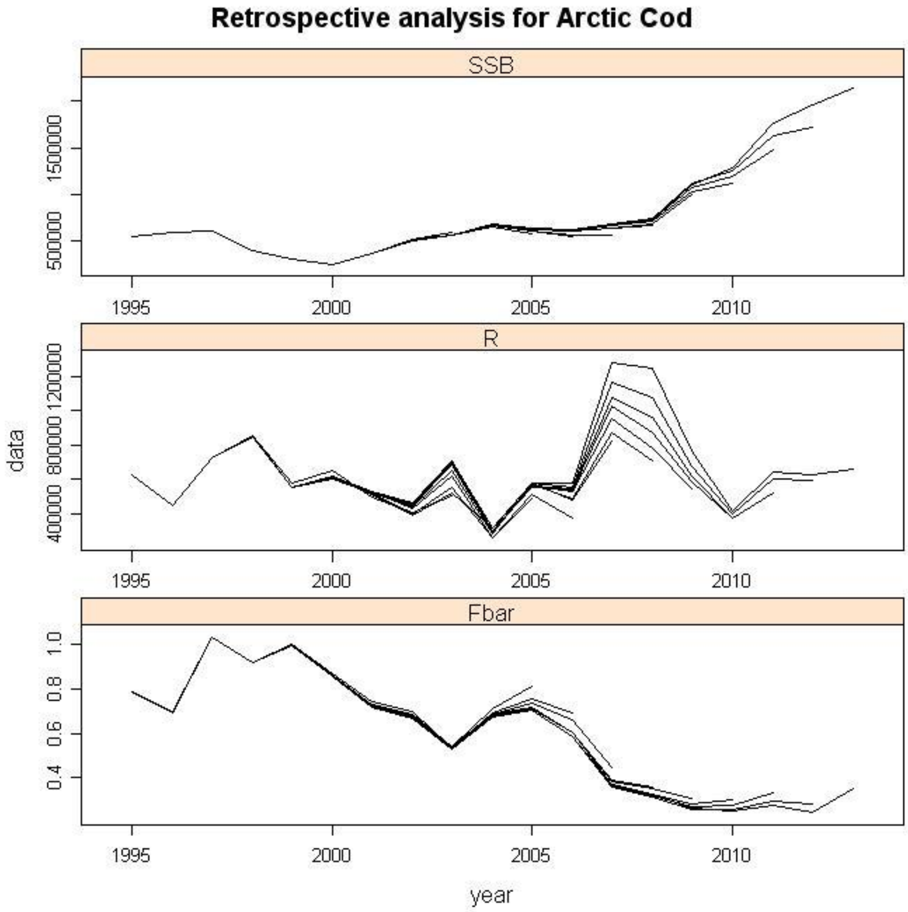


Figure 3.2b. NEA cod SSB, R and Fbar retrospective patterns for final XSA run settings.

Catchability dependent of stock size for ages less than 10

AFWG-2015 just after benchmark

XSA settings (Figures 3.2a-b, Table 3.14)

The output tables from the tuning include ages 1 and 2, just to show the year class abundance at age 1 and 2 created by the cannibalism numbers (Section 3.4.2). These age groups are not included in the tuning and in final assessment, however.

Survey indices for Fleet 15 and 16 have been multiplied by a factor 10. This was done to keep the dynamics of the surveys even for very low indices, because XSA adds 1.0 to the indices before the logarithm is taken.

During the benchmark meeting it was decided not to use shrinkage to mean abundance of population at the same age in previous years (p – shrinkage) as it may introduce an essential bias in assessment at period of intensive stock dynamic. It was also concluded to increase F shrinkage s.e. (decrease F shrinkage influence) for the same reason.

The final XSA was run using the following (adopted by the last benchmark) settings:

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 NOT shrunk towards the population mean

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

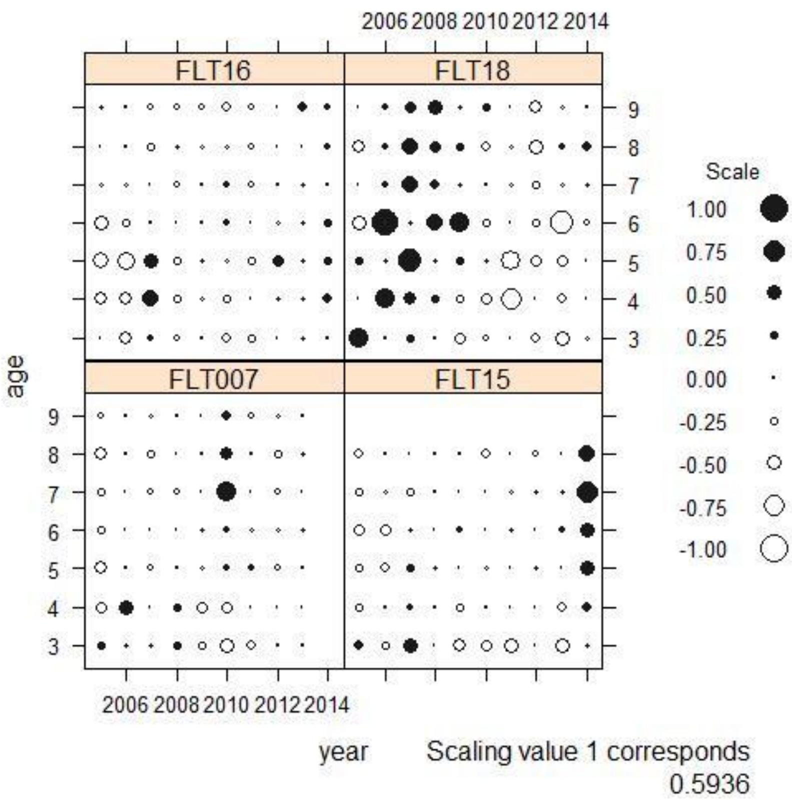


Figure 3.2a. Log catchability residuals by fleets for the tuning data used in final XSA run.

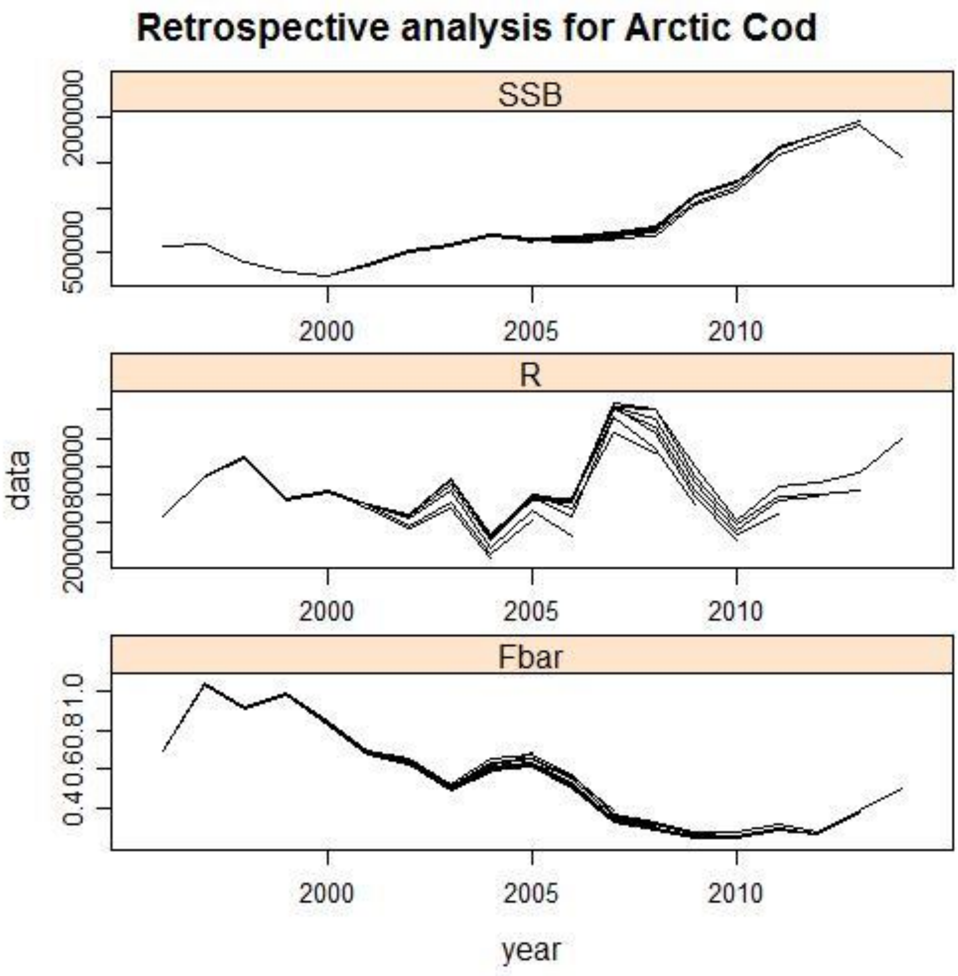


Figure 3.2b. NEA cod SSB, R and Fbar retrospective patterns for final XSA run settings.

Catchability independent of stock size for ages >9

Fleet 09 (CPUE from Russian commercial) excluded

Fleet 007 (ecosystem survey) added

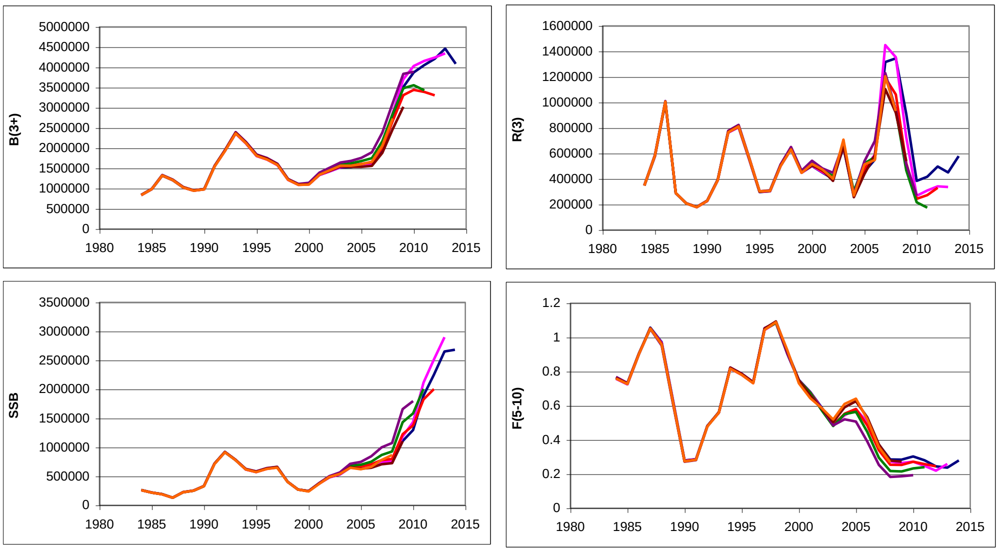


Fig. 3.11. NEA cod TSB, R, SSB and Fbar retrospective patterns from TISVPA runs

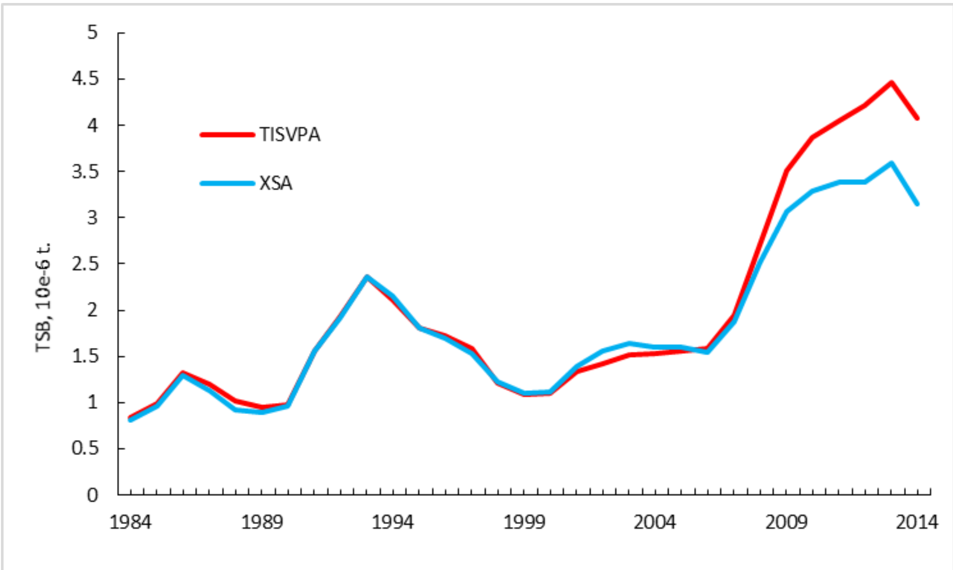


Fig. 3.14. NEA cod. Comparison of total stock biomass dynamic assessed by XSA and TISVPA.

AFWG-2016

XSA settings (Figures 3.2a-b, Table 3.14)

The output tables from the tuning include ages 1 and 2, just to show the year class abundance at age 1 and 2 created by the cannibalism numbers (Section 3.4.2). These age groups are not included in the tuning and in final assessment, however.

Survey indices for Fleet 15 have been multiplied by a factor 100, while survey indices for Fleets 007, 16 and 18 have been multiplied by a factor 10. This was done to keep the dynamics of the surveys even for very low indices, because XSA adds 1.0 to the indices before the logarithm is taken.

The final XSA was run using the following (adopted by the last benchmark) settings:

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 NOT shrunk towards the population mean

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

Although the age range for tuning fleets was increased, it was decided not to increase the age range for 'Catchability independent of stock size' accordingly.

XSA tuning diagnostics (Table 3.14, Figure 3.2a, b, 3.3)

The tuning diagnostics from XSA with cannibalism are given in Table 3.14.

Figure 3.2a shows the log catchability residuals of the tuning series, with corresponding residuals for two runs. One with same data series and parameters as used in last AFWG, while another corresponds to final run with extended age range in tuning series (see text table above). The general pattern of residuals distribution is very close to the one observed in previous year's meetings. The level of residuals in the final run is visibly higher than in the run with fewer ages included in tuning. It is not surprise that adding more time series in tuning increases discrepancy between surveys. The maximum residual from SALY assessment was 0.77, while in the final run matrix it was 1.18.

On the other hand, the information about current abundance of year classes 2004 and 2005 is very important to include in assessment. From the residual pattern it is seen that there are conflict between assessment of year class strengths taken from oldest ages and younger ones. Partly this could be explained by different assumptions about q (linear relationships for oldest age and power for ages 3-9), but it is very likely that the difference also is caused by better survival of those generations as indicated by data from recent years. It should also be noted that extending the tuning age range gave a relatively flat exploitation pattern for the older ages, in line with what has been observed in previous years, while keeping the previous tuning age range gave a fishing pattern in 2015 with a strong peak for the abundant 2004 and 2005 year classes. It is not very likely that the exploitation pattern has changed considerably from 2014 to 2015 (Figure 3.15). Possible changes in natural mortality (see e.g. Bogstad, WD 01 WKARCT 2015, Sunnanå, 2016) could also be the reason for the observed retro pattern (Figure 3.2b) as such changes are not accounted for in the XSA model. Furthermore, the model based on the previous settings suggests that the stock of large fish was heavily depleted in 2015. This is not in accordance with available data on survey abundances at the oldest ages (added in the final run) and the knowledge about the fishery in the early part of 2016 (which is not included in the tuning).

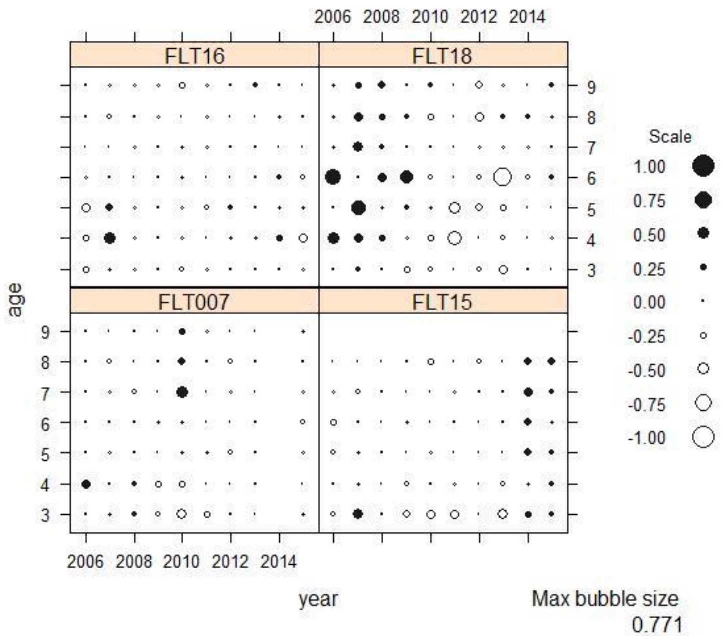
Figure 3.3 compares the estimated survivors (by end of 2015) and Fs in single fleet tunings. The single fleet runs apply the same XSA settings as the final run. The difference in survivors' estimates from single fleet runs for younger ages are rather big between fleets (more than 50%). Fleet 15 gives most optimistic estimates of survivors' abundance. This could be expected from fleet residuals diagnostic of final run as well. The final XSA run including all fleets tends to give intermediate estimates of survivors at all ages compared to single fleet runs. Single fleet tunings diagnostic results are similar to the last year. The big difference between final run and single fleet runs is explained by influence of F shrinkage. The numbers of survivors at ages 7—10 are pretty close to each other in final run, but the same estimates provided by F shrinkage are almost two times higher. Such a discrepancy creates the effect observed in Figure 3.3 as all fleets gives more accurate estimates compare to each single fleet runs where influence of shrinkage becomes more visible irrespective to very low weight of shrinkage (in general less than 1 %).

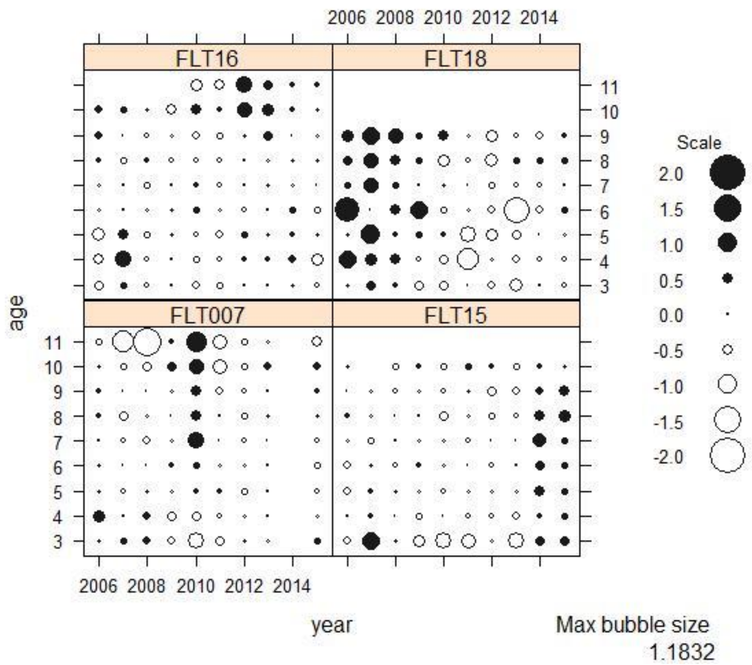
Retrospective plots of F, SSB and recruitment, going back to 2003, are shown in Figure 3.2b. Cannibalism is taken into account, but the number of cod consumed by cod was not recalculated year by year in the retrospective analysis. The retrospective pattern was satisfactory and much better since changes in the XSA model done by benchmark. It is seen in SALY run. The inclusion of new data for tuning (older ages) led to a situation observed previously (before the benchmark in 2015) – the model demonstrates a clear tendency to overestimate F and underestimate biomass in the most recent years. The biggest difference concerns the dynamic of the strong year classes 2004-2005. Their abundance has been adjusted upwards in each year's assessment. One possible explanation could be a different (better) survival of these generations compared to model assumption.

Fig 3.14 shows a comparison of the XSA assessments with and without extension of age range in comparison with the TISVPA results.

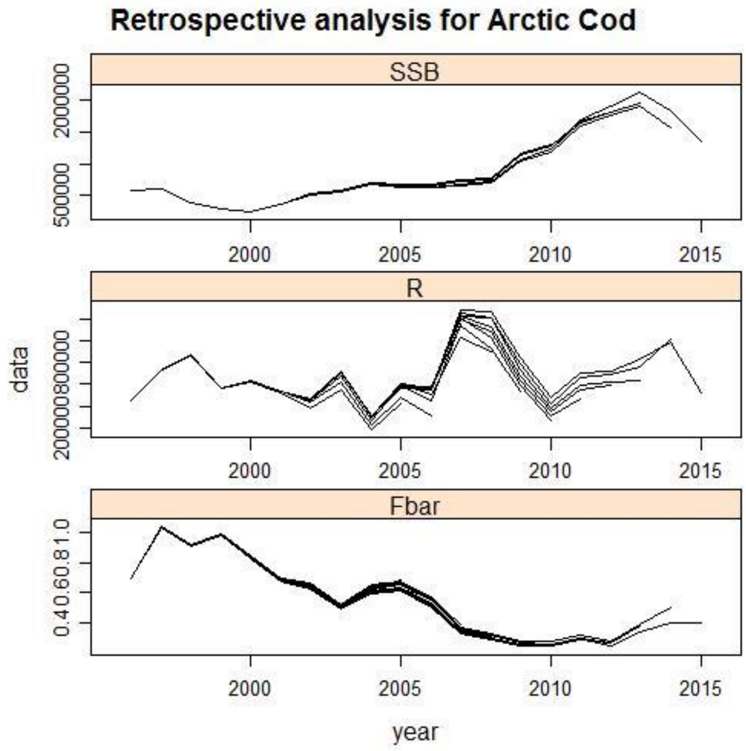
The table below shows a comparison of the XSA assessments with and without extension of age range (SALY run and Final run) for the year 2015. It is seen that including oldest ages in tuning mainly influence on those ages while changes in younger ages are rather small.

		N(2015)											
Assessment year (specification)	F(2014)	age3	age4	age5	age6	age7	age8	age9	age10	age11	TSB (2015)	SSB (2015)	F (2015)
2016 WG SALY run	0.396	514	631	390	265	149	70	71	50	26	3206	1383	0.386
2016 WG Final run	0.28	549	733	437	287	164	76	99	97	54	4242	2193	0.269
Ratio 2016 WG F/ 2016 WG SALY	0.71	1.07	1.16	1.12	1.08	1.10	1.09	1.38	1.96	2.08	1.32	1.58	0.70





3 **Figure 3.2a. Log catchability residuals by fleets for the tuning data used in the final XSArun (bottom figure) and SALY XSA run (upper figure).**



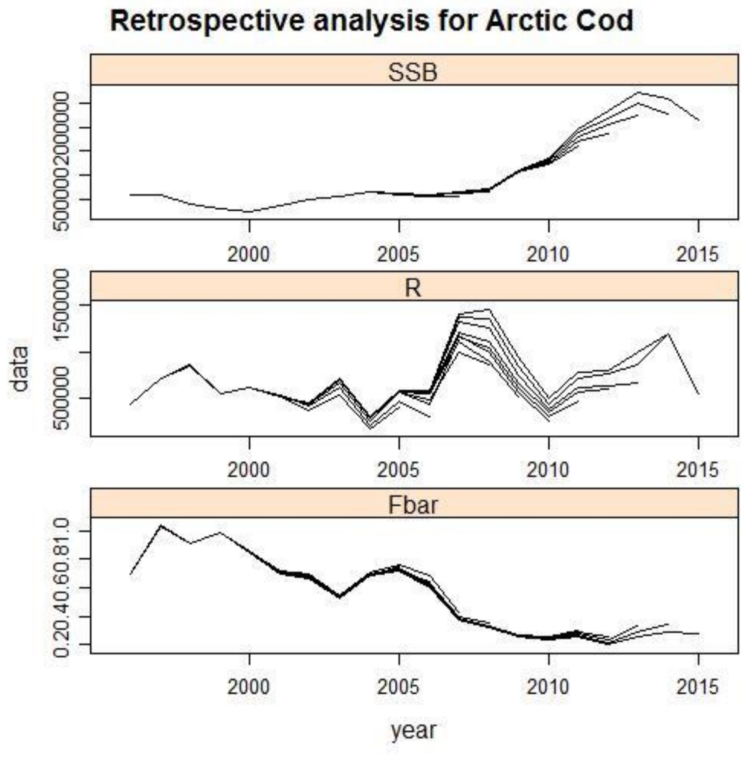


Figure 3.2b. NEA cod SSB, R and Fbar retrospective pattern for final XSA run settings (bottom figure) and SALY XSA run (upper figure).

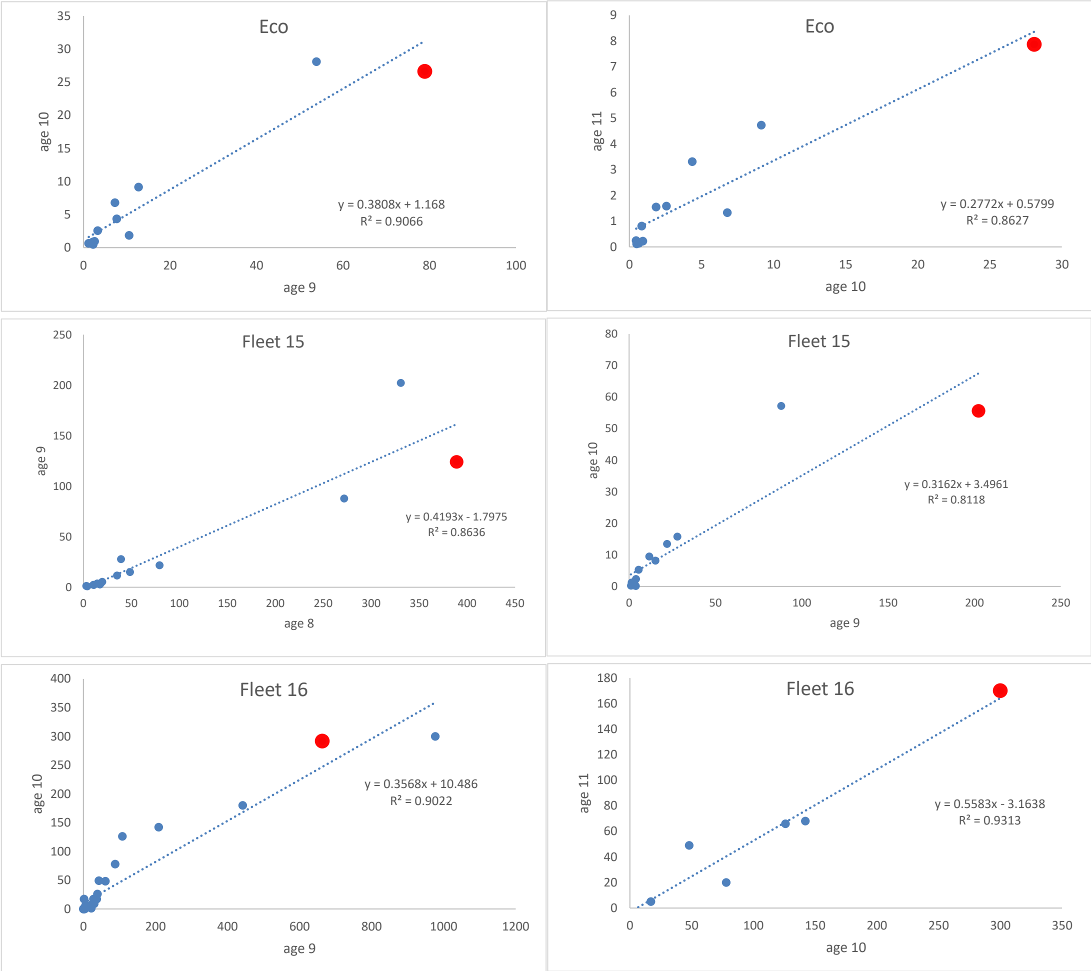


Figure 3.3a. Internal consistency of tuning fleets in oldest available age groups (red points represent the last year observation).

