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Report of the Benchmark Workshop on Roundfish and Pelagic Stocks (WKBENCH 2011)

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ICES International Council for the Exploration of the Sea

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Executive Summary

WKBENCH 2011 is the ninth Benchmark Workshop held under the ACOM procedures for assessment review. The meeting was held at IPIMAR in Lisbon, Portugal from 24–31 January 2011. The meeting was chaired by Jim Berkson (USA) and the ICES Coordinator was Bjarte Bogstad (Norway). George Tserpes (Greece) and Jim Ianelli (USA) participated in the meeting as invited external experts. There were 19 participants in the meeting representing eleven nations. The main objective for the meeting was to review data inputs and assessment methods for five stocks (North Sea saithe, North Sea haddock, NE Arctic haddock, Icelandic summer-spawning herring and southern horse mackerel) and to update Stock Annexes for these stocks (the recipes for conducting assessments to be applied by working groups over the next three to five years). No stakeholders attended the meeting. The meeting started with a note that the day set aside for a data workshop was not necessary as the data available for use in the assessments had been compiled prior to the meeting. The meeting agreed on a set of priority issues for each stock (related to data quality, data analysis, and assessment methods). All participants reviewed each of the assessments with some short discussion groups convened to deal with specific issues. The full report of the meeting includes a set of generic issues identified during the workshop and associated recommendations, followed by detailed stock-specific reports and recommendations. A key output of the workshop was an updated Stock Annex for each stock.

The workshop faced some problems in fully addressing its terms of reference. These arose from the magnitude of items to review and the active development of model alternatives and datasets during the relatively short, eight day meeting. Considerable progress was made in this regard but this limited the ability to cover all aspects of every stock thoroughly. Specific points covered included:

1) Icelandic summer-spawning herring

   a) Preliminary analysis of the stock data using a statistical catch-at-age model was consistent with the adapt model that has been used since 2005.

   b) Retrospective bias was apparent but tended to be one-sided and only over stock increases. The fact that the retrospective pattern was well contained by the confidence bands of the primary assessment was considered within the assessment uncertainty.

   c) The treatment of additional natural mortality due to *Ichthyophonous* infection was discussed during the week and an approach to present the near-term consequences to management was developed.

2) North Sea haddock

   a) This assessment presented standard XSA application and contrasted results with a statistical state-space approach developed by DTU-AQUA (SAM). Whereas the XSA showed consistent behaviour relative to retrospective patterns, the SAM results a more variable retrospective pattern

   b) A linear cohort-based approach should be used to predict growth

   c) There is support for the hypothesis that haddock in the North Sea and West of Scotland is one biological unit, but this needs more investigation by WGNSSK

   d) Reference points should be updated, but this work was not completed during the meeting

3) Southern horse mackerel

   a) The workshop explored application of a model that was developed for Chilean jack mackerel and recently accepted based on simulation test performance. Initial evaluations indicate that this approach was suitable and hence is planned for the next assessment.

   b) In the course of this evaluation, issues related to patterns in the survey data indicated some peculiarities and outliers; for example there were some years where old horse mackerel (>5 years) were relatively abundant whereas in most years these age groups were a small component of the survey results. These should be investigated in more detail and perhaps a bootstrap approach to create alternative datasets to evaluate this uncertainty.

   c) Reference points were discussed and the notion of using recent trends was developed. Specifically, a 5-year window of SSB trends (slope) and uncertainty was put into the model. Three alternative "windows" were presented (2005–2009, 2006–2010, 2007–2011). Whereas absolute scale of fishing impact (relative to biomass reference points) was not specified, this was considered useful in the near term to provide practical advice on adjustments to current TACs.

4) North Sea Saithe

   a) Analyses comparing XSA runs with and without fishery cpue data indicated that retrospective patterns degraded when they were excluded. The application of carefully evaluated log-book data using a GLM approach was seen as an improvement and should be used in the model.

   b) The data quality (e.g., estimates of catch-at-age) was noted as being a concern for this stock. For this reason, the group recommends developing a statistical catch-at-age model so that assumptions about data quality can be removed.

   c) A new survey was presented which covers the coastal region of Norway for young saithe and was considered for inclusion.

   d) There was concern over the apparent spatial distribution of the fleet in recent years to primarily the southern region. Also, prior to the next assessment the group was concerned that data from the French fleet be made available.

5) NE Arctic haddock

   a) XSA was the primary model developed for this stock and initial settings indicated that a large number of iterations were required for convergence and that this generally had the effect of increasing the stock biomass as the number of iterations increased (to reduce the catchability residuals).

   b) The retrospective pattern observed for this stock was seen as an issue and specifications on shrinkage parameter moderated this some.

Of the more general issues identified and discussed at the meeting, the key recommendations include:

1) Efforts to include external sources of natural mortality (e.g., via multispecies models, infections, etc) were generally seen as positive developments and serve to communicate how changing ecosystem conditions affect management advice.

2) That general linear models and related methods be used to improve the standardization of cpue series used in assessments.

3) That statistical catch-at-age models continue to be developed and applied for stock assessments since the data quality can be explicitly acknowledged.

4) That biological reference points be based on the latest assessment models and data where information and/or accepted model results indicate a significant change.

1 Introduction

The first couple of days of this benchmark was devoted to background presentations of each stock focusing on biology, life history, ecology, history of the fishery, history of past assessment methodologies and data used. The following days were then focused on resolving the assessment issues to the extent possible, with a view to revising the Stock Annexes for adoption for the following years and to set recommendations for future work.

The results of the Benchmark for each stock are given in Sections 2–6 and then the data collection issues are considered in Section 7. The list of participants is given in Annex 1, the Agenda in Annex 2, the Terms of Reference are given in Annex 3, and the Recommendations in Annex 4. The new stock annexes are given in Annex 5 and the Working Documents in Annex 6.

We thank IPIMAR for kindly hosting the meeting.

2 Icelandic herring

2.1 Current assessment and issues with data and assessment

The current assessment is done with NFT-Adapt on catch-at-age matrix and a tuning-series from an acoustic survey in the autumn as described in the stock annex and by Gudmundsdóttir (2011). In previous assessments, one of the main concerns has been the retrospective pattern in the outcome (e.g. ICES 2008; 2010a). Since the autumn 2008 when the herring stock was first found to be seriously infected by *Ichthyophonus hoferi*, different and new issues started to affect the assessment (Óskarsson and Pálsson, 2011; ICES, 2010a). Several other issues have been identified in previous assessment reports and other identified at WKBENCH in 2011. All these issues are listed in the table below, and if and how they were dealt with at WKBENCH:

Issue with data or assessment	Dealt with at wkbench or not
Issues related to retrospective patterns in the assessment have been highlighted in the assessment reports for some years, and has even lead to rejection of the assessment.	The retrospective patterns were addressed at WKBENCH (Gudmundsdóttir, 2011; Magnusson, 2011; Section 2.8.2 below). The conclusion was that they show a decreasing trend and they are within the 95% confidence interval of statistical assessment approaches.
Issues related to the infection of the stock include: estimating the prevalence, the corresponding M—i.e., whether all infected fish dies.	These issues were presented in Óskarsson and Pálsson (2011). The meeting concluded that the significance of additional mortality on catch advice needs to be presented but that underlying recommendations (BPA etc) (e.g. ICES 2010a) remain appropriate.
The procedure of adding the estimated M caused by the infection (Minfection) to the fixed M of 0.1 may cause problems because the fixed M is poorly determined	The currently used M of 0.1 is the same as has been estimated and used for North Sea herring (age 4+) based on previous studies and is thus defensible(see 2.8.3).
Evaluation of reference points for the stock and determination of MSY based reference points.	Preliminary results were presented (i.e., SPR and YPR evaluations) but a more complete analysis will be presented to the ICES meeting of NWWG in April 2011.
A formal evaluation of the harvest control rule (HCR) or alternative for this stock is lacking	An evaluation is planned for presentation at the ICES meeting of NWWG in April 2011.
Issues with survey data concerning its variation in time in relation to the fishery.	Dealt with by Gudmundsdóttir (2011) and concluded that estimation of the indices are appropriate (see 2.2.3)
Issues with survey data related to the age composition errors.	Dealt with by Óskarsson (2011a) and concluded that age composition computations are appropriate. (see 2.2.3)
Issue with using 5 years average fishing pattern instead of 3 years average in the stock projection, because of possible temporal trends.	This was evaluated at WKBENCH and concluded that using 3 year average is more appropriate (see 2.9.1).
Issue with projecting weight-at-age based on three year average or alternative.	Dealt with by Óskarsson (2011b) and concluded that a relationship that use the weights in the year before are more appropriate (see 2.9.1).

Issue with data or assessment	Dealt with at wkbench or not
A suggestion of using index of number at age 1 from a juvenile acoustic survey and a relationship from Gudmundsdóttir *et al.* (2007) to predict the number at age 3 in the stock projection (i.e. recruits) instead of applying the value of geometric mean across the whole time series.	Introduced at WKBENCH and concluded using juvenile survey data was reasonable but that sensitivities (in projections) should also be considered (e.g., using the geometric mean). (see 2.9.1).
Adopting an approach for the stock projection, and used in the assessment 2009 and 2010 (e.g. ICES 2010a), of decreasing the number-at-age according to the observed prevalence of infection. This assumes all infected fish die in the spring before spawning and can therefore be considered as lost to the stock.	Introduced at WKBENCH (Óskarsson and Pálsson, 2011) and concluded that this assumption was reasonable (see 2.9.1). Also that for projections, a scenario with the infection rate declining to "normal" levels in 5 years or so (using some examples from a similar outbreak that occurred in Norwegian spring-spawning herring in the 1990s).

2.2 Compilation of available data

2.2.1 Catch and landings data

No changes, or additional data, from what is described in the stock annex were used. It indicates that age-structure matrices for age 2–15+ for the period 1947 to 2010 were available.

2.2.2 Biological data

No changes, or additional data, from what is described in the stock annex were used for weight-at-age and age-at-maturity.

Because of the *Ichthyophonus hoferi* infection in the stock, the estimated natural mortality caused by it ($M_{infection}$) is estimated for each year and the estimates are then added to the fixed M=0.1 that has been used for decades for the stock. This is the same procedure as explained in the updated stock annex and was used in the 2010 assessment (ICES 2010a). Further discussion about M is found below (Section 2.8.3).

2.2.3 Survey tuning data

The only available survey tuning data for the stock is the autumn/winter acoustic survey (IS-Her-Aco-4Q/1Q).

No changes, or additional data, from what is described in the stock annex were used for the survey data. It indicates that age-structure matrices for age 3–15+ for the period 1973 to 2010 were available. There is one change from recent assessments. In the 2007–2010 stock assessments, the surveys from the fishing seasons 1997/1998 and 2001/2002 were omitted from the tuning as they were not considered to cover the stock fully. Analyses made at WKBENCH by Gudmundsdóttir (2011) did not show that they are very different from the other surveys, so it was recommended to include them again in the tuning-series. Thus they were used in the assessment introduced below.

There has been a suspicion that the age composition in the acoustic surveys of Her-Vasu might be inadequately determined for some years as results of insufficient biological sampling in the survey. Thus, the survey indices from the years 1986 to 2010 were validated by comparing them to the catch composition the same year and determine if the survey indices needs to, and then can, be revisited and recalculated with for example more adequate biological samples originating from the commercial catch (Óskarsson, 2011a). The analyses revealed that all the major discrepancies between the proportion of the age groups in the catch and in the survey could be explained by the nature and location of the fishery and/or different spatial and temporal distribution of the fishery and the acoustic surveys. Thus, there was neither reason nor justification to revisit the acoustic measurements and recalculate the indices with for example different biological samples.

The inter-annual variation in timing of the survey, taking place from October to March, has caused some concerns, particularly with respect to timing of the fishery. In the late 1990s it was tried to account for this different timing in the assessments, by lowering the indices by some means. As it was done differently each year, this procedure was stopped and the indices used as they were obtained from the surveys. But different timing means that the magnitude caught before/after the survey differs between years. This was revisited at WKBENCH and verified if this approach should be taken up again (Gudmundsdóttir, 2011). The conclusion of that work was that approximately 80% of the catches are on average taken before the survey (2009/2010 not included) and its variability between years does not give a reason to change the procedure.

2.2.4 Commercial tuning data

Not relevant.

2.2.5 Industry/stakeholder data inputs

Not relevant.

2.2.6 Environmental data

Not relevant.

2.3 Stock identity, distribution and migration issues

The Icelandic summer-spawning herring is constrained to Icelandic waters throughout its lifespan. Results from various studies including tagging experiments around the middle of last century, studies on larval transport, and studies on migration pattern and distribution, all suggest that the stock is local to Icelandic waters. Until 2010, no specific genetic studies have taken place to distinguish the stock from the two other herring stocks around Iceland (Icelandic spring-spawning herring and Norwegian spring-spawning herring). However, a project (HERMIX) with that as one of the objectives started in 2009 and is ongoing in cooperation with several institutes in Iceland, Faroe Island, Denmark, and Norway. These three stocks are distinguished on the basis of their spawning time and spawning area, as presented by their names. In practice, the maturity stage of catch samples is used to distinguish Her-Va from the other stocks in a mixed fishery.

The spawning of the stock takes place in July off the SE, S and SW coast (Jakobsson and Stefansson, 1999) with the maximum activity around middle of July (Óskarsson and Taggart, 2009). The nursery grounds are mainly in coastal areas off the NW and N coast, but occasionally also in coastal areas off the E, SE, and SW and W Iceland (Gudmundsdóttir *et al.*, 2007). The location of the overwintering of the mature and fishable stock has varied during the last 30 years (Óskarsson *et al.*, 2009). Prior to 1998 it was mainly off the SE and E Iceland but from 1998 to 2006, the overwintering took place both off the east and west coast, with increasing proportion being in the western part. Since then (winters 2006/2007 to 2009/2010), most of the stock has been located in high density in coastal waters in southern part of Breidafjördur in western Iceland.

The observed changes in location of the overwintering of the stock, or during the period of the year when the acoustic surveys takes place, have the consequences that the historical coverage of the survey is not fully spatially fixed. The procedure has been to cover at least all previously known overwintering location. Because of the changes in the overwintering distribution that have been observed both the fishing fleet and the various research surveys, the coverage of the survey has in fact increased throughout the series. However, because of good communication with the fishing fleet and information from other research surveys covering the continental shelf of Iceland, there are no reasons to suggest that significant part of the stock has been excluded from the survey in the past because of less survey coverage.

2.4 Influence of the fishery on the stock dynamics

The stock collapsed in the end of 1960s. The reason was probably related to high fishing mortality and eventual recruitment failure (Jakobsson, 1980). This indicates that the fishery affects the stock dynamics. Subsequently, a generally cautious allowed TAC based on $F_{0.1}$ has been implemented which may have helped the more or less continuous increase in stock size since then. Changes in fishing patterns may have also influenced the stock dynamics, for example the pelagic trawl fishery during the years 1996–2007 (Gudmundsdóttir, 2011), but this is poorly understood.

2.5 Influence of environmental drivers on the stock dynamic

The influence of environmental drivers on the stock dynamic has almost exclusively been examined with respect to recruitment variation. As introduced at WKBENCH, recruitment variation has been found to be positively related to sea temperature (Jakobsson *et al*., 1993) and Óskarsson and Taggart (2010) showed with generalized linear model (GLM) that 64% of the variation in the recruitment variation during 1963 to 1998 could be explained by incorporating total egg production constrained to the repeat spawners (40%), the North-Atlantic Oscillation (NAO) winter-index (18%), and ocean temperature (6%).

2.6 Role of multispecies interactions

2.6.1 Trophic interactions

Adult herring is food resource for various animals in Icelandic waters according to various researches, and listed in the Stock Annex, but the annual consumption of herring by the different predators is relatively unknown. An increased predation of herring by cod has been observed in stomach analyses in the Icelandic groundfish survey since the *Ichthyophonus* outbreak started in the herring stock in November 2008, even if it has not been quantified. However, results from the North Sea suggest that predation of herring is relatively minor (ICES, 1987) and it is probably applicable to Her-Vasu.

2.6.2 Fishery interactions

The amount of bycatch of Icelandic summer-spawning herring is estimated throughout the fishery of Norwegian spring-spawning herring off east Iceland during the summer months. The stocks are separated on the basis of their maturity stage. The estimated bycatch in recent years has been insignificant, or from 500 to 2500 tons. Apart from this, Icelandic summer-spawning herring is not considered to be in significant amount as bycatch in other fisheries, and the fishery of the stock is relatively clean fishery.

2.7 Impacts of the fishery on the ecosystem

Not relevant at this point as it has not been tackled at WKBENCH or elsewhere.

2.8 Stock assessment methods

2.8.1 Models

During the WKBENCH meeting, assessments results from three different assessment models were introduced (Gudmundsdóttir, 2011; Gudmundsson, 2011; Magnusson, 2011): NFT-ADAPT (VPA/ADPAT version 3.0.3 NOAA Fisheries Toolbox), Coleraine statistical catch-at-age model (Hilborn *et al.*, 2003), and a new version of TSA (older version see Gudmundsson, 1994).

2.8.2 Retrospective patterns

In previous years there have been concerns regarding the assessment of the stock because of retrospective patterns of the models. No assessment was provided in 2005 due to data and model problems and in the two next consecutive years, ACFM rejected the assessment due to the retrospective pattern. In the next three years' assessments (2007, 2008 and 2009), there was observed an improvement in the pattern from NFT-Adapt, but they reoccurred to some degree in 2010.

The assessments done at WKBENCH with the three different models all showed retrospective patterns, as expected, but they were seemingly worse from Coleraine (Magnusson, 2011) than NFT-Adapt (Gudmundsdóttir, 2011) and TSA (Gudmundsson, 2011). The retrospective results were contained within the 95% confidence interval of the estimated SSB for all years (Figure 2.8.2.1; Magnusson, 2011). This pattern suggests a bias towards high values during stock increases but behaviour during a declining condition is unavailable. Therefore a bias correction is inappropriate and a further study is needed to understand the cause of the observed pattern.

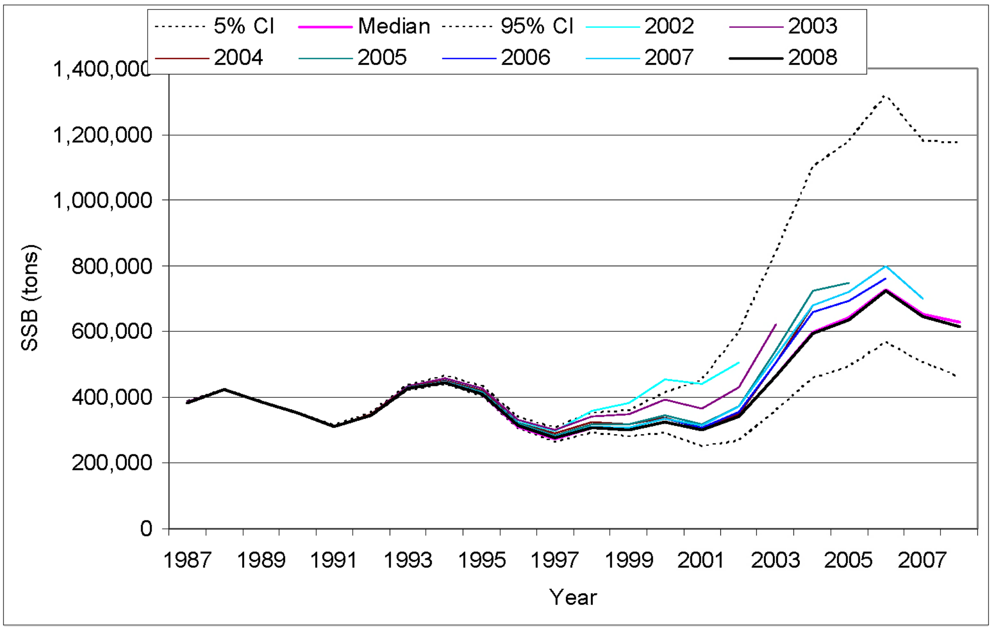

Figure 2.8.2.1. The retrospective pattern of SSB from NFT-Adapt run for 1986–2008 (varying colours) and the 95% confidence interval around the estimates (dotted lines).

2.8.3 Evaluation of the models

The results of all the models (see 2.8.1) were compared and were considered to give similar historical and current perception of the stock size (Gudmundsdóttir, 2011). The results are shown in the three figures below (red lines = NFT-Adapt, blue lines = Coleraine, black lines = TSA). It should be noted that TSA has given lower SSB than NFT-Adapt in the recent three assessments so this difference seen on the figures is known from before (e.g. ICES, 2010a).

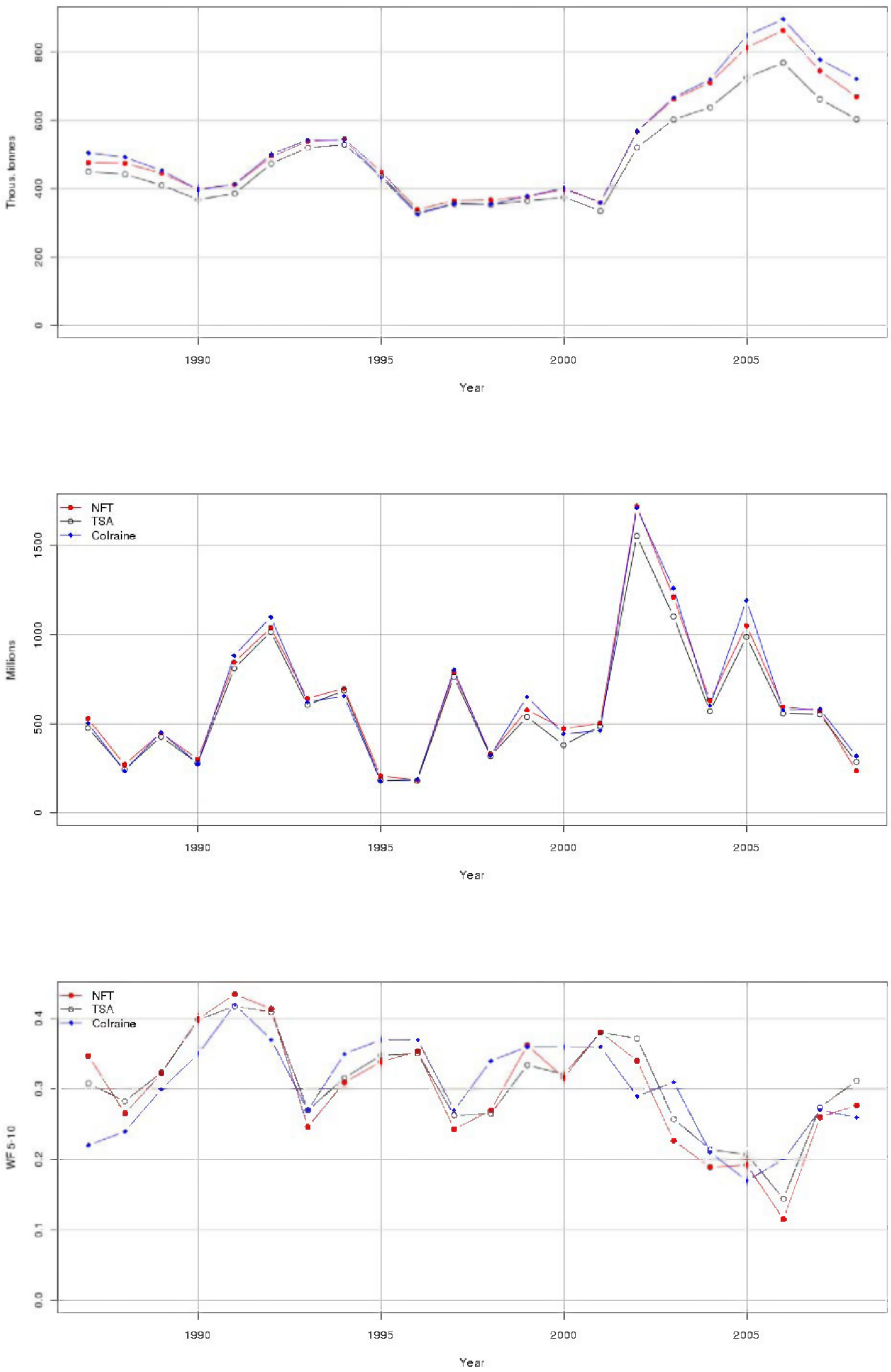

Figure 2.8.3.1.The results of the different assessment models for Her-Vasu concerning (a) SSB, (b) number-at-age 3, and (c) weighed $F_{5\text{-}10}$.

The NFT-ADAPT has been used to provide point estimates and the final assessment of the stock since 2005 to 2010 and it is run by the principal assessment scientist working with the stock. Accordingly NFT-Adapt was considered appropriate as the principal assessment tool for the stock. This software was used for all exploratory runs done during the WKBENCH meeting. The meeting encouraged the continued development and exploration of other assessment models during the updated assessments for comparative purposes.

The natural mortality used for the stock is relatively low, M=0.1, and kept fixed over all age groups (3–13+). The participants were concerned about the origins of this level since based on average longevity would indicate values more than double the assumed value. For example, the method of Hoenig (1983) for a fish stock with maximum age=20 gives a value of M~0.21.

Therefore, fixed M values of 0.1 and 0.2 for all years were used and runs where the estimated $M_{infection}$ added for the year 2009 to the natural mortality were also made. By raising the M to 0.2 the level of the spawning stock became higher historically, but it should be noted that by changing the M, then the reference points have to be changed simultaneously. However the main conclusion of these exercises is that by adding the high $M_{infection}$ to the M in the assessment and in the forecast brings the spawning stock to a very similar level in 2010 regardless of the base M used.

As a consequence of the infection affecting the stock since the fishing season 2008/2009 an extra mortality ($M_{infection}$) has been added to the natural mortality (M). The procedure by adding the estimated $M_{infection}$ to fixed M was evaluated during WKBENCH. It involved using different values of fixed M in several exploratory runs (Figure 2.8.3.2).

The stock assessors are not aware of any direct verification of the fixed M=0.1 used for Her-Vasu, and how it was determined in the beginning. The value of M used has though been evaluated with respect to ecological studies on North Sea herring with a multi-species VPA (ICES, 1987) and from earlier work providing similar values from post-WWII observations (ICES, 2010b). This supports the continued use of this value as a base mortality for the Her-Vasu stock. The estimated $M_{infection}$ to this fixed M value was recommended as the base-case scenario for this stock. The participants encouraged alternative values as sensitivities for future assessments.

It should be noted that in this adopted approach it is assumed that the mortality due to infection is completely additive to the base mortality, but it may not be the case. However, because of this, it can be considered to be a conservative approach.

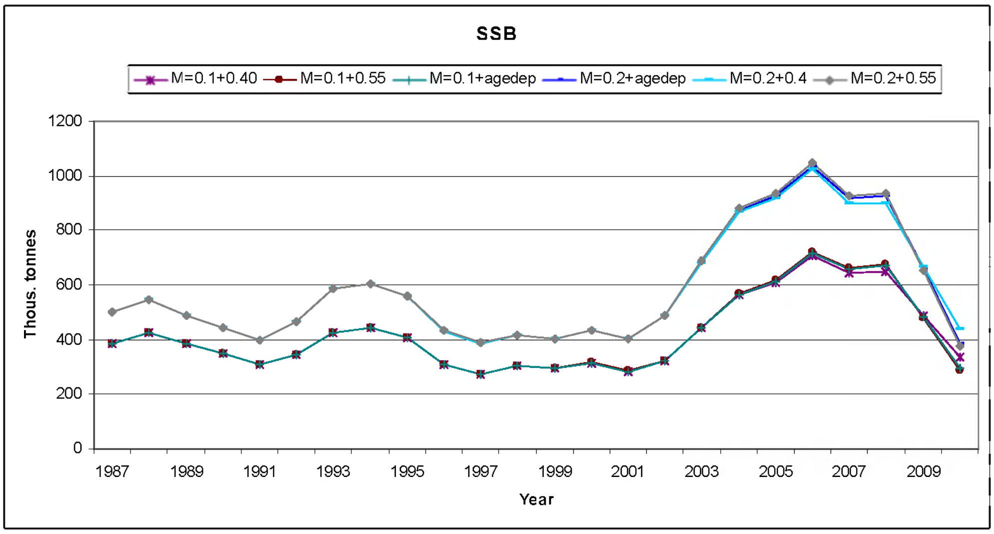

Figure 2.8.3.2. The estimated SSB of Her-Vasu for the period 1987 to 2010 of six different runs with NFT-Adapt with respect to M (as indicated on the graph).

2.8.4 Conclusion

Relative to the actual assessment, minor changes have been recommended for the final assessment adopted at WKBENCH since the last assessment (ICES, 2010a). The plus group in the catches were raised to 13 instead of 12. The age range in the survey was increased to one more age, so now ages 4–11 January 1 are used in the survey. Past estimation issues with this configuration have been resolved. The addition of the recent additional natural mortality is an easy technicality to implement for the assessment and is to be included in the assessment.

2.9 Short-term and medium-term forecasts

2.9.1 Input data

At WKBENCH there were introduced several changes in the input data from the previous procedure, and they can be seen here below.

Initial stock size: Taken from NFT-Adapt in most recent years. The number of the youngest age groups (age 3) is determined as described below (in *Stock recruitment model used)*.

If and when the stock is found to be infected by *Ichthyophonus hoferi* in the autumn of the most recent year in the assessment, the number-at-age for that year should be decreased according to the estimation of the infection prevalence before doing the projection. This was the procedure in the 2009 and 2010 assessments of the stock. The justification for this approach is that all infected fish at that time is considered to die because of it in the spring, or before the spawning occur and can therefore be considered to be ineffective in the stock.

Maturity: The same ogive as in the assessment for the year 2006 to present; i.e. no changes from before.

Natural mortality: Set to 0.1 for all ages in all years; i.e. no changes from before.

F and M before spawning: Set to 0 for F and to 0.5 for M; i.e. no changes from before.

Weight-at-age in the stock: A change in the procedure was suggested at WKBENCH. Instead of using three years average, the weight-at-age (W_{y+1}) is predicted from the mean weight of the same year class a year earlier (W_y) by applying the relationship obtained by Óskarsson (2011b): $W_{y+1} - W_y = -0.2229 \times W_y + 90.27$.

Weight-at-age in the catch: Same as used for the stock.

Exploitation pattern: A change in the procedure was suggested and approved. The fishing pattern in recent assessments has been estimated as the mean pattern of the five previous years (e.g. ICES, 2010a). At WKBENCH it was raised if it could be more appropriate to use three years means because of possible trends in the series. It was verified and the results strongly suggest that using three years average is more appropriate (Figure 2.9.1.1) as they have a stronger relationship to the observed fishing pattern than the five years means. Thus, it was decided that three years means should be used in subsequent assessments for age 3 and 4, but set 1.0 for age-5+ as in previous assessments.

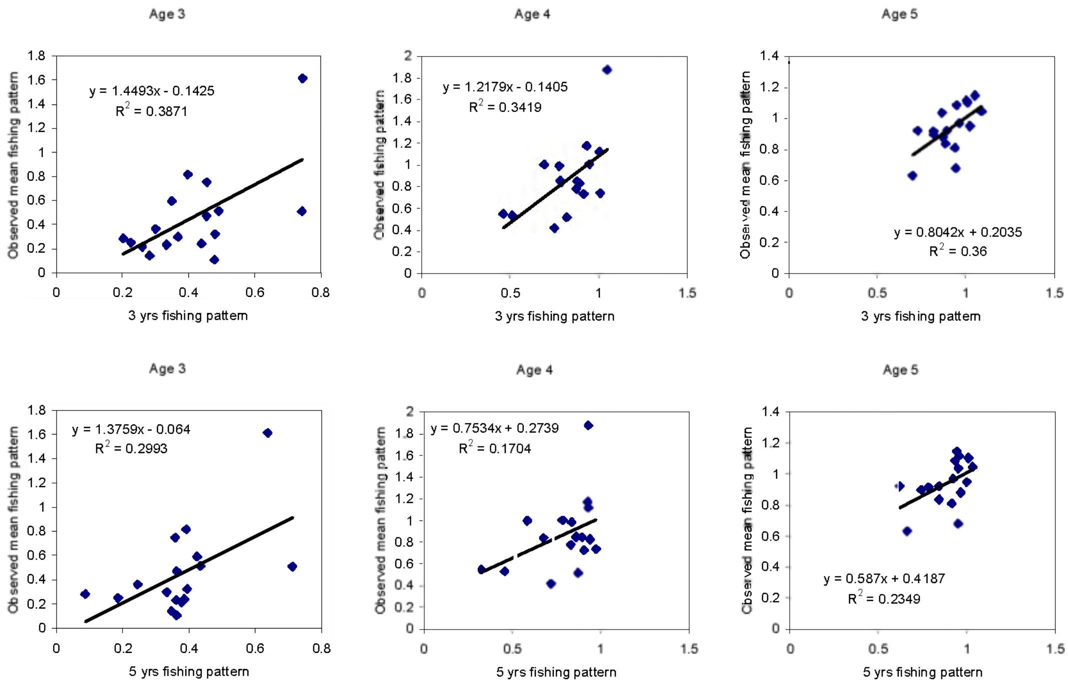

Figure 2.9.1.1. Comparison of using three years (upper panel) and five years (lower panel) average of fishing pattern to predict the fishing pattern for Her-Vasu at age 3 to 5.

Intermediate year assumptions: Not relevant.

Uncertainty in the stock prediction: This has not been provided in previous assessments. It is suggested to estimate it by using the upper and lower 95% confidence interval of the estimation of the initial stock size as estimated with NFT-Adapt for the most recent year.

Stock–recruitment model used: A change in the procedure was suggested at WKBENCH. It involves that the number at age 3 (N_{age3}, i.e. recruitment) is derived from index of number at age 1 in the Juvenile survey ($N_{age\text{-}1,\,survey}$; Survey C) two years earlier if available by applying the relationship obtained by Gudmundsdóttir *et al.* (2007):

$$\log N_{age\ 2} = 0.390 \times \log N_{age\text{-}1,\ survey} + 5.34$$

Then N_{age3} is calculated as ln (N_{age2})–Z= ln (N_{age3}), where Z=M=0.1. If survey index is not available, then the number at age 3 is equal to the geometrical mean over the whole assessment period, as done previously.

Procedures used for splitting projected catches: Not relevant.

2.9.2 Model and software

Model: Age structured

Software: An Excel spreadsheet prepared in MRI, which has been compared to results from a Fortran script used at MRI for years for herring and other species, and they have giving identical results.

It means, no changes from recent years.

2.9.3 Conclusion

The model used for the projection is the same as in previous assessments, but changes have been made on several of the input data as described above and in the Stock Annex and relates to: fishing pattern, weight-at-age, number of recruits, and number-at-age in years with *Ichthyophonus* infection.

2.10 Biological reference points

The reference points for the stock were determined and decided in 1998 (see stock-annex). A yield-per-recruit and spawning–stock biomass per recruit analysis was performed during WKBENCH to explore the reference points estimated. It is sensitive to input data, like the selection chosen. Selection was chosen as the long-term mean over the years 1987–2007. The analysis now indicates that $F_{0.1}$=0.2, which is close to the value estimated in 1998 (0.22). The F(35%SPR) is estimated as 0.25 and F_{max}=0.45 (Figure 2.10.1). Both $F_{0.1}$ and F(35%SPR) could be candidates for F_{MSY}. A more proper analysis will have to be done before the decision is taken. To explore the effect of the *Ichthyophonus* infection, a Y/R and SSB/R analysis were made with the assumption of high natural mortality (0.5) at ages 5–7 (Figure 2.10.1). The results imply clearly how the production and yield of the stock is decreased with the infection. As an example taken then fishing at F=0.2 under normal conditions would give a Y/R of 130 g and SSB/R of 785 g. To get the same SSB/R during the infection time the fishing mortality would have to be reduced to F=0.06 (blue arrows).

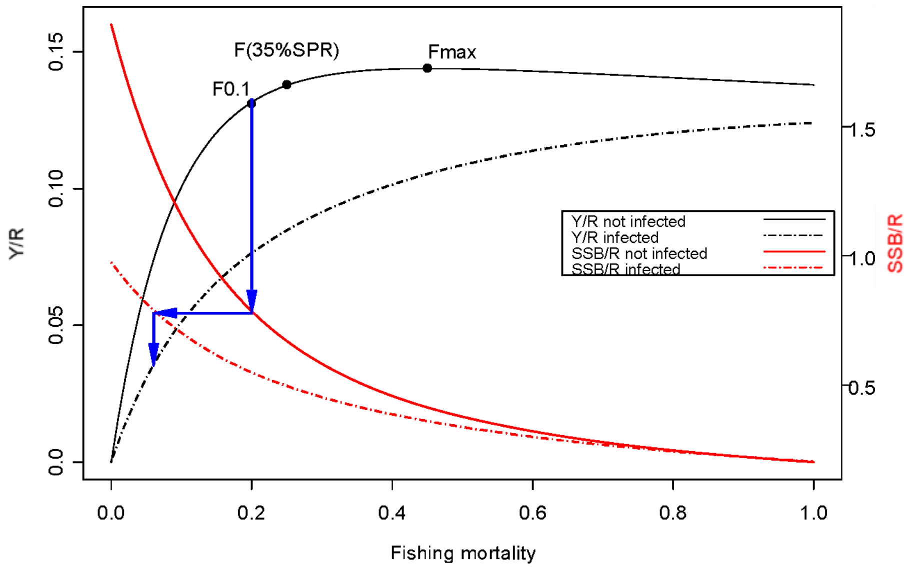

Figure 2.10.1. The estimated yield/recruits and SSB/recruits against fishing mortality of Her-Vasu as estimated with a NFT-tool for fixed M=0.1 (whole lines) and for assumption of high natural mortality (0.5) at ages 5–7 (dotted lines).

2.11 Recommendations on the procedure for assessment updates and further work

Several recommendations were provide to the stock assessors during WKBENCH and those that goes for update assessments are the following:

- Detailed evaluation of reference points for the stock and determination of MSY based reference points should take place and ideally introduced at NWWG in 2011.
- Evaluate HCRs, following revision of reference points and determination of MSY, should take place in the coming months and ideally introduced at NWWG in 2011.
- Uncertainty in the stock projection should be provided and it should be based on the uncertainty on number-at-age for the last year of the assessment.
- Medium-term projection (~five years) for the stock should be provided at update assessments in addition to a short-term projection.
- Provide results at the update assessments from sensitivity analyses from the runs for the different parameter values.

Recommendations for future work were as follows:

- In about three to five years from the cessation of the ongoing *Ichthyophonus* infection outbreak in the stock, work should be done to verify/quantify M for the pre- as well as during the *Ichthyophonus* period. Verification of reference points should be done simultaneously, if the results require. This work should be done in connection to a benchmark assessment.

- In the proposed work regarding the ICES MSY-framework, it would be informative to use total egg production of repeat spawners instead of SSB as a bases of the analyses, and compare it to the more traditional approach of using SSB. It involves using estimation of egg production and its relations to the recruitment variation provided in Óskarsson and Taggart (2010).

2.12 Implications for management (plans)

Not relevant at this point as HCR were not introduced or tackled as planed before WKBENCH. As pointed out above in the recommendations, verification of reference points, determination of the MSY framework and verification of different HCR should be done before NWWG meets in 2011 and introduced there.

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3 Horse mackerel in Division IXa

3.1 Current assessment and issues with data and assessment

History

The assessment method applied on horse mackerel stock identified with the old criteria, was a VPA-based method, (XSA, Darby and Flatman, 1994). The assessment model never converged although it was accepted by ACFM. With the new stock definition (Abaunza, 1998), statistical catch-at-age methods (mainly AMCI (Skagen, 2005) and ASAP (Legault and Restrepo, 1998) assessment packages) were the basis for the successive assessments. In general these assessments had to overcome the difficulties in getting a good fit to the auxiliary information available: the bottom-trawl surveys tuning-series. The survey-series is noisy and shows conspicuous year effects. The assessment was accepted in 2008. However, in 2009 some of the main points from the technical comments made by the reviewers were the following:

- The 2009–2006 retrospective assessment showed an over retrospective bias on both average fishing mortality and SSB. These anomalous retrospective results can be explained if different selectivity patterns occur (for one or more fleet blocks) every next year, when one more set of catch proportions at age is added to each logistic fit (which violates the model assumption of constant selectivity within the time interval of every block considered in the assessment).
- While the assessment was conducted by the WG and accepted by the RG, the ADG considered that different model structure resulted in very different SSB trajectories which raised doubt about the reliability of the assessment. While the 2009 exploratory assessment diagnostics (residuals, retrospective patterns) appeared to be reasonably reliable and improved over those of the previous assessment, the ADG considered desirable to investigate more fully various model structure before using the assessment as the basis for advice. This should be done through a benchmark.

The main issues addressed in the benchmark are:

- Resolving the year effects observed in survey data when using XSA.
- The need to allow natural mortality to vary with age.
- Allowing selectivity patterns to vary historically to observe changes in commercial fisheries.

A model extending from the previous application of ASAP using ADMB was applied which allowed for greater flexibility in making modifications and evaluating output.

3.2 Compilation of available data

3.2.1 Catch and landings data

Catch allocation for this stock between subdivisions that belong to Division IXa is described in the Stock Annex. The definition of the ICES subdivisions was set in 1992 and some of the previous catch statistics came from an area that comprises more than one subdivision. This is the case of the Galician coasts where the Subdivisions VIIIc West and Subdivision IXa North are located. Further work is necessary to collect the catches by port and to distribute them by subdivision. At the moment the required information has been collected for the period 1992–2009, and it is expected to go back in time until 1939 (Portuguese catches are available since 1927) during the next years. Only Portugal and Spain fish on this stock.

The Portuguese catches range from 40% of the total catch of the stock in 2008 (the lowest of the time-series) to 85% in 1992. The catch time-series during the assessment period shows a decreasing trend since the peak reached in 1998 until 2003, when the lowest level of the time-series was reached.

An historical evolution of catches and a description of the different fleets targeting Southern horse mackerel are described in the Stock Annex.

The Spanish catches in Subdivision IXa South (Gulf of Cádiz) are available since 2002. They will not be included in the assessment data until the time-series is completed, to avoid a possible bias in the assessment results. On the other hand, the total catches from the Gulf of Cádiz are scarce and represent less than the 5% of the total catch. Therefore, their exclusion should not affect the reliability of the assessment.

The "Prestige" oil spill had also an effect in the fishery activities in the Northern Spanish area in 2003.

Catch in numbers-at-age

The sampling scheme is believed to achieve a good coverage of the fishery (above 95% of the total catch). The number of fish aged seems also to be sufficient through the historical series. The dataseries available for the stock is 1992–2009 but there are good expectations to go back in time at least until the early 1980s.

3.2.2 Biological data

Mean length-at-age and mean weight-at-age

Both mean length-at-age and mean weight-at-age values are calculated by applying the mean weighted by the catch over the mean weights or mean lengths-at-age obtained by subdivision. The dataseries available are from 1992 to 2009.

Taking in consideration that the spawning season is very long, spawning is almost from September to June, and that the whole length range of the species has commercial interest in the Iberian Peninsula, with probably very scarce discards, there is no special reason to consider that the mean weight in the catch is significantly different from the mean weight in the stock.

Maturity ogive

Estimation procedures are detailed in Stock Annex. The proportion of maturity-at-age obtained by microscopical criteria and used in the assessment period is:

Age	0	1	2	3	4	5	6	7	8	9	10
Maturity (1992–2006)	0.04	0.31	0.83	0.98	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Maturity (2007–2009)	0.04	0.54	0.77	0.9	0.96	0.99	1.0	1.0	1.0	1.0	1.0

Natural mortality

Natural mortality has been considered to be 0.15. This level of natural mortality was adopted for all horse mackerel stocks since 1992. However, the presence of very old horse mackerel specimens in the southern stock is much scarcer than in the western or North Sea stocks. On the other hand, the available references on natural mortality estimates for other *Trachurus* species (e.g. *Trachurus capensis, Trachurus japonicus* and *Trachurus murphyi*) show higher natural mortality values, being higher than 0.3 in the majority of cases (range from 0.1 to 0.5) (Cubillos *et al.*, 2008; MFMR, 2006; Zhang and Lee, 2001). Also the assumption that natural mortality is the same for all ages is highly unrealistic, given that the chances of a 10 cm fish of being predated are much higher than those of a 30 cm fish.

As a conclusion it is considered that the value of natural mortality (0.15) is an under-estimation for southern horse mackerel stock. In addition it is generally accepted that natural mortality is very high during larval stages and decreases as the age of the fish increases, approaching a steady rate (Jennings *et al.*, 2001). The natural mortality adopted in the assessment (mean = 0.3) is dependent on age, being higher for younger ages. The adopted values are the following and are based in the estimates for other similar pelagic species, observed diet composition of fish predators in the area and taking into account the observed mean life span in southern horse mackerel.

Age	0	1	2	3	4	5	6	7	8	9	10
Nat Mor	0.9	0.6	0.4	0.3	0.2	0.15	0.15	0.15	0.15	0.15	0.15

3.2.3 Survey tuning data

The only survey datasets currently available for the assessment of southern horse mackerel are those from the bottom-trawl surveys carried out in the 4th quarter (October) by Portugal (Pt-GFS-WIBTS-Q4) and Spain (Sp-GFS-WIBTS-Q4) in ICES Division IXa. These surveys cover contiguous areas at the same time but do not cover the southern part of the stock distribution area, corresponding to the Spanish part of the Gulf of Cadiz. In that area another bottom-trawl survey (Sp-GFS-caut-WIBTS-Q4) is carried out, usually in November, but the raw data were unavailable in time for this workshop to investigate the effect of merging it with the datasets from the other areas. This work is expected to be completed in time for the next assessment working group, in June 2011.

As suggested in previous reviews of the assessment of this stock, the Spanish survey from Subdivision IXa North and the Portuguese survey are treated as a single survey, although they are carried out with different vessels and slightly different bottom-trawl gears. The catchability of these vessels (BO Cornide de Saavedra and NI Noruega) and fishing gears were compared for different fish species during project SESITS (Sánchez *et al.*, no date) and no significant differences were found for horse mackerel. Thus, the raw data (number per hour and age in each haul, including zeros) of the two datasets were merged and treated as a single dataset.

The abundance data by age and year do not follow a Normal distribution, having a big proportion of zeros and a few extreme values (see Figure 3.2.3.1). This is explained by the patchiness in the distribution of horse mackerel and by its characteristic of forming large shoals. Therefore, it is questionable whether a simple average of the number-per-hour, by age and year, is an adequate abundance index for tuning the stock assessment. Different ways of obtaining an abundance index by age and year were explored, all of them based on the smoothing of the data assuming non-Normal probability distributions. For this, we fitted Generalized Additive Models (GAM) to the raw data using the package "mgcv" (Wood, 2006) in the R statistical computing language (R Core Development Team, 2010). Data smoothing was tried with four different strategies: by year-class (one GAM for each year class, with age as covariate), by age (one GAM by age with year as covariate), by year (one GAM by year with age as covariate), and by age and year (one GAM using a bi-dimensional smoother by age and year). A log link function was used in all cases, and the error was modelled with a binomial negative distribution. Other distributions and transformations of the data were tried, but gave a worse fit than with these settings.

Figure 3.2.3.2 shows an example of the GAM fitting diagnostics with each of these four strategies. In all cases a poor fitting was obtained, with the residuals showing undesirable patterns. Figure 3.2.3.3 shows the differences between the indices matrix obtained with each of these strategies and the one obtained by a simple average of the raw data. It is clear that most of the attempted strategies to smooth the data would result in strong differences, especially for the youngest ages. Given that an acceptable fit could not be achieved with these GAMs, it was decided to use the simple averaged data as abundance indices for tuning the assessment, however further work must be carried out in the future to address better this problem.

Figure 3.2.3.4 shows the average abundance indices (mean number per hour, by age and year) used in the assessment. There are two very clear features in this dataset: a strong variability of age 0 and strong year effects (some years with higher abundance of all ages than others). The first feature may be explained by the greater aggregation tendency of these small fish in dense shoals and by their typically pelagic behaviour which makes them less available to the bottom trawl. When, by chance, one or a few of those shoals are captured by the bottom trawl (e.g. at the end of a haul when the trawl is being towed at mid-water), it contributes to a high abundance estimate of that age class. The apparent year effects in the data are more difficult to explain, and are likely due to natural variations in the availability of the fish in that time of the year and small variations in sampling effort (e.g. due to bad weather). Both the variability in age 0 and the apparent year effects must be accounted for in the assessment model to be fitted to these data.

3.2.4 Commercial tuning data

No commercial cpue data is used in this assessment. It is expected in the future to recover an historical series of cpue data from bottom-trawl Portuguese fleet.

3.2.5 Industry/stakeholder data inputs

Portuguese and Spanish fishermen, industry and stakeholders are participating in the South Western Waters Regional Advisory Committee (SWWRAC). This Committee joins all fisheries actors to propose to the European Commission and the member states statement on the fish management of the southwestern European waters. Although there are no direct data inputs in relation with this stock, the relationships and trade-offs among the members of this RAC (including Fisheries administrators and scientific personal) are main issues to have in mind for the knowledge of the data quality and the availability of these data in the future, as well as for the possible management scenarios.

No data from the industry were presented at the WKBENCH.

3.2.6 Environmental data

No environmental data were presented to WKBENCH or used in the assessment.

3.3 Stock identity, distribution and migration issues

For many years the Working Group has considered the horse mackerel in the northeast Atlantic as separated into three stocks: the North Sea, the Southern and the Western stocks (ICES, 1990; ICES, 1991). According the technical minutes from the group reviewing last year's Working Group report, they discussed and questioned the stock unit definitions. Until the results from the EU project (HOMSIR, QLK5-Ct1999-01438) were available the separation into stocks was based on the observed egg distributions and the temporal and spatial distribution of the fishery. The extremely strong 1982 year class appeared for the first time in the eastern part of the North Sea in 1987 during the third and mainly the fourth quarter. This year class was the basis for the start of the Norwegian horse mackerel fishery in the eastern part of North Sea during the third and mainly the fourth quarter. Since Western horse mackerel are assumed to have broadly similar migration patterns as NEA mackerel the Norwegian catches have been considered to be fish of western origin migrating to this area to feed. In addition there is a fishery further south in the North Sea that is considered to be fish of North Sea origin. These views were supported by results from the mentioned EU project which was reviewed by ICES (2004) which also concluded to include Division VIIIc as part of the distribution area of the western horse mackerel stock (see also Abaunza *et al*., 2008 for a comprehensive discussion of the results from the HOMSIR project). Horse mackerel off the west coast of the Iberian Peninsula have characteristics (morphometry, parasites, distribution and migratory circuit) that distinguish them from the rest of the samples collected in the northeast Atlantic. The border between southern and western horse mackerel stocks may therefore lie at the level of Cape Finisterre on the coasts of Galicia at 43°N, which is also the limit between Division VIIIc and IXa. The southern limit of the southern horse mackerel stock is not as evident due to the lack of samples from the north of Africa. Based on morphometric studies, Murta (2000) showed that the horse mackerel of the Portuguese coast was closer to the northwest coast of Morocco than to the Gulf of Cadiz in the south of Spain. However, the respective parasite composition suggests that the populations off the north of Africa and the west of the Iberian Peninsula are not part of a continuous stock.

Data from bottom-trawl surveys carried out throughout the Atlantic waters of the Iberian Peninsula during the autumn supported the existence of ontogenic migrations (Murta *et al*., 2008). Analysis of the proportion of each year class in each area off the Portuguese coast indicated that most year classes recruit to the northwest area (close to Subarea VIII) and then move progressively southwards. After six years of age, they then returned to the north.

3.4 Influence of the fishery on the stock dynamic

Looking at the historical series of the catches from Portugal (available since 1930 until now), it can be observed periods with significant high catches. However, it is clear that the current catch level is not abnormally low when compared with the catches of the first half of the 20th century. Instead, the catches from 1962–1978, appear exceptionally high when looking to the whole time-series. Many hypotheses have been proposed to explain this pattern (Murta and Abaunza, 2000) and some of them could be tested in the next future with the analysis.

The Southern Horse mackerel stock has supported a more or less stable exploitation rate since the 1980s.

3.5 Influence of environmental drivers on the stock dynamic

The southern horse mackerel stock is distributed along the western and southern Atlantic coasts of the Iberian Peninsula, which is an area subject to upwelling events. There is already evidence in the literature that horse mackerel recruitment is influenced by environmental drivers. The analysis carried out under the IN EX Fish project (IN EX FISH, FP6-022710) showed that nonlinear combinations of NAO and upwelling indices was able to explain the strength of past recruitments. The rise and fall of this horse mackerel stock was probably caused by a complex interaction of different factors, both human and natural. However, it is very likely that changes in recruitment due to upwelling and NAO events may have played an important role.

3.6 Role of multispecies interactions

3.6.1 Trophic interactions

Young horse mackerel is a feeding resource consumed by several demersal, bentic and pelagic predators present in the distribution area including: hake, monkfish, John Dory, bluefin tuna and dolphins.

Horse mackerel is mainly a zooplanktivorous species. Diet variations with fish length and water depth are correlated: small fish are closely associated with coastal areas where they feed on copepods and decapod larvae (Cabral and Murta, 2002). However, they can prey on fish as it grows and become also *Ichthyophagous* when they reach large sizes.

3.6.2 Fishery interactions

Horse mackerel is a schooling species and often close to the sea floor. Shelf attachment is a predominant distributional pattern for this stock. Therefore, horse mackerel is in relation with other fish and invertebrate species that are usually caught during the bottom-trawl surveys and share the same habitat. These species include: snipefish, boarfish, blue whiting, European hake, sardine, blue jack mackerel, squid and pelagic crabs (Sousa *et al*., 2006).

The Spanish bottom trawl fleet operating in ICES Divisions VIIIc (Western horse mackerel stock) and Subdivision IXa north (Southern stock), historically relatively homogeneous, has evolved in the last decade (approximately since 1995) to incorporate several new fishing strategies. A classification analysis for this fleet between the years 2002 and 2004 was made based on the species composition of the individual trips (Castro and Punzón, 2005). The analysis resulted in the identification of five catch profiles in the bottom otter trawl fleet: 1) targeting horse mackerel (>70% in landings), 2) targeting mackerel (>73% in landings); 3) targeting blue whiting (>40% in landings); 4) targeting demersal species; and 5) a mixed "métier". In the bottom pair trawl fleet the classification analysis showed two *métiers*: 1) targeting blue whiting; and 2) targeting hake. These results should help in obtaining standardized and more coherent cpue series from fishing fleets.

In the Portuguese area (Division IXa), Campos *et al*. (2007) classified the bottom-trawl fleet according to landing profiles (LP) and associated fleet components (FCs). The bottom-trawl fishery in Portuguese continental waters is a multi-species fishery where a large number of commercial species are landed by a fleet composed of about 100 trawlers. Six different LPs emerged from the analysis, each defined by the relative importance of target and bycatch species. A correspondence between these LPs and groups of trawlers was established, suggesting the existence of three main fleet components, or groups of trawlers involved in the same fishing pattern over time. The crustacean fleet, targeting the deep-water crustaceans, Norway lobster, *Nephrops norvegicus*, rose shrimp, *Parapenaeus longirostris*, and red shrimp, *Aristeus antennatus*, and comprising two different LPs, is composed of the most recent and technologically advanced vessels. The 'fish' fleet, mainly targeting semi-pelagic species such as the horse mackerel *Trachurus trachurus*, the Atlantic mackerel, *Scomber scombrus*, and the Chub mackerel, *Scomber japonicus*, constitutes a diversified group in terms of their technical characteristics and LPs. A small number of trawlers have the *Octopodidae*, the cuttlefish, *Sepia officinalis* and benthic fish species as their most important landings, constituting a well individualized, and previously unsuspected, fleet component.

3.7 Impacts of the fishery on the ecosystem

No data available for this analysis.

3.8 Stock assessment methods

3.8.1 Models

A model similar to AMAK (Lowe *et al*., 2009), developed by Dr James Ianelli (http://nft.nefsc.noaa.gov/AMAK.html) and adopted by the South Pacific Regional Fishery Management Organization (SPRFMO) for Chilean jack mackerel (*Trachurus murphyi*), was modified and further developed for application with the southern horse mackerel. This Assessment Method for the Ibero-Atlantic Stock of Horse-mackerel (AMISH) models the population numbers-at-age as projections forward based on recruitment estimates leading up the initial population numbers-at-age (in 1992 for this case) and subsequent annual recruitment and fishing mortalities parameters. These underlying population numbers-at-age are fit through an observation model for parameter estimation via a penalized likelihood applied to a quasi-Newton minimisation routine with partial derivatives calculated by automatic differentiation (Griewank and Corliss, 1991). The automatic differentiation and minimisation routines are those from the package AD Model Builder (ADMB). A similar model is currently used in many stock assessments in North American waters (e.g., Atka mackerel, eastern Bering Sea pollock, Pacific Ocean perch). It is a simple, well tested, and widely used methodology. The population equations, model fitting components, and model settings are listed in Tables 3.8.1.1–3.8.1.4.

The approach differs from the XSA methods in that:

- calculations proceed from the initial conditions to the present and into the future,
- the catch-at-age is not assumed to be known exactly,
- annual estimates of sampling variability (for both age composition and survey index precision) is allowed,
- fishing mortality is separable but selection-at-age is allowed to change gradually over time,
- separate components of the fishery are treated independently,
- some parameters, which are assumed constant in XSA, such as the catchability coefficients associated with tuning indices, may be allowed to change over time,
- statistical basis allows for careful consideration of data quality and the impact on the uncertainty of estimates.

The model begins in the first year of available data with an estimate of the population abundance-at-age. Recruitments are estimated for each year. In subsequent ages and years the abundance-at-age is reduced by the total mortality rate. This projection continues until the terminal year specified. If data are unavailable to estimate recruitment, the model will use the geometric mean value and hence can be projected to any arbitrary year (assuming specified catches).

The fishing mortality rates for each sector in the fishery are assumed to be separable into an age component (called selectivity) and a year component (called the F multiplier). The selectivity patterns are allowed to change over time. Expected catches are computed according to the usual catch equation using the determined fishing mortality rate, the assumed natural mortality rate, and the estimated population abundance described above. The statistical fitting procedure used with the model will try to match the indices and the catch-at-age. The emphasis of each of these sources of information depends on the values of the relative weights assigned to each component by the user.

The minimization processes proceeds in phases, in which groups of parameters are estimated simultaneously, while the remaining parameters are maintained at their initially assigned values. Once the objective function is minimized for a particular phase, more parameters are treated as unknown and added to those being estimated. This process of estimation in phases continues until all parameters to be estimated contribute to the objective function and the best set of all parameters that minimize the objective function value is determined.

The software code and input files is available on request.

Model Options chosen:

The objective function is the sum of a number of negative log-likelihoods generally following two types of error distributions: the lognormal and multinomial and details are listed in Table 3.8.1.3. The specifications of input sampling levels (in terms of sample size or variance term) are provided in Table 3.8.1.4.

The separability in the fishing mortality was assumed allowed to vary according to a shift in fleet composition. An F multiplier was estimated for the first year, and was allowed to change in time by estimating deviations to this parameter for each year. The fishing mortality at each age, year and fleet resulted from the product of the F multipliers by the selectivity parameter at each age and fleet. Three selectivity vectors were estimated, corresponding to blocks of fleets sharing a similar selectivity at age. This is a useful feature of the model that helps to avoid overparameterisation. By looking at the plots of catch-at-age by fleet, it was decided to have a common selectivity for the purse-seine fleets, together with the Portuguese bottom-trawl fleet, another one for the artisanal fleets and a third one just for the Spanish bottom-trawl fleet. One catchability parameter for the abundance index and kept fixed over time.

The model fitting is affected by statistical weights (lambdas or inverse variance functions) as part of the objective function. Specified input variance assumptions can influence the fitting of the model, by attributing a lower or higher importance to different data sources that contribute to the objective function. The variance assumption assumed the highest precision for landings data by year and fleet. The fishery proportions-at-age for the moment were assumed to have an "effective sample size" of 100 compared to the value of ten specified for the survey estimates of age composition. The survey index data was fit assuming that the coefficient of variation was 30%. These values are typical for this type of information and diagnostic plots of model fits confirmed that they are reasonable. As more data become available, these assumptions can be modified to more appropriate and potentially time-varying values.

Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1992–2008	0–11+	Yes
Canum	Catch-at-age in numbers	1992–2008	0–11+	Yes
Weca	Weight-at-age in the commercial catch	1992–2008	0–11+	Yes
West	Weight-at-age of the spawning stock at spawning time.	1992–2008	0–11+	Yes
Mprop	Proportion of natural mortality before spawning	1992–2008	0–11+	Yes
Fprop	Proportion of fishing mortality before spawning	1992–2008	0–11+	No
Matprop	Proportion mature-at-age	1992–2008	0–11+	No
Natmor	Natural mortality	1992–2008	0–11+	No
	Spanish/Portuguese bottom-trawl survey	1992–2009	0–11+	

The assessment results are described in the following figures:

Figures 3.8.1.1 and 3.8.1.2 show the fit of the model to the observed total landings and to the total landings by age respectively. Figure 3.8.1.3 shows the selectivity estimated in the fishery. Figure 3.8.1.4 shows the fit of the model to the bottom-trawl survey-series and Figure 3.8.1.5 shows the selectivity estimated for the survey. Figure 3.8.1.6 shows the estimated recruitment values including the confidence intervals and finally Figure 3.8.1.7 shows the estimated values of SSB through the time-series.

3.8.2 Sensitivity analysis

A sensitivity analysis was made to the assumed values for the natural mortality rates, given that these are the parameters, kept fixed, over which there are the least information available. The model with the final parameterisation was run with different vectors of natural mortality-at-age. One of those was the one with the rate assumed in the past in all assessments of this stock (0.15/year for all ages), while the remaining vectors had different values between ages (being higher in the young ages than in the oldest ones) and differed in the overall level of natural mortality (see Table 3.8.2.1). The changes in the assumed values for natural mortality did not have a great influence on the goodness of fit, with all cases having a similar pattern in the residuals. However, different natural mortality levels corresponded to different levels in SSB, as shown in Figure 3.8.2.1.

3.8.3 Retrospective patterns

A retrospective analysis on SSB was carried out with the final assessment, removing up to five years from the dataset. The SSB trajectory obtained was within the confidence intervals of the SSB estimates from the assessment.

3.8.4 Evaluation of the models

A model similar to the one previously used (ASAP) was explored during the workshop. Several different parameterisations were attempted, resulting in better or worse fittings to the two available data sources (catch-at-age and bottom-trawl survey). A balance between goodness of fit and parsimony in the number of parameters, in order to avoid over-sensitivity to new observations, was our main goal, which led us to the finally accepted assessment model.

3.8.5 Conclusion

Given that the latest assessments carried out for southern horse mackerel were considered as exploratory, and consequently the advice for management has not been based on the results of any stock assessment in the latest years, the assessment method developed and applied during this workshop must not be compared to a previously established methodology. Since the big change regarding stock definition and data allocation that took place in 2004, after the HOMSIR project, the assessment method that provide the most sensible results was ASAP, which is a separable statistical catch-at-age model similar to AMISH. Therefore, in this workshop there was not a radically different approach regarding this stock assessment, but instead a slightly simplified method, as compared to ASAP, was applied and some underlying assumptions on the stock population dynamics were questioned. Besides a careful choice for the model parameterisation, the changes made to the assumed natural mortality rates at age are likely to be the greatest improvement on the assessment of this fish stock.

3.9 Short-term and medium-term forecasts

3.9.1 Input data

Initial stock size: the one estimated by the assessment model.

Maturity: the same as in the previous year of the assessment.

F and M before spawning: both of them are 0.

Weight-at-age in the stock: the same as in the previous year of the assessment.

Weight-at-age in the catch: assumed equal to the weight-at-age in the stock.

Exploitation pattern: the one estimated in the assessment model.

Intermediate year assumptions: the catches by fleet are assumed to be exactly the same as the ones in the previous year.

Stock–recruitment model used: no stock–recruitment model is used, the recruitment is assumed to be stochastic in all the years (the assessment year, the intermediate and the projection year), around the geometric mean of the historical values with the same variability as the one observed in the series.

3.9.2 Model and software

Model used: Apropos designed function, named *mff*, to perform deterministic forecast, only with catch constraints (allowing the introduction of variability in the assumed recruitment values). Having the initial numbers-at-age at the beginning of the year, the total F at age in the assessment year y-1 and the assumptions we want to make on the weight-at-age, the selectivity-at-age by fleet, the maturity ogive, the natural mortality rate and the recruitment. We can project forward the population given a level of catches for the intermediate year y and for the protection year y+1. It is also possible to add some variability to the recruitments, by including a standard deviation value.

The method starts projecting the population numbers-at-age from the last assessment year with the estimated the fishing mortality rates by fleet,

$$N_0 = rec \cdot e^{\varepsilon}, \quad \varepsilon \sim N(0, \sigma)$$
$$N_1 = N_0 \cdot e^{-(M_0 + F_0) p}$$
$$N_a = N_{a-1} e^{-(M_{a-1} + F_{a-1})}, \quad a \text{ in } 2, \dots, A\text{-}1$$
$$N_A = N_{A-1} e^{-(M_{A-1} + F_{A-1})} + N_A e^{-(M_A + F_A)}$$

where rec corresponds to the assumed recruitment level, N_a are the numbers-at-age a, M_a is the natural mortality-at-age a, F_a is the fishing mortality-at-age a, σ is the standard deviation of the recruitment and p is the proportion of the year from the recruitment time to the end of the year.

For the intermediate year in the short-term projections, the population numbers-at-age are calculated assuming catch constraints by fleet, using Pope's approximation forward,

$$\lambda = \frac{catch}{\sum_a S_a N_a W_a}, \quad proportion\ to\ the\ \max imum\ that\ could\ be\ captured$$

$$C_a = \sum_a S_a N_a \lambda$$

$$N_0 = rec\, e^{\varepsilon}, \quad \varepsilon \sim N(0, \sigma)$$

$$N_1 = (N_0 - C_0 e^{M_0 p/2}) e^{-M_0 p}$$

$$N_a = (N_{a-1} - C_{a-1} e^{M_{a-1}/2}) e^{-M_{a-1}}, \quad a \text{ in } 2, \ldots, \text{A-1}$$

$$N_A = (N_{A-1} - C_{A-1} e^{M_{A-1}/2}) e^{-M_{A-1}} + (N_A - C_A e^{M_A/2}) e^{-M_A}$$

where λ is the proportion to the maximum catch that could be captured, rec corresponds to the assumed recruitment, N_a are the numbers-at-age a, M_a is the natural mortality-at-age a, F_a is the fishing mortality-at-age, S_a is the selectivity-at-age, a and p is the proportion of the year from the recruitment time to the end of the year.

The source code is available on request.

Software used*:* R (www.r-project.org)

3.9.3 Conclusion

There are no apparent reasons to move away from the methodology previously applied for short-term forecasts. For previous assessments, a set of functions were written in the R language to make short-term forecasts taking into account different management constraints to the six fleets that exploit this stock, and also to take into account natural variability in the recruitment. The management measures possible to simulate in these forecasts are just catch constraints, which correspond to the only management measure actually in place for this stock (TAC). Although the software implementation of this procedure must be further screened for errors, and improved, there is no reason at present, and until there is a change in the management scheme, for a change in methodology.

3.10 Biological reference points

No biological reference points were defined for this stock during WKBENCH.

3.11 Recommendations on the procedure for assessment updates and further work

The abundance indices currently used in the assessment, which are the mean number per hour by age and year, are likely not appropriate estimates of abundance from the statistical point of view, given the zero-inflated distribution of their values in the survey dataset. During WKBENCH no other strategy to deal with these data was tested, besides using the average number per hour by age and year. Several attempts to smooth the data were made, but given that an acceptable fitting was not achieved, the smoothed datasets were not used. A possibility worth to be tested is to put in practice a bootstrap procedure, generating a large number of replicate matrices with proportion-at-age estimates from the survey, and running the assessment method on each of these replicates. Given the execution speed of the software in which the method is implemented (ADMB) this should be a feasible procedure, which would take into account the characteristics of the survey data in a better way that a simple average of numbers-at-age.

3.12 Implications for management (plans)

The level of SSB estimated from the stock assessment is important for an evaluation of how intensive has the exploitation been, and whether a given level of fishing mortality is sustainable. However, doubts about the true values of natural mortality, and their influence on the level of estimated SSB lead us to believe that the management of this stock should be based on indicators not sensitive to a given choice of natural mortality rates.

3.13 References

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Table 3.8.1.1. Symbols definitions used for model equations.

General Definitions	Symbol/Value	Use in Catch-at-Age Model
Year index: i = {1992, …., 2010}	i	
Age index: j = { 0,1,2, …, 11+}	j	
Mean weight in year t by age j	Wt,j	
Maximum age beyond which selectivity is constant	Maxage	Selectivity parameterization
Instantaneous Natural Mortality	Mj	Fixed M=0.8,0.5,0.3,0.2,0.1…0.1, for j=0,1,2…11
Proportion females mature-at-age j	pj	Definition of spawning biomass
Sample size for proportion in year i	T_i	Scales multinomial assumption about estimates of proportion at age
Survey catchability coefficient	q^s	Prior distribution = lognormal(μ_q^s, σ_q^2)
Stock–recruitment parameters	R_0 h σ_R^2	Unfished equilibrium recruitment, steepness, variance
Virginal biomass	φ	Spawning biomass per recruit when there is not fishing
Estimated parameters		
$\phi_i(\#), R_0, h, \varepsilon_i(\#), \mu^f, \mu^s, M, \eta_j^s(\#), \eta_j^f(\#), q^s(\#)$		

Note that the number of selectivity parameters estimated depends on the model configuration.

Table 3.8.1.2. Variables and equations describing implementation of the horse mackerel assessment model.

Eq	Description	Symbol/Constraints	Key Equation(s)
1)	Survey abundance index (s) by year (Δ^s represents the fraction of the year when the survey occurs)	I_i^s	$I_i^s = q^s \sum_{j=0}^{11} N_{ij} W_{ij} S_j^s e^{-\Delta^s Z_{ij}}$
2)	Catch biomass by year	C_i	$\hat{C}_{ij}^f = \sum_{j=0}^{11} N_{ij} W_{ij} \frac{F_{ij}^f}{Z_{ij}} (1 - e^{-Z_{ij}})$
3)	Proportion-at-age j, in year i	$P_{ij},\ \sum_{j=0}^{11} P_{ij} = 1.0$	$p_{ij}^f = \frac{\hat{C}_{ij}^f}{\sum_j \hat{C}_{ij}^f}$ $p_{ij}^s = \frac{N_{ij} S_j^s e^{-\Delta^s Z_{ij}}}{\sum_j N_{ij} S_j^s e^{-\Delta^s Z_{ij}}}$
4)	Initial numbers-at-age	j = 0	$N_{1992,j} = e^{\mu_R + \varepsilon_{1992}}$
5)		0 < j < 10	$N_{1992,j} = e^{\mu_R + \varepsilon_{1993-j}} \prod_{j=1}^{j} e^{-M}$
6)		j = 11+	$N_{1992,11} = N_{1992,10} \left(1 - e^{-M}\right)^{-1}$
7)	Subsequent years (i >1992)	j = 0	$N_{i,2} = e^{\mu_R + \varepsilon_i}$
8)		0 < j < 10	$N_{i,j} = N_{i-1,j-1} e^{-Z_{i-1,j-1}}$
9)		j = 11+	$N_{i,11} = N_{i-1,10} e^{-Z_{i-1,10}} + N_{i-1,11} e^{-Z_{i-1,11}}$
10)	Year effect and individuals at age 2 and i = 1981, …, 2010	$\varepsilon_i,\ \sum_{i=1981}^{2010} \varepsilon_i = 0$	$N_{i,0} = e^{\mu_R + \varepsilon_i}$
11)	Index catchability Mean effect Age effect	$\mu^s,\ \mu^f$ $\eta_{ij},\ \sum_{j=0}^{11} \eta_{ij} = 0$	$q_i^s = e^{\mu^s}$ $s_j^s = e^{\eta_j^s}$ $j \leq$ maxage $s_j^s = e^{\eta_{maxage}^s}$ $j >$ maxage
12)	Instantaneous fishing mortality		$F_{ij}^f = e^{\mu^f + \eta_j^f + \phi_i}$
13)	Mean fishing effect	μ^f	
14)	Annual effect of fishing mortality in year i	$\varphi_i,\ \sum_{i=1992}^{2010} \varphi_i = 0$	
15)	age effect of fishing (regularized) In year time variation allowed In years where selectivity is constant over time	η_{ij}^f , $\sum_{j=2}^{12^+} \eta_{ij} = 0$ $\eta_{i,j}^f = \eta_{i-1,j}^f$	$s_{ij}^f = e^{\eta_j^f}$, $j \leq$ maxage $s_{ij}^f = e^{\eta_{maxage}^f}$ $j >$ maxage $i \neq$ change year
16)	Natural Mortality vector	Mj	0.8 0.5 0.3 0.2,0.1…0.1 for ages 0 - 11
17)	Total mortality		$Z_{ij} = \sum_f F_{ij}^f + M$

Eq	Description	Symbol/Constraints	Key Equation(s)
17)	Spawning biomass (note spawning taken to occur at mid of January)	Bi	$B_i = \sum_{j=0}^{11} N_{ij} e^{-\frac{0.5}{12} Z_{ij}} W_{ij} p_j$
18)	Recruitments (Beverton–Holt form) at age 0.	$\tilde{R}_i$	$\tilde{R}_i = \frac{\alpha B_i}{\beta + B_i}$, $\alpha = \frac{4hR_0}{5h-1}$ and $\beta = \frac{B_0(1-h)}{5h-1}$ where $B_0 = R_0 \varphi$ $\varphi = \sum_{j=2}^{12} e^{-M(j-1)} W_j p_j + \frac{e^{-12M} W_{12} p_{12}}{1-e^{-M}}$ h=0.8

Table 3.8.1.3. Specification of objective function that is minimized (i.e., the penalized negative of the log-likelihood).

	Likelihood /penalty component		Description / notes
19)	Catch biomass likelihood	$L_1 = \sum_f \lambda_4^f \sum_{i=1992}^{2010} \ln\left(\frac{C_i^f}{\hat{C}_i^f}\right)^2$	Fit to catch biomass in each year
20)	Abundance indices	$L_2 = \sum_s \lambda_1^s \sum_i \ln\left(\frac{I_i^s}{\hat{I}_i^s}\right)^2$	Survey abundances
21)	Proportion-at-age likelihood	$L_k = \sum_{k,i,j} \tau_i^k P_{ij}^k \ln\left(\hat{P}_{ij}^k\right) \quad k = 3,4$	k=3 for the fishery, k=4 for the survey
22)	Penalty on smoothness for selectivities	$L_k = \sum_k \lambda_k \sum_{j=0}^{11} \left(\eta_{j+2}^l + \eta_j^l - 2\eta_{j+1}^l\right)^2 \quad k = 6,9$	Smoothness (second differencing), Note: k=6 for the fishery, k=9 for the survey
23)	Penalty on recruitment regularity	$L_{11} = \lambda_{11} \sum_{i=1981}^{2010} \varepsilon_i^2$	Influences estimates where data are lacking (e.g., if no signal of recruitment strength is available, then the recruitment estimate will converge to median value).
24)	Recruitment curve penalty	$L_6 = \lambda_6 \sum_{i=1992}^{2010} \ln\left(\frac{N_{i,0}}{\tilde{R}_i}\right)^2$	Conditioning on stock-recruitment curve over period 1992–2007 (but reduced to have negligible effect on estimation).
25)	Overall objective function to be minimized	$\dot{L} = \sum_k L_k$	

Table 3.8.1.4. Input variance σ^2 or sample size (τ) assumptions and corresponding penalties (λ) used on log-likelihood functions in the base model.

L	Abundance index	□	τ	□L
1	Landings	0.05	-	200
2	Combined index	0.3	-	5.556
3	Fishery age composition	-	100	-
4	Survey age composition	-	10	-
5	Time-change in fishery selectivities	0.8		0.78
6	Fishery age-specific penalties	1.0	-	0.5
7	Fishery descending selectivity-with-age penalty	10	-	0.1
8	Time-change in survey selectivities	0.8		0.78
9	Survey age-specific penalties	1.0	-	0.5
10	Survey descending selectivity-with-age penalty	10	-	0.1
11	Recruitment regularity	10	-	0.1
12	S-Recruitment curve fit (for period 1992–2007, scale only)	1.9	-	0.14

Table 3.8.2.1. Different vectors of natural mortality used in the sensitivity analysis.

	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11+
Trial 1	0.8	0.5	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Trial 2	0.81	0.51	0.31	0.21	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Trial 3	0.82	0.52	0.32	0.22	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Trial 4	0.83	0.53	0.33	0.23	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Trial 5	0.84	0.54	0.34	0.24	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Trial 6	0.85	0.55	0.35	0.25	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Trial 7	0.86	0.56	0.36	0.26	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Trial 8	0.87	0.57	0.37	0.27	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Trial 9	0.88	0.58	0.38	0.28	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Trial 10	0.89	0.59	0.39	0.29	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Final	0.9	0.6	0.4	0.3	0.2	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Old	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15

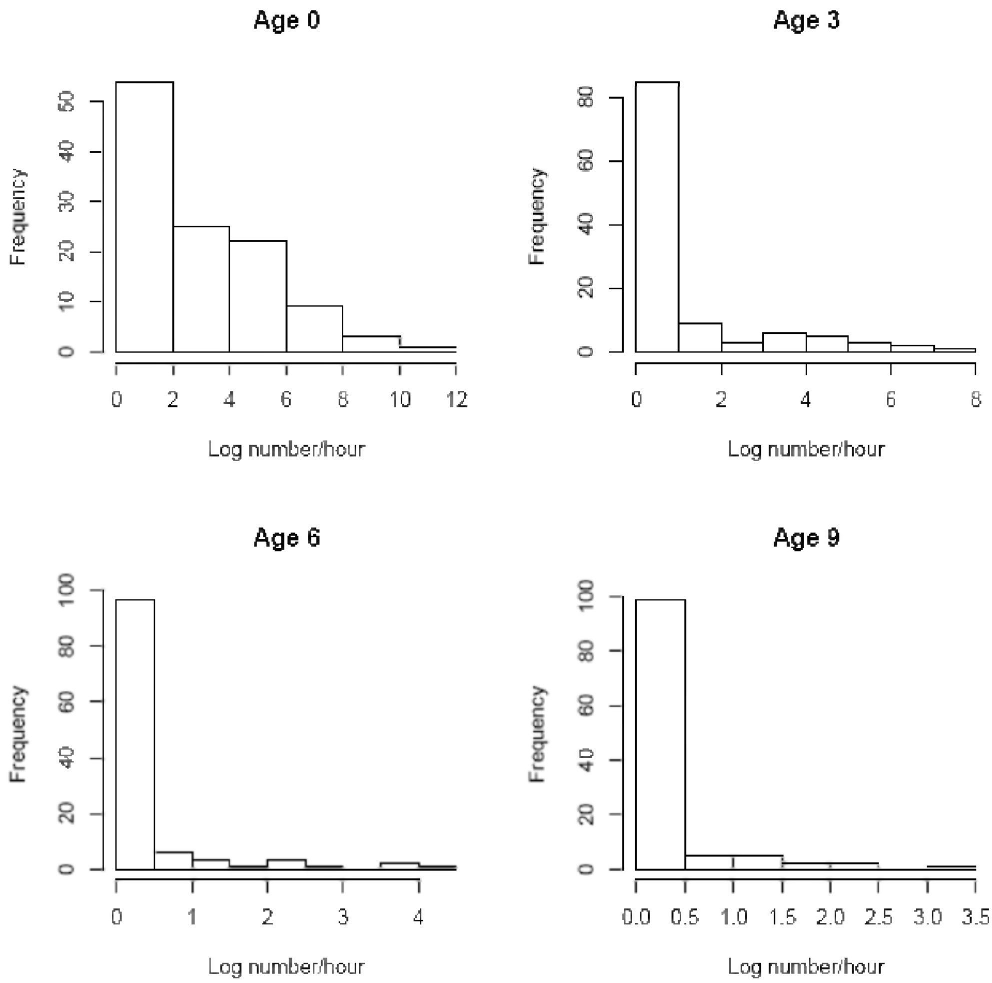


Figure 3.2.3.1.

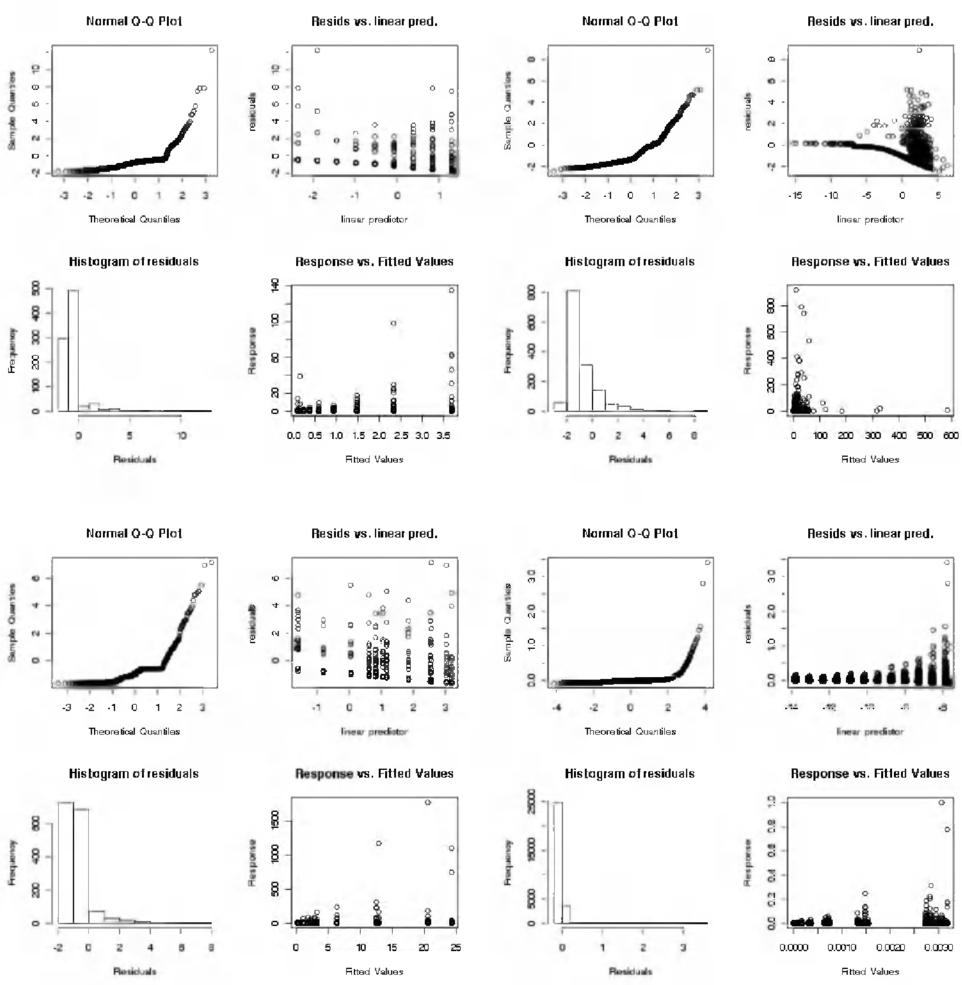

Normal Q-Q Plot
Resids vs. linear pred.
Normal Q-Q Plot
Resids vs. linear pred.
Histogram of residuals
Response vs. Fitted Values
Histogram of residuals
Response vs. Fitted Values
Normal Q-Q Plot
Resids vs. linear pred.
Normal Q-Q Plot
Resids vs. linear pred.
Histogram of residuals
Response vs. Fitted Values
Histogram of residuals
Response vs. Fitted Values

Figure 3.2.3.2.

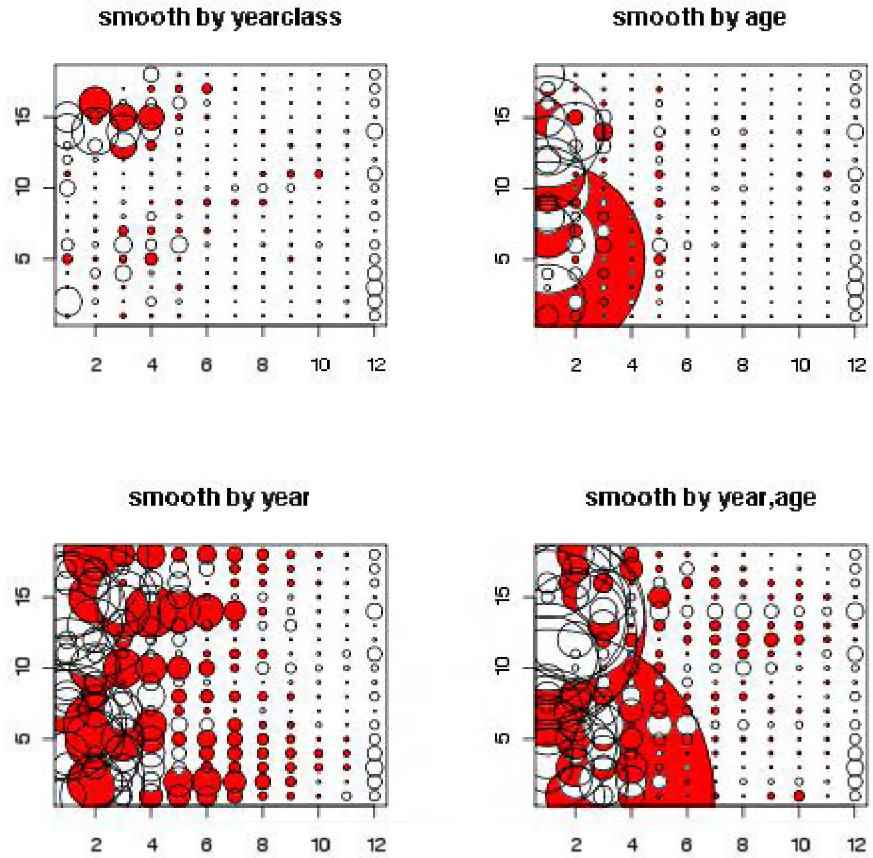

smooth by yearclass
smooth by age
smooth by year
smooth by year,age

Figure 3.2.3.3.