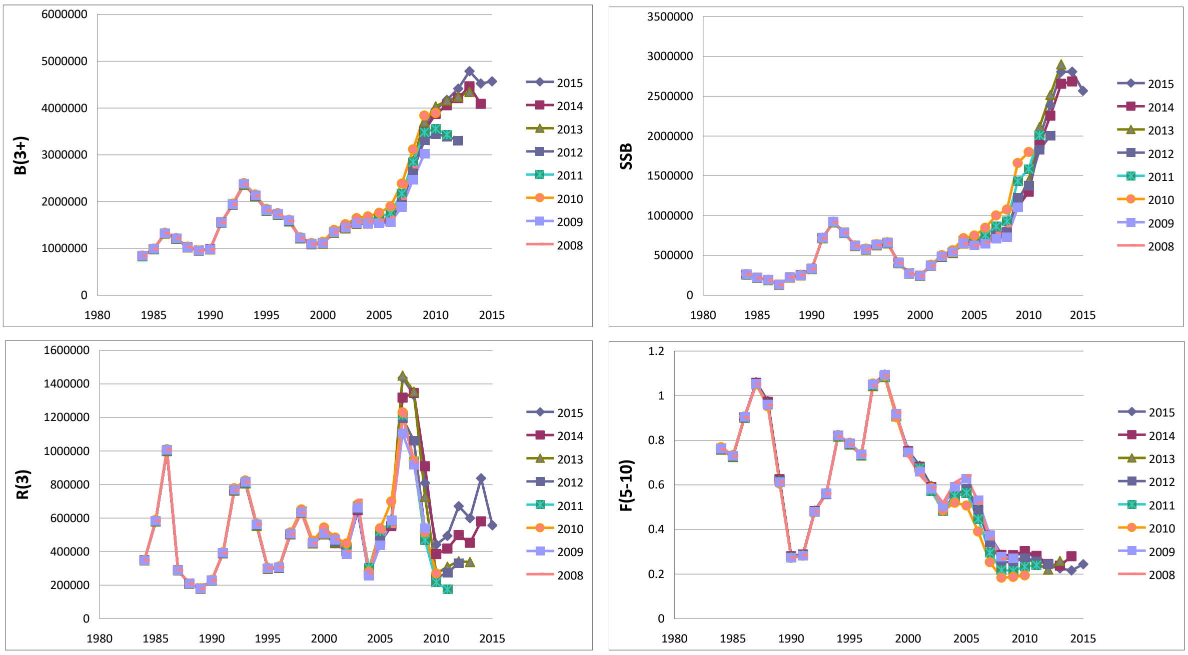


Figure 3.11. TISVPA retrospective runs

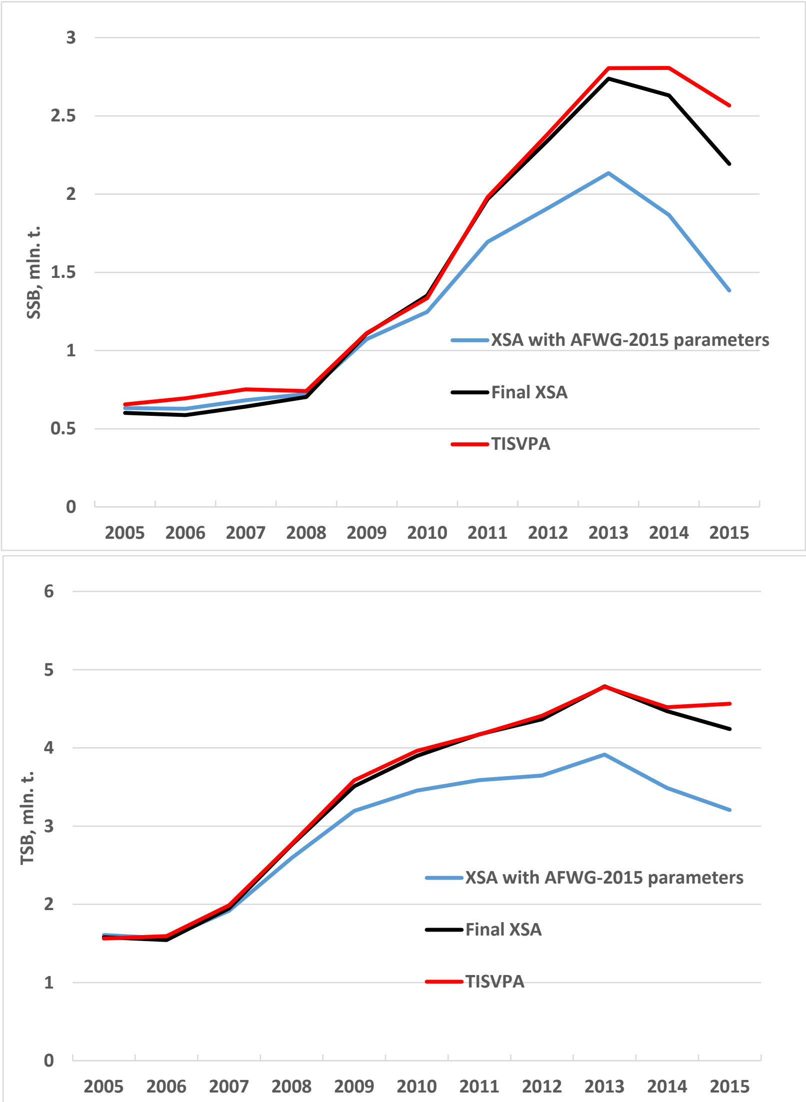


Fig. 3.14. NEA cod. Comparison of total stock biomass (bottom panel) and SSB (upper panel) dynamics assessed by XSA with SALY settings and this year final setting versus TISVPA results.

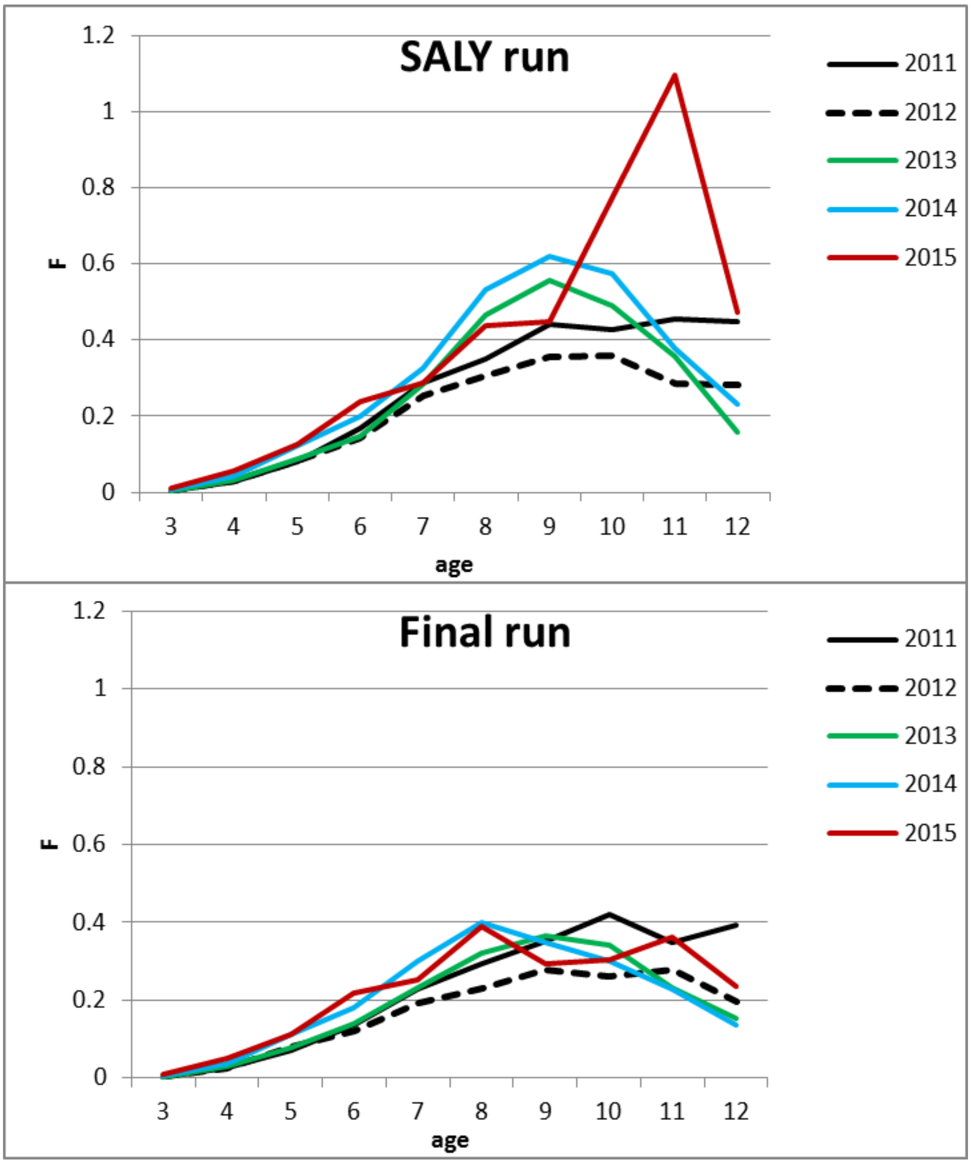


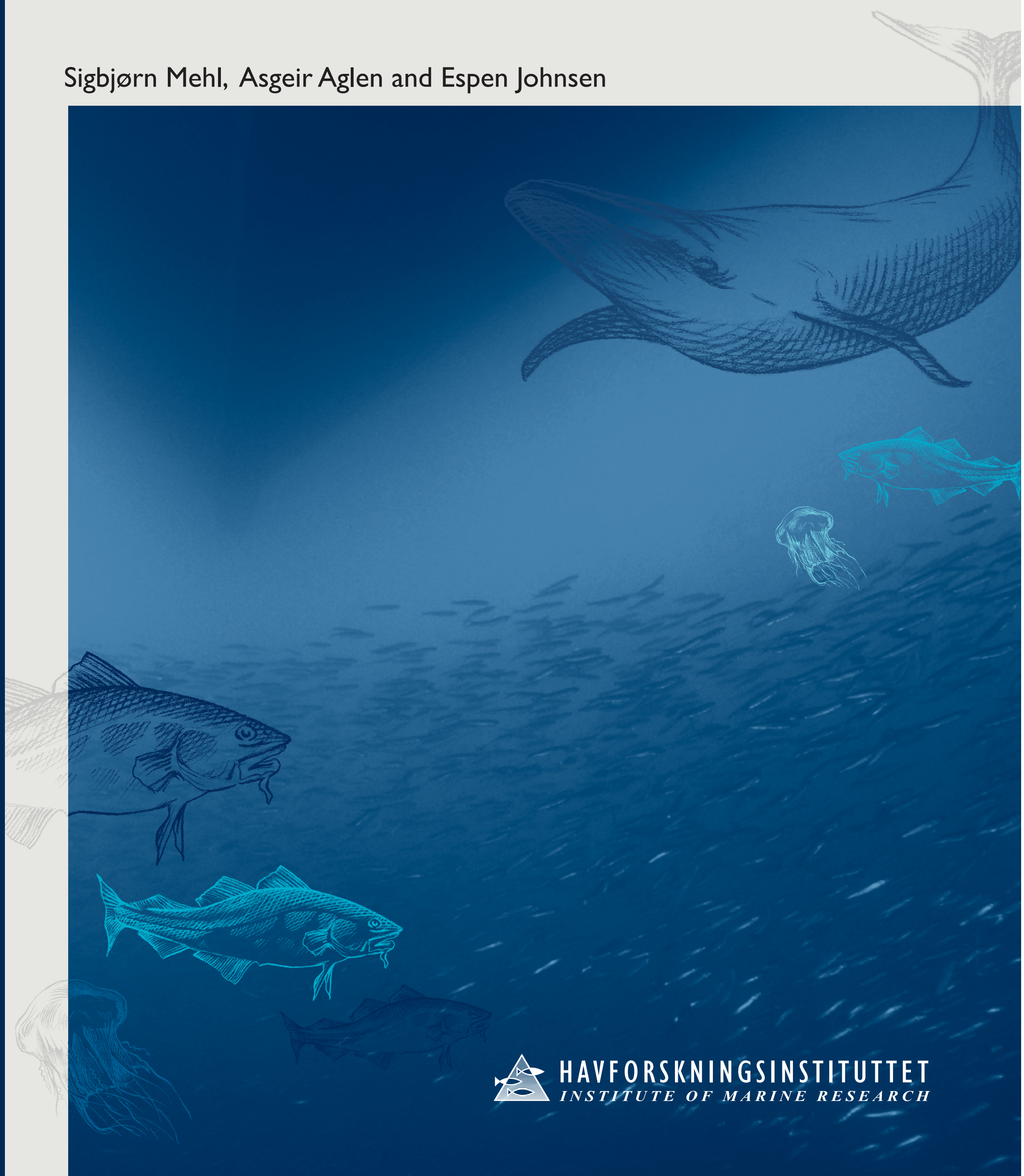
Figure 3.15. NEA cod. Fishing mortality at age in 2011-2015 derived from SALY run (with the previous year age range in tuning fleets) and Final run (with extended age range in tuning fleets used in this year assessment)

FISKEN OG HAVET

nr. 10/2016

Re-estimation of swept area indices with CVs for main demersal fish species in the Barents Sea winter survey 1994 – 2016 applying the Sea2Data StoX software

Sigbjørn Mehl, Asgeir Aglen and Espen Johnsen



Re-estimation of swept area indices with CVs for main demersal fish species in the Barents Sea winter survey 1994 – 2016 applying the Sea2Data StoX software

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CONTENTS

1 Background

The new Sea2Data software StoX was applied to re-estimate swept area indices with CVs for cod, haddock, golden redfish, beaked redfish, Norway redfish, Greenland halibut and blue whiting. Length and weight at age was also re-estimated for cod and haddock. The main difference between the SAS based Survey Program presently used and StoX swept area estimation is in the use of the age-length data. StoX does not use age-length keys (ALK) in the traditional sense with ALKs estimated for large areas. Missing age information is imputed from known age-length data within station. If age information is still missing StoX searches within strata, or lastly within all strata. If no age is available for a length group, the abundance estimate is presented as unknown age. StoX does also allow for uncertainty estimation by bootstrapping primary sampling units (PSUs).

The Institute of Marine Research (IMR), Bergen, has performed acoustic measurements of demersal fish in the Barents Sea since 1976, and in 1981 a bottom trawl survey was combined with the acoustic survey. From 1981 to 1992 the survey area was fixed (strata 1-12, Main Areas ABCD in Fig. 2.1). Due to warmer climate and an increasing cod stock in the early 1990s, the distribution area increased. The survey area was extended towards north and east, beginning in 1993 and continuing in 1994 (strata 13-23, Main Areas D'ES in Fig. 2.1). This should allow for a more complete coverage of younger age groups of cod, and since 1994 the survey has aimed at covering the whole cod distribution area in open water. For the same reason the survey area was extended further northwards in the western part in 2014 (strata 24-26 in Fig. 2.1).

In many years since 1997 Norwegian research vessels have had limited access to the Russian EEZ, and in 1997, 1998, 2007 and 2016 the vessels were not allowed to work in the Russian EEZ. In 1999 the coverage was partly limited by a rather unusually wide ice-extension. Since 2000, except in 2006 and 2007, Russian research vessels have participated in the survey and the coverage has been better, but for various reasons not complete in most years. In 2008-2015 Norwegian vessels had access to major parts of the Russian EEZ. The coverage was more complete in these years, especially in 2008, 2011 and 2014. In 2009, 2010, 2012, 2013 and 2015 the coverage in eastern areas was more limited due to strict rules regarding handling of the catch, bad weather or vessel problems. Table 2.4 presents further comments to the annual coverages. The annual survey reports (Annex I) presents survey tracks and trawl stations.

2 Material and Methods

2.1 Survey operation and data sampled

Table 2.1 presents the vessels participating in the survey in 1994-2016 with some basic trawl information. Catch data and biological samples from the Russian vessels were first converted to the IMR SPD-format, and then exported as xml-files from the NMDbiotic data base. The column with number of trawl stations includes both valid swept area hauls, other bottom trawl hauls and pelagic trawl hauls.

Table 2.1. Sea2Data cruise number, start and end data, serial numbers, number of trawl stations and valid swept area hauls for Norwegian and Russian vessel participation in the Barents Sea winter survey in 1994-2016.

Year	**Vessel**	**Cruice number**	**Start**	**End**	**Serial number**		**No. trawl stations**	**Valid swept area hauls**
					From	To		
1994	Johan Hjort	1994202	21.01	06.03	80001	80161	161	284
	G.O. Sars	1994002	01.02	10.03	80301	80404	104	
	Anny Kræmer	1994001	01.02	01.03	80501	80663	163	
1995	G.O. Sars	1995901	28.01	27.02	80001	80146	146	298
	Johan Hjort	1995901	01.02	02.03	80201	80360	160	
	Jan Mayen	1995901	01.02	23.02	80401	80529	129	
1996	G.O. Sars	1996901	06.02	05.03	80001	80129	129	312
	Johan Hjort	1996901	06.02	02.03	80201	80337	137	
	Jan Mayen	1996901	05.02	29.02	80401	80527	127	
1997	G.O. Sars	1997901	06.02	04.03	80001	80075	75	167
	Johan Hjort	1997901	06.02	01.03	80201	80322	122	
	Jan Mayen	1997901	03.02	27.02	80401	80498	98	
1998	G.O. Sars	1998002	31.01	27.02	80001	80096	96	200
	Johan Hjort	1998202	31.01	01.03	80201	80286	86	
	Jan Mayen	1998825	31.01	24.02	80401	80477	77	
1999	G.O. Sars	1999002	27.01	27.02	80001	80144	144	223
	Johan Hjort	1999203	27.01	22.02	80201	80321	121	
2000	G.O. Sars	2000002	29.01	24.02	80001	80167	167	313
	Johan Hjort	2002202	01.02	29.02	80201	80333	133	
	Varegg	2000805	28.01	28.02	80401	80556	156	
	Persey-3	0119-2000	06.02	11.02	70701	70716	16	
2001	G.O. Sars	2001002	27.01	07.03	80001	80193	193	349
	Johan Hjort	2001202	20.01	28.02	80201	80375	175	
	Persey-4	0079-2001	01.02	21.02	70701	70739	39	
2002	G.O. Sars	2002002	30.01	02.03	80001	80165	165	392
	Johan Hjort	2002203	29.01	04.03	80201	80364	164	
	Persey-3	0083-2002	29.01	27.02	70701	70829	129	
2003	G.O. Sars	2003002	27.01	05.03	80001	80164	164	312
	Johan Hjort	2003202	27.01	05.03	80301	80450	150	
	Percey-3	0085-2003	30.01	26.02	70701	70833	133	
2004	Johan Hjort	2004203	31.01	14.03	70001	70256	256	355
	G.O. Sars	2004106	31.01	15.03	70301	70471	171	
	Smolensk	0090-2004	23.02	12.03	70701	70790	90	
2005	Johan Hjort	2005203	01.02	15.03	70001	70203	203	370
	G.O. Sars	2005104	01.02	07.03	70303	70475	173	
	Smolensk	0091-2005	08.02	04.03	70701	70815	115	
2006	Johan Hjort	2006203	01.02	15.03	70001	70182	182	271
	G.O. Sars	2006103	01.02	09.03	70251	70424	173	

2007	Johan Hjort G.O. Sars	2007203 2007103	01.02 07.02	15.03 14.03	70001 70301	70181 70464	181 164	258
Year	**Vessel**	**Cruice number**	**Start**	**End**	**Serial number**		**No.trawl stations**	**Valid swept area hauls**
					From	To		
2008	Johan Hjort Jan Mayen Fridtjof Nansen Smolensk	2008202 2008701 0101-2008 0102-2008	01.02 01.02 04.02 25.01	14.03 06.03 05.03 13.02	70001 70301 70501 70701	70174 70471 70591 70745	174 171 91 45	345
2009	Johan Hjort Jan Mayen Fridtjof Nansen Vilnyus	2009202 2009701 0104-2009 0121-2009	06.02 01.02 02.02 26.02	13.03 08.03 05.03 13.03	70001 70301 70501 70701	70152 70474 70537 70744	152 174 37 44	331
2010	Johan Hjort Jan Mayen Fridtjof Nansen	2010202 2010701 0122-2010	04.02 01.02 26.02	17.03 05.03 11.03	70001 70301 70501	70159 70480 70564	159 180 64	349
2011	Johan Hjort Jan Mayen Fridtjof Nansen	2011202 2011702 0108-2011	03.02 01.02 02.02	14.03 01.03 19.02	70001 70301 70501	70154 70486 70585	154 186 85	381
2012	Helmer Hansen Libas Fridtjof Nansen	2012839 2012841 0111-2012	22.01 19.02 03.02	21.02 15.03 18.02	70301 70001 70501	70473 70073 70573	173 73 73	284
2013	Johan Hjort Vilnyus	2013201 0113-2013	31.01 07.02	13.03 08.03	70001 70701	70187 70828	187 128	295
2014	Johan Hjort Helmer Hansen Fridtjof Nansen	2014202 2014805 0114-2014	31.01 22.01 29.01	16.03 02.03 17.02	70001 70301 1	70196 70490 113	196 190 113	404
2015	Johan Hjort Helmer Hansen Fridtjof Nansen	2015202 2015841 0120-2015	27.01 20.01 22.02	14.03 16.02 03.03	70001 70301 70501	70221 70431 70538	221 131 38	292
2016	Johan Hjort Helmer Hansen Fridtjof Nansen	2016202 2016846	24.01 25.01 05.02	16.03 08.02 26.02	70001 70301 1	70283 70377 101	283 177 101	341

Table 2.2 gives an account of the sampled length- and age material from all trawl hauls. Table 2.3 gives the area covered by the survey every year since 1994, while Table 2.4 summarizes the coverage and main reasons for incomplete coverage in the whole period.

Table 2.2. Number of fish measured for length (L) and age (A) in the Barents Sea winter survey 1994-2016.

	Cod		Haddock		Golden redfish	Beaked redfish	Greenland halibut	Blue whiting
Year	**L**	**A**	**L**	**A**	**L**	**L**	**L**	**L**
1994	57290	3400	40608	1808	3157	12389	525	
1995	66264	3547	37775	1692	3785	9622	583	
1996	61559	3304	34497	1416	2510	10206	587	
1997	35381	2381	30054	1003	5429	10997	675	
1998	39044	2843	12512	859	1739	9664	649	
1999	22971	2321	12752	926	1266	6677	397	
2000	31543	2871	25881	1426	1161	8739	546	
2001	36789	2998	30921	1657	1173	7323	499	
2002	45399	3730	58464	2057	1143	6660	688	
2003	59573	2857	54838	1883	1102	4654	657	
2004	40851	3175	51705	1874	1438	5507	459	
2005	33582	3216	67921	2060	835	5166	832	
2006	19319	2683	23611	1899	728	3356	962	
2007	16556	2954	26610	2023	798	4544	973	4657
2008	26844	3809	50195	2490	897	8568	1020	1350
2009	22528	3486	40872	2433	455	9205	807	891
2010	30209	4085	35881	2367	429	8564	984	626
2011	26913	3959	29180	2260	286	6885	607	105
2012	17139	3020	33524	1854	574	5721	354	2441
2013	14525	2451	19142	1671	479	6087	263	1091
2014	22624	4501	35940	2586	563	9310	444	1846
2015	25401	3795	18483	2038	395	8933	541	1991
2016	16636	3368	25423	2067	614	8668	425	2396

Table 2.3. Area (NM²) covered (StoX estimates) in the bottom trawl surveys in the Barents Sea winter 1994-2016

	Main Area									Added
Year	**A**	**B**	**C**	**D**	**D'**	**E**	**S**	**N**	**Total**	**area**
1994	27180	9854	5165	53394	36543	11417	17557		161110	
1995	26797	9854	5165	53394	58605	13304	24783		191904	
1996	26182	9854	5165	53394	54047	5738	11809		166190	
1997[1]	27785	9854	5165	23964	2670	0	18932		88371	56200
1998[1]	27785	9854	5165	23964	5911	3829	23931		100440	51100
1999	27785	9854	5165	43230	8031	5742	18737		118545	
2000	27173	9854	5165	52314	29438	14207	25053		163204	
2001	26609	9854	5165	53394	29694	15777	24157		164652	
2002	26594	9854	5165	53394	21914	15757	24689		157369	
2003	26621	9897	5165	52072	23947	6259	23400		147361	
2004	27785	9854	5165	53394	42731	4739	20760		164428	
2005	27785	9854	5165	53394	39104	19931	24648		179883	
2006[2]	27785	9854	5165	53394	35302	13872	24691		170064	18100
2007[1]	27785	9854	5165	23911	8498	20822	27858		123894	56700
2008	27785	9854	5165	53394	23792	18873	26313		165176	
2009	27785	9854	5165	53394	31978	15739	27858		171774	
2010	27785	9854	5165	53394	17882	18562	27858		160501	
2011	27785	9854	5165	53394	33432	16835	27858		174324	
2012[2]	27785	9854	5165	53394	9917	17289	27858		151263	16700
2013	27785	9854	5165	53394	58183	21118	27858		203358	
2014[3]	27785	9854	5165	53394	54800	29897	27858	58048	208754	
2015[3]	27785	9854	5165	53394	45449	26541	27858	47263	196047	
2016[3]	27785	9854	5165	53526	29266	20342	27630	54387	173568	

[1]REZ not covered, [2]REZ (Murman coast and Area D' in 2006 and Area D' in 2012 not completely covered

[3] Additional northern areas (N) covered, not included in total and survey index calculations.

Table 2.4. Barents Sea winter surveys 1981-2016. Main Areas covered, and comments on incomplete coverage.

Year	Main Areas covered	Comments
1981-1992	ABCD	
1993-1996	ABCDD'ES	
1997	Norwegian EEZ (NEZ), S	Not allowed access to Russian EEZ (REZ)
1998	NEZ, S, minor part of REZ	Not allowed access to most of REZ
1999	ABCDD'ES	Partly limited coverage due to westerly ice extension
2000	ABCDD'ES	
2001-2005	ABCDD'ES	Russian vessel covered where Norwegians had no access
2006	ABCDD'ES	Not access to Murman coast, no Russian vessel
2007	NEZ, S	Not allowed access to REZ, no Russian vessel
2008	ABCDD'ES	Russian vessel covered where Norwegians had no access
2009	ABCDD'ES	Reduced Norwegian coverage of REZ due to catch handling
2010	ABCDD'ES	Reduced Norwegian coverage of REZ due to bad weather
2011	ABCDD'ES	Russian vessel covered where Norwegians had no access
2012	ABCDD'ES	No Norwegian coverage of REZ due to vessel problems
2013	ABCDD'ES	No Norwegian coverage of REZ due to vessel shortage
2014	ABCDD'ESN	Strata 24-26 (N) covered for the first time
2015	ABCDD'ESN	Slightly reduced/more open coverage due to bad weather
2016	ABCDD'ESN	No access to REZ, Russian vessel covered most of REZ

2.2 Swept area measurements

All vessels were equipped with the standard research bottom trawl Campelen 1800 shrimp trawl with 80 mm (stretched) mesh size in the front. Prior to 1994 a cod-end with 35-40 mm (stretched) mesh size and a cover net with 70 mm mesh size were mostly used. Since this mesh size may lead to considerable escapement of 1-year-old cod, the cod-ends were in 1994 replaced by cod-ends with 22 mm mesh size. At present a cover net with 116 mm meshes is mostly used.

The trawl is now equipped with a rockhopper ground gear (Engås and Godø 1989). Until and including 1988 a bobbins gear was used, and the cod and haddock indices from the time period 1981-1988 have since been recalculated to ‘rockhopper indices’ and adjusted for length dependent fishing efficiency and/or sweep width (Godø and Sunnanå 1992, Aglen and Nakken 1997). The sweep wire length is 40 m, plus 12 m wire for connection to the doors.

In the Norwegian Barents Sea shrimp survey (Aschan and Sunnanå 1997) the Campelen trawl has been rigged with some extra floats (45 along the ground rope and 18 along the under belly and trunk, all with 20mm diameter) to reduce problems on very soft bottom. This rigging has been referred to as “Tromsø rigging”. When the shrimp survey was terminated 2004 and later merged with the Barents Sea Ecosystem survey in 2005, improved shrimp data were also requested from the winter survey, and the “Tromsø rigging” was used in parts of the shrimp areas in 2004 (11 stations) and 2005 (9 stations). In 2006-2014 “Tromsø rigging” was used for nearly all bottom trawl stations taken by Norwegian vessels in the winter survey, while since 2015 “Tromsø rigging” has not been applied.

Vaco doors (6 m^2, 1500kg), were previously standard trawl doors on board the Norwegian research vessels. On the Russian vessels and hired vessels V-type doors (ca 7 m^2) have been used. In 2004, R/V “Johan Hjort” and “G.O. Sars” changed to a V-type door (Steinshamn W-9, 7.1m^2, 2050 kg), the same type as used on the Russian research vessels. In 2010 the V-doors were replaced by 125” Thyborøn trawl doors. R/V “Helmer Hanssen” has used Thyborøn trawl doors since the 2008 survey. In order to achieve constant sampling width of a trawl haul independent of e.g. depth and wire length, a 10-14 m rope “locks” the distance between the trawl wires 80-150 m in front of the trawl doors on the Norwegian vessels. This is called “strapping”. The distance between the trawl doors is then in most hauls restricted to the range 48-52 m regardless of depth (Engås and Ona 1993, Engås 1995). Strapping was first attempted in the 1993 survey on board one vessel, in 1994 it was used on every third haul and in 1995-1997 on every second haul on all vessels. Since 1998 it has been used on all hauls when weather conditions permitted. Strapping is not applied on the Russians vessels, but the normal distance between the doors is about 50 m (D. Prozorkevich, pers. comm.).

Standard tow duration is now 15 minutes (until 1985 the tow duration was 60 minutes and from 1986 to 2010 30 minutes). Trawl performance is constantly monitored by Scanmar trawl sensors, i.e., distance between the doors, vertical opening of the trawl and bottom contact control. In 2005-2008 sensors monitoring the roll and pitch angle of the doors were used due to problems with the Steinshamn W-9 doors. The data is logged on files, but have so far not been used for further evaluation of the quality of the trawl hauls.

The positions of the trawl stations are pre-defined. When the swept area investigations started in 1981 the survey area was divided into four Main Areas (A, B, C and D, Fig 2.1) and 35 strata. During the first years the number of trawl stations in each stratum was set based on expected fish distribution in order to reduce the variance, i.e., more hauls in strata where high and variable fish densities were expected to occur. Since the 1990s trawl stations have been spread out more evenly, yet the distance between stations in the most important cod strata is shorter (16 or 20 NM) compared to the less important strata (24, 30 or 32 NM). During the 1990s considerable amounts of young cod were distributed outside the initial four Main Areas, and in 1993 the investigated area was therefore enlarged by areas D', E, and the ice-free part of Svalbard (S) (Fig. 2.1 and Table 3.5), 28 strata altogether. In the 1993-1994 survey reports, the Svalbard area was included in area A' and the western (west of 30°E) part of area E. Since 1996 a revised strata system with 23 strata has been used (Figure 2.1). The main reason for reducing the number of strata was the need for a sufficient number of trawl stations in each stratum to get reliable estimates of density and variance. In later years a few pre-defined trawl stations have been performed north of the strata system due to increased abundance of cod in these areas, and in 2014 the investigated area was enlarged by three new strata in northwest, 24-26 (Main Area N, Fig. 2.1). However, the data are so far not included in the estimation of standard abundance indices used in the assessments.