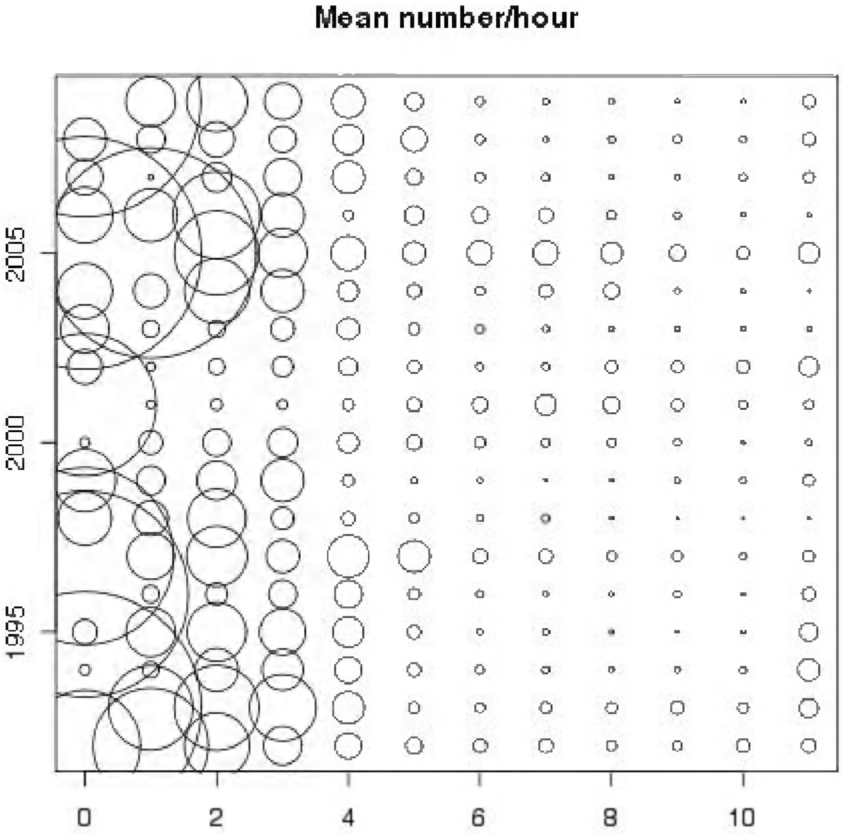


Figure 3.2.3.4.

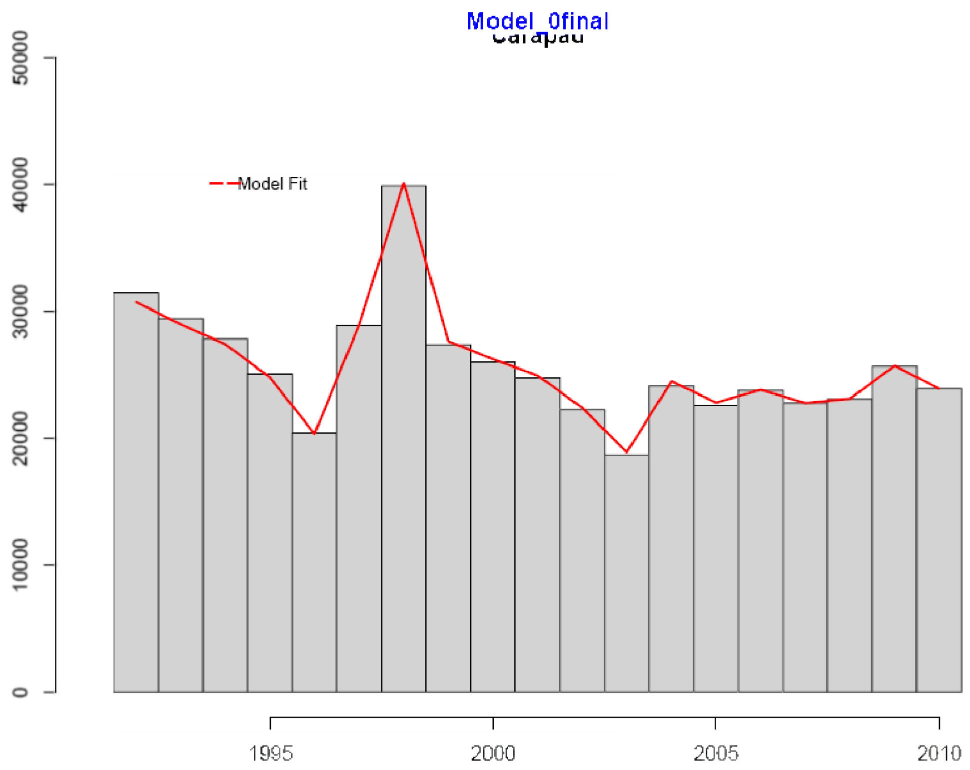
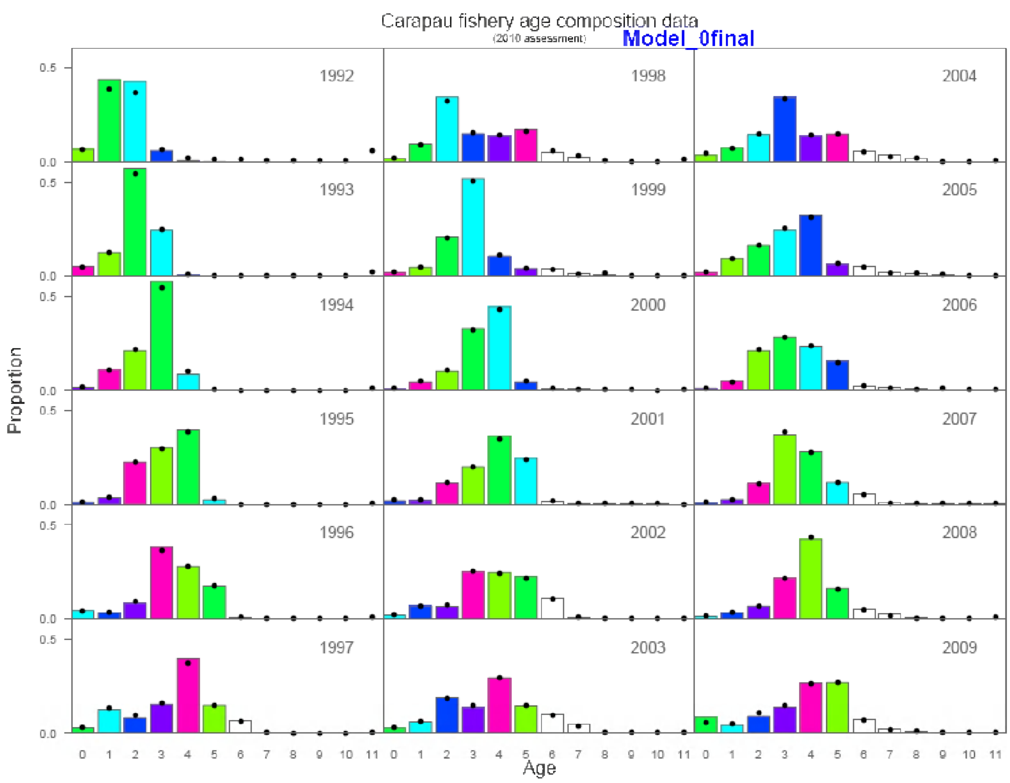


Figure 3.8.1.1.



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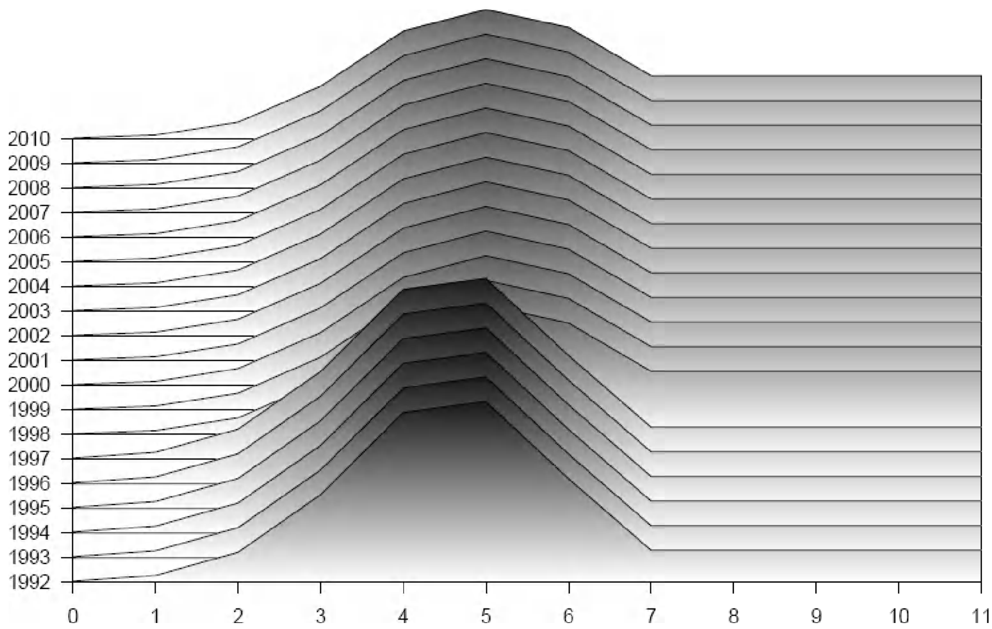

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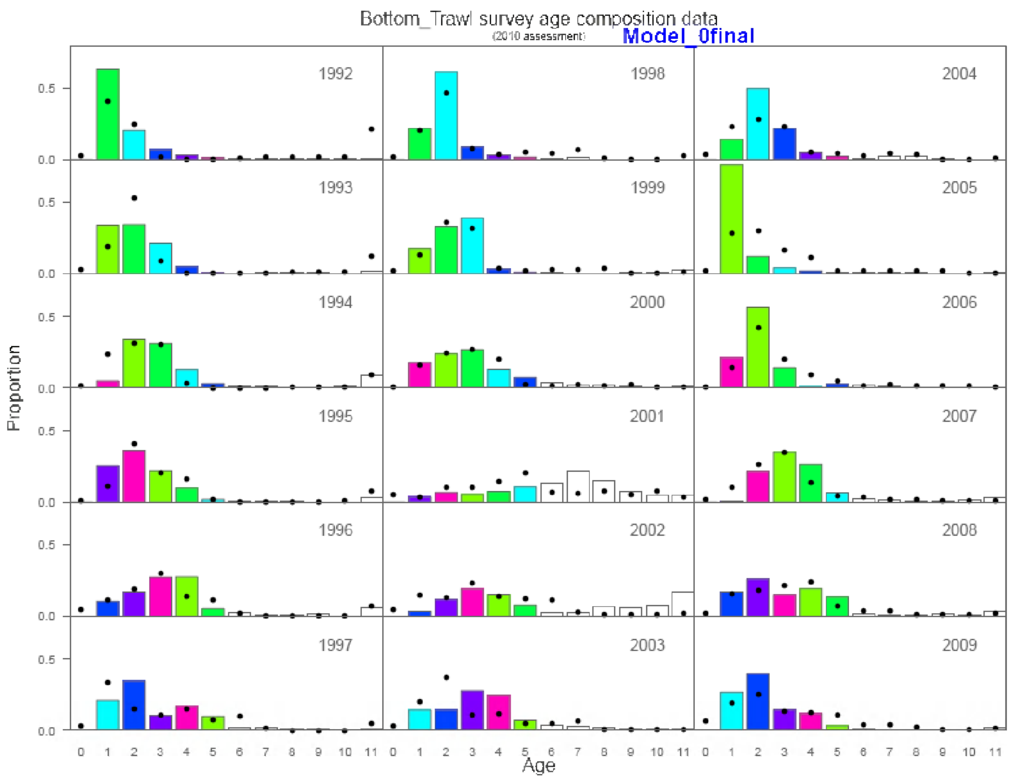

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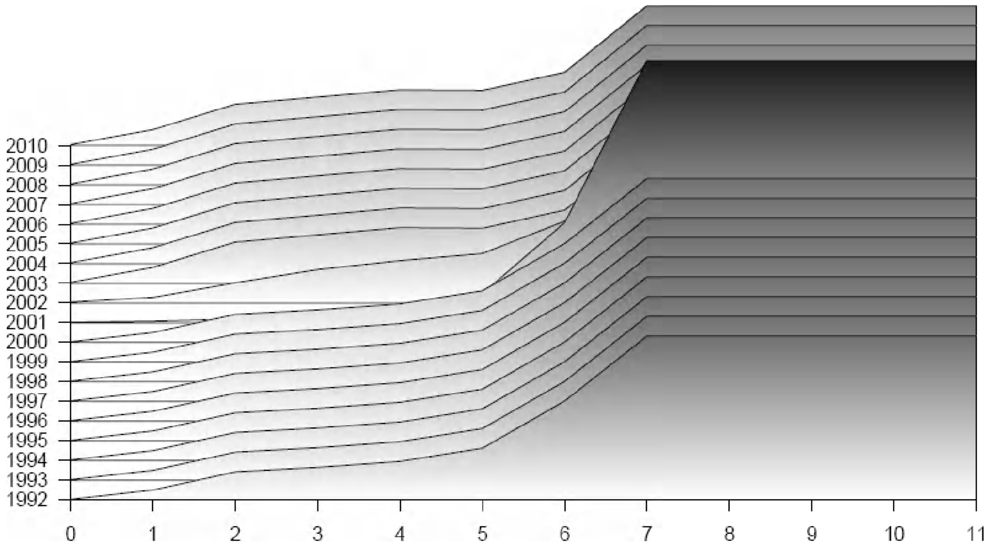

Figure 3.8.1.5.

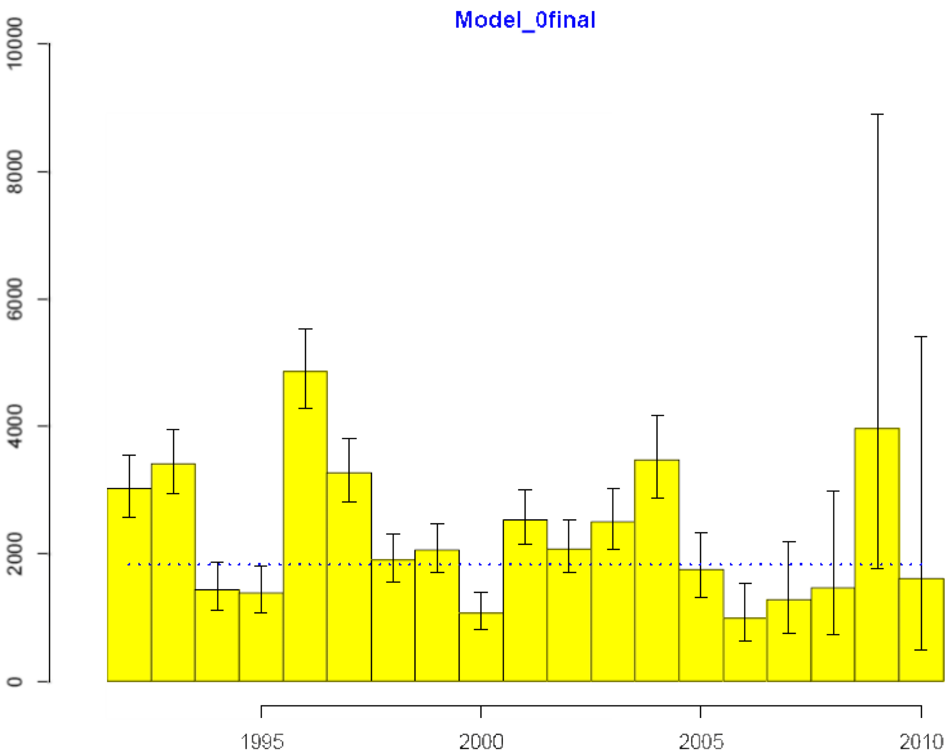

Figure 3.8.1.6.

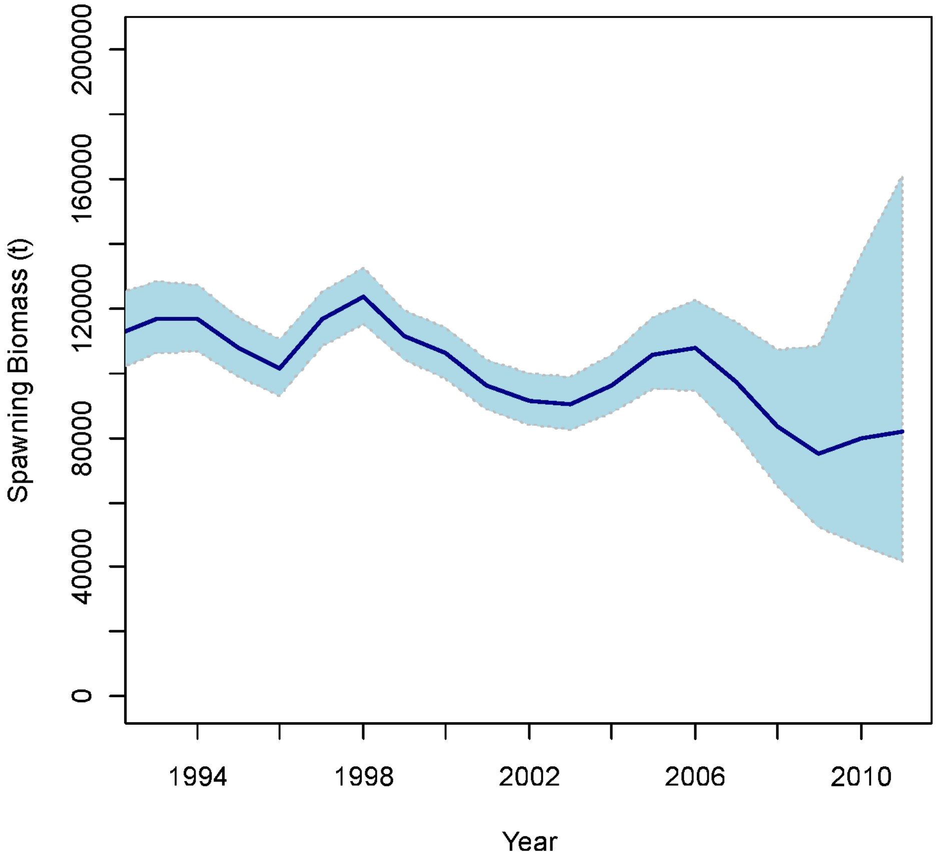

Figure 3.8.1.7.

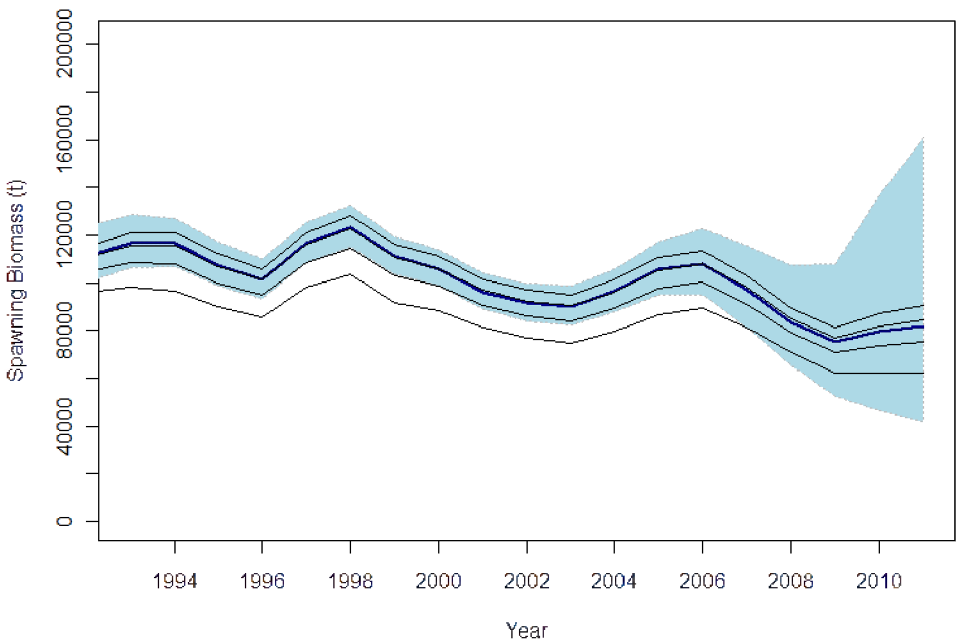

Figure 3.8.2.1.

4 Haddock in Subarea IV and Division IIIa(N)

4.1 Current assessment and issues with data and assessment

The current assessment of haddock in Subarea IV and Division IIIa(N) (referred to here as *North Sea haddock* for brevity) uses the XSA method (Darby and Flatman, 1994; Shepherd, 1999). The source data are reported landings, estimated discards generated from observed discard rates, bycatch in the Danish and Norwegian small-mesh industrial fishery, three survey cpue indices (IBTS Q1, ScoGFS Q3 and EngGFS Q3), fixed natural mortalities and maturities, and separate weight-at-age data for the three catch components. The assessment uses very light XSA shrinkage, no power model for recruiting year classes, and a catchability plateau at the oldest available age. Point estimates from the assessment are used to generate forecast catch-option tables which are the basis of ICES advice on the stock.

The 2011 meeting of WKBENCH represented the first occasion, since the instigation of the benchmark/update approach, that the North Sea haddock assessment was subjected to a full benchmark assessment. As such, it represented a valuable opportunity to explore issues of biological data and stock structure. Alternative assessments conducted using SAM (Nielsen, 2009) and SURBA (Needle, 2003) are also presented in this Section, and are compared with the extant XSA assessment.

The principal issues to be covered in this Section are follows.

- Convergence rates of the XSA method when applied to North Sea haddock.
- Stock structure of haddock in waters around northern Scotland, as characterised by surveys, spatial fishery distribution and hydro-biological modelling.
- Changes in growth rates and implications for forecasts.
- The inclusion (or otherwise) in the assessment of time-varying natural mortality and maturity estimates.
- Assessment implications of potential management measures such as discard bans.

The assistance of Andrzej Jaworski and Rui Catarino (both Marine Laboratory, Aberdeen), and Anders Nielsen (DTU-AQUA, Copenhagen) in compiling this Section are gratefully acknowledged.

4.2 Compilation of available data

4.2.1 Catch and landings data

No new catch or landings data were presented to WKBENCH.

4.2.2 Biological data

Modifications to two biological datasets were considered by WKBENCH: natural mortality and maturity.

4.2.2.1 Natural mortality

Annual estimates of natural mortality are available from key runs of the SMS model, as reported by the ICES Working Group on Multispecies Assessment Methods (e.g.

ICES-WGSAM 2008). The estimates for North Sea haddock are given in Table 4.2.1 and Figure 4.2.1. The last key run was conducted in 2007, so estimates are constant for 2007–2009. In addition, it should be emphasised that the last year of comprehensive stomach-data collection was 1991, so the food-web definitions on which SMS runs are likely to be out of date. The effects of these time-varying estimates of natural mortality on both XSA and SAM assessment model runs are explored in Section 4.8. It is immediately apparent, however, that the new estimates are quite different from the fixed values used previously, with age-0 being lower and ages 2 and above being higher, and that this is likely to have a substantial impact on assessments.

Table 4.2.1. Smoothed estimates of natural mortality from ICES-WGSAM (2008).

Year	0	1	2	3	4	5	6	7	8+
1963	1.584	1.351	0.534	0.417	0.34	0.291	0.263	0.237	0.225
1964	1.54	1.428	0.577	0.433	0.347	0.294	0.263	0.235	0.222
1965	1.498	1.499	0.618	0.447	0.354	0.296	0.263	0.234	0.22
1966	1.457	1.559	0.657	0.46	0.36	0.298	0.263	0.232	0.217
1967	1.422	1.608	0.693	0.471	0.365	0.301	0.263	0.231	0.216
1968	1.393	1.648	0.725	0.481	0.372	0.303	0.263	0.23	0.214
1969	1.373	1.68	0.753	0.49	0.379	0.306	0.263	0.23	0.214
1970	1.359	1.703	0.779	0.5	0.388	0.31	0.265	0.23	0.214
1971	1.352	1.713	0.801	0.508	0.397	0.314	0.266	0.23	0.215
1972	1.352	1.714	0.818	0.516	0.405	0.317	0.268	0.231	0.215
1973	1.357	1.707	0.83	0.522	0.411	0.319	0.27	0.232	0.215
1974	1.366	1.695	0.836	0.525	0.415	0.32	0.271	0.233	0.215
1975	1.379	1.681	0.836	0.525	0.414	0.32	0.271	0.233	0.215
1976	1.393	1.668	0.831	0.521	0.41	0.317	0.271	0.233	0.214
1977	1.406	1.656	0.822	0.513	0.402	0.312	0.268	0.232	0.213
1978	1.416	1.643	0.81	0.502	0.39	0.305	0.264	0.23	0.212
1979	1.422	1.627	0.794	0.489	0.377	0.297	0.259	0.228	0.211
1980	1.424	1.609	0.776	0.475	0.363	0.289	0.253	0.226	0.209
1981	1.422	1.586	0.756	0.461	0.349	0.281	0.247	0.223	0.208
1982	1.417	1.557	0.734	0.446	0.336	0.275	0.241	0.221	0.206
1983	1.411	1.523	0.709	0.432	0.325	0.269	0.236	0.219	0.205
1984	1.406	1.487	0.684	0.418	0.315	0.265	0.232	0.217	0.204
1985	1.401	1.452	0.659	0.404	0.307	0.261	0.229	0.216	0.203
1986	1.397	1.422	0.635	0.392	0.301	0.258	0.227	0.214	0.202
1987	1.391	1.396	0.611	0.38	0.296	0.256	0.225	0.213	0.202
1988	1.384	1.377	0.59	0.37	0.292	0.255	0.224	0.212	0.202
1989	1.376	1.362	0.57	0.361	0.29	0.254	0.224	0.212	0.202
1990	1.367	1.35	0.552	0.353	0.289	0.253	0.224	0.212	0.202
1991	1.358	1.343	0.537	0.346	0.288	0.252	0.224	0.212	0.202
1992	1.352	1.339	0.525	0.34	0.287	0.251	0.225	0.213	0.202
1993	1.348	1.339	0.516	0.335	0.288	0.251	0.225	0.213	0.203
1994	1.347	1.343	0.51	0.332	0.288	0.251	0.226	0.214	0.204
1995	1.348	1.35	0.505	0.329	0.289	0.251	0.227	0.215	0.205

Year	0	1	2	3	4	5	6	7	8+
1996	1.351	1.36	0.501	0.327	0.29	0.251	0.228	0.216	0.206
1997	1.354	1.374	0.498	0.324	0.29	0.251	0.229	0.216	0.207
1998	1.358	1.392	0.495	0.322	0.291	0.25	0.23	0.215	0.207
1999	1.362	1.417	0.493	0.32	0.291	0.25	0.231	0.214	0.208
2000	1.367	1.451	0.493	0.319	0.292	0.248	0.232	0.213	0.208
2001	1.372	1.495	0.495	0.319	0.294	0.247	0.233	0.212	0.208
2002	1.376	1.547	0.5	0.321	0.297	0.246	0.234	0.21	0.208
2003	1.376	1.603	0.508	0.325	0.301	0.246	0.236	0.209	0.208
2004	1.373	1.661	0.517	0.329	0.306	0.246	0.238	0.208	0.207
2005	1.366	1.716	0.527	0.333	0.311	0.246	0.24	0.206	0.207
2006	1.359	1.772	0.538	0.338	0.316	0.246	0.242	0.206	0.207
2007	1.351	1.827	0.549	0.342	0.321	0.247	0.244	0.205	0.207
2008	1.351	1.827	0.549	0.342	0.321	0.247	0.244	0.205	0.207
2009	1.351	1.827	0.549	0.342	0.321	0.247	0.244	0.205	0.207

Figure 4.2.1. Estimates of natural mortality from ICES-WGSAM (2008) (ages 0–2 along the top row, ages 3–5 along the bottom row). Red dots give the annual estimates, while the blue lines give the smoothed values that are recommended for use by WGSAM. The green lines give the fixed values currently used in the assessment.

4.2.2.2 Maturity

The growth dynamics of haddock in the North Sea have changed considerably over time. Figure 4.2.2 shows time-series of the parameters of von Bertalanffy curves fitted to length-at-age distributions by cohort from survey data, and demonstrates that haddock are now growing more quickly when young (higher K) but reaching a shorter eventual length (lower L_∞) than used to be the case (Baudron *et al.*, in press).

The reasons for this change are currently being investigated. One hypothesis is that haddock mature younger than they used to, and that this early maturation results in a slowing of the rate of body growth as energy is diverted to reproduction. To explore this further, we used IBTS Q1 SMALK data from the ICES DATRAS database to determine the proportion mature for ages 1–4 from 1972 to the present day (for assessment purposes, the estimates for 1972 were used for 1963–1971). The results of this analysis are presented in Table 4.2.2 and Figure 4.2.3. Although the methodology needs to be developed further, this initial analysis of these data suggests that the proportion mature-at-age has changed considerably since the start of the time-series, and that the constant maturity assumptions used in the assessment may no longer be valid. Runs of the XSA and SAM models using these interim maturity estimates are presented and discussed in Section 4.8.

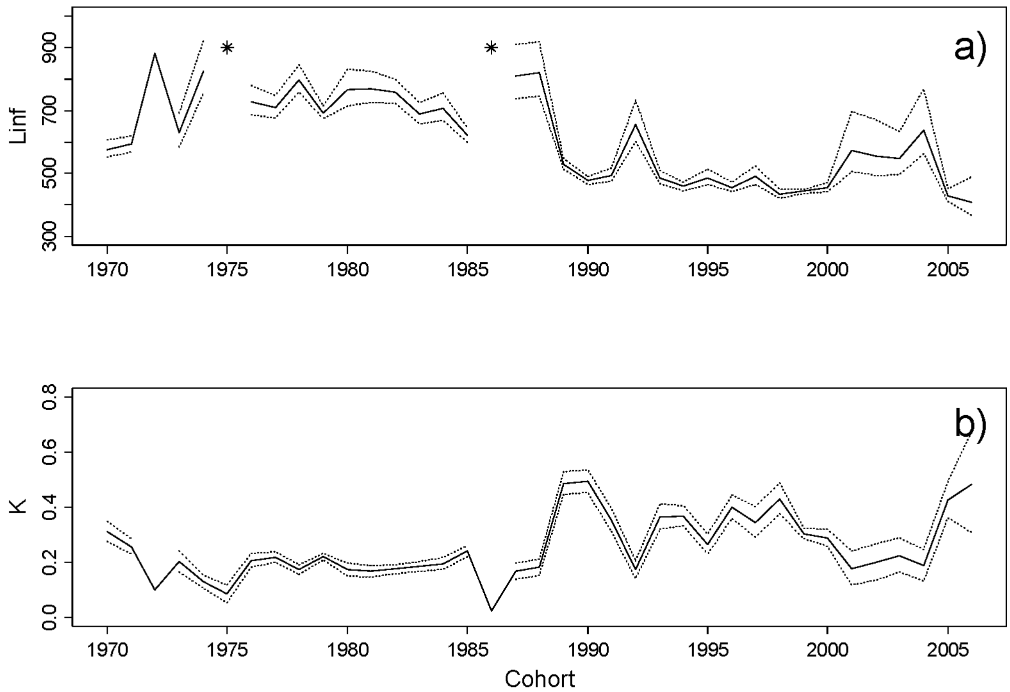

Figure 4.2.2. L_∞ **(upper) and** K **(lower) parameters from cohort-based von Bertalanffy model fits to length distributions-at-age from IBTS Q1 data. Dotted lines give 95% confidence intervals. * = outliers not shown. Source: Baudron *et al.* (in press).**

Table 4.2.2. Smoothed estimates of maturity, from IBTS Q1 SMALK data.

Year	0	1	2	3	4	5	6	7	8+
1963	0.000	0.019	0.410	0.638	0.746	1.000	1.000	1.000	1.000
1964	0.000	0.019	0.410	0.638	0.746	1.000	1.000	1.000	1.000
1965	0.000	0.019	0.410	0.638	0.746	1.000	1.000	1.000	1.000
1966	0.000	0.019	0.410	0.638	0.746	1.000	1.000	1.000	1.000
1967	0.000	0.019	0.410	0.638	0.746	1.000	1.000	1.000	1.000
1968	0.000	0.019	0.410	0.638	0.746	1.000	1.000	1.000	1.000
1969	0.000	0.019	0.410	0.638	0.746	1.000	1.000	1.000	1.000
1970	0.000	0.019	0.410	0.638	0.746	1.000	1.000	1.000	1.000
1971	0.000	0.019	0.410	0.638	0.746	1.000	1.000	1.000	1.000
1972	0.000	0.019	0.410	0.638	0.746	1.000	1.000	1.000	1.000
1973	0.000	0.025	0.414	0.649	0.751	1.000	1.000	1.000	1.000
1974	0.000	0.036	0.422	0.670	0.764	1.000	1.000	1.000	1.000
1975	0.000	0.041	0.427	0.680	0.771	1.000	1.000	1.000	1.000
1976	0.000	0.046	0.431	0.691	0.778	1.000	1.000	1.000	1.000
1977	0.000	0.051	0.435	0.703	0.785	1.000	1.000	1.000	1.000
1978	0.000	0.055	0.439	0.715	0.790	1.000	1.000	1.000	1.000
1979	0.000	0.060	0.443	0.726	0.795	1.000	1.000	1.000	1.000
1980	0.000	0.063	0.449	0.737	0.813	1.000	1.000	1.000	1.000
1981	0.000	0.064	0.457	0.750	0.838	1.000	1.000	1.000	1.000
1982	0.000	0.066	0.466	0.764	0.862	1.000	1.000	1.000	1.000
1983	0.000	0.069	0.476	0.780	0.884	1.000	1.000	1.000	1.000
1984	0.000	0.073	0.487	0.798	0.905	1.000	1.000	1.000	1.000
1985	0.000	0.078	0.499	0.817	0.924	1.000	1.000	1.000	1.000
1986	0.000	0.084	0.510	0.834	0.941	1.000	1.000	1.000	1.000
1987	0.000	0.089	0.520	0.848	0.953	1.000	1.000	1.000	1.000
1988	0.000	0.093	0.528	0.859	0.961	1.000	1.000	1.000	1.000
1989	0.000	0.097	0.534	0.867	0.966	1.000	1.000	1.000	1.000
1990	0.000	0.101	0.538	0.873	0.969	1.000	1.000	1.000	1.000
1991	0.000	0.107	0.545	0.877	0.971	1.000	1.000	1.000	1.000
1992	0.000	0.113	0.552	0.882	0.973	1.000	1.000	1.000	1.000
1993	0.000	0.120	0.560	0.886	0.974	1.000	1.000	1.000	1.000
1994	0.000	0.124	0.564	0.887	0.974	1.000	1.000	1.000	1.000
1995	0.000	0.127	0.567	0.886	0.973	1.000	1.000	1.000	1.000
1996	0.000	0.129	0.568	0.885	0.972	1.000	1.000	1.000	1.000
1997	0.000	0.132	0.573	0.885	0.972	1.000	1.000	1.000	1.000
1998	0.000	0.137	0.583	0.887	0.972	1.000	1.000	1.000	1.000
1999	0.000	0.144	0.599	0.892	0.974	1.000	1.000	1.000	1.000
2000	0.000	0.151	0.620	0.901	0.977	1.000	1.000	1.000	1.000
2001	0.000	0.155	0.642	0.910	0.980	1.000	1.000	1.000	1.000
2002	0.000	0.157	0.660	0.919	0.982	1.000	1.000	1.000	1.000
2003	0.000	0.158	0.678	0.927	0.984	1.000	1.000	1.000	1.000
2004	0.000	0.160	0.696	0.934	0.986	1.000	1.000	1.000	1.000

Year	0	1	2	3	4	5	6	7	8+
2005	0.000	0.163	0.733	0.951	0.991	1.000	1.000	1.000	1.000
2006	0.000	0.165	0.752	0.959	0.993	1.000	1.000	1.000	1.000
2007	0.000	0.166	0.771	0.968	0.996	1.000	1.000	1.000	1.000
2008	0.000	0.167	0.790	0.976	0.998	1.000	1.000	1.000	1.000
2009	0.000	0.159	0.724	0.949	0.974	1.000	1.000	1.000	1.000

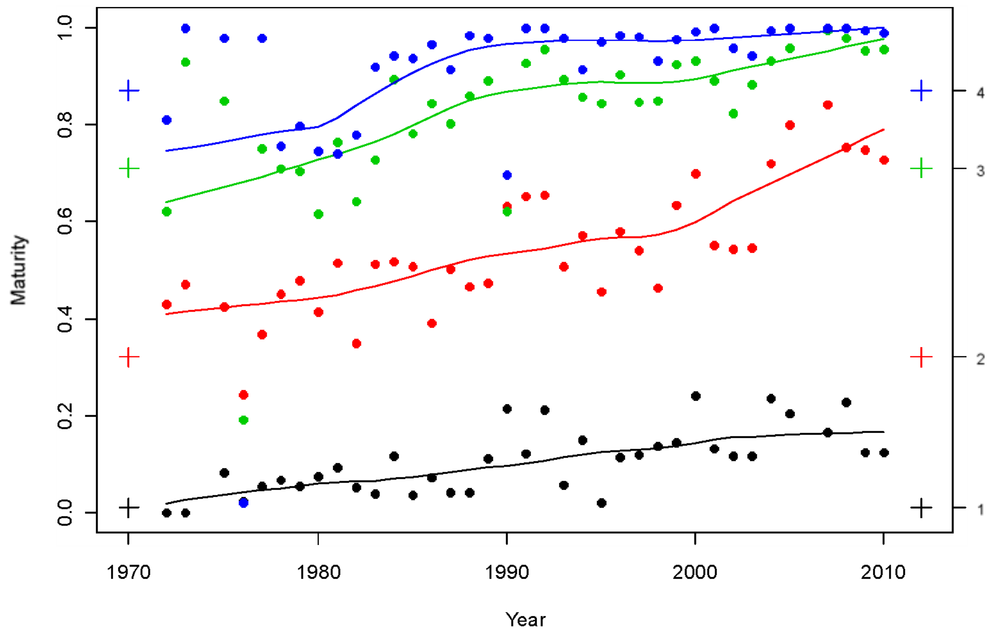

Figure 4.2.3. Estimates of proportion mature for ages 1–4 from IBTS Q1 SMALK data (via DATRAS). Dots = point estimates, lines = smoothed fits (loess smoother, span = 0.5). Crosses at each side indicate values assumed in current assessment.

4.2.3 Survey tuning data

No new survey cpue tuning data were presented at WKBENCH. However, new survey distribution maps were generated as part of a more general discussion on stock structure for haddock around northern Scotland: see Section 4.3.

4.2.4 Commercial tuning data

Commercial cpue tuning data has not been used in the assessment of North Sea haddock for several years. During preparations for the 2000 round of assessment WG meetings, it became apparent that the 1999 effort data for the Scottish commercial fleets were not in accordance with the historical series and specific concerns were outlined in the 2000 report of WGNSSK (ICES-WGNSSK 2001). Effort recording for these fleets follows the EU reporting template in which effort recording is not mandatory, and concerns remain about the validity of the historical and current estimates of commercial cpue. Consequently, no new commercial cpue series were presented at WKBENCH.

4.2.5 Industry/stakeholder data inputs

Several countries around the North Sea (in particular Scotland, England and Denmark) have implemented unilateral quota management systems which are based on discard bans (for cod, in the first instance), catch quotas and full observance using CCTV systems. Discussions are ongoing with regards to developing such a scheme for North Sea haddock, which (if implemented) will have a substantial effect on fleet dynamics, stock exploitation and the availability of data from the fishing industries. Illustrative images were presented in plenary at the WKBENCH meeting. While this is not yet directly relevant to the haddock assessment and management process, it may become so in the near future. If this occurs, it will be important that revisions to the update assessment approach be considered rapidly (via another benchmark if need be). Given this, **WKBENCH recommends that the next benchmark meeting for North Sea haddock be brought forward if haddock management changes to a system of catch quotas with an enforceable discard ban**.

No other new industry or stakeholder data inputs were provided for WKBENCH.

4.2.6 Environmental data

Results of a spatio-temporal hydrobiological model of haddock in northern UK waters (including observations on current flow-fields) were discussed at WKBENCH, and are summarised in Section 4.3. No other new environmental data were presented at WKBENCH.

4.3 Stock identity, distribution and migration issues

Within the North Sea, the southwards and eastwards distribution of haddock is limited by the oceanographic front which extends from southern Norway, passes through the Dogger Bank and reaches northeastern England: this limitation is clear from the usual survey distribution maps provided every year in the WGNSSK report (see, for example, Figure 4.3.1). However, the distinction between the North Sea (Subarea IV) stock to the east of the 4°W line, and the West of Scotland (Division VIa) to the west of it, may be artificial. Three sources of data were presented to WKBENCH to explore this issue:

1) Research-vessel survey indices.
2) VMS-based estimates of haddock fishing areas for the Scottish demersal fleet.
3) Results of spatial hydro-dynamic and biological models of juvenile advection and settlement.

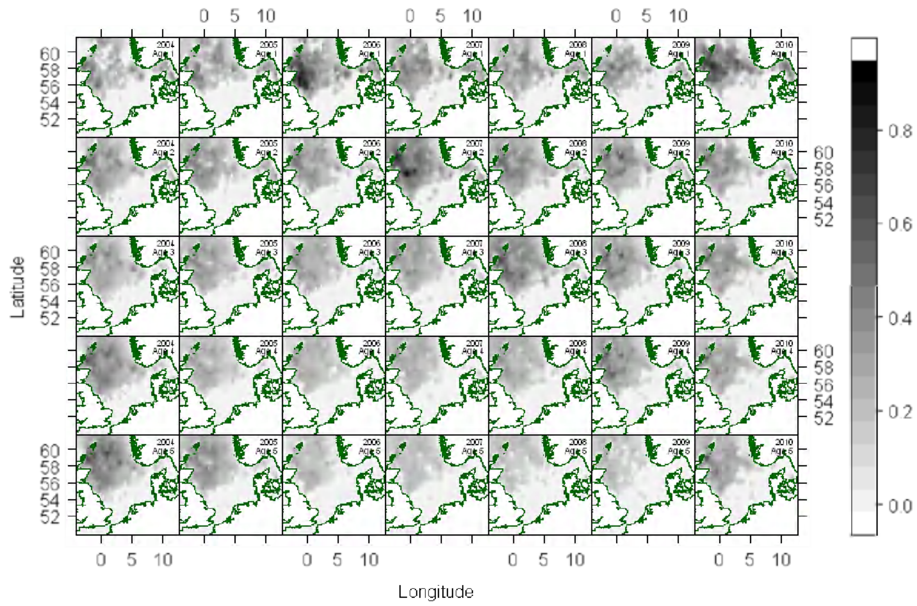

Figure 4.3.1. Spatial distribution from the IBTS Q1 survey. Contour scale (given in the bar to the right) is the square root of survey cpue, rescaled to lie between 0 and 1.

4.3.1 Research-vessel survey indices

Relative stock density indices from the North Sea IBTS Q1 series and the West of Scotland (Division VIa) were collated and plotted on the same figure. The North Sea survey is conducted roughly one month before the West of Scotland survey, so the stock indications are not strictly comparable and should be treated with caution. The resultant survey distributions (Figure 4.3.2) indicate that haddock are present in a largely unbroken arc, from the shelf edge to the west of Malin Head in Ireland across to the area around the Fladen ground in the central northern North Sea.

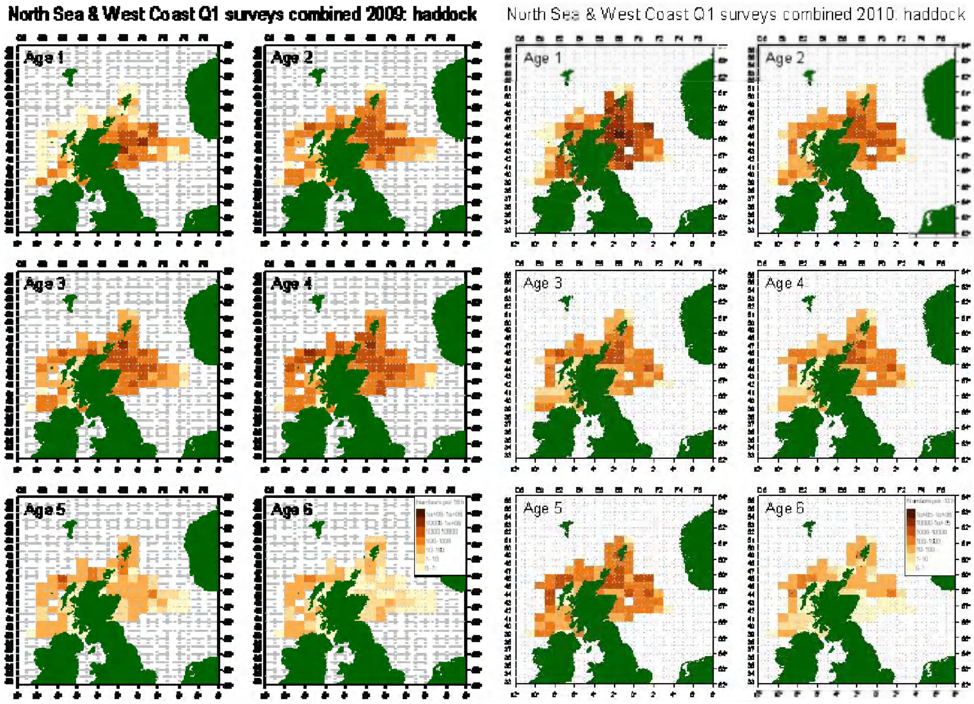

Figure 4.3.2. Relative cpue haddock indices from IBTS Q1 (North Sea) and ScoGFS Q1 (West of Scotland) surveys (2009 and 2010). Note: high quality images for 2005–2010 are available on the WKBENCH Sharepoint site (Background and working documents > Haddock in Subarea IV (North Sea) and Division IIIa > HAD_NSWS_Q1.doc).

4.3.2 VMS-based estimates of haddock fishing areas for the Scottish demersal fleet

VMS data from 2006 to the present are available from the Scottish demersal fleet (for vessels greater than 15 m in length). The available dataset was filtered to remove vessels fishing for *Nephrops* (which have selection patterns not typical of the bulk of vessels that target haddock), other vessels using mesh size of less than 100 mm (fishing for shrimps or squid, for example), and trips for which no haddock landings were reported. For the remaining trips, reported haddock landings for each trip were distributed evenly over all the VMS fishing pings for that trip (where fishing pings are defined as those for which the vessel was travelling at 4.5 knots or less: Borchers and Reid, 2008; Needle and Catarino, *in press*). Contour distribution maps were then generated based on the landed haddock tonnage (on the log scale) associated with each fishing ping. This is a potentially inaccurate procedure, as the haddock landings for a trip may all have come from one particular area rather than from all fishing activity on the trip, and additionally we have not incorporated discarding. However, this is likely to be the best available estimate of the location of haddock catches in the absence of detailed skippers' logbooks and diaries, and it is hoped that inconsistencies introduced via the averaging procedure are balanced when the entire fleet is considered.

Illustrative results are given, for February 2010 (Figure 4.3.3a) and December 2010 (Figure 4.3.3b). Although these data summaries are still in development, they clearly confirm the perception from the survey indices: haddock are distributed right across from west of the Hebrides to the Norwegian Deeps, with no clear break into West of Scotland and North Sea stock components.

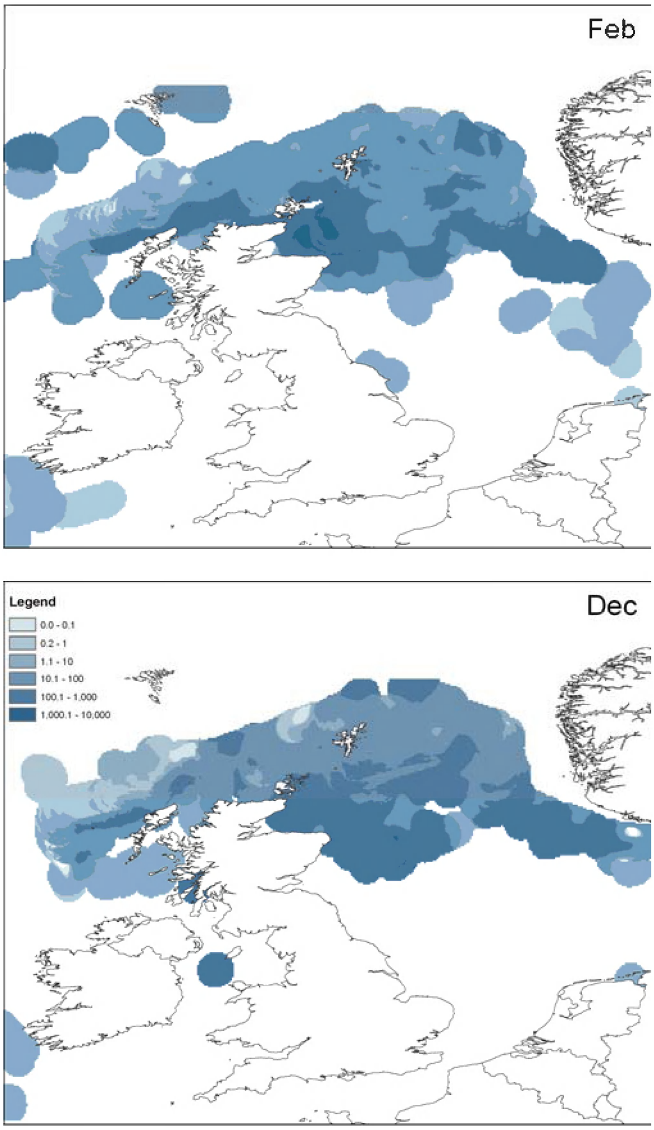

Figure 4.3.3. Distribution of fishing effort for haddock derived from VMS data from the Scottish demersal fleet for February and December 2010. See text for details. Darker colours indicate higher density of haddock landings.

4.3.3 Models of juvenile advection and settlement

Between 2006 and 2009, the Marine Laboratory, Aberdeen and the University of Strathclyde, Glasgow conducted a joint research project ("Strathaddy") on a spatially-explicit model for haddock populations in northern Scottish waters. The intention was to build on earlier work at the Marine Laboratory (the STEREO project; see, for example, Heath and Gallego, 1998) and develop a detailed spatio-temporal population model incorporating spawning areas, hydrodynamic advection and growth of juveniles, and settlement of juveniles at the appropriate development stage if suitable benthos is available. One of the key scientific aims was to try and understand the sporadic nature of recruitment to the haddock stocks around northern Scotland, and the principal policy driver was to determine the exploitation strategy that would enhance haddock conservation and sustainability.

Papers reporting the results of Strathaddy are in various stages of development, although none have yet reached full publication. However, from internal project reports we can draw modelling results that have particular relevance for discussions on haddock stock structure. Figure 4.3.4 shows approximate spawning areas for haddock, based on survey data and divided into three broad spawning components from west to east (West of Scotland, Moray Firth and Shetland). Figure 4.3.5 illustrates potential recruitment distributions of juveniles from these spawning components, assuming current flow-fields from three different years.

Young haddock experience egg, larval and juvenile stages, during which they have limited horizontal motility and are advected with the prevailing current. After a period of months they are forced to settle on the benthos and assume a demersal habitat: if no suitable benthos is available, they will be advected on further, and if no suitable area presents itself before a given cut-off point, they will die. Survival success thus depends on a combination of feeding success, predation success, hydrodynamics and distribution of suitable benthos.

From Figure 4.3.5, it is clear (given model assumptions) that the products of spawning from all three areas recruit to the adult population in a similar area: to whit, the central northern North Sea. In particular, juveniles spawned in the West of Scotland settle predominantly in that area around Shetland, and will therefore be indistinguishable to the fishery from fish spawned in that area. In the absence of tagging data and related genetic or morphological studies, we cannot determine whether haddock exhibit fidelity to their spawning areas. It would be reasonable to conclude that the haddock to the north of Scotland form one functional unit, rather than two.

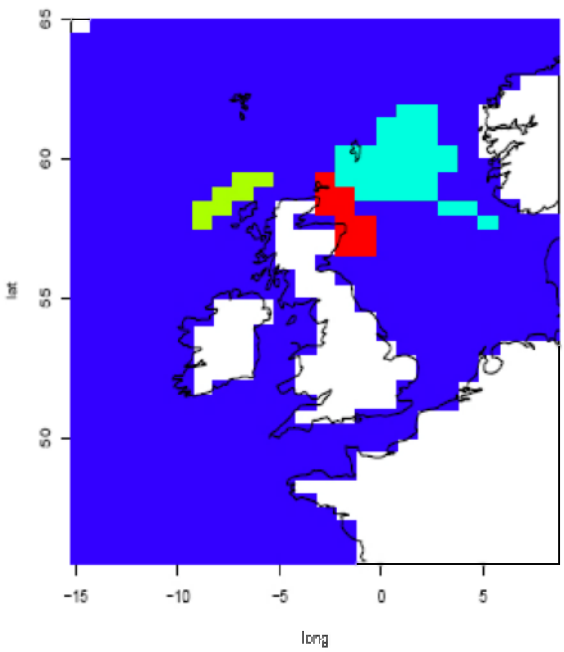

Figure 4.3.4. Haddock spawning areas identified for the Strathaddy model. Green = West of Scotland. Red = Moray Firth. Turquoise = Shetland. Source: University of Strathclyde.

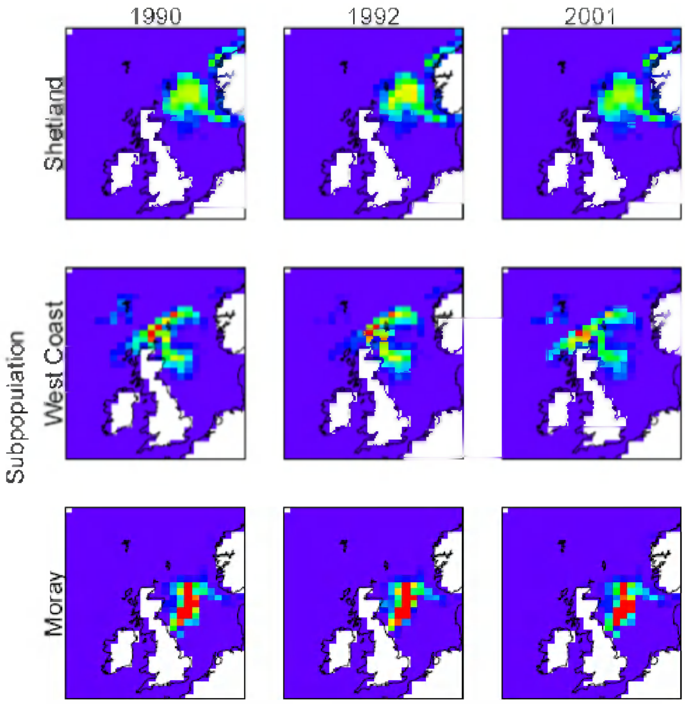

Figure 4.3.5. Spatial distribution of recruits in January 1, following spawning in the areas shown in Figure 4.3.4 in the preceding spring. Columns give results when using the observed current flow-fields from 1990, 1992 and 2001. Colours refer to density of settled recruits, with red being the most dense. Source: University of Strathclyde.

4.3.4 Stock structure and distribution conclusion

Haddock in the North Sea and West of Scotland are currently assessed and managed as two separate stocks. While not conclusive, independent evidence from research-vessel surveys, VMS data and hydrobiological stock models all provides support for the hypothesis that all these fish are in fact members of the same biological unit. If this is the case, then treating them as separate in the assessment and management cycle may be inducing unwanted bias and uncertainty, to the detriment of both the stock and the dependent fisheries.

This work is still in development, and the conclusion that there is a single stock is not yet reliable or robust enough to lead to a change in the approach taken. However, as the next step: **WKBENCH recommends that a joint IVa–VI dataset be collated in time for the assessment WGs in May 2011, and that a comparative assessment be carried out by WGNSSK using these data. This will provide further evidence for a final decision on appropriate assessment units.**

4.4 Influence of the fishery on the stock dynamic

No new information was presented on this issue.

4.5 Influence of environmental drivers on the stock dynamic

Section 4.3 above discusses a model of the effect of current flows on subsequent recruitment of young haddock in the West of Scotland and the North Sea. Apart from this, no new work on the influence of environmental drivers was presented.

4.6 Role of multispecies interactions

4.6.1 Trophic interactions

No new information was presented on this issue.

4.6.2 Fishery interactions

No new information was presented on this issue.

4.7 Impacts of the fishery on the ecosystem

No new information was presented on this issue.

4.8 Stock assessment methods

4.8.1 Models

Three assessment models for North Sea haddock were presented at the WKBENCH meeting:

1) XSA: the assessment method currently in use. The North Sea haddock assessment has been conducted using XSA since the method was developed in the early 1990s (Darby and Flatman, 1994; Shepherd, 1999), and the R-based FLXSA implementation (Kell, 2006) has been used since 2007. The assessment uses the following settings:

Convergence tolerance	tol = 1e–9
Maximum iterations	maxit = 200
Minimum SE used in the estimate of N	min.nse = 0.3
F shrinkage	fse = 2.0
Oldest age for the power q model	rage = 0
Youngest age for the q plateau	qage = 6
Shrinkage to mean N	shk.n = TRUE
Shrinkage to mean F	shk.f = TRUE
Number of years for shrinkage	shk.yrs = 5
Number of ages for shrinkage	shk.ages = 3
Tuning time window	window = 100
Number of years for time-series weighting	tsrange = 99
Power for time-series weighting	tspower = 0

2) SAM: a time-series, state-space model currently used for the assessment of a number of ICES stocks (Nielsen, 2009). SAM is based on the methodology of TSA (Fryer, 2002) with a number of modifications, and is run via a web-based interface. The main differences between SAM and XSA are that SAM is a statistical model that does not assume that catch data are measured without error.

3) SURBA: a separable survey-based model (Needle, 2003) which is used as an exploratory analysis for many ICES stocks, and as a full assessment

model for a number of stocks in the Mediterranean and further afield. To date it has been available as a Windows executable written in Fortran-90, but a new implementation in R has recently been developed and it is this version (SURBAR) which is used here. Default settings have been used for the results presented in this Section.

The results of these three models are presented separately in the following three Sections. We then compare the model outputs and reach conclusions on which model to take forward for subsequent WGNSSK assessments.

4.8.2 XSA

4.8.2.1 XSA iteration convergence

XSA does not use a statistical goodness-of-fit criterion, but instead iterates towards its solution (in a manner analogous to Newton–Raphson root finding). Concerns have been expressed previously about the large number of iterations required to reach convergence in the XSA iterative process when applied to North Sea haddock.

The 2009 meeting of the ICES Working Group on Methods of Fish Stock Assessment (ICES-WGMG 2009) explored this issue in detail. Figure 4.8.1 analyses the iteration convergence for North Sea haddock, which (for the 2010 assessment) took around 120 iterations. The danger with XSA iteration is that the model may choose to increase estimated abundance in order to reduce the magnitude of catchability residuals: this has been suggested as a possibility many times in the past (C. D. Darby, pers. comm.) and is clearly what happens in the North Sea whiting case illustrated in Figure 4.8.2, for which abundance continues to increase and for which there is no convergence.

WGMG attempted to explore this issue further through simulation testing. Ten simulated datasets were generated, following a similar approach to that used in the NOAA Toolbox (NOAA 2010), and iteration tests were applied to each one. Given that the true underlying stock was known in each case, it was possible to score the XSA model on whether the final-year estimate of SSB moved towards the true value as further iterations were applied, towards and then away from the true value, or simply away from the true value. The tests were repeated for a range of plus-group ages (7–10), two q-plateau settings (3 and 6), and 10 retrospective runs (giving 800 tests in all). The results of this analysis are summarised in Figure 4.8.3, from which WGMG concluded that in the majority of simulated datasets tested, the XSA iteration process pushed the final-year SSB estimate *away* from the true value.

The WGMG recommendations following this work were:

- FLXSA output should include the number of iterations taken to reach the solution.
- Convergence behaviour of XSA (and indeed all models) should *always* be checked.
- Slow convergence and/or high sensitivity to the number of iterations could indicate that XSA is not suitable for the stock concerned. Alternative models that do not rely on *ad hoc* assumptions and algorithms should be explored for these cases.

The first two recommendations have been applied to all subsequent WGNSSK assessments of North Sea haddock, while the third is explored in this WKBENCH report through the use of SAM and SURBA. However, there is a potential flaw with the analysis carried out by WGMG in 2009. Simulated data were generated using a model that assumed separable fishing mortality. XSA does not include explicitly this assumption, so it is possible that the conclusions regarding iteration convergence were driven in part by a potential model misspecification. Consequently, the analysis should be repeated using XSA (or a similar cohort-based model) as the data generator. We do not know if the North Sea haddock is subjected to separable fishing mortality in reality: if it isn't, then the conclusions of WGMG may not be valid for this particular case.

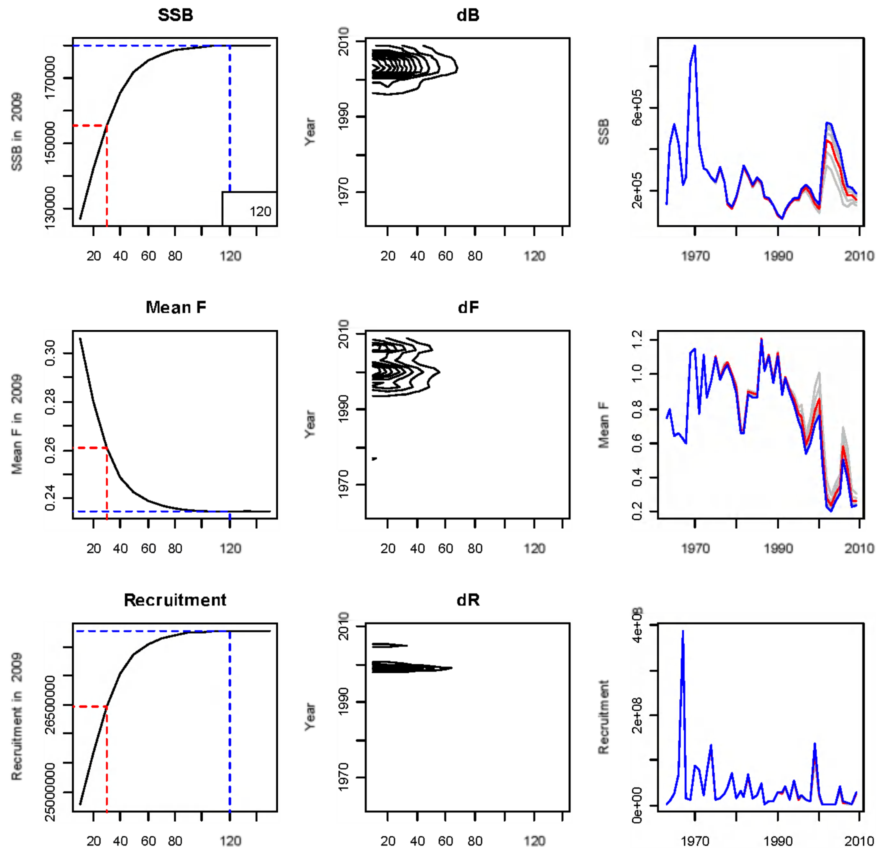

Figure 4.8.1. XSA convergence tests for North Sea haddock from the WGNSSK 2010 assessment. Top row: SSB. Middle row: mean F(2–4). Bottom row: recruitment at age 0. Left column: relationship between the estimate for 2009 and the number of iterations run (red lines indicate 30 iterations; blue lines indicate iterations required for convergence). Middle column: contour plot of difference between estimates over the whole time-series between one iteration and the next. Right plot: estimated time-series from all iterations (grey lines), with 30 iterations (red line) and converged iterations (blue line) highlighted.

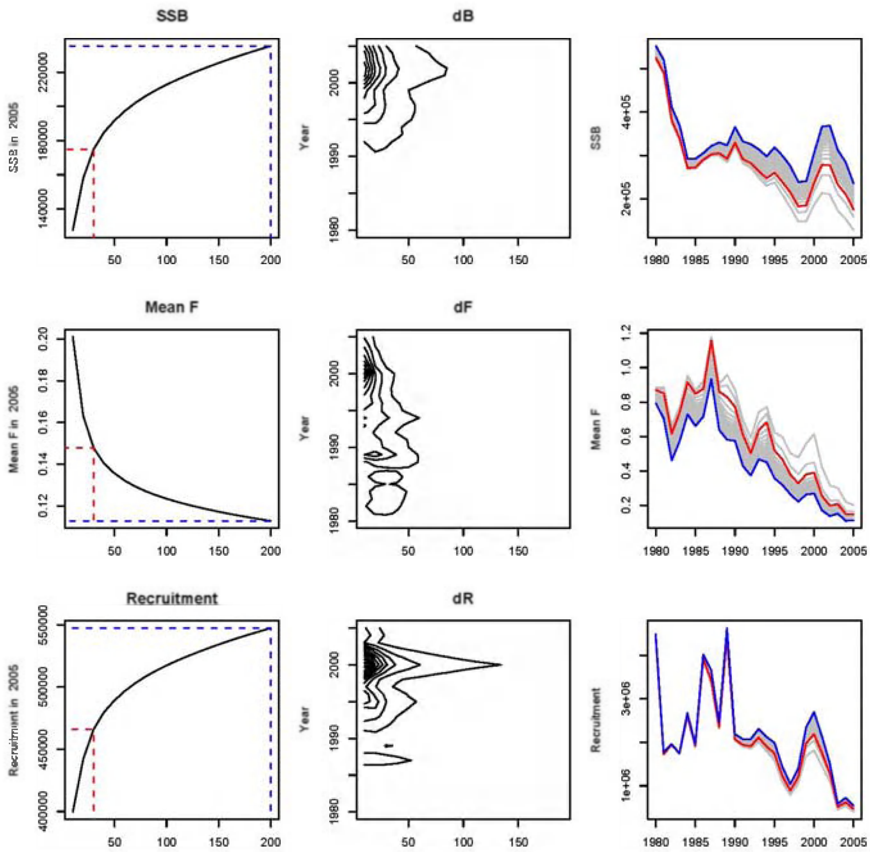

Figure 4.8.2. XSA convergence tests for North Sea whiting from the WGNSSK 2006 assessment. See caption for Figure 4.8.1 for details.

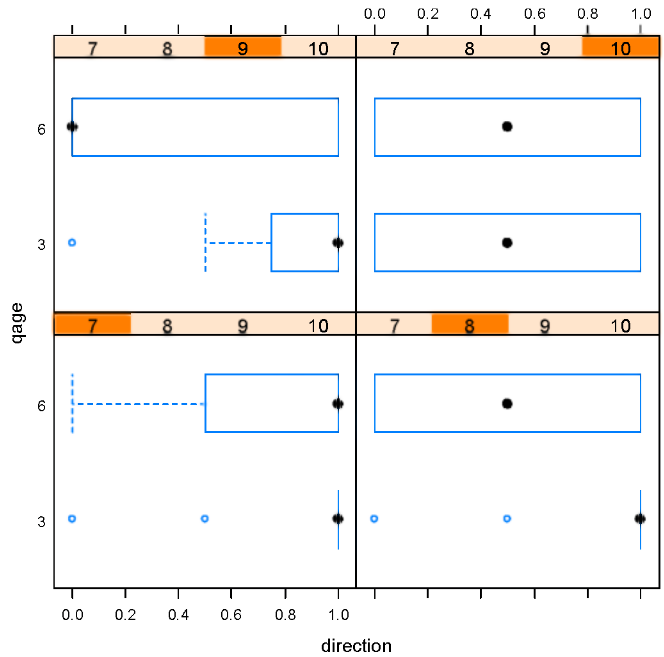

Figure 4.8.3. Box-and-whisker summaries of the convergence direction (0.0 = towards the true value, 0.5 = crossing the true value or flat, 1.0 = away from the true value) across 10 simulated datasets, each with 10 retrospective runs. The *y*-axis gives the *q*-plateau age, while the strip header for each subplot gives the plus-group age.

4.8.2.2 Time-varying natural mortality estimates in XSA

The time-varying values of M (discussed in Section 4.2.2.1) were used in an XSA run with the same parameter settings as the current WGNSSK assessment. The results are compared in Figure 4.8.4.

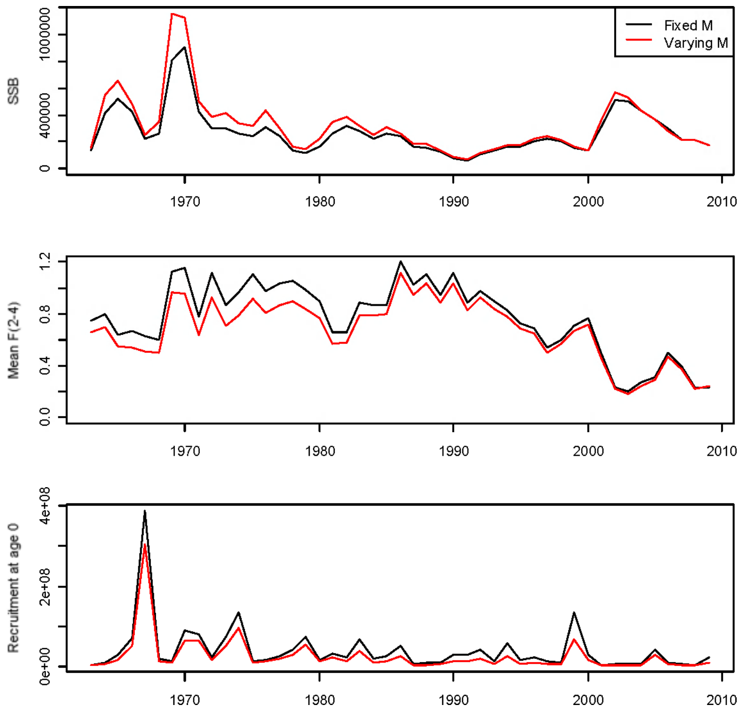

Figure 4.8.4. Time-series estimates from XSA runs using fixed and time-varying natural mortality estimates. In both cases, maturity estimates were fixed and iterations were unrestricted.

The time-varying M at age 0 is lower than the fixed M at age 0, so model assumes there must have been less fish in each cohort to begin with in order to arrive at the observed catch and survey data: hence the lower recruitment. Time-varying Ms at older ages (>1), on the other hand, are higher, so the model expects that there must have been more fish to produce the observed data: hence the higher SSB. There is also a corresponding reduction in the level of mean F(2–4). Indeed, without catch data, the model would simply reduce F to account for increased M, but with catch data included there is a limit to how much of reduction can be made. We also note that the estimates for more recent years are very similar.

Figure 4.8.5 summarises the changes in the stock–recruitment plot that occur when time-varying natural mortality is included. Essentially, the points are smeared down and to the right, and this will have an effect on biological reference points (see Section 4.10).

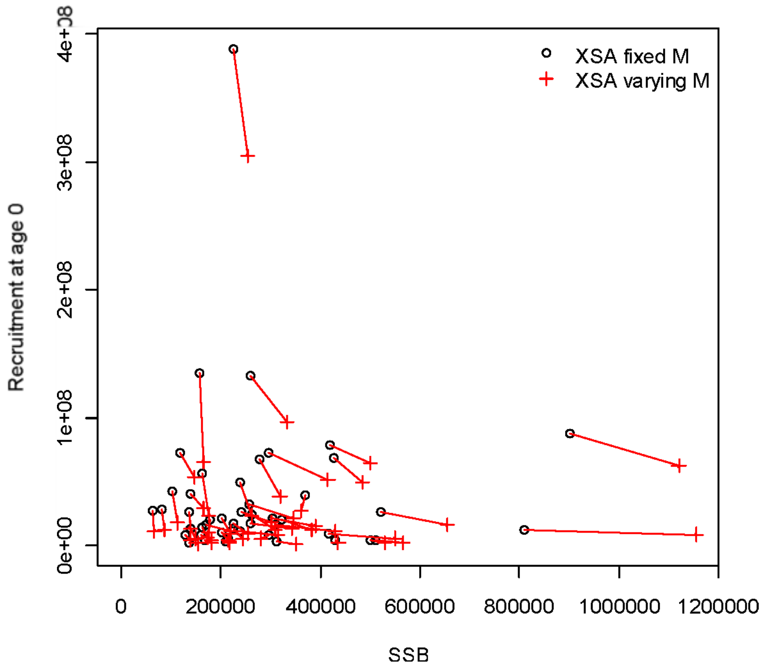

Figure 4.8.5. Comparison between stock–recruit data from XSA runs using fixed and time-varying natural mortality estimates. In both cases, maturity estimates were fixed and iterations were unrestricted.

4.8.2.3 Time-varying maturity estimates in XSA

Time-varying values of maturity (derived from IBTS Q1 and discussed in Section 4.2.2.2) were used in an XSA run with the same parameter settings as the current WGNSSK assessment, and which also included the time-varying estimates of natural mortality discussed in Section 4.2.2.1 and 4.8.2.2 (time-varying maturity has not been used independently). The results are compared in Figure 4.8.6 (time-series) and 4.8.7 (stock–recruit). We reach similar conclusions as for the case when just time-varying natural mortality estimates were used (Section 4.8.2.2), but the effects appear to be emphasised.

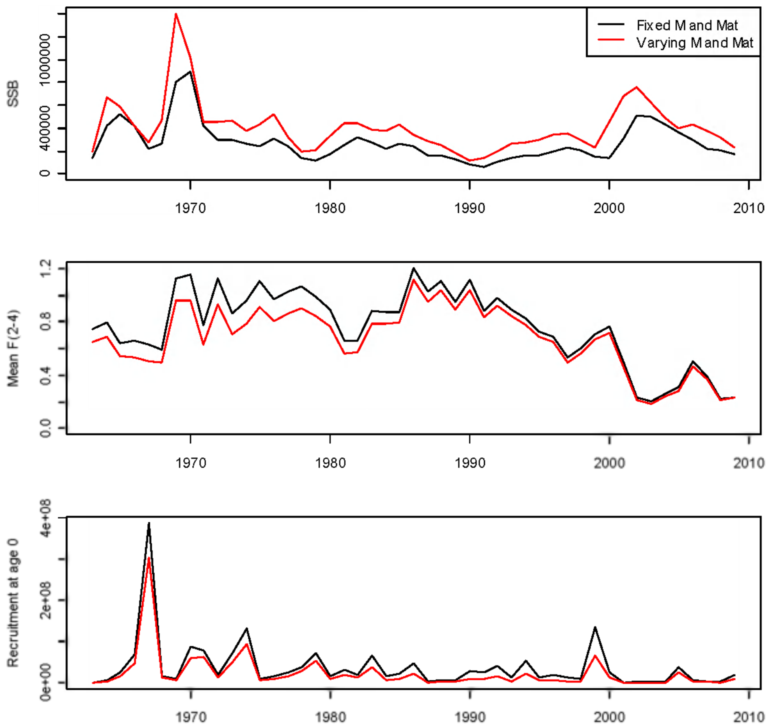

Figure 4.8.6. Time-series estimates from XSA runs using fixed and time-varying maturity estimates. In both cases, time-varying natural mortality estimates were and iterations were unrestricted.

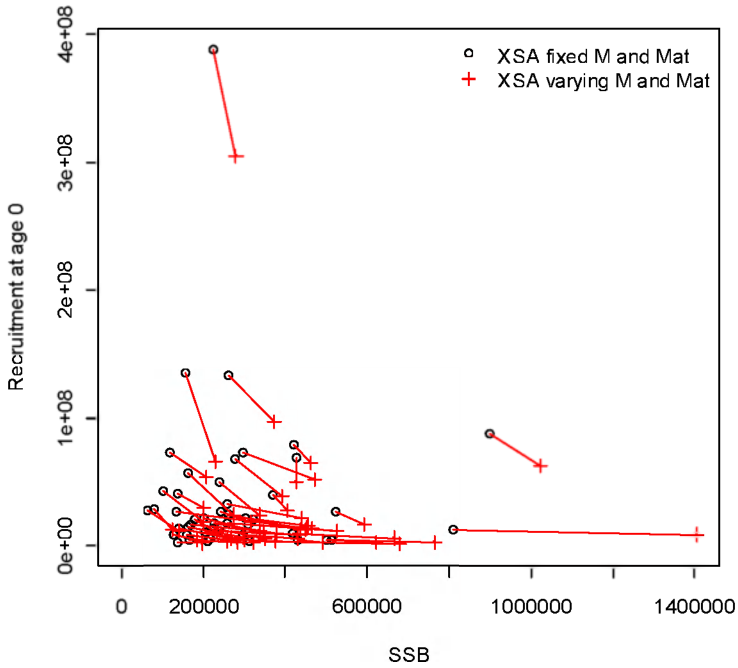

Figure 4.8.7. Comparison between stock–recruit data from XSA runs using fixed and time-varying maturity estimates. In both cases, time-varying natural mortality estimates were and iterations were unrestricted.

4.8.2.4 Retrospective XSA assessments

Ten-year retrospective XSA runs were carried out for a number of different configurations, as follows:

1) Fixed natural mortality and maturity/unrestricted iterations (Figure 4.8.8).
2) Fixed natural mortality and maturity/maximum iterations = 30 (Figure 4.8.9).
3) Fixed natural mortality and maturity/maximum iterations = 10 (Figure 4.8.10).
4) Time-varying natural mortality and maturity/unrestricted iterations (Figure 4.8.11).

These show, firstly, that the retrospective performance of XSA for the North Sea haddock assessment is extremely consistent. When iterations are unrestricted (Figure 4.8.8), there is virtually no retrospective pattern at all, implying that catches and surveys are both internally and externally consistent in how they pick up stock-dynamics signals. XSA does not allow for uncertainty in catches, but the year-to-year consistency is nevertheless remarkable. We also note that not allowing the model to converge (through limiting iterations to 30 or 10; Figures 4.8.9 and 4.8.10) reduces this consistency considerably, although the retrospective pattern remains better than (for example) the other stocks in this WKBENCH report. Finally, the use of time-varying natural mortality and maturity estimates has no discernable effect on the retrospective runs (Figure 4.8.11).

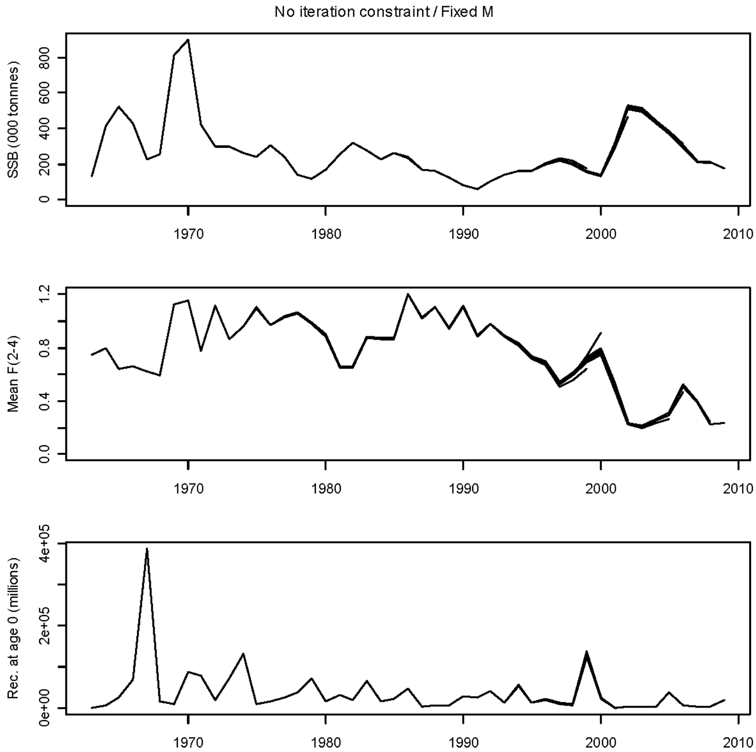

Figure 4.8.8. Results of retrospective XSA runs with fixed natural mortality and maturity, and unrestricted iterations.

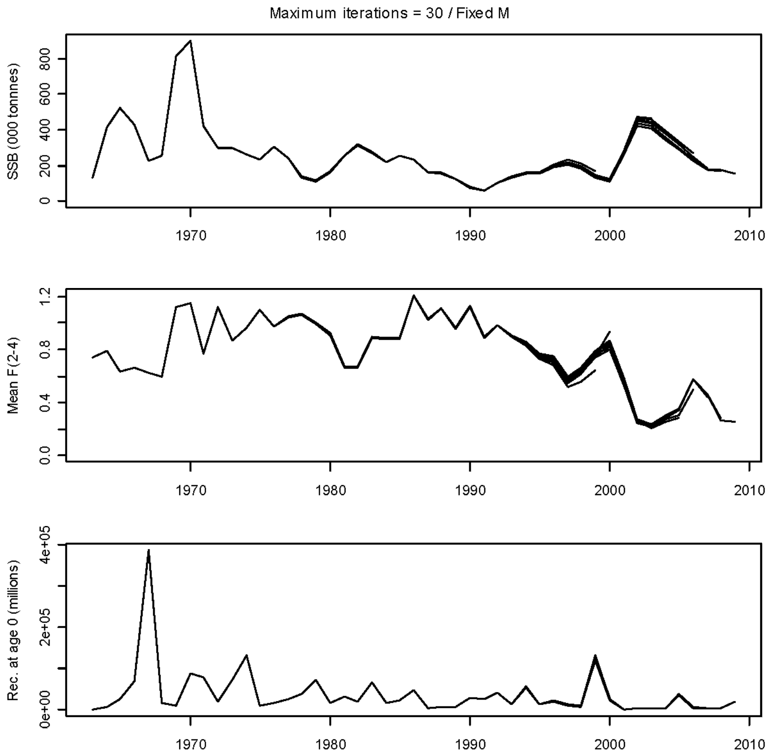

Figure 4.8.9. Results of retrospective XSA runs with fixed natural mortality and maturity, and maximum iterations = 30.

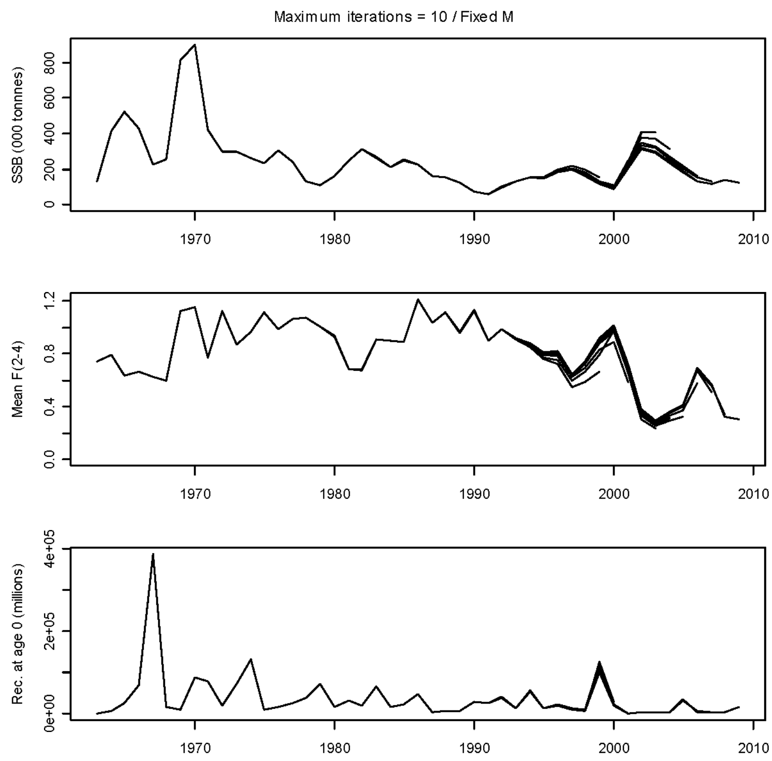

Figure 4.8.10. Results of retrospective XSA runs with fixed natural mortality and maturity, and maximum iterations = 10.

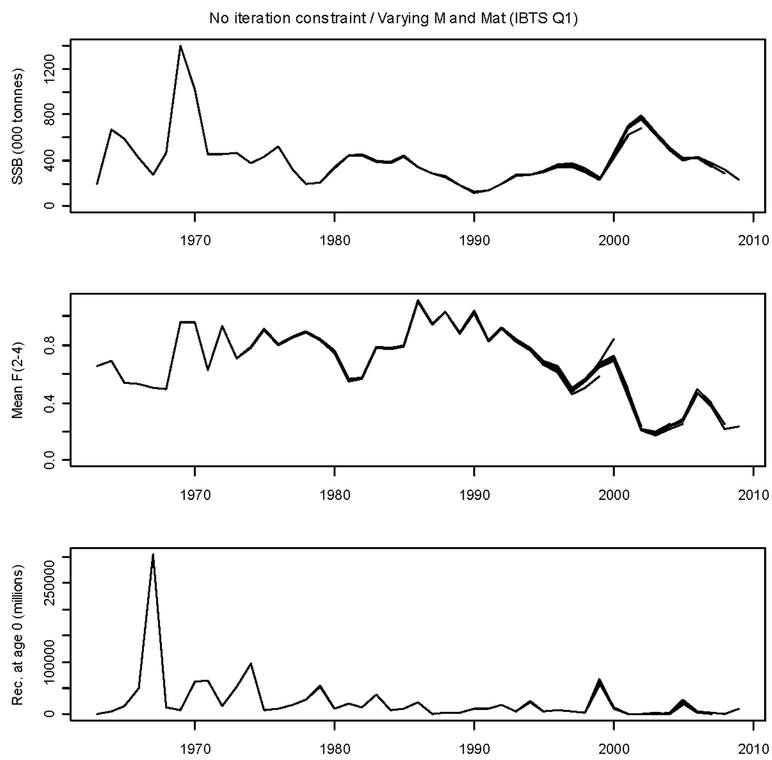

Figure 4.8.11. Results of retrospective XSA runs with time-varying natural mortality and maturity (the latter based on IBTS Q1 SMALK data), and unrestricted iterations.