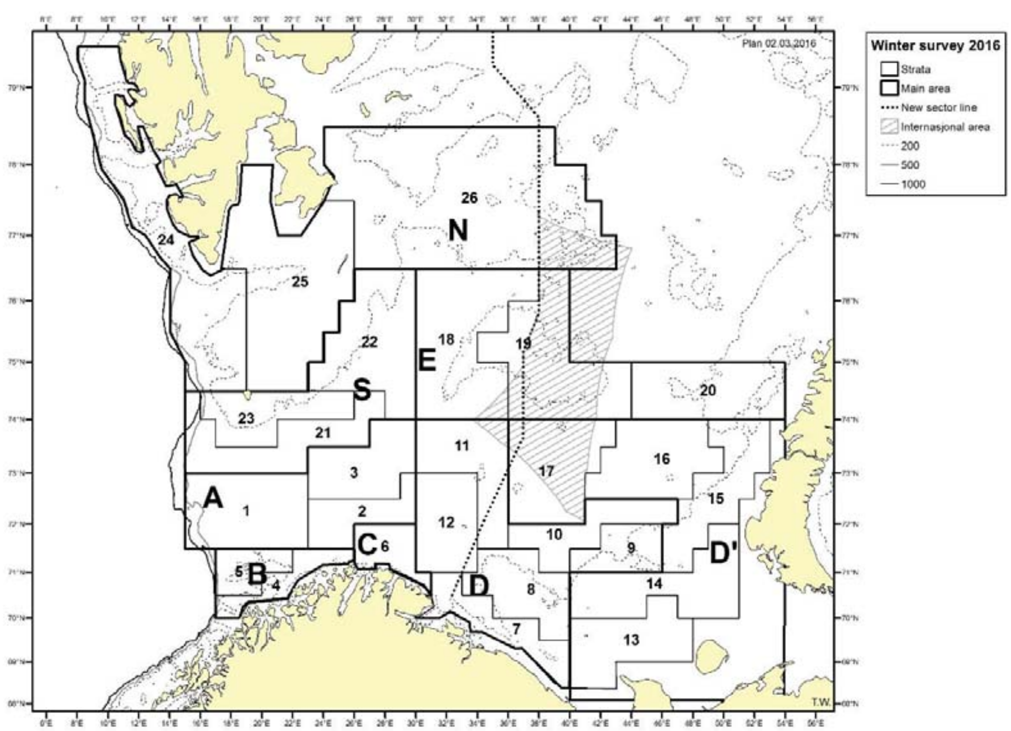

Figure 2.1. Strata (1-23) and Main Areas (A,B,C,D,D',E and S) used for swept area estimations and acoustic estimations with StoX. The Main Areas are also used for acoustic estimations with BEAM. Additional strata (24-26, Main Area N) are covered since 2014, but not included in the full time series.

Swept area fish density estimation

Swept area fish density estimates ($\rho_{s,l}$) by species (s) and length (l) were estimated for each bottom trawl haul by the equation:

$$\rho_{s,l} = \frac{f_{s,l}}{a_{s,l}}$$

$\rho_{s,l}$ number of fish of length l per n.m.^{2} observed on trawl station s

$f_{s,l}$ estimated frequency of length l

$a_{s,l}$ swept area:

$$a_{s,l} = \frac{d_s \cdot EW_l}{1852}$$

d_s towed distance (nm)

EW_l length dependent effective fishing width:

$$EW_l = \alpha \cdot l^{\beta} \text{ for } l_{\min} < l < l_{\max}$$

$$EW_l = EW_{l_{\min}} = \alpha \cdot l_{\min}^{\beta} \text{ for } l \le l_{\min}$$

$$EW_l = EW_{l_{\max}} = \alpha \cdot l_{\max}^{\beta} \text{ for } l \ge l_{\max}$$

The parameters are given in the text table below:

Species	$\boldsymbol{\alpha}$	$\boldsymbol{\beta}$	$\boldsymbol{l}_{\min}$	$\boldsymbol{l}_{\max}$
Cod	5.91	0.43	15 cm	62 cm
Haddock	2.08	0.75	15 cm	48 cm

The fishing width was previously fixed to 25 m = 0.0135 nm. Based on Dickson (1993a, b), length dependent effective fishing width for cod and haddock was included in the calculations in 1995 (Korsbrekke *et al*., 1995). Aglen and Nakken (1997) have adjusted both the acoustic and swept area time series back to 1981 for this length dependency based on mean-length-at-age information.

For redfish, Greenland halibut and blue whiting, a fishing width of 25 m was applied, independent of fish length.

2.3 Sampling of catch and use of age-length data

Sorting, weighing, measuring and sampling of the catch are done according to instructions given in Mjanger *et al*. (2016). Since 1999 all data except age are recorded electronically by Scantrol Fishmeter measuring board, connected to stabilized scales. The whole catch or a representative sub sample of most species was length measured on each station.

At each trawl station age (otoliths) and stomachs were sampled from 1 cod per 5 cm length-group. In 2007-2009, all cod above 80 cm were sampled, and in 2010 all above 90 cm, limited to 10 per station. Haddock otoliths were sampled from 1 specimen per 5 cm length-group. Regarding the redfish species *Sebastes norvegicus* and *S. mentella*, otoliths for age determination were sampled from 2 fish in every 5 cm length-group on every station. Table 3.4 gives an account of the sampled material.

The Sea2Data software StoX does not use age-length keys (ALK) in the traditional sense with ALK estimated for large areas. Missing age information is imputed from known age-length data within station. If age information is still missing StoX searches within strata, or lastly within all strata. If no age is available for a length group, the abundance estimate is presented as unknown age.

2.4 Estimation of variance

The swept area survey indices of cod and haddock made with StoX are presented together with an estimate of uncertainty (coefficient of variation; CV). These estimates were made using StoX with a stratified bootstrap routine treating each trawl station as the primary sampling unit, and using 500 iterations. The estimated CV (Standard Deviation · 100/mean) is strongly dependent on the choice of estimator for the indices. A CV of 20 % or less could be viewed as acceptable in a traditional stock assessment approach if the indices are unbiased (conditional on a catchability model). Values above this indicate a highly uncertain index with little information regarding year class strength.

2.5 StoX input, settings and filters

StoX version 2.2 and Rstox 1.4 of 05.10.2016 was used for swept-area, length and weight at age and CV estimations (http://www.imr.no/forskning/prosjekter/stox/en). R for Windows version 3.3.1 was used in the R calls (https://www.r-project.org/).

Biotic XML-files were downloaded from:
http://tomcat7.imr.no:8080/DatasetExplorer/v1/html/main.html.

Under **FilterBiotic** and **FishStationExpr**, the following filters were applied:
gear =~['3270','3271'] and **gearcondition** < 3 and **trawlquality** =~['1','3'] and **fishstationtype** != 2, the latter leaving out trawl experiments, e.g. sea testing (see Mjanger et al. 2016 and Johnsen et al. 2016 for more info about codes and filters).

In **DefineStrata**, **vintertokt_barentshav.txt** was used as basis for strata definition in 1994-2013 and **vintertokt_barentshavny.txt for 2014-2016**. Nodes for strata towards north and east have been adjusted to give the same strata area as used in the SAS based Survey Program software, where these areas were reduced according to coverage and ice border in each year. In no years the difference between the strata areas used in the two programs are larger than 1 %.

In **StratumArea** and **AreaMethod**, **Accurate** was applied.

Under **StationLengthDist** and **LengthDistType**, **NormalLengthDist** was used, and under **RegroupLengthDis**t and **LengthInterval**, **5.0** is applied.

In **SweptAreaDensity** and **FishingWithMethod**, **LengthDependent** was used for cod and haddock with parameters as given above, and **Constant** for the other species, with **FishingWidth** set to **25**.

Under **SuperIndAbundance** and **AbundWeightMethod**, **StationDensity** was used, with **LengthDist** set to **RegroupLengthDist**.

2.6 Raising of indices and adjusting of lengths and weigths

In 1997, 1998 and 2007 only the Norwegian EEZ (REZ) and parts of the Svalbard area (S) was covered. The swept-area indices for cod, haddock, golden redfish, beaked redfish and Greenland halibut has therefore been raised to also represent the Russian EEZ (REZ).

A variable part of the Svalbard area (S) is covered each year due to variable ice extension and insufficient survey time, and the indices for this area have therefore not been included in the raising procedure. For 1997 and 1998 the proportion of fish by age or size group in REZ (≈ strata 7, 8, 9, 10, 13, 14, 15, 16, 17 and 20) relative to the total area covered minus S (≈ strata 21, 22, 23) was estimated by interpolating the proportion of fish in REZ relative to the total area covered minus S in 1996 and 1999, and for 2007 by interpolating the proportion of fish in REZ relative to the total area covered minus S in 2006 and 2008. The indices for REZ was then calculated by multiplying the indices for NEZ (≈ strata 1, 2, 3, 4, 5, 6, 11, 12, 18 and 19) by these proportions, and the total indices were found by adding the indices for NEZ and S.

Length and weight at age of cod and haddock in REZ is often lower than in areas further west, especially for younger age groups, and the observed data on lengths and weights for 1997, 1998 and 2007 have therefore been adjusted. For 1997 the observed mean lengths at age and mean weights at age in NEZ+S (area covered) has been scaled by the observed ratio between values in total area and values in NEZ+S in the 1996 survey. Similarly, for 1998 mean lengths and weights at age have been scaled by the corresponding ratios in the 1999 survey. For 2007 mean lengths and weights at age have been scaled by the corresponding ratios, averaged for the 2006 and 2008 survey.

In 2006 there was not a complete coverage in southeast due to restrictions. The observations in the partially covered strata 7 were extrapolated to the full strata, and the observations in the partially covered strata 13 were extrapolated to the same area as covered in 2005. Due to incomplete coverage in 2012, the cod and haddock swept area estimates within the covered area were raised by the “index ratio by age” observed for the same area in 2008-2011 (ICES 2012) (the scaling factor for estimating adjusted total from <Total –D’> was the average ratio by age for Total/(Total-D’) in the years 2008-2011, Aglen et al. 2012).

3 Results

3.1 Cod

Table 3.1.1 presents swept area abundance indices for cod age groups 1 – 15+, where 15+ is the sum of indices for age groups 15 and older, for the standard area (strata 1-23) in 1994 to 2016, and Table 3.1.2 gives the ratio between new and old indices by age, total index and total biomass. The highest and lowest single index ratio was 3.12 and 0.38, while the highest and lowest average ratio over all age groups in one year was 1.18 and 0.96, and the highest and lowest average ratio for one age group over all years was 1.16 and 0.96. The highest and lowest ratios were mainly found for the years with raising of the indices, i.e. 1997, 1998, 2008 and 2012. The estimation of the proportion of fish in REZ relative to the total area minus Svalbard area in 1996, 1999, 2006 and 2008 was probably done more accurately using StoX, where it is more easy to include or exclude strata. The overall average index ratio was 1.04, the average total index ratio was 1.01 and the average total biomass ratio was 1.02.

Table 3.1.3 presents estimates of coefficients of variation (%) for age groups 1-14. Estimates are based on a stratified bootstrap approach with 500 replicates (with trawl stations being primary sampling unit). A CV of 20 % or less could be viewed as acceptable in a traditional stock assessment approach if the indices are unbiased (conditional on a catchability model). Values above this indicate a highly uncertain index with little information regarding year class strength. In all years CVs for age groups older than 10 years are above what could be considered as acceptable.

Tables 3.1.4 and 3.1.5 present the time series of mean length and mean weight at age for age groups 1-14 in the standard area. Age groups with few observations are marked with " + ", while no observations are marked with " - ". Observed data for 1997, 1998 and 2007 have been adjusted, see above. Since StoX does not use age-length keys (ALK) in the traditional sense with ALK estimated for large areas as done by the Survey Program, there are differences in length and weight at age for some age groups in some years. However, the overall average ratio for age 1-8 lengths was 0.98 and for age 1-9 weights 0.99.

Table 3.1.1. COD. Abundance indices (numbers in millions) from bottom trawl surveys in the Barents Sea standard area winter 1994-2016 estimated by StoX software.

	Age group															Biomass ('000 t)
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Total	
1994	1044.5	545.5	296.8	307.6	152.6	46.8	8.13	2.59	1.32	0.55	0.52	0.11	0.05	0	0	2407.0	760.2
1995	5343.8	540.2	280.4	242.1	252.3	77.1	17.9	2.33	1.13	0.55	0.59	0.19	0	0	0	6758.7	937.5
1996	5908.3	778.6	164.0	116.7	140.7	111.2	24.8	2.79	0.37	0.16	0.08	0.08	0.05	0.02	0	7247.9	725.4
1997[1]	5122.8	1413.7	315.4	69.2	75.0	60.7	26.8	4.95	0.63	0.68	0.46	0.00	0.00	0.00	0.00	7090.2	502.4
1998[1]	2512.1	492.5	355.2	167.4	31.7	26.4	17.5	8.26	0.79	0.52	0.65	0.00	0.35	0.00	0.04	3613.4	405.9
1999	479.7	353.6	189.6	181.9	61.3	12.8	6.83	5.19	0.98	0.27	0.02	0.03	0.02	0	0	1292.2	324.2
2000	128.2	242.8	247.5	130.0	112.0	27.0	4.73	1.82	1.23	0.36	0.10	0.03	0.02	0	0	895.8	364.7
2001	715.8	77.6	182.0	194.5	81.6	38.0	9.58	1.19	0.45	0.19	0.04	0	0	0	0.01	1300.9	433.8
2002	34.2	416.2	118.0	137.7	108.6	46.5	14.5	2.19	0.34	0.19	0.05	0	0	0	0.02	878.5	448.5
2003	3021.4	61.2	380.8	125.4	95.2	66.6	17.9	4.72	1.02	0.16	0.04	0	0.02	0.02	0	3774.3	546.9
2004	321.3	236.3	65.5	186.1	53.6	43.2	30.9	6.92	1.66	0.29	0.08	0.01	0.01	0	0	945.8	417.2
2005	846.8	216.4	244.8	54.8	102.7	22.4	16.4	3.80	0.88	0.30	0.04	0.02	0.03	0.04	0	1509.5	357.9
2006[2]	676.9	283.8	115.6	114.0	28.1	43.3	14.0	5.19	1.34	0.22	0.21	0.08	0	0	0	1282.6	332.2
2007[1]	584.2	369.9	365.8	127.3	68.9	13.7	23.6	6.85	2.20	0.40	0.31	0.08	0.00	0.00	0.00	1563.2	459.2
2008	69.0	103.3	192.5	300.0	115.6	40.8	18.0	8.29	1.86	0.35	0.02	0.02	0.01	0	0	850.0	694.5
2009	389.4	35.5	124.3	196.1	218.0	58.2	17.5	8.44	5.27	0.50	0.18	0.03	0.03	0	0	1053.4	740.3
2010	1031.5	96.5	37.0	114.9	155.5	144.5	39.8	11.2	3.70	1.64	0.57	0.05	0.02	0.03	0.02	1637.0	831.1
2011	615.3	225.6	85.4	50.7	129.9	138.0	103.1	16.7	4.34	1.17	0.79	0.20	0.17	0.04	0.02	1371.4	890.1
2012[3]	1429.7	124.6	258.9	70.3	36.4	93.9	136.3	49.6	9.38	2.33	0.87	0.60	0.47	0.02	0.05	2213.5	931.7
2013	439.1	147.2	70.3	119.8	64.0	41.0	65.0	76.2	33.6	2.21	2.83	0.41	0.35	0.06	0.03	1062.0	958.1
2014	499.8	148.8	180.6	85.1	67.9	47.8	32.6	46.9	31.7	9.36	1.01	0.97	0.15	0.04	0.07	1153.0	789.0
2015	1295.0	196.8	125.4	170.2	135.7	99.8	71.2	27.4	52.8	17.0	2.86	0.72	0.10	0.07	0.04	2194.8	1220.0
2016	211.9	233.5	52.7	112.7	151.5	109.0	66.7	25.8	12.8	15.0	6.52	0.99	0.50	0.17	0.14	1000.0	979.3

[1]Indices raised to also represent the Russian EEZ.
[2] Not complete coverage in southeast due to restrictions, strata 7 area set to default and strata 13 as in 2005
[3]Indices raised to also represent uncovered parts of the Russian EEZ.

Table 3.1.2. COD. Ratio new/old swept area abundance indices and total biomass in the Barents Sea winter 1994-2016.

	Age group									Total	Biomass
Year	1	2	3	4	5	6	7	8	9	10+		
1994	1.01	1.02	1.00	0.99	1.04	0.92	0.87	1.08	0.83	0.95	1.01	1.00
1995	1.02	1.00	1.02	1.00	0.99	1.01	0.97	0.97	1.41	1.21	1.01	0.99
1996	1.02	1.10	0.96	1.01	1.03	1.05	1.03	0.96	0.93	0.78	1.03	1.03
1997	1.06	1.35	1.33	1.08	1.07	1.15	0.95	0.87	0.70	2.28	1.12	1.01
1998	1.04	0.77	0.90	0.92	0.87	1.02	0.98	0.96	0.79	3.12	0.97	0.95
1999	0.99	1.04	0.90	1.05	1.06	0.96	1.05	1.02	0.82	0.85	1.00	1.02
2000	1.00	0.98	1.05	0.98	1.03	1.00	1.10	0.91	1.03	1.28	1.01	1.02
2001	1.09	1.01	0.95	1.06	0.98	0.99	1.08	1.08	1.13	1.20	1.05	1.01
2002	0.97	0.94	1.34	1.02	0.99	1.09	0.96	0.91	1.13	1.30	1.01	1.02
2003	1.01	0.77	1.01	0.97	1.05	0.99	0.98	0.96	1.02	1.20	1.00	1.00
2004	0.98	1.00	0.86	1.08	0.94	0.97	1.13	0.91	0.98	0.98	0.99	1.01
2005	1.03	0.96	0.99	0.88	1.05	0.91	1.06	0.84	0.80	1.08	1.00	1.01
2006	0.78	0.98	0.98	1.02	0.98	0.99	1.37	1.06	0.96	0.85	0.87	0.99
2007	1.20	0.94	0.99	1.50	1.10	0.93	1.32	1.43	1.22	0.60	1.09	1.16
2008	0.98	1.12	1.01	0.90	1.27	0.86	1.38	0.94	0.93	1.00	1.00	1.02
2009	1.02	0.91	1.05	0.89	1.12	0.99	0.89	1.24	1.08	0.82	1.01	1.00
2010	1.01	0.92	1.03	1.07	0.97	1.03	1.00	0.94	1.06	1.06	1.01	1.02
2011	0.99	1.01	0.97	0.94	1.06	0.99	1.08	0.99	1.11	1.00	1.00	1.02
2012	1.05	0.38	2.64	1.03	0.81	1.08	1.10	0.93	1.19	0.90	1.01	1.02
2013	1.10	0.90	0.95	1.09	0.98	1.16	1.06	0.96	1.24	1.28	1.04	1.04
2014	1.00	0.98	1.04	1.02	1.02	0.99	1.18	1.06	0.96	1.05	1.01	1.01
2015	0.96	1.10	1.01	0.93	1.15	0.81	1.15	0.85	1.36	0.77	0.98	0.99
2016	1.09	0.95	0.86	1.08	0.92	1.14	1.14	0.83	0.90	1.15	1.01	1.02

Table 3.1.3. COD. Estimates of coefficients of variation (%) for swept area abundance indices. Barents Sea standard area winter 1994-2016.

	Age group														
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1994	11	17	13	8	7	8	13	21	23	25	22	67	66	-	-
1995	8	14	11	12	10	10	12	23	33	27	43	39	-	-	-
1996	7	12	19	10	12	10	13	13	25	44	51	42	59	106	-
1997[1]	27	28	16	14	13	10	9	14	21	55	70	-	-	-	-
1998[1]	8	12	15	11	11	10	8	10	17	48	61	-	95	-	68
1999	18	28	17	14	8	10	14	29	22	62	105	94	91	-	-
2000	12	18	13	8	8	9	13	10	14	32	59	61	84	-	-
2001	11	14	17	14	9	10	13	23	25	35	59	-	-	-	-
2002	14	24	25	8	9	12	9	15	25	40	70	93	-	-	-
2003	25	33	26	18	7	7	9	11	15	39	56	65	65	-	-
2004	13	15	17	14	11	12	15	14	16	35	39	100	95	-	-
2005	9	15	26	16	16	14	12	11	17	23	60	66	43	50	-
2006[2]	12	13	14	26	17	12	20	12	17	27	54	76	-	-	-
2007[1]	26	21	15	25	7	9	14	17	19	19	33	49	84	-	-
2008	9	16	17	23	33	10	35	14	26	23	74	83	97	-	-
2009	10	9	18	12	19	14	17	25	22	26	34	62	97	-	-
2010	33	9	11	18	13	11	22	13	24	21	27	64	57	57	97
2011	7	30	11	15	16	11	9	11	26	19	49	38	58	64	99
2012[2]	46	13	65	12	14	19	20	12	24	19	23	31	48	80	92
2013	10	18	16	19	12	10	11	10	18	22	55	35	59	102	99
2014	16	10	12	12	10	10	17	13	10	17	27	34	60	132	80
2015	7	24	9	9	14	13	30	21	42	20	20	34	95	82	87
2016	9	10	9	12	9	20	22	10	14	27	21	32	30	54	57

[1] REZ not covered

[2] REZ partly covered

Table 3.1.4. COD. Length (cm) at age from bottom trawl surveys in the Barents Sea standard area winter 1994-2016 estimated by StoX software. + indicates few samples.

Age/ Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1994	11.3	17.9	30.2	44.6	55.1	65.5	73.8	78.5	87.5	97.9	97.7	100.8	122.1	-
1995	12.2	18.0	28.8	42.1	54.0	63.7	75.7	80.2	83.9	99.1	+	109.0	-	-
1996	12.1	18.9	28.7	40.6	49.3	60.9	71.7	84.8	92.2	92.2	99.5	104.6	108.7	121.0
1997[1]	10.9	15.9	26.8	39.9	49.5	59.2	69.9	81.6	91.8	+	+	-	-	-
1998[1]	9.8	18.0	29.3	40.0	50.9	58.9	67.7	76.7	87.4	+	+	-	+	-
1999	12.0	18.3	29.0	39.9	50.4	59.4	70.4	78.5	88.7	88.4	+	+	+	-
2000	12.9	20.7	28.4	39.7	51.5	61.4	70.5	76.2	84.8	81.8	99.7	+	+	-
2001	11.6	22.6	33.0	41.1	52.2	63.3	70.2	77.7	86.0	96.2	103.8	-	-	-
2002	12.0	19.5	28.6	43.6	52.1	62.0	71.3	79.5	91.0	89.3	102.3	-	-	-
2003	11.4	18.0	28.9	39.4	53.4	61.7	70.6	80.8	89.1	90.6	104.5	-	105.8	111.6
2004	10.6	18.4	31.7	40.6	51.7	61.6	68.6	79.7	90.9	88.5	91.7	+	+	-
2005	11.2	18.3	29.5	43.5	51.1	60.3	71.0	79.6	88.9	96.2	109.4	+	+	+
2006	12.0	19.5	30.9	42.1	53.6	60.2	66.4	76.5	84.5	98.8	93.2	96.3	-	-
2007[1]	13.1	21.0	29.4	40.2	53.1	62.9	68.7	76.6	87.6	94.9	102.4	+	-	-
2008	12.1	22.4	33.1	43.2	51.7	64.1	69.0	81.3	88.4	94.6	108.9	+	+	-
2009	11.2	21.2	32.1	42.6	53.1	61.7	76.5	81.8	89.3	97.9	99.9	+	+	-
2010	11.2	18.2	31.5	42.7	52.4	60.7	70.6	80.4	88.5	96.2	102.7	+	+	+
2011	11.9	19.4	29.5	41.9	51.0	60.7	68.1	78.3	85.9	95.2	101.3	111.1	111.7	119.0
2012	11.0	18.4	22.6	41.0	52.4	58.0	66.5	75.7	86.0	91.4	106.2	113.4	119.7	+
2013	11.2	19.2	31.0	41.0	51.6	62.1	69.7	76.5	81.1	95.2	92.2	110.7	110.7	+
2014	9.8	17.3	29.1	40.1	51.8	59.5	70.3	77.0	81.9	87.1	96.7	98.1	110.5	+
2015	10.5	16.2	30.0	39.9	51.2	60.5	69.0	77.6	80.1	88.9	95.4	101.4	+	+
2016	12.2	18.5	29.9	40.6	50.0	60.6	68.4	76.9	85.4	86.0	90.0	91.9	111.8	122.2

1) Adjusted lengths, REZ not covered

Table 3.1.5. COD. Weight (g) at age from bottom trawl surveys in the Barents Sea standard area winter 1994-2016 estimated by StoX software. + indicates few samples.

Age/ Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1994	12	55	260	796	1463	2372	3477	4624	6782	8420	8530	13516	20786	-
1995	15	53	239	656	1341	2194	3628	4577	5315	8907	+	12176	-	-
1996	15	62	232	632	1079	1979	3327	5479	7655	8192	9760	13013	13614	14650
1997[1]	13	46	181	592	1097	1785	2917	4928	7290	+	+	-	-	-
1998[1]	8	50	256	608	1184	1749	2601	4040	6383	+	+	-	+	-
1999	14	58	231	588	1178	1827	2994	4123	6343	7326	+	+	+	-
2000	16	74	210	558	1210	1961	3042	3842	5384	5727	9960	+	+	-
2001	14	106	336	642	1288	2233	3090	4332	5727	8571	11022	-	-	-
2002	14	67	233	747	1225	2065	3189	4577	7472	6431	11645	-	-	-
2003	13	59	229	586	1313	2013	2982	4725	6511	7552	12467	-	12885	16112
2004	10	59	276	607	1142	1946	2618	4139	6684	6988	7957	+	+	-
2005	13	61	245	724	1145	1857	2953	4224	6418	8607	12488	+	+	+
2006	13	69	280	663	1413	1965	2599	4244	5783	10131	8620	10735	-	-
2007[1]	17	71	226	638	1370	2270	2918	4254	6556	8727	11130	+	-	-
2008	15	90	336	799	1410	2449	3144	5218	6793	9494	12918	+	+	-
2009	13	84	294	704	1293	2030	4061	5082	6884	9504	9614	+	+	-
2010	11	64	307	702	1297	2031	3165	4736	6501	9016	10417	+	+	+
2011	15	65	247	667	1129	1940	2725	4003	5914	8233	9888	13213	13814	+
2012	12	62	123	609	1278	1673	2480	3772	5923	7783	12298	14876	17868	+
2013	11	65	264	591	1201	2064	2804	3839	4814	8433	8759	15101	14729	+
2014	8	49	238	592	1234	1776	2849	3942	4946	6181	8368	9212	12578	+
2015	10	47	242	574	1250	1971	2760	4077	4621	6901	8096	11366	+	+
2016	13	54	240	600	1063	1953	2703	3873	5537	6024	6965	7924	15330	25046

[1]) Adjusted weights, REZ not covered

3.2 Haddock

Table 3.2.1 presents swept area abundance indices for haddock age groups 1 – 15+ for the standard area in 1994 to 2016, and Table 3.2.2 gives the ratio between new and old indices by age, total index and total biomass. The highest and lowest single index ratio was 4.24 and 0.20, both for two older neighbour age groups in 2008. Also for haddock high and low ratios were especially found in the years with raising of the indices, i.e. 1997, 1998 and 2008. The highest and lowest average ratio over all age groups in one year was 1.26 and 0.95, and the highest and lowest average ratio for one age group over all years was 1.09 and 0.86. The overall average index ratio was 0.99, the average total index ratio was 0.98 and the average total biomass ratio was 1.01.

Table 3.2.3 presents estimates of coefficients of variation (%) for age groups 1-14. Estimates are based on a stratified bootstrap approach with 500 replicates (with trawl stations being primary sampling unit). A CV of 20 % or less could be viewed as acceptable in a traditional stock assessment approach if the indices are unbiased (conditional on a catchability model). Values above this indicate a highly uncertain index with little information regarding year class strength. In most years CVs for age groups older than 7 years are above what could be considered as acceptable.

Tables 3.3.4 and 3.4.5 present the time series of mean length and mean weight at age for age groups 1-14 in the standard area. Age groups with few observations are marked with " + ", while no observations are marked with " - ". Observed data for 1997, 1998 and 2007 have been adjusted, see above. Since StoX does not use age-length keys (ALK) in the traditional sense with ALK estimated for large areas as done by the Survey Program, there are differences in length and weight at age for some age groups in some years. However, the overall average ratio for age 1-8 lengths was 0.99 and for age 1-9 weights 1.01.

Table 3.2.1. HADDOCK. Abundance indices (numbers in millions) from bottom trawl surveys in the Barents Sea standard area winter 1994-2016 estimated by StoX software.