In addition, the number of iterations required for convergence for each retrospective run was recorded; these are summarised in Figure 4.8.12. This demonstrates clearly that the large number of iterations required is not a function of the mean level of fishing mortality in the final year, as this varies from 0.8 (when the last retro year is 1999 or 2000) to 0.3 (when the last retro year is 2008 or 2009). The required iterations vary around a mean level of ~120 in all cases.

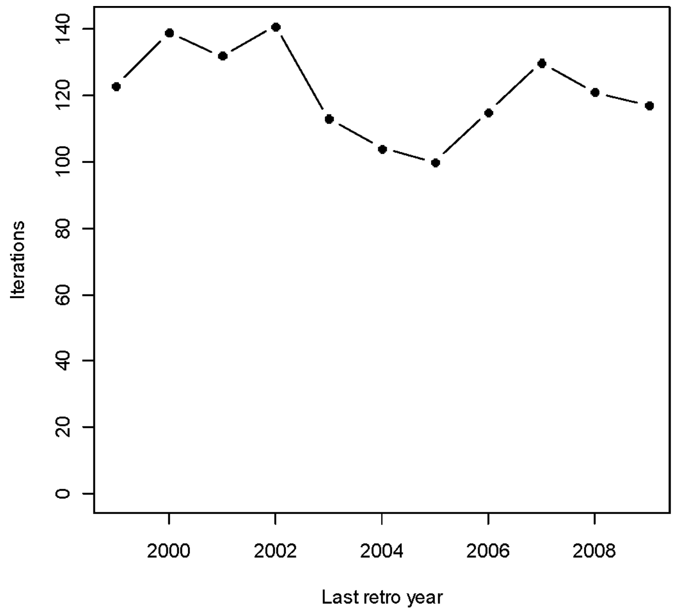

Figure 4.8.12. Iterations required for convergence for retrospective XSA runs with fixed natural mortality and maturity.

4.8.3 SAM

The initial setup and run of any SAM assessment is conducted by Anders Nielsen (DTU-AQUA, Copenhagen), once supplied with input data and suggestions for run settings. Following this step, the assessment output will be available via the SAM website (http://www.stockassessment.org), through which modifications and re-runs can be performed. This is a potentially powerful system, as no code needs to be maintained on the user's own system and full advantage can be taken of the power of the central server. However, it is still not all that straightforward to make modifications when required, and the assistance of Anders Nielsen during WKBENCH is gratefully acknowledged.

Figures 4.8.13 to 4.8.16 below summarise the standard SAM run carried out for WKBENCH (i.e. with fixed natural mortality and maturity). An additional run was performed using varying estimates for these two quantities, but it is not reported here as the conclusions regarding comparisons with XSA remained unchanged. According to its diagnostics, the assessment has performed well, with no obvious patterns or unwanted large outliers in residuals and quite tight confidence intervals.

The retrospective plot (Figure 4.8.16) does not compare well, at face value, with the equivalent XSA plot (Figure 4.8.5). SAM would appear to have introduced an element of retrospective bias, although it depends on how this is defined. In one sense, there is bias because the final-year point values of several of the retrospective F and SSB estimates lie with (and are all on one side of) the confidence interval of the full time-series estimates. On the other hand, the confidence intervals of the final-year estimates do overlap with the central value from the full time-series estimate, so in that sense there is not retrospective bias.

So it is not actually clear whether or not retrospective bias (or even noise) exists. However, the retrospective estimates are certainly more variable for SAM than for XSA, and this causes a problem for management advice. For example, pointwise SSB estimates which are revised downwards every year, when used in a management structure that demands a single value on which to base advice, will lead to downwards revisions in quotas which are driven by model revisions rather than directly by new data. Therefore, the retrospective bias (or noise) seen in the SAM run is not necessarily a problem when viewed as an internal SAM diagnostic, but it is a problem when considered in the context of the existing management structure.

A final comment on this issue is that it is not clear why the retrospective noise appears in the SAM runs. SAM allows for uncertainty in catch statistics, which XSA does not. But the XSA retrospectives (and those for SURBA; see Figure 4.8.20 below) indicate that catch and surveys are very consistent for this stock. It could be argued that the retrospective noise in SAM is more of an artefact of the model than anything else. However, this is an extreme view, if such a thing were to exist, the "real" retrospective bias would probably lie somewhere between that suggested by SAM and XSA.

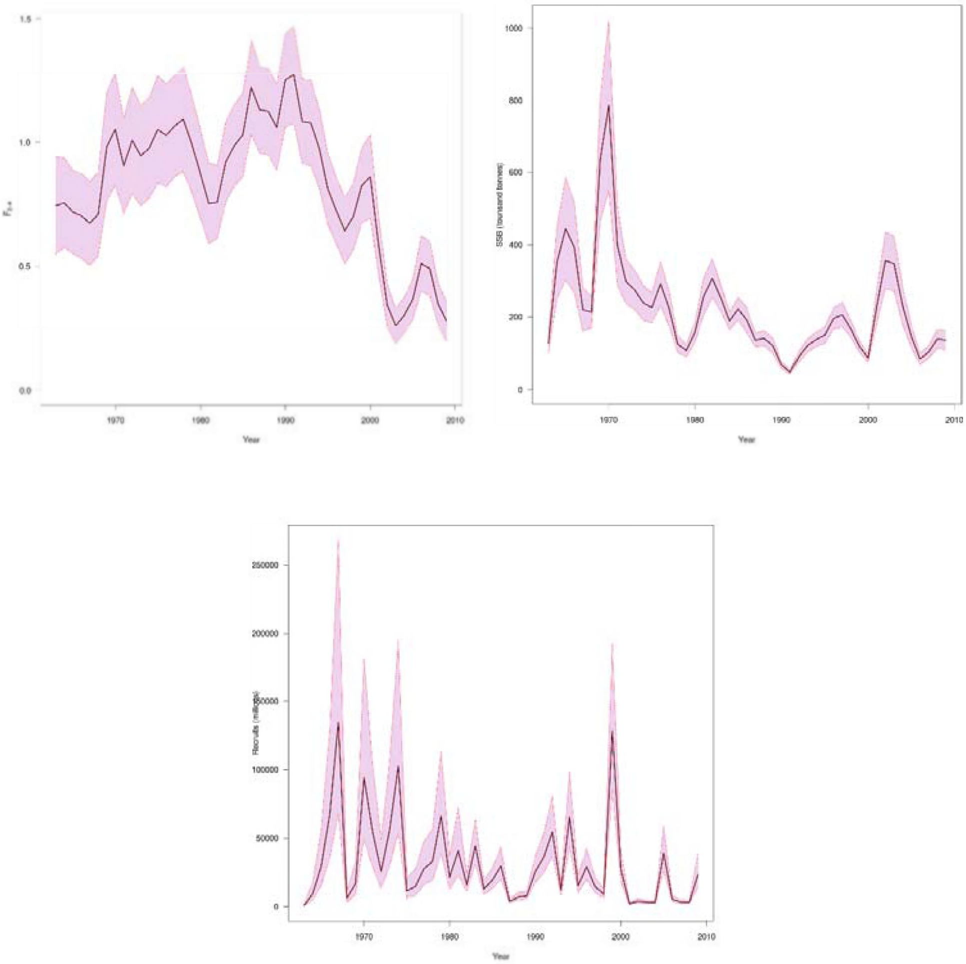

Figure 4.8.13. SAM results for standard data settings (fixed natural mortality and maturity). Top left: mean F(2–4). Top right: SSB. Bottom: recruitment at age 0. Shaded areas give approximate 95% confidence intervals.

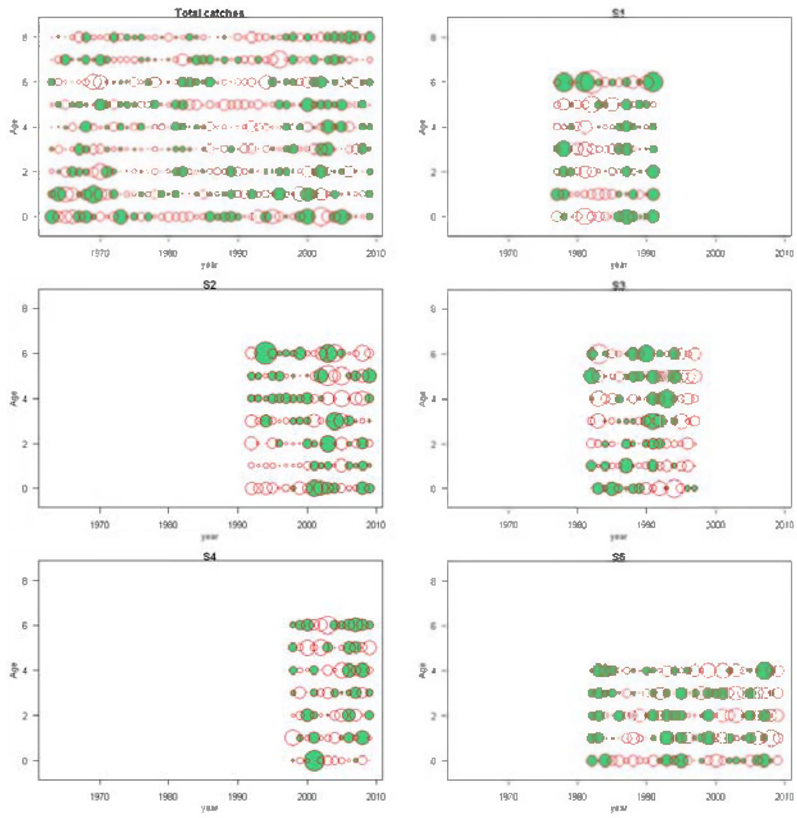

Figure 4.8.14. Normalised residuals for the standard SAM run. Red circles indicate a positive residual and filled green circle indicate a negative residual.

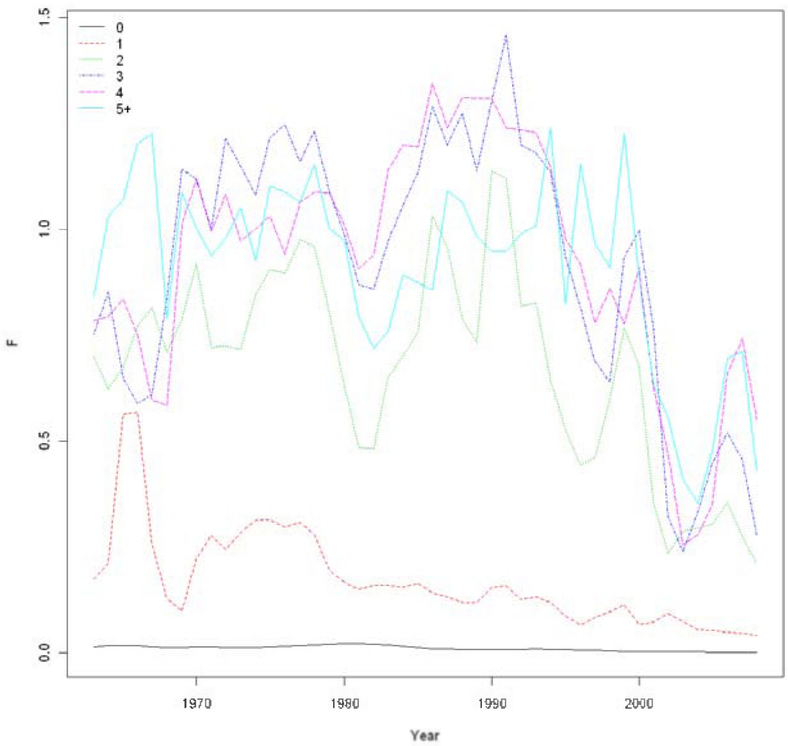

Figure 4.8.15. Estimated F-at-age for the standard SAM run.

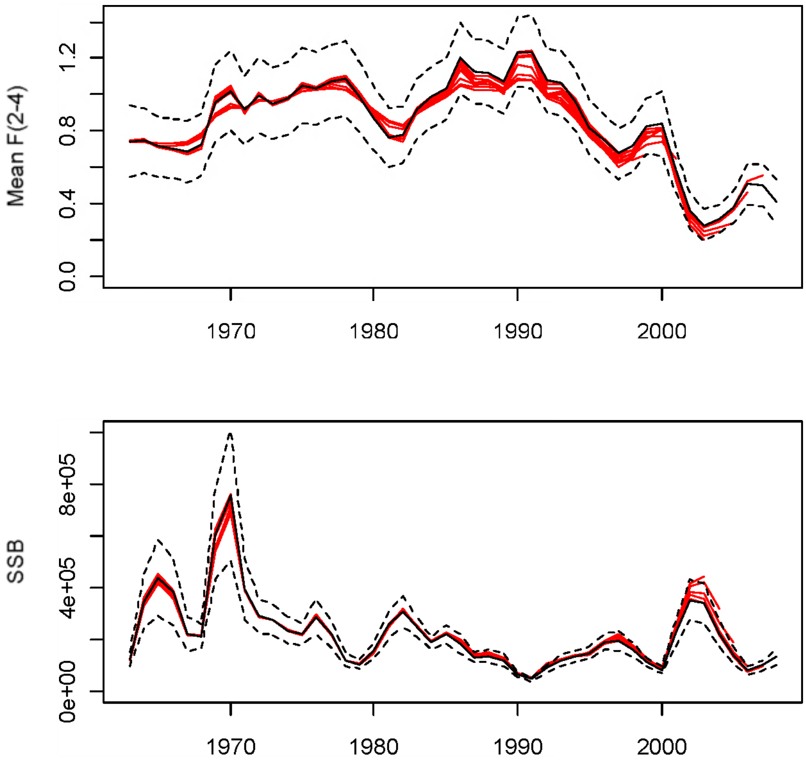

Figure 4.8.16. Retrospective runs for the standard SAM assessment. Black dashed lines give the approximate pointwise 95% confidence intervals about the full time-series run.

4.8.4 SURBA

Figures 4.8.17 to 4.8.20 summarise the SURBA model fit to the three available survey dataseries for North Sea haddock (IBTS Q1, ScoGFS Q3 and EngGFS Q3), assuming fixed natural mortality and maturity estimates. The model appears to fit the data well, with relatively tight confidence intervals and no clear pattern or outliers in residuals. Furthermore, there is very little bias or noise in retrospective runs (Figure 4.8.20), save for the final year mean Z values which are forecasts and are produced by three-year means.

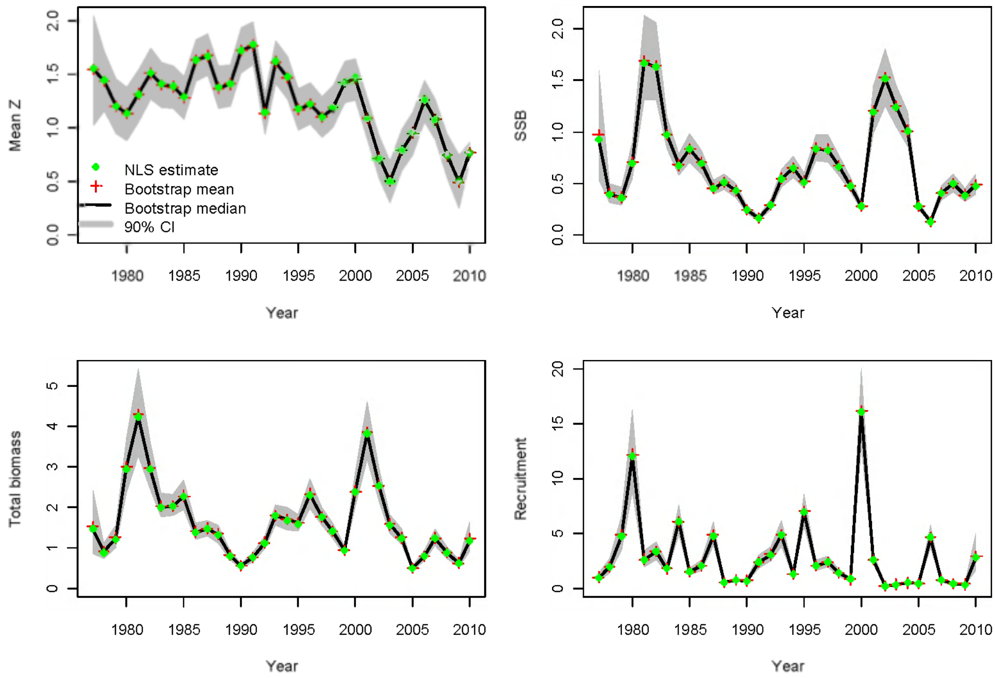

Figure 4.8.17. Stock summary estimates for the SURBA run. Lines give the bootstrap medians, while grey bands indicate the bootstrapped 90% confidence intervals. Best estimates (green dots) and the bootstrap mean (red crosses) are also shown. The scales of SSB, TSB and recruitment are determined by the scales of the mean-standardised survey data: time-series have not been further mean-standardised here.

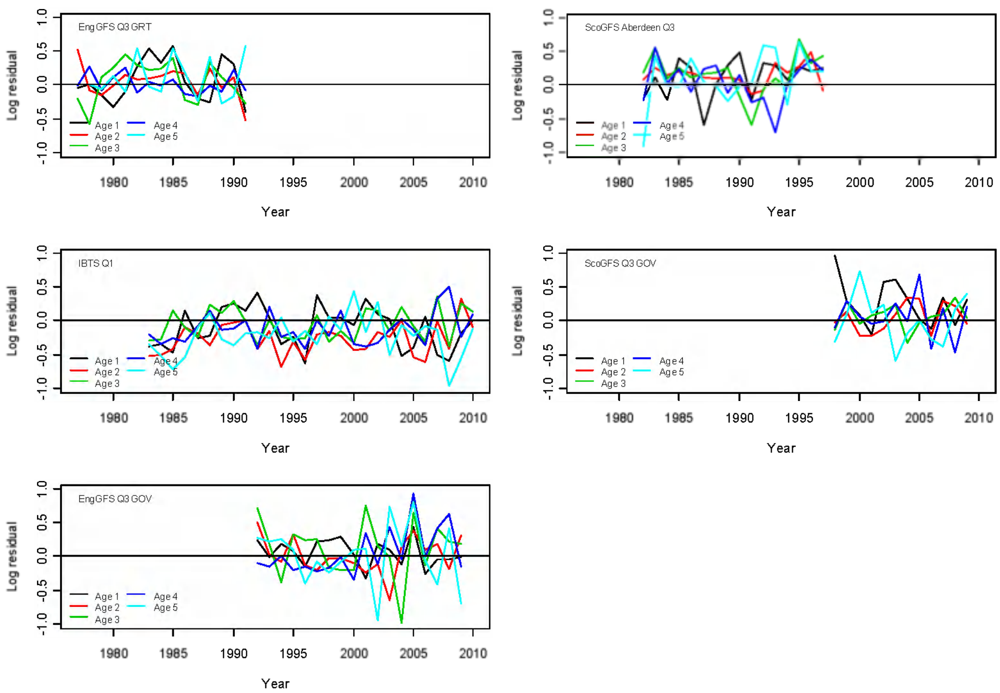

Figure 4.8.18. Survey residuals for the SURBA run.

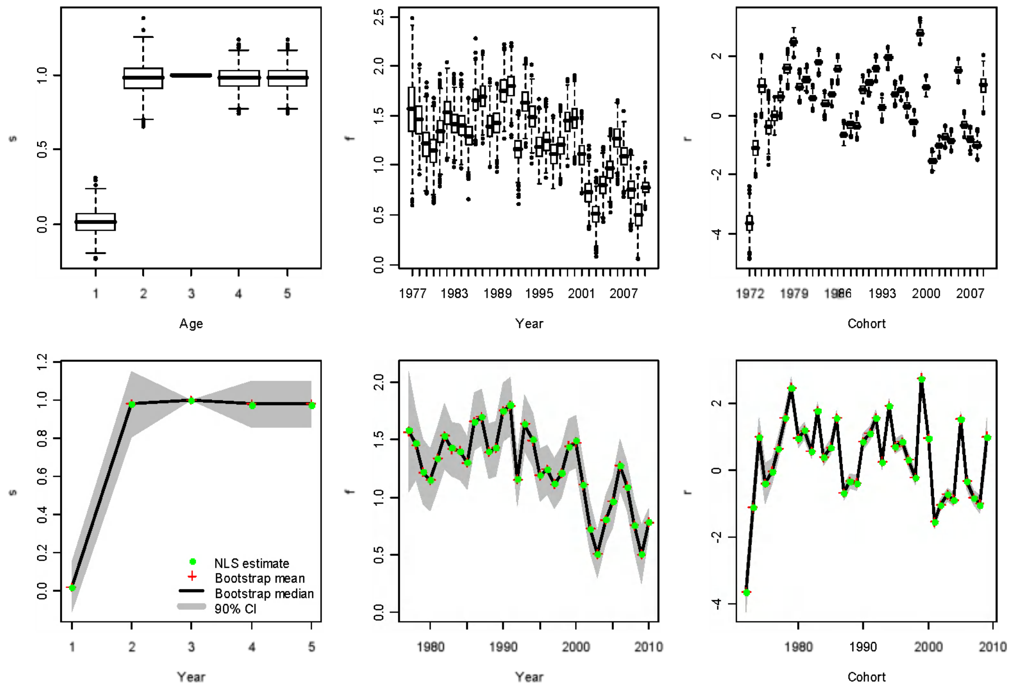

Figure 4.8.19. Parameter estimates for the SURBA run, both as box-and-whisker plots (upper row) and confidence bands (lower row; see Figure 4.8.14 for description of notation).

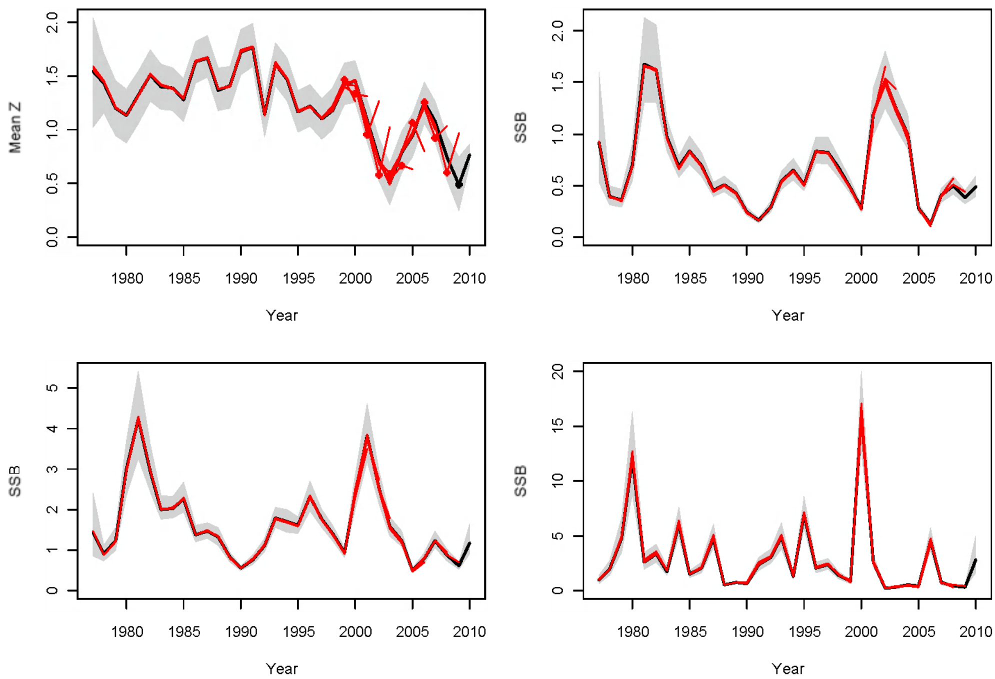

Figure 4.8.20. Retrospective runs for the SURBA analysis. Black lines and grey bands indicate median and 90% confidence intervals respectively for the bootstrapped analysis of the full-time-series. Red lines give retrospective runs. For mean Z, dots indicate the last true data-based estimate for each retrospective run: the extra forecast year estimated in each case is based on a three-year mean.

4.8.5 Conclusion

Figure 4.8.21 compares the stock summaries from XSA and SAM (both using fixed natural mortalities and maturities), while Figure 4.8.22 contrasts the stock–recruit information from the two models. SAM gives lower SSB and higher mean F results than XSA, and gives much lower estimates for some of the large early year classes (particularly 1967). For these, SAM has used a combination of time-series smoothing and the lack of corroborating survey data to conclude that the catch data had high uncertainty.

Figure 4.8.23 compares mean-standardised run outputs from XSA, SAM and SURBA. The broad trends from all three approaches are very comparable, although SURBA has a tendency to estimate larger swings in all three metrics (probably due to greater uncertainty in survey data). The current management structure for North Sea haddock relies on absolute abundance estimates, so the relative abundance output from SURBA cannot be used for this purpose and the model can be discounted as the final assessment choice (although it is still useful for comparative and exploratory analyses).

Comparing XSA and SAM, we see that there is actually little to choose between them. The principal perceived problem with XSA is the issue of slow convergence and the potential of this to lead to inflated abundance estimates. This is an aspect that cannot readily be solved, and WKBENCH has not managed to do so conclusively. We suggest that the simulation analysis of WGMG (ICES-WGMG 2009) may be unrepresentative because of model misspecification in the simulated datasets. Other than that, there is little to do on apart from a "feeling" that 120 iterations is a "lot".

The SAM model is in many ways more conceptually appealing, as it allows for the possibility of uncertainty in catch data and it has a number of other strong statistical properties. The issue of retrospective noise and/or bias cannot be avoided, however. Viewed independently of the management structure it would not be considered a problem; however, given that point estimates are required, and given that these are revised annually (and significantly) by SAM, the retrospective bias does create difficulties. It is hard to argue the benefits of a move from a method with no retrospective bias to one with retrospective bias (at least, in the context of current management). Consequently, **WKBENCH recommends that the update assessment method should remain XSA (with the current settings) for the time being**. SAM and SURBAR runs should continue to be produced as exploratory analyses.

The issue of fixed or time-varying natural mortality and maturity estimates is perhaps more straightforward. We have demonstrated that both of these quantities have changed considerably through time, and that the fixed values used for the assessment are no longer valid. **The time-varying estimates for natural mortality have been developed over a number of years by WGSAM and have a robust methodological background (although the supporting stomach-contents data is elderly), and WKBENCH concludes that they should be used in the subsequent update assessments**. The maturity estimates have been derived from IBTS Q1 data quickly during the meeting, and may be less reliable: however, the trend in maturity-at-age is very significant and cannot be ignored. **WKBENCH concludes that refined maturity estimates should be developed before the next WGNSSK meeting in May 2011 and used in subsequent update assessments.**

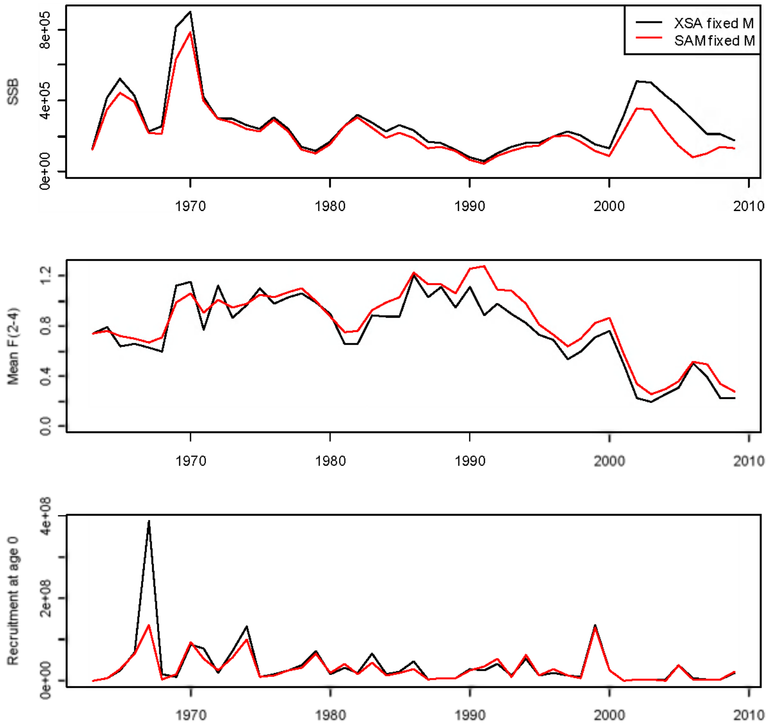

Figure 4.8.21. Stock summary results for XSA and SAM, both using fixed natural mortality and maturity data. Iterations were unrestricted for the XSA run.

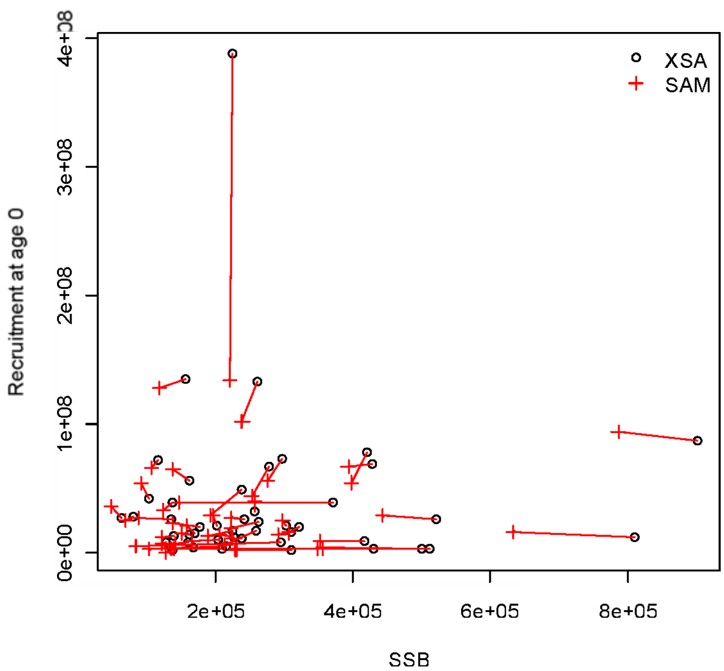

Figure 4.8.22. Comparison between stock–recruit data from XSA and SAM runs, both using fixed natural mortality and maturity estimates. Iterations were unrestricted for the XSA run.

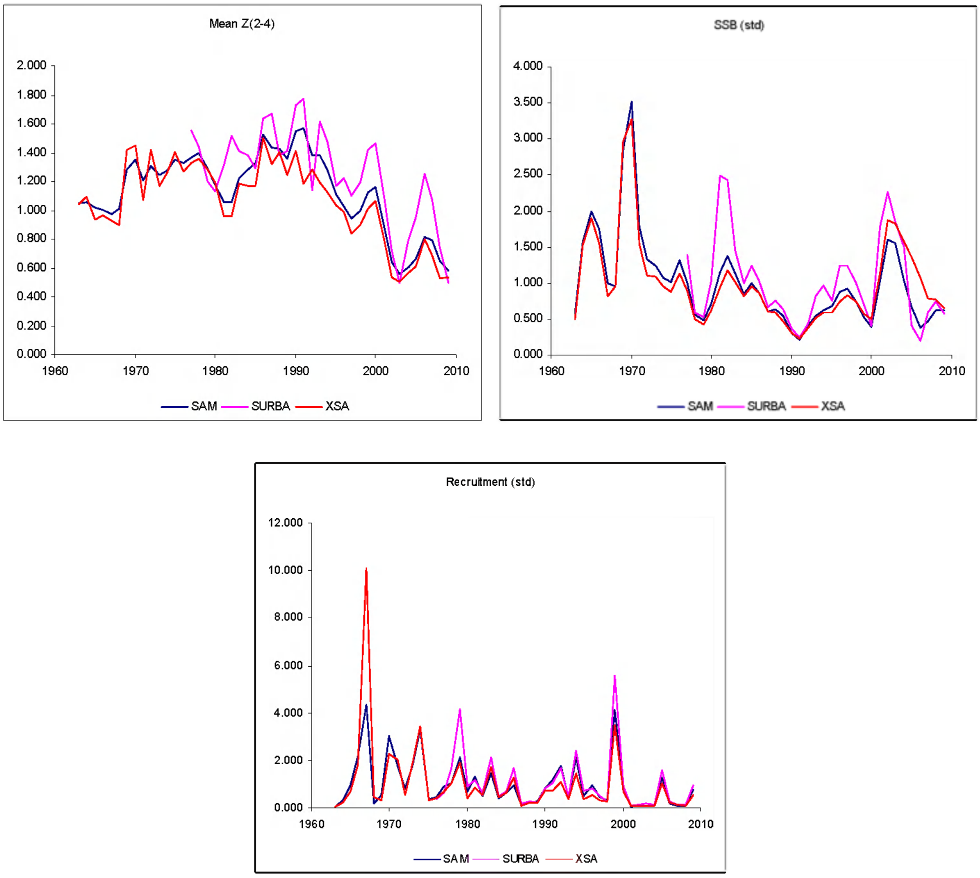

Figure 4.8.23. Stock summary results for XSA, SAM and SURBA, all using fixed natural mortality and maturity data. Mortality is expressed at Z, and SSB and recruitment estimates are mean-standardised, to allow comparisons with SURBA. Iterations were unrestricted for the XSA run.

4.9 Short-term and medium-term forecasts

The key difficulty in recent short-term forecasts for North Sea haddock has been the forecasting of weights-at-age, given that the 1999 and 2000 year classes exhibited a non-standard growth pattern (growing more slowly than would be expected). An *ad hoc* procedure was developed, in which the weights-at-age of these two year classes were forecast using proportional increments, while remaining year classes were forecast using three or five-year mean weights-at-age.

Jaworski (in press) applied twenty different growth forecasting methods (Table 4.9.1) in a hindcast analysis, in which weights-at-age forecasts from 12 years ago were compared with the observed outcomes. The test statistics were the ratio of forecast to observed weights, and the variance of the forecast. There was a general tendency to overestimate weights in forecasts (Figure 4.9.1). The most beneficial model, in terms of both test statistics, was a simple cohort-based linear model.

The abstract from Jaworski (in press) is as follows:

"Methods for predicting mean weight-at-age for four haddock (*Melanogrammus aeglefinus*) stocks in the Northeast Atlantic were evaluated. Their performance in short-term forecasts of yield (catch in weight) was tested in a retrospective analysis conducted for a 12-year period (from 1997 to 2008). For each year, the estimated yield was compared with the observed yield, both being conditional on the recorded catch numbers-at-age. Overall, regardless of the prediction method used, the forecasts generated for Rockall and Icelandic haddock were most accurate, and those for North Sea haddock least accurate. Among the examined methods, there was an overwhelming tendency to overestimate yield. No single method appeared to be superior for all the four stocks. Simple linear models for year classes regressing mean weight on age appeared an effective method for the North Sea and West of Scotland stocks. Some methods based on linear models for expected growth, with weight, age, year or year-class effects as predictors, performed well, which reflected the growth patterns specific to each stock. Application of some of the proposed methods considerably reduced the bias and increased the precision of yield forecasts as compared with the methods currently being used, particularly for North Sea and Icelandic haddock."

4.9.1 Conclusion

Jaworski (in press) has conducted an extensive hindcast testing procedure of a wide variety of methods for forecasting weights-at-age in North Sea haddock, and has been able to explore the issue in far more depth and breadth than has previously been possible. His conclusion on the method that generates the estimate with the least bias and variance appears to be robust and has been extensively peer-reviewed. Therefore, **WKBENCH recommends that weights-at-age for North Sea haddock forecasts be modelled using a linear cohort-based approach.**

Method	Model	Method code	Evaluated stocks
Log catch weight vs. log stock weight*	$\log W_{a,y} = \alpha + \beta \log W'_{a,y}$	1[a]	Iceland
Log catch weight vs. log stock weight and age†	$\log W_{a,y} = \alpha_a + \beta_a \log W'_{a,y}$	2	Iceland
Log catch weight vs. log stock weight, age, and year†	$\log W_{a,y} = \alpha_a + \beta_a \log W'_{a,y} + \gamma_y$	3	Iceland
Mean of five previous weights	$W_{a,y} = (W_{a,y-5} + \ldots + W_{a,y-1})/5$	A	All
Mean of three previous weights	$W_{a,y} = (W_{a,y-3} + \ldots + W_{a,y-1})/3$	B[b]	All
Previous weight	$W_{a,y} = W_{a,y-1}$	C	All
Mean proportional increments	$W_{a,y} = W_{a-1,y-1} \sum(W_a/W_{a-1})/n$	D	All
Linear models for year classes	$W_{a,c} = \alpha_c + \beta_c a$	E	All
SGR vs. age	$g_{a,y} = \alpha_a$	F	All
SGR vs. age and year	$g_{a,y} = \alpha_a + \gamma_y$	G	All
SGR vs. age and year class	$g_{a,c} = \alpha_a + \delta_c$	H	All
SGR vs. log weight*	$g_{a,y} = \alpha + \beta \log W_{a-1,y-1}$	I	All
SGR vs. log weight and year*	$g_{a,y} = \alpha + \beta \log W_{a-1,y-1} + \gamma_y$	J	All
SGR vs. log weight and year class*	$g_{a,c} = \alpha + \beta \log W_{a-1,c} + \delta_c$	K	All
SGR vs. log weight and age†	$g_{a,y} = \alpha_a + \beta_a \log W_{a-1,y-1}$	L	All
SGR vs. log weight, age, and year†	$g_{a,y} = \alpha_a + \beta_a \log W_{a-1,y-1} + \gamma_y$	M	All
SGR vs. log weight, age, and year class†	$g_{a,c} = \alpha_a + \beta_a \log W_{a-1,c} + \delta_c$	N	All
Combination of Methods A and D	See above	X[c]	NS
Method E for ages 1–8+	See above	Y[d]	WS
Combination of Methods 1 and J	See above	Z[e]	Iceland

Table 4.9.1. Forecast models for weights-at-age tested by Jaworski (in press).

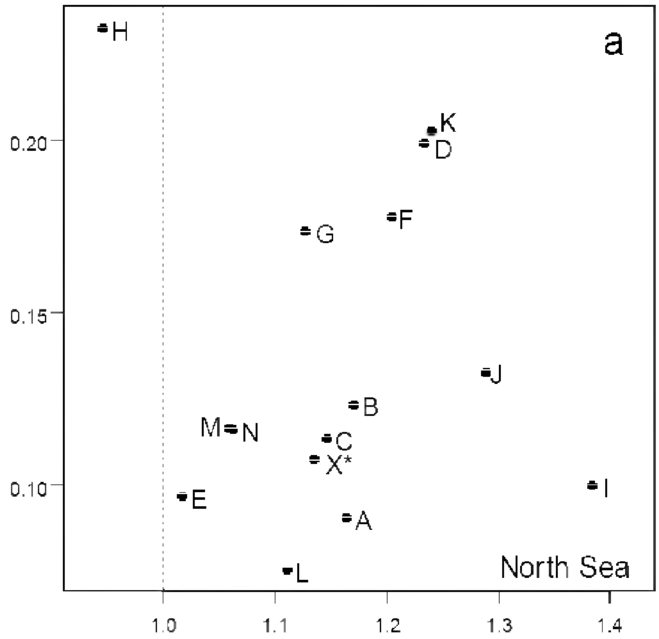

Figure 4.9.1. Results of hindcast forecast model testing from Jaworski (in press). ***x*** **axis = Mean estimated total yield (proportion of observed).** ***y*** **axis = standard deviation of forecasts.**

4.10 Biological reference points

The recommended configuration for the update assessment leads to a substantial revision of estimated abundance and biomass levels. In this context, the existing biomass reference points are no longer valid, and must be revised. In this Section, we present a suggested approach for revising these reference points: however, we encourage **WGNSSK to reconsider this issue in their May meeting**, as this re-estimation was conducted in some haste (and the assessment uses maturity estimates that are temporary only). It will also be necessary to revisit the management strategy evaluation at some time in the future, in case the target F in the management plan is no longer appropriate. We only report reference points here for the XSA assessment with time-varying natural mortality and maturity estimates, although the methodology is more generally applicable.

The existing biomass reference points for North Sea haddock are as follows, along with their technical basis:

Reference point	Value	Technical basis
B(lim)	100 kt	"Smoothed B(loss)"
B(pa)	140 kt	B(lim) * 1.4

These were developed at the ICES Study Group on the Precautionary Approach in 1999 and 2001, based on the WGNSSK stock-recruit estimates from 2000 (ICES-WGNSSK 2000). Figure 4.10.1 illustrates these estimates. From this, it is clear that "smoothed B(loss)" for this stock meant: take the third lowest SSB estimate, and round to the nearest 5 kt. The result of applying this same approach to the final recommended XSA assessment from WKBENCH (with varying natural mortality and maturity) is illustrated in Figure 4.10.2: the interim proposals from this are B(lim) = 185 kt and B(pa) = 260 kt.

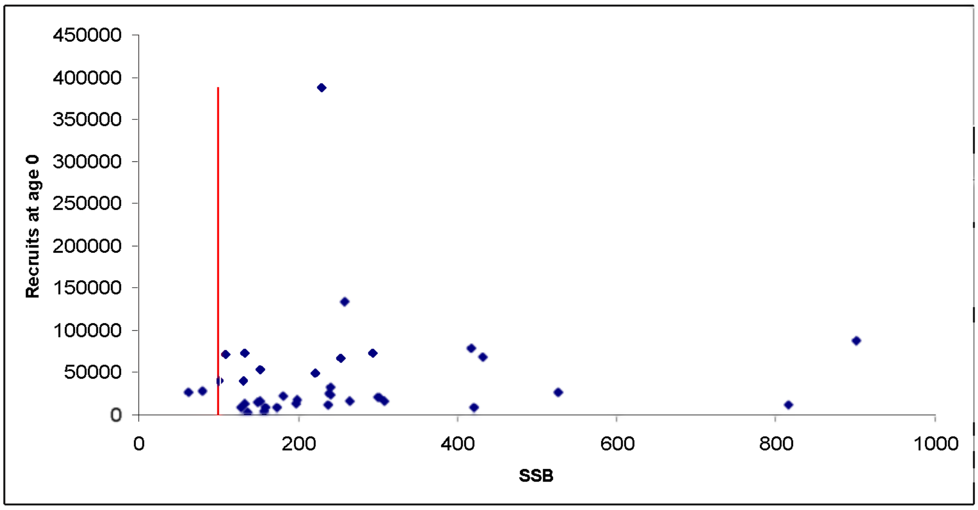

Figure 4.10.1. XSA stock–recruit estimates from WGNSSK (2000). The accepted value of B(lim) (100 kt) is shown with a red line.

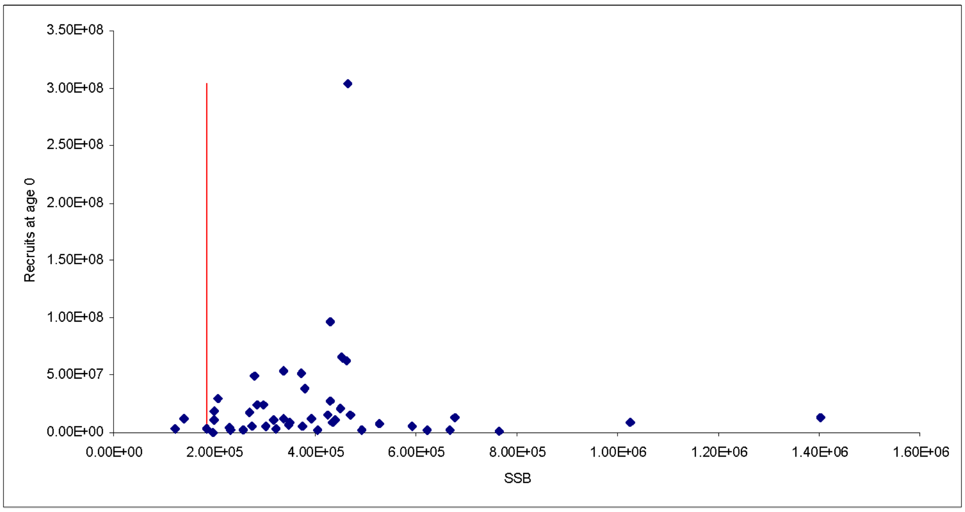

Figure 4.10.2. XSA stock–recruit estimates from WKBENCH (2011), using time-varying natural mortality and maturity estimates. The interim proposal for B(lim) (185 kt) is shown with a red line.

The implications of this approach need to be considered carefully, as any such changes may lead to a revision of the perception of stock status. The following text table compares stock status as indicated by the current assessment with that indicated by the proposed new assessment: it is clear that, although biomass estimates are larger, the stock status in relation to precautionary reference points is reduced.

	B(pa)	B(2009)	Ratio
Current assessment (fixed M and Mat)	140 kt	178 kt	1.271
Proposed new assessment (time-varying M and Mat)	260 kt	232 kt	0.892

4.11 Recommendations on the procedure for assessment updates and further work

- WKBENCH recommends that a joint IVa–VI dataset be collated in time for the assessment WGs in May 2011, and that a comparative assessment be carried out by WGNSSK using these data. This will provide further evidence for a final decision on appropriate assessment units.
- WKBENCH recommends that the **update assessment model remains XSA**, using the existing run settings. In addition, exploratory assessments using SAM and SURBA should be run each year.
- WKBENCH recommends that weights-at-age for North Sea haddock forecasts be modelled using a linear cohort-based approach.
- WKBENCH recommends that **time-varying natural mortality estimates** from WGSAM should be used in the subsequent update assessments.
- WKBENCH recommends that refined **maturity estimates** should be developed before the next WGNSSK meeting in May 2011 and used in subsequent update assessments.
- If the proposed new assessment (with time-varying natural mortality and maturity estimates) is accepted for use in subsequent updates, WKBENCH recommends that biomass and fishing mortality reference points and management strategy evaluations be revisited and potentially updated.
- WKBENCH recommends that the next benchmark meeting for North Sea haddock be brought forward if haddock management changes to a system of catch quotas with an enforceable discard ban.

4.12 Implications for management

The new assessment presented above has (potentially) considerable implications for management advice that will need to be considered carefully. The use of new natural mortality and maturity estimates, while well-justified, leads to a considerable revision in biomass time-series. The methodological changes are sufficient to warrant a revision of biomass reference points as well. Interim suggestions for these reference points are presented above; however, they change significantly the perception of the stock (from being above Bpa, to being below Bpa). Much of this change is due to the new maturity estimates, but (as stated above) these should not actually be used directly as they do not account for concomitant (and opposite) changes in fecundity. WKBENCH recommends that new biological reference points be developed for haddock *before* the new assessment is used as the basis for advice, and that said reference points be based on considerations of reproductive potential rather than SSB.

4.13 References

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5 Northeast Arctic haddock

5.1 Current assessment and issues with data and assessment

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

5) Survey indices used for tuning XSA. Residuals for ages 7–8 for all surveys in the last assessments were high in the XSA runs. There is a notable systematic difference between the time-series of abundance-at-age from the XSA and those observed in the surveys, namely that the XSA time-series is smoother and generally does not follow the relatively sharp peaks seen in the surveys. New data series were presented in AFWG (ICES, 2010) (Eco-NoRu-Btr-3Q) for investigation.

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

7) Retrospective XSA analysis shows deviations in both recent and past years.

8) Discarding and IUU catches are known and variable problems.

9) Estimates of MSY and PA reference points are needed.

5.2 Compilation of available data

5.2.1 Catch and landings data

Commercial landings data allocated to ages 1–10 (and 11+ group) from 1950 to 2009 were compiled to generate a catch-at-age matrix. Commercial landings data allocated to ages 3–14 from 1950 to 2009 were available at the WKBENCH 2011 meeting.

Data for these landings came from the ICES database with landings reported by 13 countries including sampled information from Norway, Russia, and Germany. Most landings were reported for the Russian and Norwegian trawl and longline fishery.

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

Until 2009, the main Norwegian sampling program for demersal fish (mainly cod, haddock and saithe) was port sampling, carried out on board a vessel travelling from port to port for approximately six weeks each quarter. A detailed description of this sampling program is given in Hirst *et al.* (2004). However, this program was, for economic reasons, terminated 1 July 2009. Although sampling by the 'reference fleet' and the Coast Guard has increased somewhat in recent years, this change seems to have increased the uncertainty in the catch-at-age estimates (Fotland, 2010). Haddock is mainly fished in the first half of the year, so the effect of the change will show up much stronger in the 2010 data. Nevertheless, there are already concerns that the commercial sampling could become so poor that analytical assessments cannot be made in the future.

In recent years, estimates of unreported catches (IUU catches) of haddock for the period 2002–2008 have been added to reported landings. There are different estimates of unreported catches/landings by Norway and Russian. During the benchmark, as in recent AFWG, it was decided to use the Norwegian estimates for the period 2002–2008. There has been an indication that the present catch control and reporting systems are not sufficient to prevent discarding and under-reporting of catches. However, since 2005 Port State Control has been implemented which should reduce IUU catches in the Barents Sea. The level of IUU landings in 2009 was estimated equal to zero.

No estimates of discarding of NEA haddock from commercial catches were available at the WKBENCH 2011 meeting. Discarding is a known and variable problem, but there is no knowledge about the levels. It was recognized that there is a need for estimating the magnitude of discards, but due to limitations in available time and effort, this should be done at another time and together with NEA cod. So far, there is no evidence to suggest that the amount of discards is large enough to cause problems for the assessment. For haddock, discards are thought to be more of an issue than unreported landings.

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

5.2.2 Biological data

The proportion of natural and fishing mortality before spawning was assumed to be zero, based on analysis made in previous assessments.

Stock weights and length-at-age in stock and proportion of mature fish to ages 1–11 were derived from Russian surveys in autumn (mostly October–December) for the period from 1982 to 2009 and Norwegian surveys in January–March for the period from 1982 to 2010. In 2006 the AFWG, based on previous investigations (ICES 2006), decided to smooth raw data of stock weight-at-age and maturity-at-age using models in order to remove some of the sampling variability in the estimates.

During the benchmark some corrections in weight-at-stock and maturity data from AFWG 2010 were included to correct for errors made previously in the historical data set. Influence of these corrections on the stock assessment is rather small, at average 3% of SSB (Figure 5.1).

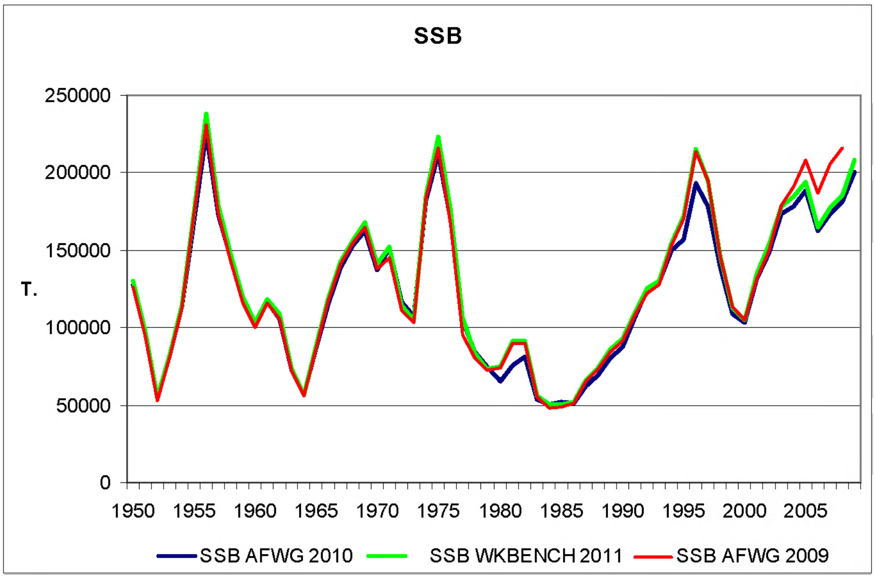


Figure 5.1. Differences between new SSB estimates (SSB WKBENCH 2011) with previous SSB estimates using corrected weight and maturity data.

No changes in the natural mortality estimation procedure were proposed during the benchmark (see Section 5.8.4). The method used by AFWG to estimate variable M caused by NEA cod consumption was checked during the meeting and confirmed.

In current AFWG practice, weight-at-age data, both in stock and in catches, maturity data, and natural mortality for the period 1950–1979 is assumed to be the average during the period with observed values (1980–current). Each year when new data become available, averages used as historical values is recalculated. During the benchmark it was decided to stop this practice and fix the data for the historical period with current estimates (1980–2010).

Details about how the weight and maturity data were derived and processed are described in the NEA haddock stock annex and in Section 5.9.1, of this report.

5.2.3 Survey tuning data

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

There were three survey abundance indexes at age from that survey available at WKBENCH 2011:

1) absolute numbers (in thousands) computed from the acoustics estimated by old method (RU-Aco-old-Q4) for the period 1985–2009 (ages 0–9);
2) absolute numbers (in thousands) computed from the acoustics estimated by new method (RU-Aco-Q4) for the period 1995–2009(ages 0–10);

3) trawl indices, calculated as relative numbers per hour trawling (RU-BTr-Q4) for the period 1983–2009 (ages 0–9).

During the benchmark meeting, the index RU-Aco-old-Q4 was investigated and it was decided not to use it in assessment because of low quality (lack of internal consistency). The indices (RU-Aco-Q4) were neither used for tuning the XSA due to a strong "year effect" observed in years with incomplete area coverage. This index needs further adjusting before it can be used for tuning. Based on an internal consistency test, the RU-BTr-Q4 index is used in tuning for ages 1–7.

The Norwegian winter (February) survey (from 2000; Joint Barents Sea survey) started in 1981 and covers the ice-free part of the Barents Sea. Two abundance indices at age from that survey were available at WKBENCH 2011:

1) swept area estimates from bottom trawl NoRu-BTr-Q1 for the period 1981–2010 (ages 1–10);
2) swept area estimates from acoustic NoRu-Aco-Q1 for the period 1981–2010 (ages 1–10).

During the meeting it was decided to use both of them for tuning XSA: NoRu-BTr-Q1 for (ages 1–8) and NoRu-Aco-Q1 for ages 1–7.

A joint ecosystem survey in August–September was started in 2004 and a new bottom-trawl index, based on this survey, is now available. This survey covers a larger portion of the distribution area of haddock. The new index Eco-NoRu-Btr-Q3 for period 2004–2009, ages 1–8, became available for AFWG 2010. This time-series has been tested as a new tuning fleet in XSA and it was found that index was acceptable for applying in NEA haddock assessment.

The WKBENCH confirmed the AFWG decision to use indexes for all surveys only for the period 1990 onwards.

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

5.2.4 Commercial tuning data

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

5.2.5 Industry/stakeholder data inputs

No additional information beyond the landings from the commercial fleet was presented for incorporation in the assessment at the Benchmark Workshop.

5.2.6 Environmental data

The strength of NEA haddock year classes is influenced by the size and structure of the spawning stock, but also by water temperature and cod predation.

Oceanographic data (water temperature and salinity) is available for a long period but this additional information is not directly used in stock assessment, although such data could assist in year-class strength estimation (see Section 5.9.1) and contain information on the distribution of the stock.

Increased overall production is expected to produce increased catches of cod, haddock and other species. An increase in primary productivity coupled with other positive effects of increased temperature on fish growth and reproduction, may cause productivity of cod, haddock and other commercially important species to increase. However, negative effects on prey species may also occur. Thus, overall effects on fish productivity are hard to predict.

Cod stomach contents from surveys for the period 1984 until current year are available. Estimated values of cod predation are included in the NEA haddock stock assessment (see Section 5.8.4).

5.3 Stock identity, distribution and migration issues

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

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

5.4 Influence of the fishery on the stock dynamic

The haddock fishery and its history are described in the stock annex. From 01.01.2011, the minimum catch size of haddock is 40 cm in the Russian EEZ, the Norwegian EEZ and the Svalbard area. The minimum mesh size in trawl codend is 130 mm.

Discards are illegal both in Russian and Norwegian EEZs, but examples of extensive discards are reported in the National news at irregular intervals. Discards are probably a varying problem and it is believed that the problem is larger when strong year classes are occurring. It is recognized that there is a need to investigate this problem further. It is possible to estimate discards similar to what has been done for NEA cod.

However, the availability of representative age–length keys is scarce (especially age–length keys from Norwegian commercial vessels).

5.5 Influence of environmental drivers on the stock dynamic

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

5.6 Role of multispecies interactions

5.6.1 Trophic interactions

Cod is the main predator on haddock, and predation by cod on young haddock is included in the assessment as an additional mortality. This is found to improve the assessment (see Section 5.8.4). Predation by cod removes on average about the same biomass as the fishery, but predation mainly takes place on ages 1–3, while the fishery starts at age 3.

Haddock mainly prey on benthic organisms. It is not known whether the current very high stock level for haddock, which will persist for some years, could significantly influence the food availability.

5.6.2 Fishery interactions

The demersal fisheries in the Barents Sea are highly mixed, and haddock is fished together with cod (particularly), but also together with saithe. About 75% of the catch is taken by trawl and the rest by other gears such as longline and gillnet. The ratio between cod and haddock quota and exploitation rate, as well as the size composition and geographical distribution of those stocks, affect the way the fishery is carried out and also influence unreported landings and discards.

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

5.7 Impacts of the fishery on the ecosystem

Bottom trawl is the most important gear and may have large effects on bottom habitats and the organisms living there. In general, the response of benthic organisms to disturbance differs with substrate, depth, gear, and type of organism (Collie *et al.*, 2000). The qualitative effects of trawling have been studied to some degree. The most serious effects of otter trawling have been demonstrated for hard-bottom habitats dominated by large sessile fauna, where erected organisms such as sponges, anthozoans and corals have been shown to decrease considerably in abundance in the pass of the ground gear. Effects on soft bottom have been less studied, and consequently there are large uncertainties associated with what any effects of fisheries on these habitats might be. Studies on impacts of shrimp trawling on clay-silt bottoms have not demonstrated clear and consistent effects, but potential changes may be masked by the more pronounced temporal variability in these habitats (Løkkeborg, 2005). The impacts of experimental trawling have been studied on a high seas fishing ground in the Barents Sea (Kutti *et al.*, 2005). Trawling seems to affect the benthic assemblage mainly through resuspension of surface sediment and through relocation of shallow burrowing infaunal species to the surface of the seafloor. Work is currently going on in the Arctic, jointly between Norway and Russia, exploring the possibility of using pelagic trawls when targeting demersal fish. The purpose is to avoid impact on bottom fauna and to reduce the mixture of other species. It will be mandatory to use sorting grids to avoid catches of undersized fish.

Lost gears such as gillnets and longline may continue to fish for a long time (ghost fishing). Some studies have examined catch efficiency of lost gillnets, but there are no estimates of the total effect. Ghost fishing in depths shallower than 200 m is usually not a significant problem because lost, discarded, and abandoned nets have a limited fishing life owing to their high rate of biofouling and, in some areas, their tangling by tidal scouring. The Norwegian Directorate of Fisheries also conducts organized retrieval surveys. All together, 14 150 gillnets of 30 meters standard length (approximately 425 km) have been removed from Norwegian fishing grounds during the period from 1983 to 2010. Several kilometers of lost longline have also been retrieved and the retrieval surveys are considered important.

5.8 Stock assessment methods

5.8.1 Models

The XSA implementation of a virtual population analysis (VPA) was used to fit the catch-at-age data from the commercial fleets and incorporates the four indexes from three trawl-acoustic surveys as tuning-series. Model runs were conducted in the FLR environment, but XSA diagnostics are presented using the VPA95 DOS version of XSA because of its more complicated and reliable tuning diagnostic. Natural mortality is set at 0.2 for all age groups but the additional mortality caused by NEA cod predation is added for age groups 1–6. Cod predation estimates in numbers, by haddock age groups, were added to the catch-at-age matrix and the estimated mortality was divided afterwards into natural mortality from cod consumption and fishing mortality. The division is done proportionally to real catches and the number consumed.

The XSA model has been used for the assessment for many years. ADAPT and TISVPA models were examined by AFWG previously and were found to give similar results. These alternative models were not tested during the WKBENCH.

5.8.2 Sensitivity analysis

As it has been reflected in previous AFWG reports (e.g. ICES, 2010) the XSA model for haddock is sensitive to choice of model parameters values. During the benchmark

XSA parameters were tested and some changes from previously used by AFWG values were proposed (see Section 5.8.4).

5.8.3 Retrospective patterns

The retrospective pattern demonstrates a reduction in SSB and increase in F from 2005 onwards, but the opposite pattern prior to the early 2000s (Figure 5.2). The reasons for such a pattern were explored during the benchmark and described below.

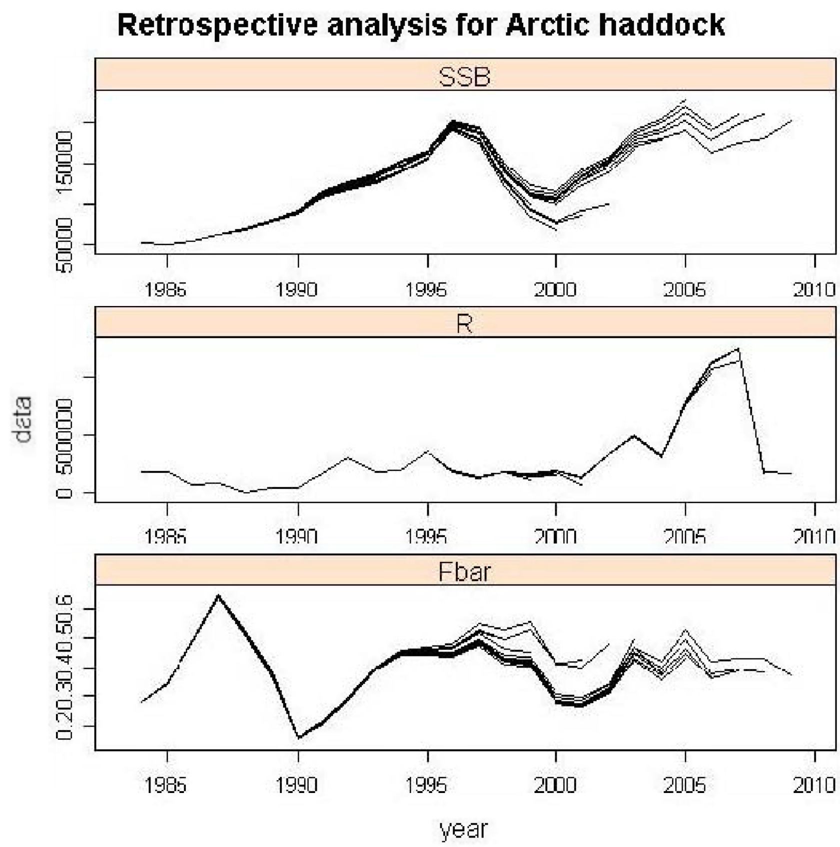


Figure 5.2. Northeast Arctic haddock. Results of retrospective runs with XSA settings from AFWG-2010.

5.8.4 Evaluation of the model

In order to understand model sensitivity and retrospective problems, a number of XSA settings were tested and new values were proposed.

Surveys chosen for XSA tuning

AFWG does not use survey indexes before 1990 because of data quality (ICES, 2010). This issue was not tested during the benchmark and only survey data for the time period from 1990 and onwards were used in tuning.

Analysis of internal surveys consistency, relationship between survey indices and catch-at-age numbers, as well as XSA diagnostic from exploratory runs (Kovalev and Tchetyrkin, 2011), led to choosing four surveys for use in the XSA model. Another two indices available for tuning were rejected. The Russian acoustic survey index calculated by the "old method" demonstrated a lack of internal consistency and has been excluded from further analysis. The other Russian acoustic survey residuals demonstrate strong year effects, particularly in the most recent years (Kovalev and Tchetyrkin, 2011). Such a high year effect could be explained by changes in area coverage (ICES, 2011), which was not taking into account in the survey index calculation. It was decided not to use this survey in tuning, but rather to study it again during the next benchmark after appropriate adjustment.

The joint ecosystem survey was not used in past assessments, but was selected for inclusion by the WKBENCH. This index shows reasonably good internal consistency for ages 1–8 and correlated well with catch-at-age data and other surveys (Kovalev and Tchetyrkin, 2011).

For three other surveys that were previously used in assessments, WKBENCH agreed to include ages 1 and 2 in XSA tuning based on internal survey consistency and a reasonably good relationship with cod consumption estimates which is included in assessment (Kovalev and Tchetyrkin, 2011).

Table 5.1. Indices chosen for tuning of XSA model for NEA haddock.

Fleets	New fleet name	First year	Last year	First age	Last age	Alpha	Beta
FLT01: Russian BT	RU-BTr-Q4	1990	2009	1 (was 3) *	7	.900	1.000
FLT02: Norwegian acoustic	NoRu-Aco-Q1	1990	2009	1 (was 3)	7	.990	1.000
FLT04: Norwegian BT	NoRu-BTr-Q1	1990	2009	1 (was 3)	8	.990	1.000
FLT007: Ecosystem	Eco-NoRu-Btr-Q3	2004	2009	1	8	.650	.750

* Shaded fleets/age groups weren't used in AFWG previous assessment.

Natural mortality from NEA cod consumption

The method used by AFWG to estimate natural mortality of haddock consumed by cod was reviewed at the benchmark (Bogstad, 2011; Kovalev and Tchetyrkin, 2011). It was found that data on cod consumption are in good correspondence with the survey indices. Inclusion cod consumption data in haddock assessment improves the correlation between catch data (+consumption) and survey indices for younger ages in XSA model and also improves the inclusion of indices for ages 1 and 2 in XSA tuning (Kovalev and Tchetyrkin, 2011, see Figures 5.3 and 5.4 as an example). The fit of tuning data to the VPA estimates for younger ages are also improved if data on cod consumption are included in the assessment (Bogstad, 2011).

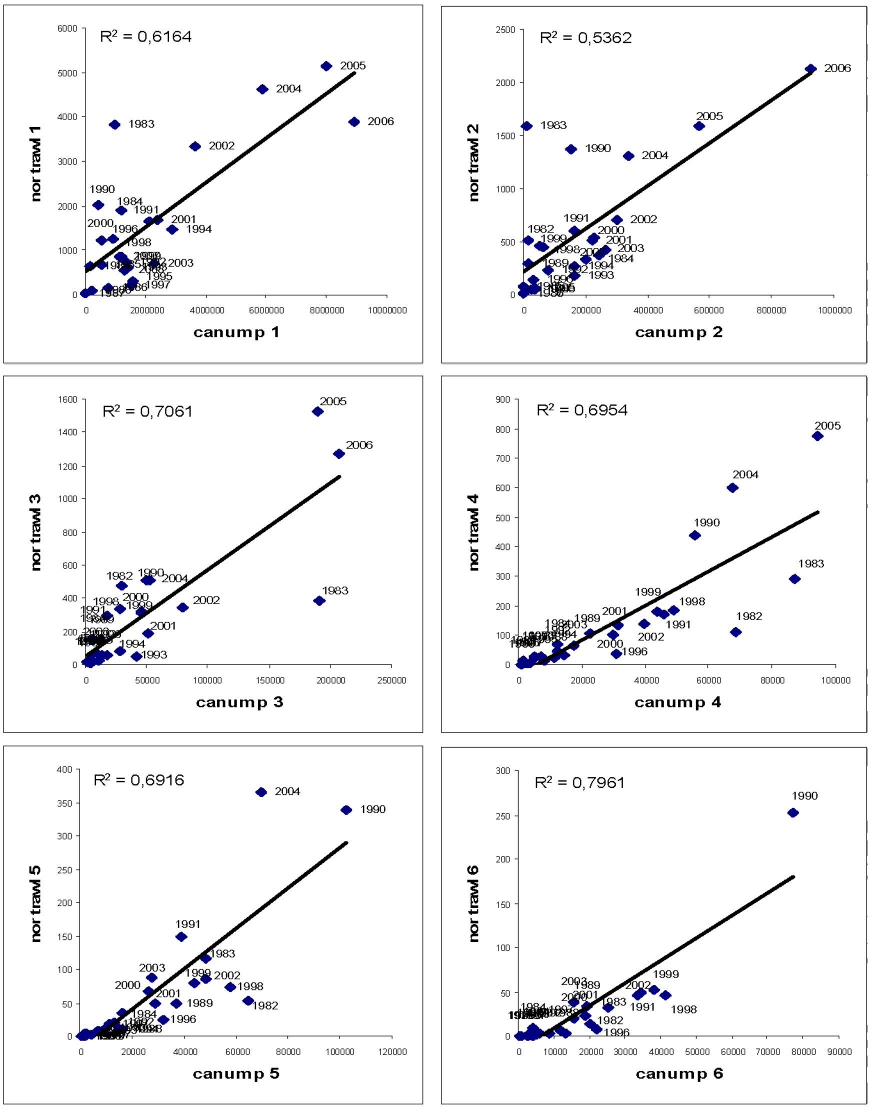


Figure 5.3. Relationship between year-class strength estimates by catch-at-age data (cod consumption included) and Norwegian/Joint trawl acoustic survey. Points are marked by year-class/generation.

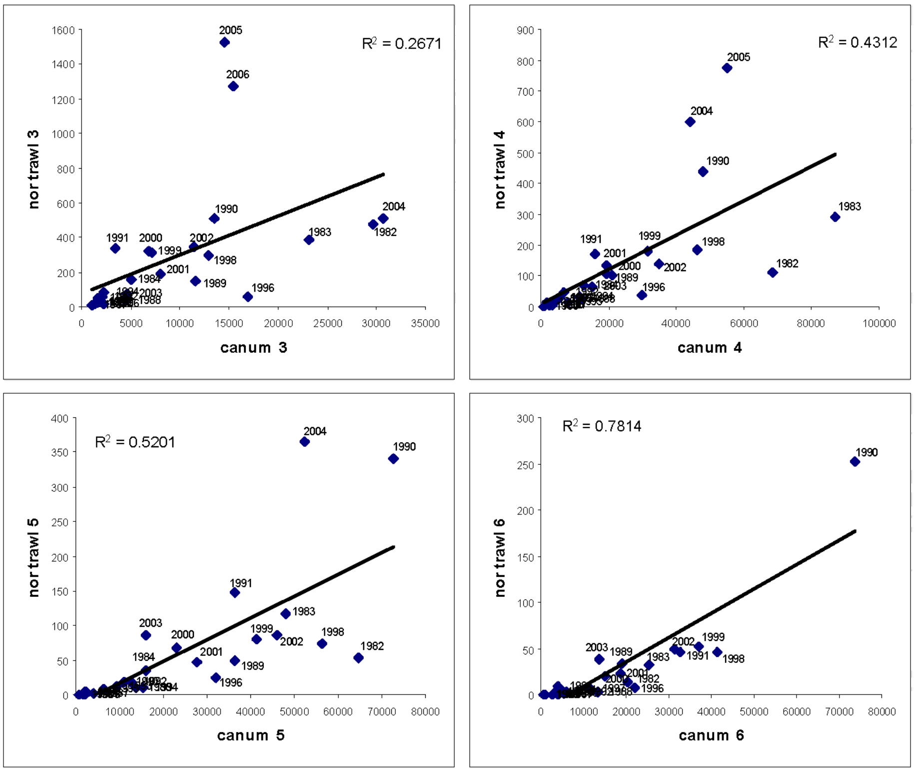


Figure 5.4. Relationship between year-class strength estimates by catch-at-age data (cod consumption NOT included) and Norwegian/Joint trawl acoustic survey. Points are marked by year-class/generation.

Q parameters

Based on results of exploratory runs (Kovalev and Tchetyrkin, 2011) it was found that there is no reason to assume q is independent of age for any ages (Figure 5.5). The last age in the surveys data is 8, so the XSA parameter "**Catchability independent of age for ages >= 9**" was chosen.

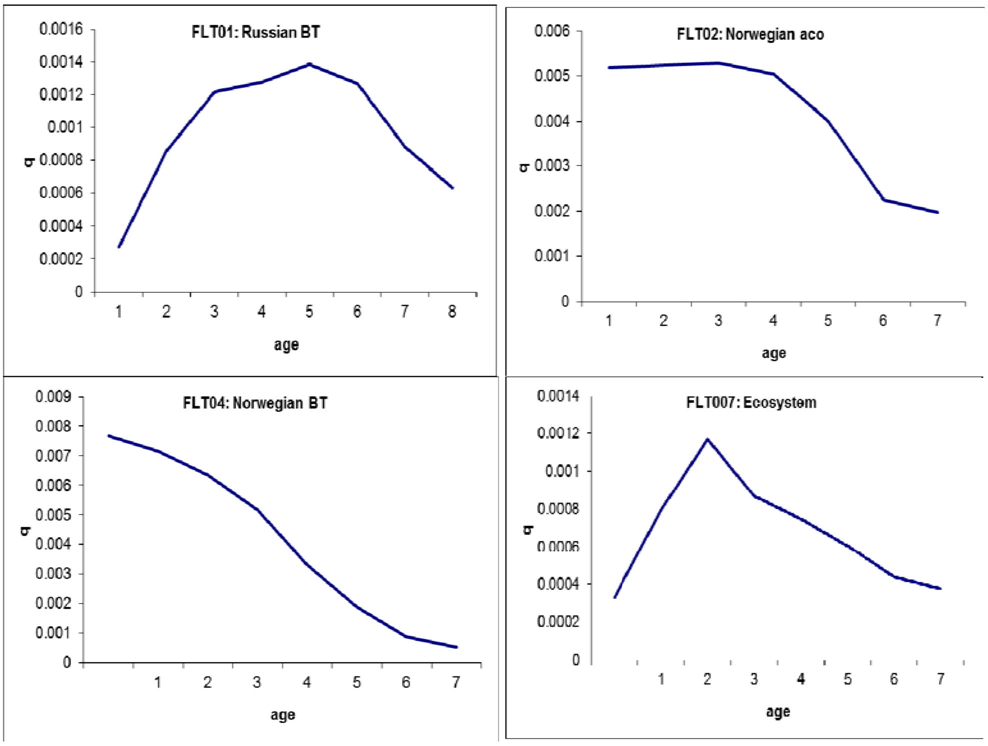


Figure 5.5. NEA haddock. Catchability for different surveys (exp(-Log q) from XSA run 1; Kovalev and Tchetyrkin, 2011). Note that: Ru-BTr-Q4 = FLT01: Russian BT; No-Aco-Q1 = FLT02: Norwegian aco; No-BTr-Q1= FLT04: Norwegian BT; Eco-NoRu-BTr-Q3 = FLT007: Ecosystem; Ru-Aco-Q4 = FLT011: Russian acou.

XSA parameter "Catchability independent of stock size"

Based on an analysis of the relationship between the survey indexes and catch-at-age data, it was decided that a power function is more suitable for most ages (Kovalev and Tchetyrkin, 2011). Using a linear relationship in XSA could lead to overestimation of more abundant year classes and underestimation of less abundant ones. So another q parameter could be set to **"Catchability independent of stock size ages < 9"**.

Results of XSA diagnostic from exploratory run confirm this conclusion (Table 5.2).

Table 5.2. Northeast Arctic haddock. Some results of XSA diagnostic from run 1 (Kovalev and Tchetyrkin, 2011). The following correspondence between the surveys acronym used in the past and in WD4 and this report and stock annex: Ru-BTr-Q4 = FLT01: Russian BT; No-Aco-Q1 = FLT02: Norwegian aco; No-BTr-Q1= FLT04: Norwegian BT; Eco-NoRu-BTr-Q3 = FLT007: Ecosystem; Ru-Aco-Q4 = FLT011: Russian acou.

	Ru-BTr-Q4		No-Aco-Q1		No-BTr-Q1		Eco-NoRu-BTr-Q3		Ru-Aco-Q4	
Age	Slope	t-value	Slope	t-value	Slope	t-value	Slope	t-value	Slope	t-value
1	0.75	1.887	0.88	0.967	0.85	1.604	0.92	0.398	0.71	2.263
2	0.63	4.864	0.76	3.151	0.68	3.367	0.6	3.59	0.68	2.37
3	0.64	4.866	0.73	3.978	0.73	2.934	0.81	0.92	0.71	1.507
4	0.68	3.145	0.69	2.982	0.71	2.648	0.82	4.126	0.73	1.285
5	0.69	2.343	0.59	2.923	0.56	4.197	0.64	3.413	0.6	2.791
6	0.72	1.809	0.68	1.756	0.58	2.875	0.96	0.174	0.59	2.235
7	0.73	1.401	0.85	0.418	0.52	3.585	0.62	2.028	0.71	2.263
8	0.71	1.079					0.23	2.796		

* Shaded cells show statistically significant difference from linear model (t>2, so power model is better for with ages).

Shrinkage

Different options for XSA shrinkage parameters were studied during the benchmark meeting. The NEA haddock stock demonstrates a rapid increase in most recent years. Fishing mortality is decreasing subsequently. In this type of stock dynamic it is difficult to support using P shrinkage and a high weight (low assumed error) for F shrinkage. Using strong shrinkage will lead to underestimation of growing stock and overestimation of declining one.

Excluding P shrinkage from XSA tuning caused some increase at stock size (SSB increased by 8% in 2009, while R at age 3 increased by 27%). On the other hand the retrospective pattern was visibly worse compared to the AFWG-2010 final run. So, more accurate estimate of stock size will be in conflict with interannual stability of assessment. Because of this, it was decided to keep this parameter on in tuning, as it is currently done by AFWG.

The decrease of the F shrinkage weight by setting s.e.=1.0 caused some increase in SSB and in R at age 3 abundance in year 2009. The difference in previous years was smaller. Nevertheless, results of a retrospective run with XSA settings from this run (run 4 of Kovalev and Tchetyrkin, 2011) were considerably different compared to the AFWG-2010 final run (ICES, 2010). The SSB and F retro patterns improved for most recent years but deviations of estimates in the historical period become much worse. A further decrease of the shrinkage weight by setting s.e.=1.5 caused a similar but stronger effect (Figure 5.6).

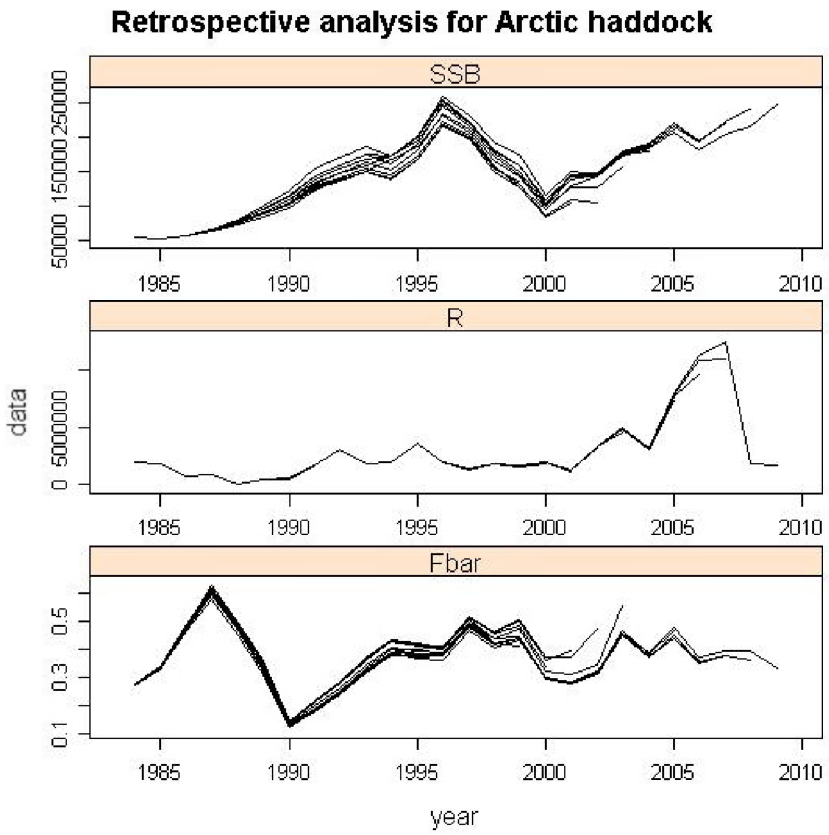
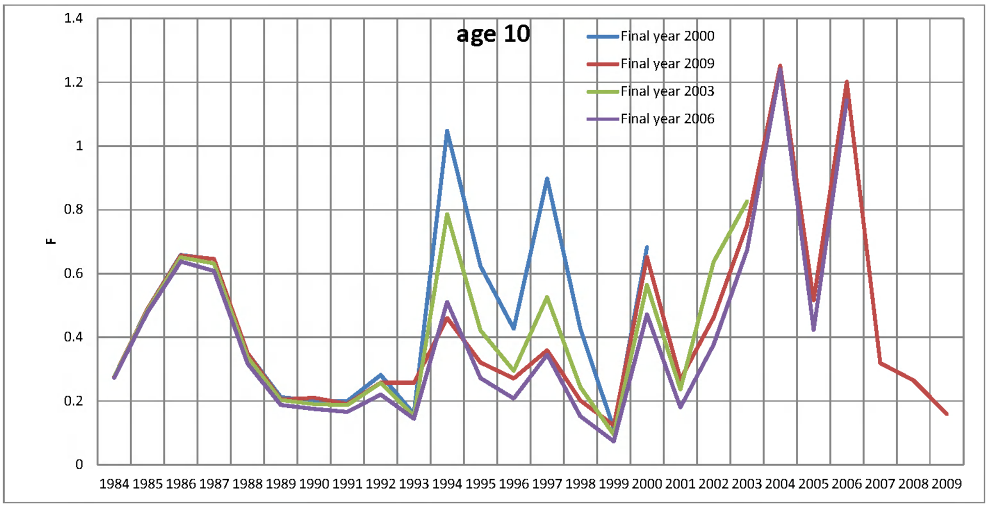


Figure 5.6. Northeast Arctic haddock. Results of retrospective runs with XSA settings from run 4 (with P and F shrinkage; s.e. for F shrinkage = 1.5) of Kovalev and Tchetyrkin, 2011.

Such a bad retrospective pattern for period 1990–2000 is explained by the influence of F estimates in older age groups, and seems to be related to the abundant year classes entering the older part of catch-at-age matrix in 1994 and after 1997. The reasons of such influence are unclear. Possible explanations are catchability issues, errors in age–length keys because of the low numbers of older ages in the samples, and not correct sampling. For younger ages the retrospective pattern is much better (Figure 5.7).



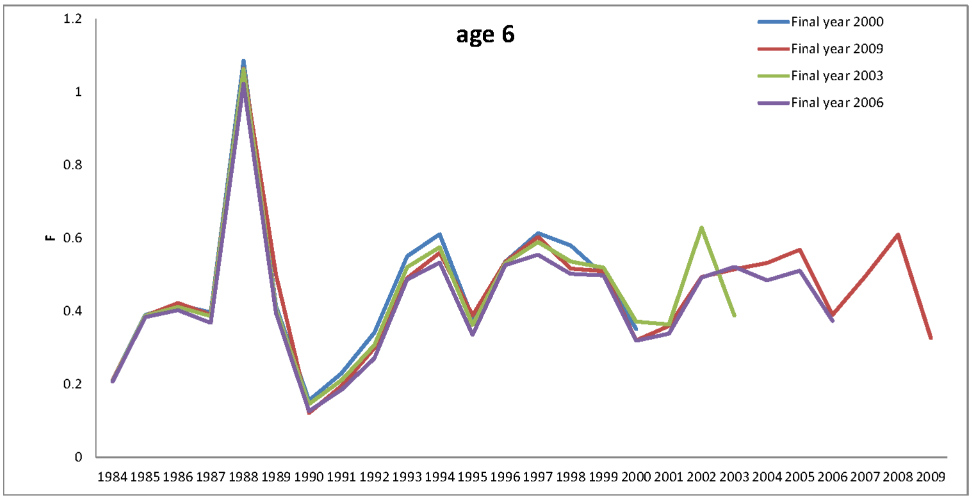
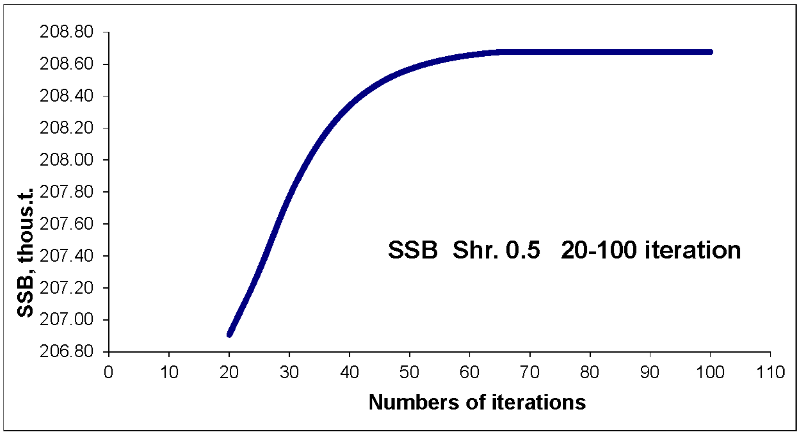


Figure 5.7. Northeast Arctic haddock. Results of retrospective runs for ages 6 and 10 with XSA settings from Kovalev and Tchetyrkin (2011) run 4 (with P and F shrinkage; s.e. for F shrinkage = 1.5).

During the discussion of possible alternatives at the benchmark meeting, the s.e.=1.5 for F shrinkage was considered to be more appropriate for use in XSA. The solution was based on the improved retrospective pattern (Figure 5.6) for the most recent years, which is presumably more reliable for stock management. It is clear from survey indexes that the stock is rapidly increasing now, at the same time F is going down. Using strong shrinkage at such a stock development means systematic underestimation of age groups with higher abundance (they have usually lower F) than previous ones. As this is the case now, it should be expected that decreasing weight of shrinkage will give more accurate estimates of year-class strengths. Nevertheless, more detailed exploration showed that this model settings leads to another problem. XSA model estimates become dependent on the number of iterations required to reach convergence (Figure 5.8). The additional iterations required in the XSA model with s.e.=1.5 for F shrinkage increases SSB estimates considerably. Such an effect does not to appear in the model with s.e.=0.5.



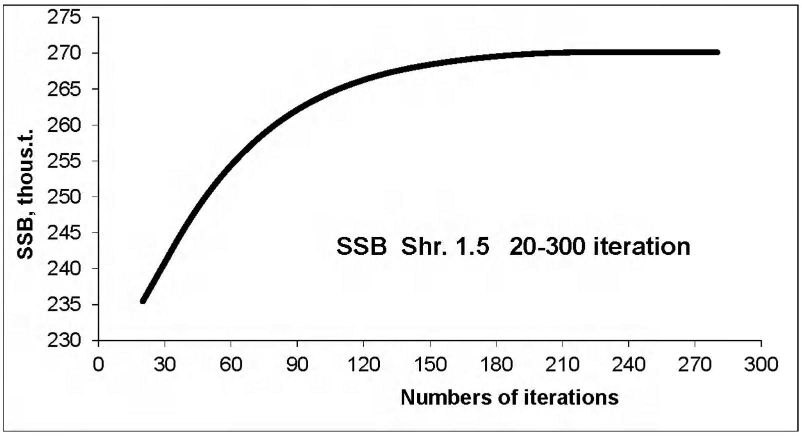


Figure 5.8. Northeast Arctic haddock. Dependence of SSB estimation within the XSA model with different settings for F shrinkage.

This makes the assessment more uncertain, particularly because the F for last true age and consequently the plus group estimated with s.e. 1.5 is significantly lower than the F estimated for previous ages (Table 5.3). Such a low F at age 10, at the same time when younger ages have much higher Fs, seems to be unrealistic, and may imply an overestimation of stock abundance, and SSB in particular.

Table 5.3. Northeast Arctic haddock. Fishing mortality coefficients for ages 6–10 estimated by XSA with different values for F shrinkage weight.

	Ratio F(s.e.=1.5)/F(s.e.=0.5)									
6	0.92	1.05	1.00	1.28	1.18	1.29	1.23	1.21	1.19	1.21
7	0.93	0.89	1.07	0.99	1.46	1.36	1.55	1.38	1.36	1.38
8	0.89	0.90	0.87	1.10	0.99	1.74	1.79	2.08	1.68	1.60
9	1.54	0.84	0.88	0.81	1.14	0.97	2.17	2.59	3.19	2.11
10	1.29	1.74	0.77	0.82	0.66	1.21	0.94	2.91	3.89	4.85

The difference between results of two runs is 29% in SSBs and 8% in total stock biomasses (Table 5.4). Difference in SSB estimates is decreasing for previous years (Figure 5.9).

Table 5.4. Northeast Arctic haddock. Total stock biomass (ages 3–11+) and SSB estimates by age groups made by XSA with different s.e. for F shrinkage.

	s.e. =0.5		s.e. =1.5			contribution of ages at difference			
age	TSB 2009	SSB 2009	TSB 2009	SSB 2009	age	TSB 2009	%	SSB 2009	part of age %
3	271697	1902	262127	1835	3	9570	0.9	67	0.0
4	360435	14778	371339	15225	4	-10903	-1.0	-447	-0.2
5	295899	53558	318042	57566	5	-22144	-2.0	-4008	-1.9
6	69433	40965	79770	47064	6	-10337	-0.9	-6099	-2.9
7	56509	47637	66165	55777	7	-9656	-0.9	-8140	-3.9
8	22532	21225	30492	28724	8	-7960	-0.7	-7499	-3.6
9	12766	12511	20801	20385	9	-8035	-0.7	-7874	-3.8
10	7110	7060	19206	19071	10	-12096	-1.1	-12011	-5.8
11	9021	9021	24493	24493	11	-15472	-1.4	-15472	-7.4
Total	1105401	208656	1192435	270140			-7.9		-29.5
difference %			107.9	129.5					

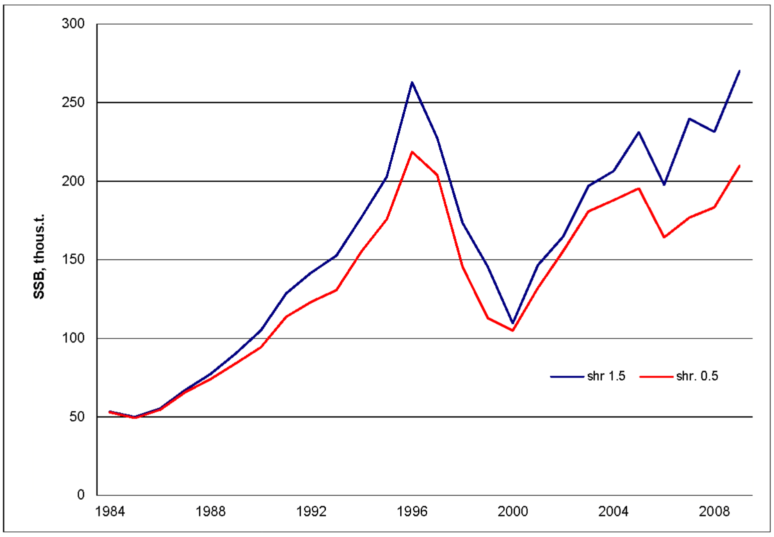


Figure 5.9. Northeast Arctic haddock. SSB estimates by XSA with different s.e. for F shrinkage.

The overall conclusion of the benchmark meeting was to keep s.e. for F shrinkage equal to 0.5, because with that parameter stock size estimations were not depending on number of XSA iterations. Such an effect of numbers of iterations on stock assessment needs to be studied before more objective decision could be made. Although, taking into account that low shrinkage may cause underestimation/overestimation of stock in situations when strong trends occur it was recommended to leave it to AFWG to change this setting to a higher value if needed.

Changes in the number of years used in shrinkage did not demonstrate a clear effect on retrospective pattern and it was decided to keep them the same as those at AFWG (5 years and 3 ages).

Tapered time weighting

Different time window sizes and taper values were tasted during the benchmark. Based on an analysis of retro patterns and XSA diagnostic (Kovalev and Tchetyrkin, 2011) it was decided to keep the AFWG settings for these parameters without changing (i.e. 20 years and power 3).

Plus group

AFWG uses the age 11+ group for most recent years. During the benchmark meeting, the 14+ group was tested. No improvement of the retro pattern was observed. As the length at age data for older ages are scarce, it was decided to keep 11+ group in future update assessments. However, time-series with 14+ should be maintained up to date.

5.8.5 Conclusion

Compare to last AFWG assessment the following changes are proposed:

- Ecosystem survey (Eco-NoRu-BTr-Q3) added to the tuning indexes;
- ages 1 and 2 in all surveys are included in tuning;
- catchability of all surveys taken as dependent of stock size for ages 7 and 8.

The combined effect of all these changes in the XSA model results is shown on Figure 5.10. The SSB in 2009 was 5% and recruitment 9% higher with the XSA run using new parameters proposed by the benchmark meeting. Residuals for all surveys were smaller in the benchmark proposed XSA settings run, when comparing with last year's assessment (Figures 5.11 and 5.12).

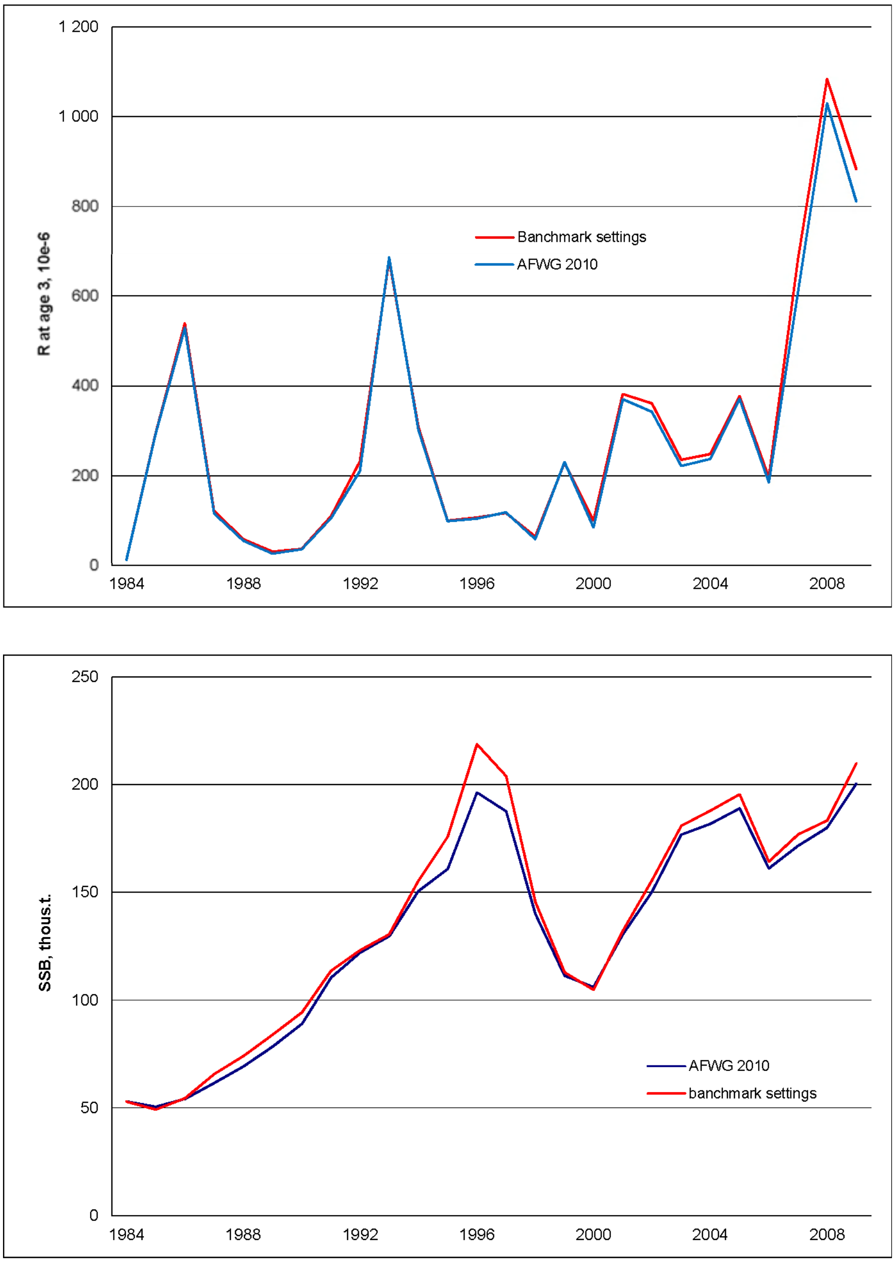
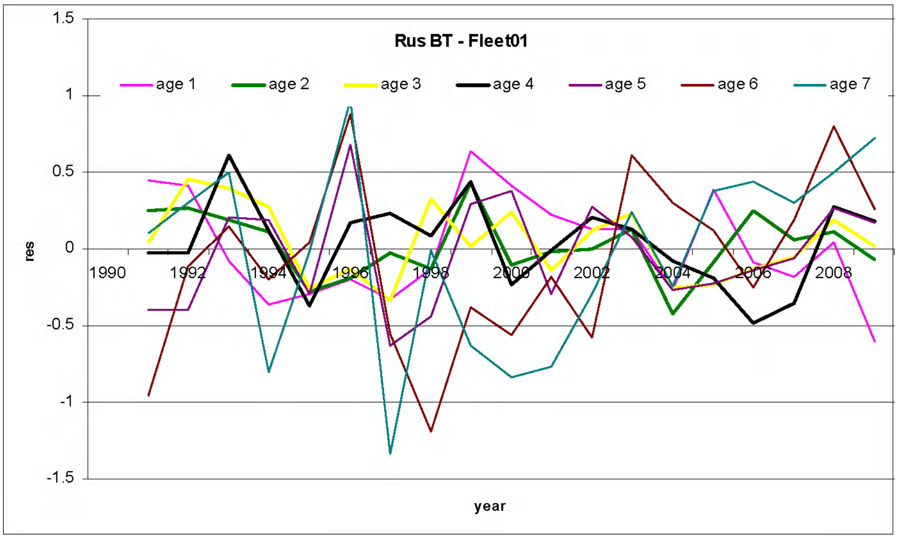
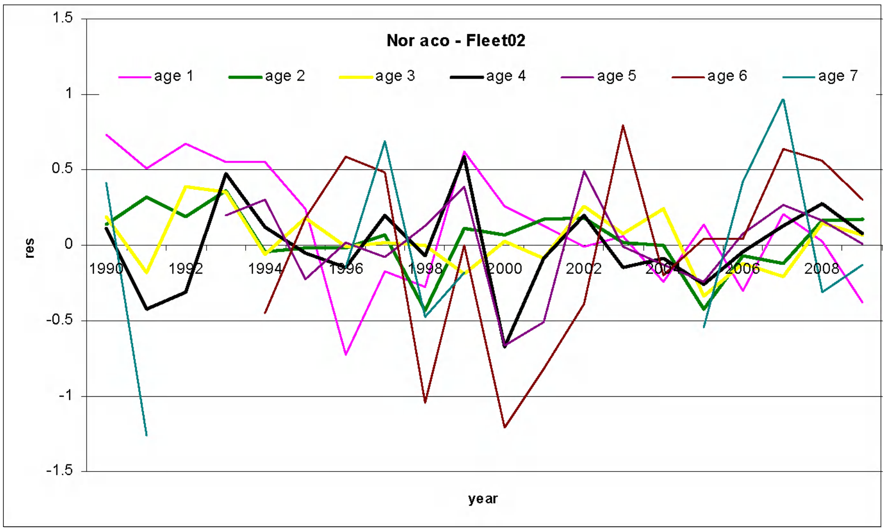


Figure 5.10. Northeast Arctic haddock. Results of XSA runs with new proposed model settings (red line: benchmark settings) and AFWG-2010 final run (blue line).


Rus BT - Fleet01
age 1
age 2
age 3
age 4
age 5
age 6
age 7
res
year
1.5
1
0.5
0
-0.5
-1
-1.5
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008


Nor aco - Fleet02
age 1
age 2
age 3
age 4
age 5
age 6
age 7
res
year
1.5
1
0.5
0
-0.5
-1
-1.5
1990
1992
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1996
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2000
2002
2004
2006
2008

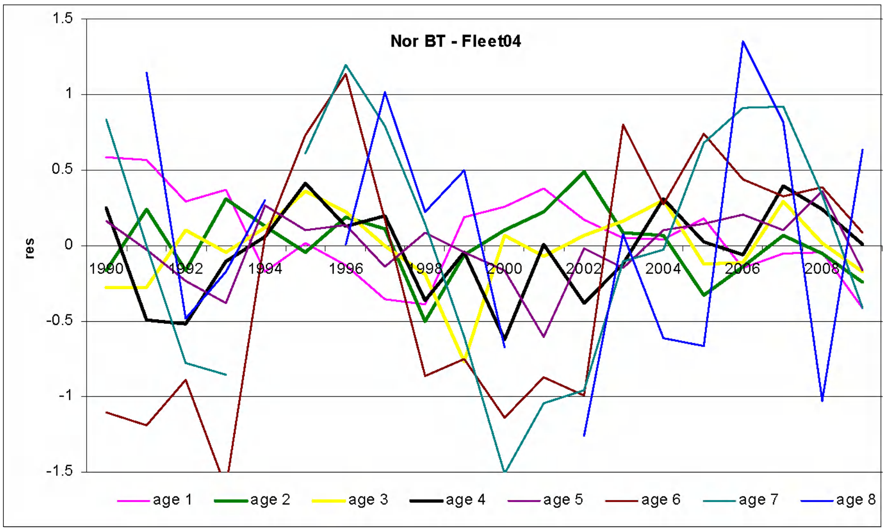
Nor BT - Fleet04
age 1
age 2
age 3
age 4
age 5
age 6
age 7
age 8
res
1.5
1
0.5
0
-0.5
-1
-1.5
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008

Figure 5.11. Northeast Arctic haddock. Surveys residuals from XSA diagnostic (AFWG-2010 predation run). Rus BT-Fleet 01 = Ru-BTr-Q4; Nor aco – Fleet02 = No-Aco-Q1; Nor BT – Fleet04 = No-BTr-Q1.

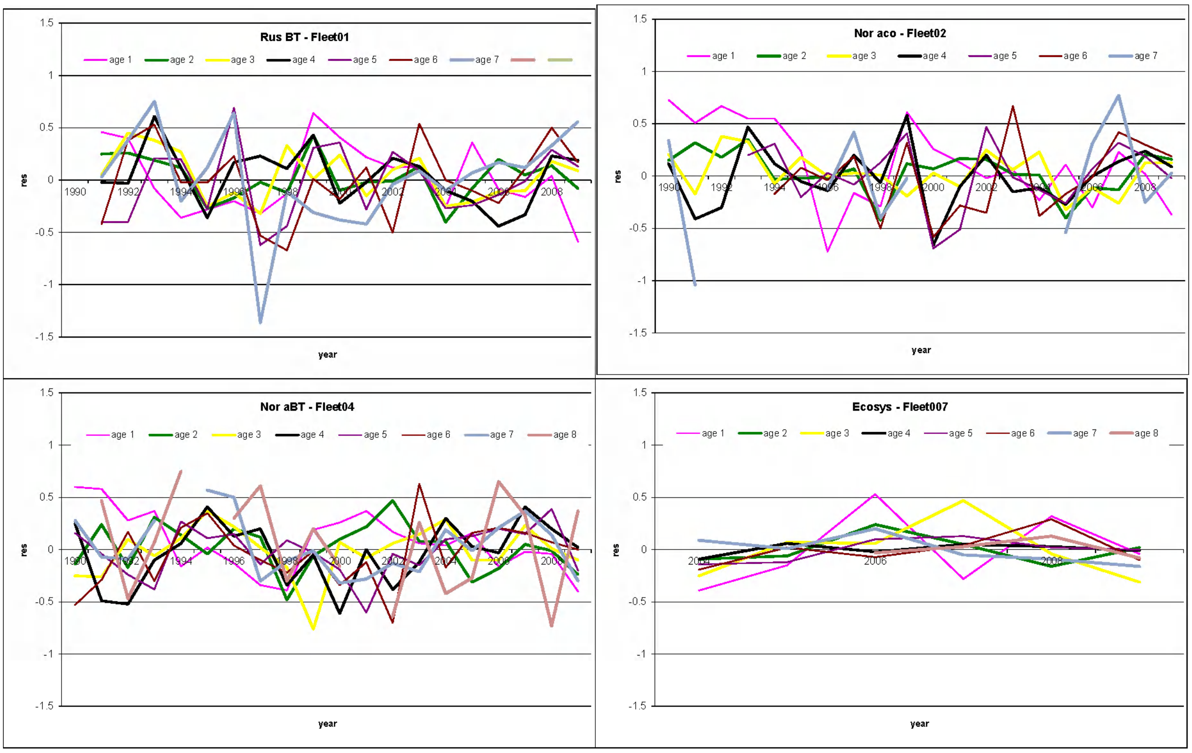

Figure 5.12. Northeast Arctic haddock. Surveys residuals from XSA diagnostic with new proposed model settings. Rus BT-Fleet 01 = Ru-BTr-Q4; Nor aco – Fleet02 = No-Aco-Q1; Nor BT – Fleet04 = No-BTr-Q1; Ecosys-Fleet007 = Eco-NoRu-BTr-Q3.

5.9 Short-term and medium-term forecasts

5.9.1 Input data

Recruitment of Northeast Arctic haddock is highly variable and stock–recruitment models do not give any reliable predictions of future recruitment. The traditional procedure to predict recruitment at age-3 has been to use the RCT3 program, where the predictions are based on survey indices. However, we know that external factors (e.g. cod predation) influence survival. Other recruitment functions, including cod predation and temperature, were tested and compared with RCT3 in preparation for the benchmark (Dingsør, 2011). All models had a tendency to underestimate the largest year classes. The models produced fairly good predictions, but the new models seemed to be more precise than the RCT3 predictions, especially for year t+2. Taking into account the similarities in the predictions and the fact NEA haddock has a one-year HCR (HCR is calculated on basis only of the stock in the prediction year, not including stock size in two following years as is done for NEA cod and saithe) it was recommended that the use of RCT3 is continued and be the main source of predicted values. However, the other models are useful for support and may give us early indications of arising problems due to increased predation from cod. It has been seen in the past that predation from cod is higher when the capelin stock is at low levels. Such an effect will be seen in the new models.

Survey data show large variations in mean length-at-age, weight-at-age, and maturity-at-age, but with clear year-class effects. At WKHAD 2006 (ICES, 2006) it was decided that weight-at-age and maturity-at-age in stock should be based on smoothed observations. Mean length-at-age is calculated from the bottom-trawl surveys for the period 1980 to 2010. A von Bertalanffy function is fitted to the data:

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

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

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

where α and β are constants and L are smoothed lengths. Norwegian maturity data is smoothed by fitting a logistic function using both age, A, and length, L, as explanatory variables:

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

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

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

A very nice by-product of these fitted models is that they enable prediction of weight-at-age and maturity-at-age two years ahead, using the fitted parameters and last year lengths as input. The Norwegian and Russian weight-at-age and maturity-at-age are then combined as arithmetic averages.

Different methods have been tested to predict weight-at-age in catches. The quality of prediction using these tested methods was not enough to warrant replacing the current AFWG routine (average weight for period with similar abundant year classes). Weight-at-age in catches is much more affected by year-effects and cohort-based models are not suitable. Average weight-at-age in catch from similar year-class strengths (strong or poor) is used in predictions.

5.9.2 Model and software

A standard MFDP program is used for prediction. Excel spreadsheets and SAS are used in weight-at-age in stock and maturity data predictions.

5.9.3 Conclusion

New methods for predicting maturity data and weight-at-age in stock data based on "smoothing models" are proposed.

5.10 Biological reference points

5.10.1 Previous HCR evaluations and MSY-related calculations

The current HCR was evaluated in 2006/2007 and found to be precautionary. Stochastic long-term simulations were used, with a biological model that included density-dependent growth and maturation. Two kinds of uncertainty were included: assessment uncertainty and uncertainty in the stock–recruitment relationship. The F_{MSY} was not calculated at that time, but all simulations showed it to lie somewhere in the range 0.25 to 0.45.

5.10.2 MSY calculations-approach

The biological model should be updated (both with recent years of data and for some processes also with different model formulations), and long-term simulations should be made in order to calculate F_{MSY} as well as the probability for SSB to fall below B_{lim}. Thus one can also find an F range for which the yield is within some percentage of the MSY (ICES, 2011) and which also is precautionary. The approach taken would be similar to the one used for evaluating MSY for cod (Kovalev and Bogstad, 2005).

5.10.3 Biological model-update

For growth, maturation and predation mortality, the same approach as previously taken could be used, just updating with more years of data.

5.10.4 Uncertainty in assessment and implementation

In addition to assessment uncertainty, uncertainty due to unreported landings and/or discards should be included in the simulations.

5.10.5 Stock–recruitment relationship

The stock–recruitment relationship used in previous stochastic simulations was rather ad hoc and needs to be revisited. Also, the recent three strong successive year classes (2004–2006) have changed the stock–recruitment relationship somewhat. Some preliminary analyses were made during the meeting, based on the 2010 assessment. The revision of this due to changes made to the assessment method during the WKBENCH meeting would probably not influence the conclusions significantly.

The stock–recruitment relationship for the 1953–2006 year classes is shown in Figure 5.13. It was attempted to fit a stochastic stock–recruitment relationship, assuming a hockey-stick curve. The method used is described by Skagen and Aglen (2002) and is the same as used in previous studies for this stock and also for Northeast Arctic cod by Kovalev and Bogstad (2005), described by Skagen and Aglen (2002).

Figure 5.13. Northeast Arctic haddock. The stock–recruitment relationship for the 1953–2006 year classes.

A segmented regression (hockey-stick) stock–recruitment relationship with log-normal error distribution was fit to the data:

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

where $\varepsilon=N(0,\sigma)$.

The fit was done using Solver in Excel spreadsheets described by Skagen and Aglen (2002). A constraint on the sum of the difference between modelled and observed recruitments being zero was applied. The following parameter values were estimated: α = 289 (million), β= 229 (thousand tonnes), σ= 1.09.

Criteria for fit and diagnostic plots

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

1) Independence between residuals and SSB

2) Probability coverage

3) The recruitment estimates should be unbiased.

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

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

Figure 5.14 shows the residuals vs. SSB, the probability coverage and observed vs. modelled recruitment for this distribution. The fit seems to be rather satisfactory according to these criteria.

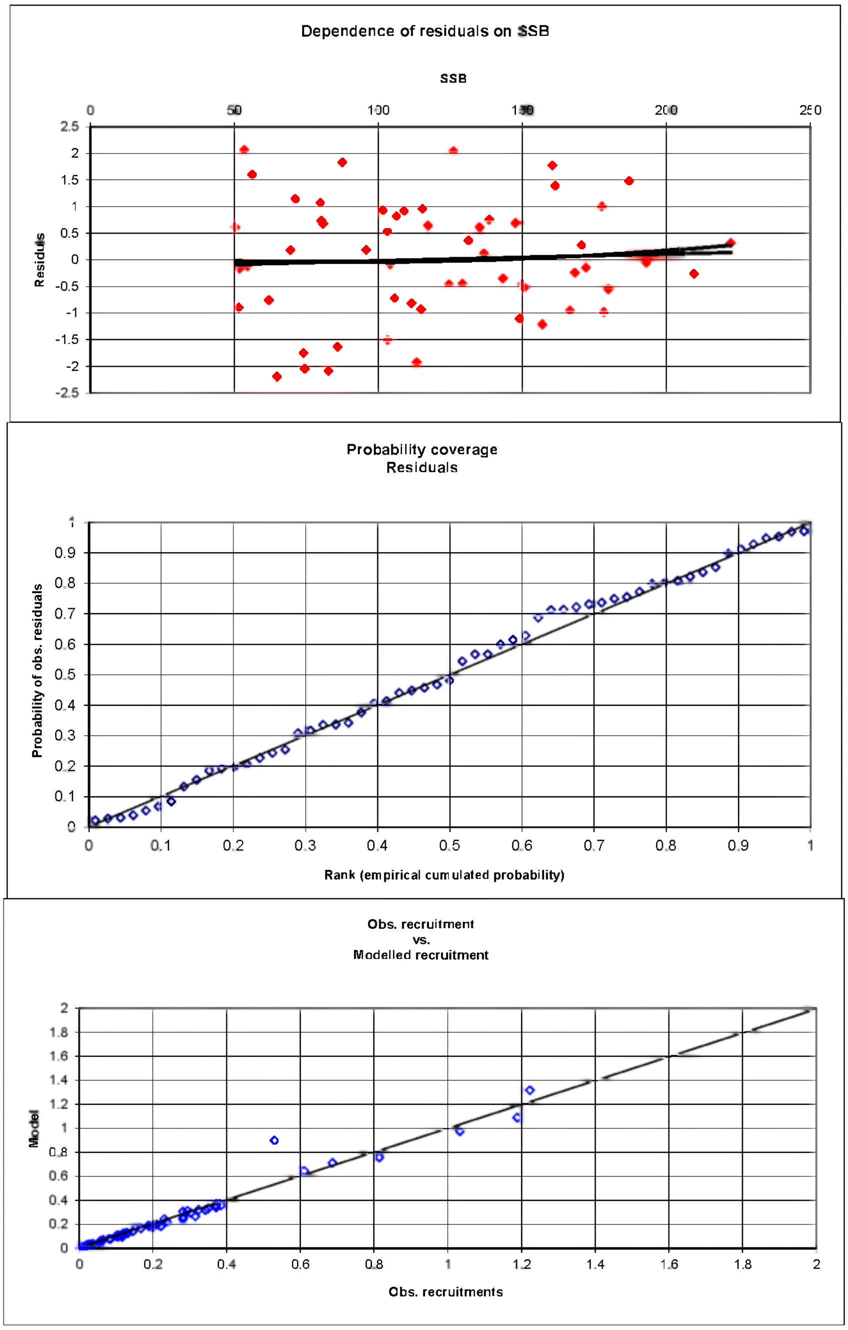

Figure 5.14. NEA haddock recruitment function. Residuals vs. SSB, the probability coverage and observed vs. modelled recruitment for this distribution.

In the model used in 2006/2007, a cyclic trend in recruitment was assumed and strong year classes were also modelled separately. The plot of residuals vs. time (Figure 5.15) does not indicate that it is particularly useful to make those assumptions in the stock–recruitment model.

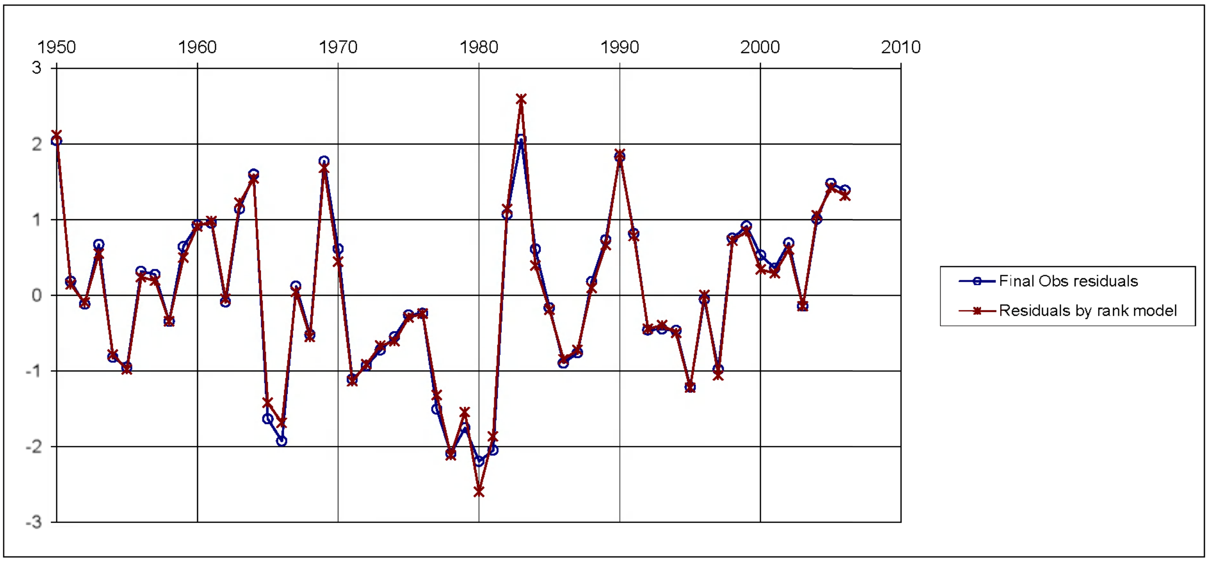

Figure 5.15. Residuals vs. Time for NEA haddock recruitment function.

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

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

The approach taken in 2007 by assuming a fixed periodicity in recruitment and modelling strong year classes separately does not seem to be appropriate.

One may also relate recruitment variation to fluctuations in environmental conditions (e.g. temperature). In some periods there seems to have been a clear relationship, but this has become blurred in recent years, and the same seems to have happened to the correlation between cod and haddock recruitment (see Bogstad *et al*., 2010).

5.10.6 Estimation of biomass reference points

Estimation of RPs will be done after the benchmark and presented at the next AFWG.

5.11 Recommendations on the procedure for assessment updates and further work

Update assessments should follow the procedures described in the stock annex (see Annex 7) and fit the catch data using the XSA model formulation, using age disaggregated survey indices and biological data.

Different setting of F shrinkage was investigated, but the overall conclusion of the benchmark meeting was to keep s.e. for F shrinkage equal to 0.5 for now. This decision was taken because stock size estimations were then less dependent on the number of XSA iterations. Such an effect of numbers of iterations on stock assessment needs to be studied before a more objective decision can be made. Although, taking into account that low shrinkage may cause underestimation/overestimation of stock in situations when strong trends occur it was recommended to leave it to AFWG to change this setting to a higher value if needed. Further work is needed to better understand the XSA model behaviour with low and high weight of F shrinkage. An objective way for choosing an appropriate parameter value is necessary.

It is desirable to have further investigations on how to predict recruitment at age three. The ICES Study Group on Recruitment Forecasting (SGRF), to be held later this year, will be a good opportunity for this work.

It is also desirable with further investigations on how to model and predict weight-at-age in catches.

It is recommended to investigate the possibility of a southwestern extension of the Joint Barents Sea survey (NoRu-BTr-Q1) to increase the coverage of the older age groups.

In 2009 the procedure for Norwegian biological sampling of Norwegian catches was changed and this has led to poor sampling of Danish seine and gillnet catches. It is desirable to improve sampling of these catch proportions.

The possibility of estimating discards should be investigated together with NEA cod.

Estimation of reference points will be done after benchmark and presented on next AFWG.

Scientists involved in assessing this stock are encouraged to explore other modelling approaches than XSA.

5.12 Implications for management (plans)

The current HCR was evaluated in 2006/2007 and found to be precautionary. Stochastic long-term simulations were used, with a biological model that included density-dependent growth and maturation. Two kinds of uncertainty were included: assessment uncertainty and uncertainty in the stock–recruitment relationship. The F_{MSY} was not calculated at that time, but all simulations showed it to lie somewhere in the range 0.25 to 0.45.

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6 Saithe in Subarea IV (North Sea), Division IIIa West (Skagerrak) and Subarea VI (West of Scotland and Rockall)

6.1 Current assessment and issues with data and assessment

The current model used in the assessment of saithe in Subarea IV (North Sea) Division IIIa West (Skagerrak) and Subarea VI (West of Scotland and Rockall) (referred to here as *North sea saithe* for brevity) is a fully deterministic VPA (i.e. XSA, Darby and Flatman, 1994) with shrinkage over the five last years and three age groups set to one times the standard error. Catches, two survey indexes and two commercial cpue indexes.

The geographical distributions of juvenile (< age 3) and adult saithe differ. Typical for all saithe stocks are the inshore nursery grounds. Juvenile saithe in the North Sea are therefore mainly distributed along the west and south coast of Norway, the coast of Shetland and the coast of Scotland. At around age 3 the individuals gradually migrate from the coastal areas to the northern part of the North Sea (57°N–62°N).

The numbers of age 4 saithe at the start of the forecast period have previously been derived from the VPA estimates, but the retrospective recruitment pattern shows that strong VPA recruitments have been overestimated.

The accepted assessment gets an unreasonably good fit because the catch-at-age data is used twice: both in the age split cpue-indexes and in the catches. The real level of uncertainty may be higher than normally assumed. It should be expected that the retrospective pattern will show more variation if the commercial tuning indices are excluded for the ages also covered in the scientific surveys. The problem is that the survey indices don't cover the oldest age-groups, and thus there are no tuning values available for the use in XSA. For these age groups the commercial cpue tuning values are needed.

The maturity curve is potentially outdated, since there has been a decrease in the individual weight in the stock for several years.

6.2 Compilation of available data

The data available to the working group (WGNSSK) have been used. In addition, the following data are provided to the benchmark: a detailed logbook database for the Norwegian and German trawler fleet and a new Norwegian survey index for young saithe.

6.2.1 Catch and landings data

The catch and landings data provided to the working group have been used here. In the data provided, landings from the industrial fleet are only specified when saithe is delivered separately, and therefore bycatch of saithe that has not been separated from the bulk catch, will not be reported as saithe. Landings-at-age data by fleet are supplied by Denmark, Germany, France, Norway, UK (England), and UK (Scotland) for Subarea IV and only UK (Scotland) for Subarea VI.

Discard data from Scotland have been available to the working group, but since there is no other available and reliable discard data, discard is not used in the assessment.

6.2.2 Biological data

Weight-at-age

Weights-at-age in the landings are measured weights from the various national observer and market sampling programs. These are also used as stock weights. There has been a decreasing trend in mean weights from the mid-1990s for ages 4 and older, but the decline now seems to be halted.

Natural mortality

A natural mortality rate of 0.2 is used for all ages and years.

Maturity

The following maturity ogive has been used in the assessment.

Age	1	2	3	4	5	6	7+
Proportion mature	0.0	0.0	0.0	0.15	0.7	0.9	1.0

An assessment of the maturity ogive ("Current") compared with maturity data for saithe taken from the IBTS-Q1 survey data in the period 1992–2010 (red line, Figure 6.2.2.1) shows that the maturity by age has not changed significantly in the period when the growth in the stock has decreased (Figure 6.2.2.2). Thus, the maturity ogive in the XSA input will not be altered. A revision of the maturity ogive could not be recommended based on these data, as the coverage over the spawning–stock might not be good. An extension of the IBTS Q1 survey covering the spawning area of saithe and the entire depth range of the mature population may give better precision for this ogive.

However, the proportion of mature-at-age is highly variable between years. This is modeled in a logistic model. The cpue weighted biological samples are used in the analysis. The proportion mature (p) is modeled using a logistic link function:

$$Log\left(\frac{p}{1-p}\right) = \alpha + \beta A + Y_i + \varepsilon$$

with A being age and Y_i a year effect parameter. Yearly estimates of age at 50% maturity was estimated as:

$$\hat{A}_i^{(50)} = \frac{1 - \hat{Y}_i - \hat{\alpha}}{\hat{\beta}}$$

The variation between years is far beyond the sampling error, but the result can be seriously biased due to the incomplete survey coverage of the stock. The proportions estimated for age groups 3 and 4 will be biased upwards since the immature part of these age groups have a poorer coverage than the mature.

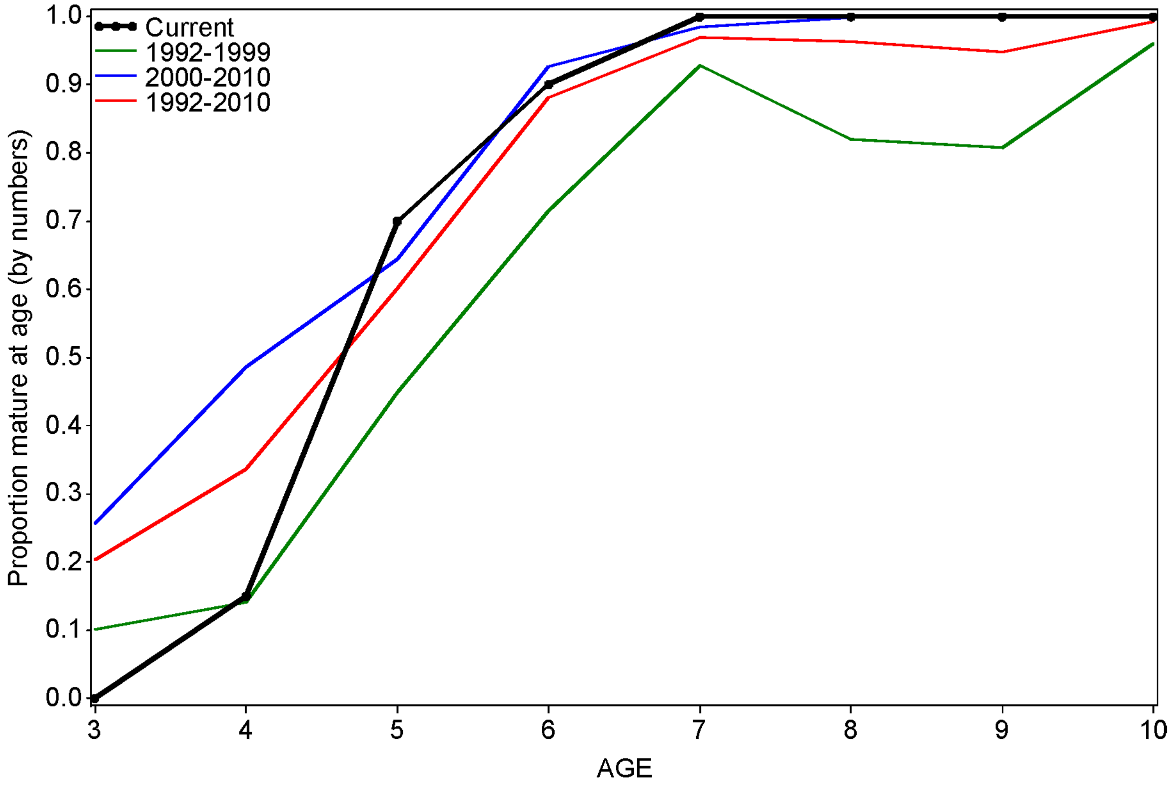

Figure 6.2.2.1. North Sea Saithe. Proportions mature-at-age estimated from IBTS Q1 for different year intervals. Biological information weighted with cpue per subarea and 5 cm length groups. "Current" is the maturity ogive currently used by the assessment WG.

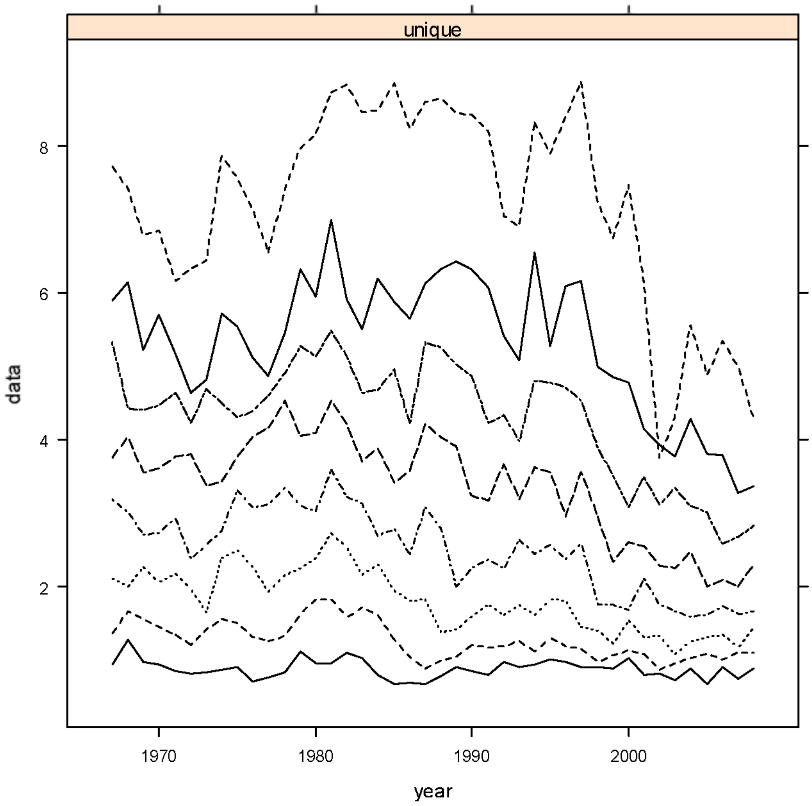

Figure 6.2.2.2. North Sea Saithe. Weight-at-age in the catches for age 3 to 10 (plusgroup). These weights are also used as weight-at-age in the stock.

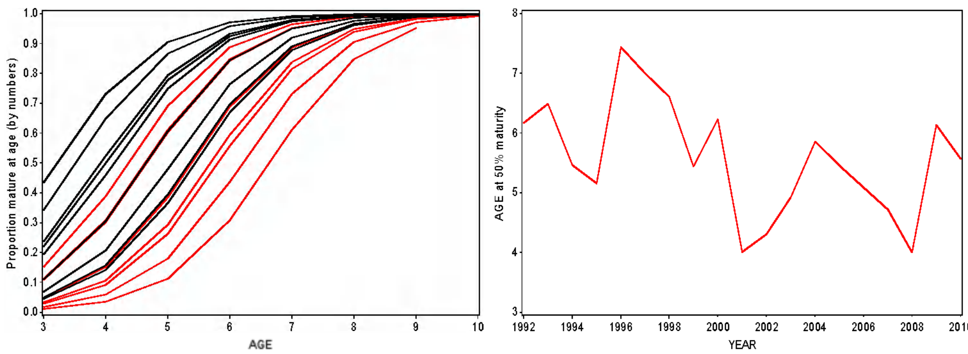

Figure 6.2.2.3. North Sea Saithe. Maturity-at-age ogives modeled with age as a continuous explanatory variable and sampling year as an additional effect. The ogives for different years are shown in the left panel, while the age at 50% maturity is visualized in the right hand panel. The red lines on the left correspond to the period 1992–1999 with black lines representing the remaining years.

6.2.3 Survey tuning data

In the past, two surveys have been presented to the working group:

- Norwegian acoustic survey, age range 3–6, year range 1995–2008 ("NORACU").

- IBTS quarter 3, age range: 3–5, year range 1991–2009 ("IBTS- Q3").

The survey indexes are presented in Table 6.2.3.1. In addition, a new youngfish index for saithe was presented to the benchmark: Norwegian Acoustic Survey of Saithe (NORASS). The survey is an acoustic survey over the sea mountains at the coast of Norway, where the most shallow peak may be from a few meters deep to 50 m below the surface (Figure 6.2.3.1). The young saithe will start migrating to these peaks in May where it concentrates in the eddies where calanus and other plankton is aboundant. The saithe are 2–5 years old, immature and approximately 35–45 cm. A purse-seine fishery starts up in the south of this area around the beginning of May, and in this period it is also assessable for an acoustic estimate. Each of the chosen peaks is crossed southnorth and eastwest and s_A-values are registered for each 0.1 nautical mile. The shape and density of saithe schools at the sea mountains is very distinctive and classifying the species is not difficult. The total area is divided in nine strata from south to north. Individual samples are caught by jigging. The samples taken by jigging is assumed to be representative for the area covered. Age-specific indexes for the total of the covered area are taken as the mean of the indexes within all stratas.

It is assumed that this area represents the main area for young saithe in the North Sea, even if there is young saithe also along the coast of Jæren, in Skagerrak and the coast of Shetland and Scotland. There may also be interchanges from saithe from north of 62 deg N, and the extension and importance of this should also be investigated. The first value of this index is shown as the last of the survey indexes in Table 6.2.3.1.

All of the scientific surveys have problems related to the coverage of the stock (age and area). The life history of saithe with choice of habitat and behaviour changing over the life cycle makes it impractical to try to get a complete coverage with only one survey. The existing survey-series should be continued and the possibility of expanding the coverage is recommened. An example could be IBTS-Q1. This survey could be expanded with trawl stations deeper than 200 m. A bottom trawl and an acoustic survey conducted during the 1st quarter could give very valuable information on age groups currently not covered in the existing surveys.

6.2.4 Commercial tuning data

Three different commercial tuning-series are available for the saithe assessment, namely the Norwegian trawl (NORTRL; Table 6.2.4.1), the French trawl (FRATRB; Table 6.2.4.2) and the German otter trawl (GEROTB; Table 6.2.4.3). Since fisheries-independent survey-series only cover the younger ages, commercial cpues are needed to tune the older ages. However, commercial cpues have serious shortcomings (e.g., hyperstability of cpues) that can bias the assessment considerably (Salthaug and Aanes, 2003). Therefore, analyses were carried out on changes in the fishing pattern and trends in cpue over time for the Norwegian trawlers and GEROTB. Disaggregated data (i.e. logbook data) from the FRATRB were not available to carry out the analysis.

An additional look at cpue and changes in fishing patterns based on Norwegian trawler logbooks

Fleet composition

The Norwegian trawler fleet targeting saithe in the North Sea has seen some recent changes in composition regarding vessel size and engine capacity (Figure 6.2.4.1). In 2000, the fleet was dominated by vessels between 30 and 50 meter overall length, but the number of vessel within this size group has declined since that time. The number of larger vessels has since stabilized. All vessel groups have seen a change towards higher capacity due to increased engine power both from vessels being refitted and newer vessels replacing older ones. The trends are shown in Figure 6.2.4.1. HP capacity is the sum of engine power within a fleet group. Fishing capacity is likely to have increased due to other technical changes like more efficient trawl gear and different operational procedures.

Yearly effort and seasonal changes

The logbooks contain information on the hours towed per day together with the engine power. Multiplying the hours towed with the engine power in horse power yields an index of effort similar to kWdays. The overall effort as hours towed and as horsepower multiplied with hours towed is shown in Figure 6.2.4.2. Both series have seen a drastic increase in effort after 2000–2001 and a more stable level after 2003. The increase in overall effort is not in any way reflected in changes in average fishing mortality in the assessment. This contradiction could be explained by the French and German trawler fleets reducing their catches in a period with strongly increasing TAC. Figure 6.2.4.3 illustrates a strong shift in the seasonal pattern over time. Such changes are likely to have an impact on catch rates. The GLM model of log(cpue) presented later assumes a fixed seasonal (monthly) pattern of catch rates throughout the time-series. We have chosen to keep this assumption since most of the trawler fleet has access to the more valuable cod resource in the Barents Sea in the first quarter. The TAC of cod have generally seen an increase over the time period analyzed.

Changes in the spatial pattern of catches

Catches from the Norwegian fleet normally concentrate in the northeastern part of the North Sea when targeting spawning aggregations (Figure 6.2.4.4). In some years catches further south also are taken. In 2008 and 2009 a southward shift away from the spawning aggregations becomes obvious, which coincides with a shift in the temporal pattern away from the first quarter. The geographical distribution of the catches in 2009 is the most southerly in the last ten years. This raises concern about a decrease in spawning aggregations not covered by the cpue indices, since the fleets can shift their fishing pattern to target smaller individuals instead.

Overall "raw" cpue

Yearly cpues were calculated as the sum of catches divided by the yearly effort values presented above. Both series shows variation over time. The cpue, using horsepower multiplied with hours towed as a measure of effort, show an overall slightly decreasing trend over the time period (Figure 6.2.4.6).

Fitting a simple model to log(cpue)

The information analyzed consisted of 16 742 observations of daily catches of saithe (other species representing less than 25% of the daily catch) together with effort (hours towed). Observations from vessels shorter than 40 meters represented a small fraction of the total catch and were removed from the analysis. A simple model was fit to predict log(cpue). A month effect was used together with a year effect and a vessel category effect (40–50 m, 50–60 m and above 60 m overall vessel length).

$$Log\left(CPUE_{y,m,v,i}\right) = Y_y + M_m + V_v + \varepsilon_i$$

The model gave a modest fit (adjusted R^2=0.11; Figure 6.2.4.7). The relative trend in the year and month effects (actually e^{Y_y} and e^{M_m}) are shown in Figure 6.2.4.8 (relative=relative to the last year/month). The inclusion of the month effect in the model together with shift in effort away from the 1st quarter changed the impression from the "raw" cpue presented above from an overall slight downward trend to the opposite. The assumption that the change in seasonal pattern is not due to any changes in the stock size or distribution should be verified/confirmed.

An additional look at cpue and changes in fishing patterns based on German logbooks

The German reference fleet consists of six characteristic medium-sized (40–60 m) vessels of the German Cutter Fleet targeting saithe mainly in the North Sea and Skagerrak area. The vessels have been engaged in the fishery for more than 15 years. A cpue index used as tuning index in the current assessment is calculated from the total catches of the reference fleet and the effort of the fleet measured in fishing hours. The catches of the reference fleet comprise between 60% and 80% of total German saithe landings (Figure 6.2.4.8).

The fishing pattern regarding landings per quarter of the year changed slightly over the last ten years with the first quarter losing some of its importance. (Figure 6.2.4.9). In contrast, catches from the second and third quarter show a slightly increasing importance over time.

The spatial distribution of catches from the reference fleet was analysed using German logbook information per ICES statistical rectangle. The spatial pattern is stable up to 2007 with a larger concentration of catches in the outflow region of the Skagerrak along the Norwegian trench and at the northeastern part of Area IV along the shelf edge (Figure 6.2.4.10). Catches from VIa only comprise a very small part of total catches and after 2006 no catches came from this region. In 2008, however, the catches from the outflow region of the Skagerrak became more important and in 2009 the catches were completely concentrated in this area. The geographically mean of latitude and longitude (center of gravity) of catches from the reference fleet show a southeast shift and this shift accelerates in 2008 and 2009 (Figure 6.2.4.11). The number of ICES squares covering 90% of the catches decreased in 2008 and 2009 (Figure 6.2.4.12). This change in fishing pattern raises concern about the concentration of the stock and a potential hyperstability of the German cpue index, leading to bias in the assessment. However, other explanations are also possible as fuel prices were exceptionally high during 2009 and German vessels may have primarily targeted the nearest fishing grounds. Also, a concentration of fishing effort on younger age groups that form schools in the southern part of the distribution area due to market demands was possible.

Cpues per subarea (subarea A <59° N; subarea B >=59°N , <61°N; subarea C >=61°N) were analysed to detect decreasing trends, especially in the northeastern part of the North Sea (subarea C) that could explain the southward shift of the fishery. A GAM model fitted to log (cpue) on haul level for the subareas individually and all areas combined showed that there are seasonal and vessel effects (Figures 6.2.4.13–6.2.4.17). Corrected for these effects, results indicate a decrease in cpue for 2009 in all subareas. However, the level is still in the range of cpues from the last five years and higher compared to the start of the time-series. In addition, the uncertainties around the year effect estimates for subarea C are high. Therefore, the trend in cpue in subarea C cannot explain the marked change in the fishing pattern in 2009. The models explained between 12.3% (subarea C) and 33.4% (subarea A and B) of the deviance indicating that the variability in subarea C is highest. The data available only allowed analyses based on effort measured in fishing hours. Search time during the hauls could not be analysed, potentially hiding trends in cpue.

Further analyses are needed when data from 2010 become available. It has to be explored whether the spatial pattern in 2009 was extraordinary or whether the new fishing pattern is continuing. Also cpue analyses based on VMS data to detect changes in search time are needed to complete the analysis.

Conclusions from the analyses

The analyses carried out on changes in the fishing pattern of Norwegian and German trawlers showed a clear sign of changes both in the importance of the first quarter, where spawning aggregations are mainly targeted and in the spatial distribution of catches. Catches from both fleets showed a southward shift in 2008 and 2009 with the shift for German trawlers being more pronounced. Analyses on cpues for both countries show no sign of a serious decline. In contrast, an increase over the last ten years was observed. The correlation between the year effect estimates from the model for the Norwegian and the model for German trawlers (all areas combined) was high (r=0.65, Figure 6.2.4.18). The increasing trend was stronger for the German vessels. Given the marked change in the fishing pattern, but the stable or even increasing cpues, hyperstability of the indices may be a serious problem. Further investigations are needed that can explain the shifts in fishing pattern. In the meantime the influence of the commercial cpues should be reduced as much as possible.

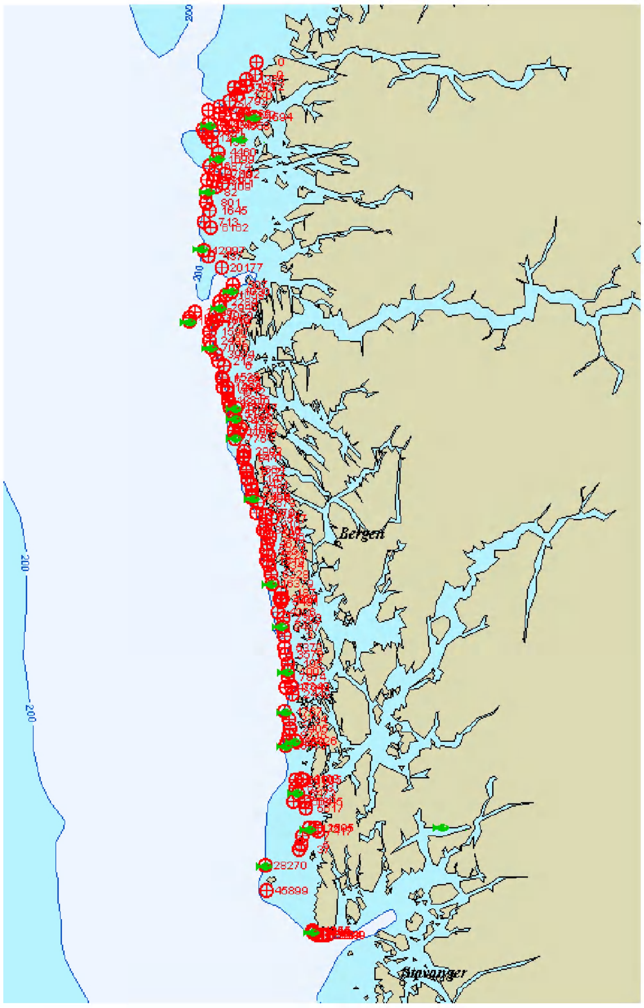

Figure 6.2.3.1. North Sea Saithe. Seamountains covered by the NORASS.

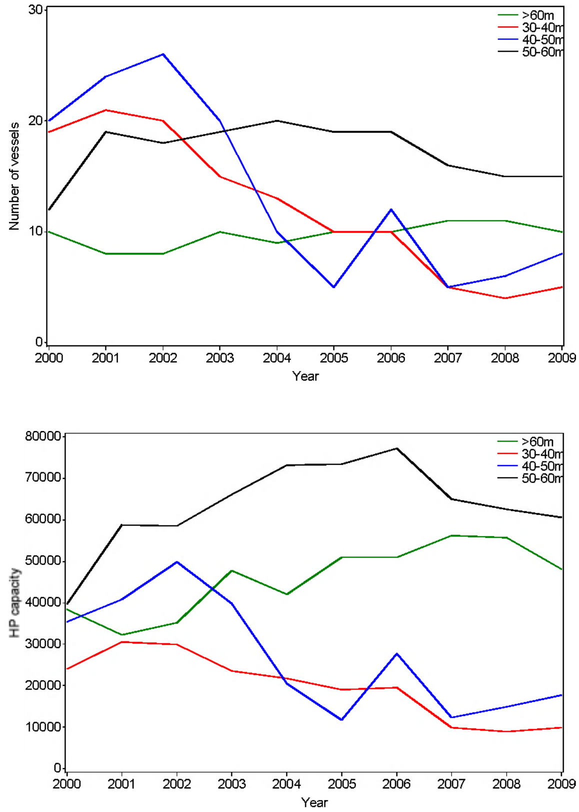

Figure 6.2.4.1. North Sea Saithe. Development of number of vessels and HP capacity over time.

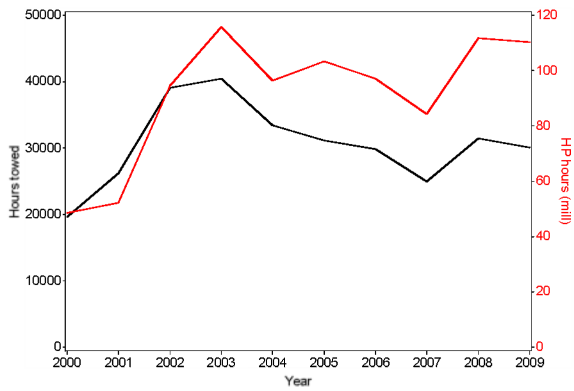

Figure 6.2.4.2. North Sea Saithe. Hours towed and HP hours per year.

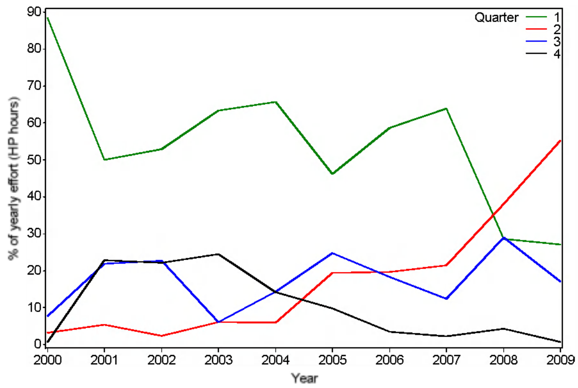

Figure 6.2.4.3. North Sea Saithe. Changes in the importance of quarter over time.

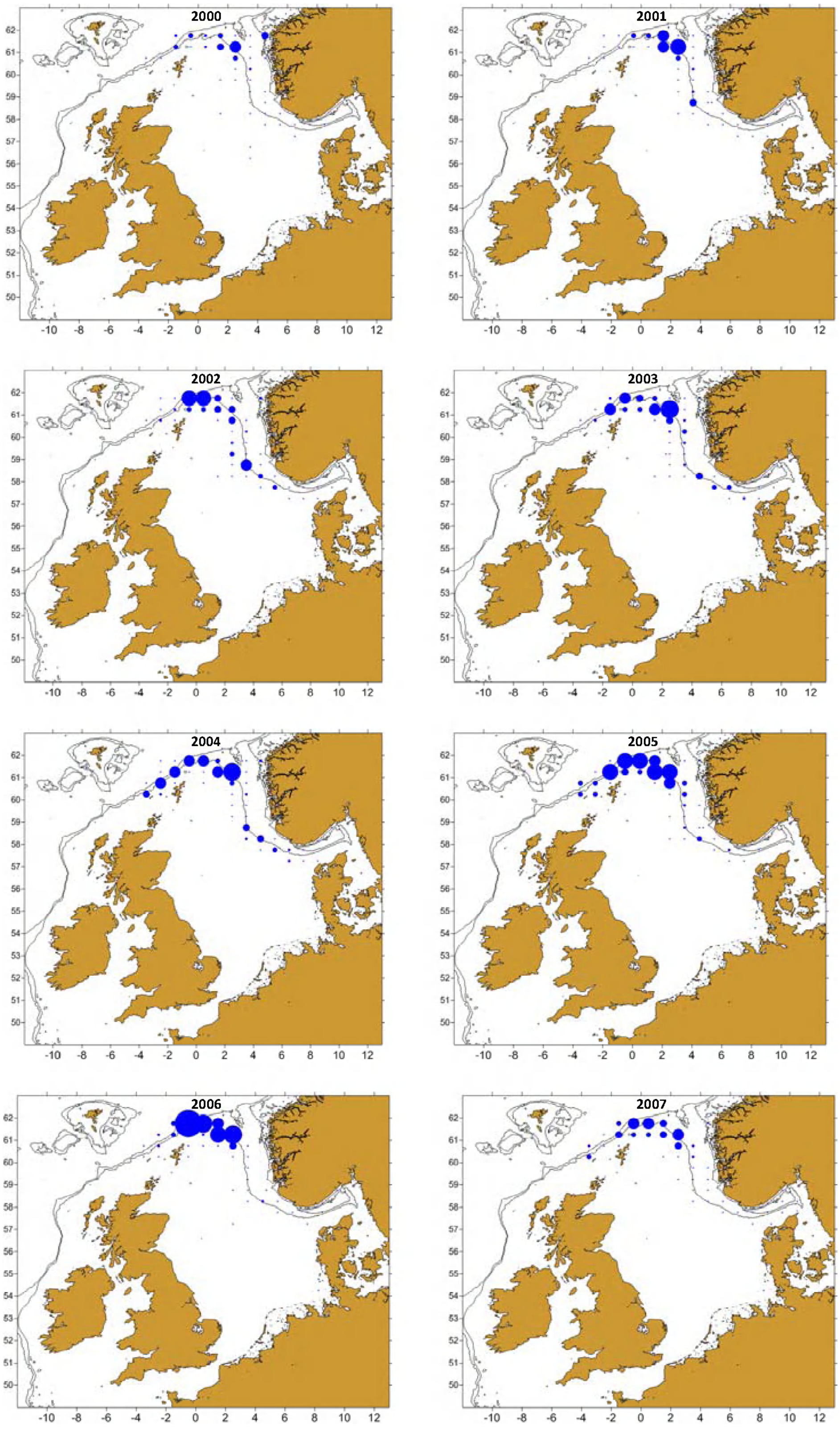

Figure 6.2.4.4. North Sea Saithe. Spatial distribution of catches of the Norwegian fleet.

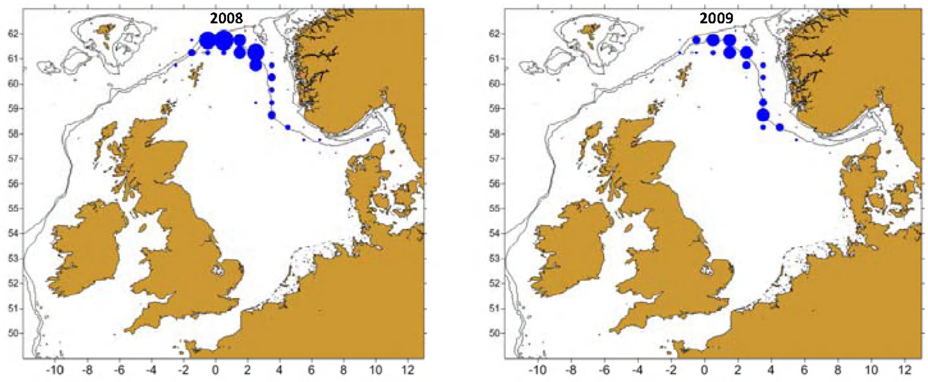

Figure 6.2.4.4. (continued).

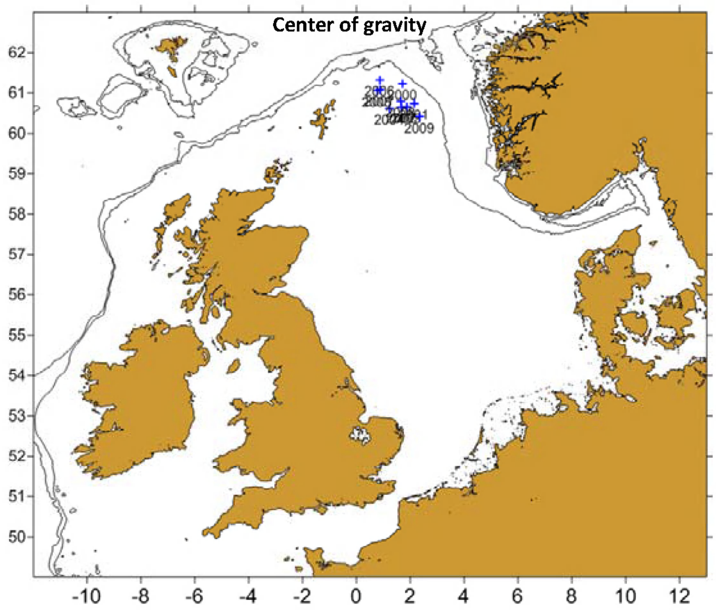

Figure 6.2.4.5. North Sea Saithe. Center of gravity of Norwegian catches.

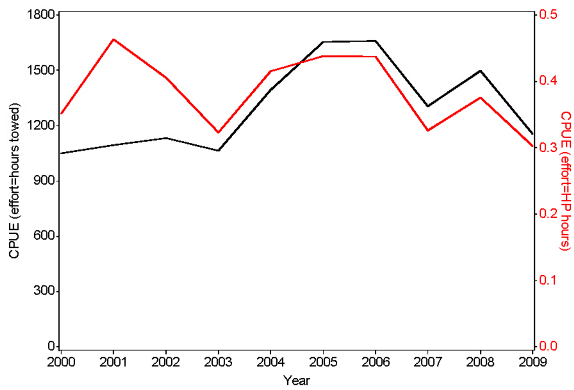

Figure 6.2.4.6. North Sea Saithe. Trend in cpue (hours towed and HP hours) over time.

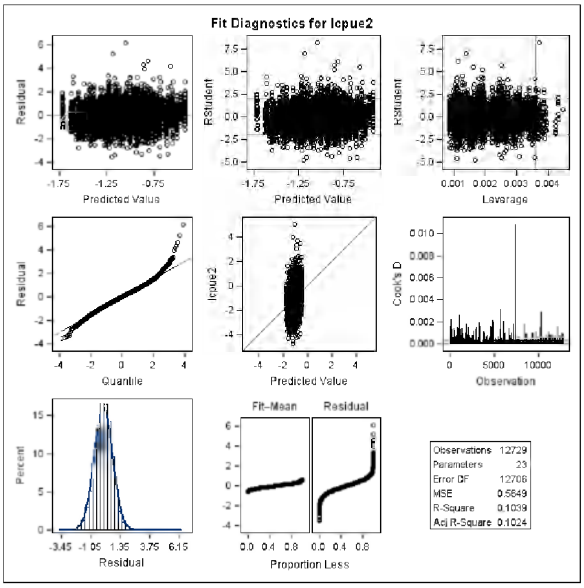

Figure 6.2.4.7. North Sea Saithe. Diagnostics of the GLM fitted to log cpue from Norwegian logbook data.

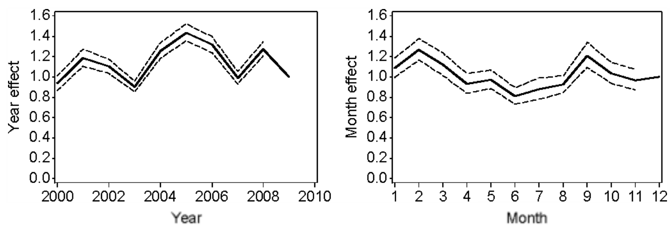

Figure 6.2.4.8. North Sea Saithe. Year and month effect of the GLM model fitted to Norwegian cpue data.

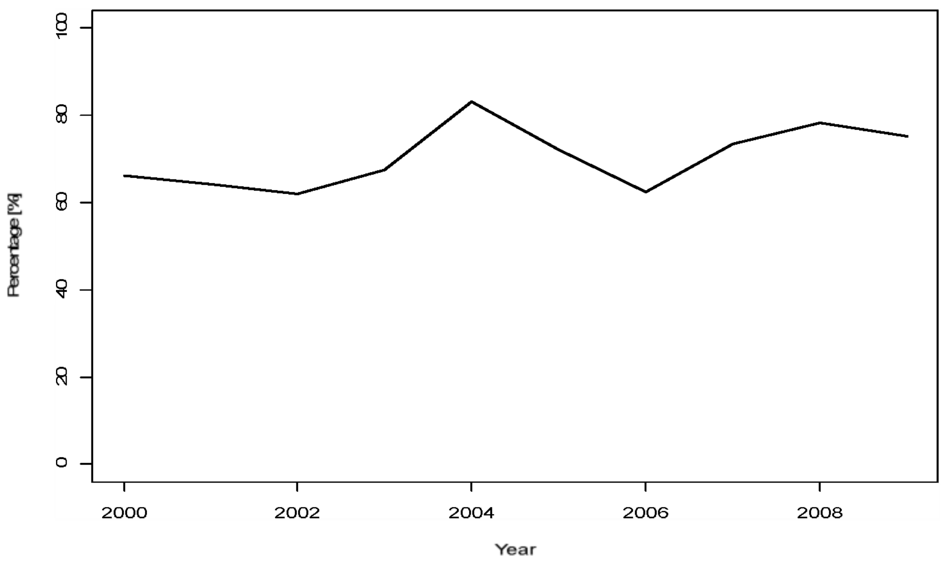

Figure 6.2.4.9. North Sea Saithe. Percentage of landings of the reference fleet on total German saithe landings.

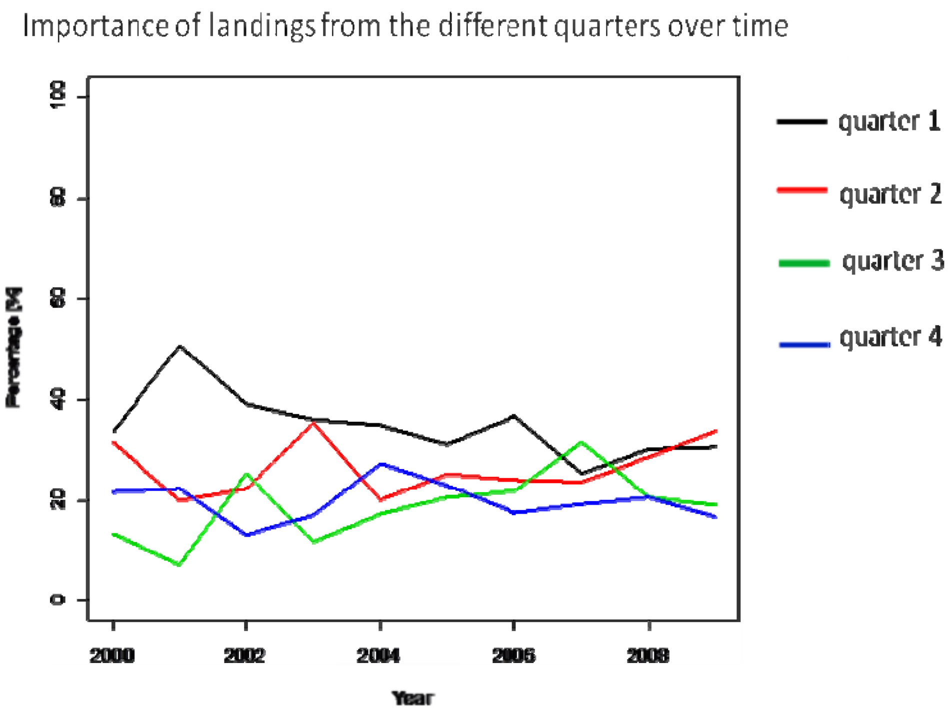

Figure 6.2.4.10. North Sea Saithe. Importance of landings from the different quarter over time.

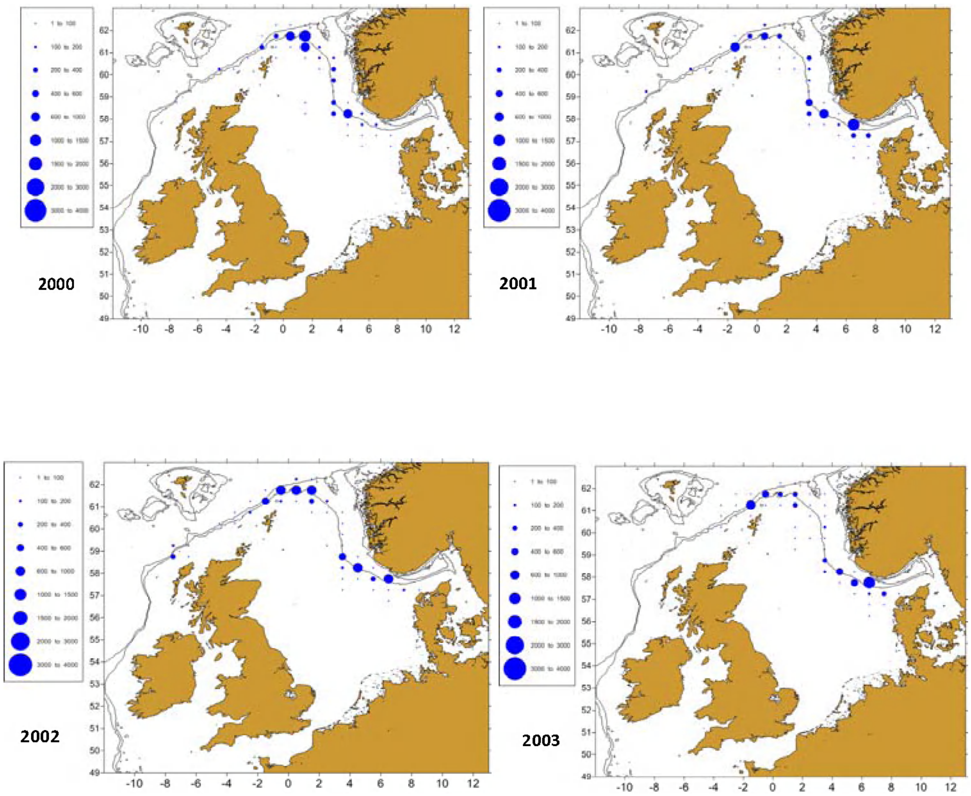

Figure 6.2.4.11. North Sea Saithe. Spatial distribution of catches of the German reference fleet.

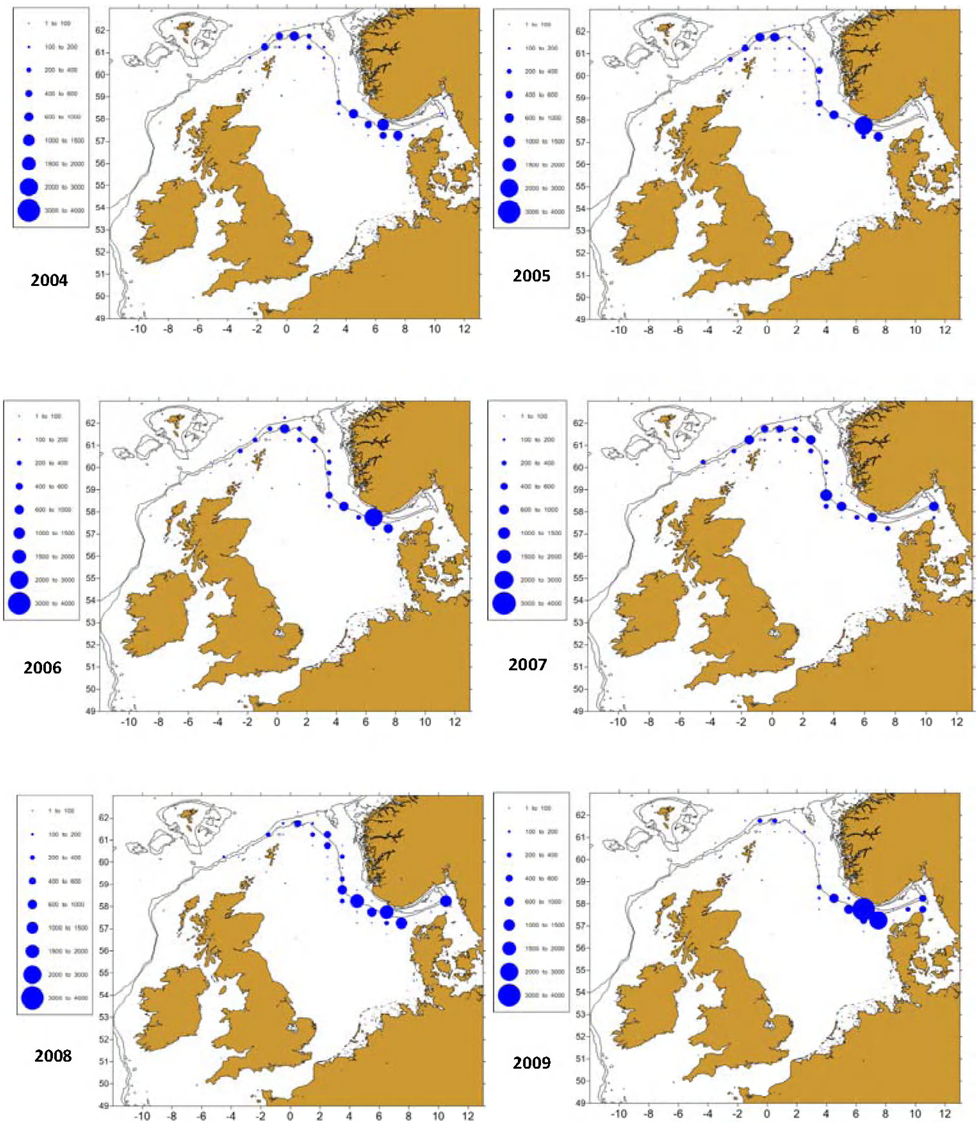

Figure 6.2.4.11. (continued).

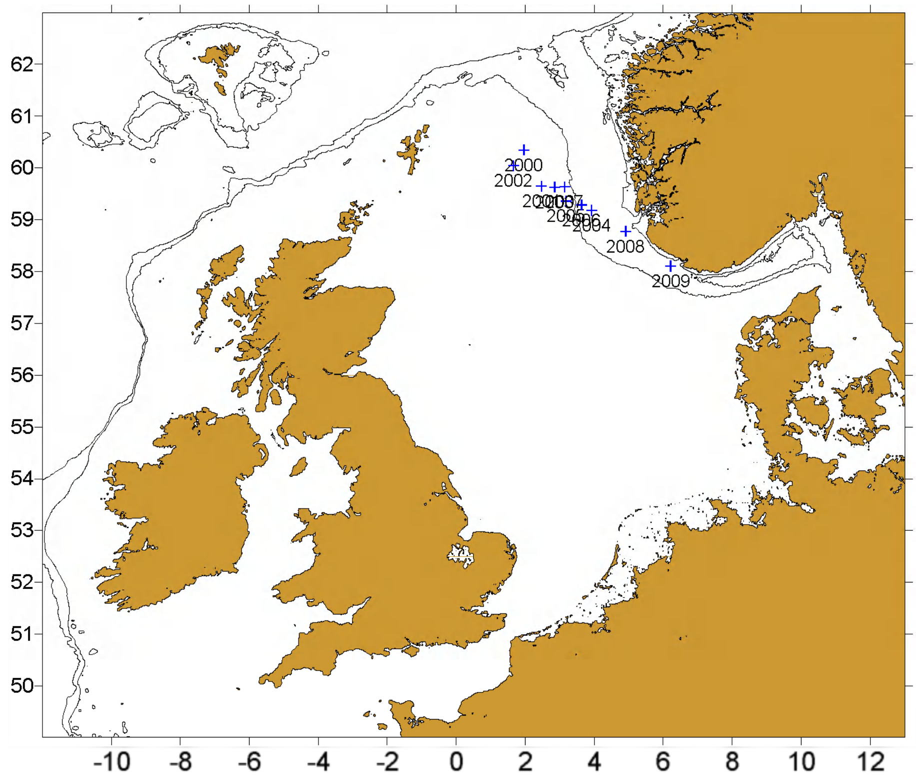

Figure 6.2.4.12. North Sea Saithe. Center of gravity for catches of the German reference fleet.

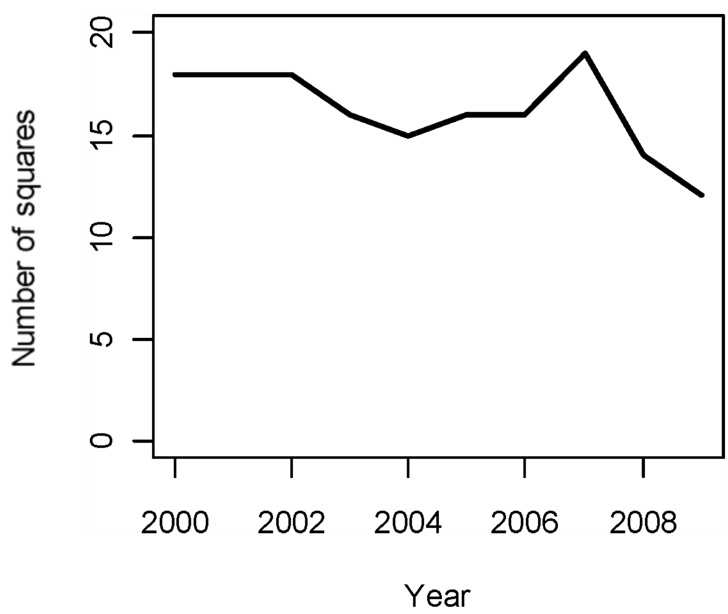

Figure 6.2.4.13. North Sea Saithe. Number of ICES squares covering 90% of total catches.

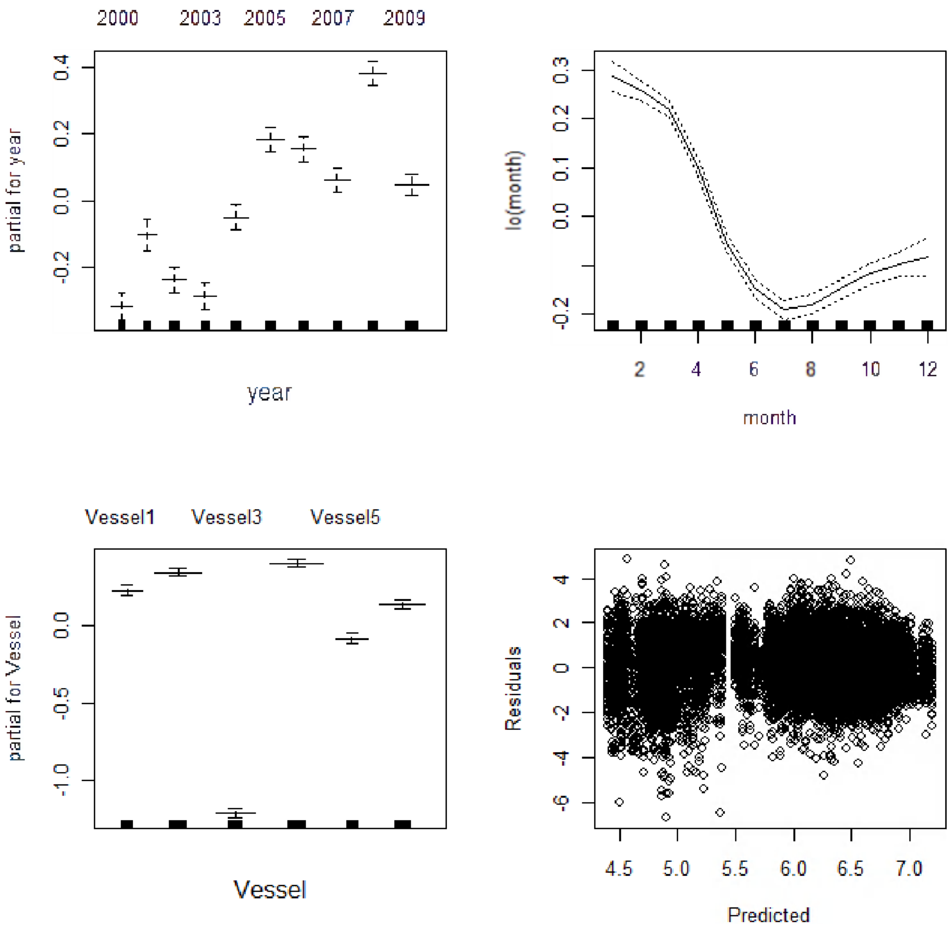

Figure 6.2.4.14. North Sea Saithe. Partial effects and residuals of the GAM model fitted to log(cpue) from German logbook data for the reference fleet (all areas combined). Year, month, and vessel were used as explanatory variables.