	Age group															Biomass
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15+**	**Total**	**('000 t)**
1994	593.5	220.9	315.2	427.9	48.3	3.39	0.14	0.17	0.16	0.14	0.45	0.04	0	0	0	1610.4	402.5
1995	1392.8	182.1	57.6	163.0	338.4	28.8	1.87	0.03	0.04	0.04	0	0.25	0.11	0	0	2165.1	435.7
1996	295.5	245.0	55.5	32.5	161.0	250.9	18.3	1.11	0	0.01	0	0.03	0.03	0	0	1059.9	453.3
1997[1]	1068.7	93.5	80.9	39.6	18.2	61.4	87.3	3.22	0.08	0	0	0	0.03	0.02	0	1452.8	284.5
1998[1]	239.2	196.0	21.2	36.1	12.8	3.24	8.15	5.94	0.56	0.03	0.02	0	0	0	0.05	523.3	85.2
1999	1186.4	79.8	57.1	15.6	9.36	2.87	0.86	1.30	0.74	0.01	0	0.02	0	0	0	1354.2	85.5
2000	817.0	429.8	24.1	35.8	6.91	4.05	0.65	0.01	0.81	0.24	0.03	0.03	0.01	0	0	1319.5	123.3
2001	1215.5	450.0	291.8	26.1	22.7	1.73	0.78	0.06	0.06	0.05	0.16	0.10	0.02	0	0.01	2009.1	226.6
2002	1652.1	464.5	313.8	186.8	11.9	8.43	0.86	0.19	0	0.10	0.15	0.04	0.04	0	0	2638.9	307.0
2003	3254.4	481.3	337.8	175.1	72.3	5.04	1.73	0.12	0.09	0.09	0.09	0.01	0.01	0	0	4328.1	408.3
2004	705.1	707.3	174.9	99.3	77.7	50.9	7.37	0.89	0.13	0.04	0.05	0.04	0.04	0.07	0	1824.2	307.5
2005	4400.9	369.6	315.7	140.1	50.9	61.7	10.2	0.25	0.08	0.01	0	0	0	0	0	5349.5	427.1
2006[2]	4879.2	1296.8	78.8	129.8	45.5	22.6	15.9	3.20	0.09	0.14	0	0.04	0	0	0.07	6470.4	449.1
2007[1]	3654.3	1679.9	459.1	81.0	84.8	26.1	5.38	2.23	1.35	0.77	0.07	0	0	0	0.03	5995.0	677.3
2008	831.1	2072.2	1578.8	581.3	52.9	54.0	7.05	10.6	0.16	0.04	0.08	0.05	0	0	0	5189.1	1099.2
2009	550.0	329.1	1237.3	760.1	372.3	25.8	12.3	0.85	0.09	0.34	0	0.01	0	0	0	3288.1	986.5
2010	1586.4	81.4	96.1	492.8	454.6	149.4	7.80	0.99	0.35	0.42	0.03	0.02	0	0	0	2870.5	760.6
2011	670.9	354.4	52.6	125.7	472.5	293.6	66.3	1.45	1.11	0	0	0.14	0.03	0	0	2038.6	834.4
2012[3]	1844.8	137.3	321.6	29.1	76.1	270.9	156.4	24.5	2.64	0.31	0.04	0.07	0	0	0	2863.7	747.2
2013	335.7	480.2	55.5	146.0	20.9	34.2	193.8	68.6	6.00	0.08	0	0	0	0	0	1340.9	602.3
2014	1129.0	119.8	370.6	30.3	100.4	21.9	46.5	95.2	40.0	1.52	0.46	0	0	0.02	0	1955.7	631.3
2015	1071.7	315.2	30.2	176.7	44.1	35.6	13.6	18.3	27.7	7.76	0.28	0.13	0	0	0	1741.2	373.2
2016	2176.2	536.6	151.7	33.5	105.0	20.1	40.7	10.0	27.3	24.4	3.94	0.90	0	0.14	0.06	3130.8	518.9

[1]Indices raised to also represent the Russian EEZ.
[2] Not complete coverage in southeast due to restrictions, strata 7 area set to default and strata 13 as in 2005
[3]Indices raised to also represent uncovered parts of the Russian EEZ.

Table 3.2.2. HADDOCK. Ratio new/old swept area abundance indices and total biomass in the Barents Sea standard area winter 1994-2016.

	Age group											
Year	1	2	3	4	5	6	7	8	9	10+	Total	Biomass
1994	0.98	0.97	0.93	0.98	0.97	1.00	0.70	1.70	0.80	1.05	0.97	0.97
1995	0.95	1.02	1.07	0.95	1.00	0.83	0.67	1.00	0.40	-	0.96	0.98
1996	0.95	0.93	1.06	0.68	1.08	0.99	1.58	1.23	-	0.70	0.97	0.98
1997	0.84	1.38	0.94	1.41	0.94	1.31	1.40	0.92	0.80	-	0.92	1.26
1998	1.12	1.42	0.93	1.09	0.97	0.95	1.02	0.73	0.80	1.00	1.19	1.09
1999	0.95	1.39	0.95	1.28	0.92	1.03	0.86	0.76	0.67	-	0.97	0.99
2000	0.96	0.95	0.89	1.01	0.82	1.01	0.81	-	1.16	1.55	0.96	0.98
2001	1.00	0.98	0.99	0.89	0.90	1.02	0.87	0.60	0.60	1.13	0.99	0.98
2002	0.98	0.87	1.00	1.01	0.68	1.03	1.08	0.63	-	1.10	0.96	0.97
2003	0.98	0.94	1.06	0.96	0.98	0.92	0.75	0.60	0.90	1.00	0.98	0.95
2004	0.98	0.99	0.93	0.97	0.97	1.10	1.25	0.81	0.65	2.40	0.98	0.99
2005	0.95	0.88	0.91	1.05	0.76	1.18	0.83	0.42	0.40	-	0.94	0.97
2006	0.95	0.99	1.02	0.92	0.94	1.15	1.05	1.03	0.90	0.83	0.96	0.97
2007	0.94	1.05	0.90	1.23	0.99	1.13	0.72	0.60	0.96	1.55	0.97	1.15
2008	0.97	0.97	1.04	0.97	0.61	1.10	1.12	4.24	0.20	1.70	0.99	0.99
2009	0.97	1.00	0.97	0.98	1.02	0.67	1.16	0.61	0.90	1.17	0.98	0.99
2010	0.98	0.73	0.93	0.97	0.95	1.14	1.11	0.99	0.58	0.78	0.97	0.99
2011	0.98	1.03	0.81	1.32	1.01	0.87	1.07	0.91	2.78	0.85	0.99	0.98
2012	0.96	1.27	1.02	0.63	0.91	0.94	1.07	1.12	1.10	1.05	0.98	0.98
2013	1.15	0.97	0.76	1.00	0.97	0.89	1.26	0.72	0.50	0.80	1.01	0.99
2014	0.94	1.02	0.99	0.68	1.00	0.89	1.09	1.04	0.78	0.38	0.95	1.02
2015	0.98	0.91	1.18	0.96	1.25	1.01	1.17	0.78	1.20	0.69	0.97	0.99
2016	0.97	0.99	0.89	1.30	0.99	0.99	1.24	0.70	0.98	0.98	0.97	0.98

Table 3.2.3. HADDOCK. Estimates of coefficients of variation (%) for swept area abundance indices. Barents Sea standard area winter 1994-2016.

	Age group													
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1994	12	13	13	13	15	25	47	45	34	61	39	100	-	-
1995	12	19	28	29	16	21	38	181	75	97	-	58	97	-
1996	14	12	11	26	29	25	60	64	-	98	-	95	96	-
1997[1]	12	34	13	15	17	21	18	57	55	-	-	-	65	92
1998[1]	15	13	13	14	16	25	18	16	35	107	106	-	-	-
1999	15	37	14	24	21	23	25	31	22	88	-	97	-	-
2000	9	11	21	10	18	14	32	51	32	35	65	91	105	-
2001	11	15	11	18	11	40	34	46	59	51	47	86	62	-
2002	9	12	11	12	19	17	27	44	-	57	52	54	80	-
2003	18	26	25	12	11	20	35	62	60	69	56	91	93	-
2004	10	12	16	14	11	12	28	26	43	56	56	94	59	51
2005	9	16	11	19	13	22	15	71	48	93	-	-	-	-
2006[2]	14	14	18	12	13	16	20	30	44	70	-	63	-	-
2007[1]	11	7	10	20	12	12	24	25	46	51	58	-	-	-
2008	12	18	17	17	20	29	29	80	45	81	67	88	-	-
2009	13	21	16	17	19	19	33	25	91	68	-	94	-	-
2010	11	17	18	23	21	22	24	32	49	64	126	150	-	-
2011	10	10	16	25	17	13	18	33	73	-	-	83	84	-
2012[2]	20	29	16	17	14	12	15	34	73	47	83	62	-	-
2013	12	12	15	15	28	25	28	14	26	49	-	-	-	-
2014	9	24	14	19	17	22	21	17	24	41	62	-	-	99
2015	8	13	26	12	40	14	27	19	21	32	44	50	-	-
2016	22	25	15	47	11	17	20	16	17	21	29	45	-	62

[1] REZ not covered
[2] REZ partly covered

Table 3.2.4. HADDOCK. Length (cm) at age from bottom trawl surveys in the Barents Sea standard area winter 1994-2016 estimated by StoX software. + indicates few samples.

Age/ Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1994	14.5	20.1	29.4	38.0	47.6	54.3	61.7	65.2	70.7	64.4	64.6	72.0	-	-
1995	15.1	18.4	28.7	34.0	42.8	51.0	59.6	60.0	67.2	68.0	-	64.7	78.6	-
1996	15.3	20.9	28.0	37.0	41.3	47.2	53.8	58.7	-	76.0	-	74.0	75.0	-
1997[1]	15.8	19.4	27.0	33.5	40.5	46.9	47.6	53.3	62.0	-	-	-	75.6	78.0
1998[1]	14.1	19.6	28.9	34.2	41.6	46.5	50.3	52.8	58.2	72.1	65.0	-	-	-
1999	14.3	18.0	32.3	38.6	46.5	51.9	56.1	55.1	58.8	62.0	-	72.0	-	-
2000	15.5	21.7	29.9	42.0	47.1	51.1	52.7	59.3	59.4	62.0	63.3	+	+	-
2001	14.6	22.1	32.1	37.6	48.0	50.1	59.2	55.0	64.9	66.3	67.7	+	+	-
2002	15.0	20.9	29.2	39.8	45.6	51.5	58.0	58.6	-	62.0	64.4	67.7	70.1	-
2003	15.8	24.0	26.4	36.5	45.8	49.8	54.5	61.2	62.6	60.3	66.0	70.0	+	-
2004	14.1	22.1	30.1	35.7	42.7	49.9	49.6	58.8	63.3	73.6	75.7	+	+	+
2005	14.8	20.6	29.9	36.1	40.4	48.4	51.5	56.2	60.8	67.0	-	-	-	-
2006	14.4	22.1	30.7	37.9	43.3	47.3	50.7	56.6	60.5	69.9	-	+	-	-
2007[1]	15.2	23.5	28.2	31.2	43.5	43.9	50.0	58.0	58.1	+	62.0	-	-	-
2008	15.7	23.7	29.6	37.9	42.7	46.0	52.9	52.5	58.5	+	63.3	63.0	-	-
2009	14.2	22.6	29.7	35.5	41.8	48.1	48.9	56.4	65.0	62.3	-	62.0	-	-
2010	14.4	19.8	30.6	36.8	40.8	45.1	49.9	59.9	58.9	62.3	+	66.5	-	-
2011	13.6	23.3	28.5	39.5	42.9	46.1	48.2	62.7	+	-	-	63.3	+	-
2012	14.6	19.2	31.6	35.1	43.7	47.1	50.2	50.8	47.6	65.0	67.0	72.0	-	-
2013	14.5	22.8	30.0	40.9	42.8	48.6	52.3	52.8	55.6	67.3	-	-	-	-
2014	15.5	18.6	31.9	39.0	46.5	52.7	53.5	55.3	54.9	60.3	59.2	-	-	75.0
2015	14.5	20.4	26.1	39.8	45.3	52.6	53.4	57.6	56.9	60.2	59.6	67.4	-	-
2016	14.8	18.4	30.8	36.0	47.8	53.0	56.0	58.5	61.3	60.3	59.8	64.0	-	72.0

1) Adjusted lengths, REZ not covered

Table 3.2.5. HADDOCK. Weight (g) at age from bottom trawl surveys in the Barents Sea standard area winter 1994-2016 estimated by StoX software. + indicates few samples.

Age/ Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1994	25	87	248	539	1056	1601	2201	2846	3439	2680	2712	3890	-	-
1995	30	71	221	380	775	1331	2005	2070	2685	2905	-	2502	3972	-
1996	32	93	218	472	668	1020	1537	1768	-	4630	-	4018	3626	-
1997[1]	35	85	188	329	619	1034	1064	1532	2474	-	-	-	3731	4130
1998[1]	24	89	232	416	815	1032	1298	1559	2006	3740	3040	-	-	-
1999	27	75	335	570	1022	1435	1791	1722	2011	2440	-	3525	-	-
2000	32	110	275	736	1061	1366	1521	2123	2239	2588	2741	+	+	-
2001	28	107	337	581	1145	1402	2147	1896	2903	3110	2965	+	+	-
2002	30	85	245	618	940	1375	1940	2048	-	2352	2670	3252	3497	-
2003	36	129	192	490	958	1209	1479	1933	2479	2533	3055	3470	+	-
2004	23	98	271	456	750	1162	1204	1958	2658	3926	4157	+	+	+
2005	29	98	261	474	666	1093	1372	1976	2120	2730	-	-	-	-
2006	25	109	302	561	810	1083	1358	1917	2102	3991	-	+	-	-
2007[1]	30	114	246	356	894	956	1388	2135	2508	+	2959	-	-	-
2008	32	113	245	553	832	1080	1573	1417	2120	+	2280	2840	-	-
2009	26	96	225	442	747	1147	1275	1726	2377	2563	-	2594	-	-
2010	27	87	270	466	658	949	1260	1897	2143	2512	+	3184	-	-
2011	21	117	220	520	727	939	1163	2285	+	-	-	+	2805	-
2012	28	73	305	432	816	1015	1285	1282	1219	2683	2980	3264	-	-
2013	24	113	272	644	783	1130	1350	1495	1836	3098	-	-	-	-
2014	32	68	357	611	1014	1424	1551	1677	1671	2141	2184	-	-	4800
2015	23	88	201	588	848	1423	1465	1921	1834	2078	2256	3133	-	-
2016	27	74	283	465	1057	1456	1745	2071	2303	2263	2416	2803	-	3467

[1]) Adjusted weights, REZ not covered

3.3 Golden redfish (*Sebastes norvegicus*)

Table 3.3.1 presents swept area abundance indices by length groups in 1994 to 2016, and Table 3.3.2 gives the ratio between new and old indices by length groups, total index and total biomass. The highest and lowest single index ratio was 2.14 and 0.26, both for length groups with low indices in years with raising of the indices. The highest and lowest average ratio over all length groups in one year was 1.04 and 0.94, and the highest and lowest average ratio for one length group over all years was 1.03 and 0.99. The overall average index ratio was 1.00, the average total index ratio was 1.01 and the average total biomass ratio was 0.98.

Table 3.3.3 presents estimates of coefficients of variation (%) by length groups. A CV of 20 % or less could be viewed as acceptable in a traditional stock assessment approach if the indices are unbiased (conditional on a catchability model). Values above this indicate a highly uncertain index with little information regarding year class strength. In most years CVs for most length groups are above what could be considered as acceptable.

Table 3.3.1. Golden redfish (S*ebastes norvegicus*). Abundance indices (numbers in thousands) from bottom trawl surveys in the Barents Sea standard area winter 1994-2016 estimated by StoX software.

	Length group (cm)													Biomass
Year	**5-9**	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**	**45-49**	**50-54**	**55-59**	**≥60**	**Total**	**(tons)**
1994	675	7493	10100	12840	10914	17834	10065	4799	1645	937	202	121	77623	31841
1995	387	4658	13515	13118	10398	15429	16223	10587	3112	852	455	148	88883	42151
1996	40	715	3291	5983	8863	14089	15709	7502	2692	893	168	165	60010	35775
1997[1]	0	500	1197	2809	6522	22751	28797	8235	1747	1092	239	97	73985	44977
1998[1]	51	4525	2043	10795	73085	30862	14707	6984	1712	456	142	0	145363	49253
1999	181	928	2070	4002	4351	6275	6143	5474	2618	738	75	0	32854	20330
2000	533	1122	1506	4196	4895	5146	3611	1908	620	466	89	0	24092	10946
2001	55	411	398	2452	5802	5463	4509	3239	1154	343	96	37	23960	13896
2002	133	1053	2043	1854	3955	4204	3335	3654	1656	619	192	28	22726	13242
2003	0	478	1303	1538	4192	4081	2765	3204	1996	548	123	327	20554	13399
2004	700	195	420	973	2842	4365	5404	3858	2281	562	140	45	21786	15758
2005	0	119	203	362	1110	2090	3849	4664	2730	1276	299	128	16831	16389
2006[2]	0	0	0	178	2495	5534	6307	4155	3179	950	124	12	22934	18790
2007[1]	0	97	453	214	772	1526	2823	4275	2742	1194	197	58	14351	14553
2008	1736	2540	201	171	440	710	1969	2547	3049	1231	157	19	14768	12647
2009	0	0	86	0	39	436	1745	3779	4200	1959	267	101	12728	17237
2010	372	2017	1168	527	136	60	833	1062	2073	1596	205	128	10175	9787
2011	342	3187	2068	288	402	125	274	2329	3030	1912	131	243	14332	13302
2012[3]	805	4375	3995	1835	550	316	881	3645	4083	1775	320	85	22664	16011
2013	75	7418	4896	3952	1550	355	878	821	1284	1594	384	451	23658	11456
2014	128	1043	1440	3005	3363	1023	507	1427	2139	1176	633	193	16077	12087
2015	139	881	1467	3019	2603	2013	458	720	1237	1216	874	82	14710	10120
2016	748	1291	1484	2396	4290	3673	3391	1658	2147	2307	1114	250	24749	18189

[1] Indices raised to also represent the Russian EEZ

[2] Not complete coverage in southeast due to restrictions, strata 7 area set to default and strata 13 as in 2005

[3] Indices not raised to also represent uncovered parts of the Russian EEZ.

Table 3.3.2. GOLDEN REDFISH. Ratio new/old swept area abundance indices and total biomass in the Barents Sea standard area winter 1994-2016.

	Length group (cm)										
Year	**5-9**	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**	**>45**	**Total**	**Biomass**
1994	0.96	1.15	1.09	1.10	0.95	0.92	1.11	1.09	1.04	1.03	0.97
1995	0.65	0.93	1.03	1.14	1.14	0.97	0.94	0.97	0.97	1.01	0.90
1996	1.00	1.02	0.94	0.93	0.94	1.20	0.95	0.95	1.00	1.00	0.94
1997	-	1.00	0.80	0.88	0.99	1.06	1.03	0.98	0.96	1.01	0.91
1998	0.26	0.75	0.82	1.03	1.48	1.22	1.12	1.01	1.00	1.25	0.96
1999	0.91	1.03	0.99	1.00	0.95	0.98	1.02	1.03	1.04	1.00	1.11
2000	1.07	1.02	1.00	1.00	1.04	1.03	1.03	1.06	0.98	1.02	1.05
2001	0.55	1.03	1.00	1.02	1.02	0.99	1.00	1.01	1.02	1.01	1.06
2002	1.33	1.05	1.02	1.03	1.04	1.03	1.01	1.02	1.00	1.02	0.98
2003	-	0.96	1.09	1.03	0.97	1.07	1.02	0.97	1.03	1.02	0.95
2004	1.00	0.98	1.05	0.97	0.98	0.99	0.98	0.96	0.95	0.98	0.95
2005	-	1.19	1.02	0.91	1.01	1.05	1.01	1.01	1.01	1.01	0.97
2006	-	-	-	0.89	1.00	1.02	1.03	1.01	1.02	1.02	1.02
2007	-	0.97	0.91	2.14	1.29	0.42	0.59	0.91	1.02	0.78	0.84
2008	0.96	0.98	1.01	0.86	1.10	1.01	1.04	1.02	1.01	1.00	1.02
2009	-	-	0.86	-	0.39	1.09	1.03	1.02	0.99	1.00	0.97
2010	0.93	1.01	0.97	0.88	1.36	0.60	1.04	0.97	1.03	0.99	1.01
2011	1.14	1.03	0.98	0.96	1.01	1.25	0.91	1.01	1.02	1.02	1.00
2012	1.01	0.99	1.00	0.97	0.92	1.05	0.98	1.01	1.01	1.00	0.99
2013	0.75	0.99	0.89	0.99	0.91	0.89	0.98	1.03	1.03	0.97	1.02
2014	1.28	0.95	0.96	1.00	0.99	1.02	1.01	1.02	1.01	1.00	1.03
2015	1.39	0.98	0.98	1.01	0.96	1.01	0.92	1.03	1.00	0.98	0.96
2016	0.94	0.99	0.99	1.00	1.02	1.02	1.00	0.98	0.99	1.00	0.89

Table 3.3.3. Golden redfish (S*ebastes norvegicus*). Estimates of coefficients of variation (%) for swept area abundance indices. Barents Sea standard area winter 1994-2016.

	Length group (cm)										
Year	**5-9**	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**	**45-49**	**50-54**	**55-59**
1994	51	42	22	27	18	34	13	29	20	23	40
1995	47	39	38	31	16	33	31	33	21	22	34
1996	68	51	47	25	16	27	25	20	16	24	46
1997[1]	-	40	30	28	20	64	71	37	14	19	34
1998[1]	67	28	25	56	82	64	48	42	27	28	44
1999	62	38	37	35	33	25	33	59	57	29	70
2000	46	27	21	24	22	28	28	26	22	21	56
2001	53	28	31	24	31	27	38	50	29	26	45
2002	54	61	51	25	29	23	28	39	49	26	41
2003	-	29	34	34	27	23	16	20	27	36	70
2004	72	38	26	32	35	54	52	26	30	22	54
2005	-	73	46	32	20	25	31	22	23	34	65
2006[2]	-	-	-	46	46	45	37	30	22	18	43
2007[1]	-	69	61	56	31	21	23	27	23	17	32
2008	33	30	41	60	42	27	22	23	17	24	64
2009	-	-	69	-	73	31	30	24	23	24	29
2010	54	31	45	51	41	70	31	34	17	19	31
2011	45	37	23	48	30	55	40	66	44	33	48
2012[2]	38	41	21	21	35	40	28	40	45	29	43
2013	55	40	27	17	22	45	38	39	38	27	44
2014	61	35	31	22	21	26	37	35	28	26	26
2015	64	44	33	29	26	24	30	36	27	18	37
2016	50	28	22	24	26	25	19	23	28	20	29

[1] REZ not covered

[2] REZ partly covered

3.4 Beaked redfish (*Sebastes mentella*)

Table 3.4.1 presents swept area abundance indices by length groups in 1994 to 2016, and Table 3.4.2 gives the ratio between new and old indices by length groups, total index and total biomass. The highest and lowest single index ratio was 1.86 and 0.67, both for length groups with low indices. For 1994 the new indices were considerable higher for most length groups. The highest and lowest average ratio over all length groups in one year was 1.33 and 0.89, and the highest and lowest average ratio for one length group over all years was 1.04 and 0.98. The overall average index ratio was 1.01, the average total index ratio was 1.02 and the average total biomass ratio was 1.03.

Table 3.4.3 presents estimates of coefficients of variation (%) by length groups. A CV of 20 % or less could be viewed as acceptable in a traditional stock assessment approach if the indices are unbiased (conditional on a catchability model). Values above this indicate a highly uncertain index with little information regarding year class strength. In most years CVs for length groups between 10 and 29 cm are at a level that could be considered as acceptable.

Table 3.4.1. Beaked redfish (*Sebastes mentella*)[1]. Abundance indices (numbers in millions) from bottom trawl surveys in the Barents Sea standard area winter 1994-2016 estimated by StoX software.

	Length group (cm)										Biomass
Year	**5-9**	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**	**>45**	**Total**	**('000 t)**
1994	8.3	295.7	479.4	488.4	74.4	74.4	17.1	2.6	0.1	1440.4	161.2
1995	310.1	83.9	570.6	390.5	82.7	57.7	23.9	2.8	0.4	1522.5	153.0
1996	214.6	101.5	198.5	342.9	136.0	42.0	16.6	1.4	0.2	1053.8	127.9
1997[2]	64.6	118.45	22.0	242.4	258.2	70.2	39.1	4.4	0.1	819.4	165.3
1998[2]	1.0	88.0	62.4	101.4	203.2	40.0	12.9	1.7	0.2	510.7	96.1
1999	2.1	6.8	69.5	36.8	171.2	73.9	21.8	3.2	0.7	385.4	98.8
2000	9.2	12.9	40.2	78.0	142.2	94.8	24.5	7.0	1.5	410.3	111.5
2001	9.8	23.1	7.2	56.8	78.8	74.7	9.6	0.6	0.1	260.8	65.3
2002	16.5	7.5	19.3	36.5	96.2	116.7	23.9	1.4	0.03	318.1	90.2
2003	3.8	4.1	10.3	12.6	70.4	198.1	45.9	5.7	0.3	351.1	139.4
2004	2.2	3.0	6.9	18.5	32.8	86.3	31.6	1.9	0.8	183.4	68.4
2005	0	6.3	7.4	10.7	28.4	153.7	86.2	3.8	0.2	296.6	131.3
2006[3]	100.0	1.9	9.6	14.6	22.8	103.8	82.8	2.7	0.7	338.8	108.2
2007[2]	374.2	121.8	2.8	6.7	12.3	121.0	120.7	7.1	0	766.7	136.6
2008	858.2	359.1	26.8	4.6	11.5	103.6	165.4	4.7	0.1	1533.9	169.3
2009	95.3	324.7	135.5	5.4	8.8	67.1	162.6	5.8	0.4	805.7	155.1
2010	652.2	276.0	214.7	64.2	7.1	73.6	191.3	5.9	0.4	1485.4	198.1
2011	501.6	229.7	212.5	149.0	14.1	46.6	157.3	4.9	0.2	1315.8	177.8
2012[4]	129.4	280.1	86.4	125.3	47.3	14.4	153.9	17.7	0.2	854.7	170.7
2013	249.6	226.6	245.4	159.2	143.2	35.2	193.3	27.1	0.3	1279.8	242.2
2014	90.7	175.3	250.1	113.7	124.6	50.6	115.1	13.8	0.2	934.1	170.2
2015	175.2	110.7	216.2	302.2	289.8	214.8	170.9	18.1	0.2	1498.0	344.6
2016	615.1	105.3	148.6	331.5	213.1	162.7	123.6	14.1	0.6	1714.6	262.5

[1] Includes unidentified *Sebastes* specimens, mostly less than 10cm
[2] Indices raised to also represent the Russian EEZ
[3] Not complete coverage in southeast due to restrictions, strata 7 area set to default and strata 13 as in 2005
[4] Indices not raised to represent uncovered parts of the Russian EEZ

Table 3.4.2. BEAKED REDFISH. Ratio new/old swept area abundance indices and total biomass in the Barents Sea standard area winter 1994-2016.

	Length group (cm)										
Year	**5-9**	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**	**>45**	**Total**	**Biomass**
1994	1.20	1.14	1.66	1.72	1.45	1.07	0.86	1.86	1.00	1.47	1.38
1995	1.18	1.18	0.89	0.77	0.91	0.84	0.76	0.72	0.80	0.91	0.83
1996	1.01	1.01	1.04	1.02	1.01	1.00	1.00	1.00	0.67	1.02	1.04
1997	1.02	0.98	0.89	0.87	0.95	0.99	0.98	0.85	1.00	0.94	0.99
1998	0.77	1.00	1.00	1.00	1.00	0.99	1.00	1.55	1.00	1.00	1.01
1999	0.95	1.00	1.02	1.00	1.02	1.04	1.04	1.03	1.00	1.03	1.02
2000	1.02	1.02	1.02	1.02	1.00	0.98	0.92	1.01	1.00	1.00	0.98
2001	1.05	1.03	1.03	1.03	1.02	1.02	1.02	1.00	1.00	1.03	1.03
2002	1.02	1.04	1.01	0.88	0.93	1.03	1.04	1.00	1.00	0.98	0.99
2003	0.97	1.05	1.03	1.02	0.99	0.99	0.98	0.95	1.00	0.99	1.02
2004	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.95	1.00	1.00	0.98
2005	-	1.02	1.01	1.00	1.00	1.00	1.00	0.97	1.00	1.00	1.01
2006	1.01	1.00	0.98	1.00	1.00	1.01	1.01	1.00	1.00	1.01	1.05
2007	1.01	1.05	1.12	1.03	1.03	1.03	1.02	1.09	-	1.02	1.00
2008	1.01	1.01	1.02	0.87	0.97	0.91	0.92	0.96	1.00	0.99	1.05
2009	1.01	1.01	1.01	1.00	1.01	1.02	1.02	1.02	1.00	1.01	1.04
2010	1.01	1.01	1.01	1.01	1.00	1.00	1.00	1.00	1.00	1.01	1.03
2011	1.01	1.01	1.01	1.01	1.01	1.00	1.01	1.00	1.00	1.01	1.05
2012	1.02	1.02	1.02	1.02	1.03	1.02	1.02	1.02	1.00	1.02	1.07
2013	1.01	1.01	1.01	1.01	1.00	1.00	1.01	1.00	1.00	1.01	1.01
2014	1.02	1.01	1.00	1.01	1.01	0.99	0.98	1.00	1.00	1.01	1.03
2015	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02
2016	1.00	1.01	1.02	1.02	1.02	1.02	1.03	1.02	1.00	1.01	1.01

Table 3.4.3. Beaked redfish (*Sebastes mentella*)[1]. Estimates of coefficients of variation (%) for swept area abundance indices. Barents Sea standard area winter 1994-2016.

Year	Length group (cm) 5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49
1994	40	14	25	28	20	23	26	49	53
1995	18	25	23	25	17	20	18	34	39
1996	18	23	27	22	19	36	23	37	58
1997[2]	18	15	13	11	14	17	26	53	53
1998[2]	28	16	21	14	17	16	21	31	77
1999	20	17	15	11	18	22	29	56	65
2000	16	12	17	12	16	21	31	64	76
2001	17	14	14	12	13	19	17	26	67
2002	57	13	15	18	16	21	19	31	65
2003	56	17	18	17	18	27	27	43	88
2004	19	15	15	19	16	14	18	21	59
2005	-	23	15	16	16	17	21	38	40
2006[3]	11	49	25	28	18	17	16	24	85
2007[2]	15	23	18	13	15	24	19	41	59
2008	14	15	29	23	20	23	22	24	45
2009	13	10	18	22	40	28	22	24	46
2010	14	12	12	18	22	31	31	22	80
2011	10	12	10	15	16	32	25	27	56
2012[3]	16	12	13	11	21	32	37	54	44
2013	15	15	35	23	32	29	39	41	49
2014	10	12	11	15	21	22	30	27	48
2015	14	11	14	18	26	22	19	29	52
2016	10	11	13	20	16	16	18	18	58

[1] Includes unidentified *Sebastes* specimens, mostly less than 10cm

[2] REZ not covered

[3] REZ partly covered

3.5 Norway redfish (*Sebastes viviparus*)

Table 3.5.1 presents swept area abundance indices by length groups in 1994 to 2016, and Table 3.5.2 gives the ratio between new and old indices by length groups and total index. No biomass estimates are available from StoX since individual weights are not measured. The highest and lowest single index ratio was 1.68 and 0.74, both in the largest length group with low indices. For 1994 and 1995 the new indices were considerable higher for most length groups. The highest and lowest average ratio over all length groups in one year was 1.43 and 0.94, and the highest and lowest average ratio for one length group over all years was 1.05 and 1.02. The overall average index ratio was 1.03 and the average total index ratio was 1.04.