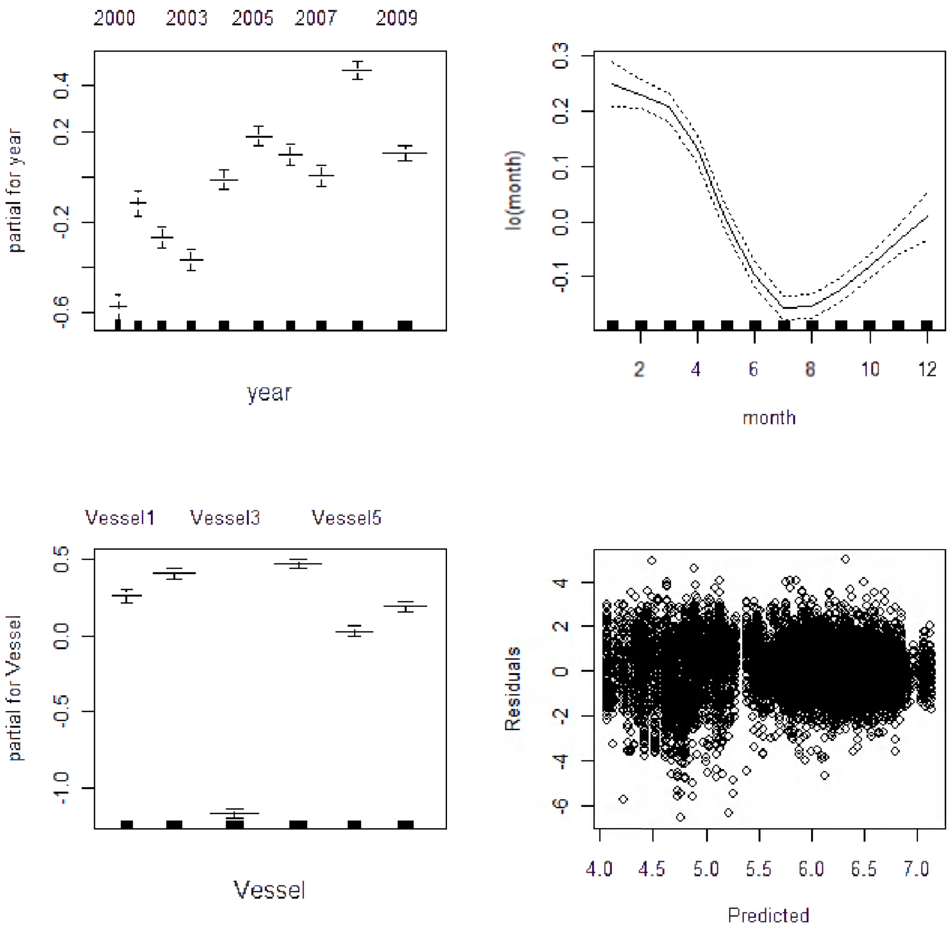

Figure 6.2.4.15. North Sea Saithe. Partial effects and residual of the GAM model fitted to log(cpue) from German logbook data for the reference fleet (subarea A). Year, month and vessel were used as explanatory variables.

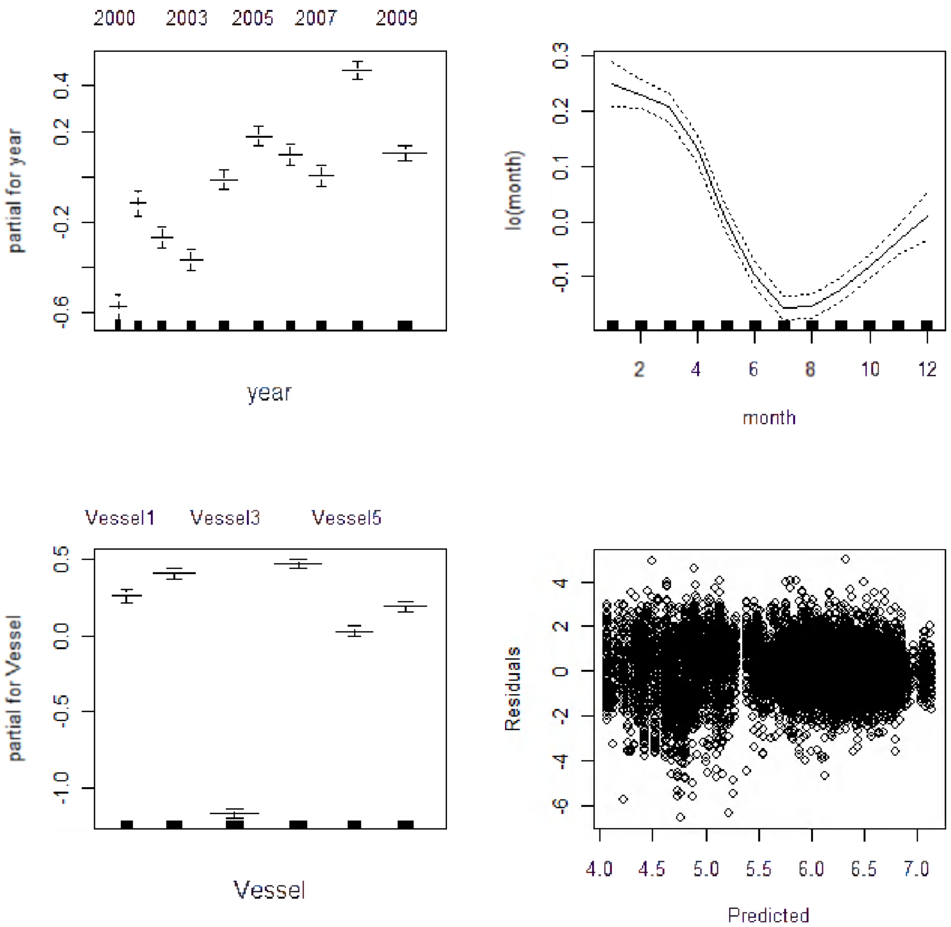

Figure 6.2.4.16. North Sea Saithe. Partial effects and residuals of the GAM model fitted to log(cpue) from German logbook data for the reference fleet (subarea B). Year, month, and vessel were used as explanatory variables.

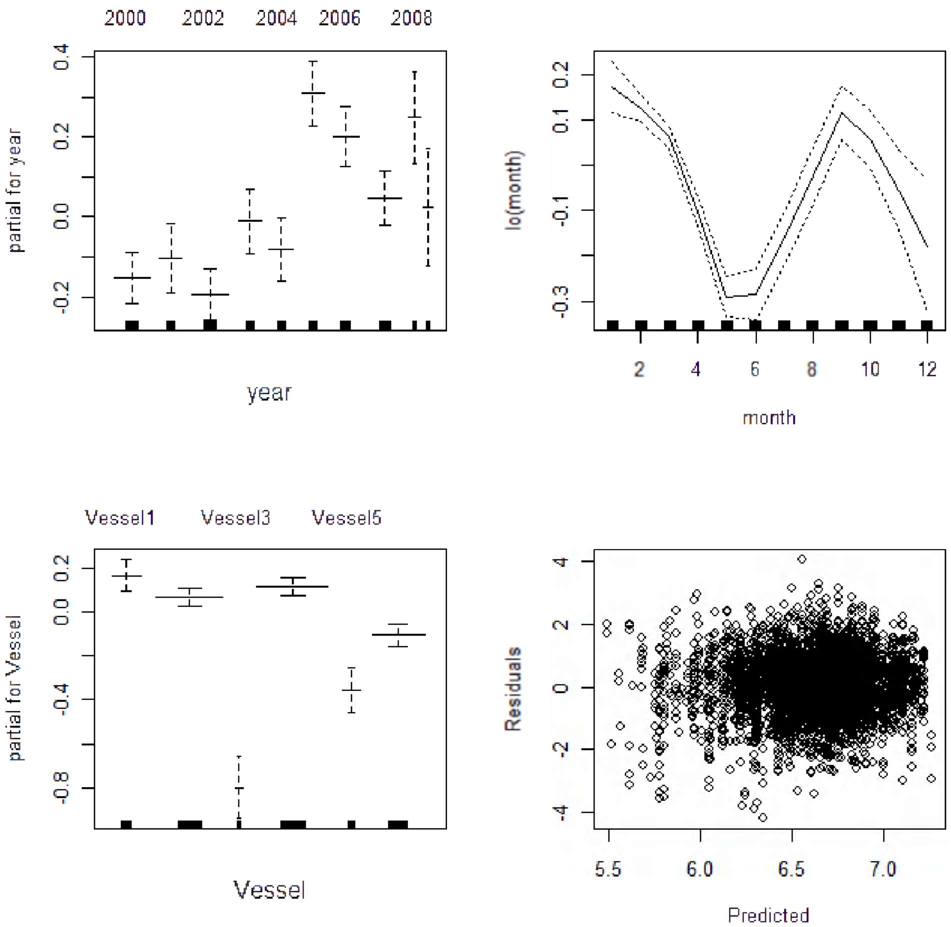

Figure 6.2.4.17. North Sea Saithe. Partial effects and residuals of the GAM model fitted to log(cpue) from German logbook data for the reference fleet (subarea C). Year, month, and vessel were used as explanatory variables.

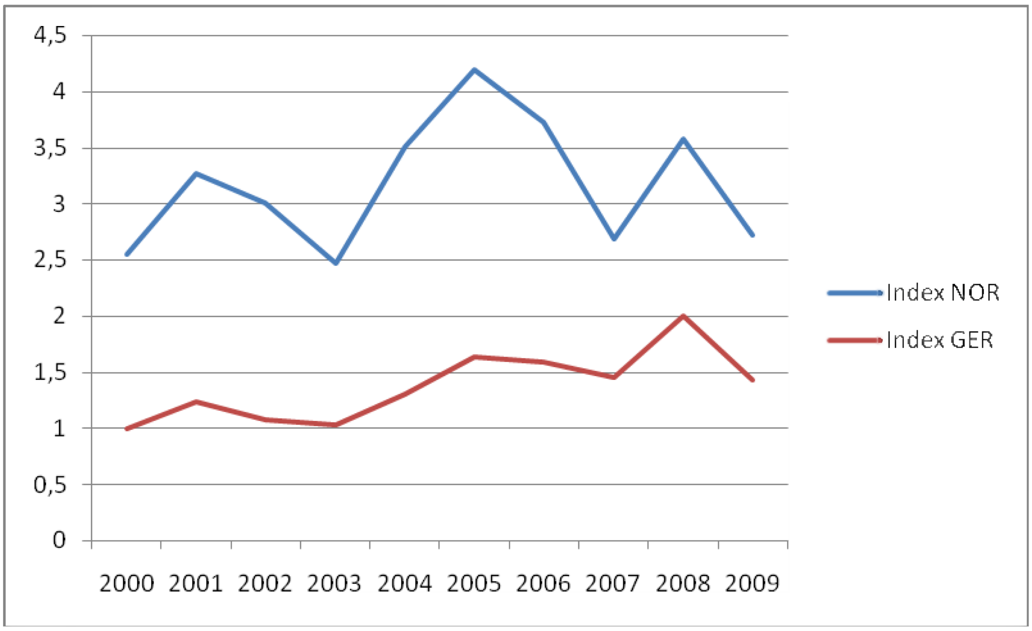

Figure 6.2.4.18. North Sea Saithe. Year effect estimates from the GLM model for the Norwegian trawlers compared to the year effect estimates from the GAM model for the German trawlers.

Table 6.2.3.1. North Sea Saithe. Survey indexes from NORACU, IBTS Q3, and the NORASS, presented in the standard XSA-format.

NORACU				
1995	2008			
1	1	0.5	0.75	
3	6			
1	56244	4756	1214	174
1	21480	29698	6125	4593
1	22585	16188	24939	3002
1	15180	48295	13540	11194
1	16933	21109	27036	4399
1	34551	82338	14213	13842
1	72108	28764	17405	3870
1	82501	163524	17479	4475
1	67774	107730	41675	4581
1	34153	43811	31636	6413
1	48446	36560	27859	10174
1	18909	58132	11378	7922
1	77958	12070	32445	2384
1	7122	18989	4180	10262
IBTSq3				
1991	2008			
1	1	0.5	0.75	
3	5			
1	1.946	0.402	0.064	
1	1.077	2.76	0.516	
1	7.965	2.781	1.129	
1	1.117	1.615	0.893	
1	13.959	2.501	1.559	
1	3.825	6.533	1.112	
1	3.756	3.351	7.461	
1	1.027	3.921	1.333	
1	2.1	2.019	2.949	
1	3.479	8.836	1.081	
1	21.496	6.173	3.937	
1	10.748	18.974	1.327	
1	19.272	23.802	13.402	
1	4.979	6.896	3.158	
1	8.893	6.87	4.994	
1	10.636	29.82	2.934	
1	34.018	5.594	11.763	
1	3.467	5.86	1.122	
YoungFishSurvey				
2006	2010			
1	1	0	1	
2	5			
1	15.63	7.66	17.89	1.86
1	9.83	55.47	6.28	20.01
1	5.10	30.89	23.42	2.40
1	7.96	27.68	11.83	4.35
1	18.29	30.79	5.07	1.35

Table 6.2.4.1. North Sea Saithe. Available tuning indices from the commercial fleets.

FRATRB_IV

1990				2008			
1		1		0		1	
3				9			
21758	3379.574	2471.553	1405.54	304.063	290.298	32.728	14.813
15248	1381.383	2538.766	731.379	372.239	130.79	67.67	11.93
7902	717.161	1480.817	498.716	73.572	24.402	7.133	5.741
13527	3917.8	2253.44	1162.23	103.625	8.299	8.648	6.183
14417	1770.754	3652.84	1381.104	434.086	38.895	5.317	2.71
14632	3151.807	1682.869	921.653	225.695	70.393	24.088	13.317
16241	895.031	4286.247	1053.226	535.95	107.63	24.634	15.158
12903	1087.28	1914.745	3175.192	190.091	83.908	16.535	13.738
13559	799.753	2538.413	1870.453	1480.902	52.256	23.023	10.381
14588	852.467	1233.817	2666.699	620.174	399.661	24.212	13.688
8695	889.314	1993.229	1038.898	1195.148	214.774	180.514	31.751
6366	724.1021	1339.454	2372.881	269.951	144.906	25.554	29.28
11022	3275.662	7576.645	1220.435	1242.118	175.302	151.434	40.935
10536	1516.931	3235.528	2354.784	264.339	325.113	80.521	112.883
5234	447.218	977.66	1020.943	494.617	92.582	35.628	19.772
3015	406.936	660.534	643.107	428.406	209.713	15.685	14.262
5710	1681.537	3142.212	551.3929	144.5056	199.2849	39.65778	13.23932
8255	4200.934	1040.925	2807.48	240.7597	99.80143	3.070924	1
7016	878.509	1522.508	245.447	949.847	164.900	34.288	33.320

NORTRL_IV1

1980	1992						
1	1	0	1				
3	9						
18317	186	1290	658	980	797	261	60
28229	88	844	1345	492	670	699	119
47412	6624	12016	2737	2112	341	234	19
43099	4401	4963	8176	1950	2367	481	357
47803	20576	7328	2207	3358	433	444	106
66607	27088	21401	5307	1569	637	56	46
57468	5297	29612	3589	818	393	122	25
30008	2645	18454	2217	290	235	201	198
18402	3132	2042	2214	141	157	74	134
17781	649	2126	835	694	309	154	65
10249	804	781	924	519	203	63	12
28768	14348	4968	1194	518	203	51	56
35621	3447	9532	4031	1087	465	165	109

NORTRL_IV2

1993	2009						
1	1	0	1				
3	9						
24572	7635	4028	2878	1018	526	365	252
30628	3939	16098	4276	926	251	72	203
32489	4347	9366	5412	833	1644	273	203
40400	3790	14429	4414	2765	1144	189	16
36026	2894	5266	9837	1419	892	299	72
24510	1376	8279	5454	5662	977	489	243
21513	813	2595	6869	2368	3602	1168	346
15520	284	1628	2054	4261	1066	1203	221
23106	4808	5228	6513	935	1235	509	390
38114	4015	12063	3474	3775	981	1632	1050
41645	1630	5451	10452	3602	4432	792	1004
32726	663	2677	5709	6578	2256	2640	656
34964	1202	3080	5177	9204	6954	1728	1434
30190	797	4116	3842	4611	7310	3974	811
26354	1563	1442	4684	3506	2655	3121	887
32550	2308	10354	3664	8357	2155	1619	1234
34360	1071	3257	5936	1254	5334	1636	933

GER_OTB_IV

1995	2009						
1	1	0	1				
3	9						
21167	1158	2359	1350	589	152	30	16
19064	510	3167	1081	517	257	148	41
21707	816	2475	3636	292	163	70	24
20153	591	2744	1395	1776	238	100	39
18596	284	1065	2264	943	1015	77	36
12223	542	2185	823	1216	242	325	38
11008	892	1329	2317	372	532	249	155
12789	650	3658	1230	1100	99	140	69
14560	500	1399	2630	438	392	58	72
13708	334	2040	1928	1079	200	235	47
11700	434	510	1623	1543	787	205	119
10815	374	1575	690	668	685	350	147
12606	937	713	2813	607	405	417	175
12871	477	3151	627	1662	354	220	223
16692	359	759	1263	316	708	314	271

6.2.5 Industry/stakeholder data inputs

The results of the North Sea Commission fishers survey in 2009 (Figure 6.2.5.1) does not cover fishers outside the European Union (i.e. Norway) that catch the majority of the TAC. Landings in the latest years have been below the TAC. This can be an effect of low prices on saithe, high fuel costs, and, for the Norwegian fleet, the large cod TAC in northern Norway.

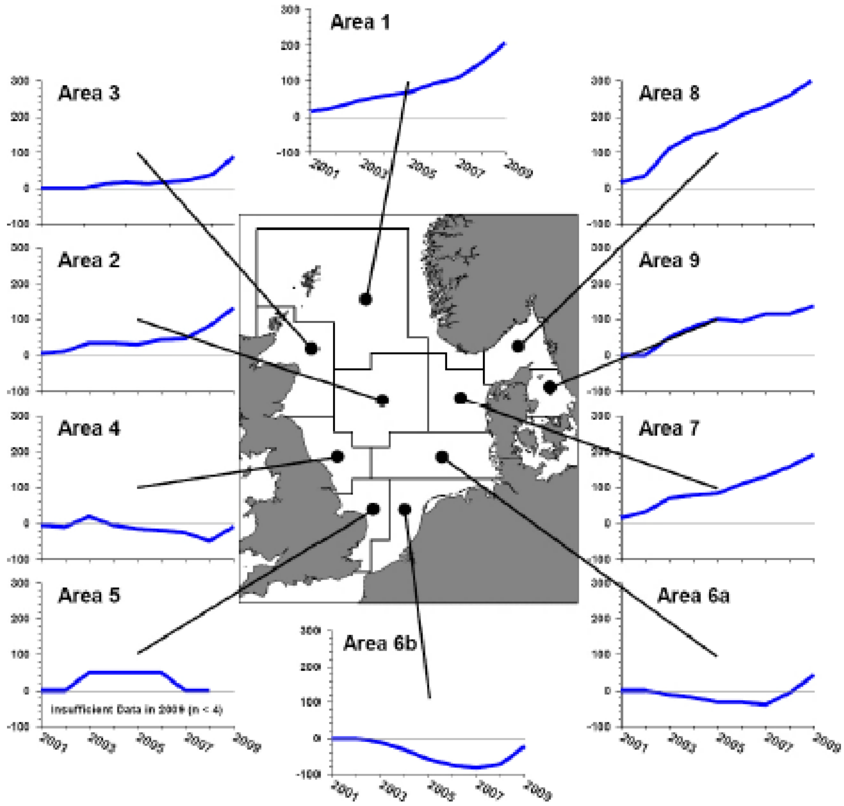

Figure 6.2.5.1. Saithe in Subareas IV and VI, and Division IIIa. Results of the North Sea Commission fishers survey 2009.

6.2.6 Environmental data

6.3 Stock identity, distribution and migration issues

No stock identity information was presented to WKBENCH.

6.4 Influence of the fishery on the stock dynamic

No new information on influence of the fishery on the stocks dynamic was presented to WKBENCH.

6.5 Influence of environmental drivers on the stock dynamic

Tagging experiments by various countries have shown that exchange takes place between all saithe stock components in the northeast Atlantic. In particular, exchange between the saithe stock north of 62°N (Northeast Arctic saithe) and saithe in the North Sea has been observed.

Variation in currents around the spawning in the northern part of the North Sea may also lead to egg and larvae being carried both south and north of 62 deg N.

6.6 Role of multispecies interactions

6.6.1 Trophic interactions

When saithe exceed 60–70 cm in length, the diet changes from plankton (krill, copepods, fish larvae) to fish (mainly Norway pout, blue whiting, haddock and herring). Large saithe (>70 cm) have a highly migratory behaviour and feeding migrations extend from far into the Norwegian Sea to the Norwegian coast.

The impact of a large saithe stock on prey species such as Norway pout and herring is unknown. Poor spatial and temporal sampling of stomach data of saithe makes the estimation of the saithe diet uncertain.

6.6.2 Fishery interactions

Saithe in the North Sea are mainly taken in a direct trawl fishery in deep water along the Northern Shelf edge and the Norwegian Trench. Norwegian, French, and German trawlers take the majority of the catches. In the first quarter of the year the fisheries are directed towards mature fish in spawning aggregations, while concentrations of immature fish (age 3–4) often are targeted during the rest of the year. In recent years the French fishery has deployed less effort along the Norwegian Trench, while the German and Norwegian fisheries have maintained their effort there. There might be a significant change in fishing pattern both in the Norwegian and German fisheries in the last decade (see above).

The main fishery developed in the beginning of the 1970s. The fishery in Subarea VI consists largely of a directed French, German, and Norwegian deep-water fishery operating on the shelf edge, and a Scottish fishery operating inshore. In both areas most of the saithe do not enter the main fishery before age 3, because the younger ages are staying in inshore waters. A small proportion of the total catch is taken in a limited purse seine fishery along the west coast of Norway targeting juveniles (age 2–4). In the Norwegian coastal purse seine fishery inside the 4 nm limit (south of 62°N), the minimum landing size is 32 cm.

Since the fish are distributed inshore until they are about 3 years old, discarding of young fish is assumed to be a small problem in this fishery. Problems with bycatches in mixed fisheries when saithe quotas are exceeded may cause discarding. French and German trawlers are targeting saithe and have larger quotas, so the problem may be less in these fleets. The Norwegian trawlers move out of the area when the boat quotas are reached (no discarding is allowed), and in addition the fishery is closed if the seasonal quota is reached.

Most of the fisheries targeting saithe will give a clean fishery; however, there is little information available about the bycatch in industrial trawling that may be significant. In the data provided, landings from the industrial fleet are only specified when saithe is delivered separately, and therefore bycatch of saithe that has not been separated from the bulk catch, will not be reported as saithe.

6.7 Impacts of the fishery on the ecosystem

All fisheries influence an ecosystem by removal of biomass. Multispecies impacts from saithe fisheries have been estimated in the WGMIXFISH and will vary from year to year, dependent on management plans and fisheries.

6.8 Stock assessment methods

6.8.1 Models

The current model used in the assessment is a fully deterministic VPA (i.e. XSA, Darby and Flatman, 1994) with shrinkage over the last five years and three age groups set to one times the standard error. Catches, two survey indexes and two commercial cpue indexes were used. At WKBENCH a new assessment using the same assessment model, but with different tuning data were tested. This new assessment is refered as "benchmark assessment" for brevity. The previous assessment (the 2009 assessment with a four year forecast) that was used as basis for advice prior to this benchmark meeting is referred as "accepted assessment". The tuning indexes and age groups for the accepted assessment and the benchmark assessment are shown in Table 6.8.1.1. In the benchmark assessment, i) age groups 3–5 of the commercial indexes were excluded, ii) and a new acoustic survey (NORASS, see description in Section 6.2.3.) and a new commercial cpue index (NORTRL, Norwegian trawl) are included.

The accepted assessment gets an artificial good fit because the catch-at-age data is used twice: both in the age split cpue-indexes and in the catches. The real level of uncertainty may thereby not have been clearly communicated It should therefore be expected that the retrospective pattern will show more variation if the commercial tuning indexes are excluded for the ages also covered in the scientific surveys. The survey indices don't cover the oldest age-groups. For these age groups the commercial cpue tuning values are used.

Table 6.8.1.1. Tuning indices and age groups used in previously "accepeted" assessment and in the benchmark assessment for Saithe in Subarea IV, VI and Division IIIa.

Tuning Index	Age, accepted assessment	Age, benchmark assessment
NORACU	3–6	3–6
IBTS Q3	3–5	3–5
NORTRL	(not used)	6–9
GEROTB	3–9	6–9
FRATRB	3–9	6–9
NORASS	(not used)	3–4

The analysis of two of the cpue indices (Section 6.2) showed a marked change in the fishing pattern but stable or even increasing cpues, indicating that hyperstability of the indices may be a serious problem. Further investigations are needed to explain the shifts in fishing pattern. Until then, the influence of the commercial cpues should be reduced as much as possible due to the following possible effects: (1) the cpues may be hyperstable due to the nature of the fishery, (2) there may be effects due to technological creeping, and (3) the area fished has decreased.

The analysis of the NORTRL and GEROTB suggests that these indexes are performing differently, and for some years, covering different parts of the stock distribution by area. At the same time, there are questions about the discard data (not included in the assessment, and not available for Norwegian catches or international catches taken in the Norwegian zone).

The survey indexes from IBTS Q3, NORACU and NORASS all show the same trends for the ages 3–5.

To evaluate the effect of the change of age groups in the commercial indices, the assessment was run with the following settings: (1) All settings identical to the previously accepted assessment. (2) For the benchmark assessment, All settings identical to the previously accepted assessment, only using ages 6–9 from commercial cpue and including the NORASS index and the NORTRL index.

Retrospective patterns

1) Rerun of the previously accepted assessment.

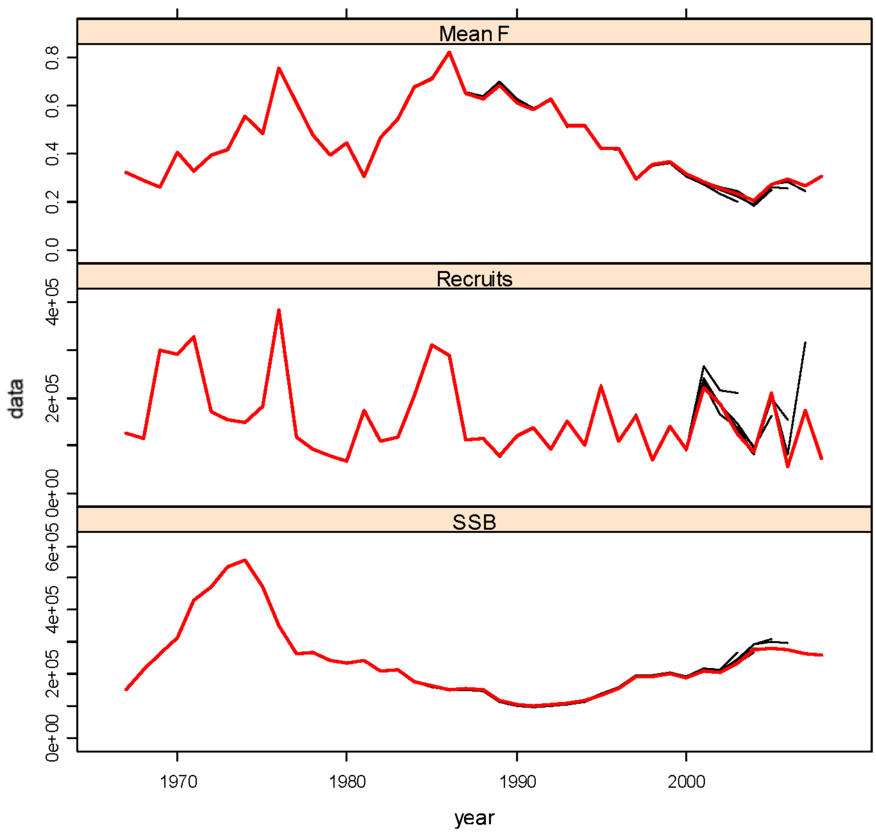

Figure 6.8.1.1. North Sea Saithe. The retrospective pattern from the previously accepted assessment.

2) Benchmark assessment: same as the previously accepted assessment, only using age 6–9 from the commercial indexes and including the NORASS and NORTRL (age 6–9) indexes (see Table 6.8.1.1).

The retrospective pattern can be divided into two data sources: the commercial (black) and the survey (red) retrospective pattern (Figure 6.8.1.2). Trends in the survey index are more variable, and mean F values estimated with the surveys now are higher. The recruit estimate is higher based on commercial values only, while the SSB has a lower level based on commercial indices.

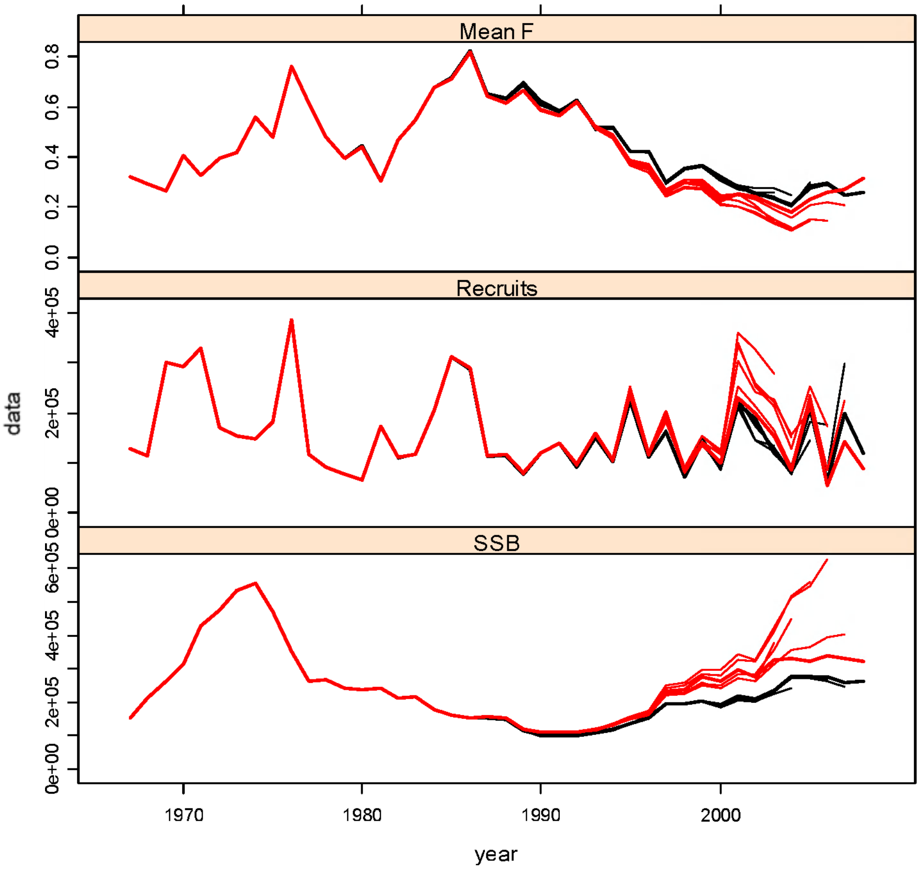

Figure 6.8.1.2. North Sea Saithe. The retrospective pattern in the benchmark assessment shown for the two groups of indexes used: red: surveys; black: cpue from fisheries.

The retrospective pattern in the full benckmark assessment is shown in Figure 6.8.1.3.

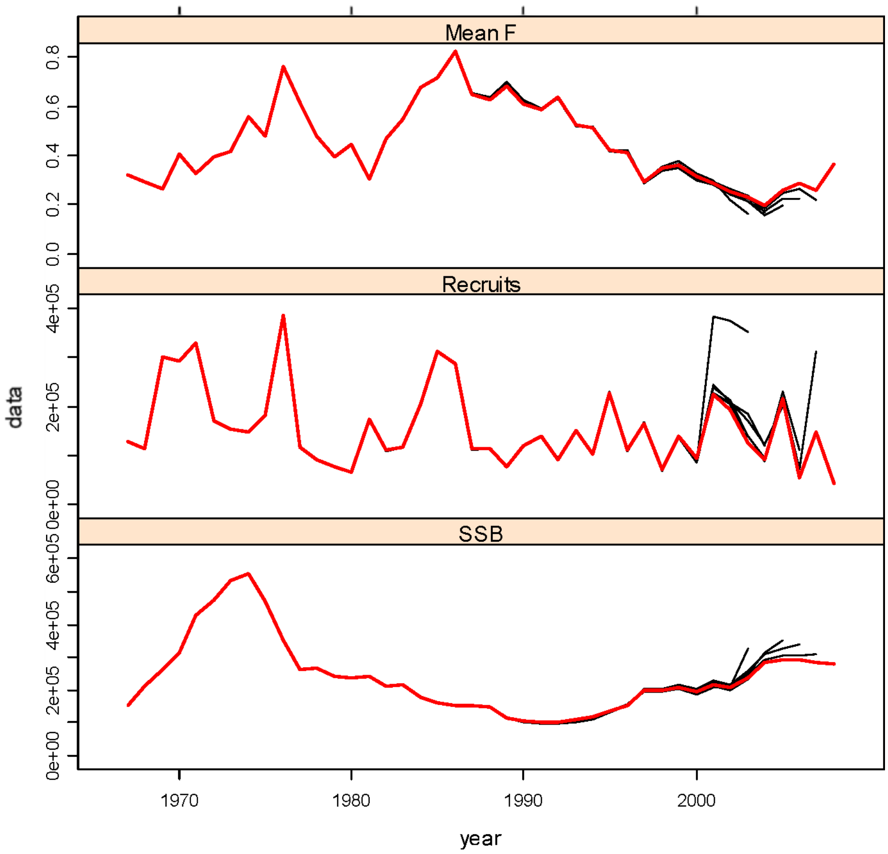

Figure 6.8.1.3. North Sea Saithe. The retrospective pattern in the benchmark assessment.

The variation in the retrospective pattern for the recruits is still high, as would be expected (Figure 6.8.1.4).

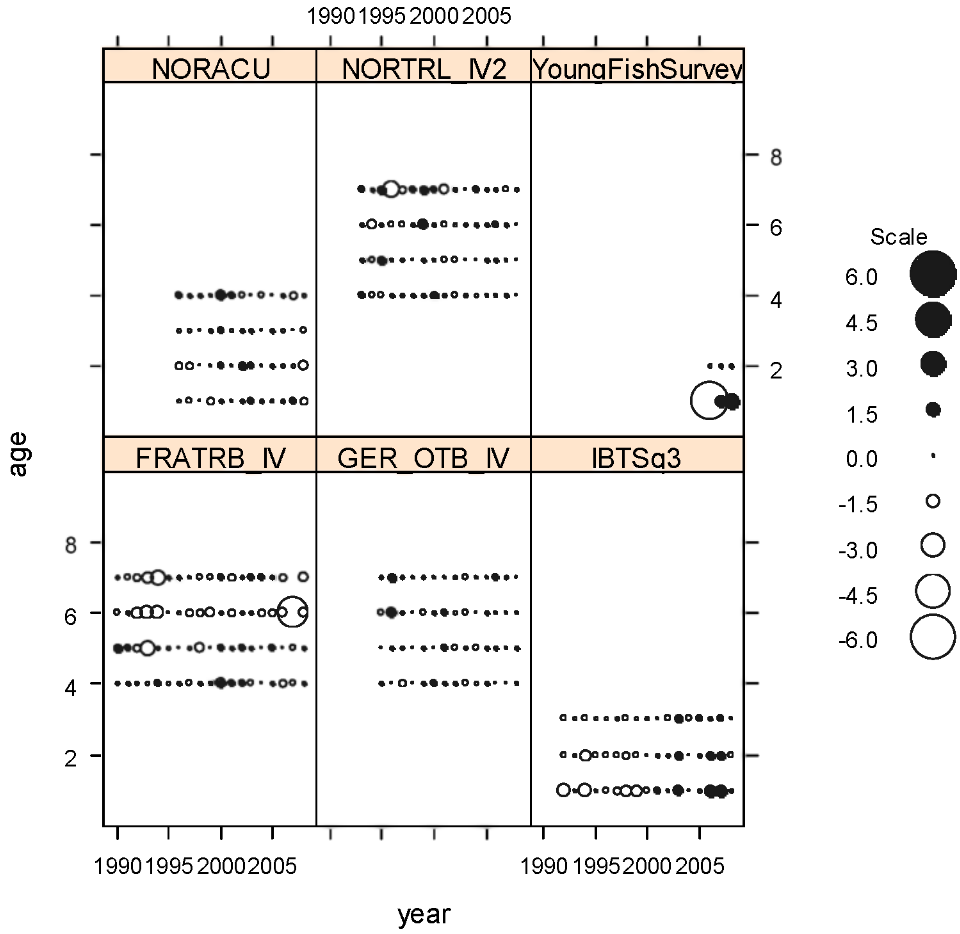

Figure 6.8.1.4. North Sea Saithe. Log residuals for the indices used in the benchmark assessment.

6.8.2 Conclusion

WKBENCH agrees with the input data used in the "benchmark assessment", and recognizes that it is an improvement in relation with the "previously accepted assessment". However WKBENCH recognizes that further investigation on the input data and methodology to assess this stock is needed, and therefore recommends the assessement working group proceed with the investigation initiated at this meeting, and working on the preparation of another benchmark, to be conducted in a near future (i.e. in two years time if progress are presented to the WGNSSK). Maturation-at-age appears to be varying significantly and the impact of such variation should be studied when more reliable information on maturation is available.

6.9 Short-term and medium-term forecasts

Because the assessment on which the advice is based is currently a fully deterministic XSA, the short-term projection can be done in FLR using FLSTF. Weight-at-age in the stock and weight-at-age in the catch are taken to be the mean of the last three years. The exploitation pattern is taken to be the mean value of the last three years. Population numbers at ages 4 and older are XSA survivor estimates, numbers at age 3 are taken from the geometric mean for the years 1988–assessment year.

No medium-term projections are done for this stock.

6.9.1 Conclusion

No new developments were made during WKBENCH. The output of the "benchmark assessment" should be used as input data for short-term forecast.

6.10 Biological reference points

The biological reference points derived in 2006 (ICES, 2006) are:

$F_{0.1}$	0.10	F_{lim}	0.60
F_{max}	0.22	F_{pa}	0.40
F_{med}	0.35	B_{lim}	106 000 t
F_{high}	>0.49	B_{pa}	200 000 t

These reference points refer to an F_{bar} from ages 3 to 6. The proportion of catches taken by purse seine decreased significantly in the early 1990s. This caused a change in the exploitation pattern as the purse seiners mainly targeted young saithe. Therefore, it may be more appropriate to use a reference F that does not include age 3.

The influence on the maturity ogive from the observed decrease in the weight-at-age is unknown, but it is reasonable to believe that the spawning capacity of the stock will be affected.

The F_{MSY} for the stock was analysed at the WGNSSK 2010 (ICES, 2010). The estimation of F_{MSY} values for Saithe was carried out with the Cefas ADMB module (methodology see Section 1.3.1 in the working group report). As sensitivity analysis F_{MSY} was also estimated using FLR (methodology see Section 1.3.2 in the working group report). For both methodologies the sensitivity against different stock–recruitment relationships (Ricker, Bev–Holt, Hockey stick) was tested. In addition, using FLR, the sensitivity of F_{MSY} estimates to different input values was analysed (i.e. the impact of using a three year mean compared to a seven year mean for the exploitation pattern, and the impact of using different values for weight-at-age). Both choices can be seen as representative for the recent period of low weights-at-age (Figure 6.2.2.2). A retrospective analysis of how F_{MSY} values varied in time completed the analysis.

Since there is no complete 2010 data, the assessment were based on data until 2009.

The fit to stock–recruitment data was poor for all types of recruitment relationships (Figure 11.9.1 in WGNSSK 2010). There are no data near the origin. However, the AIC criterion was highest for the Ricker curve (AIC=60.9), the AIC for the Beverton–Holt and Hockey stick recruitment curve were lower and very similar (AIC=58.0 and 58.2). The estimated deterministic F_{MSY} value was 0.28 for the Ricker, 0.24 for the Beverton–Holt and 0.32 for the Hockey stick recruitment curve (Table 11.9.1 in WGNSSK 2010). The medians of bootstrap estimates were 0.30, 0.20 and 0.30, with each having considerable variability.

Based on the AIC criterion, the Ricker recruitment curve could be rejected. For the Beverton–Holt curve the point of maximum curvature lies outside the range of observations and the steepness is poorly defined (Figure 6.10.1). Therefore, the hockey stick recruitment curve was chosen as being most appropriate. The median value of the bootstrap estimates was 0.3. This was chosen as the target for advice recognizing the considerable amount of uncertainty around the estimate (see ICES, 2010, Section 11).

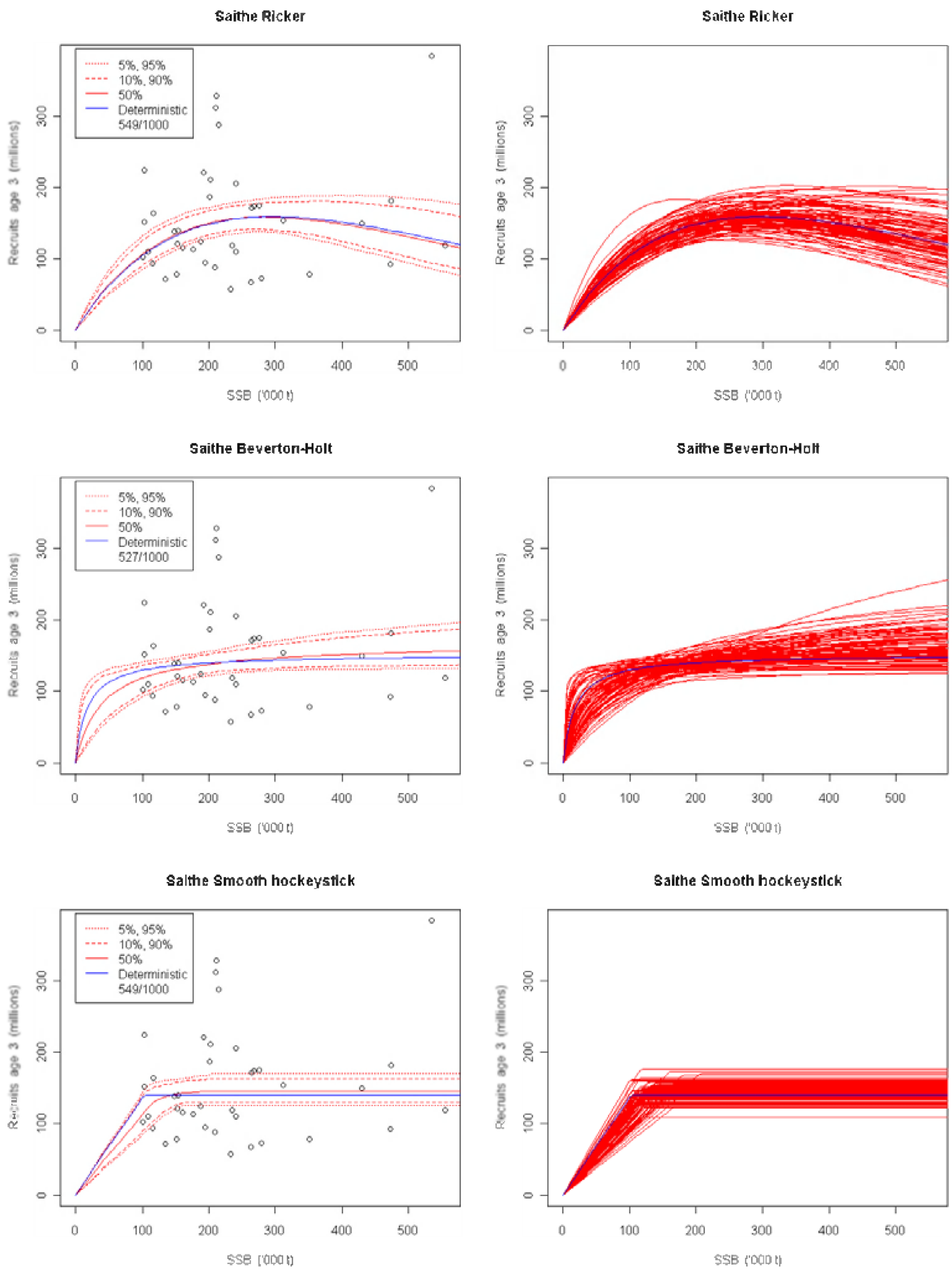

Figure 6.10.1. North Sea Saithe. Figure 1 (a) Ricker, (b) Beverton–Holt and (c) smooth hockey stick curves fitted to the North Sea saithe stock and recruitment curves. The 95th, 90th, median, 10th and 5th percentiles derived from MCMC resampling are illustrated in red, the deterministic estimates in blue.

A revised maturity ogive can give different results in these analyses. A revised maturity index should be considered for the next benchmark of the stock.

6.11 Recommendations on the procedure for assessment updates and further work

The use of cpue indexes as tuning values for the year classes that are covered by surveys should be avoided.

WKBENCH recommends the WGNSSK to use the "benchmark assessment" as basis for advice in the incoming years, until new methodology /input data is benchmarked.

An acoustic index that can cover the spawning–stock of saithe should be developed in parallel with the Norwegian part of the IBTS Q1 survey.

6.12 Implications for management (plans)

None identified.

6.13 References

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7 Data problems relevant to data collection programmes

STOCK	DATA PROBLEM	HOW TO BE ADDRESSED IN DCR	BY WHO
Stock name	Data problem identification	Description of data problem and recommend solution	Who should take care of the recommended solution and who should be notified on this data issue (e.g. a specific ICES member country, RCMs, PGCCDBS)
Northeast Arctic haddock	Termination of Norwegian port sampling of commercial catches in mid-2009		Norway, PGCCDBS
North Sea saithe and haddock	Lack of recent stomach sampling – important in order to identify multispecies interactions (growth, predation)	Include stomach sampling in DCR	EU, Norway, PGCCBDS
Southern Horse Mackerel			

Annex 1: List of participants

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Annex 2: Agenda

WKBENCH Timetable 24–31 January 2011								Week 4
	Monday[1]	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday
	24	25	26	27	28	29	30	31
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
9:00		NS Haddock: Presentation + discussion	Working session: data and methods scrutiny	Working session: data and methods scrutiny	Working session: data and methods scrutiny	Report writing	Report writing	Haddock in Subareas I and II: report and SA (plenary)
10:00	Opening (Jim and Bjarte)							
	Coffe break (15 min)	Coffee break	Coffee break	Coffee break	Coffee break	Coffee break	Coffee break	Coffee
11:00	Herring in Va: Presentation + discussion	SN Saithe: Presentation + discussion	Working session: data and methods scrutiny	Working session: data and methods scrutiny	Working session: data and methods scrutiny	Report writing	Report writing	Horse mackerel in Division IXa: report and SA (plenary)
12:00								
	Lunch	Lunch	Lunch	Lunch	Lunch	Lunch	Lunch	Lunch
13:00								

[1] Day 1 and 2 stock presentations: 1. Basic biology, ecology, and fisheries information, 2. Data availability and issues, and 3. Assessment methods, results, and issues. (around 1 hour). Discussion with external experts around 0.5 to 1 hour.

WKBENCH Timetable 24–31 January 2011								Week 4
14:00	Haddock in Subareas I and II: Presentation + discussion	Sum up from (Jim)	Overview on progress from each stock leader on assessment	Overview on progress from each stock leader on assessment and forecast	Overview on progress: assessment forecast and ref. points	Report writing	Report writing	Herring in Division Va: report and SA (plenary)
		Working session: data and methods scrutiny	Working session: data and methods scrutiny		Sum up from (Jim)			Saithe in Subarea Iv and VI and Division IIIa: report and SA (plenary)
15:00	Horse mackerel in Division IXa				Working session and report writing		Plenary: report general section	
	Coffee break (15 min)	Coffee break	Coffee break	Coffee break	Coffee break	Coffee break	Coffee break	Recommendations and closure (plenary)
16:00	Horse mackerel in Division IXa (cont.)	Working session: data and methods scrutiny	Working session: data and methods scrutiny	Working session: data and methods scrutiny	Working session and report writing	Report writing	Haddock in Subarea IV and Division IIIa report and SA (plenary)	Coffee
17:00	Sum up from (Jim)							

Annex 3: WKBENCH Terms of Reference

2010/2/ACOM39 The **Benchmark Workshop on Saithe, Haddock, Herring and Horse Mackerel Stocks** (WKBENCH) chaired by External Chair Jim Berkson, USA, ICES coordinator Bjarte Bogstad, Norway and two invited external experts George Tserpes, Greece and Jim Ianelli, USA, will meet in Lisbon (Portugal), 24–31 January 2011 to:

a) Evaluate the appropriateness of data and methods to determine stock status and investigate methods for short-term outlook taking agreed or proposed management plans into account for the stocks listed in the text table below. The evaluation shall include consideration of fishery-dependent, fishery independent, environmental, multi-species and life-history data.

b) Agree and document the preferred method for evaluating stock status and (where applicable) short term forecast and update the stock annex as appropriate.

c) If no new analytical assessment method can be agreed, then an alternative method (the former method, or a trends based assessment) should be put forward.

d) Evaluate the possible implications for biological reference points, when new standard analyses methods are proposed. Propose new MSY reference points taking into account the WKFRAME and ADG-MSY results.

e) Develop recommendations for future improving of the assessment methodology and data collection.

f) As part of the evaluation:

i) Conduct a one day data compilation workshop. Stakeholders shall be invited to contribute data (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality. As part of the data compilation workshop consider the quality of data including discard and estimates of misreporting of landings;

ii) Consider the possible inclusion of environmental drivers for stock dynamics in the assessments and outlook;

iii) Evaluate the role of stock identity and migration;

iv) Evaluate the role of multispecies interactions on the assessments.

Stock	Assessment Lead
Saithe in Subarea IV (North Sea) Division IIIa West (Skagerrak) and Subarea VI (West of Scotland and Rockall)	Irene Huse
Haddock in Subarea IV (North Sea) and Division IIIa	Coby Needle
Haddock in Subareas I and II (Northeast Arctic)	Alexey Russkikh
Herring in Division Va (Icelandic summer-spawners)	Asta Gudmundsdóttir
Horse mackerel (*Trachurus trachurus*) in Division IXa (Southern stock)	Alberto Murta

The Benchmark Workshop will report by 14 February 2011 for the attention of ACOM.

Annex 4: Recommendations

Recommendation	For follow up by
1. WKBENCH encountered some difficulties in addressing its terms of reference. Generally the level of participation among participants to comment on each of the five stocks was excellent. However, dealing with five stocks in the course of an 8-day meeting was challenging. The five stocks considered at WKBENCH were a rather odd collection; two pelagic and three demersal stocks from four species from widely different geographical areas. The assessment issues to be looked at were also quite different. This set-up does not give much synergy effect from benchmarking the stocks together. WKBENCH recommends that fewer/more similar stocks are covered at future benchmark meetings. 2. A significant portion of the preparation required for a successful benchmark was not completed prior to the WKBENCH. This included data analyses, running assessment models, and preparing tables and plots of the results. This greatly delayed the progress of the WKBENCH during the course of the week. It should be recognized by all stock assessment teams that due to the extremely limited time available to conduct new work during a benchmark, the majority of work should be completed prior to the meeting. The primary purpose of a benchmark meeting is to review current work, not to complete a new assessment.	ACOM
3. There were some shortcomings in cpue tuning-series (particularly for saithe). WKBENCH recommends that statistical methods such as use of general linear models and related methods be used to standardize cpue time-series used in assessments.	WGNSSK

Recommendation	For follow up by
Assessment methods 4. The workshop discussed a range of issues around analytical assessment methods. Key issues included: 1) the relative advantages and disadvantages of "XSA" type methods versus "statistical catch-at-age" methods; 2) concern over retrospective patterns, 3) the tendency for situations when large numbers of iterations in XSA for convergence generally leads to larger stock sizes, 4) robustness of assessment methods to poor or missing data; and 5) the need to evaluate uncertainty in model results (e.g. using classical variance estimates, non-parametric bootstrap, or MCMC protocols). To the extent that time and resources permitted, the implications of some of these issues for specific assessments were investigated in the workshop but much more work needs to be done. The majority of this work can and should be completed prior to the benchmark, allowing for the time to be spent presenting and discussing results and implications. WKBENCH notes and applauds moves to develop and apply new assessment methods to some stocks (such as Coleraine for Icelandic herring, SAM for NS haddock, and the model developed for horse mackerel). The advantages of these methods are that data quality can be explicitly included and results provide explicit estimates of uncertainty in assessments and model-based projections. WKBENCH recommends continued application of such alternative models and where practical, conduct parallel assessments.	Assessment WGs

Annex 5: Stock Annexes

Stock Annex: Icelandic summer-spawning herring

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Icelandic summer-spawning herring (Her-Va)
Working Group	NWWG
Date	31.01.2011; during WKBENCH
Revised by	Guðmundur J. Óskarsson and Ásta Guðmundsdóttir

A. General

A.1. Stock definition

The Icelandic summer-spawning herring is constrained to Icelandic waters throughout its lifespan. Results from various researches including, tagging experiments around middle of last century, studies on larval transport, and studies on migration pattern and distribution, all suggest that the stock is local to Icelandic waters. Until 2010, no specific genetic studies have taken place to distinct the stock from the two other herring stocks around Iceland (Icelandic spring-spawning herring and Norwegian spring-spawning herring). However, a project (HERMIX) with that as one of the objectives started in 2009 and is ongoing in cooperation with several institutes in Iceland, Faroe Island, Denmark, and Norway. These three stocks are distinguished on the basis of their spawning time and spawning area, as presented by their names. In practice, the maturity stage of catch samples is used to distinguish Her-Va from the other stocks in a mixed fishery.

A.2. Fishery

Since at least the year 2000, the herring fishery has been conducted by big vessels that in most cases have onboard both purse-seines and mid-water-trawls that are used as needed in the fishery. Usually, most of the catch is taken by purse-seine (ICES, 2008). Bycatch in the herring fishery is normally insignificant as the fishing season is during the over-wintering period when the herring is in large dense schools.

A2.1. Prior to 1980

The catches of Icelandic summer-spawning herring increased rapidly in the early 1960s due to the development of the purse-seine fishery off the south coast of Iceland. This resulted in a rapidly increasing exploitation rate until the stock collapsed in the late 1960s. A fishing ban was enforced during 1972–1975. The annual catches have since increased gradually to over 100 000 t.

A2.2. 1980 onwards

Until the autumn 1990, the herring fishery took place during the last three months of the calendar year. During 1990–2008 the autumn fishery continued until January or early February of the following year, and has started in September/October since 1994. In 2003 the season was further extended to the end of April and in the summers of 2002 and 2003 an experimental fishery for spawning herring with a catch of about 5000 t each year was conducted at the south coast.

In the beginning of this period, the fleet consisted of multi-purpose vessels, mostly under 300 GRT, operating with purse-seines and driftnets. In recent 20 years, larger vessels (up to 1500 GRT) have been gradually taking over the fishery, and today they represent the whole herring fishing fleet. Consequently, the number of vessels participating in the fishery has shown decreasing trend in the 2000s from around 30 down to 15 in 2010. Simultaneously, the average size of the vessels has increased. These vessels are combination of purse-seiners and pelagic trawlers operating in the herring (Her-Va and Norwegian spring-spawners), capelin (*Mallotus villosus*), blue whiting (*Micromesistius poutassou*) fisheries, and in recent years also the NE-Atlantic mackerel (*Scombrus scombrus*) and Mueller's pearlside (*Maurolicus muelleri*) fisheries.

Since the 1997/1998 fishing season to around 2007/2008, there was a fishery for Her-Va both west and east off Iceland, with gradual increase off the west coast. This west coast fishery of the stock had until then hardly taken place since the middle of the 1960s (Jakobsson, 1980; Óskarsson *et al*., 2009a). In the most recent years (2006 to 2010), most of the catches have been taken in a small area off the west coast in the southern part of the bay Breiðafjörður (Figure 1; e.g. ICES, 2008; 2009). As a consequence, it is nearly exclusive purse-seine fisheries, while the pelagic trawl fisheries, first introduced in 1997/1998, contributed earlier to around 20–60% of the catches for several years.

A2.3. Fishery regulations

The fishery of the summer-spawning herring is currently regulated by regulations set by the Icelandic Ministry of Fisheries in 2006 (no. 770, 8. September 2006). According to it, fishery of juveniles herring (27 cm and smaller) is prohibited and to prevent such a fishery, area closures are enforced.

The fishery can take place from 1st September to 31st May each fishing season (1st September–31st August) in nets, purse-seines and mid-water trawls. The mid-water trawling is only allowed outside of the 12 nautical miles zones with some additional areal restrictions. Use of sorting grids in the mid-water trawls can be required in some areas, if necessary to avoid bycatch.

If nets are used in the herring fishery, the minimum mesh size (stretched) is 63 mm.

The annual total allowable catch is decided by the Ministry of Fisheries. Since 1985, the decision has more or less been based on the advices given by the Marine Research Institute, with very small discrepancy (ICES, 2010).

A.3. Ecosystem aspects

A3.1. Geographic location and timing of spawning

The spawning of the stock takes place in July off the SE, S and SW coast (Jakobsson and Stefansson, 1999) with the maximum activity around middle of July (Óskarsson and Taggart, 2009). The nursery grounds are mainly in coastal areas off the NW and N coast, but occasionally also in coastal areas off the E, SE, and SW and W Iceland (Gudmundsdottir *et al*., 2007). The location of the overwintering of the mature and fishable stock has varied during the last 30 years (Óskarsson *et al*., 2009a). Prior to 1998 it was mainly off the SE and E Iceland but from 1998 to 2006, the overwintering took place both off the east and west coast, with increasing proportion being in the western part. Since then (winters 2006/2007 to 2009/2010), most of the stock has been located in high density in coastal waters in northern part of Breidafjördur in western Iceland.

A3.2. Diet

The variation in the diet composition of the Icelandic summer-spawning herring is poorly known due to limited examinations. The main prey is probably Calanoids (e.g. *Calanus finmarchicus*) but other zooplankton groups and species, and fish eggs and larvae could also be significant part of the diet according to small preliminary research made by MRI on stomach contents of herring in a relatively restricted area SW off Iceland in 2008 (Óskarsson *et al.*, 2008).

A3.3. Predators

Adult herring is food resource for various animals in Icelandic waters according to various researches. The animals include mink whale (*Balaenoptera acutorostrata*), humpback whale (*Megaptera novaeangliae*), several sea bird species, cod (*Gadus morhua*) and pollack (*Pollachius virens*), but the annual consumption of herring by the different predators is relatively unknown. An increased predation of herring by cod has been observed in stomach analyses in the Icelandic groundfish survey since the *Ichthyophonus* outbreak started in the herring stock in November 2008, even if it has not been quantified.

A3.4. Diseases and parasites

In November 2008, the Marine Research Institute in Iceland got the information from the commercial fleet fishing on Her-Va that the stock was seemingly infected by some parasite or had some disease. Within few days it was identified as a major outbreak of the protista parasite *Ichthyophonus hoferi*. A thorough examination of the fishable stock during the winter 2008/2009 indicated that 32% of the stock was infected (Oskarsson *et al.*, 2009; Oskarsson and Pálsson, 2009) and 43% during the winter 2009/2010 (Óskarsson *et al.*, 2010). During the period from 1991 to 2000, the prevalence of *Ichthyophonus* infection in the stock was determined inter-annually but only a minor infection was observed during that period, or in around 1 per every 1000 individuals examined. The source of the infection outbreak is unknown (Oskarsson and Pálsson, 2009) but the infection is transmitted with resting spores of the parasite that must be eaten in one way or another by the herring since they need an acid environment to be activated (Spanggard *et al.*, 1995). Since the stock is not feeding during the overwintering period, the stock get the infection on the feeding grounds, which is also supported by the development of the infection in the stock as seen from an extensive sampling of the stock throughout the winters (Óskarsson *et al.*, 2009; 2010). In the autumn 2010, the infection rate was still high in the stock according to preliminary figures or 37% (Óskarsson and Pálsson, 2011).

In juvenile herring the prevalence of infection was also high in most of the distribution area during both the winters and the infection reached over a very extensive area, or all coastal areas around Iceland except for the east coast. As this infection is believed to be fatal to all infected herring (Sinderman, 1958), this outbreak has had huge effects on the size of the herring stock as well as on recruitment into the fishing and spawning stock.

A thorough summation of results covering the *Ichthyophonus* infection in the herring stock and its relevance to the analytical assessment of the stock is given by Óskarsson and Pálsson (2011).

A3.5. Recruitment variation of the stock

The recruitment variation of the stock has been examined in two papers, first by Jakobsson *et al*. (1993) and then more thoroughly by Óskarsson and Taggart (2010). The main conclusions from Jakobsson *et al*. (1993) by analysing the period from 1947 to 1991 was that the stock–recruitment relationship was most adequately fitted with a Cushing model and the recruitment increased strictly with increasing stock size with no signs of decreased recruitment at high stock level (i.e. a dome-shaped relation). Furthermore, environmental changes, and particularly the sea temperature affects the recruitment even if it was noted that two of the four largest year classes were produced in periods considered to be warm and two in periods considered to be cold.

Óskarsson and Taggart (2010) examined the recruitment variation of the stock during 1963–1999 with generalized linear models (GLM) with special focus on the impact of the maternal effects as well as various ecological and environmental factors. The best model explained 64% of the variation in the recruitment of the stock and incorporates total egg production constrained to the repeat spawners (40%), the NAO winter-index (18%), and ocean temperature (6%). The latter two represent the winter and spring period subsequent to year-class formation. Contribution of recruit spawners to the total egg production were of no significance in explaining variation in the recruitment despite the fact that they could contribute to as much as 55% of the egg production. The spawning potential of the repeat spawners was suggested to replace total SSB when determining recruitment potential in the stock assessment, which in addition to the incorporation of oceanographic factors, was considered to provide a more precautionary and risk-adverse approach. The ocean temperature off northern Iceland (Siglunes) was found to have a marginal effect on the recruitment of the stock; consistent with the results of Jakobsson *et al*. (1993) where average recruitment was reduced during the relatively cold period of 1965 through 1971. The primary nursery grounds for the stock are off northern Iceland (Figure 1), though larvae and juveniles are also found elsewhere (Gudmundsdóttir *et al*., 2007). They concluded that oceanographic variability, as reflected in the positive effects of lagged winter NAO index and ocean temperature indices, influences recruitment through the survival of larvae during their first winter–spring. The conclusion is substantiated by the positive relation between age-3 recruitment and larval and post-larval abundance indices at age-1 and -2 in the ISS stock that indicate that the year-class strength is determined during the first year of larval development (Gudmundsdóttir *et al*., 2007).

Similar to Jakobsson *et al*. (1993), Óskarsson and Taggart (2010) observed that the recruitment of the stock increased continuously with increases in total egg production of repeat spawners and there is no indication of density-dependence even as SSB and the egg production increased above historical estimates. In the end they conclude that it is more appropriate to use size structured estimates of fecundity as well a spawning experience (e.g. egg production of repeat spawners) in place of simply total egg production and SSB, especially, from a management perspective, at low SSB and when the size structure is truncated, and to do so prior to assessing potential oceanographic influences. Doing so should result in more accurate short-term predictions of the recruitment. Their best generalized linear model (GLM) explained 64% of the variation in the recruitment variation during 1963 to 1998 and incorporated total egg production constrained to the repeat spawners (40%), the North Atlantic Oscillation (NAO) winter-index (18%), and ocean temperature (6%).

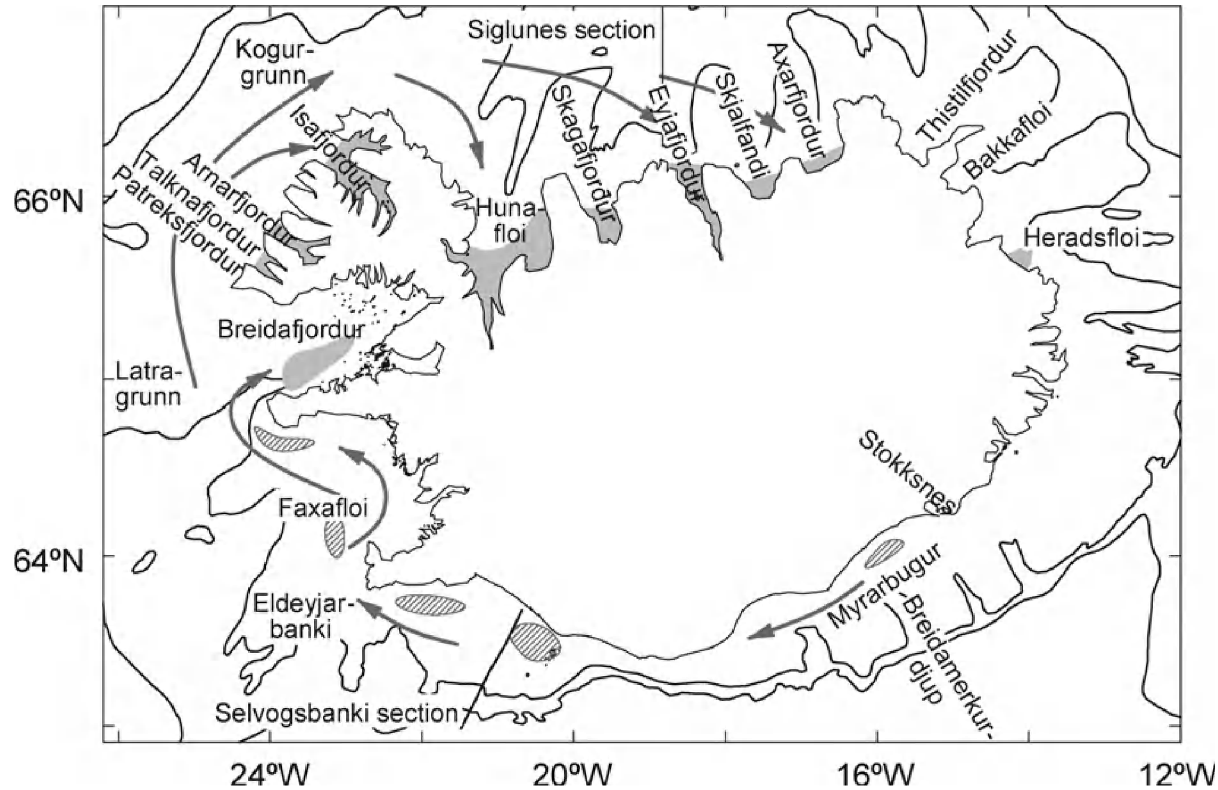

Figure 1. The names of some fjords and banks around Iceland referred to in the text. Grey shading indicates the nursery areas, and stripes the spawning areas, and the arrows show the directions of larval drift (adopted from Gudmundsdóttir *et al.*, 2007).

B. Data

B.1. Commercial catch

B1.1. Landings

Information about landings of the fishery fleet is collected by the Icelandic Directorate of Fisheries. They have access to both landings in the harbours (the official landing) and the registered catch in the digital logbook kept by all the vessels. The logbooks keep information about timing (day and time), location (latitude and longitude), fishing gear, catch size, and species composition in the catch of each fishing operation for each vessel.

Biological samples from the catch are taken at sea by the fishermen or in the harbours by people from MRI and/or inspectors from the Directorate of Fisheries and then analysed by MRI (record at least the fish length, weight, age (from scales), sex, maturation, and weight of sexual organs). The information from the samples is then used along with the total landing data and the logbook data to estimate the composition of the total landings. It includes estimating **Caton** (catch-in-weight), **Canum** (catch-at-age-in numbers), **Weca** (weight-at-age-in-the-catch), and length composition in the catch.

The annual estimations of the composition of the total landings (e.g. the catch-at-age matrix) are based on dividing the annual landings into cells according to the fishing gear, geographical location and month of fishing. The number of cells used in the calculation each year depends on number of factors, including the spatial and temporal distribution of the fishery, the fishing gear used and intensity of biological sampling, and has ranged from three to ten during the years 2004 to 2010. The number of weight-at-length relationships and length-at-age relationships applied differs between years and is in the range of 1–2 in both cases. Since 1990 to present, all available length measurements are used for the estimations in the cells, while length of aged fish was only used in earlier estimations. Length measurements done by inspectors of the Directorate of Fisheries are though usually omitted as inspectors tend to focus on catches that are suspected to consist of small herring and give therefore often biased length distributions.

A planed re-aging of herring from the catch samples in the fishing seasons 1994/1995 through 1997/1998 was not finished in February 2010 and because of limited manpower at the Marine Research Institute it will be postponed further. When the re-aging is accomplished the number-at-age in the catch will be re-estimated. Previous work suggests though that only small changes can be expected.

B1.2. Discards

Discards are illegal in Icelandic waters. Normally, discards are considered to be insignificant in the fishery of Icelandic summer-spawning herring. There are few exceptions in the past 35 years where discards were estimated to be significant (1990–1995; ICES, 2008). These exceptions are related to large year classes being entering the fishery and juveniles have been numerous in the catch. Surveillance by inspectors from the Directorate of Fisheries during each fishing season is considered adequate in verifying if a discard is ongoing.

B.2. Biological

B.2.1. Weight-at-age of the stock

The weight-at-age in the stock is estimated from the commercial catch samples combined over the whole fishing area. Since the fishery takes place in the autumns and the winters (around September through January), the weight-at-age represents that period.

B.2.2. Natural mortality, M

Natural mortality is assumed to be constant, M=0.1, for the whole range of ages and years. There are no direct estimates of M but the estimate of M=0.1 has been evaluated numerically by Jakobsson *et al.* (1993). They concluded, through comparison of acoustics- and VPA based stock size estimations that the assessed level of M ranged from 0.1 to 0.15. Because of the *Ichthyophonus* infection in the stock, a higher M has been set for the year 2009 (M=0.1+0.39=0.49), 2010 (age dependent, see Table B.2.2.1), and 2011 (M=0.1+0.41=0.51), which reflects the prevalence of the infection and the stock number (see above in A.3.4.; Óskarsson and Pálsson, 2011). It has been considered appropriate to add $M_{infection}$ to the fixed natural mortality of the stock, M=0.1, so that M used in the assessment is consistent with the observed infection levels. For sensitivity, alternative values for M will be conducted and include scenarios where we assume the infection rate becomes unimportant (say in about five years) and M returns to the base rates for projection purposes. For future assessments, the prevalence of infection will need to be monitored.

Table B.2.2.1. The total acoustic estimate (Ntotal) of Icelandic summer-spawning herring in the winter 2009/2010 for age groups 3 to 11, the number of infected herring (Ninfected) and estimates of prevalence of *Ichthyophonus* infection (Pinfected) of the whole stock when weighed with the herring quantity of the different locations, and finally the corresponding estimate of natural mortality caused by the infection ($M_{infected} = -(\log_2(N_{total} - N_{infected}) - \log_2(N_{total}))$).

Age (years)	Acoustic estimate Ntotal (´106)	Ninfected (´106)	Weighed Pinfected %)	Minfected	M in assessment
3	337.3	160.2	47.5	0.64	0.74
4	525.4	248.6	47.3	0.64	0.74
5	466.9	207.8	44.5	0.59	0.69
6	273.6	113.3	41.4	0.53	0.63
7	335.3	132.1	39.4	0.50	0.6
8	156.5	60.1	38.4	0.48	0.58
9	140.7	52.6	37.4	0.47	0.57
10	149.3	54.6	36.6	0.46	0.56
11	36.9	13.2	35.7	0.44	0.54
Total	2421.8	1042.6	43.0	0.56	0.66

B.2.3. Age-at-maturity

The age-at-maturity of the Icelandic summer-spawning stock was until 2006 estimated annually from the commercial catches alone (ICES, 2008). Such estimates are a subject to various source of errors including that the year classes that are becoming mature might have spatial distribution that is linked to if they are mature or not. For example, mature individuals of a given year class would be more likely to join the older fully mature age groups than the immature individuals. It indicates also that the estimate of age-at-maturity from the catch samples can be incorrect because the most important age groups are poorly representative in the commercial catches. That was the main reason for the decision taken in 2006 that the maturity-at-age from 2006 and onwards was assumed to be constant (Óskarsson and Guðmundsdóttir, 2006), which was based on analyses of catch and survey data and is as follows:

Age	<3	3	4	5+
Proportion mature	0.00	0.20	0.85	1.00

Analyses and comparison of estimates from commercial catch data, survey data and estimates based on fish scale growth layers indicate, however, that the maturity ogive of the non-fishable part of each age class in the stock is equivalent to the fishable part for the years 1962 to 2002 (Óskarsson and Guðmundsdóttir, 2011). It gives support to the age-at-maturity values used in the assessment of the stock until 2006, originating from the traditional method in estimating the age-at-maturity from simply commercial catch samples. However, since the spatial distribution of the stock is completely different in recent years, where most of the fishable stock is overwintering in a small area off the west coast (Óskarsson *et al.*, 2009a), compared to the period which the analyses cover, using the commercial catch samples to estimate the age-at-maturity cannot be recommended for the most recent years. Thus, to get reliable estimates of age-at-maturity that is independent of the stock distribution, Óskarsson and Guðmundsdóttir, (2011) recommend a re-establishment of determination of age of first spawning from the fish scales growth layer, which took place during the period 1964 to 1992. Until then and following analyses of those data, the maturity ogive of the stock in the assessment should be fixed as shown in the table above.

B.2.4. Ageing of the stock

The age of the stock is determined from the fish scales and the number of annual winter-rings +1 gives the age in years.

B.2.5. Fecundity of the stock

The fecundity variation of the Icelandic summer-spawning herring has been estimated in two papers, by Jakobsson *et al*. (1969) and later more thoroughly by Óskarsson and Taggart (2006). The latter paper indicates that the fecundity at length relation to be: Fecundity [$\times 10^3$] = 15.9 × Length [cm] - 382.2. It indicates that herring at average length in the catch (32 cm) spawns around 127 thousands eggs in a season and release all the eggs at once. Furthermore, Fulton's condition factor K (=$100 \times \text{Weight} \times \text{Length}^{-3}$) explains a trivial (1.5%) but significant amount of the residual variation in potential fecundity of the stock, and appears to have the greatest effect among smaller length classes.

B.3. Surveys

A. Autumn/winter survey (IS-Her-Aco-Q4/Q1)

Currently, one survey is available and applied as a tuning-series for the analytical assessment of the Icelandic summer-spawning herring stock. It is an acoustic research survey, which has been ongoing annually since 1974 except for the winters 1976/1977, 1982/1983, 1986/1987, and 1994/1995. These surveys have been conducted in October–December and/or January. The survey area varies spatially as the survey is focused on the adult and incoming year classes. The surveyed area is decided on the basis of all available information on the distribution of the stock in previous and the current year, which include information from the fishery. Thus, the survey area varies spatially as the survey is focused on the adult and incoming year classes. As normally practiced in acoustic surveys, trawl samples are used to get information about the schools species and length composition. Detailed information and the results of the surveys are given inter-annually in internal reports at MRI, and later summarized in the assessment reports.

B. Spawning survey (IS-Her-Aco-Q3)

In the summer 2009 and 2010, acoustic surveys were conducted on the spawning grounds of the Icelandic summer-spawning herring. The surveys, which took place in a ten day period at the beginning of July just before the maximum of the spawning activity around the middle of July (Óskarsson and Taggart, 2009), covered all the known spawning grounds of the stock. The main purpose of these surveys was to get estimates of the prevalence of *Ichtyhophonus* infection in the stock, but also to get acoustic abundance estimates of the stock. The working group involved in the assessment of the stock considers that the results of this acoustic survey can be used as a tuning-series within an analytical assessment when and if the time-series becomes sufficiently long. The main advantage of this survey above the traditional autumn/winter survey (above) is that its spatial and temporal coverage is consistent and fixed between years. Thus, hopefully this survey will continue for some years, so the quality and reliability can be verified including how well it is following the stock trend according to the assessment and the autumn/winter survey.

C. Juvenile survey (IS-Her-Aco-Juv-Q4/Q1)

In addition to the acoustic survey aimed at the fishable part of the stock, there have been occasionally acoustic surveys off the NW, N, and NE coast of Iceland aimed at estimating the year-class strength of the juveniles. This survey was undertaken in November to December most years during 1980 to 2003, but had not taken place since 2003, until it was resurrected in January 2009. It was again undertaken in the autumns of 2009 and 2010. The results of these measurements have normally not been used in the assessment or stock projection directly, even if the year-class indices at age-1 herring derived from the survey showed a significant relationship to recruitment of the stock at age 3 (Gudmundsdóttir *et al.*, 2007). Because of this relationship, and to utilize the information from this survey, the survey abundance index of age 1 herring will be used to predict the number at age 3 for the stock in the short-term projections from the assessment 2011 and on, given that survey information are available.

B.4. Commercial cpue

The commercial cpue data is not considered relevant to the assessment because of the nature of the fishery and due to the continuous development of the vessels and the equipment used in the fishery.

B.5. Other relevant data

None.

C. Assessment: data and method

Model: Age structured

Software: NFT-ADAPT (VPA/ADAPT version 3.0.3 NOAA Fisheries Toolbox)

Alternatives evaluated and available for future comparisons include a new version of TSA (older version, see Gudmundsson, 1994). Also, a statistical catch-at-age was presented (Coleraine: Hilborn *et al.*, 2003) and it was consistent with other models and may be useful for presenting and comparing uncertainty estimates in the future.

The NFT-ADAPT has been used for point estimate and final assessment of the stock since 2005 to 2010.

Model Options: The model options differ slightly between years, but are given in tables or text in the WG assessment reports (e.g. ICES, 2008).

The youngest age groups in the assessment runs from catch data is age 3 and oldest age 13+.

The data used from the tuning-series (IS-Her-Aco-Q4/Q1) are age groups 4–11.

Years used are 1987 onwards.

The IMSL parameters used are the defaults except the following three:

Scaled gradient tolerance of 6.055454E-05

Scaled step tolerance of 1.0E-18

Relative function tolerance of 1.0E-18

Survey weighting factors were 1.0 for each age except:

In 1989 weighting factors used as 0.01 for 8 years and older

In 1990 and 1991 weighting factors used as 0.01 for 9 years and older

In 1992 weighting factors used as 0.01 for 10 years and older

In 1993 weighting factor used as 0.01 for age 11 year

In 2004 weighting factor used as 0.01 for age 10 year and older

In 2005 and 2007 weighting factor used as 0.01 for age 11

Earliest age in Terminal Year+1: Geometric mean over 1987–2006

Calculation Method Full-F in Terminal Year: Classic Method

F at oldest age in Terminal Year: Use F at oldest true age calculation method

F at oldest true age calculation method: Use arithmetic average

F oldest age calculation method: Use ages 8–11

Plus group calculation: Forward

F-plus group ration: 1 for all years.

Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1947–last data year	2–15+	Yes
Canum	Catch-at-age in numbers	1947–last data year	2–15+	Yes
Weca	Weight-at-age in the commercial catch	1947–last data year	2–15+	Yes
West	Weight-at-age of the stock .	1947–last data year	2–15+	Yes
Mprop	Proportion of natural mortality before spawning	1947–last data year	2–15+	No-set to 0.5 for all ages in all years
Fprop	Proportion of fishing mortality before spawning	1947–last data year	2–15+	No-set to 0 for all ages in all years
Matprop	Proportion mature at age	1947–last data year	2–15+	No-since 2005 set 0.2 for age-3 and 0.85 for age-4
Natmor	Natural mortality	1947–last data year	2–15+	No-set to 0.1 for all ages in all years*

***Because of the *Ichthyophons* outbreak in the stock, M that accounted for the mortality caused by the infection (0.39) was added to 0.1 for the year 2009, giving M=0.49 (see Section B.2.2.).**

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1	IS-Her-Aco-Q4/Q1	1974–last data year	2–15+ (age 3–10 used in tuning)
Tuning fleet 2			
Tuning fleet 3			
….			

D. Short-term projection

Model used: Age structured

Software used: An Excel spreadsheet prepared in MRI, which has been compared to results from a Fortran script used at MRI for years for herring and other species, and they have giving identical results.

Initial stock size: Taken from NFT-Adapt in most recent years. The number of the youngest age groups (age 3) is determined as described below (in *Stock recruitment model used*).

If and when the stock is found to be infected by *Ichthyophonus hoferi* in the autumn of the most recent year in the assessment, the number-at-age for that year should be decreased according to the estimation of the infection prevalence before doing the projection (ICES, WKBENCH 2011). The reason is that all infected fish at that time is considered to die because of it in the spring, or before the spawning occur and can therefore be considered to be ineffective.

Maturity: The same ogive as in the assessment for the year 2006 to present.

Natural mortality: Set to 0.1 for all ages in all years.

F and M before spawning: Set to 0 for F and to 0.5 for M.

Weight-at-age in the stock: The weight-at-age (W_{y+1}) is predicted from the mean weight of the same year class a year earlier (W_y) by applying the relationship obtained by Óskarsson (2011): $W_{y+1} - W_y = -0.2229 \times W_y + 90.27$.

Weight-at-age in the catch: Same as used for the stock

Exploitation pattern: Average of three last years for age-3 and 4, but set 1.0 for age-5+ (ICES, WKBENCH 2011).

Intermediate year assumptions: Not relevant

Uncertainty: Estimated by using *the upper and lower 95% confidence interval* of the estimation of the initial stock size as estimated with NFT-Adapt for the most recent year.

Stock–recruitment model used: Number at age 3 (N_{age3}, i.e. recruitment) is derived from index of number at age 1 in the Juvenile survey ($N_{age-1, survey}$; Survey C) two years earlier if available by applying the relationship obtained by Gudmundsdóttir *et al.* (2007):

$$\log N_{age\,2} = 0.390 \times \log N_{age-1, survey} + 5.34$$

Then N_{age3} is calculated as ln (N_{age2})–Z= ln (N_{age3}), where Z=M=0.1. If the survey index is not available, then the number at age 3 is equal to the geometrical mean over the whole assessment period, as done previously.

Procedures used for splitting projected catches: Not relevant

E. Medium-term projections

Medium-term projections have not been completed in recent assessments for this stock. The reason was reliance of the fishery on intermittent large year classes, and the fluid nature of the fishery and related assessment, which was considered to make the usefulness of medium-term projections questionable.

At WKBENCH (ICES, 2011), it was considered relevant to include also a medium-term projection (~five years) for the stock. The model used and input data are the same as described above for the short-term projection concerning, *initial stock size, maturity, F and M before spawning, weight-at-age in the stock and catch, and exploitation pattern*. The *number of recruits* (age-3) for each year is derived from the index of number at age 1 in the Juvenile survey if available (see above in short-term projections), but otherwise it is set equal to the geometric mean over the whole assessment period.

F. Long-term projections

It has not been completed in recent assessments.

G. Biological reference points

The Working Group has pointed out that managing this stock at an exploitation rate at or above $\mathbf{F}_{0.1}$ has been successful in the past, despite biased assessments (ICES, 2008). The Northern Pelagic and Blue Whiting Fisheries Working Group agreed in 1998 with the SGPAFM on using $\mathbf{F}_{pa}= \mathbf{F}_{0.1}= 0.22$, $\mathbf{B}_{pa}= \mathbf{B}_{lim} * e^{1.645\sigma}= 300\,000$ t where $\mathbf{B}_{lim}= 200\,000$ t. The Study Group on Precautionary Reference Points for Advice on Fishery Management met in February 2003 and concluded that it was not considered relevant to change the $\mathbf{B}_{lim}$ from 200 000 t.

The fishing mortality during 1990 to 2007 has been on the average 0.308 (ICES, 2008) or approximately 40% higher than the intended target of $F_{0.1}=0.22$. This is despite the fact that the managers have followed the scientific advice and restricted quotas with the aim of fishing at the intended target. During this time period the SSB has remained above B_{lim}. As there is an agreed management strategy that have been applied since the fishery was reopened after it collapsed in late 1960s, it is proposed to use $F_{0.1} = \mathbf{F}_{pa}$ as F_{target}.

H. Other issues

In November 2008, an *Ichthyophonus hoferi* infection was observed in the Icelandic summer-spawning herring (see above). This infection is believed to be lethal for herring the stock and will increase the M in the stock accordingly over this period, which must be quantified more accurately retrospectively as the time passes on. Another source of uncertainty regarding the infection relates to the period prior to the autumn 2008. Information given by fishermen in the autumn 2008, indicates that they had started to observe infected herring already in the winter 2007/2008. MRI did not have any information about it at that time and were not running a program to determine *Ichthyophonus* infection. Thus, the magnitude of infection prior to the autumn 2008 is unknown and thereby the additional natural mortality rate related to the infection.

H.1. Historical overview of previous assessment methods

The summer-spawning herring stock collapsed in late 1960s due to overfishing and environmental changes (Jakobsson *et al.*, 1993). The spawning stock has increased from about 10 thousand tonnes in 1972 to about 700 thousand tonnes around the middle of the 2000s.

During the recovery period, the assessments were based on acoustic surveys. These surveys, during the early and mid-1970s, were considered very uncertain. During late 1980s and early 1990s the assessment tool used was a homemade Adapt type of VPA. The stock was consistently overestimated during the late 1980s and the early 1990s. The difference between the acoustic values and those obtained from VPA was about 30%. The most likely cause of this error was considered to be the use of too low target strength (TS) values in the acoustic surveys (Jakobsson *et al.*, 1993). The TS value was raised about 30% or to similar value as used for other herring stocks in the NE Atlantic and the old acoustic values in the tuning file corrected. Until 2002 the homemade Adapt-type of VPA was used for the final assessment of the Icelandic summer-spawning herring stock. Assessment tools like XSA and AMCI were run along as well for some years. In 2003–2004, AMCI runs were accepted as the final assessment. NFT-Adapt, which was first applied in the 2004 assessment, has been the main assessment tool since 2005, even if it was first in 2008 accepted as the final assessment. Both TSA (Gudmundsson, 1994) and XSA have been run along with NFT-Adapt for comparison as alternative tools. In all these assessments, one sided retrospective pattern is seen, especially in the years 2002–2005, but it has diminished in the last years. The reasoning for this pattern is not known.

In 2005 there was a large uncertainty regarding the assessment of the stock and no assessment was considered reliable enough by ACFM. The same happened in the 2006 and 2007 assessments. Assessments use to be consistently biased in overestimating the spawning stock for some years. Several reasons have been mentioned to account for this overestimation problem, including: (1) discrepancies in the catch and survey; (2) a possible higher natural mortality because of much more widespread spatial distribution of the stock since 1997, which means more accessibility for predators; (3) higher mortality related to the fishery with the pelagic trawl, but from 1997 to 2006 around 20–60% of the catch was taken by pelagic trawl; (4) the reduction of the part of the stock that was acoustically measured east of Iceland.

Summary of data ranges used in recent assessments:

Data	2007 assessment	2008 assessment	2009 assessment	2010 assessment
Catch data	Years: 1986–(AY-1) Ages: 3–12+	Years: 1978–(AY-1) Ages: 3–12+	Years: 1978–(AY-1) Ages: 3–12+	Years: 1978–(AY-1) Ages: 3–12+
Survey: IS-Her-Aco-Q4/Q1	Years: 1986–(AY-1) Ages: 4–10	Years: 1986–(AY-1) Ages 4–10	Years: 1986–(AY-1) Ages 4–10	Years: 1986– (AY-1) Ages 4–10
Survey: B	Not used	Not used	Not used	Not used
Survey: C	Not used	Not used	Not used	Not used

AY=Assessment year.

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Stock Annex: Southern Horse Mackerel

Stock	Horse Mackerel in Division IXa (Southern horse mackerel)
Working Group:	WGANSA
Date:	30 January 2011
Revised by	Alberto Murta, Pablo Abaunza, Jim Ianelli (WKBENCH, 2011)

A. General

A.1. Stock definition

Stock units

For many years the Working Group has considered the horse mackerel in the northeast Atlantic as separated into three stocks: the North Sea, the Southern and the Western stocks (ICES, 1990; ICES 1991). Until the results from the EU project (HOMSIR, QLK5-Ct1999-01438), were available, the separation into stocks was based on the observed egg distributions and the temporal and spatial distribution of the fishery. The extremely strong 1982 year class appeared for the first time in the eastern part of the North Sea in 1987, during the third and mainly the fourth quarter. This year class was the basis for the start of the Norwegian horse mackerel fishery in the eastern part of North Sea during the third and mainly the fourth quarter. Since Western horse mackerel are assumed to have broadly similar migration patterns as NEA mackerel the Norwegian catches have been considered to be fish of western origin migrating to this area to feed. In addition, there is a fishery further south in the North Sea which is considered to be fish of North Sea origin. These views were supported by results from the mentioned EU project which was reviewed in ICES (2004) which also concluded to include Division VIIIc as part of the distribution area of the western horse mackerel stock (see also Abaunza *et al.*, 2008 for a comprehensive discussion of the results from the HOMSIR project). Horse mackerel off the west coast of the Iberian Peninsula have characteristics (morphometry, parasites, distribution and migratory circuit) that distinguish them from the rest of the samples collected in the northeast Atlantic. The border between southern and western horse mackerel stocks may therefore lie at the level of Cape Finisterre on the coasts of Galicia at 43°N, which is also the limit between Division VIIIc and IXa. The southern limit of the southern horse mackerel stock is not as evident due to the lack of samples from the north of Africa. Based on morphometric studies, Murta (2000) showed that the horse mackerel of the Portuguese coast was closer to the northwest coast of Morocco than to the Gulf of Cadiz in the south of Spain. However, the respective parasite composition suggests that the populations off the north of Africa and the west of the Iberian Peninsula are not part of a continuous stock.

Data from bottom-trawl surveys carried out throughout the Atlantic waters of the Iberian Peninsula during the autumn supported the existence of ontogenic migrations (Murta *et al.*, 2008). Analysis of the proportion of each year class in each area off the Portuguese coast indicated that most year classes recruit to the northwest area (close to Area 8) and then move progressively southwards. After six years of age, they return to the north.

Allocation of catches to stocks

Based on spatial and temporal distribution of the horse mackerel fishery, the catches were allocated to the three stocks as follows:

Western stock: Divisions IIa, IIIa (western part), Vb, IVa (third and fourth quarter), VIa, VIIa–c,e–k and VIIIa–e. Although it seems strange that only catches from western part of Division IIIa are allocated to this stock, the catches in the western part of this Division taken in the fourth quarter often are taken in neighbouring area of catches of western fish in Division IVa. The Working Group is not sure if catches in Divisions IIIa and IVa during the first two quarters are of western or North Sea origin. Usually this is a minor problem because the catches here during this period are small. However, in 2006 relatively larger catches were taken in this area during the first half of the year (3600 tons) and these catches were allocated to the North Sea stock. In 2007, 2100 tons were caught during the two first quarters in Divisions IVa and IIIa and were allocated to the North Sea stock.

North Sea stock: Divisions IIIa (eastern part), IVa (first and second quarter), IVb,c and VIId. The catches in 3–4 quarters of Divisions IVa and IIIa and 1–4 quarters from Divisions IVb,c and VIId were allocated to the North Sea stock. In 2007, some small catches were reported from Divisions IIIb (4 tons) and IIIc (21.5 tons) and were allocated to the North Sea stock.

Southern stock: Division IXa. All catches from these areas are allocated to the southern stock.

A.2. Fishery

The catches of horse mackerel in Division IXa (Subdivision IXa North, Subdivision IXa Central-North, Subdivision IXa Central-South and Subdivision IXa South) are allocated to the Southern horse mackerel stock. In the years before 2004 the catches from Subdivisions VIIIc West and VIIIc East, were also considered to belong to the southern horse mackerel stock.

The Spanish catches in Subdivision IXa South (Gulf of Cádiz) are available since 2002. They will not be included in the assessment data until they are available for all assessment years, to avoid a possible bias in the assessment results. On the other hand, the total catches from the Gulf of Cádiz are scarce and represent less than the 5% of the total catch. Therefore, their exclusion should not affect the reliability of the assessment.

The "Prestige" oil spill had also an effect on the fishery activities in the Spanish area (Division IXa North) in 2003. The Spanish catches increased markedly from 1991 until 1998, whereas the Portuguese catches were more stable, showing a smooth decreasing trend since the peak observed in 1992 (with a secondary peak in 1998).

Catches in Subdivisions IXa Central-North showed a decreasing trend whereas in Subdivision IXa North they increased markedly until 1998, and since then, the catches always have been higher than 7000 t. The catches from bottom trawlers are the majority in both countries. The rest of the catches are taken by purse seiners, especially in the Spanish area and by the artisanal fleet which is much more important in the Portuguese area.

Description of the Portuguese fishing fleets operating in Division IXa (data provided by the Portuguese Fisheries Directorate) and catch horse mackerel (only trawlers and purse seiners):

Gear	Length	Storage	Number of boats
Trawl	10-20	Freezer	2
Trawl	20-30	Freezer	7
Trawl	30-40	Freezer	5
Trawl	0-10	Other	259
Trawl	10-20	Other	68
Trawl	20-30	Other	60
Trawl	30-40	Other	29
Purse seine	0-10	Other	79
Purse seine	10-20	Other	103
Purse seine	20-30	Other	79

Note that horse mackerel is also caught in all polyvalent and most small scale fisheries.

Description of the Spanish fishing fleets operating in Division IXa including the Gulf of Cádiz (Southern stock) and Division VIIIc (Western stock) (Hernández, 2008):

Gear	Bottom trawl	Purse seine	Lgline Bottom	Lgline surface	Gillnet (big mesh size)	Gillnet	Other artisanal
Number	282	410	100	67	35	57	5379
Construction year (mean)	1996	1992	1990	1995	1990	1993	1982
Length	9–35 (22.9)	8–38 (21)	6–28 (15.1)	18–38 (27.6)	4–28.6 (14)	12–27 (17.2)	3–27 (7)
Power	66–800 (322.3)	24–1100 (302.5)	12–476 (150.3)	175–780 (418.9)	10–500 (141.8)	50–408 (164.9)	2–450 (32.6)
Tonnage	6–228 (81.2)	4–221 (56.6)	2–118 (26)	37–206 (116)	1–110 (23.7)	10–99 (27.6)	0.3–83 (3.5)

It is indicated the range and the arithmetic mean (in parenthesis). Data from official census (Hernández, 2008). Note that horse mackerel in the Spanish area is mainly fished by bottom trawlers and purse seiners.

The Spanish bottom-trawl fleet operating in ICES Divisions VIIIc (Western stock) and Subdivision IXa north (Southern stock), historically relatively homogeneous, has evolved in the last decade (approximately since 1995) to incorporate several new fishing strategies. A classification analysis for this fleet between the years 2002 and 2004 was made based on the species composition of the individual trips (Castro and Punzón, 2005). The analysis resulted in the identification of five catch profiles in the bottom otter trawl fleet: 1) targeting horse mackerel (>70% in landings), 2) targeting mackerel (>73% in landings); 3) targeting blue whiting (>40% in landings); 4) targeting demersal species; and 5) a mixed "métier". In the bottom pair trawl fleet the classification analysis showed two métiers: 1) targeting blue whiting; and 2) targeting hake. These results should help in obtaining standardized and more coherent cpue series from fishing fleets.

In the Portuguese area (Division IXa) Silva and Murta (2007) classified trawl fleet in two main types: those targeting fish and cephalopods species and those fishing crustaceans. Looking at the the fishing trips of those that catch fish and cephalopods, they identified three main clusters: 1) targeting horse mackerel, 2) targeting cephalopods, and 3) a poorly defined mixed cluster.

In 2005, the landings of blue whiting increased, probably due to increased market demand and consequent reduction of discards, resulting in a fourth specific cluster. The Crustacean trawl clusters do not follow the same pattern every year, depending on the abundance of the two main target crustacean species, which are Norway lobster and deep-water rose shrimp. There can be one target species by cluster or mixed clusters with different percentages of these two species.

A.3. Ecosystem aspects

Influence of environmental drivers on the stock dynamic

The southern horse mackerel stock is distributed along the western and southern Atlantic coasts of the Iberian Peninsula, which is an area subject to upwelling events. There is already evidence in the literature that horse mackerel recruitment is influenced by environmental drivers. The analysis carried out under the IN EX Fish project (Frid *et al.*, 2009) showed that non-linear combinations of NAO and upwelling indices were able to explain the strength of past recruitments. The rise and fall of this horse mackerel stock was probably caused by a complex interaction of different factors, both human and natural. However, it is very likely that changes in recruitment due to upwelling and NAO events may have played an important role.

Role of multispecies interactions

Horse mackerel is a schooling species and often close to the sea floor. Shelf attachment is a predominant distributional pattern for this stock. Therefore, horse mackerel is in relation with other fish and invertebrate species that are usually caught during the bottom-trawl surveys and share the same habitat. These species are mainly: snipefish, boarfish, blue whiting, European hake, sardine, blue jack mackerel, squid and pelagic crabs (Sousa *et al.*, 2006).

Trophic interactions

Young horse mackerel is a feeding resource consumed by several demersal, benthic and pelagic predators present in the distribution area like: hake, monkfish, John Dory, bluefin tuna and dolphins.

Horse mackerel is mainly a zooplanktivorous species. Diet variations with fish length and water depth are correlated: small fish are closely associated with coastal areas where they feed on copepods and decapod larvae (Cabral and Murta, 2002). However, they can prey on fish as they grow. They become *Ichthyophagous* when they reach large sizes.

B. Data

B.1. Commercial catch

Mean length-at-age and mean weight-at-age

Both mean length-at-age and mean weight-at-age values are calculated by applying the mean, weighted by the catch, over the mean weights or mean lengths-at-age obtained by Subdivision.

Taking in consideration that the spawning season is very long, from September to June, and that the whole length range of the species has commercial interest in the Iberian Peninsula, with probably very scarce discards, there is no special reason to consider that the mean weight in the catch is significantly different from the mean weight in the stock.

Catch in numbers-at-age

The sampling scheme is believed to achieve a good coverage of the fishery (above 95% of the total catch). The number of fish aged seems also to be sufficient through the historical series. Catch in numbers-at-age have been obtained by applying a quarterly ALK to each of the catch length distribution estimated from the samples of each subdivision. In the case of Subdivision IXa north, the catch in number estimates before 2003 have changed. In previous years the age–length key applied to the length distributions from Subdivision IXa north had included otoliths from Division VIIIc, which has been defined recently as part of the western stock. Since 2003, the catch in numbers-at-age from Subdivision IXa north were estimated using age–length keys which included only otoliths from Division IXa.

B.2. Biological

Maturity-at-age

For multiple spawners, such as horse mackerel, macroscopical analysis of the gonads cannot provide a correct and precise means to follow the development of both ovaries and testes. Histological analysis has to be included because it provides precise information on oocyte developmental stages and it can distinguish between immature gonads and regressing ones, or those partly spawned (Abaunza *et al.*, 2008). The HOMSIR project provided microscopical maturity ogives from the different IXa subdivisions. The maturity ogive from Subdivision IXa South is adopted here as the maturity-at-age for all years until 2006 of the southern stock, since it was based on a better sampling than in the others subdivisions. The percentage of mature female individuals per age group was adjusted to a logistic model.

In 2007 a new estimate of maturity proportion by age was available for Division IXa for the application of the Daily Egg Production Method (DEPM). This maturity ogive was then adopted since 2007 and will be revised with new data collected in the DEPM to be carried out in 2010.

Natural mortality

Natural mortality has been considered to be 0.15. This level of natural mortality was adopted for all horse mackerel stocks since 1992. However, the presence of very old horse mackerel specimens in the southern stock is much scarcer than in the western or North Sea stocks. On the other hand, the available references on natural mortality estimates for other *Trachurus* species (e.g. *Trachurus capensis, Trachurus japonicus* and *Trachurus murphyi*) show higher natural mortality values, being higher than 0.3 in the majority of cases (range from 0.1 to 0.5) (Cubillos *et al.*, 2008; MFMR, 2006; Zhang, 2001). Also, the assumption that natural mortality is the same for all ages is highly unrealistic, given that the chances of a 10 cm fish of being predated are much higher than those of a 30 cm fish.

As a conclusion, it is considered that the value of natural mortality (0.15) is an underestimation for southern horse mackerel stock. It is generally accepted that natural mortality is very high during larval stages and decreases as the age of the fish increases, approaching a steady rate (Jennings *et al.*, 2001). The natural mortality adopted in the assessment (mean = 0.3) is dependent on age, being higher for younger ages. The adopted values are the following and are based in the estimates for other similar pelagic species, observed diet composition of fish predators in the area and taking into account the observed mean life span in southern horse mackerel.

Age	0	1	2	3	4	5	6	7	8	9	10
Nat Mor	0.9	0.6	0.4	0.3	0.2	0.15	0.15	0.15	0.15	0.15	0.15

B.3. Surveys

The only survey datasets currently available for the assessment of southern horse mackerel are those from the bottom-trawl surveys carried out in the 4th quarter (October) by Portugal (Pt-GFS-WIBTS-Q4) and Spain (Sp-GFS-WIBTS-Q4) in ICES Division IXa. These surveys cover contiguous areas at the same time but do not cover the southern part of the stock distribution area, corresponding to the Spanish part of the Gulf of Cadiz. In that area another bottom-trawl survey is carried out Sp-GFS-caut-WIBTS-Q4), usually in November, but the raw data were unavailable in time for this workshop to investigate the effect of merging it with the datasets from the other areas. This work is expected to be completed in time for the next assessment working group, in June 2011.

As suggested in previous reviews of the assessment of this stock, the Spanish survey from Subdivision IXa North (Sp-GFS-WIBTS-Q4) and the Portuguese survey (Pt-GFS-WIBTS-Q4) are treated as a single survey, although they are carried out with different vessels and slightly different bottom-trawls. The catchability of these vessels (BO Cornide de Saavedra and NI Noruega) and fishing gears were compared for different fish species during project SESITS (EU Study Contract 96-029) and no significant differences were found for horse mackerel. Thus, the raw data (number per hour and age in each haul, including zeros) of the two datasets were merged and treated as a single dataset.

The abundance data by age and year do not follow a Normal distribution, having a big proportion of zeros and a few extreme values. This is explained by the patchiness in the distribution of horse mackerel and by its characteristic of forming large shoals. Therefore, it is questionable whether a simple average of the number-per-hour, by age and year, is an adequate abundance index for tuning the stock assessment. Different ways of obtaining an abundance index by age and year were explored, all of them based on the smoothing of the data assuming probability distributions other than the Normal one. For this, we fitted Generalized Additive Models (GAM) to the raw data using the package "mgcv" (Wood, 2006) in the R statistical computing language (R Core Development Team, 2010). Data smoothing was tried with four different strategies: by year class (one GAM for each year-class, with age as covariate), by age (one GAM by age with year as covariate), by year (one GAM by year with age as covariate), and by age and year (one GAM using a bi-dimensional smoother by age and year). A log link function was used in all cases, and the error was modelled with a binomial negative distribution. Other distributions and transformations of the data were tried, but with worse fittings than with these settings.

An example of the GAM fitting diagnostics with each of these four strategies showed in all cases a poor fitting, with the residuals showing undesirable patterns. Looking at the differences between the indices matrix obtained with each of these strategies and the one obtained by a simple average of the raw data, it is clear that most of the attempted strategies to smooth the data would result in strong differences, especially for the youngest ages. Given that an acceptable fit could not be achieved with these GAMs, it was decided to use the simple averaged data as abundance indices for tuning the assessment. Further work must be carried out in the future to better address this problem.

Two very clear features can be observed in the abundance indices dataset: a strong variability of age 0 and strong year effects (some years with higher abundance of all ages than others). The first feature may be explained by the greater aggregation tendency of these small fish in dense shoals and by their typically pelagic behaviour, which makes them less available to the bottom trawl. When, by chance, one or a few of those shoals are captured by the bottom trawl (e.g. at the end of a haul when the trawl is being towed at mid-water), it contributes to a high abundance estimate of that age class. The apparent year effects in the data are more difficult to explain, and are likely due to natural variations in the availability of the fish in that time of the year and small variations in sampling effort (e.g. due to bad weather). Both the variability in age 0 and the apparent year effects must be accounted for in the assessment model to be fitted to these data.

Recent work suggests that horse mackerel has indeterminate fecundity (Gordo *et al.*, 2008), which makes the Annual Egg Production Method (AEPM) unsuitable to estimate SSB for this species. For species with indeterminate fecundity, the Daily Egg Production Method (DEPM) must be used instead. The existence of different series of data from egg surveys covering the whole area of the southern horse mackerel stock makes it possible to obtain egg production estimates using DEPM.

For this stock, a total of three SSB estimates, for the years 2002, 2005 and 2007, were made available. The SSB estimate and variance for 2007 was obtained from a DEPM egg survey directed at horse mackerel. Details of the sampling procedure, data obtained and methods followed are available from the 2008 report of the Working Group on Mackerel and Horse Mackerel Egg Surveys (ICES, 2008. ICES CM 2008/LRC:09). However, some details were corrected after the WGMEGS report, namely the total egg distribution area (which was corrected from 1.7e11 sq.meter to 7.1e11 sq.meter) and the fitting of the mortality curve to the egg abundance data, which was done using a GLM with a log link and assuming a Poisson distribution for the variance, instead of the non-linear regression described in the WGMEGS report. This resulted in a change of egg production from 13 eggs/sq.meter to 17 eggs/sq.meter.

The 2002 and 2005 estimates were obtained with egg abundance data collected during the surveys directed at sardine in 2002 and 2005 and from horse mackerel adult samples collected at the same time of those surveys. The methodology followed to estimate SSB was the same as the one for 2007, although the area covered in the egg sampling, which corresponded to the sampling grid for sardine, was smaller than in 2007.

There are different criteria that can be used to estimate the spawning fraction, such as the presence of migratory nucleus, hydrated oocytes or post-ovulatory follicles (POF). Estimates of SSB were obtained for the three years with all these criteria, and the obtained trends in SSB were parallel but with different levels. The POF criteria, assuming POF last for two days as in other species at similar temperatures (Ganias *et al.*, 2003; Hunter and Macewicz, 1985) was the one providing the lowest CV, being therefore adopted to use in the assessment. However, given the uncertainty in the absolute value of SSB, partly due to the choice of the criteria for the spawning fraction, the SSB index for the assessment must be treated as relative and a corresponding catchability parameter has to be estimated.

Still another source of uncertainty is the egg distribution area, which was roughly defined and kept fixed for the three years. In all these egg surveys, there are several transects with the presence of eggs in the most offshore station, which indicates that the area with egg presence must, in some cases, be extended further away from the coast. However, a good approximation of that area is impossible to obtain with the available data.

B.4. Commercial cpue

No commercial cpue data is used in the stock assessment.

B.5. Other relevant data

There were no other data considered at this time.

C. Assessment: data and method

Model used: AMISH (Assessment Method for the Ibero-Atlantic Stock of Horse-Mackerel).

A model similar to the one adopted by the South Pacific Regional Fishery Management Organization (SPRFMO) for the assessment of Chilean jack mackerel (*Trachurus murphyi*) was modified for application with horse mackerel. This method (Lowe *et al.*, 2009) models the population numbers-at-age as projections forward based on recruitment estimates leading up the initial population numbers-at-age (in 1992 for this case) and subsequent annual recruitment and fishing mortalities parameters. These underlying population numbers-at-age are fit through an observation model for parameter estimation via a penalized likelihood applied to a quasi-Newton minimisation routine with partial derivatives calculated by automatic differentiation (Griewank and Corliss, 1991). The automatic differentiation and minimisation routines are those from the package AD Model Builder (ADMB). A similar model is currently used in many stock assessments in North American waters (e.g., Atka mackerel, eastern Bering Sea pollock, Pacific Ocean perch). It is a simple, well tested, and widely used methodology. The population equations, model fitting components, and model settings are listed in Tables 1–4.

The approach differs from the XSA methods in that:

- calculations proceed from the initial conditions to the present and into the future,
- the catch-at-age is not assumed to be known exactly,
- the inclusion of annual estimates of sampling variability (for both age composition and survey index precision) is allowed,
- fishing mortality is separable but selection-at-age is allowed to change gradually over time,
- separate components of the fishery are treated independently,
- some parameters, which are assumed constant in XSA, such as the catchability coefficients associated with tuning indices, may be allowed to change over time,
- statistical basis allows for careful consideration of data quality and the impact on the uncertainty of estimates.

The model begins in the first year of available data with an estimate of the population abundance-at-age. Recruitments are estimated for each year. In subsequent ages and years the abundance-at-age is reduced by the total mortality rate. This projection continues until the terminal year specified. If data are unavailable to estimate recruitment, the model will use the geometric mean value and hence can be projected to any arbitrary year (assuming specified catches).

The fishing mortality rates for each sector in the fishery are assumed to be separable into an age component (called selectivity) and a year component (called the F multiplier). The selectivity patterns are allowed to change over time. Expected catches are computed according to the usual catch equation using the determined fishing mortality rate, the assumed natural mortality rate, and the estimated population abundance described above. The statistical fitting procedure used with the model will try to match the indices and the catch-at-age. The emphasis of each of these sources of information depends on the values of the relative weights assigned to each component by the user.

The minimization processes proceeds in phases, in which groups of parameters are estimated simultaneously, while the remaining parameters are maintained at their initially assigned values. Once the objective function is minimized for a particular phase, more parameters are treated as unknown and added to those being estimated. This process of estimation in phases continues until all parameters to be estimated contribute to the objective function and the best set of all parameters that minimize the objective function value is determined.

The software code and input files is available on request.

Model Options chosen:

The objective function is the sum of a number of negative log-likelihoods generally following two types of error distributions: the lognormal and multinomial and details are listed in Table 3. The specifications of input sampling levels (in terms of sample size or variance term) are provided in Table 4.

The separability in the fishing mortality was allowed to vary according to a shift in fleet composition. An F multiplier was estimated for the first year, and was allowed to change in time by estimating deviations to this parameter for each year. The fishing mortality at each age, year and fleet resulted from the product of the F multipliers by the selectivity parameter at each age and fleet. Three selectivity vectors were estimated, corresponding to blocks of fleets sharing a similar selectivity-at-age. This is a useful feature of the model that helps to avoid overparameterisation. By looking at the plots of catch-at-age by fleet, it was decided to have a common selectivity for the purse-seine fleets, together with the Portuguese bottom-trawl fleet, another one for the artisanal fleets and a third one just for the Spanish bottom-trawl fleet. One catchability parameter for the abundance index was kept fixed over time.

The model fitting is affected by statistical weights (lambdas or inverse variance functions) as part of the objective function. Specified input variance assumptions can influence the fitting of the model, by attributing a lower or higher importance to different data sources that contribute to the objective function. The variance assumption assumed the highest precision for landings data by year and fleet. The fishery proportions-at-age for the moment were assumed to have an "effective sample size" of 100 compared to the value of ten specified for the survey estimates of age composition. The survey index data was fit assuming that the coefficient of variation was 30%. These values are typical for this type of information and diagnostic plots of model fits confirmed that they are reasonable. As more data become available, these assumptions can be modified to more appropriate and potentially time-varying values.

D. Short-term projection

Model used: Apropos designed function, named *mff*, to perform deterministic forecast, only with catch constraints (allowing the introduction of variability in the assumed recruitment values). Having the initial numbers-at-age at the beginning of the year, the total F at age in the assessment year y-1 and the assumptions we want to make on the weight-at-age, the selectivity-at-age by fleet, the maturity ogive, the natural mortality rate and the recruitment. We can project forward the population given a level of catches for the intermediate year y and for the protection year y+1. It is also possible to add some variability to the recruitments, by including a standard deviation value.

The method starts projecting the population numbers-at-age from the last assessment year with the estimated the fishing mortality rates by fleet,

$$N_0 = rec \cdot e^{\varepsilon}, \quad \varepsilon \sim N(0, \sigma)$$
$$N_1 = N_0 \cdot e^{-(M_0 + F_0) p}$$
$$N_a = N_{a-1} e^{-(M_{a-1} + F_{a-1})}, \quad a \text{ in } 2, \ldots, A-1$$
$$N_A = N_{A-1} e^{-(M_{A-1} + F_{A-1})} + N_A e^{-(M_A + F_A)}$$

where rec corresponds to the assumed recruitment level, N_a are the numbers-at-age a, M_a is the natural mortality-at-age a, F_a is the fishing mortality-at-age a, σ is the standard deviation of the recruitment and p is the proportion of the year from the recruitment time to the end of the year.

For the intermediate year in the short-term projections, the population numbers-at-age are calculated assuming catch constraints by fleet, using Pope's approximation forward,

$$\lambda = \frac{catch}{\sum_a S_a \cdot N_a \cdot W_a}, \quad proportion\ to\ the\ maximum\ that\ could\ be\ captured$$

$$C_a = \sum_a S_a \cdot N_a \cdot \lambda$$

$$N_0 = rec \cdot e^{\varepsilon}, \quad \varepsilon \sim N(0, \sigma)$$

$$N_1 = (N_0 - C_0 e^{M_0 \cdot p/2}) e^{-M_0 \cdot p}$$

$$N_a = (N_{a-1} - C_{a-1} e^{M_{a-1}/2}) e^{-M_{a-1}}, \quad a \text{ in } 2, \ldots, A\text{-}1$$

$$N_A = (N_{A-1} - C_{A-1} e^{M_{A-1}/2}) e^{-M_{A-1}} + (N_A - C_A e^{M_A/2}) e^{-M_A}$$

where λ is the proportion to the maximum catch that could be captured, rec corresponds to the assumed recruitment, N_a are the numbers-at-age a, M_a is the natural mortality-at-age a, F_a is the fishing mortality-at-age, S_a is the selectivity-at-age, a and p is the proportion of the year from the recruitment time to the end of the year.

The source code is available on request.

Software used*:* R (www.r-project.org)

Initial stock size: the one estimated by the assessment model

Maturity: the same as in the previous year of the assessment

F and M before spawning: both of them are 0

Weight-at-age in the stock: the same as in the previous year of the assessment

Weight-at-age in the catch: assumed equal to the weight-at-age in the stock

Exploitation pattern: the one estimated in the assessment model

Intermediate year assumptions: the catches by fleet are assumed to be exactly the same as the ones in the previous year

Stock–recruitment model used: no stock–recruitment model is used, the recruitment is assumed to be stochastic in all the years (the assessment year, the intermediate and the projection year), around the geometric mean of the historical values with the same variability as the one observed in the series.

Procedures used for splitting projected catches:

E. Medium-term projections

No medium-term projection has been performed for this stock

Model used:

Software used:

Initial stock size:

Natural mortality:

Maturity:

F and M before spawning:

Weight-at-age in the stock:

Weight-at-age in the catch:

Exploitation pattern:

Intermediate year assumptions:

Stock–recruitment model used:

Uncertainty models used:

- Initial stock size:
- Natural mortality:
- Maturity:
- F and M before spawning:
- Weight-at-age in the stock:
- Weight-at-age in the catch:
- Exploitation pattern:
- Intermediate year assumptions:
- Stock–recruitment model used:

F. Long-term projections

No long-term projection has been performed for this stock.

Model used:

Software used:

Maturity:

F and M before spawning:

Weight-at-age in the stock:

Weight-at-age in the catch:

Exploitation pattern:

Procedures used for splitting projected catches:

G. Biological reference points

Reference points have not been defined for this stock.

H. Other issues

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Table 5. Symbols definitions used for model equations.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: i = {1992, …., 2010}	i	
Age index: j = { 0,1,2, …, 11+}	j	
Mean weight in year t by age j	Wt,j	
Maximum age beyond which selectivity is constant	Maxage	Selectivity parameterization
Instantaneous Natural Mortality	Mj	Fixed M=0.8,0.5,0.3,0.2,0.1…0.1, for j=0,1,2…11
Proportion females mature at age j	pj	Definition of spawning biomass
Sample size for proportion in year i	T_i	Scales multinomial assumption about estimates of proportion at age
Survey catchability coefficient	q^s	Prior distribution = lognormal(μ_q^s , σ_q^2)
Stock-recruitment parameters	R_0 h σ_R^2	Unfished equilibrium recruitment, steepness, variance
Virginal biomass	ϕ	Spawning biomass per recruit when there is not fishing
Estimated parameters		
φ_i □ □ $,R_0, h, \varepsilon_i$ □□ $,\mu^f, \mu^s, M, \eta_j^s$ □□ $,\eta_j^f$ □□ $,q^s$ □□		

Note that the number of selectivity parameters estimated depends on the model configuration.

Table 6. Variables and equations describing implementation of the horse mackerel assessment model.

Eq	Description	Symbol/Constraints	Key Equation(s)
1)	Survey abundance index (s) by year (Δ^s represents the fraction of the year when the survey occurs)	I_i^s	$I_i^s = q^s \sum_{j=0}^{11} N_{ij} W_{ij} S_j^s e^{-\Delta^s Z_{ij}}$
2)	Catch biomass by year	c,	$\hat{C}_{ij}^f = \sum_{j=0}^{11} N_{ij} W_{ij} \frac{F_{ij}^f}{Z_{ij}} (1 - e^{-Z_{ij}})$
3)	Proportion at age j, in year i	$P_{ij}, \sum_{j=0}^{11} P_{ij} = 1.0$	$p_{ij}^f = \frac{\hat{C}_{ij}^f}{\sum_j \hat{C}_{ij}^f}$ [illegible]
4)	Initial numbers at age	j = 0	$N_{1992,j} = e^{\mu_R + \varepsilon_{1992}}$
5)		0 < j < 10	$N_{1992,j} = e^{\mu_R + \varepsilon_{1993-j}} \prod_{j=1}^{j} e^{-M}$
6)		j = 11+	$N_{1992,11} = N_{1992,10} \left(1 - e^{-M}\right)^{-1}$
7)	Subsequent years (i >1992)	j = 0	$N_{i,2} = e^{\mu_R + \varepsilon_i}$
8)		0 < j < 10	[illegible]
9)		j = 11+	$N_{i,11} = N_{i-1,10} e^{-Z_{i-1,10}} + N_{i-1,11} e^{-Z_{i-1,11}}$
10)	Year effect and individuals at age 2 and i = 1981, …, 2010	$\varepsilon_i, \sum_{i=1981}^{2010} \varepsilon_i = 0$	$N_{i,0} = e^{\mu_R + \varepsilon_i}$
11)	Index catchability Mean effect Age effect	μ^s, μ^f $\eta_{ij}, \sum_{j=0}^{11} \eta_{ij} = 0$	$q_i^s = e^{\mu^s}$ $s_j^s = e^{\eta_j^s}$ $j \le$ maxage $s_j^s = e^{\eta_{maxage}^s}$ $j >$ maxage
12)	Instantaneous fishing mortality		$F_{ij}^f = e^{\mu^f + \eta_j^f + \varphi_i}$
13)	Mean fishing effect	μ^f	
14)	Annual effect of fishing mortality in year i	$\varphi_i, \sum_{i=1992}^{2010} \varphi_i = 0$	
15)	age effect of fishing (regularized) In year time variation allowed In years where selectivity is constant over time	η_{ij}^f, $\sum_{j=2}^{12^+} \eta_{ij} = 0$ $\eta_{i,j}^f = \eta_{i-1,j}^f$	$s_{ij}^f = e^{\eta_j^f}$, $j \le$ maxage $s_{ij}^f = e^{\eta_{maxage}^f}$ $j >$ maxage $i \ne$ change year
16)	Natural Mortality vector	Mj	0.8 0.5 0.3 0.2,0.1…0.1 for ages 0 - 11
17)	Total mortality		$Z_{ij} = \sum_f F_{ij}^f + M$

Eq	Description	Symbol/Constraints	Key Equation(s)
17)	Spawning biomass (note spawning taken to occur at mid of January)	Bi	$B_i = \sum_{j=0}^{11} N_{ij} e^{-\frac{0.5}{12} Z_{ij}} W_{ij} p_j$
18)	Recruitments (Beverton-Holt form) at age 0.	$\tilde{R}_i$	$\tilde{R}_i = \frac{\alpha B_i}{\beta + B_i}$, $\alpha = \frac{4hR_0}{5h-1}$ and $\beta = \frac{B_0(1-h)}{5h-1}$ where $B_0 = R_0 \varphi$ $\varphi = \sum_{j=2}^{12} e^{-M(j-1)} W_j p_j + \frac{e^{-12M} W_{12} p_{12}}{1-e^{-M}}$ h=0.8

Table 7. Specification of objective function that is minimized (i.e., the penalized negative of the log-likelihood).

	Likelihood /penalty component		Description / notes
44)	Catch biomass likelihood	$L_1 = \sum_f \lambda_4^f \sum_{i=1992}^{2010} \ln\left(\frac{C_i^f}{\hat{C}_i^f}\right)^2$	Fit to catch biomass in each year
19)	Abundance indices	$L_2 = \sum_s \lambda_1^s \sum_i \ln\left(\frac{I_i^s}{\hat{I}_i^s}\right)^2$	Survey abundances
20)	Proportion at age likelihood	$L_k = \sum_{k,i,j} \tau_i^k P_{ij}^k \ln\left(\hat{P}_{ij}^k\right) \qquad k = 3,4$	k=3 for the fishery, k=4 for the survey
21)	Penalty on smoothness for selectivities	$L_k = \sum_k \lambda_k \sum_{j=0}^{11} \left(\eta_{j+2}^l + \eta_j^l - 2\eta_{j+1}^l\right)^2 \quad k = 6,9$	Smoothness (second differencing), Note: k=6 for the fishery, k=9 for the survey
22)	Penalty on recruitment regularity	$L_{11} = \lambda_{11} \sum_{i=1981}^{2010} \varepsilon_i^2$	Influences estimates where data are lacking (e.g., if no signal of recruitment strength is available, then the recruitment estimate will converge to median value).
23)	Recruitment curve penalty	$L_6 = \lambda_6 \sum_{i=1992}^{2010} \ln\left(\frac{N_{i,0}}{\tilde{R}_i}\right)^2$	Conditioning on stock-recruitment curve over period 1992–2007 (but reduced to have negligible effect on estimation).
24)	Overall objective function to be minimized	$\dot{L} = \sum_k L_k$	

Table 8. Input variance σ^2 or sample size (τ) assumptions and corresponding penalties (λ) used on log-likelihood functions in the base model.

L	Abundance index	□	τ	□L
1	Landings	0.05	-	200
2	Combined index	0.3	-	5.556
3	Fishery age composition	-	100	-
4	Survey age composition	-	10	-
5	Time-change in fishery selectivities	0.8		0.78
6	Fishery age-specific penalties	1.0	-	0.5
7	Fishery descending selectivity-with-age penalty	10	-	0.1
8	Time-change in survey selectivities	0.8		0.78
9	Survey age-specific penalties	1.0	-	0.5
10	Survey descending selectivity-with-age penalty	10	-	0.1
11	Recruitment regularity	10	-	0.1
12	S-Recruitment curve fit (for period 1992–2007, scale only)	1.9	-	0.14

Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1992–2008	0–11+	Si
Canum	Catch-at-age in numbers	1992–2008	0–11+	Si
Weca	Weight-at-age in the commercial catch	1992–2008	0–11+	Si
West	Weight-at-age of the spawning stock at spawning time.	1992–2008	0–11+	Si
Mprop	Proportion of natural mortality before spawning	1992–2008	0–11+	Si
Fprop	Proportion of fishing mortality before spawning	1992–2008	0–11+	No
Matprop	Proportion mature-at-age	1992–2008	0–11+	No
Natmor	Natural mortality	1992–2008	0–11+	No
	Spanish-Portuguese bottom-trawl survey	1992–2009	0–11+	

Stock Annex: Haddock in Subarea IV and Division IIIa(N)

Stock	Haddock in Subarea IV and Division IIIaN (Skager rak)
Working Group	ICES Working Group on the Assessment of Demer sal Stocks in the North Sea and Skagerrak (WGNSSK)
Date	May 2009
Author	Coby Needle
Revisions	Coby Needle [WKBENCH], January–February 2011

A. General

A.1. Stock definition

Haddock in Subarea IV and Division IIIaN (Skagerrak) occupy the northern and central North Sea and Skagerrak and are possibly linked to the Division VIa stock on the West of Scotland. Haddock in this area are seldom found below 300 m (although Rockall haddock can be found much deeper), and North Sea haddock prefer depths between 50 m and 200 m. They are found as juvenile fish in coastal areas in particular in the Moray Firth, around Orkney and Shetland, along the continental shelf at around 200 m and continuing round to the Skagerrak. Adult fish are predominantly found around Shetland and in the northern North Sea near the continental shelf edge.

A.2. Fishery

Most of the information presented below pertains to the Scottish demersal whitefish fleet, which is provided with the bulk of the available quota and consequently takes the largest proportion of the haddock stock. This fleet is not just confined to the North Sea, as vessels will sometimes operate in Divisions VIa (off the west coast of Scotland) and VIb (Rockall): it is also a multi-species fishery that lands a number of species other than haddock.

A.2.1. Management plans

In 1999 the EU and Norway "agreed to implement a long-term management plan for the haddock stock, which is consistent with the precautionary approach and is intended to constrain harvesting within safe biological limits and designed to provide for sustainable fisheries and greater potential yield." This plan was implemented in January 2005, updated in December 2006, and implemented in revised form in January 2007. It consists of the following elements:

1) Every effort shall be made to maintain a minimum level of Spawning–Stock Biomass greater than 100 000 tonnes (Blim).
2) For 2007 and subsequent years the Parties agreed to restrict their fishing on the basis of a TAC consistent with a fishing mortality rate of no more than 0.3 for appropriate age groups, when the SSB in the end of the year in which the TAC is applied is estimated above 140 000 tonnes (Bpa).
3) Where the rule in paragraph 2 would lead to a TAC which deviates by more than 15% from the TAC of the preceding year the Parties shall estab-

lish a TAC that is no more than 15% greater or 15% less than the TAC of the preceding year.

4) Where the SSB referred to in paragraph 2 is estimated to be below Bpa but above Blim the TAC shall not exceed a level which will result in a fishing mortality rate equal to 0.3–0.2*(Bpa–SSB)/(Bpa–Blim). This consideration overrides paragraph 3.

5) Where the SSB referred to in paragraph 2 is estimated to be below Blim the TAC shall be set at a level corresponding to a total fishing mortality rate of no more than 0.1. This consideration overrides paragraph 3.

6) In order to reduce discarding and to increase the spawning–stock biomass and the yield of haddock, the Parties agreed that the exploitation pattern shall, while recalling that other demersal species are harvested in these fisheries, be improved in the light of new scientific advice from inter alia ICES.

7) In the event that ICES advices that changes are required to the precautionary reference points Bpa (140 000 t) or Blim (100 000 t) the parties shall meet to review paragraphs 1–5.

8) No later than 31 December 2009, the parties shall review the arrangements in paragraphs 1 to 7 in order to ensure that they are consistent with the objective of the plan. This review shall be conducted after obtaining *inter alia* advice from ICES concerning the performance of the plan in relation to its objective.

In October 2007, ICES evaluated this plan and concluded that it could "*provisionally be accepted as precautionary and be used as the basis for advice*." The methods used to reach this conclusion (along with illustrative results) are given in Needle (2008). ICES considers that the agreed Precautionary Approach reference points in the management plan are consistent with the precautionary approach, provided they are used as lower boundaries on SSB, and not as targets.

The plan was modified during 2008 to allow for limited interannual quota flexibility, following the meeting in June of the Norway-EC Working Group on Interannual Quota Flexibility and subsequent simulation analysis (Needle, 2008).

Further technical conservation measures

EU technical regulations in force are contained in Council Regulation (EC) 850/98 and its amendments. This regulation prescribes the minimum target species composition for different mesh size ranges. In 2001, haddock in the whole of NEAFC region 2 were a legitimate target species for towed gears with a minimum codend mesh size of 100 mm. As part of the cod recovery measures, the EU and Norway introduced additional technical measures from 1 January 2002 (EC 2056/2001). The basic minimum mesh size for towed gears for cod from 2002 was 120 mm, although in a transitional arrangement running until 31 December 2002 vessels were allowed to exploit cod with 110-mm codends provided that the trawl was fitted with a 90-mm square mesh panel and the catch composition of cod retained on board was not greater than 30% by weight of the total catch. From 1 January 2003, the basic minimum mesh size for towed gears for cod was 120 mm. The minimum mesh size for vessels targeting haddock in Norwegian waters is also 120 mm.

At the December Council 2006 (EC 41/2006), additional derogations were introduced to allow additional days fishing in the smaller mesh (90 mm) trawl fishery where vessels fitted a square mesh window close to the cod end to allow for improved selectivity of these gears (and hence the possibility of lower haddock discards). The change in mesh size was expected to shift exploitation patterns to older ages and increase the weight-at-age for retained fish from younger age classes. Improvements in the exploitation pattern were not immediately observed, however, and it was not possible to determine if this was due to confounding effects from other fleet segments.

Effort restrictions in the EC were introduced in 2003 (EC 2341/2002, Annex XVII, amended in EC 671/2003). Effort restriction measures were revised for 2005 (EC 27/2005, Annex IV). Effort regulations for 2008 in days at sea per vessel and gear category are summarised in the following table, which only shows changes in 2008 compared to 2007 (2006 is included for comparison). The changes (2007–2008) are intended to lead to a cut in effort of 10% for the main gears catching cod.

Maximum number of days a vessel can be present in the North Sea, Skagerrak and Eastern Channel, by gear category and special condition (see EC 40/2008 for more details). The table only shows changes in 2008 compared to 2007, but 2006 is also included for comparison.

Description of gear and special condition (if applicable)	Area			Max days at sea		
	IV,II	Skag	VIId	2006	2007	2008
Trawls or Danish seines with mesh size ≥120 mm	x	x	x	103	96	86
Trawls or Danish seines with mesh size ≥100 mm and <120 mm	x	x	x	103	95	86
Trawls or Danish seines with mesh size ≥90 mm and <100 mm	x		x	227	209	188
Trawls or Danish seines with mesh size ≥90 mm and <100 mm		x		103	95	86
Trawls or Danish seines with mesh size ≥70 mm and <90 mm	x			227	204	184
Trawls or Danish seines with mesh size ≥70 mm and <90 mm			x	227	221	199
Beam trawls with mesh size ≥120 mm	x	x		143	143	129
Beam trawls with mesh size ≥100 mm and <120 mm	x	x		143	143	129
Beam trawls with mesh size ≥80 mm and <90 mm	x	x		143	132	119
Gillnets and entangling nets with mesh sizes ≥150 mm and <220 mm	x	x	x	140	130	117
Gillnets and entangling nets with mesh sizes ≥110 mm and <150 mm	x	x	x	140	140	126
Trammelnets with mesh size <110 mm. The vessel shall be absent from port no more than 24 h.	x		x	205	205	185*

*** For member states whose quotas less than 5% of the Community share of the TACs of both plaice and sole, the number of days at sea shall be 205.**

In early 2008, a one-net rule was introduced in Scotland as part of the new conservation credits scheme (Section 13.1.4). This is likely to have improved the accuracy of reporting of landings to the correct mesh size range. However, Scottish seiners were granted a derogation from the one-net rule until the end of January 2009, and were allowed to carry two nets (e.g. 100–119 mm as well as 120+ mm). They were required to record landings from each net on a separate logsheet and to carry observers when requested (ICES-WGFTFB 2008).

Under the provisions laid down in point 8.5 of Annex IIa to the 2008 year's EU TAC and Quota Regulation, Scotland implemented in 2008 a national KWdays scheme known as the **Conservation Credits Scheme**. The principle of this two-part scheme involves credits (in terms of additional time at sea) in return for the adoption of and adherence to measures which reduce mortality on cod and lead to a reduction in discard numbers. The initial scheme was implemented from the beginning of February 2008 and granted vessels their 2007 allocation of days (operated as hours at sea) in return for observance of Real Time Closures (RTC) and a one-net rule, adoption of more selective gears (110mm square meshed panels in 80 mm gears or 90 mm SMP in 95 mm gear), agreeing to participate in additional gear trials and participation in an enhanced observer scheme.

For the first part of 2008 the RTC system was designed to protect aggregations of larger, spawning cod (>50 cm length). Trigger levels leading to closures were informed by commercial catch rates of cod observed by FRS on board vessels. During 2008, there were 15 such closures. Protection agency monitoring suggested good observance. A joint industry/science partnership (SISP) undertook a number of gear trials in 2008 examining methods to improve selectivity and reduce discards, and an enhanced observer scheme was announced by the Scottish Government.

The RTC system was expanded in 2009 (144 closures), 2010 (165 closures) and 2011 (35 closures to 22nd February). The area covered by each closure has also been increased, and their shape can be modified to account for local bathymetry. Needle and Catarino (in press) used VMS data to analyse the movements of vessels affected by closures during 2009, and concluded that such vessels did move to areas of lower cod abundance during the first and third quarters (the second and fourth quarters were inconclusive).

Scotland has also been instrumental in the development of Catch Quota Management (http://www.scotland.gov.uk/Topics/marine/Sea-Fisheries/17681/catchquota). Participating vessels are fitted with CCTV and other remote electronic monitoring systems and are required not to discard any cod. Additional cod quota (up to 30%) is made available to these vessels, with the intention to "catch less and land more". As of February 2011, evaluations of the progress of this scheme and its effect on the fishery and stocks are underway. While the scheme does not yet cover haddock, the consequent changes in fleet dynamics are likely to affect patterns of exploitation on haddock, and the implications will need to be considered carefully in future advice.

Fleet changes and development

The number of Scottish-based vessels (over 10 m) in the demersal sector was reduced by approximately one third (98 vessels) during 2002, the bulk of this being due to vessels accepting decommissioning. Although the decommissioning scheme encompassed all vessel types and sizes, the vessels eventually decommissioned included a significant number of older boats and those with track record of catching cod. Amongst the remaining vessels there has been a reduction in the segment operating seinenet or pair seine. The observed shift towards pair trawling from single-vessel seine and trawls in the early 2000s may have implied an increase in catchability, but the decommissioning rounds in 2002 and 2003 included a slightly higher proportion of pair trawlers, resulting in no real overall change in fleet composition.

The number of Scottish based vessels (over 10 m) in the demersal sector was reduced by 67 in a further decommissioning round in 2004. More recently, increased fuel prices have resulted in a shift from twin trawl to single trawl and pair seine/trawl by many boats in the Scottish demersal mixed fishery sector (ICES-WGFTFB 2006). The observed shift towards pair trawling from single seine may be explained by a standardization of reporting and recording of gear types. Vessels previously participating in the seinenet class may have included vessels operating pair seine whereas this classification is now recorded as pair trawl.

In 2005, there was an expansion in the squid fishery in the Moray Firth area resulting from increased effort from smaller (<10 m) vessels, and from a number of larger vessels that had switched from demersal fisheries for haddock and cod, to squid fisheries, in order to avoid days-at-sea restrictions (ICES-WGFTFB 2006). The mesh regulation for squid fishing is 40 mm codend, which could lead to bycatch/discard of young haddock and cod. In 2006 and 2007, the squid fishery declined: vessels that shifted away from squid targeted *Nephrops* instead. However, the potential remains for high bycatches of young gadoids in the future, given the small mesh size used.

During 2008, a number of Scottish vessels switched focus to the Rockall area to take advantage of the increased quota there. The economic benefit of being able to land more haddock outweighed the costs involved in steaming to Rockall in a climate of increased fuel prices. This fishery is very dependent on good weather, however, and is not a consistent feature. At the same time, several vessels switched from whitefish fishing in Division VIa to *Nephrops* exploitation in Subarea IV using 80 mm gear (ICES-WGFTFB 2008). This may have implications for haddock bycatch in the *Nephrops* fishery, although (under the stipulations of the Scottish conservations credits scheme; see above), nets in the 80 mm range will had to have a 110 mm square mesh panel installed from July 2008. Compliance was close to 100% during 2008. Trials suggested that this square-mesh panel increased the 50% selection length (L_{50}) for haddock by around 30%, which implied increased escapement of young haddock from the *Nephrops* fishery.

Also during 2008, a number of Scottish vessels moved from twin to single trawls, and there was also an increase in the use of pair trawl/seine. Some high-powered whitefish vessels switched to *Nephrops* and were targeting North Sea grounds with double bag trawls. This was very much driven by fuel costs, and may have had implications for reduced lpue and increases in discarding.

Analysis of fishing effort trends in the major fleets exploiting North Sea cod indicates that fishing effort in those fleets has been decreasing since the mid-1990s due to a combination of decommissioning and days-at-sea regulations (STECF-SGRST-05-01 and 04, 2005). The decrease in effort is most pronounced in the years 2002 and beyond.

Information presented to ICES in 2008 noted that the UK large mesh demersal trawl fleet category (>100 mm, 4A) has been reduced by decommissioning and days-at-sea regulations to 40% of the levels recorded in the EU reference year of 2001. There was a movement into the 70–90 mm sector to increase days at sea in 2002 and 2003, but the level of effort stabilised in 2004. The effort of the combined trawl gears has shown a continued decrease of 36% overall, from the EU reference year of 2001 (STECF-SGRST-05-01 and 04, 2005).

A.3. Ecosystem aspects

The North Sea haddock stock is characterised by sporadically high recruitment leading to dominant year classes in the fishery. These large year classes may grow more slowly than less abundant year classes, possibly due to density-dependent effects. Haddock primarily prey on benthic and epibenthic invertebrates, sandeels and demersal herring egg deposits. They are an important prey species, mainly for saithe and other gadoids.

B. Data

B.1. Commercial catch

Age compositions

Three components of the North Sea haddock catch are considered: landings for human consumption, discards and industrial bycatch. The sources of information on these components were as follows (for the 2010 assessment):

		Belgium		Denmark		France		Germany		Netherlands		Norway		Sweden		United Kingdon	
		WG	SA	WG	SA	WG	SA	WG	SA	WG	SA	WG	SA	WG	SA	WG	SA
Catches	Landings	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Discards	N	N	Y	Y	NP	N	Y	Y	NP	N	NP	N	Y	Y	Y	Y
Length Composition	Landings	NR	N	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Discards	NR	N	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Age–Length Key		NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Age Composition	Landings	NP	N	Y	Y	NP	N	NP	NP	NP	N	Y	Y	Y	Y	Y	Y
	Discards	NP	N	Y	Y	NP	N	NP	NP	NP	N	NP	N	Y	Y	Y	Y
Weight-at-age		NP	N	Y	Y	NP	N	Y	Y	NP	N	Y	Y	Y	Y	Y	Y
Maturity Information		NR	N	NR	N	NR	N	NR	N	NR	NR	NR	NOR	NR	N	NR	NOR
Sex ratio		NR	N	NR	NR	NR	NR	NR	N	NR	NR	NR	N	NR	N	NR	NOR
Tuning fleets	Commercial fleets	NP	N	NP	N	NP	N	NP	N	NP	N	NP	N	NP	NP	Y2	NBQ
	Surveys-at-sea	NP	N	NP	N	NP	N	NP	N	NP	N	NP	N	NP	NP	Y3	Y3

In this table, the notes in the WG columns indicate the following: Y = provided to the WG, NP = not provided to the WG and NR = not requested. In the SA columns: Y = used in the assessment, NBQ = not used due to bad quality, NTS = not used due to short or inconsistent data time-series, NOR = not used due to other reason, and NR = not relevant.

Data exploration

The standard plots used in exploratory data analysis of North Sea haddock catch data include:

1) Time-series of proportion of total catch discarded by age.

2) Log catch curves by cohort (total catch).

3) Negative gradients of log catches per cohort, averaged over mean *F* ages (total catch).

4) Bivariate correlations by cohort (total catch), with fitted regression lines. That is, catch numbers-at-age 0 are plotted against catch numbers-at-age 1 for each cohort, then age 0 against age 2, and so on for all age combinations.

5) Results of a separable VPA analysis generated using either the Lowestoft VPA implementation (Darby and Flatman, 1994) or the FLR equivalent.

B.2. Biological Information

Weight-at-age

Weights-at-age data are provided for the stock, total catch, landings, discards and human consumption. Values are derived from length sampling carried out by Denmark, Germany, Norway, Sweden and the UK (see table above), to which fixed weight–length relationships are then applied. Weights-at-age are also collected on the IBTS surveys, but these are not yet used directly in the assessment.

Maturity and natural mortality

The growth dynamics of haddock in the North Sea have changed considerably over time. WKBENCH (ICES-WKBENCH 2011) demonstrated that haddock are now growing more quickly when young but reaching a shorter eventual length than used to be the case. At the same time, survey-based sampling indicates that the maturation age has reduced, with the proportion mature of age-2 fish increasing from around 35% in the early 1970s to around 80% now. However, estimation of the effect of increasing maturity and changing growth on reproductive potential is not straightforward, as fecundity has also changed through time (see comments in ICES-WKBENCH 2011, and the section on "Biological Reference Points" below). The conclusion from WKBENCH was that:

- "WKBENCH recommends that refined maturity estimates should be developed before the next WGNSSK meeting in May 2011 and used in subsequent update assessments."

WKBENCH also considered the issue of natural mortality *M*, which previously had been assumed to be fixed through time. Annual estimates of natural mortality are available from key runs of the SMS model, as reported by the ICES Working Group on Multispecies Assessment Methods (e.g. ICES-WGSAM 2008). The last key run was conducted in 2007, so estimates are constant for 2007–2009. In addition, it should be emphasised that the last year of comprehensive stomach-data collection was 1991, so the food-web definitions on which SMS runs are based are likely to be out of date to a certain extent. The effects of these time-varying estimates of natural mortality on both XSA and SAM assessment model runs were explored by WKBENCH. The new estimates are quite different from the fixed values used previously, with *M* for age-0 being lower and for ages 2 and above being higher, and that this is likely to have a substantial impact on assessments. The subsequent recommendation was:

- "WKBENCH recommends that time-varying natural mortality estimates from WGSAM should be used in the subsequent update assessments."

Finally, WKBENCH carried out interim test assessments using the new estimates of maturity and natural mortality, and also produced interim estimates of corresponding biological reference points (which are considerably different to before). These need to be revisited before they can be considered as the basis for advice (see the section on "Biological Reference Points" below).

Recruitment

Recruitment to the North Sea haddock stock is very sporadic, and is characterised by occasional large year classes interspersed by several years of poor recruitment. The reasons for this are unknown. It is likely (see ICES-WKBENCH 2011) that larval haddock spawned to the West of Scotland (Division VIa) settle as demersal juveniles in the northern North Sea, before (possibly) returning west to spawn subsequently.

B.3. Surveys

Five survey-series are used in the assessment of North Sea haddock. The survey data used in the 2010 assessment are summarised below:

Country	Fleet	Quarter	Code	Year range	Age range available	Age range used
Scotland	Groundfish survey	Q3	ScoGFS Aberdeen Q3	1982–1997	0–8	0–7
	Groundfish survey	Q3	ScoGFS Q3 GOV	1998–2009	0–8	0–7
England	Groundfish survey	Q3	EngGFS Q3 GRT	1977–1991	0–10+	0–7
	Groundfish survey	Q3	EngGFS Q3 GOV	1992–2009	0–10+	0–7
International	Groundfish survey	Q1	IBTS Q1 (backshifted)	1982–2010	1–5+	1–4

The Scottish and English groundfish survey time-series are both split, to reflect changes in the vessel and gear used which are thought to have substantially affected survey catchability. The collated IBTS Q3 time-series, to which both ScoGFS Q3 and EngGFS Q3 contribute, is also available for the assessment but has not been used to date: the principal reason is that it was historically not available in time for the assessment working group meeting in September, but it also has a shorter time-series.

Data exploration

In recent assessments, exploratory data analysis using survey time-series has included:

1) Distribution plots by age and year.
2) Survey log cpue by age.
3) Log survey catch curves by cohort.

4) Bivariate correlations of survey indices by cohort, with fitted regression lines. That is, indices at age 0 are plotted against indices at age 1 for each cohort, then age 0 against age 2, and so on for all age combinations.
5) Results of SURBA model fits (Needle, 2003). These give estimated mean *Z*, relative SSB and relative recruitment trends, along with confidence intervals.

B.4. Commercial cpue

Commercial cpue (or lpue) data are not used for tuning the final assessment. During preparations for the 2000 round of assessment WG meetings it became apparent that the 1999 effort data for the Scottish commercial fleets were not in accordance with the historical series and specific concerns were outlined in the 2000 report of WGNSSK (ICES-WGNSSK 2001). Effort recording is still not mandatory for these fleets, and concerns remain about the validity of the historical and current estimates of commercial cpue. In addition, the lpue indices from Scottish commercial fleets presented at previous WGs (ScoLtr and ScoSei) can no longer be generated in that form due to changes in EU definitions of fishery métiers.

B.5. Other relevant data

No other relevant data have been used in the assessment to date.

C. Historical stock development

Model used as a basis for advice

The advice is based on assessments carried out using the XSA model (Shepherd, 1992; Darby and Flatman, 1994) implemented as the FLXSA module of the FLR library of the R statistical package. WKBENCH recommended that exploratory runs of both the SAM (Nielsen, 2010) and SURBA (Needle, 2003) also be carried out each year to confirm (or otherwise) the indications of stock dynamics from the update XSA run.

Model options chosen

XSA/FLXSA model settings used in the WGs from 2007 to 2010 were as follows:

ASSESSMENT YEAR		2007	2008	2009	2010
Model		XSA	FLXSA	FLXSA	FLXSA
q plateau		6	6	6	6
F shrinkage		2.0	2.0	2.0	2.0
Power model ages		None	None	None	None
Plus-group		8	8	8	8
Tuning fleet year ranges	EngGFS Q3	77–91; 92–06	77–91; 92–07	77–91; 92–08	77–91; 92–08
	ScoGFS Q3	82–97; 98–06	82–97; 98–07	82–97; 98–08	82–97; 98–08
	IBTS Q1*	82–06	82–07	82–08	82–08
Tuning fleet age ranges	EngGFS Q3	0–7			
	ScoGFS Q3	0–7			
	IBTS Q1*	0–4			

*Backshifted.

The default update setting is that used in the 2010 WG, with the addition of extra years as required.

D. Short-term projection

Initial stock size

Deterministic starting populations taken from VPA survivors.

Maturity

Average of final three years of assessment data.

Natural mortality

Average of final three years of assessment data.

F and M before spawning

Both taken as zero.

Weight-at-age in the catch

Jaworski (in press) applied twenty different growth forecasting methods in a hindcast analysis, in which weights-at-age forecasts from 12 years ago were compared with the observed outcomes. The test statistics were the ratio of forecast to observed weights, and the variance of the forecast. There was a general tendency to overestimate weights in forecasts, while the most beneficial model, in terms of both test statistics, was a simple cohort-based linear model.

Jaworski's analysis provided an extensive hindcast testing procedure of a wide variety of methods for forecasting weights-at-age in North Sea haddock, and explored the issue in far more depth and breadth than had previously been possible. His conclusion on the method that generates the estimate with the least bias and variance appears to be robust and has been extensively peer-reviewed. Therefore, WKBENCH recommended that weights-at-age for North Sea haddock forecasts be modelled using a linear cohort-based approach. Weights-at-age *a* for cohort *c* are fit with the linear model.

$$W_{a,c} = \alpha_c + \beta_c a$$

where parameters α_c and β_c are cohort-specific. For recent cohorts, for which there are fewer than two data points, weights-at-age are taken as an average of three previous weights at the same age (as estimates of α_c and β_c cannot be generated for these cohorts).

Weight-at-age in the stock

These are assumed to be the same as weight-at-age in the catch. A future benchmark should consider the use of weights-at-age measured during research-vessel surveys for stock weights.

Exploitation pattern

Fishing mortalities for forecasts are taken to be a three-year average scaled to the final year. WGNSSK in 2010 concluded that fishing mortality in 2010 was likely to be at a similar level to that estimated for 2009, and used a scaled average to reduce the effect of uncertainty in that 2009 estimate.

Intermediate year assumptions

The available haddock quota has generally not been fully utilized in the past, and a TAC constraint on the forecast has not been thought to be necessary. However, uptake has started to increase, and in 2010 it was observed that segments of the Scottish demersal fleet did exhaust their quota (probably due to further restrictions in cod catching). Therefore, in future assessments it will be necessary to reconsider the question of whether a TAC-constrained forecast is required.

Stock–recruitment model used

North Sea haddock shows no detectable influence of stock size on subsequent recruitment. In addition, there are no observed indications of incoming year-class strength available to WGNSSK. The ScoGFS and EngGFS Q3 survey indices are not yet available at the time of the assessment meeting. The IBTS Q1 indices are available, but do not include age-0 recruiting fish as these are too small to be caught (or are not yet hatched) when the survey takes place. For this reason, recruitment estimates of the incoming year class are based on a mean of previous recruitment.

In the past, a strong haddock year class has generally been followed by a sequence of low recruitments. In order to take this feature into account, the geometric mean of the five lowest recruitment values over the period from 1994 to $y – 3$ (where y is the year of the assessment WG) has been assumed for recruitment in the years y, $y + 1$ and $y + 2$. Recruitment estimates for years $y – 2$ and $y - 1$ are not included in this calculation, because the most recent two XSA estimates of recruitment are thought to be relatively uncertain.

Procedures used for splitting projected catches

Three year average of catch component ratios.

E. Medium-term projections

Medium-term projections, in the sense of biological simulations assuming fixed mortality, are no longer carried out for this stock on an annual basis. However, management simulations are regularly performed to evaluate management plan proposals, and these are similar in some ways to medium-term projections (see Section A.2.1 above).

F. Long-term projections

Yield and spawning–stock-biomass per recruit analyses are carried out for this stock as part of the annual assessment process. The MFYPR software is used for this purpose.

G. Biological reference points

The Precautionary Approach reference points for cod in IV, IIIa (Skagerrak) and VIId have been unchanged since 2007. They are:

	TYPE	VALUE	TECHNICAL BASIS
Precautionary approach	B(lim)	100 000 tonnes	Smoothed B(loss)
	B(pa)	140 000 tonnes	B(pa) = 1.4 * B(lim) (*)
	F(lim)	1.0	F(lim) = 1.4 * F(pa) (*)

	F(pa)	0.7	10% probability that SSB(MT) < B(pa)
Targets	F(HCR)	0.3	Based on HCR simulations and agreed in the management plan

***The multiplier of 1.4 is derived from exp(σ²), where σ² ~ 0.34 is intended to reflect the variability of the time-series concerned (B or F).**

In its report of January 2011, WKBENCH recommended that the biological reference points for North Sea haddock be revised in time for the 2011 advisory round: "If the proposed new assessment (with time-varying natural mortality and maturity estimates) is accepted for use in subsequent updates, WKBENCH recommends that biomass and fishing mortality reference points and management strategy evaluations be revisited and potentially updated." The use of revised maturity values without due consideration of concomitant changes in fecundity and reproductive potential could result in misleading advice, and WKBENCH concluded that reference points based on reproductive potential would probably serve the advisory process best. This issue will be revisited in time for the WGNSSK meeting in May 2011.

Yield and spawning biomass per recruit reference points

The estimation of MSY and F_{msy} was first carried out by WGNSSK in 2010. A total of nine estimates were provided, each with associated confidence limits. The principal model used was an equilibrium age-structured model, described below: analyses were also conducted using an ADMB implementation and FLR modules, but these are widely available and are not further described here.

This implementation was developed in the Marine Laboratory, Aberdeen, and is coded in R. It was used to generate F_{msy} estimates for the WKFRAME meeting (ICES-WKFRAME 2010), and the following text is adopted from that report.

F_{msy}, B_{msy} and MSY can be calculated for any given stock, using a combination of fitted stock–recruit, yield-per-recruit and SSB-per-recruit curves. The estimation proceeds as follows:

1) Draw a stock–recruit plot: that is, a curve illustrating the fitted relationship between recruitment R and spawning–stock biomass S. Denote this curve by $R = \mathbf{G}(S)$.

2) Draw a second plot, containing both yield-per-recruit and spawner-per-recruit curves. Denote these by $Y/R = \mathbf{H}(F)$ and $S/R = \mathbf{I}(F)$.

3) For any given F (say, F'), the corresponding point on the spawner-per-recruit curve is given by $S'/R' = \mathbf{I}(F')$.

4) Take the reciprocal, so that $R'/S' = 1/\mathbf{I}(F')$. This denotes the *slope* of a straight line on the stock–recruit plot, that passes through the origin and cuts the curve at $(S', \mathbf{G}(S')) = (S', R')$. Hence such a line on a stock–recruit plot does not specify directly a particular fishing mortality rate, but the reciprocal of its slope does.

5) Iterate through multipliers $E_i \in [0.0, 2.0]$, and hence fishing mortalities (since $F_i = E_i \times F_{sq}$). For any E_i, $R_i / S_i = 1/\mathbf{I}(F_i) = 1/\mathbf{I}(E_i \times F_{sq})$. This is the slope of the line on the stock–recruit plot that intersects the stock–recruit curve at (S_i, R_i).

6) The yield-pre-recruit curve is written as $Y/R = \mathbf{H}(F)$. From this we can obtain yield $Y = R \times \mathbf{H}(F)$. For a given E_i, $Y_i = R_i \times \mathbf{H}(F_i) = R_i \times \mathbf{H}(E_i \times F_{sq})$. Plotting these for all *i* gives the yield curve $Y = \mathbf{J}(F)$, for which we can obtain F_{msy} by maximising:

$$F_{msy} = F \text{ such that } \frac{dY}{dF} = 0.$$

7) Note that the same procedure can be carried out for spawning biomass, so we can plot yield *Y* against spawner biomass *S* to estimate at what biomass yield is maximised.

The calculation is repeated for 1000 bootstrapped stock–recruit curves, which are obtained by sampling from a multivariate normal distribution determined by the variance-covariance matrix of the estimated stock–recruit model parameters.

The assumed form of the underlying stock–recruit curve is very influential in the derivation of Fmsy estimates, but is also very difficult to determine for North Sea haddock. The main drawback of this particular implementation is that it only includes the Ricker stock–recruit model so far, and thus does not permit evaluation of the sensitivity of Fmsy estimates to stock–recruit assumptions. It also does not yet allow for annual variation in biological parameters such as growth and maturity. On the other hand, it does carry out retrospective Fmsy estimation automatically.

H. Other issues

No other issues.

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Stock Annex: Haddock in Subareas I and II

Stock	Haddock in Subareas I and II (Northeast Arctic)
Working Group	Arctic Fisheries Working Group
Date	31.01.2011
Revised by	WKBENCH 2011/Alexey Russkikh (stock coordinator), Gjert Endre Dingsør

A. General

A.1. Stock definition

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

A.2. Fishery

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

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

In recent years Norway and Russia have accounted for more than 90% of the landings. Before the introduction of national economic zones in 1977, UK (mainly England) landings made up 10–30% of the total. Each country fishing for haddock and engaged in the stock assessment provide catch statistic annually. Summary sheets in the AFWG Report indicate total yield of haddock by Subareas I, IIa and IIb, as well as catch by each country by years. Catch information by fishing gear used by Norway in the haddock fishery is used internally when making estimations at AFWG meeting. Catch quotas were introduced in the trawl fishery in 1978 and for the fisheries with conventional gears in 1989. Since January 1997 sorting grids have been mandatory for the trawl fisheries in most of the Barents Sea and Svalbard area. Discarding is prohibited.

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

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

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

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

A.3. Ecosystem aspects

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

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

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

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

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

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

B. Data

B.1. Commercial catch

Norway

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

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

The age distribution and weight-at-age for the Norwegian catches were estimated using the software based on the method of Hirst *et al.* (2005). In this method, the three different types of available samples (age and weight samples, age and weight stratified by length groups, and length samples) are modelled simultaneously using a previously developed Bayesian hierarchical model (Hirst *et al.*, 2004). This method replaced the traditional method in 2006, and the time-series of Norwegian catch-at-age (early 1980s and onward) was updated based on the modelling approach. The old method involved allocating unsampled catches to sampled catches based on judgements on "distance criteria's" (in area, time and sometimes gear) and the use of ALK's to fill holes in the sampling frame.

Russia

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

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

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

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

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

Germany

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

Other nations

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

Table below shows which country supplied which kind of data:

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

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

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

The result files can be found at ICES (SharePoint) and with the stock co-ordinator as ASCII files on the Lowestoft format.

B.2. Biological

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

B.3. Surveys

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

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

The indices (RU-Aco-Q4) were not used for tuning the XSA due to a strong "year effect" observed in years with incomplete area coverage. This index needs further adjusting before it can be used for tuning. Based on internal consistency test the RU-BTr-Q4 index is used in tuning for ages 1–7.

Norwegian winter (February) survey (from 2000-Joint Barents Sea survey, NoRu-BTr-Q1 and NoRu-Aco-Q1)

The survey started in 1981 and covers the ice-free part of the Barents Sea. Both swept area estimates from bottom trawl and acoustic estimates are produced. The swept area estimates are used in the tuning for ages 1–8. The survey is described in Jakobsen *et al.* (1997) and Aglen *et al.* (2002).

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

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

1) swept area estimates from bottom trawl NoRu-BTr-Q1 for the period 1981–2010 (ages 1–10);
2) swept area estimates from acoustic NoRu-Aco-Q1 for the period 1981–2010 (ages 1–10).

For tuning XSA used: NoRu-BTr-Q1 for (ages 1–8) and NoRu-Aco-Q1 for ages 1–7.

Joint Norwegian-Russian Ecosystem survey (Eco-NoRu-Btr-Q3)

The bottom-trawl estimates from the joint ecosystem survey in August–September, starting in 2004. This survey covers a larger portion of the distribution area of haddock. The new index Eco-NoRu-Btr-Q3 for period 2004–2009 ages 1–8 became available for AFWG 2010. This time-series have been tested as new tuning fleet in XSA and it was found that the index was acceptable for use in the NEA haddock assessment.

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

B.4. Commercial cpue

Russia

No Russian data are used in the stock assessment.

Norway

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

B.5. Other relevant data

Not used.

C. Assessment: data and method

Model used: XSA

Software used: FLR suite and VPA95 suite

Model Options chosen:

Tapered time weighting applied, power = 3 over 20 years

Catchability independent of stock size for ages >9

Catchability independent of age for ages >= 9

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

S.E. of the mean to which the estimate are shrunk = 0.500[2]

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

Prior weighting not applied

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[2] the low shrinkage value adopted (i.e. 0.5) may cause underestimation/overestimation of stock in situations when strong trends occur. It is recommend that AFWG evaluate the appropriateness of this value in such situations and to change this setting to higher value if needed.

Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1950–last data year	1–11+	Yes
Canum	Catch-at-age in numbers	1950–last data year	1–11+	Yes
Weca	Weight-at-age in the commercial catch	1983–last data year	1–11+	Yes, set equal to west for 1950–1982
West	Weight-at-age of the stock at start of year.	1950–last data year	1–11+	Yes
Mprop	Proportion of natural mortality before spawning	1950–last data year	1–11+	No-set to 0 for all ages in all years
Fprop	Proportion of fishing mortality before spawning	1950–last data year	1–11+	No-set to 0 for all ages in all years
Matprop	Proportion mature-at-age	1950–last data year	1–11+	Yes, set equal to average for 1950–1980
Natmor	Natural mortality	1950–last data year	1–11+	Includes annual est. of predation by cod from 1984, otherwise set to 0.2 for all ages in all years

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1 (RU-BTr-Q4)	Russian bottom trawl survey, October–December	1983–last data year	1–7
Tuning fleet 2 (BS-NoRu-BTr-Q1)	Joint Norwegian-Russian trawl survey, February	1982–last data year	1–8
Tuning fleet 3 (BS-NoRu-Aco-Q1)	Joint Norwegian-Russian Acoustic survey, February	1980–last data year	1–7
Tuning fleet 4 (Eco-NoRu-Btr-Q3)	Joint Norwegian-Russian Ecosystem survey	2004–last data year	1–8

D. Short-term projection

Model used: Age structured

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

Initial stock size: Estimated in XSA as abundance of individuals that survive the terminal year for age 3 and older.

Recruitment at age 3 for the start year and the two consecutive years is estimated from survey data in RCT3.

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

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

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

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

Weight-at-age in the catch and natural mortality: show strong patterns related to periods of good recruitment. The Working Group believes that the estimated recruitment in the most recent years is so high that it will affect growth. The Working Group therefore decided to use similar trends in weight-at-age, and natural mortality as has been observed in previous periods following good recruitment.

Exploitation pattern: For current year it is taken to be at the level of previous year ($F_{Status\ quo}$) or to be equal to average for the recent three years; for subsequent years method used to determine this parameter and its substantiation are given in the AFWG Reports. In 2010 the average fishing pattern observed in the three last years, scaled to F status quo was used for distribution of fishing mortality-at-age for 2010–2012.

Intermediate year assumptions:

Stock–recruitment model used: None

Procedures used for splitting projected catches: Not relevant

E. Medium-term projections

Not used in assessment.

F. Long-term projections

Not used in assessment.

G. Biological reference points

	Type	Value	Technical basis
MSY	MSY Btrigger	Not defined	
Approach	FMSY	Not defined	
	Blim	50 000 t	Poor recruitment has resulted from SSBs lower than 50 000 t; all moderate or large year classes have been produced at higher SSBs.
Precautionary	Bpa	80 000 t	Blim*1.67
Approach	Flim	0.49	Median value of Floss
	Fpa	0.35	Fmed

H. Other issues

H.1. Historical overview of previous assessment methods

Summary of data ranges used in recent assessments:

Data	2006 assessment	2007 assessment	2008 assessment	2009 assessment	2010 assessment
Catch data	Years:1950–2005 Ages: 1–11+	Years: 1950–2006 Ages: 1–11+	Years: 1950–2007 Ages: 1–11+	Years: 1950–2008 Ages: 1–11+	Years: 1950–2009 Ages: 1–11+
Cod consumption data	Available: Years 1984–2005 Ages: 0–6 Used ages: 1–6	Available: Years1984–2006 Ages: 0–6 Used ages: 1–6	Available: Years1984–2007 Ages: 0–6 Used ages: 1–6	Available: Years1984–2008 Ages: 0–6 Used ages: 1–6	Available: Years1984–2009 Ages: 0–6 Used ages: 1–6
Fleet 01 Survey: RU-BTr-Q4	Available: Years1983-2005 Ages 0+ 9 Used 1991-2005 ages: 1–7	Available: Years1983-2006 Ages 0+ 9 Used 1991-2006 ages: 1–7	Available: Years1983-2007 Ages 0+ 9 Used 1991-2007 ages: 1–7	Available: Years1983-2008 Ages 0+ 9 Used 1991-2008 ages: 1–7	Available: Years1983-2009 Ages 0+ 9 Used 1991-2009 ages: 1–7
Fleet 02 Survey: NoRu-Aco-Q1	Available: Years1980-2006 Ages 110+ Used: shifted 1990-2005 ages: 1–7	Available: Years1980-2007 Ages 1 10+ Used: shifted 1990-2006 ages: 1–7	Available: Years1980-2008 Ages 1 10+ Used: shifted 1990-2007 ages: 1–7	Available: Years1980-2009 Ages 1 10+ Used: shifted 1990-2008 ages: 1–7	Available: Years1980-2010 Ages 1 10+ Used: shifted 1990-2009 ages: 1–7
Fleet 04 Survey: NoRu-BTr-Q1	Available: Years1982-2006 Ages 1 10+ Used: shifted 1990-2005 ages: 1–8	Available: Years1982-2007 Ages 1 10+ Used: shifted 1990-2006 ages: 1–8	Available: Years1982-2008 Ages 1 10+ Used: shifted 1990-2007 ages: 1–8	Available: Years1982-2009 Ages 1 10+ Used: shifted 1990-2008 ages: 1–8	Available: Years1982-2010 Ages 1 10+ Used: shifted 1990-2009 ages: 1–8

Harvest control rule

The harvest control rule (HCR) was evaluated by ICES in 2007 (AFWG 2007) and found to be in agreement with the precautionary approach. The agreed HCR for haddock is as follows (Protocol of the 36th Session of The Joint Norwegian Russian Fishery Commission, 10 October 2007):

- TAC for the next year will be set at level corresponding to F_{pa}.
- The TAC should not be changed by more than +/-25% compared with the previous year's TAC.
- If the spawning stock falls below B_{pa}, the procedure for establishing TAC should be based on a fishing mortality that is linearly reduced from F_{pa} at B_{pa} to F= 0 at SSB equal to zero. At SSB-levels below B_{pa} in any of the operational years (current year and a year ahead) there should be no limitations on the year-to-year variations in TAC.

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

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Stock Annex: North Sea Saithe (Subarea IV, Division IIIa and Subarea VI)

Stock	Saithe in Subarea IV (North Sea) Division IIIa West (Skagerrak) and Subarea VI (West of Scotland and Rockall)
Working Group	WGNSSK
Date	January 2011
Revised by	WKBENCH/ Irene Huse

A. General

A.1. Stock definition

The saithe stock is defined to be a single stock in ICES Subarea IV, Division IIIa and Subarea VI. The stock assessment is done accordingly.

A.2. Fishery

Saithe in Subarea IV, Division IIIa and Subarea VI (referred to here as *North Sea saithe* for brevity) are mainly taken in a direct trawl fishery in deep water along the Northern Shelf edge and the Norwegian Trench. Norwegian, French, and German trawlers take the majority of the catches. In the first quarter of the year the fisheries are directed towards mature fish in spawning aggregations, while concentrations of immature fish (age 3–4) often are targeted during the rest of the year. A small proportion of the total catch is taken in a limited purse-seine fishery along the west coast of Norway targeting juveniles (age 2–4). In the Norwegian coastal purse-seine fishery inside the 4 nm limit (south of 62°N), the minimum landing size is 32 cm.

The main fishery developed in the beginning of the 1970s. The fishery in Subarea VI consists largely of a directed French, German, and Norwegian deep-water fishery operating on the shelf edge, and a Scottish fishery operating inshore. In recent years the French fishery has deployed less effort along the Norwegian Trench. There seems to have been a temporal change in the Norwegian fishery, and more of the effort is now in the 2nd quarter. The German fleet in the last few years has concentrated almost all of its effort in the shallow waters south of southern Norway.

Since the fish are distributed inshore until they are about three years old, discarding of young fish is assumed to be a small problem in this fishery. However, low prices and mixed catches might lead to high grading. In fleets that are targeting saithe, the quota is less limiting, and the problem may be less in these fleets. Norwegian legislation requires the Norwegian trawlers to move out of the area when the boat quotas are reached, and in addition, the fishery is closed if the seasonal quota is reached.

In 2009 the landings were estimated to be around 105 529 t in Subarea IV and Division IIIa, and 6963 t in Subarea VI, which are both well below the TACs for these areas (125 934 and 13 066 t respectively). Significant discards are observed only in Scottish trawlers. However, as Scottish discarding rates are not considered representative of the majority of the saithe fisheries, these have not been used in the assessment. Ages 1 and 2 are mainly distributed close to the shores and are very scarce in the main fishing areas for saithe.

Conservation schemes and technical conservation measures

Management of saithe is by TAC and technical measures. The available kw-days at sea for community vessels are restricted via the cod management plan (Council regulation 1342/2008). Only some vessels were exempted from these effort restrictions in 2009 due to low bycatch (<1.5%) of cod. In the Norwegian zone (south of 62°N) the current minimum landing size is 40 cm, while in the EU zone it is 35 cm. Discards are not allowed in the Norwegian zone. Minimum mesh size in the in the Norwegian zone is 120 mm for Norwegian trawlers, and 110 mm for community vessels.

A.3. Ecosystem aspects

The geographical distributions of juvenile (< age 3) and adult saithe differ. Typical for all saithe stocks are the inshore nursery grounds. Juvenile saithe in the North Sea are therefore mainly distributed along the west and south coast of Norway, the coast of Shetland and the coast of Scotland. At around age 3, the individuals gradually migrate from the coastal areas to the northern part of the North Sea (57°N–62°N).

The age at first maturity is between 4 and 6 years, and spawning takes place in January–March at about 200 m depth along the Northern Shelf edge and the western edge of the Norwegian Trench. Larvae and post-larvae are widely distributed in Atlantic water masses across the northern part of the North Sea, and around May the 0-group appears along the coasts (of Norway, Shetland and Scotland). The mechanisms behind the 0-group's migration from oceanic to coastal areas remain unknown, but it seems like they are actively swimming towards the coasts. The west coast of Norway is probably the most important nursery ground for saithe in the North Sea.

When saithe exceeds 60–70 cm in length the diet changes from plankton (krill, copepods, fish larvae) to fish (mainly Norway pout, blue whiting, haddock and herring). Large saithe (>70 cm) have a highly migratory behaviour and the feeding migrations extend from far into the Norwegian Sea to the Norwegian coast.

Tagging experiments by various countries have shown that exchange takes place between all saithe stock components in the northeast Atlantic. In particular, exchange between the saithe stock north of 62°N (Northeast Arctic saithe) and saithe in the North Sea has been observed.

A sharp decline in the mean weight-at-age was observed from the mid-1990s, but now seems to be halted. There is insufficient information to establish whether this decline is linked to changes in the environment. The reduced growth rates have an effect on stock productivity and the consequences need to be further explored. However, there are no indications that the observed decline in weight-at-age is density-dependent.

The impact of a large saithe stock on prey species such as Norway pout and herring is unknown. Poor spatial and temporal sampling of stomach data of saithe makes the estimation of the saithe diet uncertain.

B. Data

B.1. Commercial catch

Landings-at-age data by fleet are supplied by Denmark, Germany, France, Norway, UK (England), and UK (Scotland) for Subarea IV and only UK (Scotland) for Subarea VI.

In the data provided, landings from the industrial fleet are only specified when saithe is delivered separately, and therefore bycatch of saithe that has not been separated from the bulk catch will not be reported as saithe.

B.2. Biological

Weight-at-age

Weights-at-age in the landings are measured weights from the various national observer programmes, reference fleet and market sampling programs. These weights are also used as stock weights. There has been a decreasing trend in mean weights from the mid-1990s for ages 4 and older, but the decline now seems to be halted.

Natural mortality

A natural mortality rate of 0.2 is used for all ages and years.

Maturity

Following maturity ogive is used for all years:.

Age	1	2	3	4	5	6	7+
Proportion mature	0.0	0.0	0.0	0.15	0.7	0.9	1.0

B.3. Surveys

Three Surveys are available:

- Norwegian acoustic survey, 1995–present (NORACU)
- IBTS quarter 3, age range: 1991–present (IBTS-Q3)
- Norwegian acoustic survey for saithe, 2006–present (NORASS)

B.4. Commercial cpue

Three commercial tuning-series are available:

- French demersal trawl, age range: 3–9, year range 1990-present (“FRATRB”)
- German otter trawl, age range: 3–9, year range 1995– present (“GEROTB”)
- Norwegian bottom trawl, age range: 3–9, year range 1980–present (“NORTRL”)

  (Part 1: 1980–1992, part 2: 1993–present)

C. Assessment: data and methods

Model used: XSA (Darby and Flatman, 1994)

Software used: FLXSA

Model Options chosen:

Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1967–present	3–10+	No

Canum	Catch-at-age in numbers		
Weca	Weight-at-age in the commercial catch		
West	Weight-at-age of the spawning stock at spawning time.		
Mprop	Proportion of natural mortality before spawning		
Fprop	Proportion of fishing mortality before spawning		
Matprop	Proportion mature-at-age	See Section B2: maturity	No
Natmor	Natural mortality	See Section B2: Natural mortality	No

Tuning data:

Type	Name	Year range	Age range
FRATRB	French demersal trawl	1990–present	6–9
GEROTB	German otter trawl	1995–present	6–9
NORTRL	Norwegian bottom trawl	1980–present	6–9
NORACU	Norwegian acoustic survey	1995–present	3–6
IBTS-Q3	International bottom trawl survey in the North Sea, in the 3th quarter	1992–present	3–5
NORASS	Norwegian acoustic survey for saithe	2006–present	3–4

XSA settings:

Age range:	3–10+
Catch data:	1967–2006
F_{bar}:	3–6
Time-series weights:	Tricubic over 20 years
Power model for ages:	No
Catchability plateau:	Age 7
Survivor est. shrunk towards the mean F:	5 years/3 ages
S.e. of mean (F-shrinkage):	1.0
Min. s.e. of population estimates:	0.3
Prior weighting:	No
Number of iterations before convergence:	51

D. Short-term projection

Because the assessment on which the advice is based is currently a fully deterministic XSA, the short-term projection can normally be done in FLR using FLSTF. Weight-at-age in the stock and weight-at-age in the catch are taken to be the mean of the last three years. The exploitation pattern is taken to be the mean value of the last three years. Population numbers-at-ages 4 and older are XSA survivor estimates, numbers-at-age 3 are taken from the geometric mean for the years 1988–assessment year.

Model used:

Software used*:* FLSTF

Initial stock size: Population numbers-at-ages 4 and older are XSA survivor estimates, numbers-at-age 3 are taken from the geometric mean for the years 1988–assessment year.