Table 3.5.3 presents estimates of coefficients of variation (%) by length groups. A CV of 20 % or less could be viewed as acceptable in a traditional stock assessment approach if the indices are unbiased (conditional on a catchability model). Values above this indicate a highly uncertain index with little information regarding year class strength. In most years CVs for most length groups are far above what could be considered as acceptable.

Table 3.5.1. Norway redfish (*Sebastes viviparous*). Abundance indices (numbers in thousands) from bottom trawl surveys in the Barents Sea standard area winter 1994-2016 estimated by StoX software.

	Length group (cm)						
Year	**5-9**	**10-14**	**15-19**	**20-24**	**25-29**	**>30**	**Total**
1994	75355	94809	17218	12818	1377	279	201857
1995	10716	68713	22737	9349	3306	503	115325
1996	439	45798	43673	35921	5498	87	131417
1997[1]	898	24202	28857	18768	4397	0	77122
1998[1]	703	9835	42183	20801	2939	91	76102
1999	1577	10134	11675	2921	707	35	27049
2000	1011	5127	37429	22122	2118	140	67947
2001	249	2243	30082	34405	3802	120	70901
2002	332	3345	17674	15168	1276	88	37884
2003	234	4306	22603	31019	4277	181	62619
2004	102	1794	24462	32769	3294	291	62712
2005	172	1582	16444	37360	6153	356	62068
2006[2]	819	4480	3653	10381	2244	205	21782
2007[1]	704	5238	15652	34395	2448	80	58517
2008	0	1882	5910	21022	4561	30	33344
2009	506	528	3096	11032	3405	419	18988
2010	1712	455	10134	53181	7572	22	73076
2011	533	1250	2169	7758	2197	106	14013
2012[1]	586	3950	4080	29157	6212	74	44059
2013	1211	9522	3302	23464	8545	100	46144
2014	11388	17755	21079	64094	15135	1990	131441
2015	7384	27351	30768	65870	9048	88	140509
2016	2795	26824	18396	29229	11286	933	89464

[1] Indices not raised for uncovered parts of the Russian EEZ, *Sebastes viviparus* is mainly found in NEZ
[2] Not complete coverage in southeast due to restrictions, strata 7 area set to default and strata 13 as in 2005

Table 3.5.2. NORWAY REDFISH. Ratio new/old swept area abundance indices in the Barents Sea standard area winter 1994-2016.

	Length group						
Year	**5-9**	**10-14**	**15-19**	**20-24**	**25-29**	**>30**	**Total**
1994	1.57	1.48	1.15	1.04	1.15	1.40	1.43
1995	1.41	1.29	1.04	1.18	1.38	1.68	1.24
1996	0.88	1.02	1.03	1.01	1.00	0.87	1.02
1997	1.00	1.02	1.01	1.01	1.02	-	1.01
1998	1.00	1.06	1.01	1.01	1.01	0.91	1.01
1999	0.99	1.01	1.02	1.01	1.01	-	1.00
2000	1.12	1.07	1.03	1.02	1.01	1.40	1.03
2001	0.83	1.02	1.02	1.02	1.03	1.20	1.01
2002	1.11	1.08	1.04	1.05	1.06	0.88	1.05
2003	1.17	1.08	1.06	1.03	1.02	0.91	1.04
2004	1.02	1.00	1.00	1.00	1.00	0.97	1.00
2005	0.86	0.99	1.02	1.01	1.01	0.89	1.02
2006	1.02	1.02	1.01	1.02	1.02	1.03	1.04
2007	1.01	1.01	1.00	0.94	0.72	0.80	0.94
2008	-	1.05	1.02	1.01	1.01	-	1.01
2009	1.01	1.06	1.00	1.01	1.00	1.05	1.00
2010	1.01	0.91	1.01	1.01	1.01	-	1.01
2011	1.07	1.04	1.03	1.03	1.05	1.06	1.00
2012	0.98	1.01	1.02	1.01	1.00	0.74	1.00
2013	1.01	1.01	1.00	1.01	1.01	1.00	1.00
2014	1.16	1.06	1.04	1.05	1.04	1.00	1.05
2015	0.98	0.99	0.99	0.98	0.99	0.88	0.98
2016	1.00	0.98	1.01	0.99	1.00	0.93	0.99

Table 3.5.3. Norway redfish (*Sebastes viviparous*). Estimates of coefficients of variation (%) for swept area abundance indices. Barents Sea standard area winter 1994-2016.

	Length group (cm)					
Year	**5-9**	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**
1994	34	52	25	39	41	70
1995	42	31	43	34	70	89
1996	62	24	31	36	51	57
1997[1]	84	31	27	48	56	-
1998[1]	39	20	43	68	71	79
1999	78	58	32	25	37	65
2000	52	29	47	48	41	51
2001	39	26	31	30	34	85
2002	61	34	20	23	46	83
2003	73	34	35	30	31	76
2004	57	36	38	35	24	66
2005	69	35	40	31	34	69
2006[2]	75	75	25	30	21	58
2007[1]	75	78	39	39	29	87
2008	-	58	32	28	42	73
2009	61	48	25	24	27	61
2010	47	42	47	52	57	97
2011	51	59	50	48	45	75
2012[2]	45	30	48	45	43	100
2013	58	32	25	41	51	98
2014	43	36	40	40	41	79
2015	38	32	34	43	53	100
2016	37	28	29	28	23	46

[1] REZ not covered

[2] REZ partly covered

3.6 Greenland halibut

Table 3.6.1 presents swept area abundance indices by length groups in 1994 to 2016, and Table 3.6.2 gives the ratio between new and old indices by length groups and total index. Indices for fish < 10 cm has been excluded in the comparisons. The highest and lowest single index ratio was 1.58 and 0.32, both for length groups with low indices. For 1994 the new indices were somewhat higher for most length groups, while they were lower for 1995. The highest and lowest average ratio over all length groups in one year was 1.10 and 0.93, and the highest and lowest average ratio for one length group over all years was 1.07 and 0.98. The overall average index ratio was 1.02, the average total index ratio was 1.03 and the average total biomass ratio was 1.01.

Table 3.6.3 presents estimates of coefficients of variation (%) for length groups. Estimates are based on a stratified bootstrap approach with 500 replicates (with trawl stations being primary sampling unit). A CV of 20 % or less could be viewed as acceptable in a traditional stock assessment approach if the indices are unbiased (conditional on a catchability model). Values above this indicate a highly uncertain index with little information regarding year class strength. In most years only CVs for length groups between 40 and 59 cm are at a level that could be considered as acceptable.

Table 3.6.1. GREENLAND HALIBUT. Abundance indices (numbers in thousands) from bottom trawl surveys in the Barents Sea standard area winter 1994-2016 estimated by StoX software.

	Length group (cm)																Biomass
Year	**≤14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**	**45-49**	**50-54**	**55-59**	**60-64**	**65-69**	**70-74**	**75-79**	**≥ 80**	**Total**	**(tons)**
1994	0	0	21	76	148	1117	3139	4740	3615	1941	889	541	21	0	0	16248	19228
1995	298	0	0	0	90	129	2877	7182	5739	2027	1622	839	489	86	0	21378	27459
1996	4121	0	0	0	62	124	1214	4086	4634	1871	1112	638	337	74	12	18285	20256
1997[1]	0	68	0	0	55	163	949	4313	5629	2912	1609	643	300	65	21	16728	24214
1998[1]	68	220	945	578	481	487	1088	4016	6591	3076	1798	707	326	93	44	20518	27248
1999	43	84	241	436	566	269	784	1701	3097	1669	1094	491	89	75	0	10640	14681
2000	140	184	344	836	1722	3857	2253	1560	2144	1714	1191	615	249	76	0	16883	17246
2001	68	49	147	179	737	1525	3716	3271	2302	2010	1088	529	160	50	39	15871	18224
2002	271	0	70	34	382	1015	1916	3803	3250	2279	1138	976	242	159	114	15648	21198
2003	51	0	74	19	304	715	1842	3008	4765	2235	714	561	245	146	0	14678	19635
2004	106	104	15	0	319	1253	1229	1717	2277	1227	798	298	148	94	26	9615	11872
2005	263	70	159	1139	2235	2621	4206	3782	3847	2037	917	585	336	118	0	22314	22293
2006[2]	0	72	94	414	1968	5149	4613	5743	4283	2132	891	449	258	34	18	26118	25579
2007[1]	0	18	146	1869	1418	3114	5710	5947	4287	2205	963	658	391	80	89	26896	28006
2008	0	0	0	243	1708	5974	4654	6136	5198	3403	827	638	174	82	50	29088	30153
2009	55	0	0	26	1044	4327	8133	4551	4084	2266	996	627	442	253	154	26960	28919
2010	0	0	0	99	678	3648	5729	6560	4897	2467	1064	552	229	128	41	26092	25979
2011	51	0	0	0	216	4396	5864	5498	5237	3698	699	936	327	252	97	27271	31552
2012[3]	77	0	0	0	51	1145	4524	5366	4517	2774	1147	195	73	0	48	19917	22656
2013	0	0	0	0	0	511	5368	4868	5374	3687	1944	939	348	313	154	23504	31748
2014	0	0	46	92	156	368	2271	5587	5903	3555	2251	1369	154	260	79	22090	31112
2015	367	0	61	0	284	1612	3187	6452	7249	6752	3350	1936	587	334	0	32172	46828
2016	205	0	124	511	950	1953	3486	4539	5479	5613	1999	1973	646	98	80	27657	35539

[1] Indices raised to also represent the Russian EEZ

[2] Not complete coverage in southeast due to restrictions, strata 7 area set to default and strata 13 as in 2005

[3] Indices not raised to also represent uncovered parts of the Russian EEZ.

Table 3.6.2. GREENLAND HALIBUT Ratio new/old swept area abundance indices and total biomass in the Barents Sea standard area winter 1994-2016.

Year	Length group (cm)															Biomass
	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	≥ 80	Total	
1994	-	-	1.31	0.77	1.04	0.94	1.20	1.23	1.25	1.08	1.18	1.23	0.84	-	-	1.17	1.18
1995	1.00	-	-	-	1.08	0.87	0.89	0.78	0.77	0.72	0.69	0.92	1.04	1.51	-	0.80	0.73
1996	1.31	-	-	-	1.02	1.00	1.04	1.03	1.05	1.03	1.07	1.08	0.97	1.01	1.00	1.09	1.04
1997	-	1.05	-	-	0.32	0.72	1.11	0.99	1.02	1.07	1.04	1.02	1.06	0.98	0.95	1.02	1.02
1998	0.85	1.01	0.94	1.30	0.90	1.21	1.02	1.03	1.04	1.03	1.04	1.12	0.97	1.22	1.02	1.04	1.05
1999	1.05	1.02	0.92	1.02	0.98	1.02	1.04	1.00	1.01	1.02	1.02	1.02	0.82	1.01	-	1.00	1.00
2000	1.15	1.00	1.07	0.97	0.98	1.00	1.03	0.98	1.00	1.00	1.02	1.09	1.03	1.01	-	1.01	1.01
2001	1.00	1.00	1.14	1.01	1.11	1.04	1.01	1.00	1.02	1.01	1.01	1.01	0.78	1.04	0.98	1.02	1.01
2002	1.01	-	0.99	1.03	0.94	1.02	0.99	1.03	1.02	1.03	1.03	1.00	1.05	1.01	1.19	1.02	1.01
2003	1.02	-	1.04	1.12	1.03	1.06	1.03	1.03	1.03	1.02	1.01	0.92	1.06	1.17	-	1.02	1.01
2004	1.58	1.01	1.00	-	1.01	1.01	1.00	1.00	1.00	1.00	1.01	1.00	1.01	0.99	1.00	1.01	1.01
2005	1.02	1.01	1.01	1.01	1.02	0.97	1.01	1.03	1.01	1.02	0.98	1.00	1.02	1.02	-	1.01	1.02
2006	-	1.00	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.02	1.02	1.00	1.00	1.01	0.99
2007	-	1.00	1.05	1.09	1.06	1.08	1.19	1.22	1.09	1.13	1.42	1.20	1.11	1.03	1.00	1.15	1.17
2008	-	-	-	1.01	1.01	0.91	0.98	1.02	1.01	1.01	1.02	1.00	1.01	1.04	1.04	0.98	1.01
2009	1.00	-	-	1.04	1.01	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.03	1.02	1.03	1.02	1.01
2010	-	-	-	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.00	1.01	1.02	0.98	1.01	0.89
2011	1.02	-	-	-	1.01	1.01	1.01	1.01	1.01	1.01	1.02	1.01	1.01	1.00	1.04	1.01	0.99
2012	1.00	-	-	-	1.00	1.02	1.02	1.02	1.03	1.01	1.02	1.01	0.99	-	1.04	1.02	1.02
2013	-	-	-	-	-	1.02	1.57	1.03	1.04	1.03	1.01	1.02	1.01	1.02	1.01	1.11	1.05
2014	-	-	1.02	1.01	1.03	1.00	1.04	1.03	1.03	1.02	1.00	1.03	1.12	1.07	1.00	1.03	1.01
2015	1.06	-	0.95	-	1.02	1.00	1.00	0.99	0.98	0.99	1.04	0.99	1.01	0.98	-	0.99	1.02
2016	1.02	-	1.10	1.06	1.03	1.02	1.03	1.03	1.04	1.07	1.06	1.06	1.02	1.01	1.03	1.05	1.03

Table 3.6.3. GREENLAND HALIBUT. Estimates of coefficients of variation (%) for swept area abundance indices. Barents Sea standard area winter 1994-2016.

	Length group (cm)														
Year	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**	**45-49**	**50-54**	**55-59**	**60-64**	**65-69**	**70-74**	**75-79**	**80-84**
1994	0	0	105	57	46	28	17	20	17	15	20	26	97	-	-
1995	91	-	-	-	71	40	18	22	25	24	27	41	63	94	-
1996	33	-	-	-	69	45	22	25	18	19	36	29	40	58	-
1997[1]	-	53	-	-	82	48	26	23	18	16	16	24	28	73	101
1998[1]	66	53	26	44	42	18	22	23	28	26	28	31	33	50	101
1999	91	54	53	26	32	31	24	21	18	16	18	25	52	51	-
2000	71	66	72	83	56	58	41	20	22	23	21	36	45	54	-
2001	92	99	85	47	40	48	44	46	37	14	17	34	43	56	-
2002	71	-	70	104	29	27	17	13	16	16	14	27	24	37	55
2003	66	-	63	95	30	27	20	44	34	32	44	28	38	37	-
2004	78	59	97	-	26	17	16	16	17	17	15	29	39	46	92
2005	66	70	37	46	33	15	19	17	16	20	25	24	28	64	-
2006[2]	-	81	81	67	32	18	18	11	11	16	22	22	30	67	-
2007[1]	-	99	52	23	20	13	12	12	14	14	24	37	26	44	99
2008	-	-	-	36	20	21	15	14	18	14	22	20	43	56	68
2009	98	-	-	103	23	14	16	16	19	18	17	21	26	46	53
2010	-	-	-	57	26	18	13	12	14	18	19	23	45	57	101
2011	66	-	-	-	43	18	15	14	17	14	25	26	33	46	70
2012[2]	93	-	-	-	100	23	13	14	14	11	24	70	72	-	-
2013	-	-	-	-	-	44	39	12	16	20	19	33	50	50	-
2014	-	-	99	68	68	37	20	14	20	18	18	24	53	51	72
2015	83	-	99	-	49	24	22	15	13	18	34	37	33	46	-
2016	-	-	101	50	43	31	21	34	26	31	16	20	36	70	98

[1] REZ not covered

[2] REZ partly covered

3.7 Blue whiting

Table 3.7.1 presents swept area abundance indices by length groups in 1994 to 2016, and Table 3.7.2 gives the ratio between new and old indices by length groups, total index and total biomass index for the years with Survey program estimates, i.e. 2001 to 2016. Swept area indices have not been estimated by the Survey Program prior to year 2001. In early years biomass estimates are not available from StoX since individual weights were not measured. Indices for fish < 10 cm has been excluded in the comparisons. The highest and lowest single index ratio was 2.00 and 0.30, both for length groups with low indices. The highest and lowest average ratio over all length groups in one year was 1.38 and 0.88, and the highest and lowest average ratio for one length group over all years was also 1.06 and 1.01. The overall average index ratio was 1.04, the average total index ratio was 1.03 and the average total biomass ratio was 1.03.

Table 3.7.3 presents estimates of coefficients of variation (%) by length groups. In most years CVs for most length groups are above what could be considered as acceptable.

Table 3.7.1. BLUE WHITING. Abundance indices (numbers in millions) from bottom trawl surveys in the Barents Sea standard area winter 1994-2016 estimated by StoX software.

	Length group (cm)									Biomass
Year	**5-9**	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**≥40**	**Total**	**(‘000 t)**
1994	0	0	1.2	13.6	25.7	10.9	1.1	0.1	52.6	NA
1995	0	0.5	0.8	2.4	10.3	10.8	3.9	0.2	29.0	NA
1996	0	80.0	1371.8	8.4	18.6	7.1	3.8	0.1	1489.9	38.2
1997[1]	0	608.7	681.5	273.8	3.1	5.3	1.8	0.1	1574.3	NA
1998[1]	0	1.2	34.5	42.2	3.6	1.5	1.4	0.1	84.5	NA
1999	0	0.02	11.0	40.0	16.1	5.0	1.7	0.1	74.0	NA
2000	0	12.3	557.5	44.1	25.7	4.4	0.7	0.1	644.9	NA
2001	0.04	311.6	1420.8	631.5	46.0	5.4	1.6	0.1	2417.0	NA
2002	0	0.9	428.9	636.3	77.6	17.5	3.2	0.1	1164.4	56.6
2003	0	3.9	220.5	493.4	73.4	28.0	4.0	0.3	823.4	48.1
2004	0	7.1	712.0	821.6	276.2	37.8	1.1	0.2	1856.0	95.8
2005	0	125.1	717.2	984.7	223.3	31.8	0.1	0.1	2082.4	105.0
2006[2]	0	0	164.4	1500.5	598.0	69.0	2.0	0.1	2333.9	172.9
2007[1]	0	0	4.0	628.0	299.3	23.5	1.6	0.4	956.8	79.8
2008	0	0	0.3	12.1	126.1	19.8	1.3	0.1	159.7	20.6
2009	0	0	0.02	2.7	50.6	21.2	1.5	0.02	76.1	11.4
2010	0	0	0.5	1.6	9.4	16.9	1.0	0	29.4	5.2
2011	0	0	0.1	0.3	2.8	5.1	2.5	0	10.6	2.2
2012[1]	0	85.6	674.6	1.1	1.8	5.3	2.0	0.3	770.7	18.2
2013	0	0	75.3	395.9	12.6	11.5	6.8	0.1	502.2	28.6
2014	0	0	182.1	34.2	9.7	1.6	1.5	0.04	229.2	8.5
2015	0	115.6	907.4	141.2	40.8	8.8	7.4	0	1221.3	34.2
2016	0	0.1	260.0	367.6	38.0	6.3	3.0	0.1	674.9	39.1

[1] Indices not raised for uncovered parts of the Russian EEZ, blue whiting is mainly found in areas A, B, C and S
[2] Not complete coverage in southeast due to restrictions, strata 7 area set to default and strata 13 as in 2005

Table 3.7.2. BLUE WHITING Ratio new/old swept area abundance indices and total biomass in the Barents Sea standard area winter 2001-2016.

Year	Length group (cm) 10-14	15-19	20-24	25-29	30-34	35-39	≥40	Total	Biomass
2001	1.02	1.02	1.03	1.03	1.02	1.07	1.00	1.02	-
2002	1.13	0.99	0.97	0.96	0.96	1.03	1.00	0.97	0.97
2003	1.22	1.15	1.01	0.90	0.94	0.63	0.30	1.03	0.90
2004	0.99	0.99	0.99	1.00	1.01	1.00	1.00	0.99	0.99
2005	1.00	1.00	1.00	1.00	1.01	1.00	0.50	1.00	0.99
2006	-	1.01	1.01	1.01	1.01	1.00	1.00	1.01	1.01
2007	-	1.00	1.06	1.08	1.09	1.07	1.33	1.07	1.09
2008	-	1.00	1.01	1.00	1.01	1.00	1.00	1.00	1.07
2009	-	1.00	1.00	1.01	1.01	1.07	1.00	1.01	1.12
2010	-	0.70	0.84	1.00	1.12	1.25	-	1.05	1.22
2011	-	2.00	1.50	1.12	1.09	1.19	-	1.18	1.23
2012	1.02	1.02	1.00	1.20	1.15	1.05	1.00	1.02	0.97
2013	-	1.01	1.01	1.01	1.01	1.00	2.00	1.01	1.01
2014	-	1.02	1.01	1.01	1.00	1.00	1.00	1.02	1.01
2015	0.99	1.02	1.01	0.99	1.00	1.00	-	1.01	0.82
2016	1.00	1.03	1.02	1.01	1.00	1.00	1.00	1.02	1.09

Table 3.7.3. BLUE WHITING. Estimates of coefficients of variation (%) for swept area abundance indices. Barents Sea standard area winter 1994-2016.

Year	Length group (cm)							
	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44
1994	-	-	94	68	51	28	31	49
1995	-	59	55	51	66	32	28	48
1996	-	49	79	56	49	30	33	59
1997[1]	-	30	29	33	36	29	37	70
1998[1]	-	91	60	33	35	33	28	70
1999	-	98	26	27	28	31	43	71
2000	-	37	21	20	25	29	31	95
2001	69	21	18	25	26	35	39	90
2002	-	56	25	17	20	33	52	69
2003	-	87	47	23	17	27	58	83
2004	-	86	23	19	15	14	30	61
2005	-	28	25	16	24	24	71	90
2006	-	-	17	12	13	26	46	61
2007[1]	-	-	50	16	12	17	42	84
2008	-	-	51	59	27	22	47	82
2009	-	-	97	60	21	20	61	95
2010	-	-	91	80	29	25	33	-
2011	-	-	100	88	45	48	62	-
2012[2]	-	32	30	39	45	38	29	98
2013	-	-	70	31	57	44	44	99
2014	-	-	23	23	24	27	18	137
2015	-	50	21	21	31	31	37	-
2016	-	96	33	24	17	27	29	97

[1] REZ not covered

[2] REZ partly covered

4 Conclusions

For all species and in most years the StoX swept area estimates are quite similar to those obtained by the Survey Program. The largest deviations were found for age or length groups with low indices and/or in years with raising of the indices. Also estimates of length and weight at age for cod and haddock are comparable to those from the Survey Program.

For beaked redfish, Norway redfish and Greenland halibut the StoX indices for 1994 and 1995 were more different than the Survey Program indices compared to other years and other species in the same years. However, when the Survey Program was rerun for these years and species, the estimates were almost similar to the StoX indices. One explanation may be that when the original Survey Program estimates were made in 1994 and 1995, another strata system was applied. The one presently used was established in 1996. The input data may also have been changed/corrected since 1994 and 1995.

It is recommended that the present time series obtained by StoX become the “official” time series that are used for stock assessment and other purposes. The CV estimates show that some indices should be used with care for assessment purposes, i.e. for older age groups of cod and haddock, small and large beaked redfish and Greenland halibut, and all length groups of the other species. It is further recommended that StoX is used to estimate swept area indices with CVs and population parameters from future demersal fish winter surveys in the Barents Sea.

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Note on SAM setup for Northeast Arctic Cod

Anders Nielsen

April 10, 2017

The basic state-space assessment model (SAM) is described in Nielsen & Berg (2014). The model has been continuously developed and adapted for different stocks (e.g. to include tagging data and biomass indices). The current implementation (https://github.com/fishfollower/SAM) is now an R-package based on Template Model Builder (TMB) (Kristensen et al. 2016).

The data set used to assess Northeast Arctic Cod contains catches at age $(C_{a,y})_{a=3...15+,y=1946...2015}$ and age-specific indices from four scientific surveys $(I_{a,y}^{(s=1)})_{a=4...12,y=1981...2016}$ (FLT15: NorBarTrSur), $(I_{a,y}^{(s=2)})_{a=4...12,y=1985...2016}$ (FLT16: NorBarLofAcSur), $(I_{a,y}^{(s=3)})_{a=3...12,y=1982...2015}$ (FLT18: RusSweptArea), and $(I_{a,y}^{(s=4)})_{a=3...12,y=2004...2015}$ (FLT007: Ecosystem). In addition to the observations on catches and surveys a set of biological parameters are available, these are: Mean weight in stock $W_{a,y}^{(s)}$, mean weight in catch $W_{a,y}^{(s)}$, proportion mature $P_{a,y}$, and an estimate of natural mortality $M_{a,y}$.

Model

The model for Northeast Arctic Cod is a state–space model. The states α are the log-transformed stock sizes $\log N_3, \ldots, \log N_A$ and fishing mortalities $\log F_3, \ldots, \log F_{A-1}$ corresponding to total age specific catches. It is assumed that $F_{A+} = F_{A-1}$. In any given year y the state is the combined vector $\alpha_y = (\log N_3, \ldots, \log N_A, \log F_3, \ldots, \log F_{A-1})'$. The transition equation describes the distribution of the next years state from a given state in the current year. The following is assumed:

$$\alpha_y = T(\alpha_{y-1}) + \eta_y$$

The transition function T is where the stock equation and assumptions about stock–recruitment enters the model. The equations are:

$$\log N_{3,y} = \log(N_{3,y-1})$$
$$\log N_{a,y} = \log N_{a-1,y-1} - F_{a-1,y-1} - M_{a-1,y-1}\ , \qquad 4 \le a < A$$
$$\log N_{A,y} = \log(N_{A-1,y-1} \exp^{-F_{A-1,y-1}-M_{A-1,y-1}} + N_{A,y-1} \exp^{-F_{A,y-1}-M_{A,y-1}})$$
$$\log F_{a,y} = \log F_{a,y-1}\ , \qquad 3 \le a \le A-1$$

Here $M_{a,y}$ is the age and year specific natural mortality parameter, which is assumed known from outside sources. $F_{a,y}$ is the total fishing mortality.

The prediction noise η is assumed to be Gaussian with zero mean, and three separate variance parameters. One for recruitment ($\sigma^2_{N_{a=3}}$), one for survival ($\sigma^2_{N_{a>3}}$), one for fishing mortality at age (σ^2_F). The N-part of η is assumed uncorrelated, and the F-part is assumed correlated according to an AR(1) correlation structure, such that $\text{cor}(\Delta\log(F_{a,y}), \Delta\log(F_{\tilde{a},y})) = \rho^{|a-\tilde{a}|}$.

The observation part of the state–space model describes the distribution of the observations for a given state α_y. Here the vector of all observations from a given year y is denoted x_y. The elements of x_y are age-specific log-catches $\log C_{a,y}$ and age-specific log-indices from scientific surveys $\log I^{(s)}_{a,y}$. The combined observation equation is:

$$x_y = O(\alpha_y) + \varepsilon_y$$

The observation function O consists of the catch equations for total catches and scientific surveys. The measurement noise term ε_y is assumed to be Gaussian. An expanded view of the observation equation becomes:

$$\log C_{a,y} = \log\left(\frac{F_{a,y}}{Z_{a,y}}(1-e^{-Z_{a,y}})N_{a,y}\right) + \varepsilon^{(c)}_{a,y}$$
$$\log I^{(s)}_{a,y} = \log\left(Q^{(s)}_a e^{-Z_{a,y}\frac{D^{(s)}}{365}} N_{a,y}\right) + \varepsilon^{(s)}_{a,y}$$

Here Z is the total mortality rate $Z_{a,y} = M_{a,y} + F_{a,y}$, $D^{(s)}$ is the number of days into the year where the survey s is conducted, $Q^{(s)}_a$ are model parameters describing catchability coefficients. The variance of ε_y is setup such that each data source catches, and the four scientific surveys have their own covariance matrix.

Observation uncertainty is important e.g. to get the relative weighting of the different information sources correct, so a lot of effort has been invested in getting the optimal options into SAM. In Berg and Nielsen (2016) different covariance structures are compared for four ICES stocks. It was found that irregular lattice AR(1) observation correlation structure was optimal for surveys. The covariance structures tested were inspired by a previous study (Berg et al. 2014) of the structures obtained from survey calculations. In the paper Albertsen et al. (2016) 13 different observational likelihood formulations were evaluated for four ICES stocks. It was found that the multivariate log-normal representation was among the optimal in all four cases.