Maturity:

F and M before spawning:

Weight-at-age in the stock: Mean of the last 3 years

Weight-at-age in the catch: Mean of the last 3 years

Exploitation pattern: mean value of the last three years

Intermediate year assumptions:

E. Medium-term projections

No medium-term projections are done for this stock.

F. Long-term projections

No long-term projections are done for this stock.

G. Biological reference points

	Type	Value	Technical basis
MSY	MSY $B_{trigger}$	200 000 t	Default value B_{pa}
Approach	F_{MSY}	0.30	Stochastic simulation using hockey-stick stock–recruitment
Precautionary approach	B_{lim}	106 000 t	B_{loss} = 106 000 t (estimated in 1998).
	B_{pa}	200 000 t	affords a high probability of maintaining SSB above B_{lim}
	F_{lim}	0.6	Floss the fishing mortality estimated to lead to stock falling below B_{lim} in the long term.
	F_{pa}	0.4	implies that $B_{eq} > B_{pa}$ and $P(SSB_{MT} < B_{pa}) < 10\%$.

Precautionary reference points were derived in 2006 and are:

$F_{0.1}$	0.10	F_{lim}	0.60
F_{max}	0.22	F_{pa}	0.40
F_{med}	0.35	B_{lim}	106 000 t
F_{high}	>0.49	B_{pa}	200 000 t

In 2010 the working group estimated the F_{MSY} to be 0.3. The F_{MSY} should be reanalyzed if changes are found in the maturity.

These reference points refer to an F_{bar} from ages 3 to 6. The proportion of catches taken by purse seine decreased significantly in the early 1990s. This caused a change in the exploitation pattern as the purse seiners mainly targeted young saithe. Therefore, it may be more appropriate to use a reference F that does not include age 3. The influence on the maturity ogive from the observed decrease in the weight-at-age is unknown, but it is reasonable to believe that the spawning capacity of the stock will be affected.

H. Other issues

H1. Historical stock development:

The settings in final XSA assessment for the years 2007 to 2010 are listed below. In 2011 WKBENCH meeting a new survey-series were included (NORASS, ages 3–4), and ages 3–5 of commercial tuning-series were excluded.

Year of assessment:	2007	2008	2009	2010
Assessment model:	XSA	no change	no change	No assessment
Fleets:	FRAtrb (age range: 3–9, 1990 onwards)	no change	no change	Not available
	GERotb (age range: 3–9, 1995 onwards)	no change	no change	
	NORacu (age range: 3–6, 1996 onwards)	no change	no change	Not available
	IBTSq3 (age range: 3–5, 1992 onwards)	no change	no change	Uncertain, no Norwegian effort
Age range:	3–10+	no change	no change	
Catch data:	1967–2006	1967–2007	1967–2008	1967–2009
Fbar:	3–6	no change	no change	
Time series weights:	Tricubic over 20 years	no change	no change	
Power model for ages:	No	no change	no change	
Catchability plateau:	Age 7	no change	no change	
Survivor est. shrunk towards the mean F:	5 years/3 ages	no change	no change	
S.e. of mean (F-shrinkage):	1.0	no change	no change	
Min. s.e. of population estimates:	0.3	no change	no change	
Prior weighting:	No	no change	no change	
Number of iterations before convergence:	51	47	47	No assessment was done

I. References

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Annex 6: Working documents

6.1. List of Working Documents presented to WKBENCH

Below is the list of working documents (WD) presented to WKBENCH. All the WD presented in the meeting and referred to in the report section and/or stock annexes are under Annex Section 6.2.

Available in Annex 6.2.	WD code	Title/subject	Authors	File name
Stock: Herring in Division Va (Icelandic summer-spawners)				
Yes	WKBENCH_her-vasu_2	The *Ichthyophonus hoferi* outbreak in the Icelandic summer-spawning herring stock during the autumns 2008 to 2010	Guðmundur Óskarsson and Jónbjörn Pálsson	WKBENCH2011_Her_vasu_WD2_Infection
Yes	WKBENCH_her-vasu_3	Icelandic summer-spawning herring: An analysis of the signals in the catch- and survey data and preliminary assessments	Asta Gudmundsdóttir	WKBENCH2011_Her_vasu_WD3_Exploration
Yes	WKBENCH_her-vasu_4	Assessment of the stock size of Icelandic summer spawn herring by time-series analysis.	Gudundur Gudmundsson	WKBENCH2011_Her_vasu_WD4_TSA
No	WKBENCH_her-vasu_5	Referencepoints and HCR.	Asta Gudmundsdóttir and Einar Hjorleifsson.	
Yes	WKBENCH_her-vasu_6	Predictions of whole body weight of Icelandic summer-spawning herring	Guðmundur Óskarsson	WKBENCH2011_Her_vasu_WD6_Weights

Available in Annex 6.2.	WD code	Title/subject	Authors	File name
Yes	WKBENCH _her-vasu_7	Stock assessment of Icelandic summer-spawning herring/ Analytical assessment with Colraine	Árni Magnússon	WKBENCH_HER_vasu_WD7_Coleraine
Yes	WKBENCH _her-vasu_WD8	Evaluation of the survey indices from the autumn/winter surveys of Icelandic summer-spawning herring	Guðmundur Óskarsson	WKBENCH2011_Her_vasu_WD8_SurveyIndices
Stock: Haddock in Subareas I and II (Northeast Arctic)				
Yes	WKBENCH11-had-arct -WD1	Inclusion of cod predation on haddock in the NEA haddock assessment	B. Bogstad	wd_1_had_arct_cod-haddock-predation
Yes	WKBENCH11-had-arct – WD2	Are there differences in length-at-age and weight-at-age of haddock between Norwegian and Russian survey data?	Harald Gjøsæter	WD2_had_arct Length-weight haddock Gjøsæter
Yes	WKBENCH11-had-arct – WD3	Recruitment prediction for NEA haddock	Gjert E. Dingsør	WD3_had_arct Recruitment prediction for NEA haddock
Yes	WKBENCH11-had-arct – WD4	XSA model settings for North-east Arctic haddock	Y.A. Kovalev and A.A. Tchetyrkin	WD 06_AFWG_2010 Norwegian biological sampling as basis for catch at age
Yes	WKBENCH11-had-arct – WD6	Data availability and critical gaps in knowledge in estimation of Catch-at-age for three stocks in the Norwegian Northeast Arctic fishery	Åge Fotland	WD4_had_arct XSA

6.2. Relevant Working documents at WKBENCH

Stock: Herring in Division Va (Icelandic summer-spawners)

The *Ichthyophonus hoferi* outbreak in the Icelandic summer-spawning herring stock during the autumns 2008 to 2010

ICES, WKBENCH 2011, WD Her-Vasu No. 2

by Guðmundur J. Óskarsson and Jónbjörn Pálsson, MRI, Iceland.

Abstract

An outbreak of *Ichthyophonus* infection in the Icelandic summer-spawning herring was first observed in November 2008; consequently a comprehensive research programme was launched to estimate its magnitude. These researches continued the two following autumns and winters. The infection rate in the adult part of the stock was estimated to be 32%, 43% and 37% during the autumns 2008–2010, respectively. All existing information from the literature indicate that the infection causes a dead within at maximum six months, while preliminary results for the Icelandic stock indicate that this could take some longer time. Estimates of infection in herring juveniles on the nursery grounds off the NW and N coast over the same period indicated further how widely distributed the infection and the source of the infection was. The consequences of the infection on the development of the stock size are apparent. The increase in the natural mortality has been estimated directly from the infection rate and the estimates should be used in analytical assessment of the stock, at least until the estimates can be verified with some stock assessment software packages some years after the outbreak ceases. Even if the prevalence of the infection is still high in the autumn 2010, there are indications that the outbreak could be vanishing.

Introduction

In November 2008, the Marine Research Institute (MRI) in Iceland was informed by the commercial fleet fishing on the Icelandic summer-spawning herring that the stock was seemingly infected by some parasite or had some disease. It was quickly identified by the Institute for Experimental Pathology of the University of Iceland and scientist at MRI as infection by the protozoan parasite *Ichthyophonus hoferi*.

There are several *Ichthyophonus* epidemics in herring known from the literature. For example in the early 1990s in the Norwegian spring-spawning herring and North Sea herring (both having prevalence of around 10%; Kramer-Schadt *et al.*, 2010; Patterson, 1996) and off the east coast of Canada during the years 1930–1931 (Gulf of Main with prevalence of around 70%; Lauckner, 1984) and 1954–1955 (Gulf of Saint Lawrence with prevalence of around 50%; Lauckner, 1984). *Ichthyophonus* is not only found in herring, it has been found in at least 80 different fish species (Lauckner, 1984). In North Sea there is for example, constant infection found in haddock and plaice at various levels and the same is off the east coast of Canada (Lauckner, 1984) and in plaice in Iceland (Jónbjörn Pálsson, personal data).

Herring get the infection by oral intake of resting spores of *Ichthyophonus*, which are either floating freely in the sea or inside of the herring's prey (Jones and Dawe, 2002). For example, *Ichthyophonus* has been found in *Calanus* species (Torgersen *et al.*, 2002; Lauckner, 1984), which are generally one of the most important prey species for herring. In the acid herring stomach, the spores are activated. They grow through the digestive tract wall and end in the blood vessels and circulate over the whole body. The parasite settles particularly in blood rich organs, such as the heart and kidney and start to produce more spores there that then circulates further around the body. This leads to an escalation in the infection within the fish and researches indicate that the fish will generally die within 100 days or at maximum within six months (Sinderman, 1958; McVicar, 1981) because of the infection. There seems to be a common conception that all herring infected by *Ichthyophonus* will die because of it (Sinderman, 1958; McVicar, 1981).

It is not well known what factors are responsible for setting off the epidemics. For example, researches on the Norwegian spring-spawning herring (Kramer-Schadt, *et al.*, 2010) and Pacific herring (Marty *et al.*, 2003) did not find relatedness between herring infection and stock size. The peaks in the infection of Norwegian spring-spawning herring were, however, found to be associated with strong year classes and overall good body condition (Kramer-Schadt *et al.*, 2010). The sea temperature could have some effects on the infection where culture experiments indicate that *Ichthyophonus* grows only at temperature from 3–20°C, with highest growth at 10°C (Sindermann and Scattergood, 1954, see in Lauckner, 1984). No clear indications have appeared that can answer what initiated the current *Ichthyophonus* epidemic in the Icelandic herring stock (Óskarsson and Pálsson, 2009).

As soon as the cause of the infection was discovered, a massive program was launched by MRI to estimate the magnitude of the infection in the stock. It involved both increased sampling from the catch of the commercial fleet and increased effort in research surveys. The objective here is to reveal the main results of these researches, including the spatial and temporal variation in magnitude of the infection and information about the nature and development of the infection over the winters as represented by the data.

As a background information, the Icelandic summer-spawning herring has in recent four decades been almost exclusively fished during the overwintering period of the stock or from around September through February. The highest catch rate is usually in November (ICES 2009; 2010). Since the autumn 2007 and to at least the autumn of 2010, most of the stock overwintered in relatively small areas west of Iceland, or in the northern part of the bay Breiðafjörður (Figure 1). Consequently, the fishery during this period was more or less limited to that area. This westerly distribution of the stock that started gradually from around 1995 is opposite to the easterly and south-easterly distribution of the stock that existed since the middle of the 1960s (Jakobsson, 1980; Óskarsson *et al.*, 2009a).

Material and methods

The samplings

The prevalence of the infection in the stock was estimated from data from two different sources, from catch samples and from research survey samples. It was requested by MRI that the fishing vessels would generally collect from every fishing operation with purse seine (or pelagic trawl if used) total 50 herrings and either freeze them onboard or deliver them fresh to MRI personnel. This procedure meant that if a vessel needed for example to use the purse-seine three times to fill the vessel, it would collect 3×50 herring. This approach was followed during the fishing seasons 2008/2009 to 2010/2011, but in some periods more samples were requested. That was for example in January to March 2010 when the fishing vessels had finished their fishing quota but to secure sampling over this period, an additional quota of 7 kt was given to the vessels with the obligation to deliver at least 10x50 fish sample from purse-seine fishery weekly during January and February.

Samples were also collected during the acoustic surveys with either pelagic- or bottom trawls (Table 1). In some cases purse-seine samples were obtained from fishing vessels operating in the same area at the same time. The main purposes of the research surveys were to get an estimate of the stock size using the acoustical instruments and to get estimates of the intensity of the *Ichthyophonus* infection in the stock, both the adult part and the juveniles. However, estimates of prevalence of *Ichthyophonus* infection in herring caught by purse-seine are considered more reliable than data from towed fishing gears where the probability of escape of healthy individuals is higher than infected and sick individuals (Holst, 1996). Therefore, we used data from purse-seine samplings in making predictions for the stock whenever possible and used only samples from pelagic- and bottom trawls for areas and periods where purse-seine samples were unavailable. Over this almost three years period, we have also learned that the catch size in the trawls have to be above certain size, or several tons, for the prevalence estimates to be comparable to purse-seine estimates, and therefore reliable. The actual catch size depends of course also on the towing time. Thus, the catch size is also considered when selecting samples where and when trawl samples are required. The infection estimates during these three seasons for the fishable part of the stock relies almost entirely on purse-seine samples while the estimates for the juveniles rely exclusively on trawl samples.

The juvenile surveys cover the considered main nursery grounds of the herring stock, or the fjords in NW Iceland and the fjords and bays off N Iceland. It has been observed that the abundance index of age-1 herring can be used to predict the future year-class strength, while not the age-2 index (Gudmundsdóttir *et al.*, 2007). It was considered to be a consequence of either different distribution of age-2 herring or less catchability, but since this is the case, only the age-1 indices are considered here. Generally, the boundaries between age-1 and age-2 herring followed Gudmundsdóttir *et al.* (2007), or herring <15 cm is set to age-1 and herring at 15 to 20 cm set to age-2. This was verified and adjusted with aging of the herring.

The total number of samples from the fishable stock over this period came to 598 and included 46 thousands individuals (Table 2). Samples of juvenile herring, or age-1, came to total 20 with total 1215 individuals and were as well constrained to the different years and areas (Table 4).

Analyses of the samples

All the traditional measurements and recordings were done on each sampled herring, consisting of: total length (cm), whole body weight (g), sex, maturity stage, ovarian weight (g), and age determined from scales (not for all the samples). In addition, the heart was removed for further examination. To determine if fish where infected by *Ichthyophonus* or not, the hearts were examined macroscopically under a dissecting microscope as recommended by ICES (1993). The hearts were classified into three different stages: Stage-0, uninfected; Stage-1, light infection (white cysts visible); Stage-2, serious infection (many cysts visible, often making the heart freckly, and the pericardium often connate to the heart). Finer classification of the hearts was done additionally by divide the Stage-2 into three stages according to their visual appearance (Óskarsson *et al.*, 2010), but they are not explored in this paper.

To obtain average inter-annual estimates of the infection in the fishable part, as well as the different year classes of the juveniles, the average infection estimates (i.e. prevalence of the infection) for the different areas were weighed with the abundance estimates (N_{total}) from the acoustic surveys, which gave the number of infected fish in the stock ($N_{infected}$). The corresponding estimate of natural mortality caused by the infection $M_{infected}$ was then determined as follows:

$$M_{infected} = -(\log_2(N_{total} - N_{infected}) - \log_2(N_{total})).$$

Results

The fishable stock

2008/2009

The *Ichthyophonus* infection determined from catch samples in Breiðafjörður (Figure 1), where most of the stock was found during the wintering in 2008/2009, was in the range of 14 to 72%, with average of 33.7% (SD=9.3, N=73). There were some variations in prevalence of the infection on a weekly basis over the observation period, ranging from 28.1 to 48.9% (Figure 2a). However, the proportion at stage 1 (light infection) decreased over the period (Figure 2a), with corresponding increase in proportion at stage 2 (serious infection). Apparently, there was a difference in prevalence of the infection among areas (Figure 3). The lowest prevalence was found off the SE coast near Breiðamerkurdjúp (in January 2009), but the highest near Keflavik (see locations in Figure 1).

The total infection in the adult stock during the winter 2008/2009 was estimated from data of heart inspection of 4957 individuals and abundance estimations from the acoustic measurements in the December and January surveys (Table 3a). The ratio between the total number of individuals and number of infected individuals in the stock provided estimation of 32.2% infection rate which corresponds to $M_{infected}$= 0.39.

When exploring all available data from Breiðafjörður, there was no systematic difference among the age groups or the length groups in prevalence of infection (Figure 4). There was some indication for higher prevalence of infection for age 6 and for length 27 and 28 cm, but there is not a consistency there because fish at age 6 is all above 30 cm in length.

2009/2010

The purse-seine catch samples in Breiðafjörður, (Figure 1) where most of the stock was found during the wintering in 2009/2010, indicated that the *Ichthyophonus* infection was in the range of 30 to 73%, with overall estimate of 44.4% (SD=9.8, N=58). The prevalence of the infection did not change much on a weekly basis over the observation period and was in the range of 36 to 56% (Figure 2b). However, the proportion at stage 1 (light infection) decreased over the period (Figure 2b), with corresponding increase in proportion at stage 2 (serious infection). It should be noted that the sampling in January and February was based on the research catch quota so the number of stations was generally lower in each period then (1 to 3) but the number of samples per station was higher (300 to 500).

Different from 2008/2009, there was a clear linear decline in prevalence of infection as the fish was older and larger (Figure 5), particularly for fish >27 cm (r^2=0.955, n=9, p<0.001; arc-sine transformed) and >3 years old (r^2=0.851, n=8, p<0.01; arc-sine transformed). Herring at length ≤27 cm and age ≤3 year had on average infection of 54.6% and 49.6%, respectively. Thus, the prevalence of the infection was highest for the youngest and the smallest fish but lowest for the oldest and largest fish.

The bases for the determination of the total infection in the adult stock during the winter 2009/2010 and the subsequent mortality rate, were heart inspection of 5856 individuals and abundance estimates from the acoustic measurements in the October surveys (Table 3b). Apparently, there was a difference in prevalence of the infection among areas, with the lowest estimates in Breiðamerkurdjúp off the SE coast. Because of the observed length dependent infection rate in Breiðafjörður (Figure 5), the total infection in the stock was also calculated for the different age groups separately (Table 4). The estimated proportion infected in the whole fishable stock (>26 cm) was 43.0%, which corresponds to $M_{infected}$= 0.56.

2010/2011

The prevalence of the infection in the autumn 2010 was a similar level as the two previous fishing seasons, or on average 37.4% (Table 3 and Figure 2c), which corresponds to $M_{infected}$=0.41. This estimate for this season should be regarded as preliminary figures as the catch samples collected have not all been analysed. It includes that the data will be analysed to determine if the prevalence of the infection is length/age dependent as in 2009/2010 or not as in 2008/2009. It is clear that the proportion of lightly infected herring (Stage 1) is lower now in the beginning of the seasons compared to two previous years, indicating that the infected herring has further developed infection the autumn 2010.

The juveniles

2008/2009

The 2007 year class, at age-1, was observed in the highest number in Skjálfandi (Figure 1) and in that area no *Ichthyophonus* infection was observed in the herring (Table 5a). In other areas, the abundance was lower with often high prevalence of infection. The estimated strength of the 2007 year-class index, when the mortality due to the infection has been accounted for comes therefore to 516 million individuals.

2009/2010

The 2008 year class was in the highest number in Eyjafjörður and had overall low prevalence of *Ichthyophonus* infection, or around 4% (Table 5b). The estimated strength of the 2008 year-class index, when the mortality due to the infection has been accounted for, is 758 million individuals.

2010/2011

The abundance estimate of the 2009 year class was low compared to the two previous years (Table 5c) and in a historical perspective (Guðmundsdóttir *et al*., 2007). The highest estimate of the 1 year olds was from Eyjafjörður as the winter before. The prevalence of the infection was also low or 0.8% and it means that the year-class strength index is estimated to be 85 million individuals.

Discussion

The fishable stock

The results show that the *Ichthyophonus* outbreak in the Icelandic summer-spawning herring since it was first detected in the autumn 2008 and until the winter 2010/2011 is serious and have had and will have further affects on the stock development in the coming years. There are several assumptions that we have made when interpreting the data. Two of the assumptions are discussed below (in the section "Implications to the stock assessment") and another involves that we have interpreted the data as there is no new infection occurring in Breiðafjörður during the overwintering, meaning that the herring is already infected when entering the overwintering areas. That is based on our observations of: (1) near a constant proportion of uninfected herring throughout the season (Figure 2a–c); (2) the resting spores that distribute the infection must be eaten in one way or another to be activated (i.e. need an acid environment; Spanggard *et al.*, 1995) but the herring is not feeding during the overwintering period. We further suggest that the main mortality takes place late in the winter or early spring but to an insignificant degree on the overwintering grounds. It is supported by (1) no indications of mass mortality over the winter on the overwintering grounds; (2) seemingly development of infection according to the time-series where fish are going from stage-1 to stage-2 through the winter (Figure 2a–c); (3) finer scaling of the stage-2 (divided into three stages on the basis of the development of the infection) does not indicate a high mortality rate until in the late winter (Óskarsson *et al.*, 2010). An alternative hypothesis regarding the development of the infection and the corresponding mortality is that fish is dying because of the infection throughout the season. To compensate for the removal of fish because of the mortality so the ratio of uninfected fish would be near constant as observed (Figure 2a–c), fish would have to get infected on the overwintering grounds (i.e. new infection). According to this hypothesis, the mortality because of the infection would, for an example, explain the observed almost a linear decrease in abundance of herring in Breiðafjörður between four acoustical estimations undertaken from October 2009 to February 2010 (Óskarsson *et al.*, 2010). Thus, the hypothesis implies that there is a massive mortality ongoing through the season, but observations from divers during the winter 2008/2009 did not support that as very few dead fish were found lying on the bottom. A mass mortality of infected herring was observed in the end of March 2009 in Vestmannaeyjar harbour, off the south coast, while no mortality had been observed there during the winter. Related to this, several tips were given to MRI regarding dying herring on shores in the winter 2008/2009 and they came all in March or thereafter. Furthermore, as mentioned above if the alternative hypothesis is true, then the difference between the abundance estimations in October 2009 and February 2010 mentioned above (Óskarsson *et al.*, 2010) is mainly because of the mortality caused by the infection (54% lower abundance estimate) and happening between the measurements. However, in February 2010, the prevalence of the infection was still around 43% which indicated that a further mortality was going to take place. This would also apply for the winter 2008/2009, but such a drastic decline in the stock (~55%) was not observed in the acoustic measurements between the two winters. Thus, even if the alternative hypothesis cannot be fully rejected and could logically be correct, we find no support for its existence. On the other hand, the data and observations support our interpretation, which indicate that the herring got the infection during the post-spawning feeding season (~August–September) and during the pre-spawning feeding season (~April–June) but not on the overwintering grounds. The infection develops over the winter months and the mortality because of it takes then place in the spring from March and onwards. The reasons for the drop in the acoustic measurements throughout the winter 2009/2010 are therefore not believed to be consequences of the mortality but because of changes in distribution and/or behaviour of the stock (see further in Óskarsson *et al.* (2010) and an internal report at MRI by G. Óskarsson, R. Pálsson and Á. Gudmundsdóttir (2009)). Moreover, there was a low proportion of seriously infected fish (near the end of Stage 2, around 5%; Óskarsson *et al.*, 2010) in the period between October and November measurements, but should have been at least 22% to compensate for the drop in the acoustic measurements.

The proportion of lightly infected herring (Stage 1) was relatively low in the autumn 2010 in comparison to the two earlier autumns (Figure 2a–c). It could indicate that the stock was not getting infection during the late summer, meaning that the infection outbreak could be retrieving. Supporting this was the observation of the 2007 year class in Breiðamerkurdjúp in the autumn 2010 with almost no infection (1%). This pattern of generally a sincere developed infection in the autumn 2010 was also observed in the younger age groups on the nursery grounds off W and N Iceland. However, the surface waters off the south and west coast off Iceland were exceptional warm during the summer 2010 mainly related to stable and strong thermocline due to calm weather condition. Thus, it is possible that warmer seawater was simply speeding up the development of the infection in the herring, considering that the *Ichthyophonus* growth is temperature dependent (Sindermann and Scattergood, 1954, see in Lauckner, 1984). The question if the *Ichthyophonus* outbreak in the stock is coming to an end in the winter 2010/2011 will therefore not be answered with any confident until the summer 2011.

In the beginning of July during the summer 2009 and 2010, acoustic surveys were conducted on the spawning grounds of the stock off the SW, S, and SE coast to estimate the infection rate and for acoustic measurements (MRI, internal survey reports). The prevalence of the infection of the pre-spawning herring was near 30% in the both summers, where half of the herring was considered lightly infected (Figure 6). The infection detected in the summer months has been considered to be either also determined in the winter before or the subsequent autumn. In other words, the assumption has been made that only one generation of the infection exists in the stock over a year and it is most adequately estimated during the overwintering of the stock. It is based on observations from the time-series of the infection (Figure 6), the incubation period of the infection of minimum six months (Figure 6; Óskarsson *et al.*, 2010), and the difference among acoustic abundance measurements of the stock between adjoining winters that is less than mortality of all this infection would cause, i.e. one generation during the summer and another during the winter (ICES, 2010). This is discussed further below.

The juveniles

The number of age-1 herring estimated acoustically on the nursery grounds off NW and N Iceland has been found to be a valid index to predict the number at age 2 in the stock a year later (Gudmundsdóttir *et al.*, 2007). Consequently, it was important to estimate the prevalence of the infection of the juveniles during the outbreak and along with the abundance estimates they provide the indices of age-1 herring. However, it must be considered that the relationship between the abundance index of age-1 and number at age-2 was determined from years with no *Ichthyophonus* infection and the infection now that is observed in all age groups (Óskarsson *et al*., 2009b; 2010) can lead to lower number at age-2 than predicted from the relationship.

Considering infection rate of the adults and the juveniles, beside that the juveniles are probably rather stationary in the fjords that they drifted in as larvae, it is obvious that the source of the infection reached over a wide area, or from the SE coast and clockwise to the NE coast of Iceland (Óskarsson and Pálsson, 2009).

Implications to the stock assessment

The results are considered to provide a valid estimate of the prevalence of the infection during the autumns and overwintering of the stock. There is an uncertainty related to the number of generations of the infection over the year. However, when considering both that the time from a herring gets infected until it dies because of it seems to be minimum six months and the herring stock is seemingly only getting infected when feeding on the feeding grounds, the assumption of one generation of infection in the stock over the year seems reasonable. In other words, at this point there are no indications to suggest that the infection rate estimated over the summer period, during spawning (Figure 6), should be used additionally to the infection rate measured during the overwintering when estimating the total mortality caused by the infection inter annually. Another important assumption made, which is supported by the literature and observations on the Icelandic summer-spawning herring over the infection period, is that all infected herring will die because of it within in several months. The two assumptions above imply that the mortality rate over the year because of the infection is considered to be well represented by the estimates of the prevalence of the infection during the overwintering of the stock. Yet another uncertainty involves if mortality because of the infection, $M_{infection}$, should be added to the fixed natural mortality of the stock, M=0.1, used in the analytical assessment. Presently there is no way to verify it either numerically or biologically, so it is considered appropriate to add $M_{infection}$ to the M=0.1 to come up with the M used in the assessments. This procedure exemplifies how the stock was assessed in the stock assessments in 2009 and 2010 (ICES 2009; 2010). It means that M for 2008, 2009 and 2010 in the future stock assessments should be as indicated for $M_{infection}$ in Table 3 and Table 4 in addition to the fixed M of 0.1. Finally, it is suggested to estimate M for these years retrospectively and independently in about five years from now by means of VPAs or TSA (time-series analyses).

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Table 1. Overview of the research surveys since the autumn 2008 to 2010 and aimed for acoustic measurements of Icelandic summer-spawning herring and estimation of the *Ichthyophonus* infection in the stock.

Year	Vessel	Period	Survey No.	Area	Main target
2008	RV Dröfn	Dec. 5–17	1	SW and W coastal areas	Adults and juveniles
2008	RV Bjarni Sæmundsson	Dec. 7–11	2	SW and W off Iceland	Adults
2009	RV Dröfn	Jan. 18–30	3	N coastal areas	Juveniles
2009	RV Dröfn	Feb. 21–22	4	Breiðafjörður	Adults
2009	RV Árni Friðriksson	Feb. 4–6	5	E and SE off Iceland	Adults
2009	RV Bjarni Sæmundsson	Jul. 3–12	6	Spawning grounds, SW and S	Adults
2009	RV Dröfn	Oct. 23–27	7	Breiðafjörður	Adults
2009	Four charter vessels	Oct. 21–27	8	E, SE, S, SW, and W off Iceland	Adults
2009	RV Dröfn	Nov. 18–Dec. 2	9	Breiðafjörður and NW and N coastal areas	Adults and juveniles
2010	RV Dröfn	Jan. 16–18	10	Breiðafjörður	Adults
2010	RV Dröfn	Feb. 27–28	11	Breiðafjörður	Adults
2010	RV Bjarni Sæmundsson	Jan. 15–19	12	SW and W off Iceland	Adults
2010	RV Bjarni Sæmundsson	Jun. 29–Jul.7	13	Spawning grounds, SW and S	Adults
2010	Four charter vessels	Oct. 17–21	14	E, SE, S, SW, and W off Iceland	Adults
2010	RV Dröfn	Oct. 18–21	15	Breiðafjörður	Adults
2010	RV Dröfn	Nov. 3–16	16	Breiðafjörður and NW and N coastal areas	Adults and juveniles

Table 2. Overview of the sampling of Icelandic summer-spawning herring during the fishing seasons 2008/2009, 2009/10 and 2010/2011 in both all the distribution areas and in the main distribution area, Breiðafjörður, from commercial catch and from research surveys (number 1–12 refers to No. in Table 1) where BT stands for bottom trawl and PS purse-seine.

		Overall		Breiðafjörður*		
Season	Survey	# samples	# herring examined	# samples BT	# samples PS	# herring examined
2008/09	Catch samples	101	5015		73	3582
2008/09	1	15	925	2	2	350
2008/09	3	16	820	4	3	350
2008/09	4	5	249	5	0	249
	Total	137	7009	11	78	4531
2009/10	Catch samples	99	10 951	18	70	7920
2009/10	7	8	702	8		
2009/10	9	11	1079	1	1	150
2009/10	10	5	499	4		
2009/10	12	1	50			
	Total	124	13 281	31	71	8070
2010/11‡	Catch samples	24	1891		23	1846
2010/11‡	14	2	145			
2010/11‡	15	5	432	5		432
2010/11‡	16	7	524			
	Total	38	2992	5	23	2278
Grand total		598	46 564	94	344	29 758

* Only PS samples were considered significant and representative of the stock in the infection determinations.

‡ Will be revisited in the spring 2011 when more data are available.

Table 3. The estimates of prevalence of *Ichthyophonus* infection in Icelandic summer-spawning herring according to catch samples ($P_{infected}$) taken from October–January in (a) 2008/2009, (b) 2009/2010, and (c) 2010/2011 (sample size provided), the number of herring in the different areas according to acoustic measurements (N_{total}; length >26 cm), estimated number infected ($N_{infected}$) and corresponding estimate of $P_{infected}$ of the whole stock when weighed with the herring quantity of the different locations (see locations in Figure 1).

		From catch samples		From acoustic measurements			
	Location	Sample size	Pinfected (%)	Ntotal (×106)	Ninfected (×106)	Weighed Pinfected %)	Minfected
(a) 2008/2009	Breiðamerkurd.	450	12.7	274.7	34.9		
	Vestm.eyjar	300	59.7	16.0	9.6		
	Keflav./Hafn.	439	70.2	45.0	31.6		
	Breiðafjörður	3582	33.7	1645.1	554.4		
	Ísafjörður	86	63.0*	50.0	31.5		
	Papagrunn	152	6.6‡	27.2	1.8		
	Total	5009		2058.0	663.7	32.3	0.39
(b) 2009/2010	Breiðafjörður	5326	45.9	2114.0	960.0		
	Breiðamerkurd.§	530	20.9	246.0	51.0		
	Total	5856		2360.0	1012.0	42.9	0.56**
(b) 2010/2011	Breiðafjörður	1377	39.0	1414.5	551.6		
	Breiðamerkurd.§	217	29.1	278.2	81.0		
	Total	1594		1692.7	632.6	37.4‡‡	0.41‡‡

* Estimated from research surveys because no catch samples available.

‡ Two samples taken in a capelin survey on RV Árni Friðriksson.

§ Samples from both purse seines and pelagic trawls.

** Length-dependent, see Table 4.

‡‡ Will be reanalyzed in the spring 2011 when more data are available.

Table 4. The total acoustic estimate (N_{total}) of Icelandic summer-spawning herring in the winter 2009/2010 for age groups 3 to 11, the number of infected herring ($N_{infected}$) and estimates of prevalence of *Ichthyophonus* infection ($P_{infected}$) of the whole stock when weighed with the herring quantity of the different locations, and finally the corresponding estimate of natural mortality caused by the infection ($M_{infected} = -(\log_2(N_{total} - N_{infected}) - \log_2(N_{total}))$).

Age (years)	Acoustic estimate Ntotal (´106)	Ninfected (´106)	Weighed Pinfected %)	Minfected
3	337.3	160.2	47.5	0.64
4	525.4	248.6	47.3	0.64
5	466.9	207.8	44.5	0.59
6	273.6	113.3	41.4	0.53
7	335.3	132.1	39.4	0.50
8	156.5	60.1	38.4	0.48
9	140.7	52.6	37.4	0.47
10	149.3	54.6	36.6	0.46
11	36.9	13.2	35.7	0.44
Total	2421.8	1042.6	43.0	0.56

Table 5. The prevalence of *Ichthyophonus* infection ($P_{infected}$) for age-1 Icelandic summer-spawning herring during the winters (a) 2008/2009, (b) 2009/2010, and (c) 2010/2011 for the different areas (see in Figure 1) covered in the acoustic research surveys (Table 1). The sample size is provided in addition to the number of herring in the areas according to acoustic measurements (N_{total}), and estimated number of individuals surviving the mortality caused by the infection ($N_{survive}$).

	Location	Samples size	Pinfected (%)	Ntotal (x106)	Nsurvive (x106)
(a) 2008/2009	Vestm.eyjar		60*	2.1	0.8
	Kefl./Hafnarf.		70*	0.0	0.0
	Breiðafjörður		34*	0.0	0.0
	Patreksfjörður	68	63	55.1	20.4
	Arnarfjörður			0.0	0.0
	Ísafjörður	25	68	62.3	19.9
	Húnaflói	50	42	92.4	53.6
	Skagafjörður			0.0	0.0
	Eyjafjörður		0‡	5.0	5.0
	Skjálfandi	100	0	416.3	416.3
	Total	269	18	633.2	516.1
(b) 2009/2010	Jökulfirðir	99	2.0	56.3	55.2
	Miðfjörður	100	1.0	74.9	74.1
	Steingrímsfj.	85	3.5	9.6	9.3
	Eyjafjörður	309	4.5	580.0	553.9
	Skjálfandi	98	2.0	65.2	63.9
	Total	691	3.8	787.2	757.5
(c) 2010/2011	Ísafjörður	21	0.0	5.6	5.6
	Skötujörður	23	17.4	2.8	2.3
	Miðfjörður.	97	1.0	19.5	19.3
	Eyjafjörður	90	0.0	57.6	57.6
	Skjálfandi	24	0.0	0.0	0.0
	Total	255	0.8	85.4	84.7

* The percentages used are according to samples across all length groups.

‡ No sample was getted from the area and it is therefore set to 0.

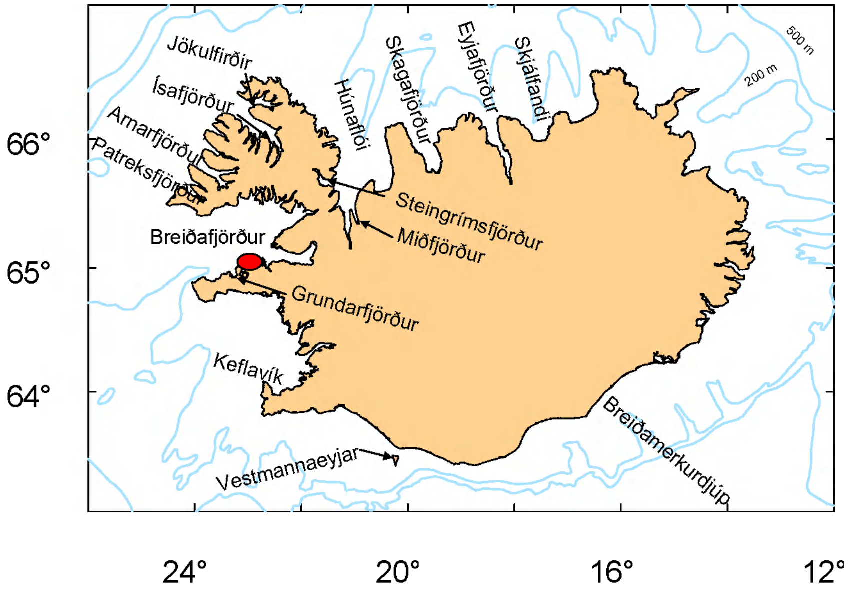
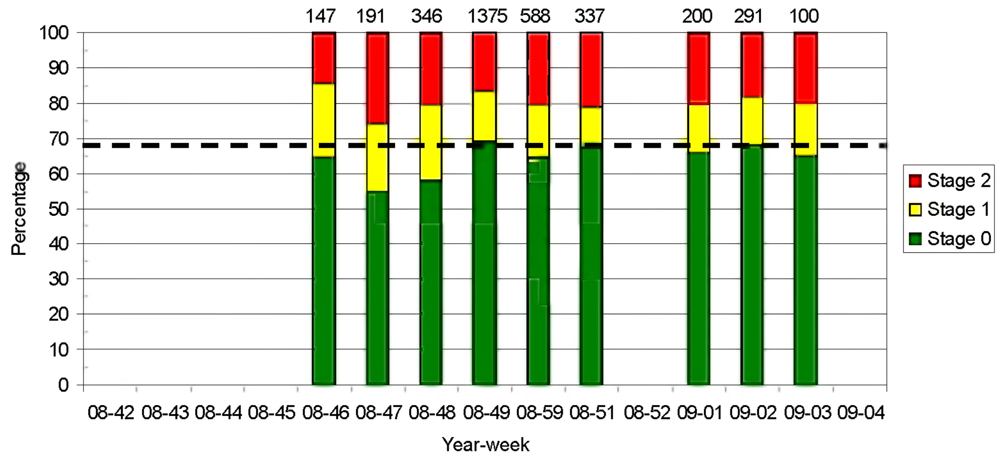
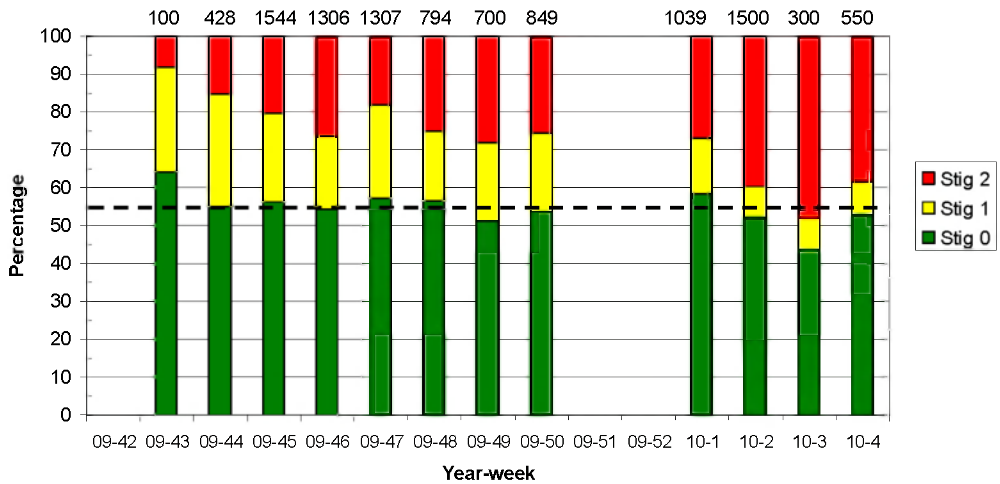


Figure 1. The locations of the areas that are referred to in the text. The red circle denotes the main overwintering area of the Icelandic summer-spawning herring in the winters 2008/2009 to 2010/2011 in Breiðafjörður.

(a)


147
191
346
1375
588
337
200
291
100
Percentage
Year-week
08-42 08-43 08-44 08-45 08-46 08-47 08-48 08-49 08-59 08-51 08-52 09-01 09-02 09-03 09-04
Stage 2
Stage 1
Stage 0

(b)


100
428
1544
1306
1307
794
700
849
1039
1500
300
550
Percentage
Year-week
09-42 09-43 09-44 09-45 09-46 09-47 09-48 09-49 09-50 09-51 09-52 10-1 10-2 10-3 10-4
Stig 2
Stig 1
Stig 0

(c)

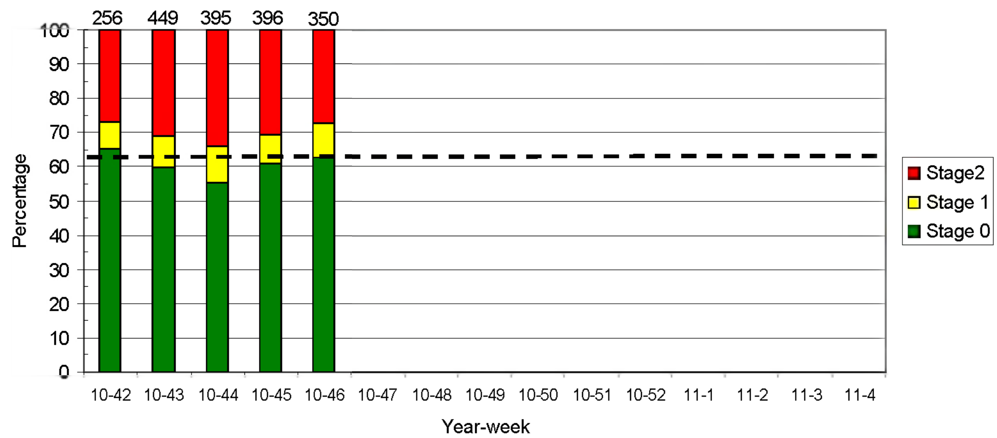

256
449
395
396
350
Percentage
Year-week
10-42 10-43 10-44 10-45 10-46 10-47 10-48 10-49 10-50 10-51 10-52 11-1 11-2 11-3 11-4
Stage2
Stage 1
Stage 0

Figure 2. The prevalence of the different infection stages (0 to 2; 0 indicating no infection) of Icelandic summer-spawning herring in catch samples in Breiðafjörður (see Figure 1) for the different weeks (indicated as year-week) of sampling during the fishing seasons (a) 2008/2009, (b) 2009/2010, and (c) 2010/2011. The dotted lines represent the weighed mean infection and the numbers above the sample sizes.

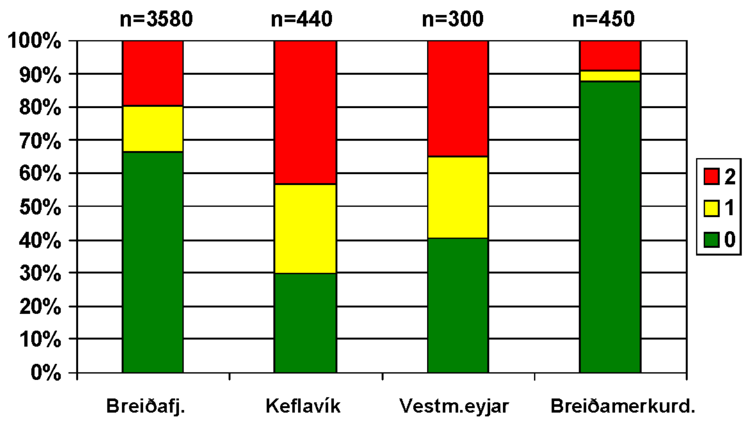


Figure 3. The prevalence of the different infection stages (0 to 2; 0 indicating no infection) of Icelandic summer-spawning herring in catch samples during the fishing season 2008/2009 in four different areas (see locations on Figure 1).

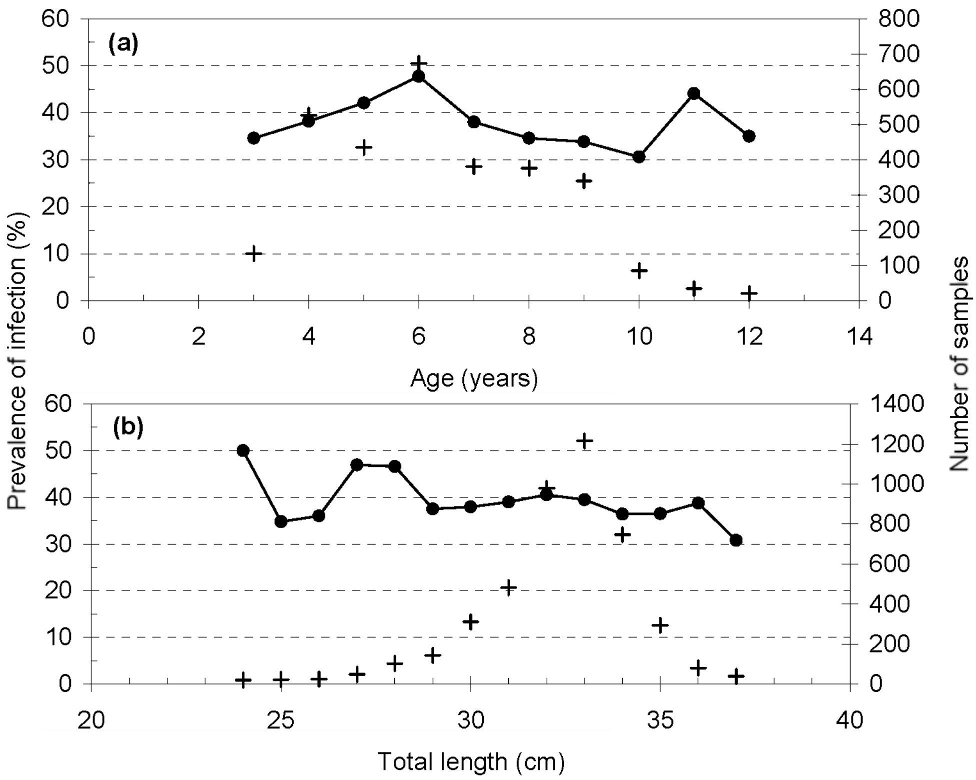


Figure 4. The prevalence of infection (filled dots on left y-axes) and the number (n) of examinated fish (+ on right y-axes) of (a) different age groups and (b) of different length groups of Icelandic summer-spawning herring from all available samples in the winter 2008/2009 in Breiðafjörður (see Figure 1). Age and length groups with n<20 were omitted.

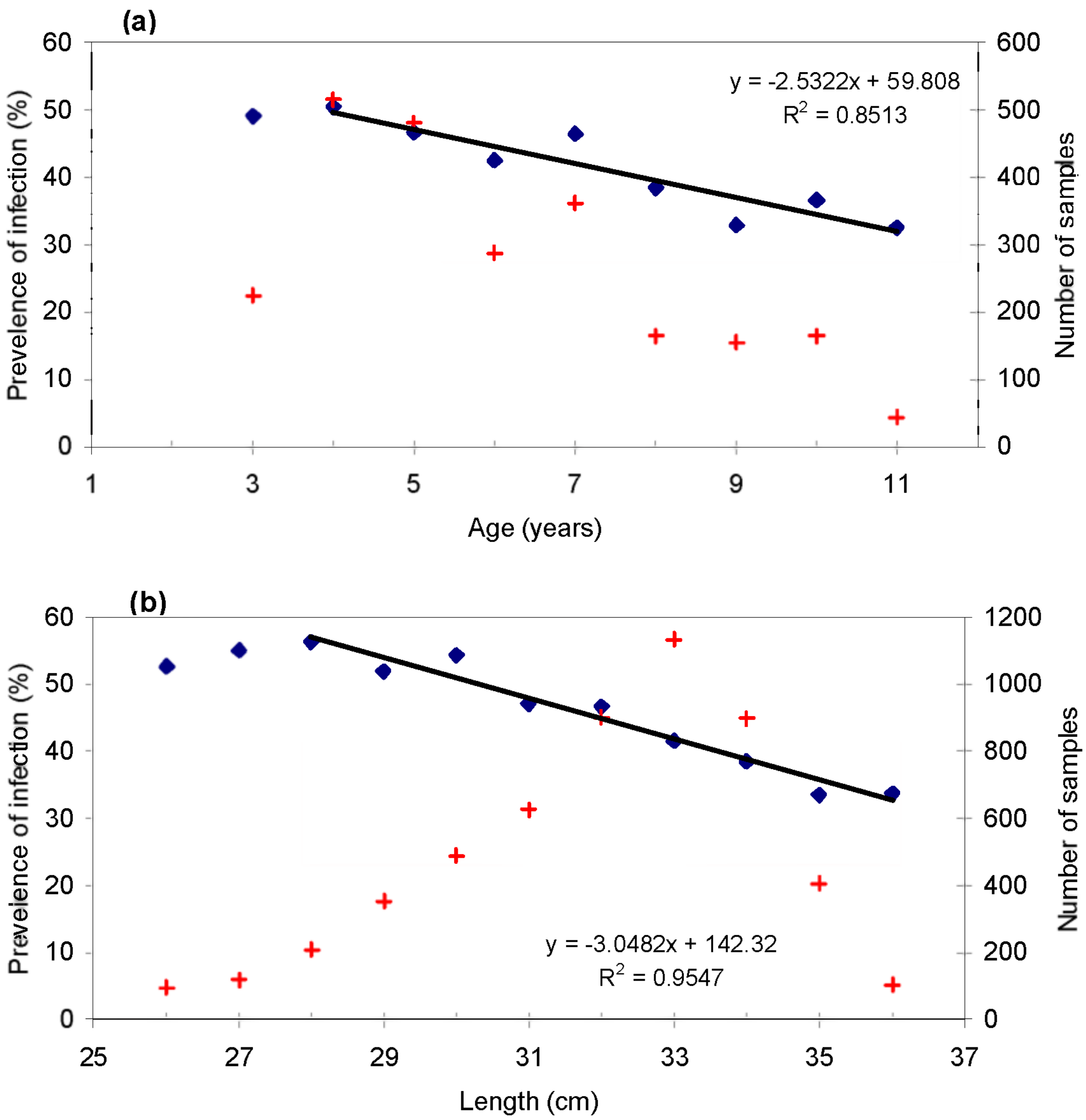


Figure 5. The prevalence of infection (filled dots on left y-axes) and the number (n) of examinated fish (+ on right y-axes) of (a) different age groups (N=2394) and (b) of different length groups (N=5326) of Icelandic summer-spawning herring taking in purse-seine in October–December in 2009 in Breiðafjörður (Figure 1). Age and length groups with n<40 were omitted.

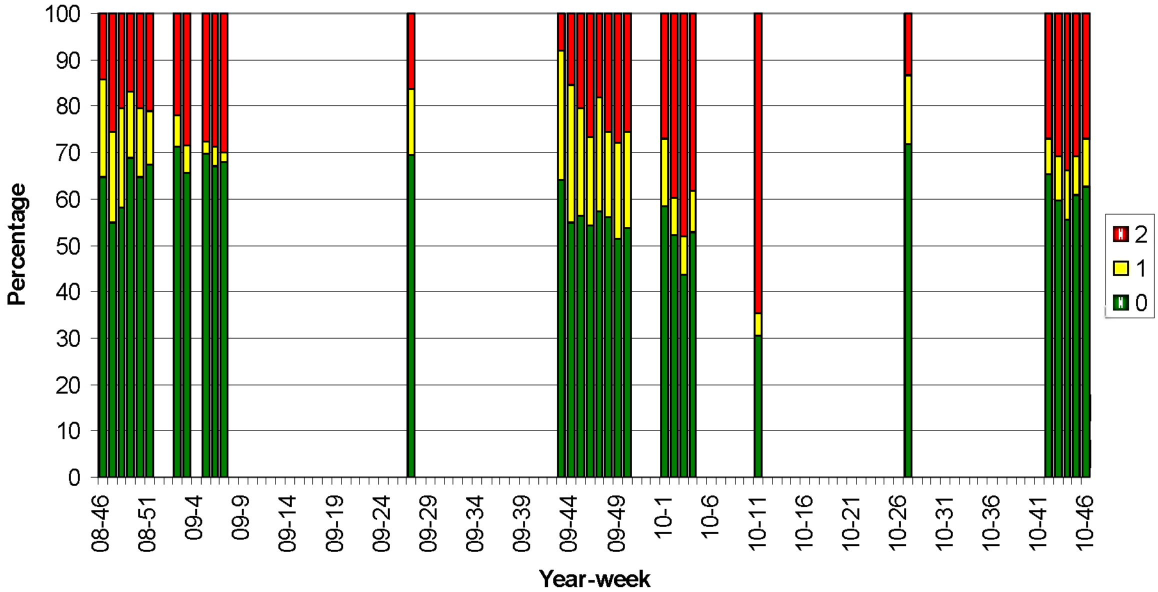


Figure 6. The prevalence of the different infection stages (0 to 2; 0 indicating no infection) of Icelandic summer-spawning herring in catch samples in Breiðafjörður (see Figure 1) for the different years and weeks of sampling during the fishing seasons 2008/2009–2010/2011 and in survey samples on the different spawning grounds of the stock in week 27 in 2009 and 2010.

Icelandic summer-spawning herring; An analysis of the signals in the catch-and survey data and preliminary assessments

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Introduction

The Icelandic summer-spawning herring stock collapsed late 1960s but did recover. It has been monitored by yearly acoustic surveys since 1973. From late 1970s until 2002 VPA were used to assess the Icelandic summer-spawning herring stock. (As biological sampling from the catch took place further back in time assessments have been made back to 1947 (NPBWWG 1998)). Since then several softwares have replaced it. Among these software packages are AMCI, TSA and NFT-Adapt. The NFT-Adapt has been used since 2005 as the main assessment tool. All these exercises with the software packages have been done due to a retrospective patterns in the assessment, which is very prominent around 2000. Due to this pattern the age range in the time-series was reduced from age 15+ to 12+ in the catch data and instead of using age 5+ from the acoustic-series as one index the indices at age 3–9 are used as they are. The year range has also been shortened to 1986.

The aim with this paper is to analyse the signals in the data available for the Icelandic summer-spawning herring since the recovery of the stock, or from 1975–2009, and decide on which to use. Data from both catches and from acoustic surveys are available.

Landings

The landings since 1951 are shown in Figures 1 and 2; the proportion taken by different gears since 1975. The stock collapsed late 1960s and a fishing ban was enforced during the years 1972–1974. The stock recovered and the landings increased to around 100 000 tonnes around 1990. The landings have since then been close to 100 000 and exceeded 150 000 tonnes in 2005 and 2006. Due to an *Ichthyophonus* infection in the stock since 2008 the landings have decreased drastically and were almost 50 000 tonnes in 2009.

Catch data

The data used are those presented in the NWWG report in spring 2010 (ICES, 2010).

Catches in numbers were plotted by age and years (Figure 3). The figure shows the variation in the numbers of year classes in the fishery each year. In some years there is mainly one year class in the fishery, like the 1979 year class in the years 1983 to 1985, in other years, like 1991 and 1992, there are quite many year classes in the fishery and in yet another years they are just two dominating the fishery, as in 2003.

The most abundant ages in the fishery are ages 3–9 (Figures 3 and 4), but only big year classes are caught in some amount at age 8 and 9. Around 90% of the catches in numbers are from these ages. In the years 1979 to 1990 much smaller proportion was taken at age 3 than in the other years, suggesting one should start a new separable period in 1979 and in 1991, if thinking of using a separable model for the assessment.

When the data are arranged by year classes the removals from the year classes are seen (Figures 5 to 7). The yield from the year classes is very variable. The yield from the 1976 year class is about 110 millions in numbers and about 30 000 tonnes in weight, whereas the yield from the 1999 year class so far is in excess of eight and seven times respectively more in numbers and weight.

Catch-curves for year classes 1975 to 2005 were examined (Figure 8). The pattern of the data above age 10 looks noisy. There is a difference in how the year classes have been exploited. In the rebuilding phase of the stock it was tried to "spare" some year classes so the exploitation was not the same then as now in the past years. The year classes from 1975 to 1977 have two tops. The 1980 and 1981 year classes are both considered small and look "flat" whereas the big year class from 1989 seems to drop "normally". Year classes 1982 to 1986 were not fully recruited to the fishery until age 6. But from year class 1987 onwards the year classes have been fully in the fishery at age 4, with 3 exceptions, namely the 1991, 2000 and 2003 year classes which were fully in the fishery at age 3. Overall it looks like that the mortality sign, Z, is close to 0.4.

For the year classes 1996 and younger the last datapoint drops down (Figure 8). This is caused by the lower quota allocated in the fishing season starting in 2009.

Until the assessment in 2005, age 15 was used as a plus group but since the assessment in 2006 age 12 has been used as a plusgroup. Even though there are not so many numbers in the oldest age groups they add up to some amount in several years. Lowering the plus group to age 12 means that about 6–10% of the catches in the corresponding years would fall in that group in five cases. On the other hand lowering it to 13 would mean that only 5% of the catches would fall in that group in three cases during this period (1975–2009). Which criteria to use when deciding on a plus group is not clear to me.

The log catch ratio (LCR) for ages 2 to 14 is shown in Figure 9. The ratio is quite variable, especially for the oldest and the youngest ages. It is also very high for the oldest ages. When plotting it for the central ages, that is ages 4 to 10 (Figure 10), it looks a bit better, but even though variable. The average LCR over ages 5 to 10 is also shown on the plot. There are several periods of increase in the LCR over the time. The last point is very high, due to small quota in the 2009/2010 season as a consequence of the *Ichthyophonus* infection.

To summarise:

- Total mortality seems to be around 0.4 since 1989.
- There may be 2 or even more separable periods in the series.
- The plus group should be lowered to age 12 or 13.

Survey data

The data used are those presented in the NWWG report in spring 2010 (ICES, 2010) and results from an acoustic survey in autumn 2010 on the overwintering area (survey report is available).

The herring stock has been monitored by acoustic surveys since 1973. The acoustic surveys are surveys on the overwintering area, which in some years can be different from the fishing area, like the fishing season 2006/2007 when the main fishing took place south of Iceland, while the overwintering area was in Breidafjördur, a large bay west of Iceland. The overwintering areas have also changed over the years (Jakobsson, 1980; Óskarsson *et al.*, 2009). Since 2007/2008 almost all the fishing has taken place on the overwintering area.

Results from the surveys, age disaggregated indices, have been used as tuning-series in stock assessments since late 1970s. Until 1986 only the most recent acoustic estimates were used each year. In early 1990s it was realised that the stock was overestimated in the acoustic surveys due to too low TS value. Therefore the TS value was changed in 1993 and the time-series recalculated (Jakobsson *et al.*, 1993). These values have been used since 1993 in the assessments.

Similar plots by ages, years and year classes were made for the acoustic data as for the catch data (Figures 11 and 12). The same "medium/big" year classes which are seen in the catch data can be followed in the survey. The small ones are hardly seen. It can be related to the sampling, as the small year classes may be poorly represented in the survey samples. The main age groups in the survey are ages 3 to 8 (Figures 11–13). In the first years there were only few age groups in the survey, but have increased with time. They were also less numerous in the first years. The 1999 year class is the most numerous one hitherto. Only the year classes from 1999–2002 have been observed in great numbers at age 2.

Log index and log-index ratio

In Figure 14 the log of the survey indices are plotted by year classes 1971–2004 in the years 1975–2010. Year effects are visible in the survey and the overall picture suffers from the missing surveys. The indices are noisy, especially for older ages. The year classes were also plotted on a log scale one by one (Figures 15–16). For those year classes who are not punctuated it looks like that they are fully recruited to the survey at age 4. They also look noisy for the oldest ages. As very few aged fish are behind the indices at age 13 and 14 in most years the indices for those ages should be skipped.

Only few data points are for the year classes 1967–1970 in the time-series and there is no clear mortality signal in these points.

For year class 1971 and 1973–1975 there is a mortality signal up to age 10 but noise for older ages. Year class 1972 is a small one and noise dominates signal.

Year classes 1976–1978 are also small ones. The curves look quite similar in the survey, have a steep slope for the youngest and oldest ages but are flat in the middle. For year class 1977 there are only two scales behind the index at age 12, so it should be skipped. The same applies for the 1978 year class at age 11.

Due to very few aged fish the indices are very noisy and untrustworthy for year class 1979 above age 10; for year class 1980 above age 9; for year class 1981 above 8 and for year class 1982 above age 9. So there is a valid mortality signal only in few age groups for these year classes.

Year classes 1983 and 1984 have some mortality signal up to age 10, but are noisy above that age. Year class 1985 is small/intermediate and the log index ratio is relatively flat.

Year classes 1986 and 1987 have a similar shape and show a mortality signal up to ages 12. The slope is steep, for year class 1985 the slope for ages 5–7 is -0.9 and for 10–12 it is -0.7.

The year classes 1988 and 1989 are much bigger than the 1986 and 1987 year classes. They have a mortality sign up to ages 11/12 but are a bit noisy in the oldest ages. Their slope is not so steep, around -0.4.

Year classes 1990 and 1991 are also considered big. They have the same trend, the slope around –0.6 for ages 4–9. Above age 10 they become a bit noisy. For year class 1991 the indices should be skipped as from age 12 due to very few scales in the key used to calculate the indices.

Year classes 1992 and 1993 are small. They look similar in the survey, flat over the middle ages. Due to few scales the indices should be skipped for ages 11 and older for the 1992 year class, and for ages 10 and older for the 1993 year class. This flat curve over middle ages means that the log catch ratio is 0, which could indicate that there has been a change in the catchability during the late 1990s. It can also be that noise dominates any mortality signal as these year classes are small and worse sampled in the survey that the big ones.

Year classes 1994 and 1995 look similar. They are flat up to age 7/8, fall steeply to age 9/10 and are just noisy above that. The slope of the 1994 year class is -0.33 for ages 4–8, but -0.142 for the 1995 year class for ages 3–7. This flat curve for the 1995 year class means that the year class was growing by every assessment made during that time. For year class 1995 ages 11 and older should be skipped and from ages 13 for the 1994 year class.

Again there is a pair of similar year classes in the survey, the 1996 and 1997 ones. They look noisy above age 7/8 but have a clear mortality signal up to that age.

Year class 1999 is the biggest one seen hitherto. There is a signal in the data up to age 11. The 1998 year class is smaller and has a more zigzag formed curve. It is questionable if the numbers at age 11 and 12 are not just noise.

Year classes 2000 and 2001 look similar and have a mortality signal up to age 9 or even 10. The increase in year classes 1998 and 2000 in the year 2010 is a bit strange in the light of the *Ichtyophonus* infection.

Year classes 2002–2004 can only be followed up to ages 6–8. The year classes 2003 and 2004 have a similar shape as the 2001 year class. They are nearly flat at ages 4–6. Year class 2002 is closer to the 2000 year class, with an astonishing high value at age 8 (the 2010 value).

Observations from the catch curve analyses from the survey can be summarised as follows:

- There is a lot of noise in the data but usable signals can generally be obtained from around age 4–8, with number of exceptions.
- The year classes seem to be fully recruited to the survey at age 4.
- Before age 3 the indices are noisy.
- The expected increased mortality because of the *Ichthyophonus* infection starting from the 2009 survey is not apparent from the catch curves.
- Some year classes:
  - show just noise;
  - are zig-zagged as cause of year effects;
  - have a flat curve at the middle ages, mostly the small year classes;
  - show mortality signal only part of the age range;
  - show mortality signal up to age 12 (1971, 1986, 1987, 1988, 1989, 1990, 1996);

- the slope of the year classes is very variable, from being almost flat to -0.9.

The log index ratio from the survey is shown in Figure 17 and for ages 4–10 in Figure 18. It is quite variable and noisy, especially for the youngest and oldest ages. The log-ratio for age 10 in 2005 is far too high. It is caused by an untrustworthy index at age 11 from the 1995 in 2006. The mean of the ages 4–8 is shown in Figure 18. There is an increase in the LCR from 1977–1980 and from 1990–1992. There is a decrease in LCR from 2002–2008. The increase in LCR in the last year is suggested to be caused by the *Ichthyophonus* infection, but it must be considered that there is a lot of noise in the data.

Correlation within a survey

The correlation between ages in the survey were plotted (Figure 19). An inconsistency in the survey can be seen for example through the 1999 year class. It is alternately above and below the regression line from age 3 onwards, just reflecting the zigzag shape of the log of the index-curve for that year class. Which age groups can be used in an assessment? With regard to R-squared then one would probably decide on age groups 3–10.

Timing of the survey

In the first years after the reopening of the fishery the surveys took place at the end of the fishing season, most often in the beginning/middle of December. It has, however, changed over time. The surveys have usually taken place from the beginning of December to the end of January. An exception is the survey in the fishing season 1998/1999 as it was in the beginning of November. Both in 2009 and 2010, the survey took place in late October, or before the fishery started.

In late 1990s it was tried to account for the different timing in the assessments, by lowering the indices by some means. As it was done differently each year, this procedure was stopped and the indices used as they were obtained from the surveys. But different timing means that the magnitude caught before/after the survey differs between years. A rough estimate is as follows:

Fishing season	Percent catch taken before the survey
1990/91	99
1991/92	63
1992/93	86
1993/94	98
1994/95	No survey
1995/96	84
1996/97	75
1997/98	78
1998/99	40
1999/00	93

Fishing season	Percent catch taken before the survey
2000/01	79
2001/02	75
2002/03	90
2003/04	85
2004/05	100
2005/06	100
2006/07	100
2007/08	76
2008/09	95
2009/10	3

The conclusion drawn from the table above is that approximately 80% of the catches are taken before the survey (2009/2010 not included). The fishing season 1998/1999 is outstanding with only 40%. In the assessments made up to now it has been assumed that all of the catches were taken before the survey.

As from the 2007 assessment the surveys from the fishing seasons 1997/1998 and 2001/2002 were omitted from the tuning as they were not considered to cover the stock fully. The analyses here do not show that they are very different from the other surveys, so they will be included again.

It is suggested to:

- use survey indices from age 3 up to age 12 where possible (3–9 has been used in the last assessments);
- skip the fishing season 2009/2010 as the *Ichtyophonus* infection had then infested the stock.

Assessment

An assessment (NFT-Adapt) from 2009 exists (NWWG 2009). Data used are:

c@a: 3–12+, 1986–2008

i@a: 3–9 at the end of the years 1987–2008, which are ages 4–10 in the beginning of 1988–2009 (the surveys are supposed to be at JAN 1 in NFT Adapt)

There were some starting problems with getting the NFT-Adapt running. The run from 2009 (base run) could be reproduced but the program could not be run after adding any data. Finally it worked, but both the Scaled Step Tolerance and the Relative Function Tolerance were tightened to 1.0E-18 and the Scaled Gradient Tolerance was loosened to 6.05545E-05.

The following runs were made and compared to the one from 2009.

- Include the surveys again from 1997/1998 and 2001/2002
- Begin in 1987

- downweighting the “untrustworthy” indices
- use 13 as a plusgroup instead of 12
- use ages up to age 12 where possible in the survey
- a long run, by using data from 1977–2008
- the catches in numbers were split between years corresponding to the ratio of catches taken before/after the survey
- without the survey from 1998/1999

Inclusion of the surveys from 1997/1998 and 2001/2002 didn't have any eye-catching effect so they were included again. Neither did the splitting of the catch data have any effect, so catches in numbers were kept as they have been used up to now. On the basis of the runs made then the age range in the catch data was chosen to be 3–13+, and in the survey indices 3–10.

Inclusion of longer time period affected the assessment (Figure 20). This results most likely from the estimated survey catchability for these two runs (Figure 21). It is higher for the shorter and newer period. In the first years of the rebuilding period then there were almost no older fishes, likely causing the catchability to be lower. Therefore it is considered more appropriate to use the shorter period.

The final run (run8) includes therefore ages 3–13+ from the catch data and ages 3–10 from the survey data in the years 1987–2008. The input file and the output files are on the SharePoint with the names RUN8.DAT and RUN8.OUT).

The residuals from the final run are shown in Figure 22. The 1984 year class has negative residuals for all ages.

A retrospective run was made (Figure 23). There is a still the same retrospective pattern in the assessment as in 2009, whereas the SSB is overestimated and the Fs underestimated. A retrospective plot of the catchabilities shows some changes. These changes are likely just marginal and not significant.

Comparison with other models

Assessments of the stock were also done by using TSA (WD 4) and Colraine (WD 9). A comparison of the biomass Jan-1 for ages 3–11 is shown in Figure 25. This age range was chosen as Colraine was run with age 12 as the plusgroup, NFT-Adapt with 13 as the plusgroup and TSA with 12 as the oldest age and no plusgroup. The trend is the same by all assessments but there is a difference in the level the last years. Colraine has the higest level and TSA the lowest with NFT-Adapt in the middle.

A weighted F with stocknumbers is used for this stock instead of an average F. Now age range 5–10 is used. In the old days the age range was 5–15. The weighted F 5–10 from the 3 assessment models is shown in Figure 26. The Fs from the NFT-Adapt and the TSA models are more in line with each but largely they show the same.

Recruitment estimated by the programs is shown in Figure 27. The same goes for this figure as the biomass, the trend is the same, but different level in the last year.

The year classes 2000 and 2002 are estimated much higher by Colraine than by the other models (Figure 28) which results in higher biomass in the recent years. The stock numbers at age in the year 2005 are shown in Figure 29.

Remark

Three models have been used to assess the data from the Icelandic summer spawning herring. They all show similar trend but at different level the last years. The plus group in the catch data was upgraded to 13 and one more index from the acoustic survey was included. The results were the same. Since 2005 NFT-Adapt has been the main assessment tool but TSA have also been run and looked at. All the three models were run to the fishing season 2008/2009. Since then the *Ichtyophonus* infection has infested the stock. In these years (with the infection) the assessment model were run with a higher M, as high as the estimated ratio in the samples taken over the fishing season. It will be very interesting to have a discussion about how to make an assessment under such abnormal conditions like the *Ichtyophonus* infection.

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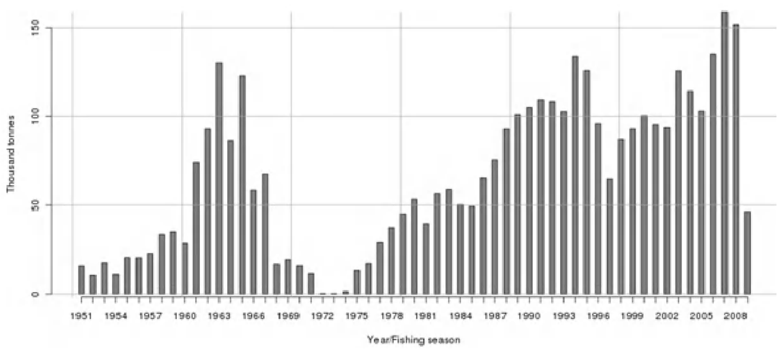


Figure 1. ISSH. Landings in thousand tonnes since 1951.

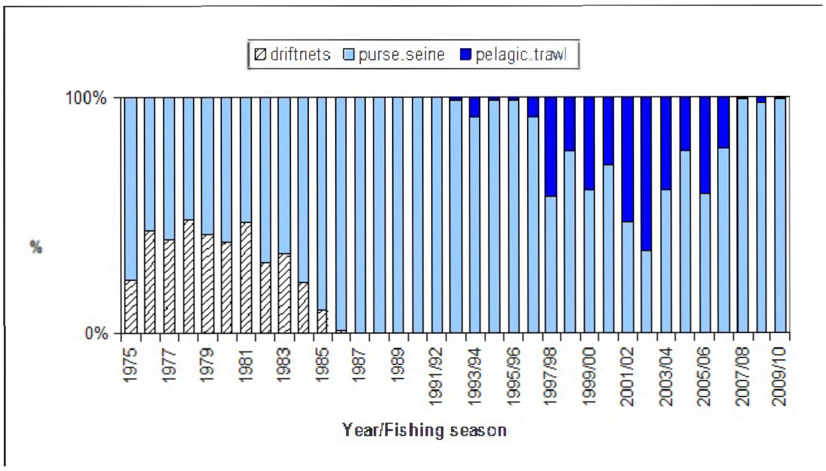


Figure 2. ISSH. Proportion of the total catches taken by different gears.

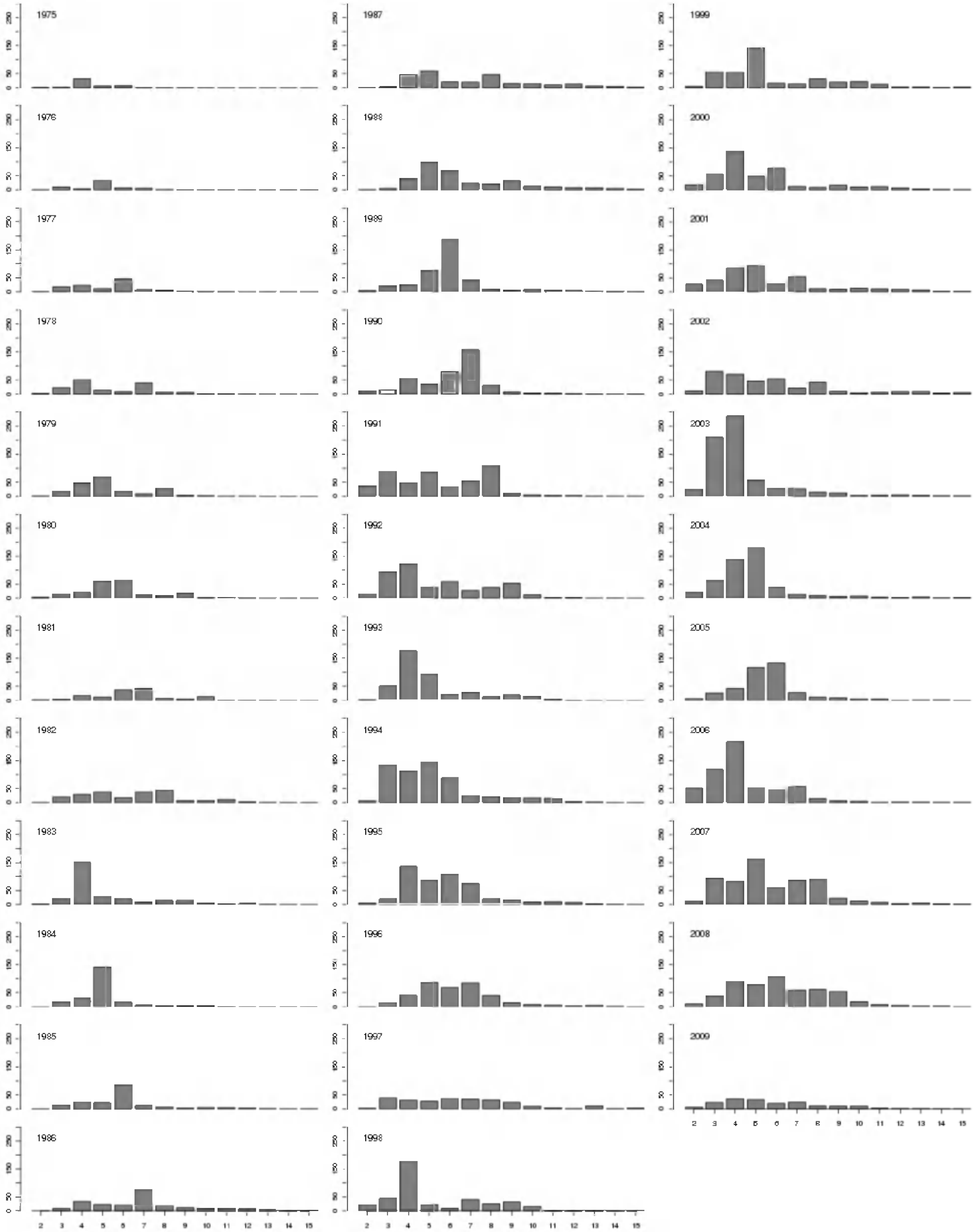


Figure 3. ISSH. Catches in numbers (millions) by age and years.

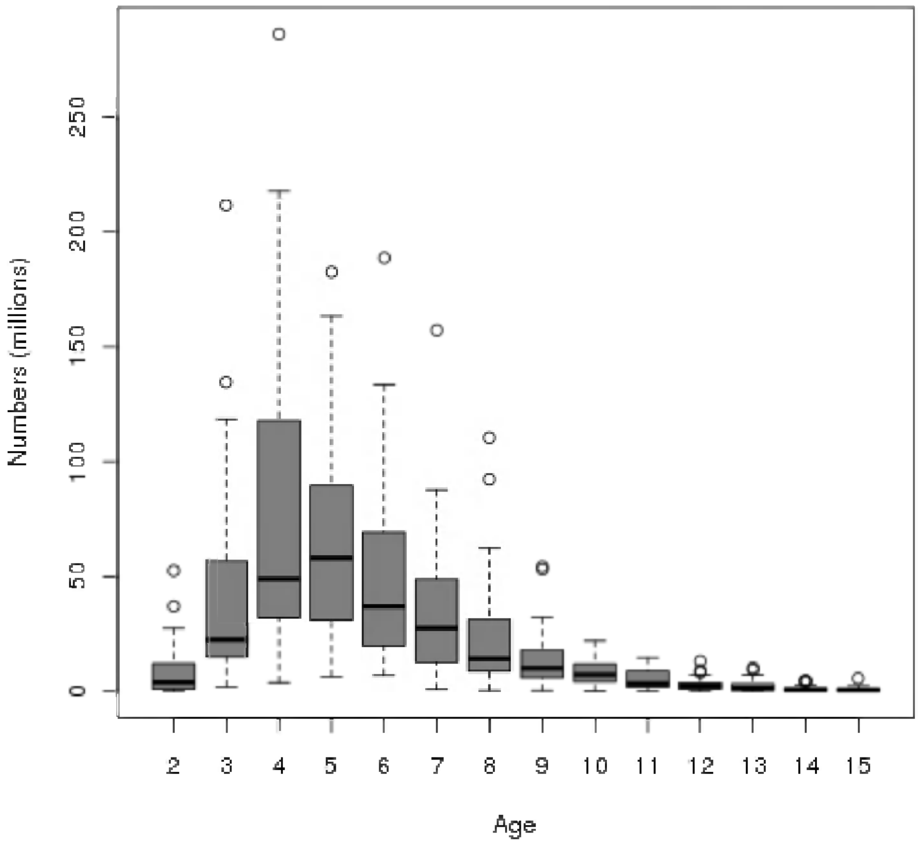


Figure 4. ISSH. Boxplot of catches in numbers by age over the years 1975–2009.

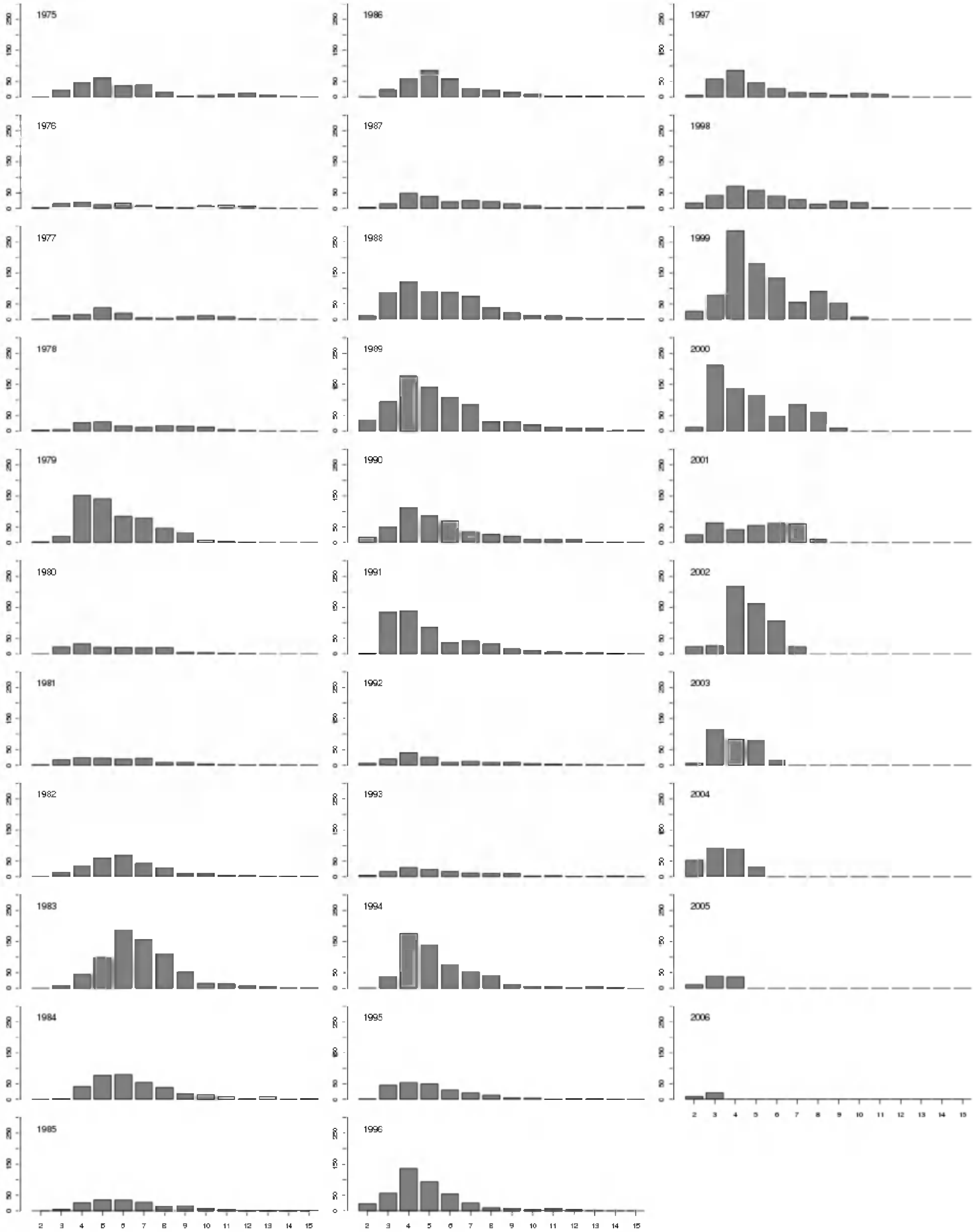


Figure 5. ISSH. Catches in numbers (millions) by age and yearclasses.

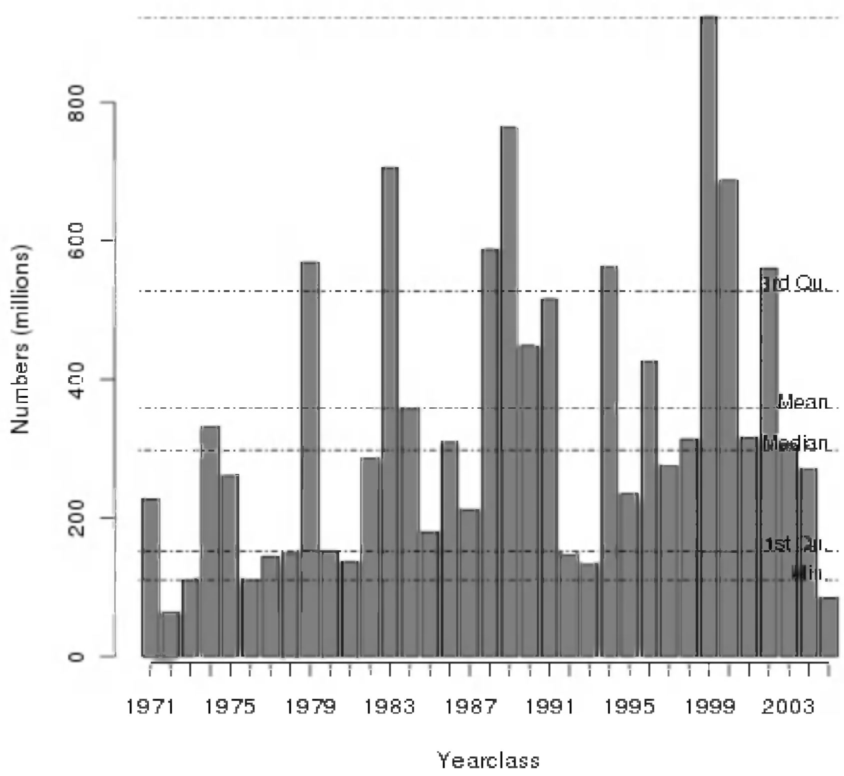


Figure 6. ISSH. Catches in numbers by year classes in the years 1975–2009. The summary is calculated over year classes 1973–2000.

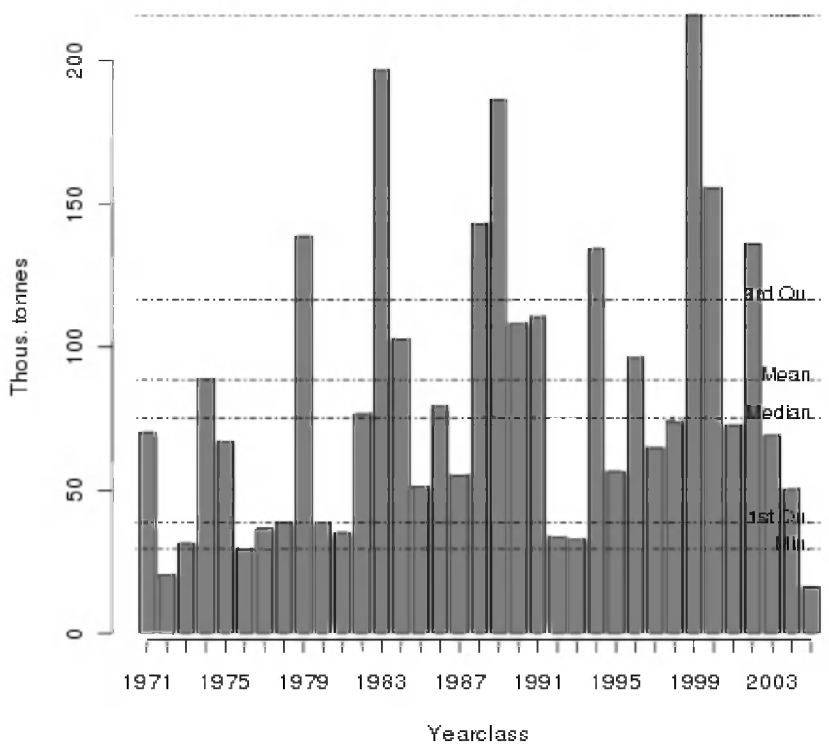


Figure 7. ISSH. Catches in weights (thous. tonnes) by year classes in the years 1975–2009. The summary is calculated over year classes 1973–2000.