To describe the options investigated for Northeast Arctic Cod consider a yearly vector $C_y = (C_{a=3,y}, \ldots, C_{a=A,y})$ of age specific observations from a fleet (survey or commercial). Assume first that the $\log(C_y)$ is multivariate Gaussian:

$$\log(C_y) \sim N(\log(\widehat{C}_y), \Sigma)$$

where Σ is the covariance matrix, and $\hat{C}_y$ is the vector of the usual model predictions. The covariance matrix is specified from a vector of standard deviations $\sigma = (\sigma_3 \dots \sigma_A)$ and a correlation matrix ρ (by $\Sigma_{a\tilde{a}} = \sigma_a \sigma_{\tilde{a}} \rho_{a\tilde{a}}$). Four options are available for the correlation ρ: Independent ($\rho = I$), auto-regressive of order 1 ($\rho_{a\tilde{a}} = 0.5^{\theta|a-\tilde{a}|},\ \theta > 0)^{\star}$, irregular auto-regressive of order 1 ($\rho_{a\tilde{a}} = 0.5^{|\theta_a - \theta_{\tilde{a}}|},\ \theta_3 = 0 \leq \theta_2 \leq \dots \leq \theta_A$), and unstructured (parameterized by the Cholesky of ρ). The options for covariance structure can be set for each fleet individually. **

For Northeast Arctic Cod a run was first conducted with unstructured covariance for all fleets. The estimated covariances were visually inspected. Inspired by the freely estimated covariances, and since the correlations were almost exclusively positive for the survey fleets, the simpler irregular auto-regressive structure was used for the surveys and independent for the catches. This structure was investigated, and found satisfactory, by residual plots.

Residual computation

The residual calculation procedure in the state-space assessment models can be difficult, but is extremely important when evaluating the assumed covariance structure. The standard practice of calculating the residuals (as 'observed' minus 'predicted' divided by an estimate of the standard deviation) is strictly only valid for models with purely independent observations. It is not valid for state-space models, where an underlying unobserved process is introducing a correlation structure in the (marginal) distribution of the observations. It is also not valid if the observations are directly assumed to be correlated (e.g. multivariate normal, or multinomial for age compositions). The problem is that the resulting residuals will not become independent.

To get independent residuals the so-called 'one-observation-ahead' residuals are computed. The residual for the n'th observation is computed by using the first $n-1$ observations to predict the n'th. Details can be found in Thygesen et. al. (2017).

Likelihood and approximation

The likelihood function for this is set up by first defining the joint likelihood of both random effects (here collected in the α_y states), and the observations

*This parametrization is equvivalent to the more common $\phi^{|a-\tilde{a}|}$, where $0 < \phi < 1$

**It is also possible to supply external weights for each individual observation. This option can be used in two ways. To set the relative weighting, or to actually set the fixed variance of each individual observation.

(here collected in the x_y vectors). The joint likelihood is:

$$L(\theta, \alpha, x) = \prod_{y=2}^{Y} \{\phi(\alpha_y - T(\alpha_{y-1}), \Sigma_\eta)\} \prod_{y=1}^{Y} \{\phi(x_y - O(\alpha_y), \Sigma_\varepsilon)\}$$

Here θ is a vector of model parameters. Since the random effects α are not observed inference should be obtain from the marginal likelihood:

$$L_M(\theta, x) = \int L(\theta, \alpha, x) d\alpha$$

This integral is difficult to calculate directly, so the Laplace approximation is used. The Laplace approximation is derived by first approximating the joint log likelihood $\ell(\theta, \alpha, x)$ by a second order Taylor approximation around the optimum $\hat{\alpha}$ w.r.t. α. The resulting approximated joint log likelihood can then be integrated by recognizing it as a constant term and a term where the integral is know as the normalizing constant from a multivariate Gaussian. The approximation becomes:

$$\int L(\theta, \alpha, x) d\alpha \approx \sqrt{\frac{(2\pi)^n}{\det(-\ell''_{\alpha\alpha}(\theta, \alpha, x)|_{\alpha=\hat{\alpha}_\theta})}} \exp(\ell(\theta, \hat{\alpha}_\theta, x))$$

Taking the logarithm gives the Laplace approximation of the marginal log likelihood

$$\ell_M(\theta, x) = \ell(\theta, \hat{u}_\theta, x) - \frac{1}{2}\log(\det(-\ell''_{uu}(\theta, u, x)|_{u=\hat{u}_\theta})) + \frac{n}{2}\log(2\pi)$$

Results

Basic results graphs are following. Most results look fairly well behaved. The retrospective plot of recruits at age 3 less eratic than for age 3.

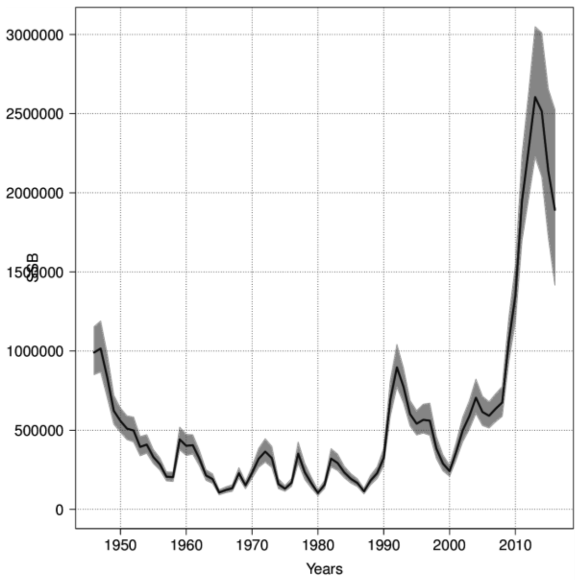

Figure 1: Spawning stock biomass.

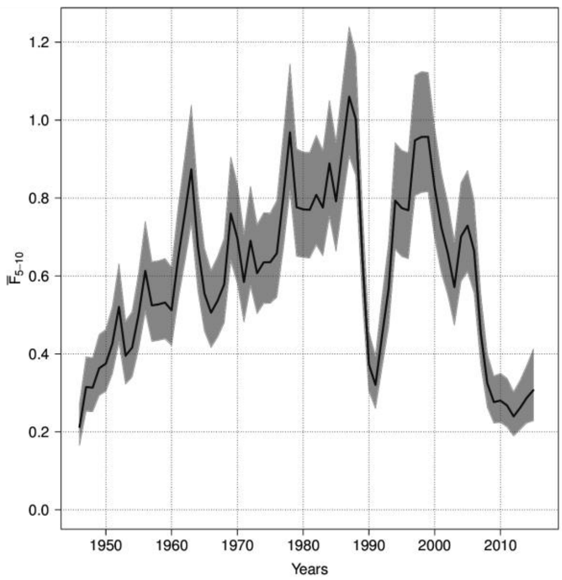

Figure 2: Average fishing mortality ages 5—10.

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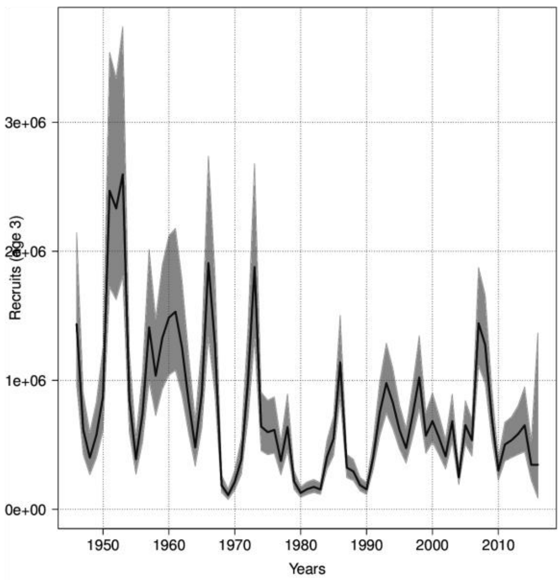

Figure 3: Recruitment at age 3

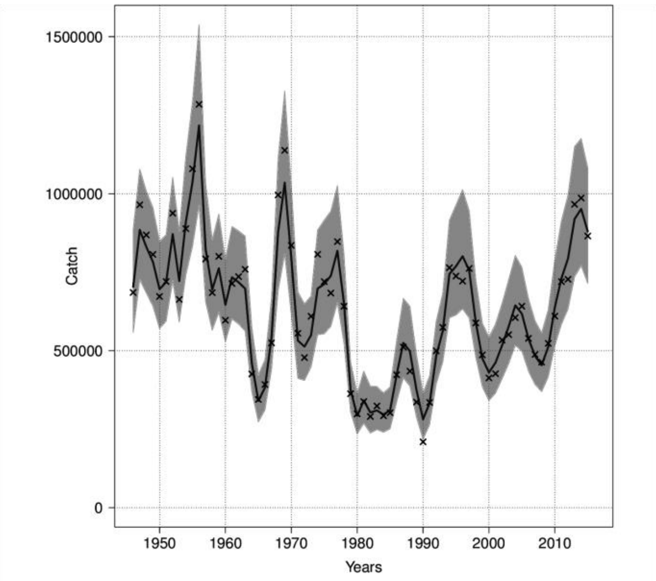

Figure 4: Total catch in weight. Total catch in weight is not used in the likelihood of the model, so this is an additional validation.

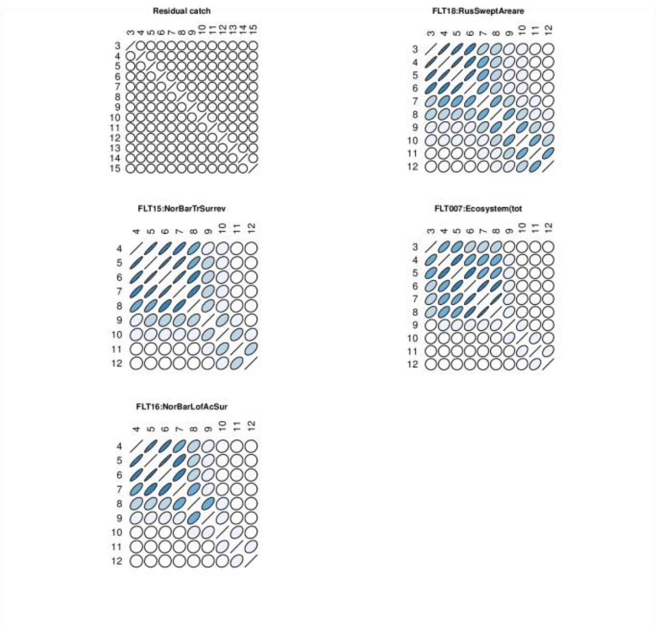

Figure 5: The estimated correlation pattern. White circles means no correlation. Blue narrow ellipses are highly positive correlation.

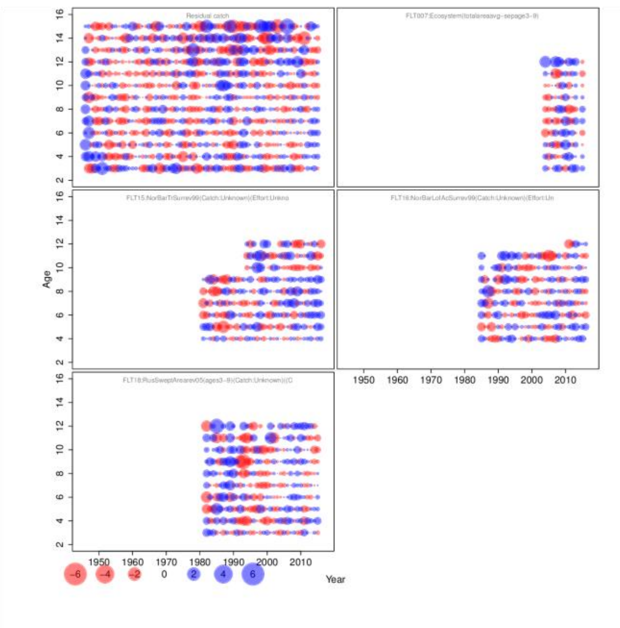

Figure 6: One-observation-ahead prediction residuals for the five fleets.

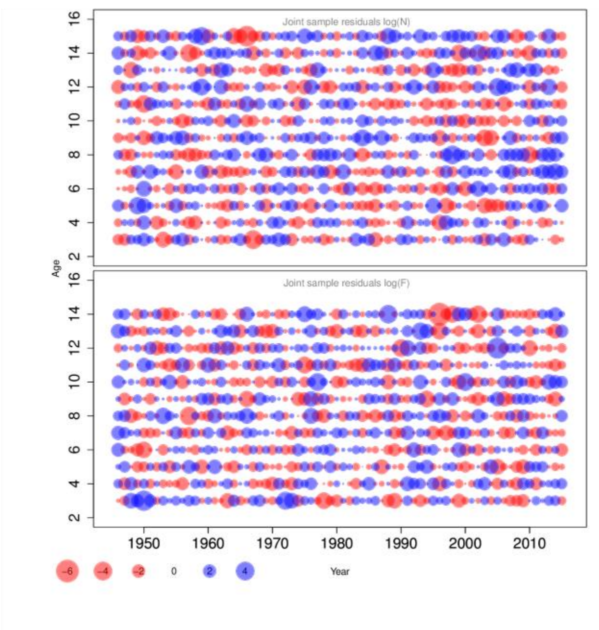

Figure 7: Single joint sample process residuals for $\log(N)$ and $\log(F)$.

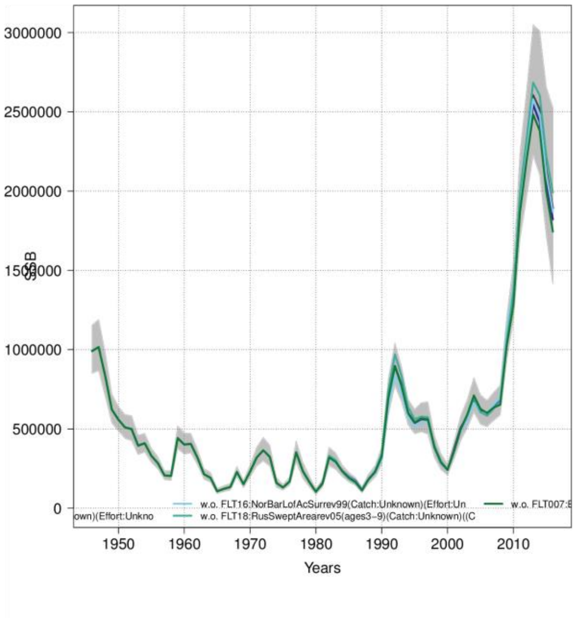

Figure 8: Leave-one-out diagnostics for spawning stock biomass

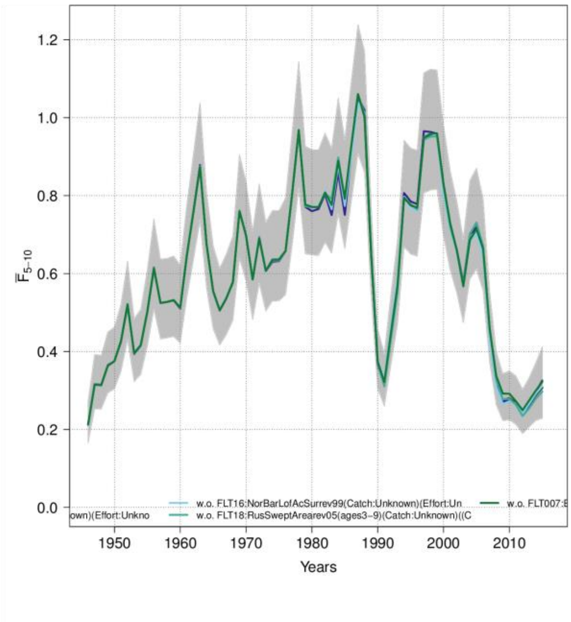

Figure 9: Leave-one-out diagnostics for average fishing mortality

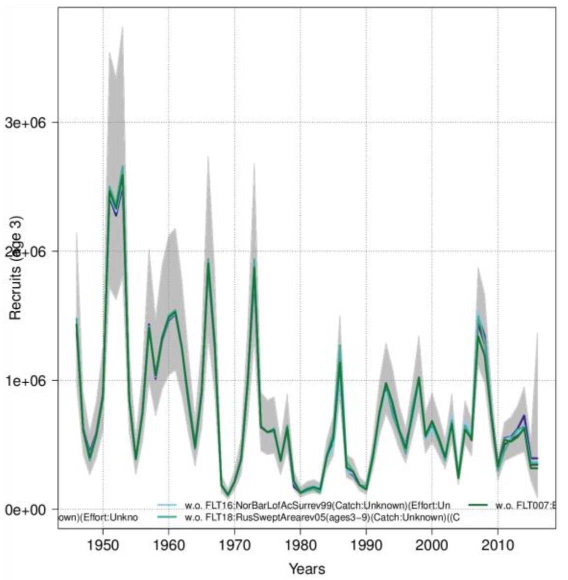

Figure 10: Leave-one-out diagnostics for recruitment at age 3

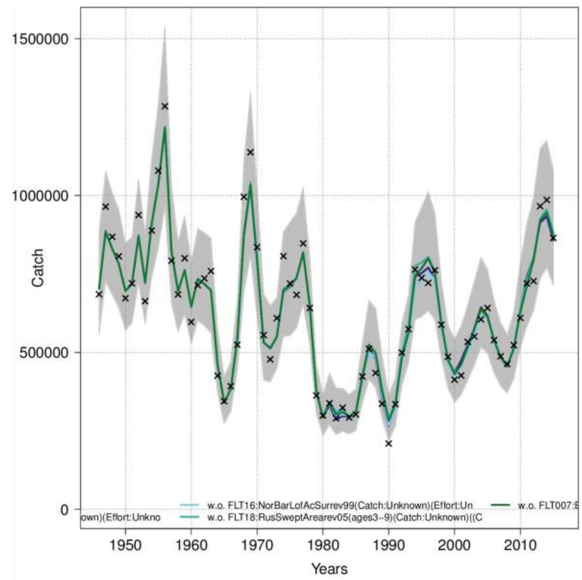

Figure 11: Leave-one-out diagnostics for total catch weight

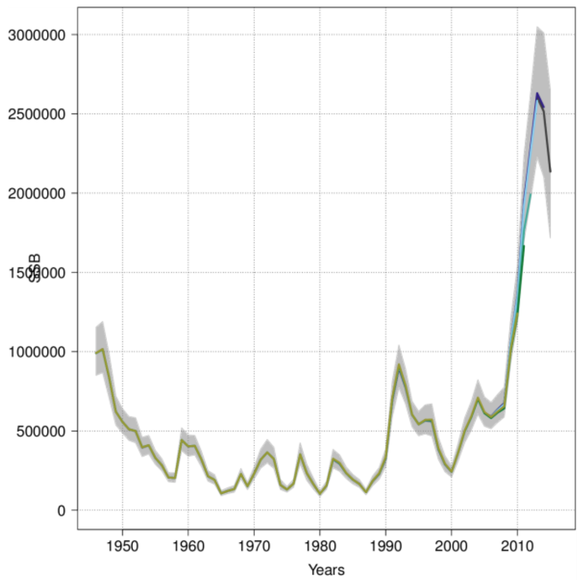

Figure 12: Retrospective diagnostics for spawning stock biomass

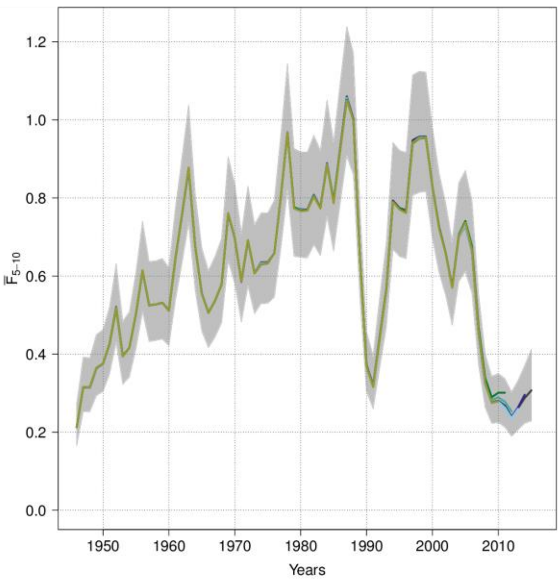

Figure 13: Retrospective diagnostics for average fishing mortality

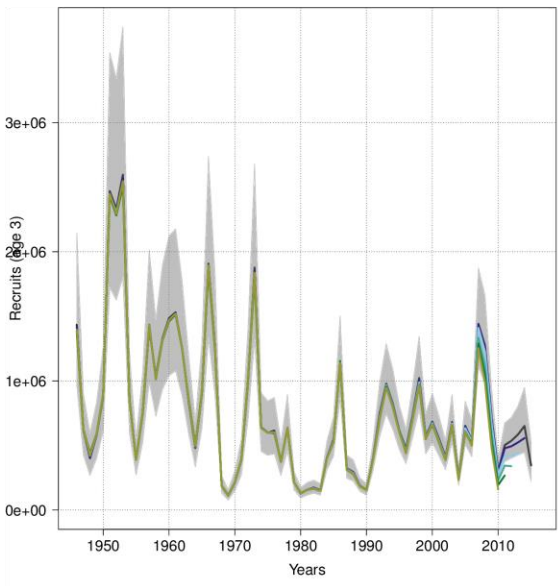

Figure 14: Retrospective diagnostics for recruitment at age 3

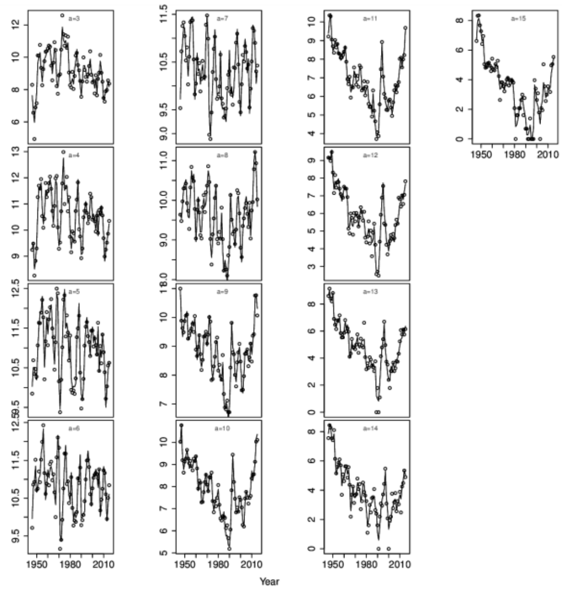

Figure 15: Observation time series for each age (circles) compared to the model predicted (line) for the residual catches.

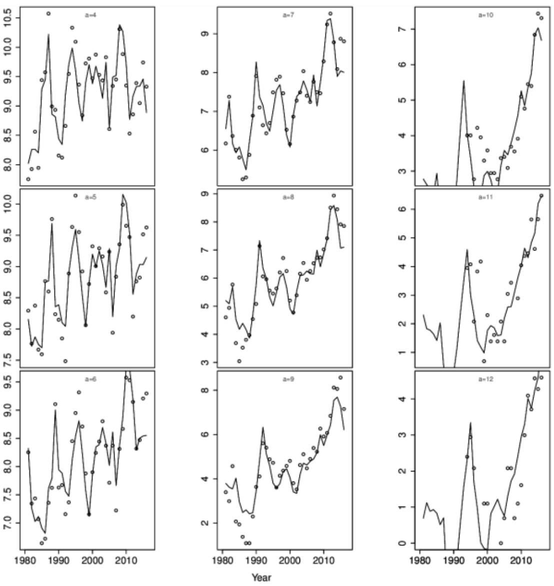

Figure 16: Observation time series for each age (circles) compared to the model predicted (line) for the survey fleet FLT15: NorBarTrSur

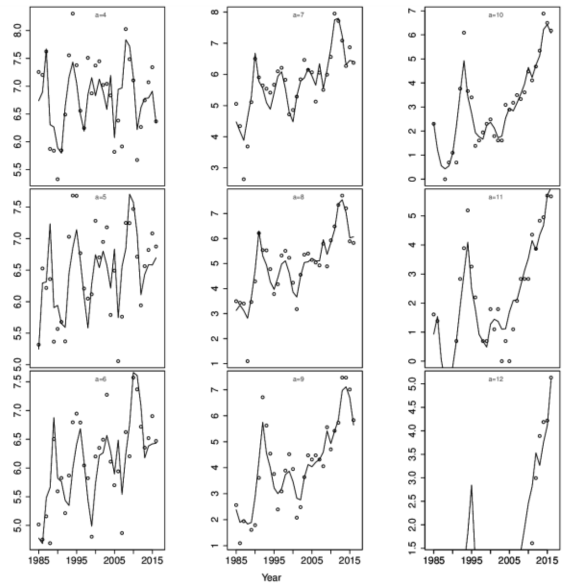

Figure 17: Observation time series for each age (circles) compared to the model predicted (line) for the survey fleet FLT16: NorBarLofAcSur

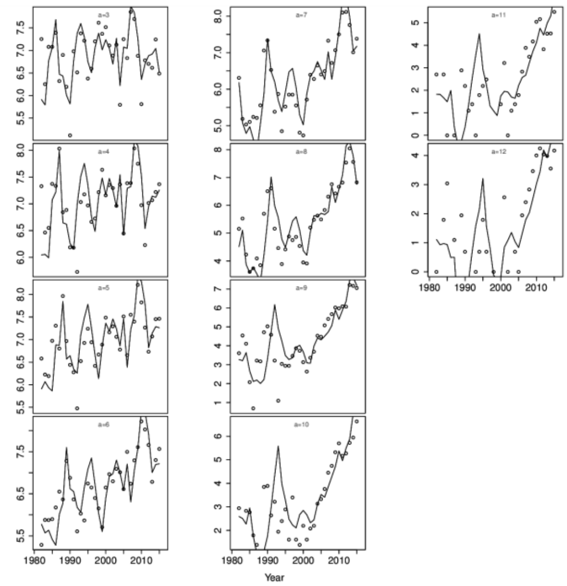

Figure 18: Observation time series for each age (circles) compared to the model predicted (line) for the survey fleet FLT18: RusSweptArea

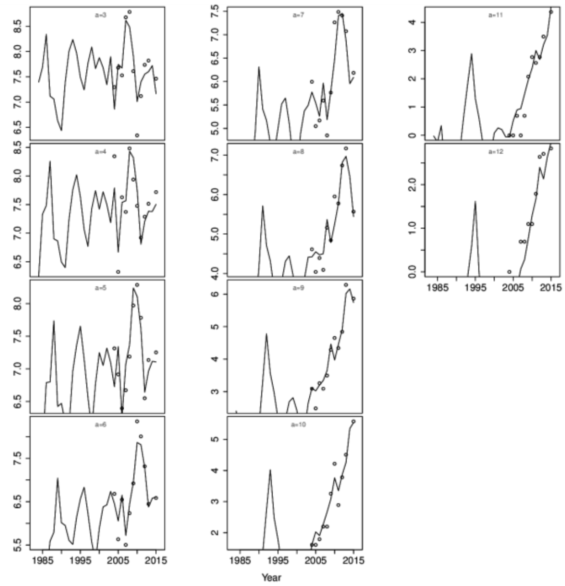

Figure 19: Observation time series for each age (circles) compared to the model predicted (line) for the survey fleet FLT007: Ecosystem

WD11

A. Aglen

B. IMR, norway

Barents Sea Winter Survey acoustic abundance estimates, with extended age distribution for the period 2002-2017.

In the NEA cod tuning, this time series has been combined with (added to) the Lofoten acoustic survey, and has been labelled as Fleet 16. For the Lofoten survey the estimates for ages 10-12 are probably available, while older ages may require some reanalyzing of survey data.

	Age group															Total	Biomass ('000 t)
Year	1	2	3	4	5	6	7	8	9	10(10+)	11	12	13	14	15+		
1994	858.3	577.2	349.8	404.5	193.7	63.6	12.1	3.7	1.7	0.9						2465.4	950
1995	2619.2	292.9	166.2	159.8	210.1	68.8	16.7	2.1	0.7	1.0						3537.4	713
1996	2396.0	339.8	92.9	70.5	85.8	74.7	20.6	2.8	0.3	0.4						3083.8	450
1997[1]	1623.5	430.5	188.3	51.7	49.3	37.2	22.3	4.0	0.7	0.1						2407.5	322
1998[1]	3401.3	632.9	427.7	182.6	42.3	33.5	26.9	13.6	1.7	0.3						4762.8	506
1999	358.3	304.3	150.0	96.4	45.1	10.3	6.4	4.1	0.8	0.3						976.0	224
2000	154.1	221.4	245.2	158.9	142.1	45.4	9.6	4.7	3.0	1.1						985.4	481
2001	629.9	63.9	138.2	171.6	77.3	39.7	11.8	1.4	0.5	0.21	0.028	0.000	0.000	0.000	0.000	1134.7	408
2002	18.2	215.5	69.3	112.2	102.0	47.0	18.0	3.0	0.4	0.17	0.09	0.000	0.000	0.000	0.012	585.9	416
2003	1693.9	61.5	303.4	114.4	129.0	114.9	34.3	7.7	1.9	0.40	0.04	0.030	0.000	0.000	0.000	2461.5	731
2004	157.6	105.2	33.6	92.8	30.7	27.6	17.0	5.9	1.2	0.16	0.09	0.005	0.003	0.000	0.000	471.8	241
2005	465.3	119.6	123.9	33.7	62.8	16.9	14.5	4.2	1.0	0.27	0.06	0.05	0.031	0.019	0.000	842.4	249
2006[2]	544.6	216.6	79.8	59.1	15.5	25.6	8.8	4.5	1.4	0.31	0.12	0.10	0.000	0.000	0.000	956.5	222
2007[1]	125.0	61.7	80.3	37.1	30.4	9.1	14.1	5.0	2.1	0.51	0.17	0.065	0.012	0.000	0.000	365.6	198
2008	68.8	97.6	210.2	306.1	140.6	69.4	21.6	12.2	3.1	0.8	0.03	0.07	0.007	0.000	0.000	930.4	846
2009	321.5	30.6	182.6	178.3	137.1	35.0	12.5	5.2	3.7	0.68	0.18	0.027	0.015	0.000	0.000	907.3	541
2010	485.4	59.4	34.7	121.9	174.7	162.3	44.4	13.8	3.5	2.51	0.85	0.06	0.06	0.040	0.010	1103.6	932
2011	389.4	124.8	47.1	29.1	80.4	107.7	105.4	17.1	4.5	1.52	0.85	0.25	0.29	0.06	0.002	908.6	777
2012[2]	950.6	72.7	133.9	52.7	37.7	69.4	126.1	77.0	10.4	3.44	1.66	0.60	0.23	0.042	0.08	1536.4	1030
2013	470.6	110.8	64.1	85.0	70.8	51.7	86.0	123.8	70.1	4.98	5.59	0.75	0.54	0.48	0.05	1145.3	1536
2014	630.1	139.1	220.0	117.8	91.5	65.1	37.5	77.3	63.2	22.41	1.92	1.13	0.28	0.07	0.29	1467.7	1301
2015	1140.8	127.0	94.9	154.2	118.3	98.0	80.4	20.5	68.3	21.89	3.19	0.67	0.24	0.08	0.024	1928.5	1308
2016	142.9	120.7	41.0	58.3	96.7	63.4	51.2	21.9	15.0	15.45	6.32	1.17	1.02	0.07	1.17	635.2	827
2017[2]	543.1	63.5	104.2	44.0	52.5	71.6	39.3	27.1	14.0	5.62	3.30	5.27	0.66	0.47	0.09	975.0	757

The first use of the StoX software to estimate cod abundance by age from the ecosystem 2004-2015

Wd to IBPArcticCod 3.-6. April 2017

Edda Johannesen and Sigbjørn Mehl

Background

The StoX software is developed at IMR (http://www.imr.no/forskning/prosjekter/stox/nb-no, Johnsen et al 2016). StoX estimates abundance with uncertainty. A strata system is needed to run StoX. StoX has been used to recalculate swept area estimates from the winter survey (Mehl et al. 2016), but has not been used for swept area estimation based on the ecosystem survey data - partly because a suitable strata system has not been included for this survey. Abundance index by age for cod from the ecosystem survey data has been calculated by PINRO (e.g. ICES 2016).

StoX has several advantages as it is free, it is relatively easy to use, it is transparent as all model settings and the data are stored together with the output, it is flexible and it provides estimates of uncertainty. StoX is increasingly used at IMR and also internationally (e.g. for the international mackerel survey, the international blue whiting survey, the North Sea sprat and herring survey). Here we provide the first estimates of cod abundance estimates by age from the ecosystem survey using StoX. This is not intended as the "final" version but to show the potential use of StoX.

Methods

StoX baseline settings and strata system

Here a strata system developed for a different purpose (the NRC project FISHDIV) is used (Figure 1A). The strata system included 11 strata that were chosen to be relatively similar in size and homogenous with regard to temporal development of temperature and abundance of older cod, as well as to account for differences in coverage in different years (Ellingsen et al. in prep.). In addition a strata west and north of Spitsbergen/Svalbard was included for the purpose of this WD. The 500 meter depth contour was used to delimit the Barents Sea.

The data was the "official" data from the survey stored at the Institute of Marine Research in:

http://tomcat7.imr.no:8080/DatasetExplorer/v1/html/main.html.

A filter in Stox ("FishStationExpr" under "FilterBiotic" under "Baseline") was used to remove denser stations (2005: 69, 2006: 164, 2007: 40) from two areas : the "shrimp area" (based on the design of the shrimp survey (Aschan and Sunnanå 1997) that was discontinued in 2004) and an area in south east in the Russian EEZ (2006 only, Figure 2). In addition only stations set out at predefined locations were included. Stations coded as special stations, pelagic stations and stations with technical problems (with the gear etc.) were excluded using filters in StoX (see Mehl et al. 2016). Maps of the stations included for each year are found in Figure 1

StratumArea was set to "Accurate". "RegroupLengthDist" were "LengthInterval" was set to 5 cm. that is because otoliths for age readings and individual weights are taken from each 5 cm length group at the survey.

Default settings were used elsewhere

Bootstrap and impute age

All or most of the cod at the survey is length measured. If the catch is subsampled, StoX calculated the total number of individuals based on the proportion subsampled. To get estimates by age rather than length, a routine in StoX ("ImputebyAge") search for individuals within the same length group and station which has a value for age. If such individuals are found, one of them is randomly selected and the age of that individual is used for individuals with missing age readings. If no adequate individuals are found, the same exercise is done on a stratum resolution, or finally, on a survey resolution (all strata).

Bootstrapping (resampling with replacement) is done by strata. Here 500 runs were used. The CV is estimated from the bootstraps in StoX. The estimates provided here is the mean, and the 5% lowest and highest estimates.

Results

The mean bootstrap estimates are presented in Table 1 and the CVs in Table 2. The estimates for the oldest age groups are very uncertain (Table 2).

The time series of mean estimates by year, 5% and 95% percentile for ages 1-12 are given in Figure 3.

The consistency (the correlation between age 1 in year y and age 1+1 in year y+1 is given in Figure 4. The consistency was highest for ages 5-11.

The temporal development of the strong 2004 and 2005 year classes are shown in Figure 5. Changes in distributions of these two yearclasses from 2004-2013 are shown in Figure 6.

Age vs length is plotted in Figure 7.

Summary and recommendations

There are some obvious errors in the age readings in the Norwegian data that should be checked. Better routines for quality check of age reading from the ecosystem survey should be implemented. Since the ecosystem survey was originally a capelin survey, and because of the many different task performed at the ecosystem survey the quality and the routines for quality check of cod data has not been as good as for e.g. the winter survey. This should be improved, together with a more complete quality check of the whole data set for cod 2004-2016.

The temporal development of the strong 2004 and 2005 year classes shows an increase up to age 5 and 6 (2010), suggesting incomplete coverage the youngest ages of these year classes. However, the high estimate in 2010 has a high CV. Most likely cohorts 2004-2005 had low catchability, e.g. because they were distributed high up in the water column, although there might be some issues related to the survey design and incomplete spatial coverage.

The CV's found here are in most cases comparable to the CV found at the winter survey (Mehl at al 2017).

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Aschan, M and Sunnanå, K. 1997. Evaluation of the Norwegian Shrimp surveys conducted in the Barents Sea and the Svalbard area 1980-1997. ICES CM 1997/Y:07.

ICES. (Aglen, A., Berg, E., Bogstad, B., Dingsør, G.E., Fotland, Å., Hallfredsson, E.H., Harbitz, A., Howell, D., Mehl, S., Planque, B., Staby, A., Vollen, T. et al.) 2015. Report of the Arctic Fisheries Working Group, ICES HQ, Copenhagen, Denmark, 19-25 April 2016. ICES CM 2016/ACOM: 06. 621 pp.

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Mehl, S., Aglen, A. and Johnsen, E. 2016. Re-estimation of swept area indices with CVs for main demersal fish species in the Barents Sea winter survey 1994-2016 applying the Sea2Data StoX software. Fisken og havet 10/2016. Institute of Marine Research, Bergen, Norway. 43 pp.

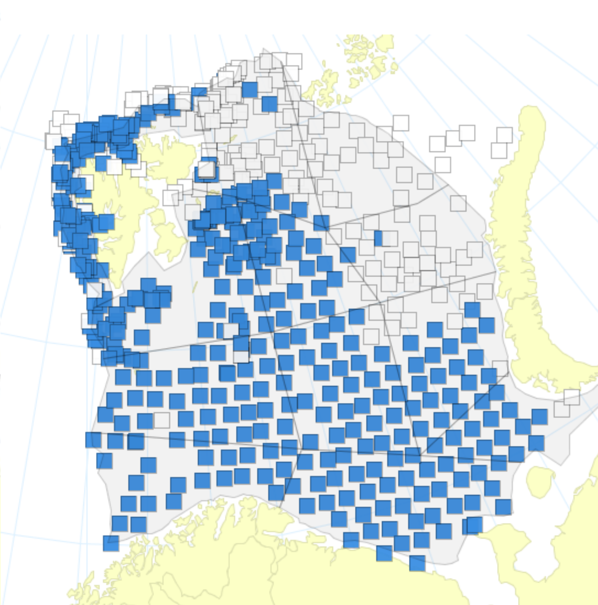
Table 1. Swept area estimates of cod ages 1 to 17 (million individuals) from the Barents Sea ecosystems survey 2004-2016.

Year/age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
2004	274.4	246	96.72	333.7	204.98	115.4	58.29	16.32	2.85	0.74	0.15	0.06	0	0.2	0	0	0
2005	256.4	125.2	190.9	42.89	136.73	44.77	25.69	9.38	2.61	0.89	0.06	0	0.06	0	0	0	0
2006	332.1	365.3	154.9	150.1	51.54	69.65	22.25	11.3	4.11	1.02	0.37	0	0	0	0	0	0
2007	260.6	313.7	367.2	111.4	75.4	13.71	24.86	4.71	1.87	0.3	0	0.38	0	0.1	0	0	0
2008	101.2	307.5	406.2	486.7	111.2	70.77	14.13	21.61	4.76	1.13	0.67	0.27	0.1	0	0	0.1	0
2009	393.2	66.81	244.3	276.4	452.32	161.4	37.08	12.57	10.91	3.67	1.1	0.39	0.25	0	0	0	0
2010	254.9	77.67	52.9	229.8	591.52	641.5	178.3	52.98	10.53	8.99	2.56	0	0.11	0.2	0	0	0
2011	240.2	121.7	116.3	107.1	275.76	435.6	255	45.62	10.73	2.53	1.71	0.67	0.33	0	0	0	0
2012	866.9	178.3	181.2	156.2	96.98	244.6	216	134.1	16.68	5.33	2.2	1.79	0.61	0.2	0.28	0	0
2013	479.8	573.3	259.2	168.7	138.44	66.15	151.7	156	71.69	10.2	3.58	2.4	0.31	0.5	0.19	0	0
2014	259.3	121.9	218.8	137.6	150.73	92.07	42.21	88.7	87.82	37.07	4.3	1.11	1.09	0.3	0.18	0.11	0
2015	394.6	143	183.2	255	186.9	83.84	83.3	43.27	45.75	31.54	9.16	2.1	0.26	1	0	0.1	0
2016	351.5	441.7	107.3	139.3	163.45	109.7	62.99	35.94	15.01	14.31	5.74	2.33	0.52	0.5	0.12	0.32	0.31

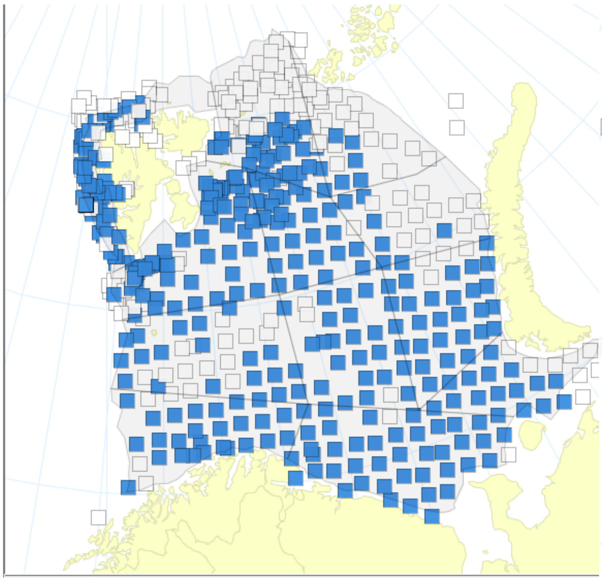
Table 2. CV (%) of abundance estimates of cod ages 1 to 17 from the Barents Sea ecosystems survey data.

Year/age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
2004	25	17	18	28	27	14	14	13	18	28	72	96		57			
2005	15	19	16	20	16	12	11	12	29	33	99		101				
2006	12	13	15	22	18	17	15	14	18	45	45						
2007	20	15	18	21	31	16	13	20	30	56		75		106			
2008	18	20	20	25	17	19	20	14	18	35	49	91	102			97	
2009	12	15	25	24	34	32	13	13	13	22	29	55	64				
2010	11	15	17	22	32	43	51	52	55	40	89		99	97			
2011	19	14	18	28	15	14	15	16	15	27	31	44	53				
2012	10	12	15	17	23	22	14	20	13	20	30	25	38	61	66		
2013	9	10	16	15	15	14	19	14	12	16	20	28	52	41	67		
2014	13	16	15	13	22	21	14	13	28	44	25	34	48	69	95	94	
2015	13	15	18	19	15	16	22	13	18	22	19	37	63	52		97	
2016	25	36	31	31	17	15	15	16	19	16	18	43	53	62	99	93	95

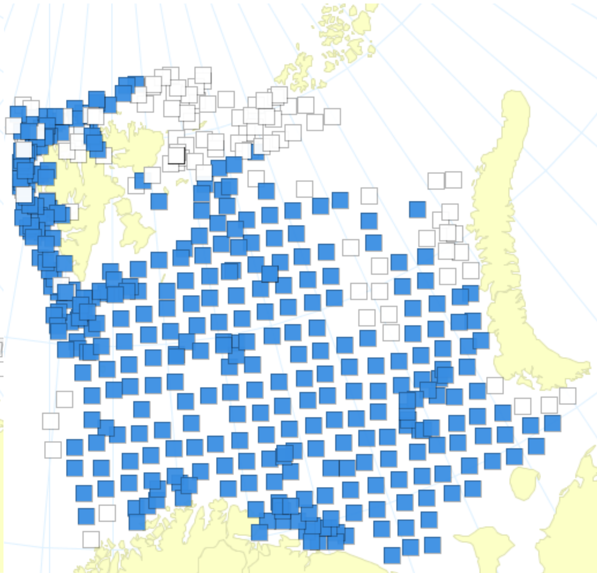
A) Strata system from fishdiv project



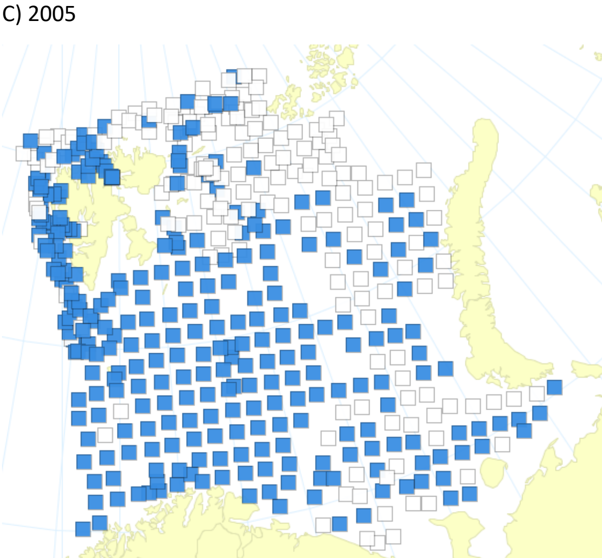
b) 2004



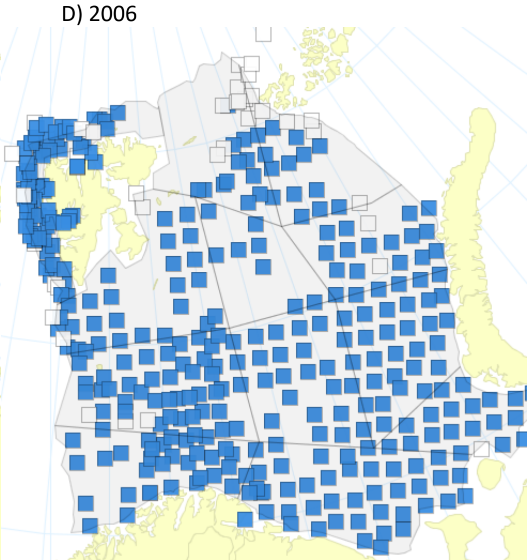
C) 2005



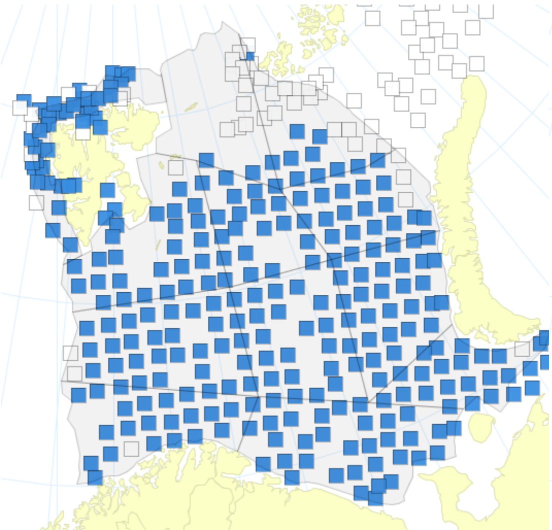
D) 2006



E) 2007



F) 2008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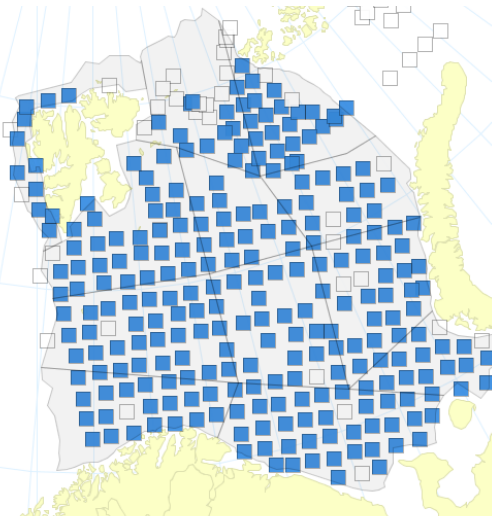
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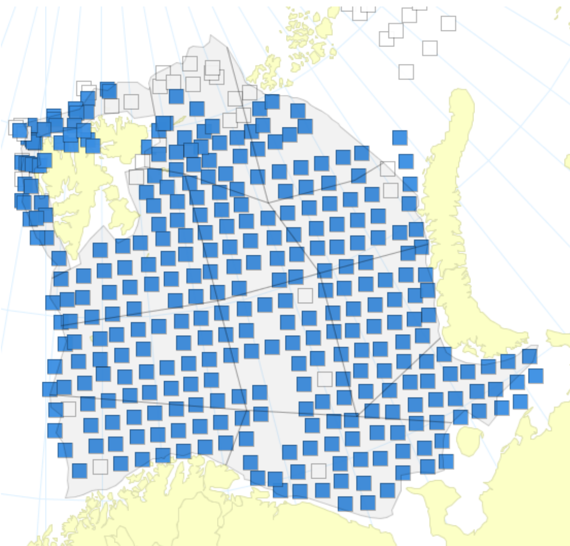
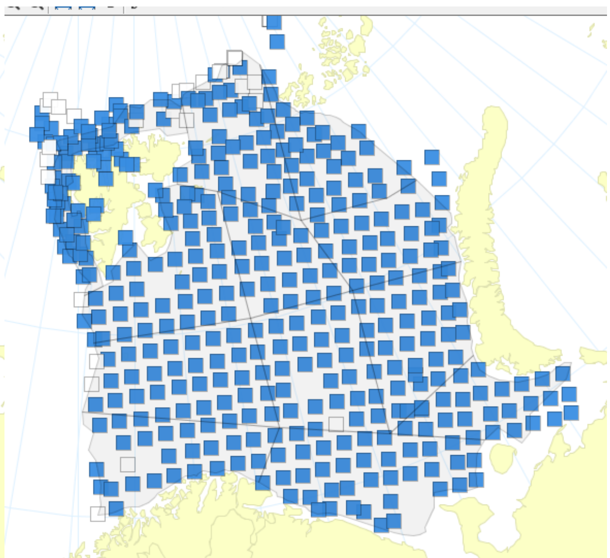
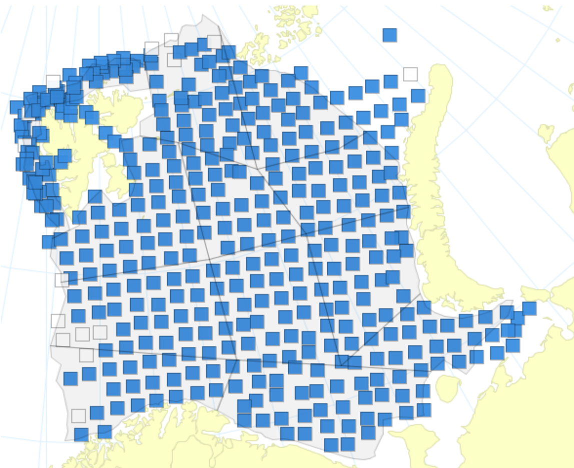
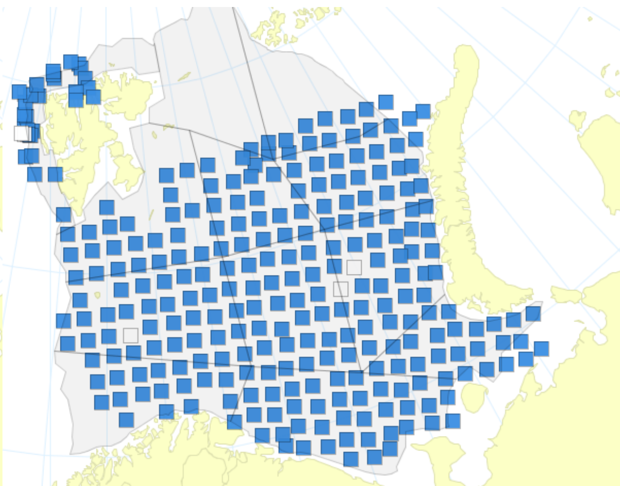
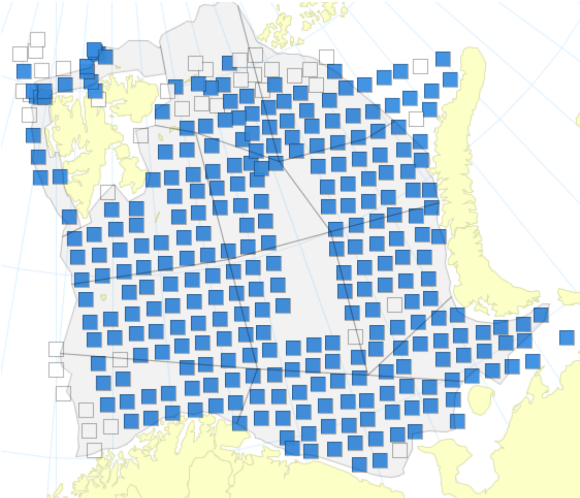

I) 2011

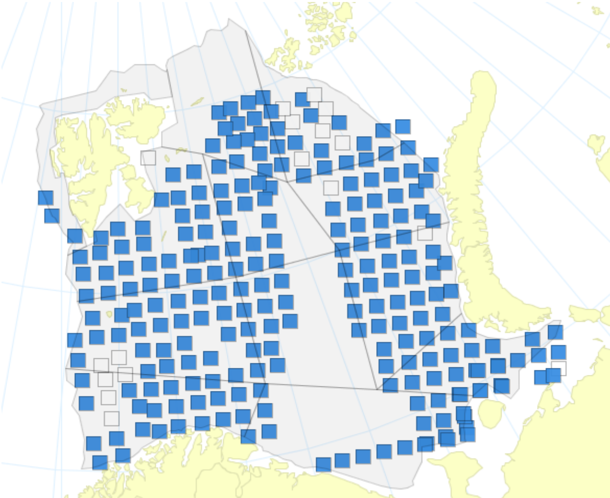

J) 2012


K) 2013


L) 2014



M) 2015



N) 2016

Figure 3. Strata system (A) and stations included in swept area estimates 2004 (b) to 2016 (N) . Blue squares stations with cod, white squares stations without cod. Screen dumps from StoX. The basic survey design is a 35 by 35 nm grid. North and west of Svalbard/Spitsbergen and aloing the shelf break there are steep depth gradients and a denser grid has been used, albeit somewhat variable amoing years. Denser stations in the survey area from the shrimp survey 2005-2007 are documented also a denser grid in southeast – flat fish survey ?(Figure 2), the reasoning behind denser stations in other areas has not been documented. “Holes” in survey grid 2004-2013 is due to stations that has been removed due to technical problems with the gear or other problems leading to shortage of survey time. In 2014 the northern area was not surveyed due to very unusual ice conditions limiting access. In 2015, the large hole is due problems with permission to trawl in the loophole, the poor coverage in 2016 it is due restrictions in the loophole and due to Russian military rehearsals.

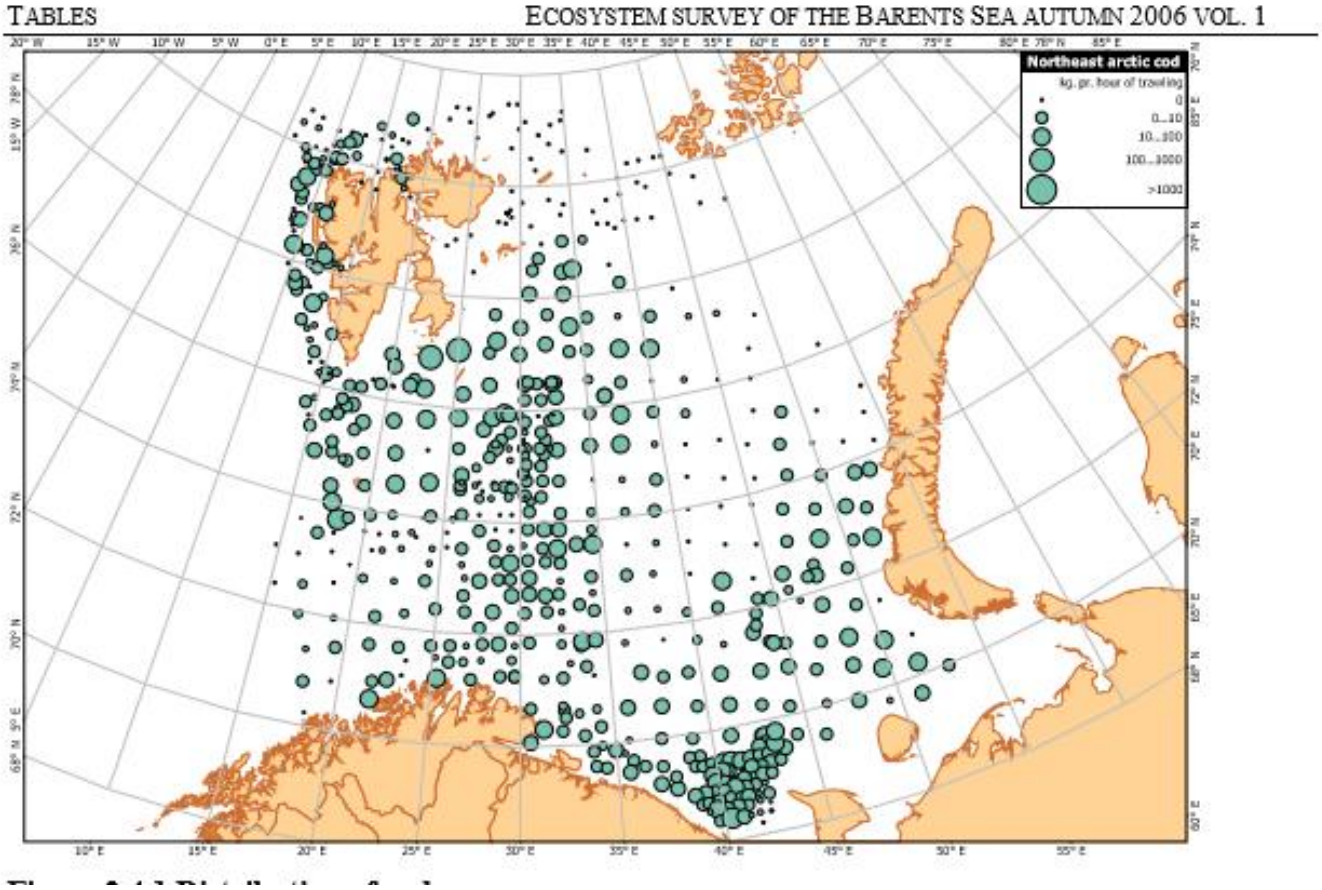


Figure 2. Cod catches ecosystem survey 2006. In the “shrimp area” Western entrance of the BS, and the Hopen Deep south-east of Svalbard/Spitsbergen) and in southeast, stations were “rarified” be excluding stations that were closer than 10 nm to stations in the regular grid. The maps is taken from Anon 2006.

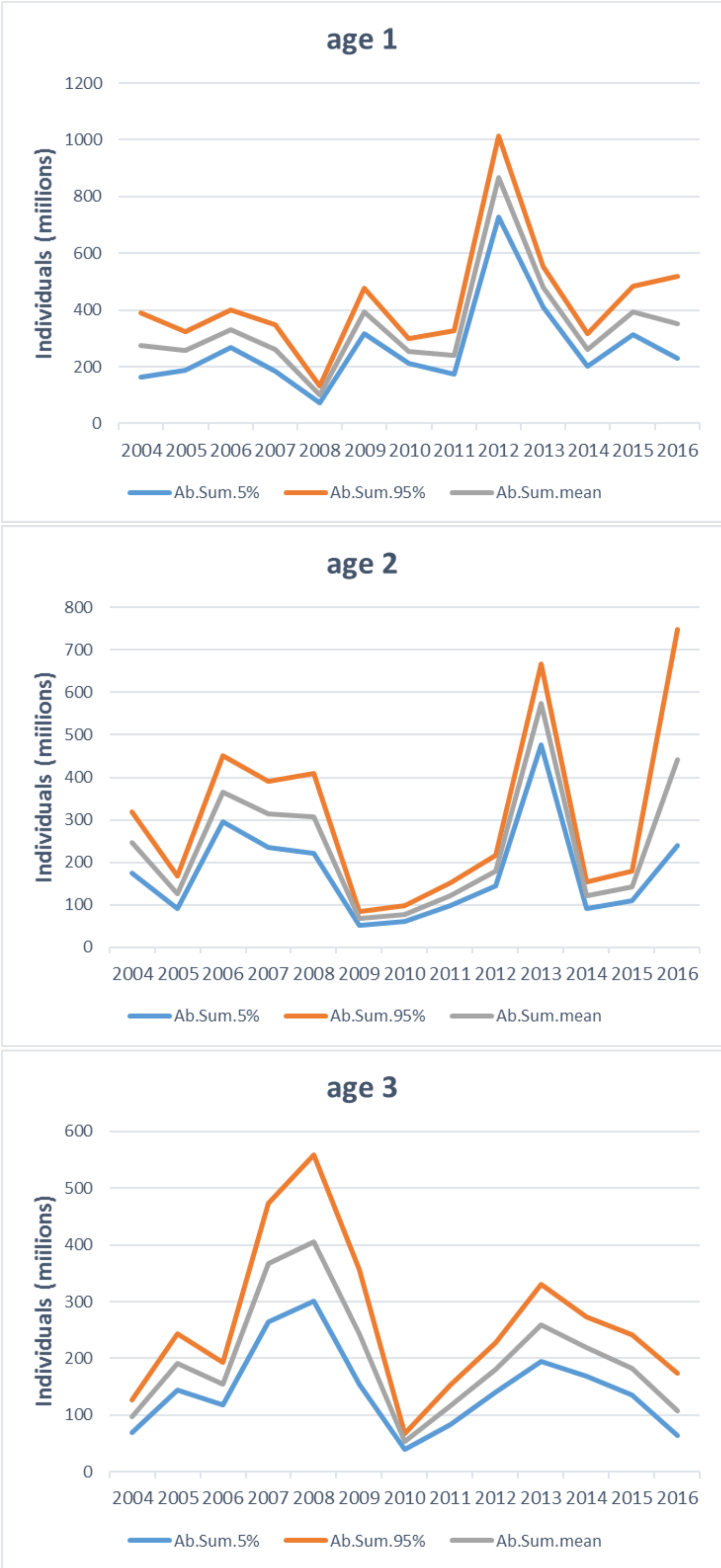


Figure 3. Bootstraps estimates by year), mean (grey line, 5% (blue) and 95% (orange) percentile.

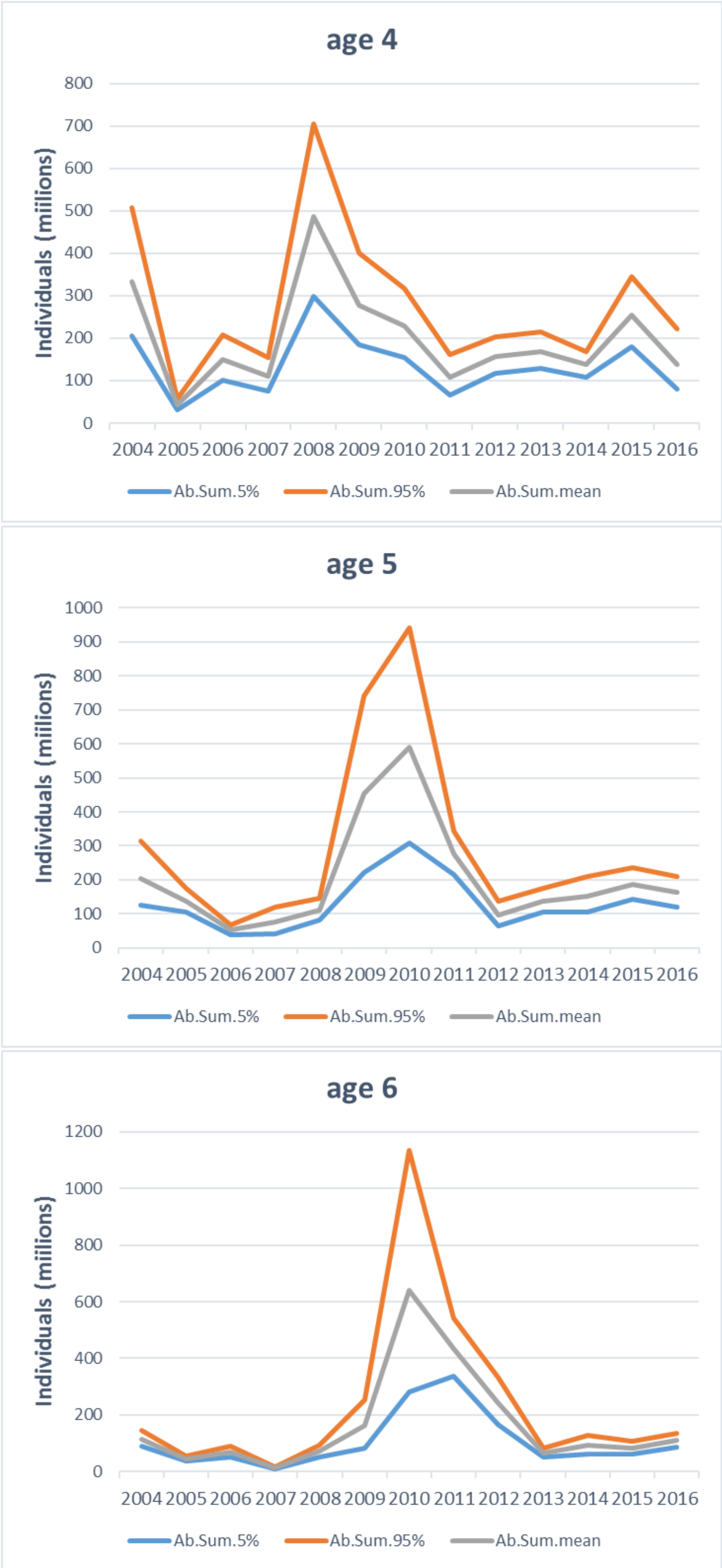


Figure 3 continued. Bootstraps estimates by year), mean (grey line, 5% (blue) and 95% (orange) percentile.

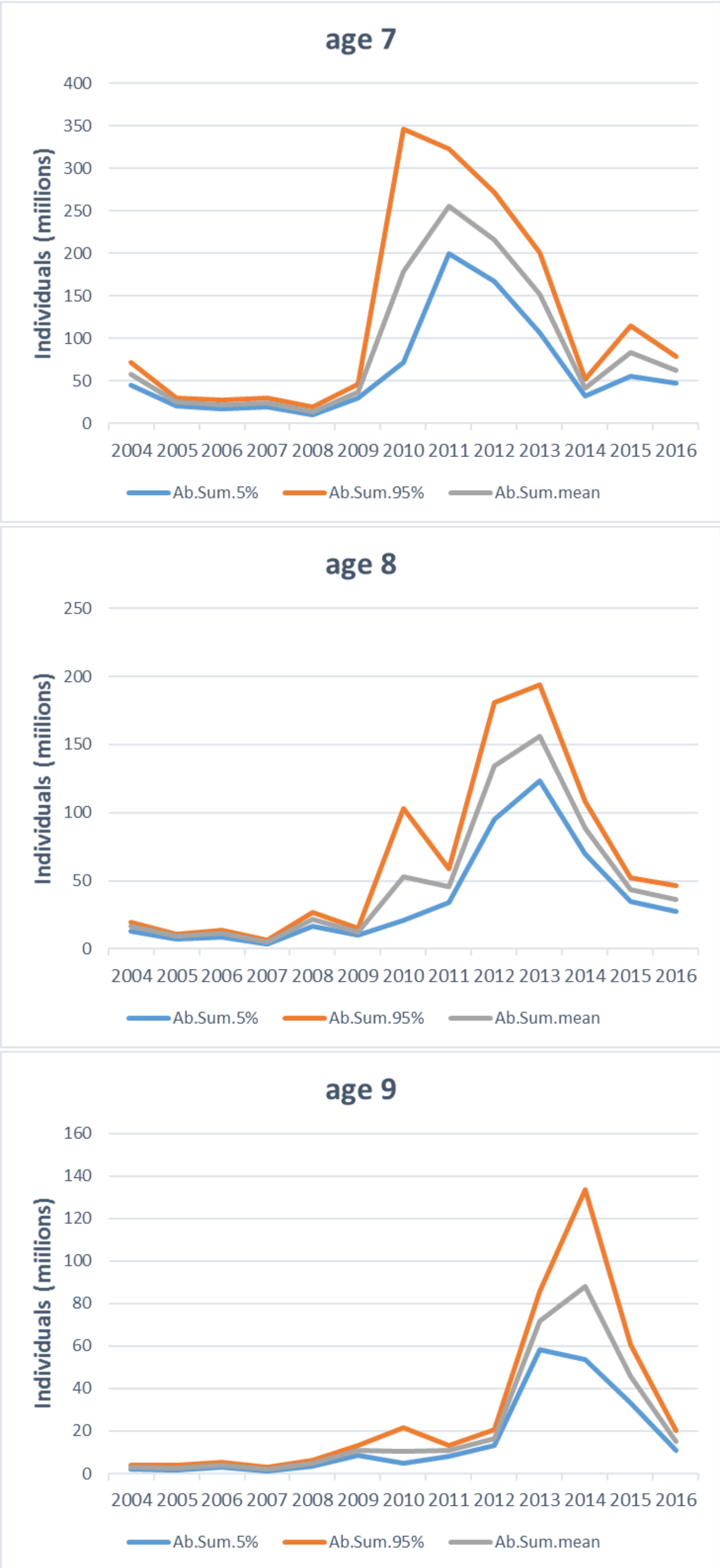


Figure 3 continued. Bootstraps estimates by year), mean (grey line, 5% (blue) and 95% (orange) percentile.

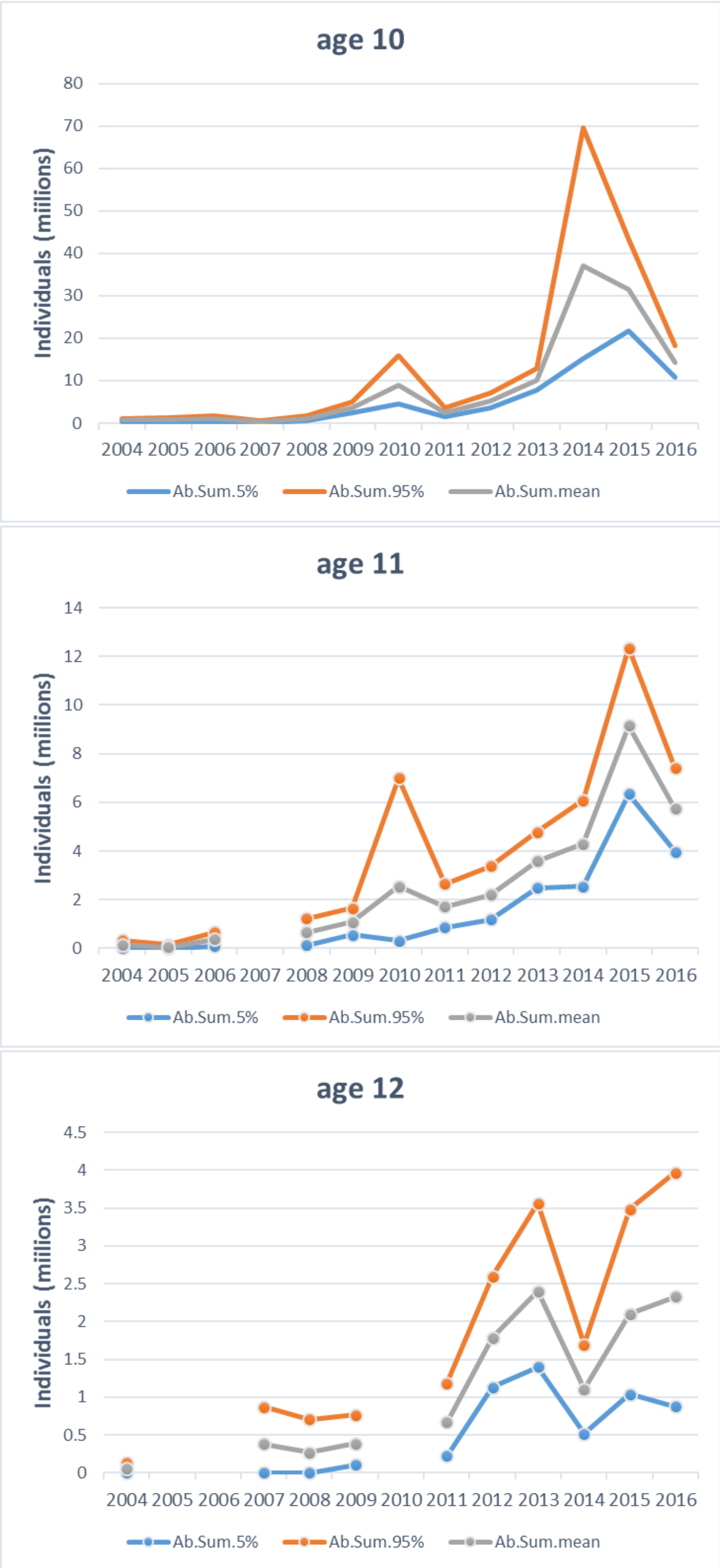


Figure 3 continued. Bootstraps estimates by year), mean (grey line, 5% (blue) and 95% (orange) percentile.

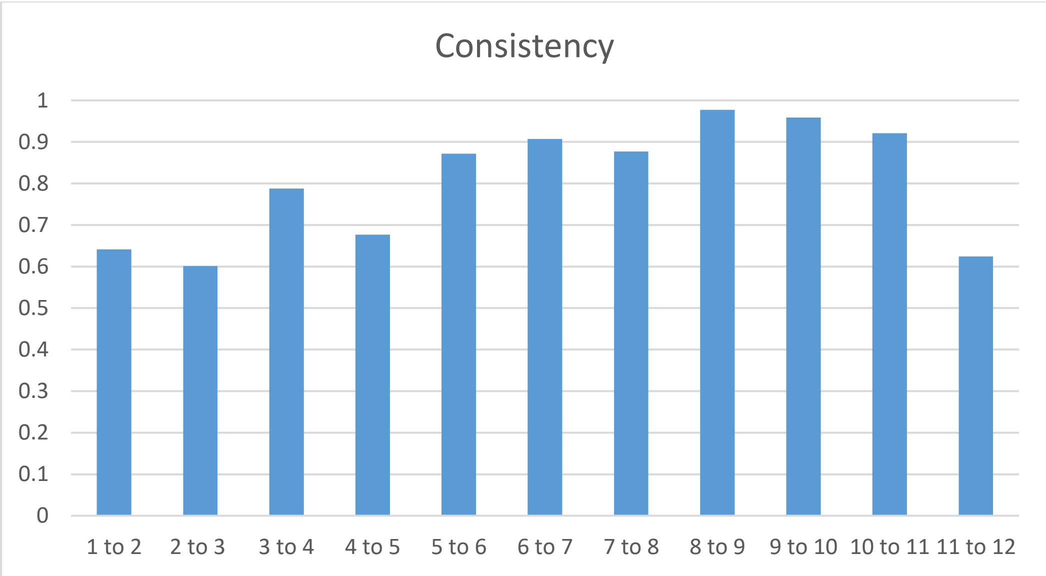


Figure 4. Consistency as the correlation between abundance estimate of age i in year y and abundance of age i+1 in year y+1.

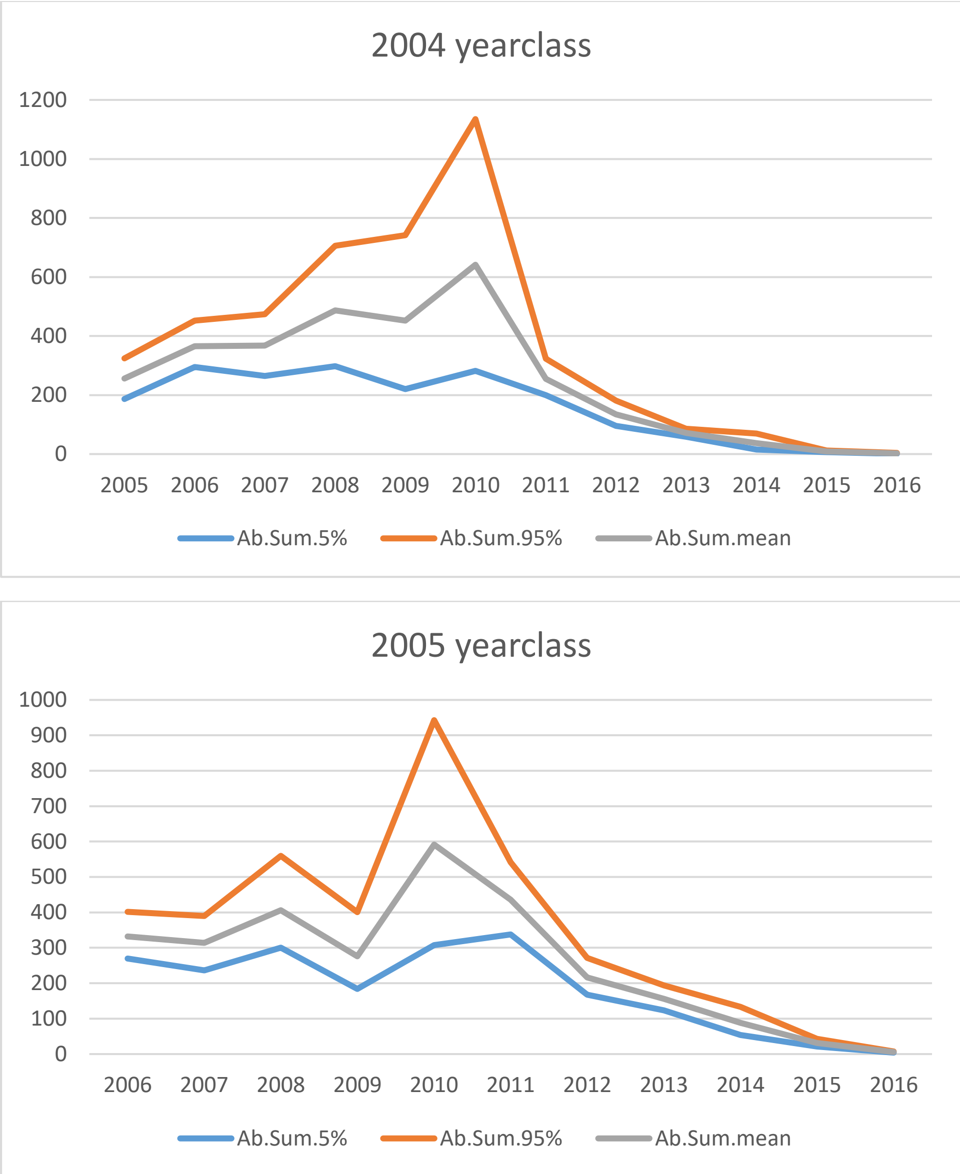


Figure 5. Development of year class 2004 and 2005 in 2005 to 2016. Million individuals.

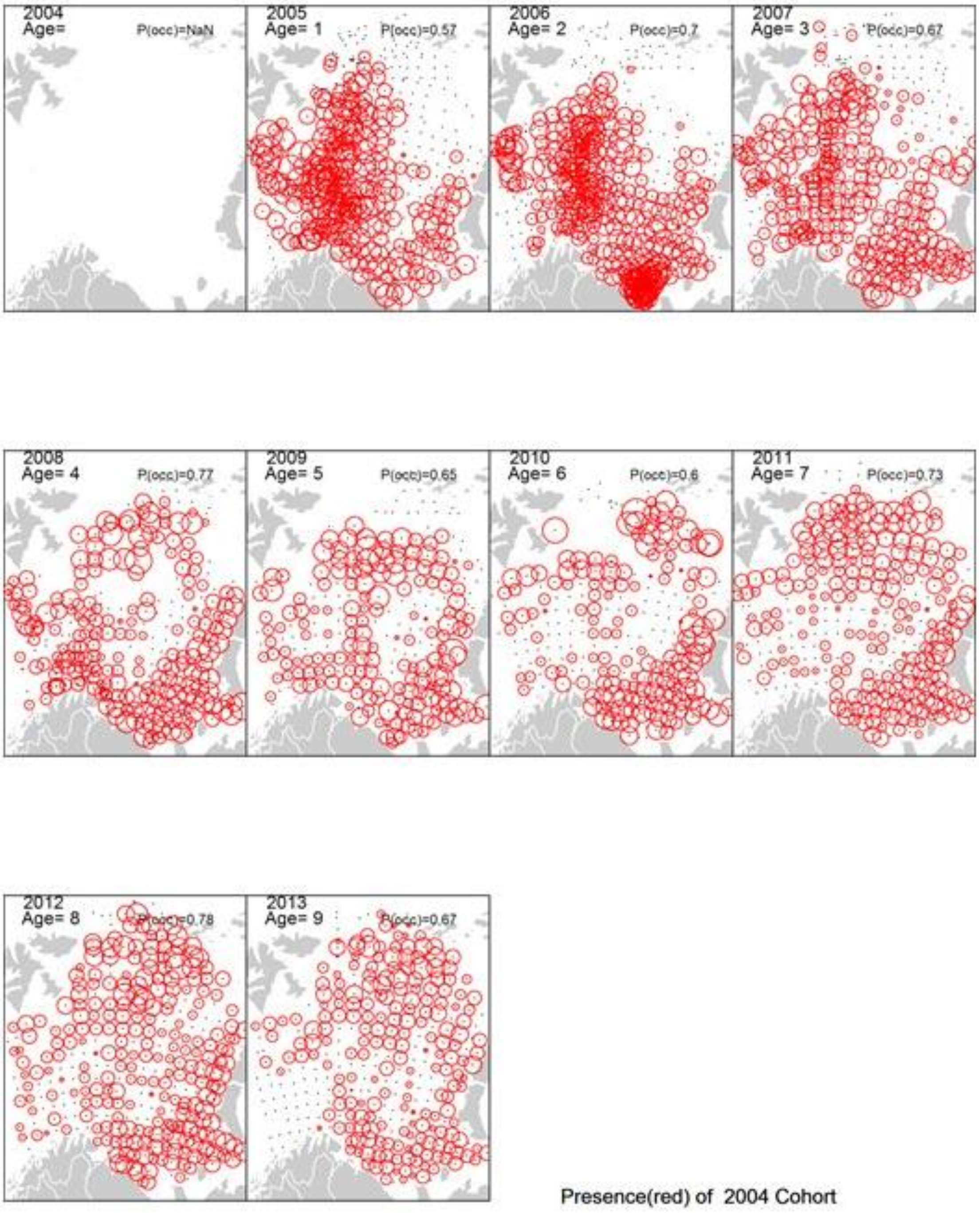


Figure 6a. Maps of catches of the 2004 year class at the ecosystem survey 2004-2013.

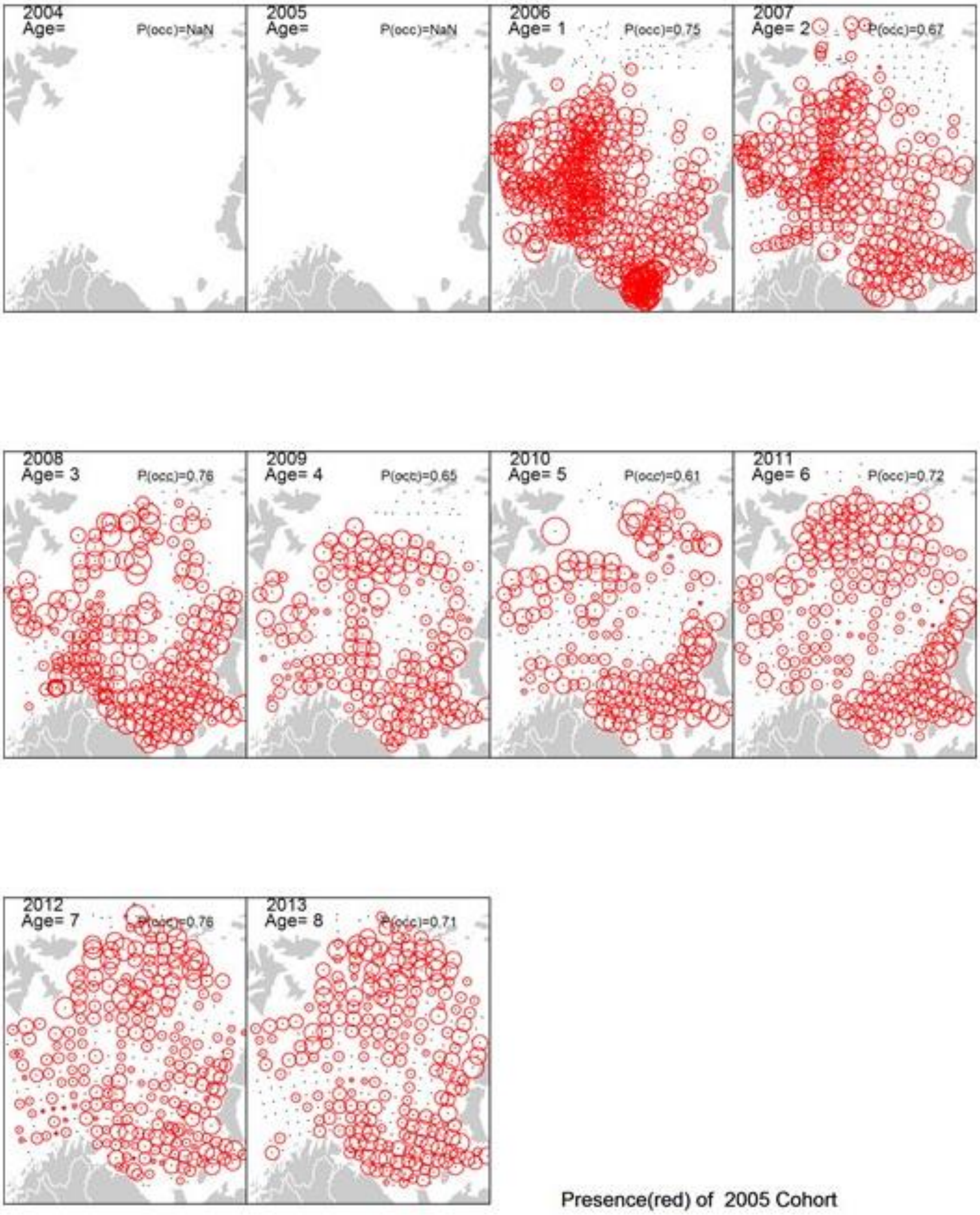


Figure 6b. Maps of catches of the 2005 year class at the ecosystem survey 2004-2013.

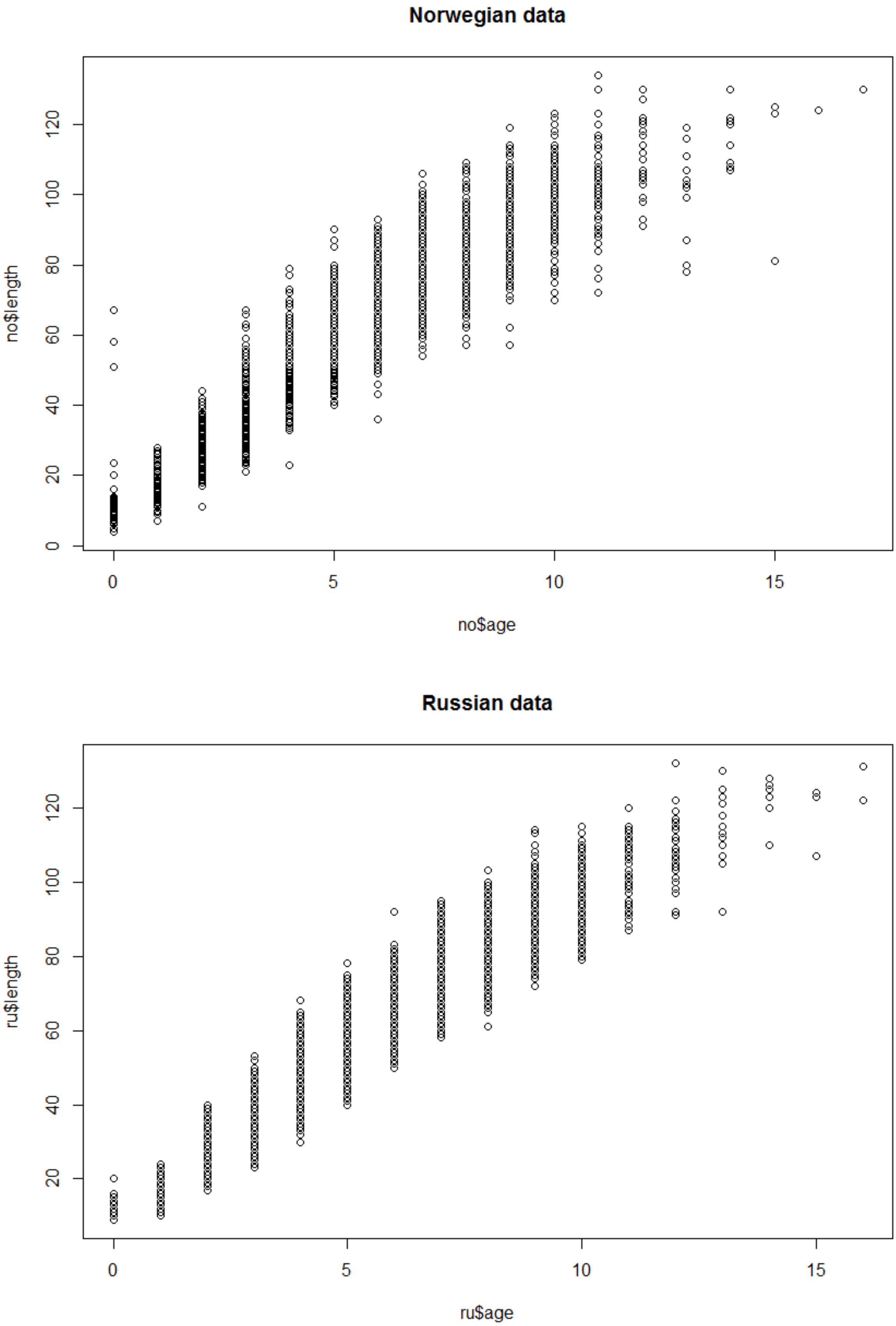


Figure 7. Age vs length data from ecosystem survey 2004-2006, split by nation.