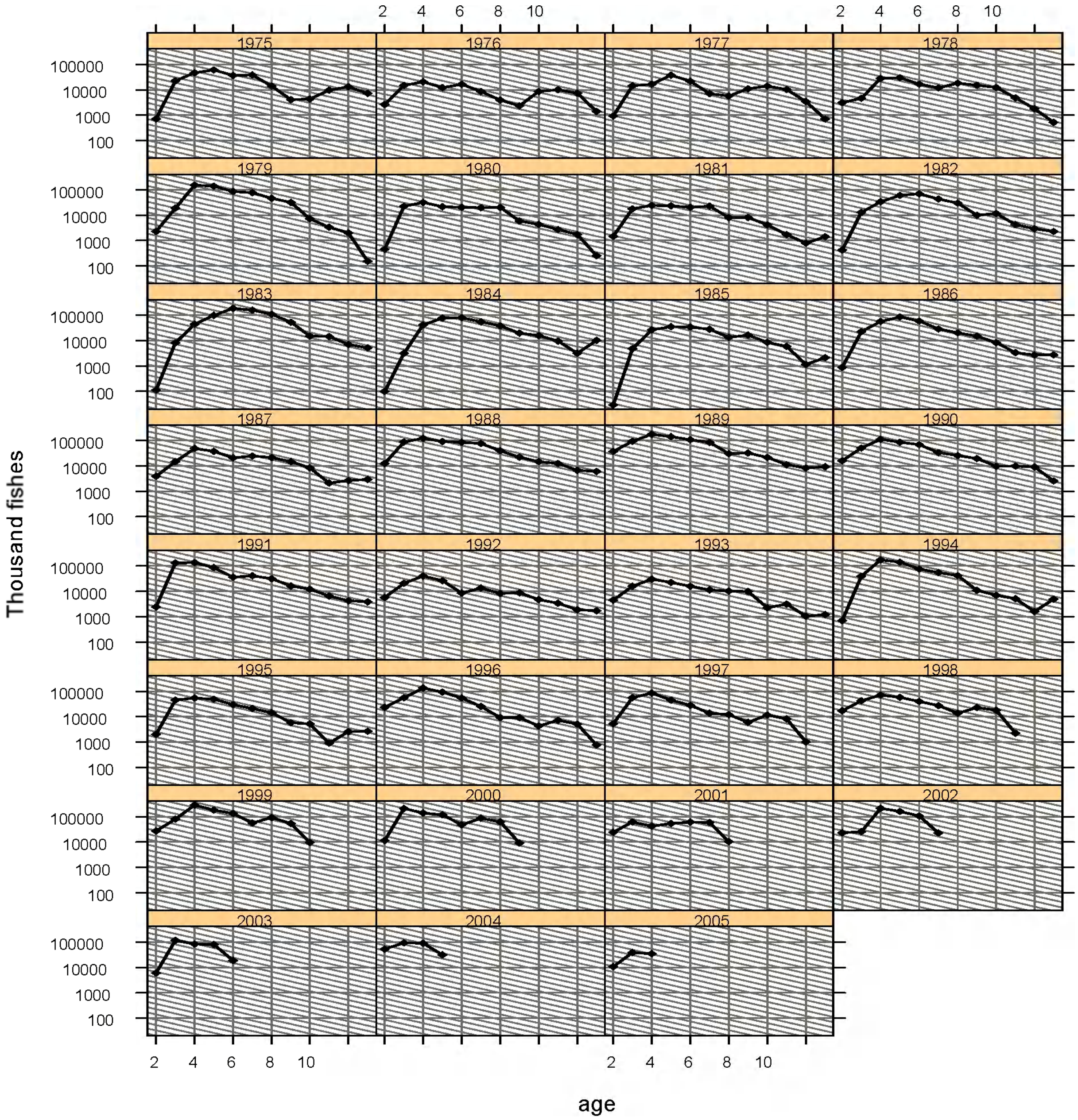


Figure 8. ISSH. Catch-curves by year classes 1973–2005. Grey lines correspond to Z=0.4. (The figure is from the NWWG report in spring 2010).

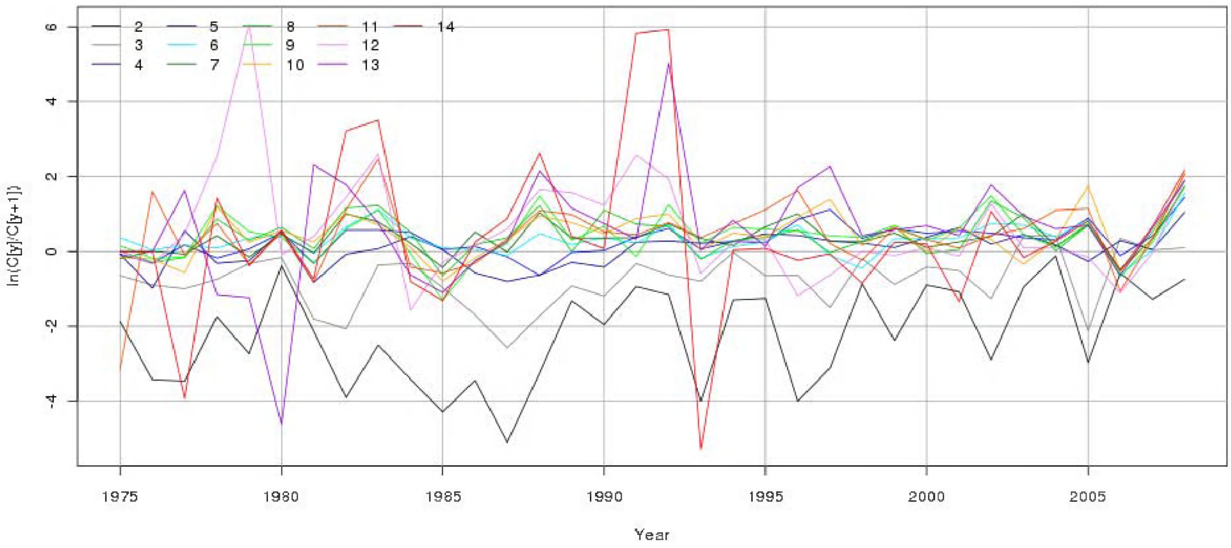


Figure 9. ISSH. Log catch ratio 1975–2009 for ages 2 to 14.

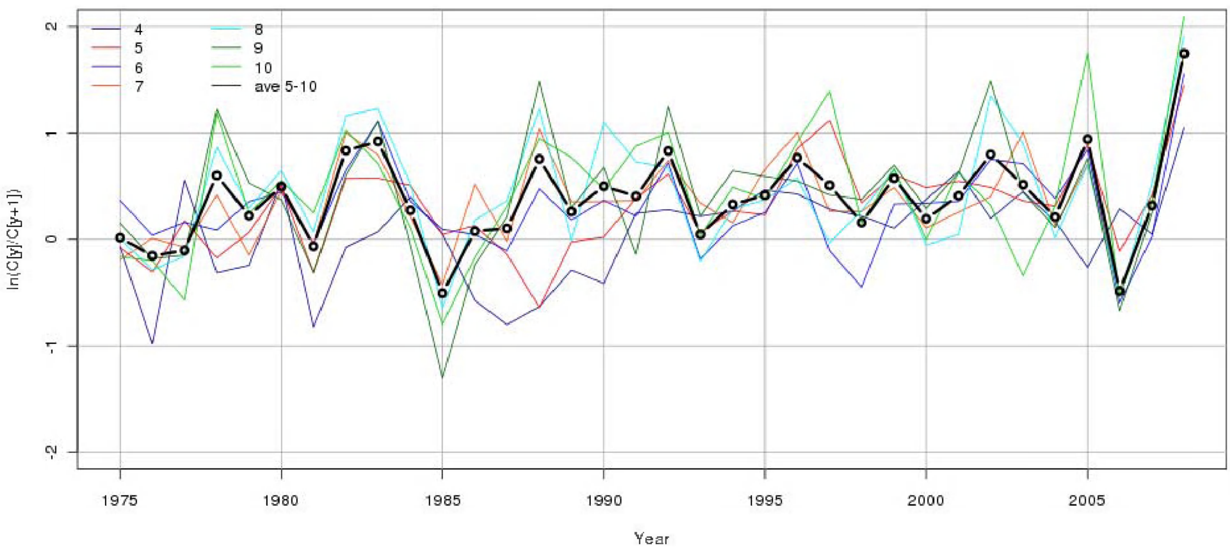


Figure 10. ISSH. Log catch ratio in 1975–2009 for ages 4 to 10. The thick black line is an average over ages 5 to 10.

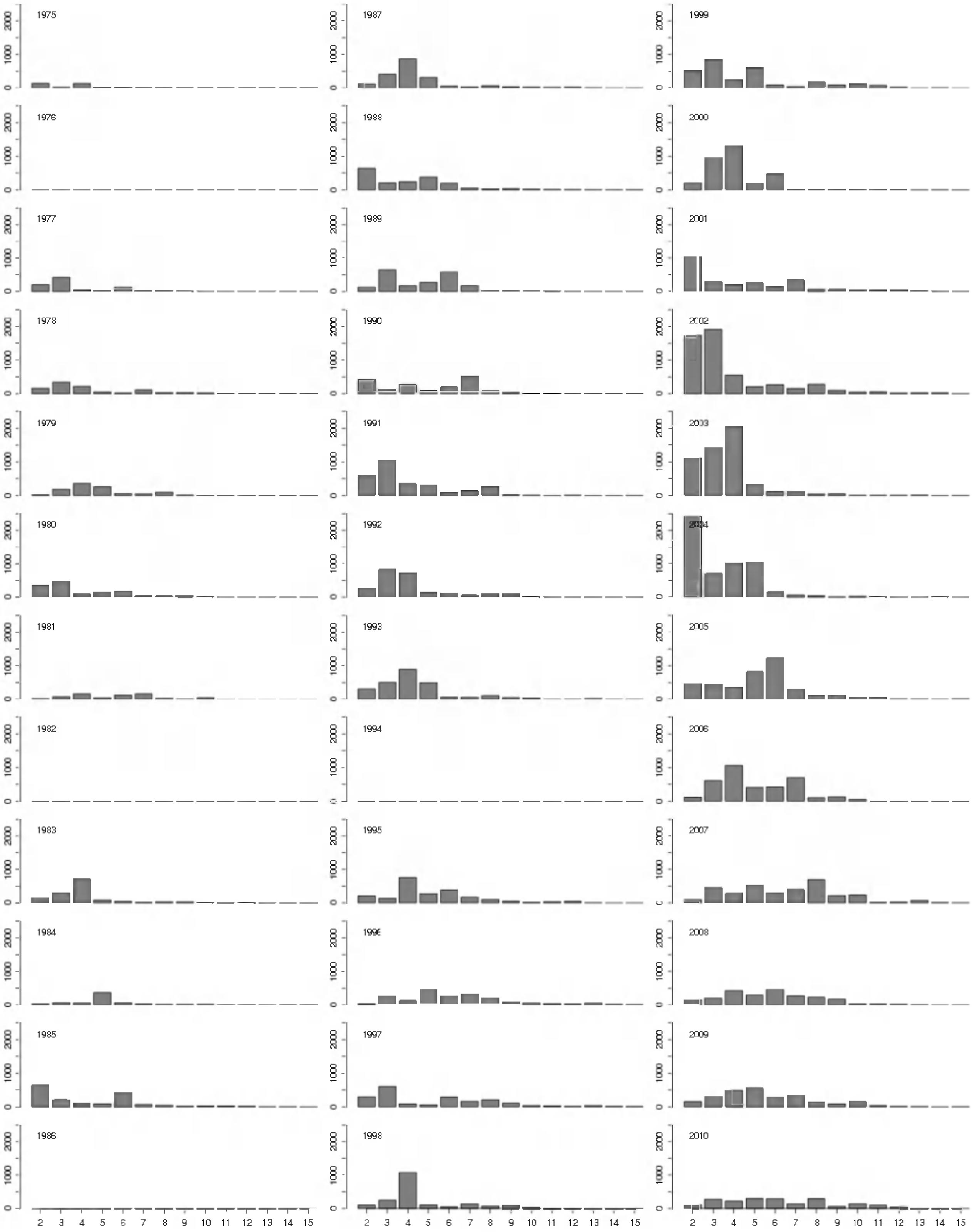


Figure 11. ISSH. Survey indices in numbers by age and years.

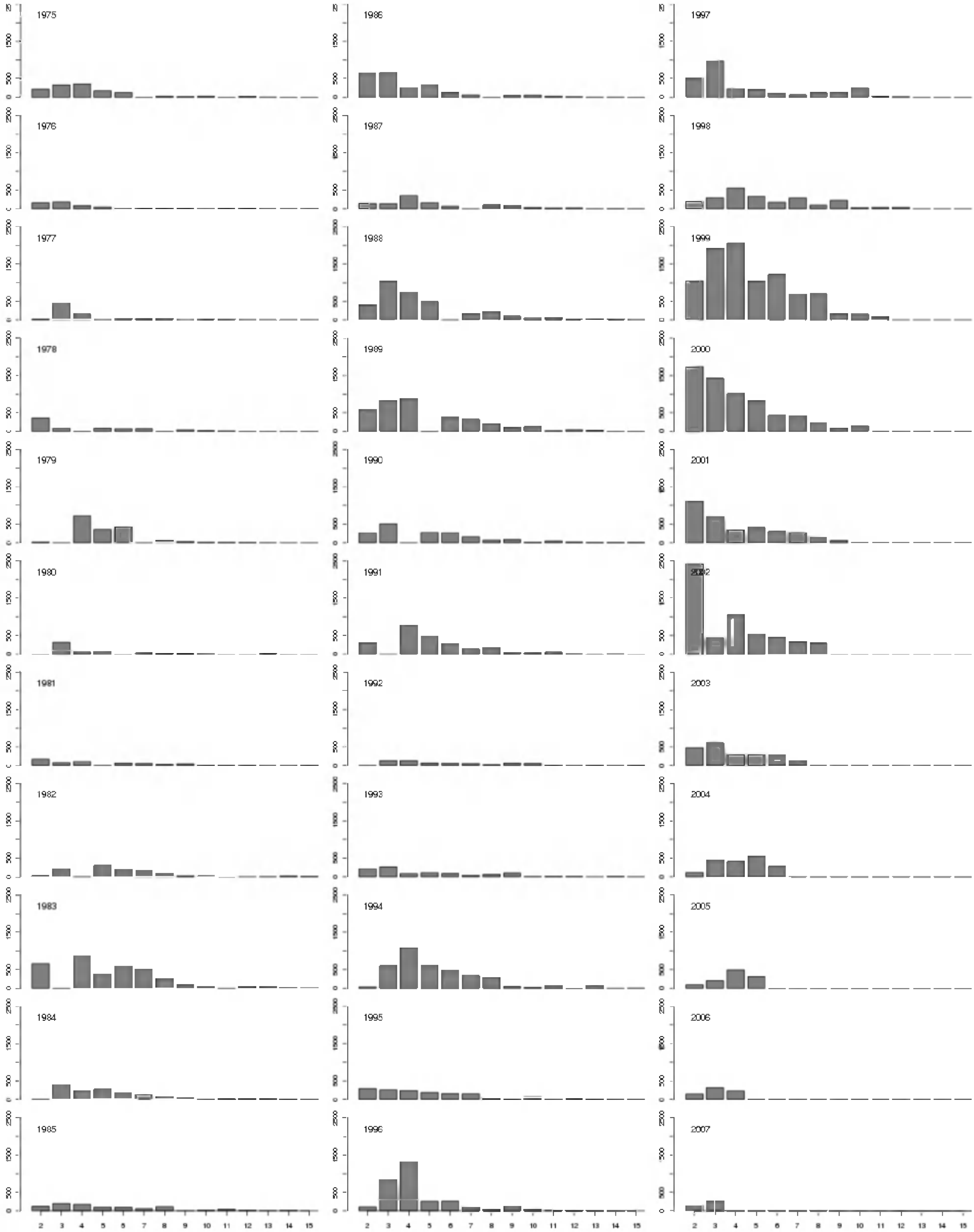


Figure 12. ISSH. Survey indices in numbers by age and year class.

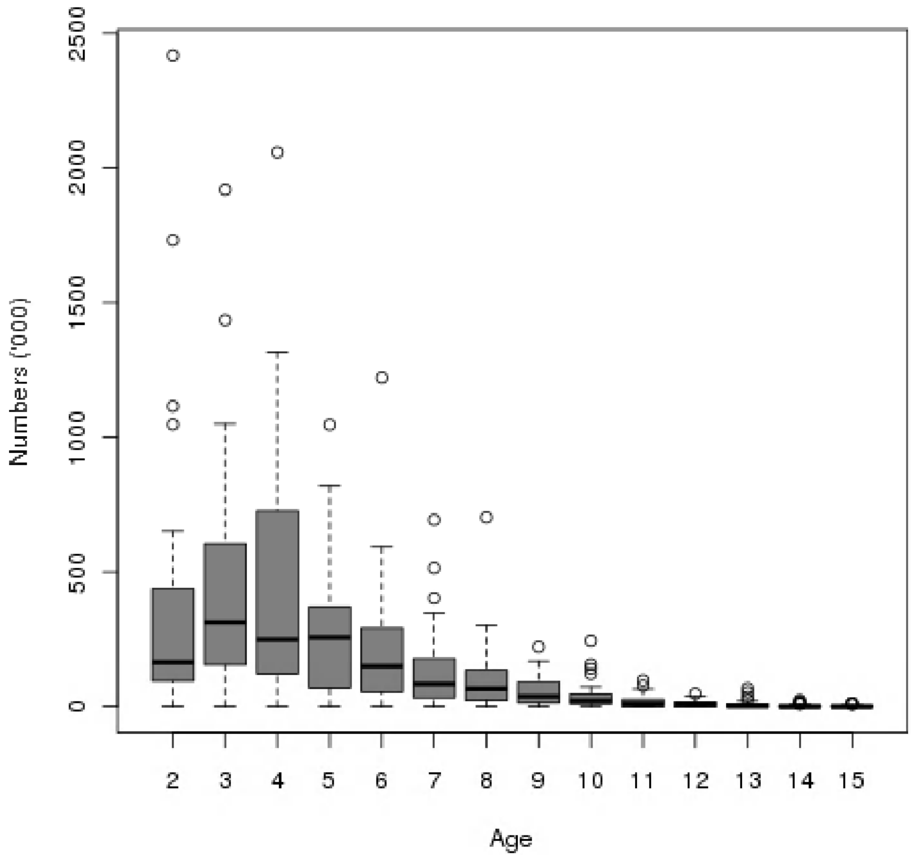


Figure 13. ISSH. Boxplot of survey indices at age in numbers.

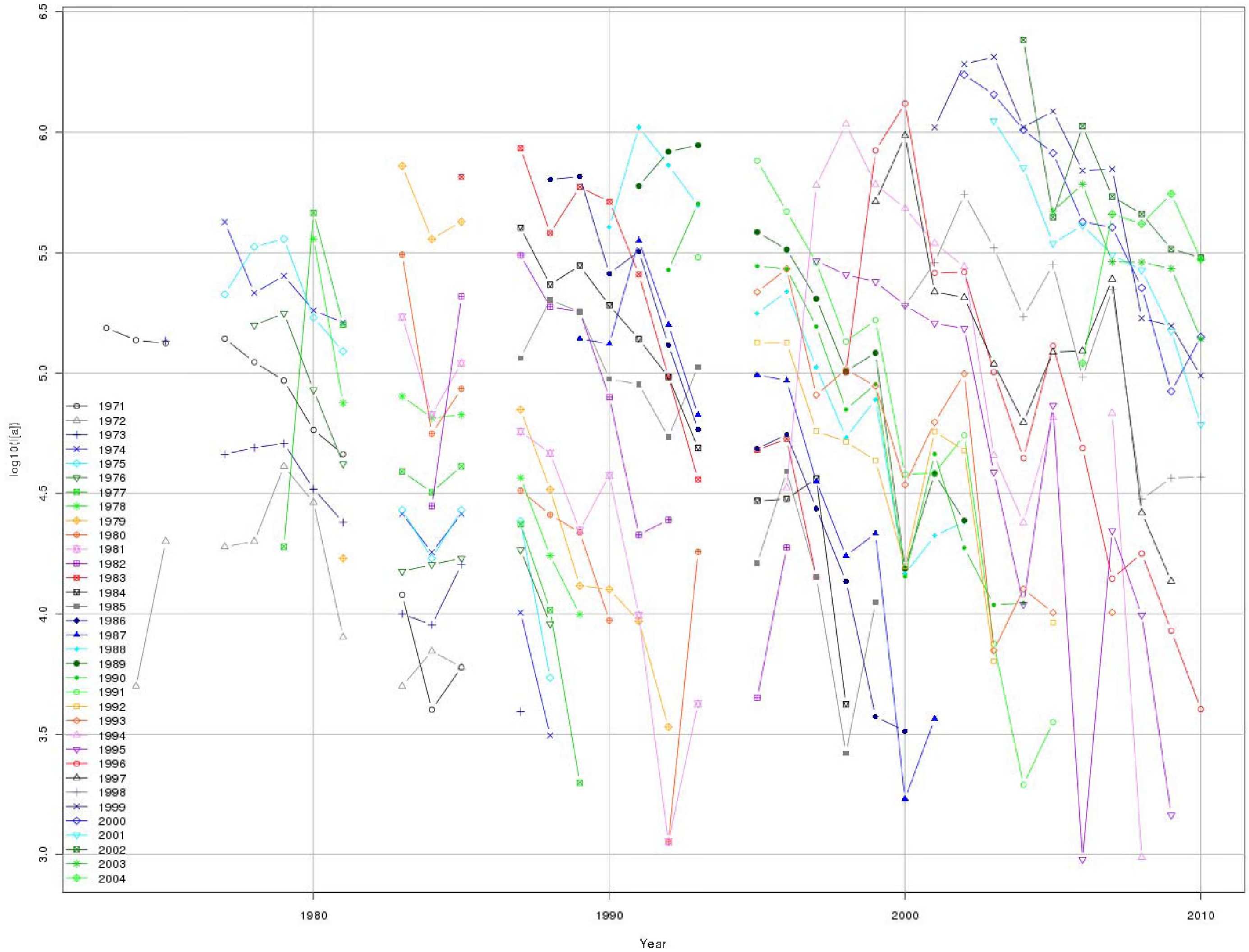


Figure 14. ISSH. Acoustic survey log indices by year classes 1971–2004.

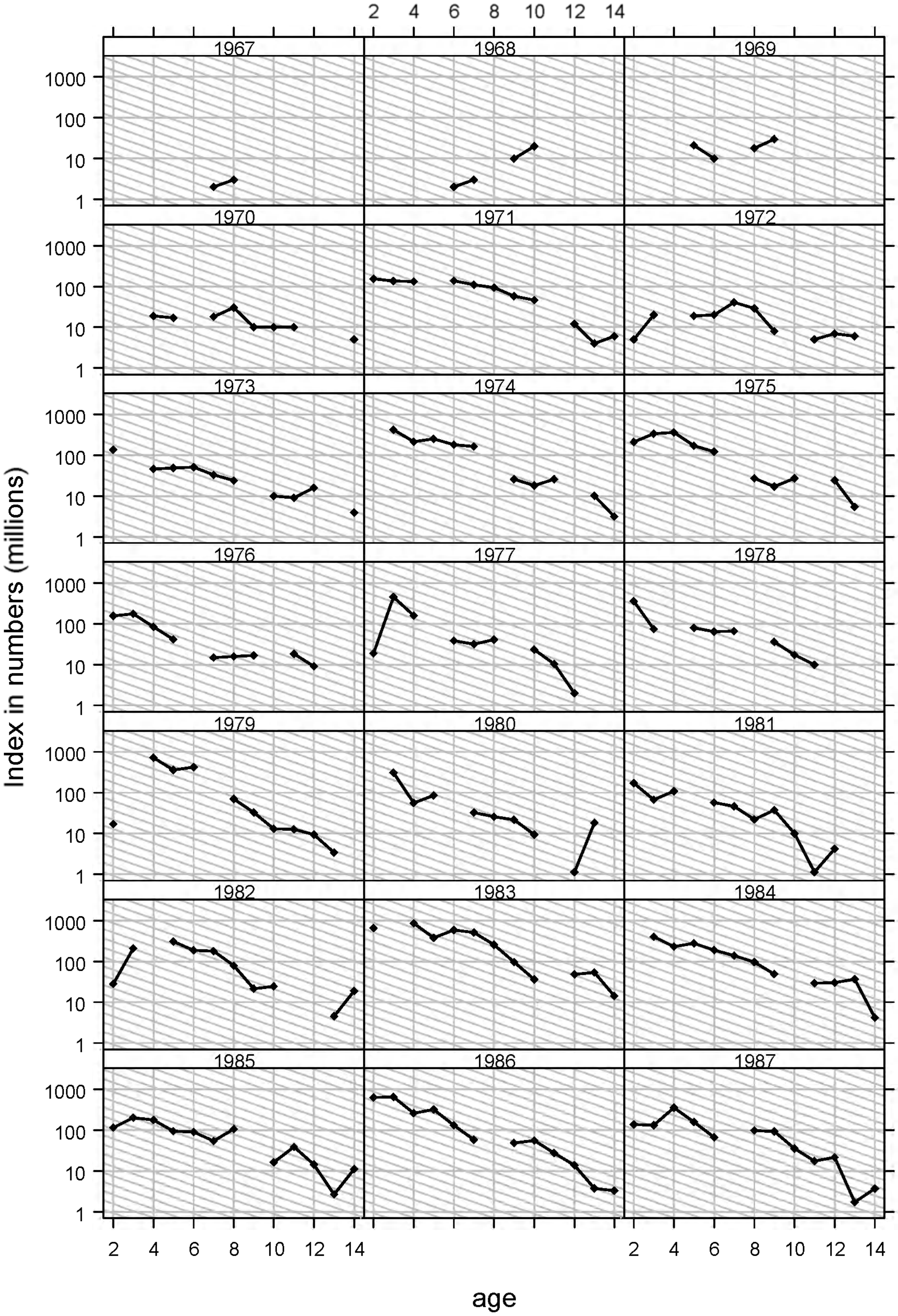


Figure 15. ISSH. Catch curves from survey data by year classes 1966–1987. The grey lines corresponds to Z=0.4.

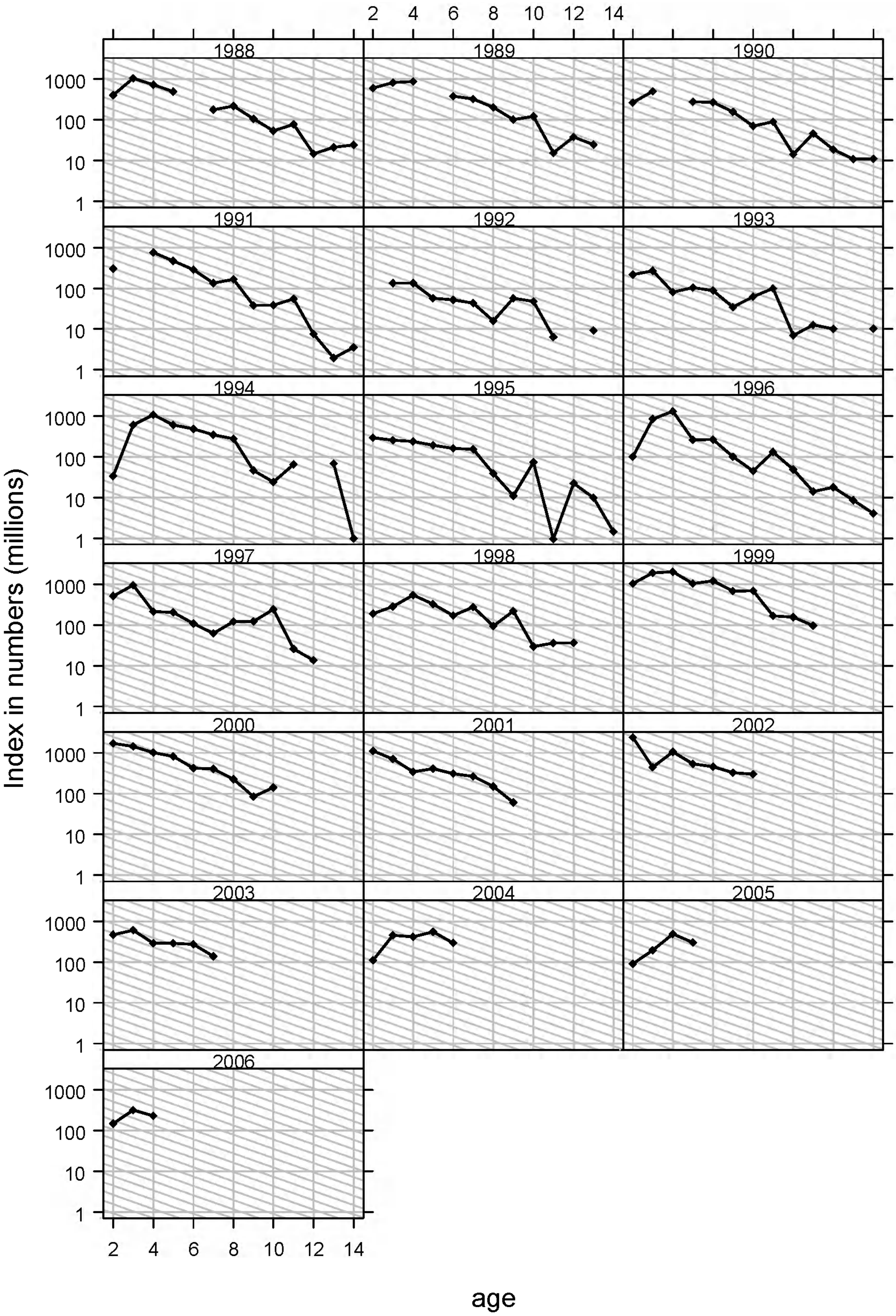


Figure 16. ISSH. Catch curves from survey data by year classes 1988–2006. The grey lines corresponds to Z=0.4.

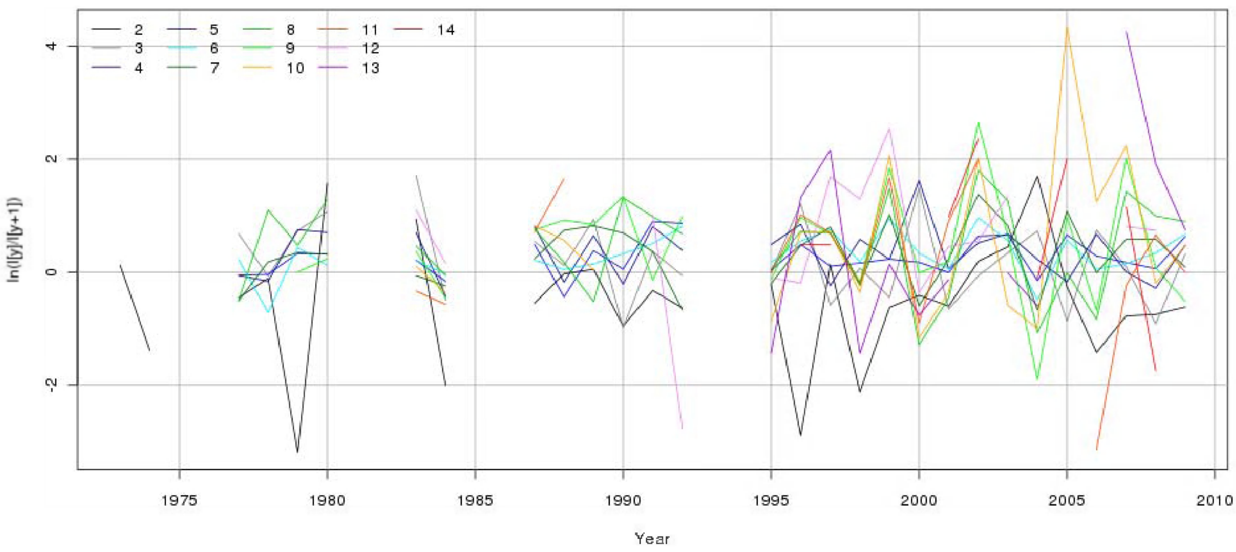


Figure 17. ISSH. Log index ratio at age from the survey.

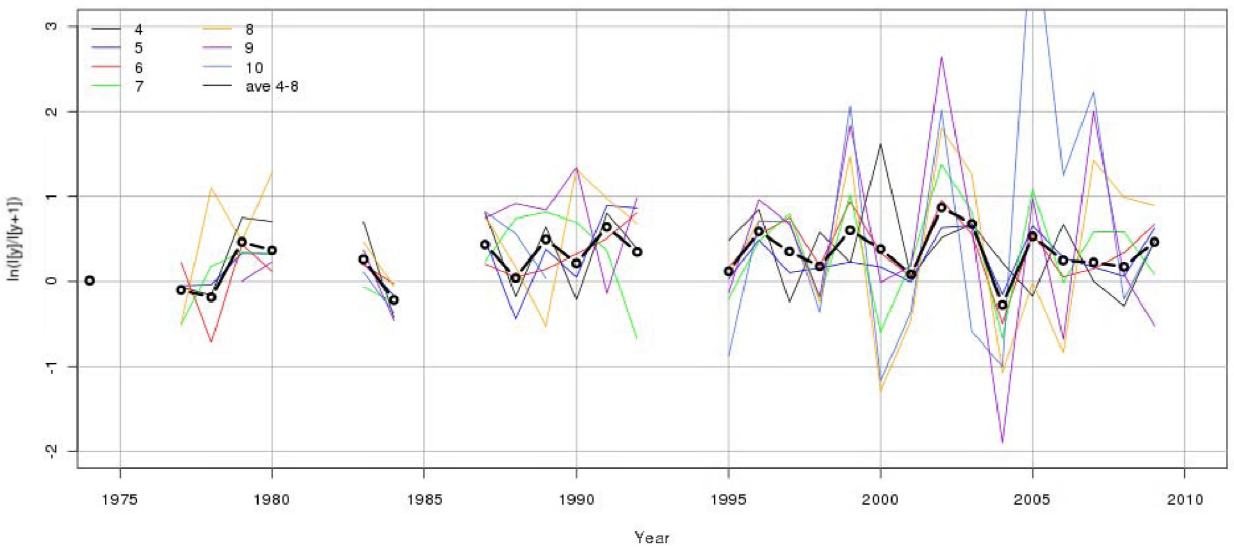


Figure 18. ISSH. Log index ratio at age over ages 4 to 10 from the survey. The black thick line is an average over ages 4–8.

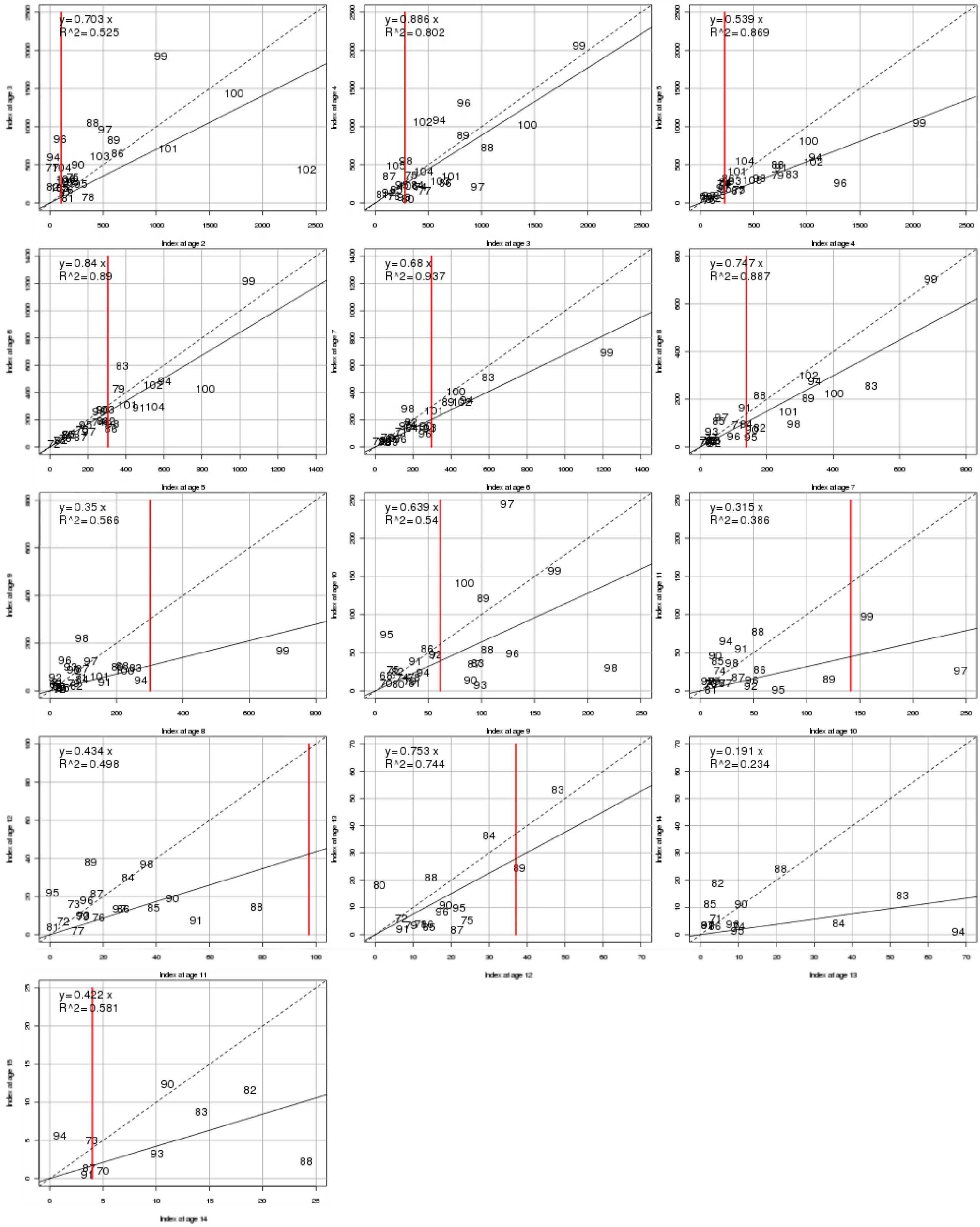


Figure 19. ISSH. Correlation within the acoustic survey.

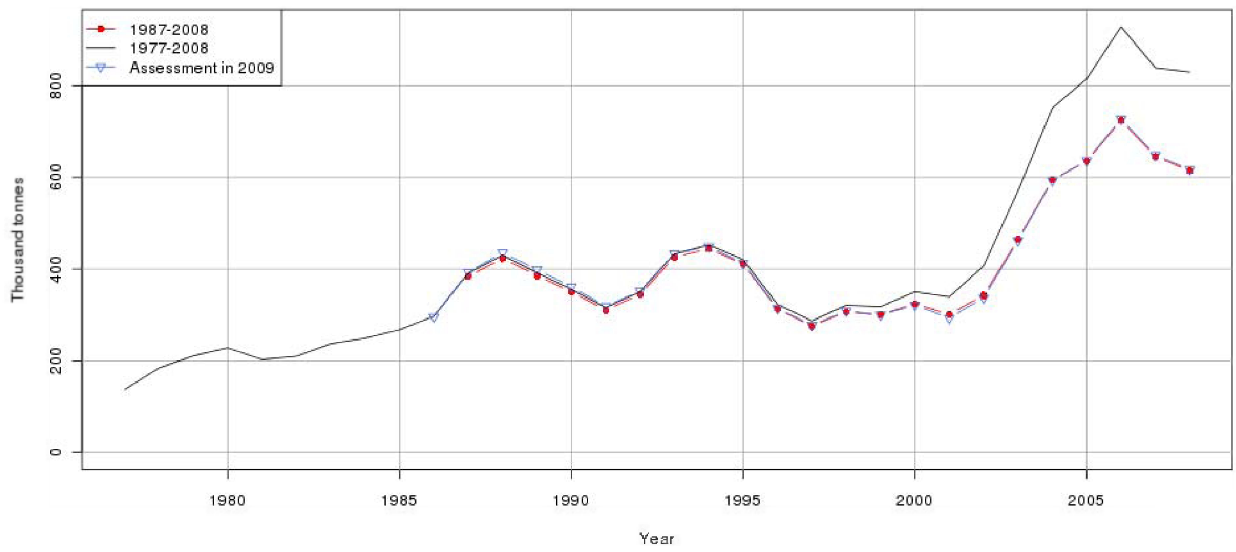


Figure 20. ISSH. SSB trajectories from three runs.

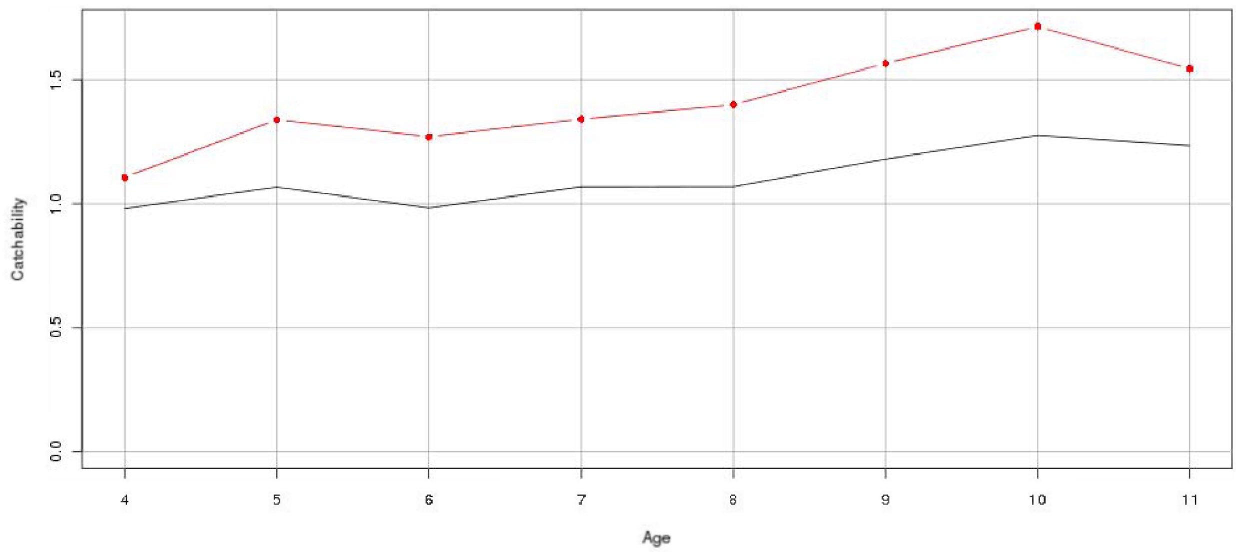


Figure 21. ISSH. Calculated catchability for age 4–11 from runs with data from 1977–2009 (black line) and 1987–2008 (run8, red line with dots).

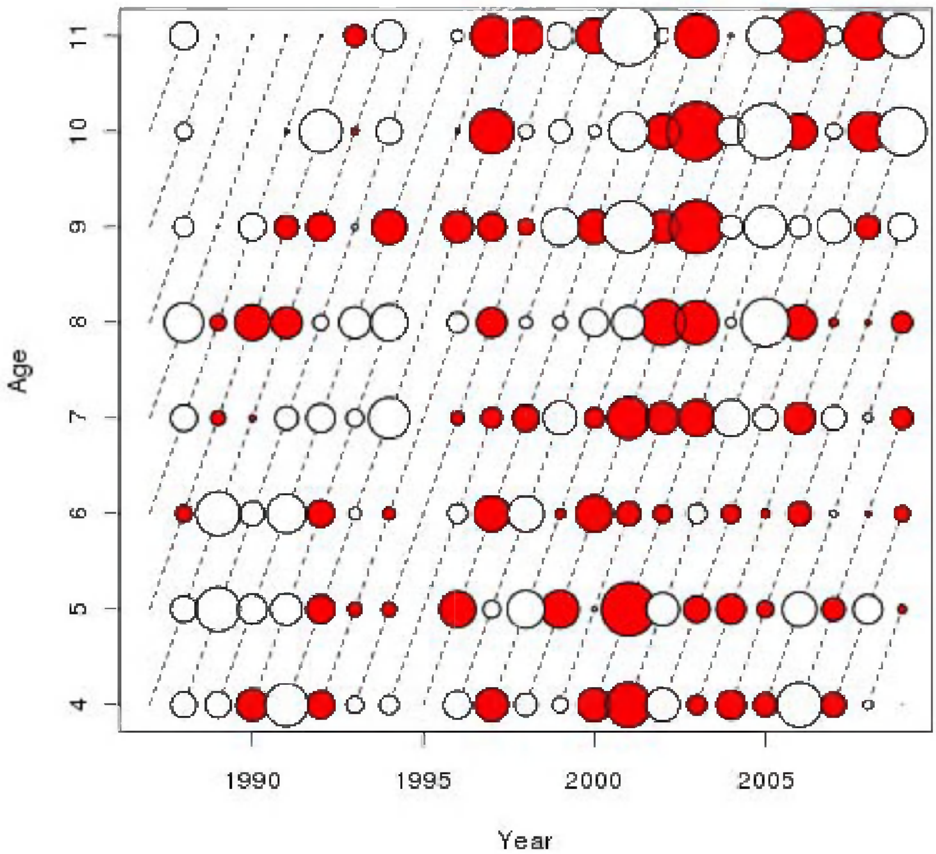


Figure 22. ISSH. Survey residuals from run8.

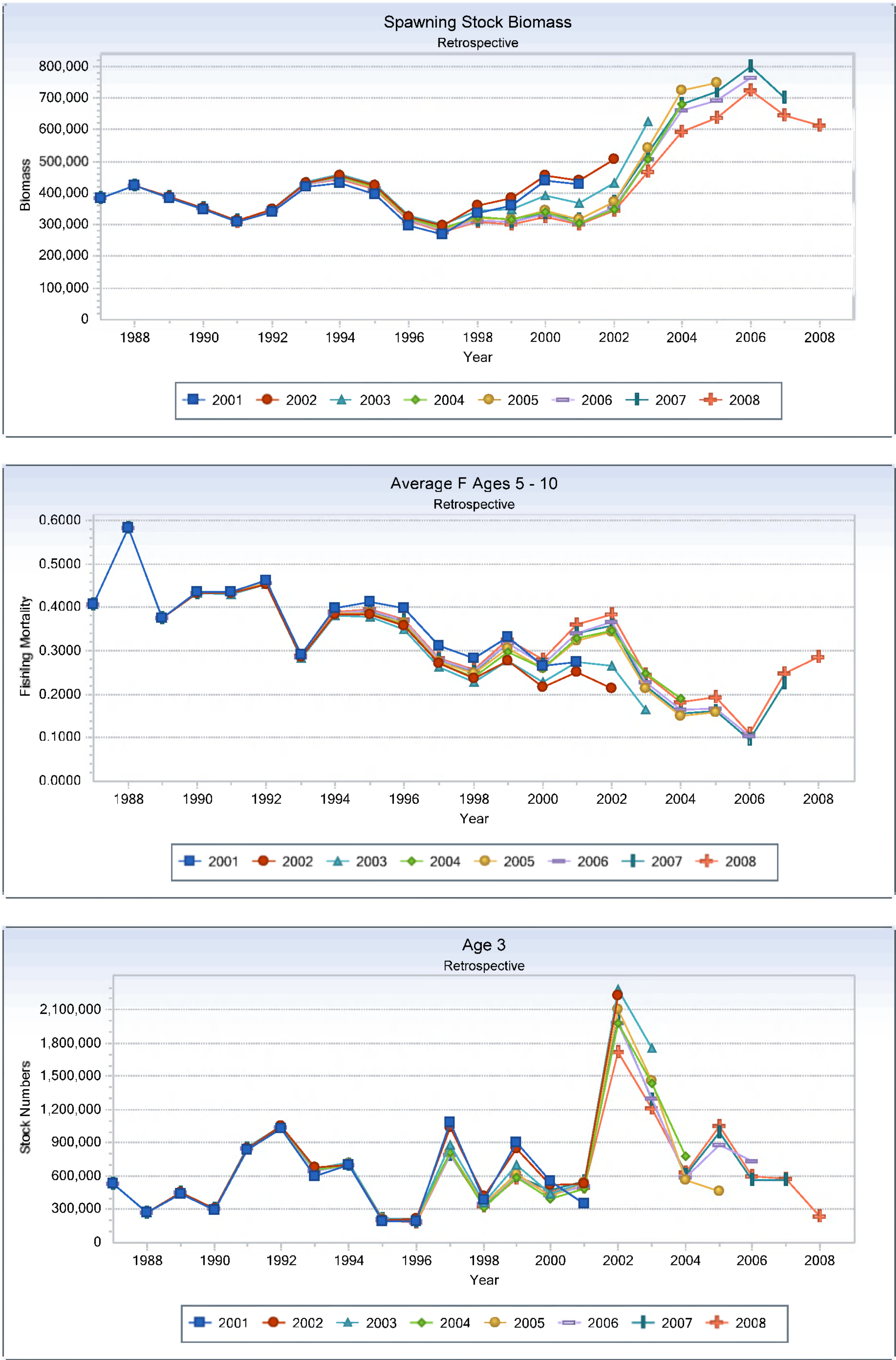


Figure 23. ISSH. Retrospective plot of SSB, average F 5–10 and recruitment at age 3 (from run8).

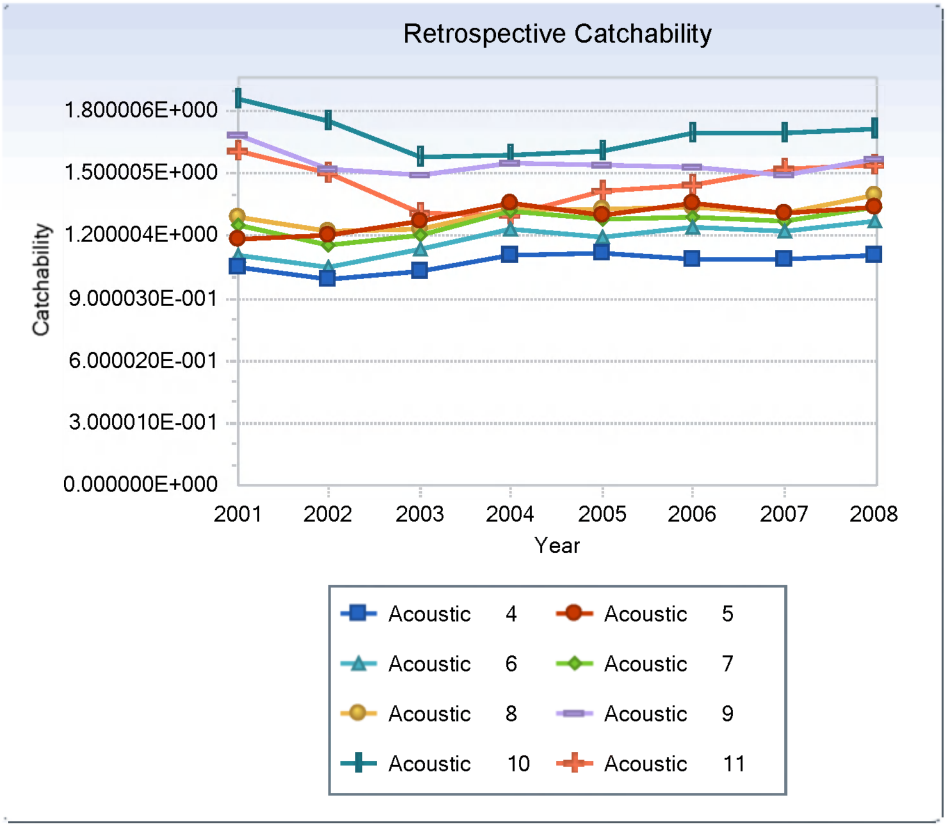


Figure 24. ISSH. Retrospective plot of catchabilities from 2001–2008.

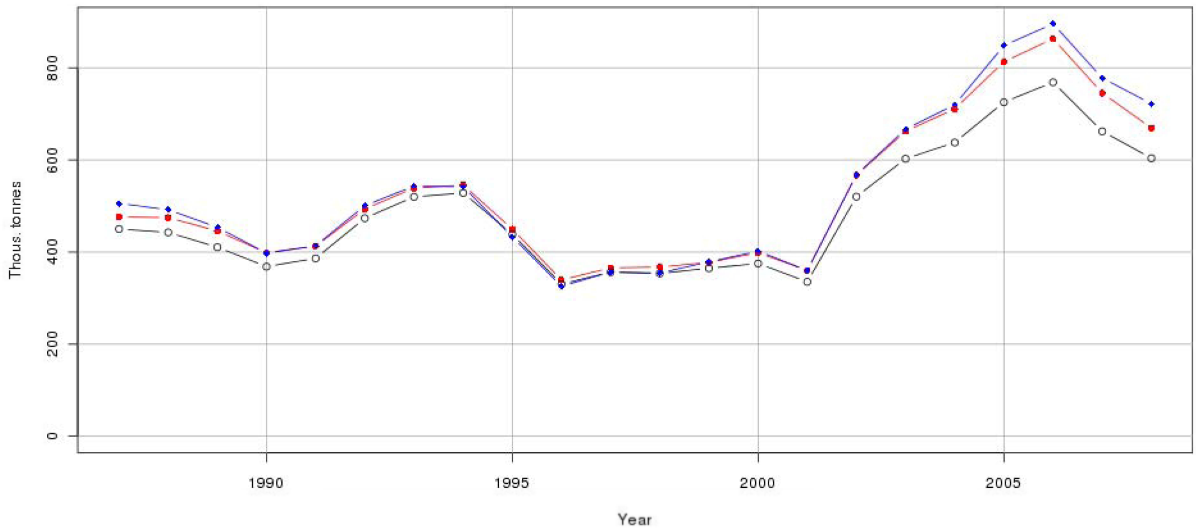


Figure 25. ISSH. Biomass January 1 for ages 3–11 as estimated by three different assessment programs, Colraine (blue), NFT-Adapt (red) and TSA (black, open circles).

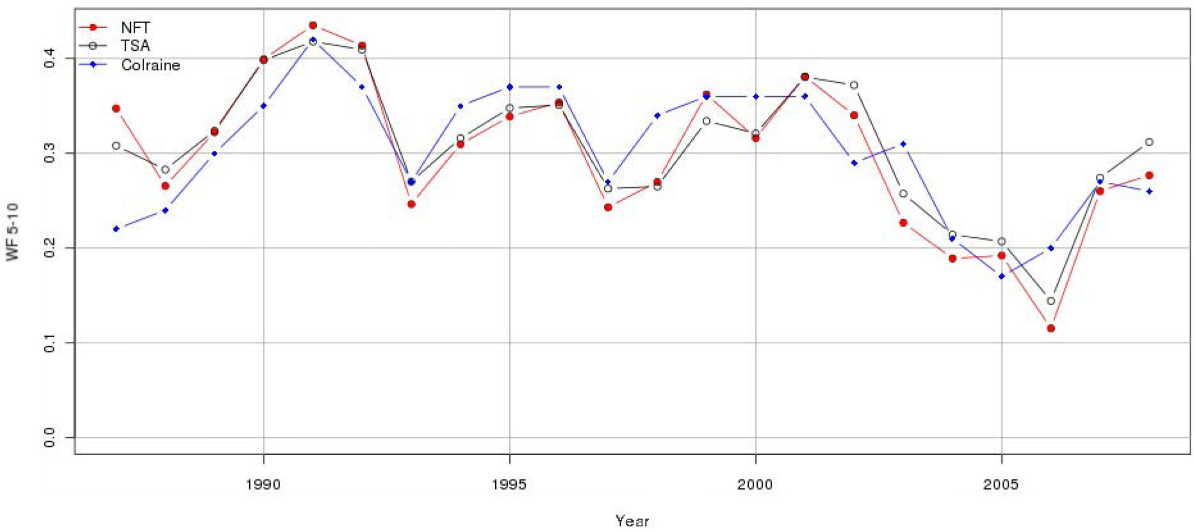


Figure 26. ISSH. Weighted F 5–10 with stocknumbers from 3 assessment models.

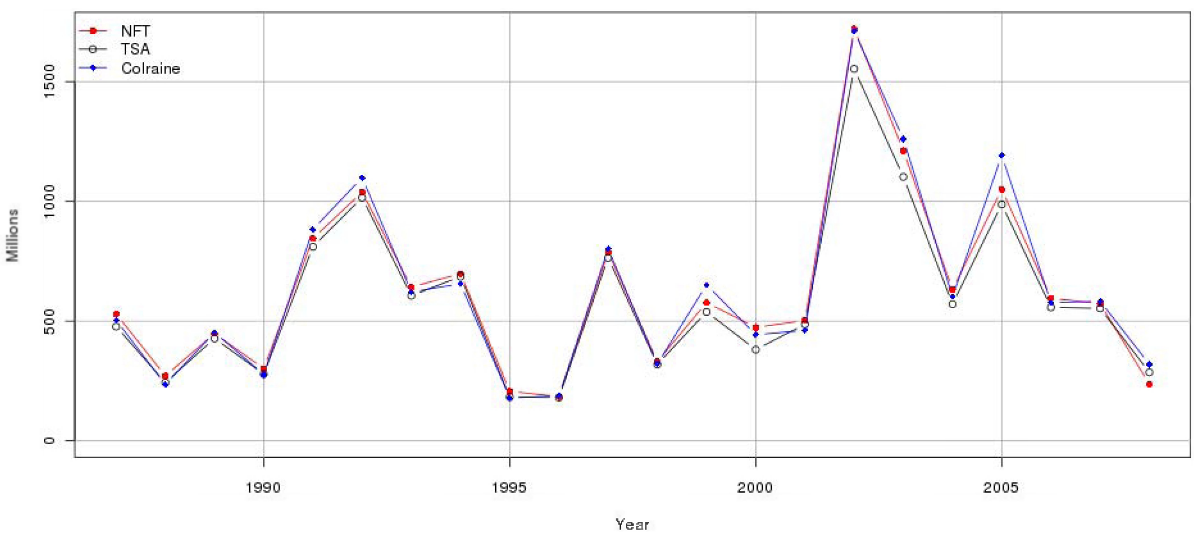


Figure 27. ISSH. Recruitment-at-age 3 as estimated by three different assessment programs, Colraine, NFT-Adapt and TSA.

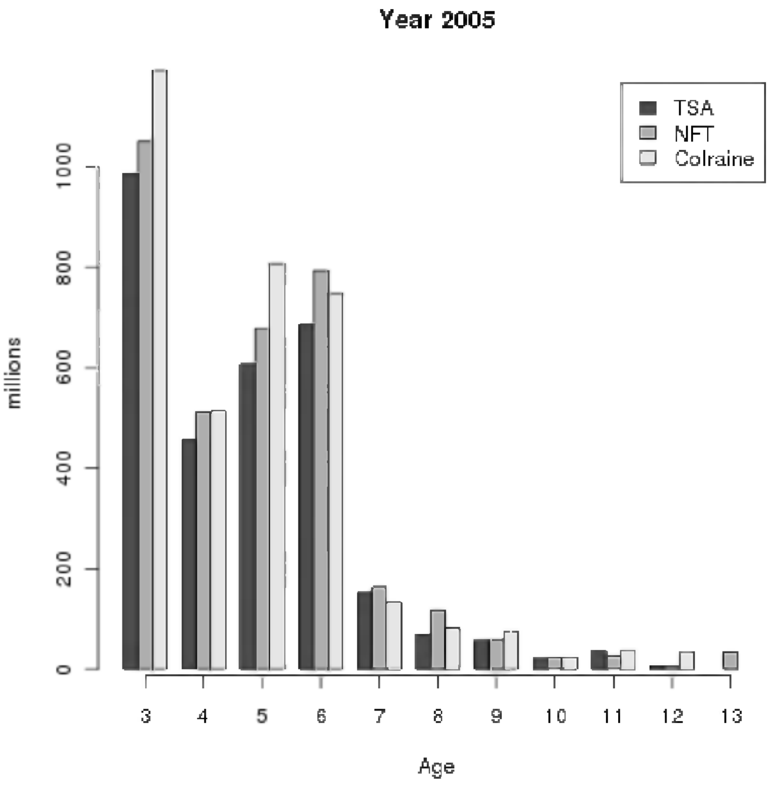


Figure 28. ISSH. Stock in numbers by age in the year 2005 by the three assessment models.

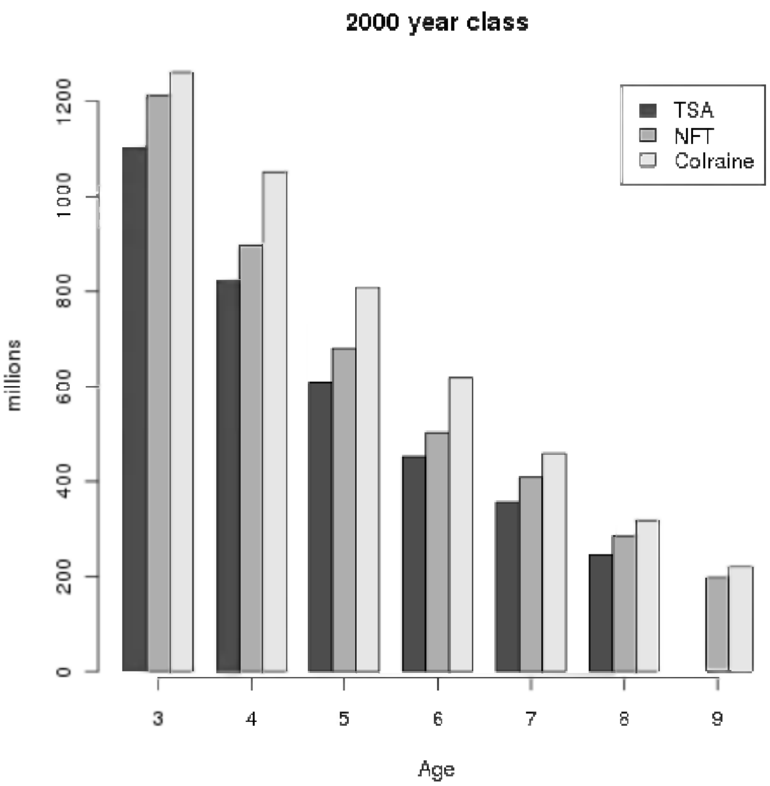


Figure 29. ISSH. Year class 2000 by age as estimated by the three assessment models.

Assessment of the stock size of Icelandic summer spawn herring by time-series analysis

by Gudmundur Gudmundsson, Science Institute, University of Iceland

A description of the time-series method is appended on pages 6–12, including equations and definition of symbols, referred to in the following text.

The present analysis is based on catch-at-age- and acoustic survey data. Because of the exceptional mortality from infection by *Ichtyophonus hoferi* in 2009 and 2010, the model selection and retrospective analyses are based on the data from 1987–2008. The survey index is missing in 1994. Part of the area was not accessible for surveying in 1997 and 2001, but there is no indication of exceptional residuals in these years so that no modification of the survey data was applied. The catch-at-age data includes ages from 3–12 years and the survey index from 2–9 years.

Estimated parameters with standard deviations, obtained by the Hessian matrix, are presented in Table 1 below and estimates of stocks and fishing mortality raters in Tables 3 and 4 on page 3. The estimation is carried out with a3=6years and a4=8 years.

Table 1.

PARAMETER	ESTIMATE	S.D.
r0	6.21	0.13
ξ10	-1.08	0.19
ξ30	-1.65	0.57
σr	0.58	0.08
θf1	0.13	0.03
σζ3	0.57	0.12
σζ4	0.29	0.12
σψ1	0.21	0.04
σψ3	0.28	0.14
σξ1*	0.85	0.20
θc1	0.15	0.04
θc2	0.05	0.04
θc3	3.61	2.13
θi1	0.35	0.05
θi2	0.22	0.09
θi3	4.49	0.40
ϱc	0.20	0.18
ϱi	0.49	0.08
χ10	-6.30	0.22
χ20	-0.79	0.32
χ30	-0.51	0.30

***Applies only to two year's age.**

Recruitment is supposed to be log-normally distributed with estimated standard deviation 0.58.

Permanent variations in logF are produced by two random walk terms. The standard deviation of the innovations is determined by $\sigma_{\psi 1}$ and $\sigma_{\psi 3}$ according to equations (7)–(9).

The estimated random elements in the time-series analysis of the herring are large compared with results from other Icelandic stocks. No meaningful estimates of the average or random variations of the natural mortality rate could be obtained and the present analysis was carried out with a constant M=0.1.

The estimated standard deviations of the total transitory variations of the logarithmic values of catch-at-age, fishing mortality rates and survey indices is presented in Table 2.

Table 2.

AGE	2	3	4	5	6	7	8	9	10	11	12
cat		0.18	0.16	0.15	0.15	0.16	0.18	0.21	0.25	0.30	0.36
fat		0.48	0.29	0.20	0.16	0.17	0.19	0.19	0.19	0.19	0.19
iat	1.05	0.49	0.40	0.36	0.36	0.40	0.49	0.62			

The variance of c_{at} is obtained from equation (6). The variance of f_{at} is the sum of the variance of $\delta_{f,at}$ in equation (7) and the sum of the product of the variances of $\delta_{\zeta jt}$ multiplied by the squared values of respective $\Gamma_{f,j,a}$. The variance i_{at} includes estimated transitory variations in catchability at two years.

The assumption of a constant rate of natural mortality implies that actual variations in M are expressed by the estimated random effects in other variables. But in normal conditions, variations in an M that is of the order of 0.1 are small, compared with the estimated random effects in c, f and i.

Estimated first order correlations by age in the residuals of catches and survey indices (equations (1) and (3)) are positive (0.20 and 0.49, Table 1) which indicates that errors in age-reading are not a major source of the observed irregularities in the data. This is similar with our experience from other stocks.

There was no indication of stock-dependence so that all estimation was carried out with ϕ_a=1.

Surveys are designed and conducted with the aim of avoiding systematic variations in catchability unless they are accounted for. But marine research institutions do not control nature which can also affect catchability. Equation (11) provides the means of including systematic variations in catchability by random walk or linear trend. A normal null hypothesis about the parameters is that $\theta_{\chi 1}$ and the variance of the residuals are zero. There is no significant evidence against this here and most of the analysis is carried out with the zero values for these parameters. However, the estimated value of $\theta_{\chi 1}$ is 0.024 annual increase in log-catchability with a standard deviation of 0.014. This implies a decrease in the estimated total biomass in 2008 from 612 to 481 thousand tonnes.

As no residuals are included in the stock equation (2) or the definition of natural mortality in equation (13), $r_{2,t} = r_{3,t+1}$ in the smoothed estimates in Table 3.

There is no indication of serial correlation or non-normality in the residual statistics presented with Tables 5 and 6 on page 4.

The same parameters were estimated in all retrospective runs, presented on page 5. With the exception of the results with terminal year 2002, the discrepancies are in tolerable agreement with the estimated accuracy.

Table 3. Estimated stock of Icelandic summer spawn herring, (Million fish).

	total biomass	2	3	4	5	6	7	8	9	10	11	12
1987	464.	243.6	477.4	935.7	307.3	82.09	63.97	95.21	38.82	33.82	28.14	33.45
1988	449.	427.9	243.6	426.9	783.6	224.30	55.12	39.87	53.09	23.12	19.92	16.73
1989	414.	279.0	427.9	215.8	350.1	600.30	135.58	28.85	19.31	23.20	11.02	9.47
1990	371.	810.6	279.0	367.1	168.6	249.76	395.13	79.80	17.59	11.61	13.39	6.31
1991	389.	1015.8	810.6	238.3	278.6	119.96	158.80	230.53	42.99	9.66	6.62	7.60
1992	475.	606.2	1015.8	654.5	168.3	175.02	78.89	98.55	126.05	26.92	5.52	3.96
1993	521.	686.2	606.2	835.8	473.5	114.95	104.31	51.16	59.53	69.95	15.73	3.29
1994	532.	183.2	686.2	498.9	601.0	338.05	84.60	68.92	36.57	39.99	47.80	10.69
1995	452.	180.9	183.2	510.1	345.6	411.00	231.22	61.65	45.75	23.86	26.14	31.42
1996	336.	764.3	180.9	145.7	344.6	229.89	264.98	142.56	39.33	28.19	14.73	15.92
1997	360.	319.0	764.3	149.1	99.8	228.95	146.09	163.69	91.13	24.18	17.74	8.98
1998	359.	538.7	319.0	653.0	108.2	67.46	163.62	99.90	114.96	62.70	16.09	12.31
1999	369.	380.9	538.7	246.2	447.1	75.78	50.35	111.20	69.18	78.73	43.53	11.43
2000	387.	486.8	380.9	433.0	171.5	286.52	51.61	33.66	71.80	45.56	51.55	28.54
2001	350.	1553.6	486.8	295.1	281.5	110.63	185.89	35.59	23.68	48.63	31.68	35.37
2002	529.	1102.5	1553.6	397.5	193.6	174.11	70.88	116.06	22.90	14.91	31.18	20.12
2003	610.	571.3	1102.5	1335.9	295.0	131.83	109.58	44.62	69.59	13.66	9.21	19.61
2004	640.	987.7	571.3	822.0	941.5	210.00	92.38	75.45	29.56	48.99	9.61	6.20
2005	728.	557.6	987.7	458.0	607.0	686.61	153.08	68.89	56.60	21.39	36.28	6.91
2006	779.	553.7	557.6	873.5	372.3	451.16	502.20	112.19	50.60	41.68	15.32	26.68
2007	667.	286.3	553.7	399.8	605.5	282.50	355.61	398.17	89.09	40.29	33.19	12.33
2008	612.	440.8	286.3	419.3	280.2	410.36	199.13	244.68	275.79	61.59	27.68	23.12

Standard deviation of logarithmic stock values 2008, adjusted for errors in parameter estimates

2008	(90.)	0.526	0.302	0.218	0.193	0.193	0.191	0.211	0.225	0.236	0.246	0.259

Table 4. Estimated fishing mortality rate of Icelandic summer spawn herring.

	Average F, 4-10y	3	4	5	6	7	8	9	10	11	12
1987	0.328	0.012	0.077	0.215	0.299	0.374	0.484	0.419	0.429	0.420	0.424
1988	0.460	0.021	0.099	0.171	0.404	0.548	0.627	0.731	0.641	0.644	0.632
1989	0.347	0.055	0.148	0.245	0.334	0.430	0.403	0.416	0.450	0.460	0.440
1990	0.391	0.058	0.176	0.251	0.366	0.450	0.519	0.505	0.472	0.470	0.476
1991	0.397	0.114	0.248	0.365	0.350	0.412	0.522	0.398	0.484	0.450	0.434
1992	0.397	0.097	0.224	0.288	0.423	0.398	0.451	0.512	0.479	0.454	0.472
1993	0.285	0.098	0.232	0.245	0.243	0.341	0.283	0.340	0.312	0.324	0.317
1994	0.339	0.197	0.276	0.297	0.319	0.323	0.367	0.403	0.390	0.378	0.366
1995	0.358	0.131	0.301	0.309	0.342	0.395	0.371	0.396	0.396	0.406	0.374
1996	0.350	0.103	0.295	0.321	0.354	0.382	0.348	0.387	0.363	0.395	0.351
1997	0.266	0.065	0.221	0.292	0.237	0.280	0.253	0.274	0.308	0.266	0.259
1998	0.262	0.159	0.280	0.256	0.195	0.286	0.270	0.280	0.266	0.243	0.266
1999	0.312	0.119	0.262	0.349	0.284	0.307	0.337	0.319	0.324	0.323	0.314
2000	0.309	0.176	0.364	0.342	0.336	0.278	0.272	0.294	0.274	0.284	0.285
2001	0.360	0.106	0.328	0.400	0.351	0.386	0.342	0.363	0.349	0.356	0.345
2002	0.367	0.060	0.199	0.290	0.389	0.383	0.458	0.446	0.402	0.390	0.437
2003	0.266	0.195	0.254	0.241	0.256	0.279	0.318	0.258	0.255	0.299	0.273
2004	0.207	0.121	0.204	0.218	0.218	0.195	0.187	0.223	0.200	0.231	0.219
2005	0.198	0.032	0.110	0.197	0.214	0.211	0.209	0.207	0.236	0.209	0.213
2006	0.157	0.233	0.268	0.177	0.138	0.132	0.131	0.128	0.128	0.118	0.122
2007	0.269	0.178	0.258	0.290	0.251	0.274	0.268	0.269	0.276	0.262	0.261
2008	0.308	0.152	0.276	0.325	0.311	0.329	0.310	0.288	0.320	0.316	0.304

Standard deviation of logarithmic fishing mortality rates, adjusted for errors in parameter estimates

0.348 0.254 0.232 0.226 0.245 0.260 0.264 0.272 0.273 0.273

Table 5. Standardized residuals of catch-at-age.

	3	4	5	6	7	8	9	10	11	12
1989	-0.06	0.18	0.59	0.91	-0.88	-0.99	-0.47	-1.14	0.27	-0.20
1990	-0.09	-0.26	0.39	0.95	1.31	-0.14	1.25	0.51	-1.11	-0.53
1991	1.25	0.87	0.62	0.64	0.57	1.21	-1.63	0.49	0.57	-0.76
1992	1.03	-0.14	-0.65	-0.49	0.87	0.94	0.57	0.91	-0.08	0.91
1993	0.21	0.45	-1.04	-1.81	-1.11	0.24	0.51	-1.11	-0.19	-0.40
1994	1.37	0.91	0.00	0.09	1.20	0.53	2.21	1.48	0.51	0.36
1995	-1.29	-0.22	0.15	-0.11	0.83	1.85	0.89	1.17	0.98	-0.19
1996	-1.43	0.17	-1.31	0.29	0.20	0.02	1.16	0.11	0.78	-0.83
1997	0.67	-0.76	-0.60	-2.74	-0.78	-1.45	-0.36	0.48	-1.03	-1.89
1998	0.14	2.15	-0.01	-1.95	-0.07	0.44	0.54	0.03	-1.60	-0.12
1999	0.45	0.27	0.76	-0.34	0.97	0.44	0.81	0.50	0.61	0.05
2000	0.00	0.73	0.46	-0.60	-0.50	0.35	-0.63	-0.34	-0.43	-0.16
2001	0.13	-0.33	-0.67	-0.31	-0.59	0.76	1.98	0.16	1.03	0.15
2002	-0.01	0.30	-0.81	-0.67	-0.15	-0.15	1.28	0.52	-0.86	1.06
2003	1.36	1.38	0.14	-0.78	-1.41	-0.16	-2.81	-2.01	0.38	-0.97
2004	-0.20	-0.25	0.37	0.01	-1.36	-2.57	-1.10	-1.99	0.50	0.26
2005	-1.38	-1.48	0.29	0.46	0.27	0.11	-0.56	0.39	-1.05	-0.70
2006	1.30	2.75	0.60	-1.56	-1.41	-0.99	-0.91	-1.49	-2.85	-2.45
2007	1.23	0.51	2.10	1.84	1.92	1.46	1.94	2.07	1.11	0.89
2008	-0.48	-0.33	1.01	0.80	1.38	0.49	-0.49	0.75	0.70	-0.03

$r_a = 0.50$, $r_t = 0.03$, $r_{coh} = 0.19$.

$\gamma_1 = -1.12$, $\gamma_2 = 0.47$.

Table 6. Standardized residuals of survey indices.

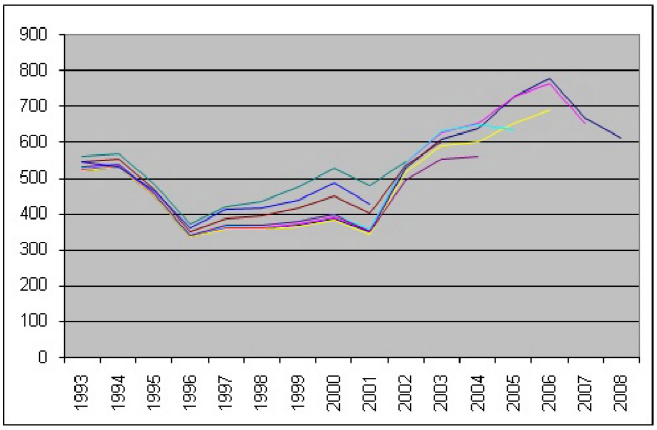
	2	3	4	5	6	7	8	9
1989	-0.62	-0.17	-0.63	-0.66	0.31	0.38	-0.37	0.36
1990	0.26	-1.83	-1.77	-1.45	-0.38	1.16	-0.06	1.46
1991	0.57	0.61	0.68	0.00	0.04	0.46	0.79	-0.84
1992	-0.09	0.35	-0.19	-0.34	-0.68	0.43	0.98	0.24
1993	0.00	-0.06	0.32	0.16	-0.63	-0.59	2.48	0.66
1994	-0.01	-0.02	-0.01	-0.02	-0.01	0.01	0.01	0.02
1995	-0.27	-1.72	0.41	0.26	0.69	0.68	2.23	1.04
1996	-1.80	-0.81	-0.48	-0.21	0.74	0.85	1.29	1.82
1997	0.02	1.04	-2.30	-2.30	-0.48	0.07	0.33	0.32
1998	-0.88	-0.85	1.92	-0.50	-1.09	-0.81	-0.66	-0.25
1999	0.49	1.10	-0.15	0.26	0.13	0.02	0.66	0.52
2000	-0.33	0.86	1.93	0.03	0.51	-0.90	-1.02	-1.04
2001	1.08	-0.55	-1.77	-1.73	0.32	0.69	1.33	1.85
2002	1.47	1.47	1.26	-0.64	-0.22	1.08	0.77	1.99
2003	1.08	1.07	1.85	0.34	-1.16	-1.43	-1.12	-1.69
2004	1.71	0.15	0.51	0.56	-0.44	-1.20	-1.73	-2.05
2005	0.33	-0.87	-0.66	0.60	1.38	1.40	1.08	1.01
2006	-0.87	0.05	1.59	0.42	-0.84	0.10	-0.68	1.09
2007	-1.01	0.21	-0.92	-0.28	0.12	-0.09	0.60	1.13
2008	-0.57	-0.86	-0.07	0.27	0.24	0.66	-0.38	-1.05

$r_a = 0.46$, $r_t = -0.02$, $r_{coh} = 0.19$.

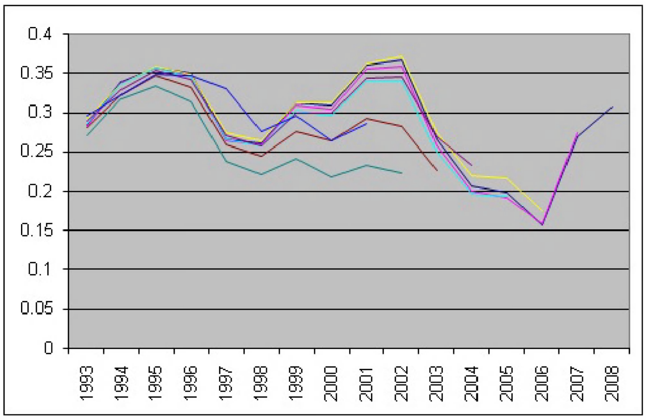
$\gamma_1 = 0.56$, $\gamma_2 = -0.46$.

Retrospective analyses

Terminal years 2001–2008.



Total biomass, 3–12 years, 1000 tonnes.



Average F, 4–10 years.

Time-series models for analysis of catch-at-age observations

This is a description of the time-series methodology, currently applied in assessment of several Icelandic stocks by observed catch-at-age and survey indices. It is a combination of estimation procedures, described by Gudmundsson (1994 and 2004) with some later modifications. Analysis of survey indices below catchable ages follows the second paper except that it is combined with the analysis of older fish and catch-at-age data, instead of introducing estimates of the stock at the youngest catchable age externally. The main departures from the 1994 paper are that logarithmic values of stocks and catches-at-age are analyzed and the estimation of variations in selectivity has been modified. Natural mortality is modelled in a similar way as Aanes *et al*. (2007).

The main purpose of the analysis is to use given relationships between the variables to estimate the unobserved values of stocks and mortality rates by the observed values of catches and catch per unit effort. Unobserved series are called state variables in the present methodology. This is multivariate time-series analysis, where observations of catch-at-age or survey index at a given age constitute the series.

From the point of view of time-series analysis, this is a state-space problem in multivariate time-series analysis. The unknown series of state variables are estimated from the observed catches and indices. The number of observed series is rather large and they are very short. The relationships between observations and state variables are non-linear but fairly well known, although some parameters need to be estimated. There are several sources of substantial random elements; measurement errors, sampling variations, natural variations in mortality and catchability and social- and technological changes in fishing.

For linear relationships and normally distributed residuals, the Kalman filter can be employed to calculate the likelihood function for estimation of parameters, and the least squares estimate of the state variables in the last period. The non-linearity of the present models affects the calculation of covariance matrices, required in this procedure. It can be resolved by linear approximations, but this introduces bias. The Kalman filter methodology is described by (Harvey, 1989) and arrangements to deal with the catch-at-age analysis by Gudmundsson (1994).

Models

The notation is conventional; age and time are measured in years. Small letters denote logarithmic values of respective variable.

C_{at} catch in numbers of fish of age a in year t,

N_{at} stock in numbers at the beginning of year t,

F_{at} fishing mortality rate,

M_{at} natural mortality rate,

$Z_{at} = F_{at} + M_{at}$ total mortality rate,

I_{at} survey index,

a1 youngest age in survey data,

a2 youngest age in catch-at-age data,

a3 constant catchability in survey for $a \geq a3$,

a4 constant catchability for $a \geq a4$,

a5 oldest fish in survey data,

a6 oldest fish in catch-at-age data.

More symbols and parameters will be explained as they appear in the text. In practice F refers to recorded catches and M includes unrecorded discards and landings as well as natural mortality. Small letters will denote logarithmic values.

The catch observations are connected with the stocks and mortality rates through the equation.

$$c_{at} = f_{at} - z_{at} + \log(1 - e^{-Z_{at}}) + n_{at} + \varepsilon_{c,at}, \qquad (1)$$

where measurement errors are represented by the serially uncorrelated residuals $\varepsilon_{c,at}$. The stock equation is

$$n_{at} = n_{a-1,t-1} - F_{a-1.t-1} - M_{a-1,t-1} + \delta_{n,at}. \qquad (2)$$

The residuals $\delta_{n,at}$ are often left out. Literally they represent migration at the beginning of the year. If the natural mortality rate is regarded as known and the fishing mortality rate represented by a manageable time-series model, stocks and fishing mortality rates can be estimated from catch-at-age data and equations (1) and (2), (Gudmundsson, 1994). But usually catch-at-age analysis is combined with catch-per-unit of effort data.

In the catchable ages, a catch-per-unit of effort index from a survey is related to the stock through the model

$$i_{at} = q_{at} + \phi_a(n_{at} - \tau Z_{at}) + \varepsilon_{i,at}, \qquad a \geq a2, \qquad (3)$$

where q_{at} denotes log-catchability and ϕ_a allows a relationship where the index is not proportional to the stock. The survey is supposed to take place at the same time each year, denoted by τ. (Generalization to more than one survey- or fleet data is simple in principle. But the specification of appropriate covariance matrices is very difficult and this will not be considered here).

Useful indices can often be obtained from young ages where negligible catches are taken. Natural mortality in these ages is high and variable according to age and so are variations in catchability. As no observations of mortality are available, it is not possible to estimate stock size with these data. Never the less, they contain valuable information about the relative size of respective cohort. Instead of equations (2) and (3), with inaccessible mortality rates in these ages, we define

$$r_{at} = r_{a-1,t-1} + \delta_{n,at}, \qquad a1 < a \leq a2 \qquad (4)$$

and

$$i_{at} = q_{at} + \phi_a r_{at} + \varepsilon_{i,at}, \qquad (5)$$

where r_{at} is the expected size of the cohort when it reaches the age a2 and $r_{a2,t} = n_{a2,t}$ (Gudmundsson, 2004). The residuals $\delta_{n,at}$ in equation (4) represent irregular variations in natural mortality at age a-1 in year t-1. Variations in catchability and natural mortality cannot be separated and are represented by q_{at}. The residuals $\varepsilon_{i,at}$ include irregular variations in catchability that are not included in the definition of q_{at}, as well as sampling- and measurement errors in the survey indices.

The variances of the residuals in equations (1)–(5) vary with age. The standard deviation of $\varepsilon_{c,at}$ is represented by a parabola:

$$\sigma_{c,a} = \theta_{c1} + \theta_{c2}(a - \theta_{c3})^2 \qquad (6)$$

and correlation across ages by a first order autoregressive process with correlation ϱ_c. The variances of the residuals $\delta_{n,at}$ and $\varepsilon_{i,at}$ are defined in the same way with similar parameter notation.

For the youngest age we usually start with a constant value,

$$r_{a1,t} = r_0 + \delta_{r,t}$$

where $\delta_{r,t}$ represents the variation in recruitment.

With catch-at-age observations, survey indices and a given or narrowly specified rate of natural mortality, it is possible to estimate stock values without modelling the fishing mortality rate. This avoids the errors incurred by inevitable misspecification of the models, but looses the advantage of taking into account regular aspects, including stochastic ones, of the fishing mortality. In my experience the modelling is preferable.

The logarithmic fishing mortality rate is modelled as a linear combination of functions of age, multiplied by state variables, $\zeta_{j,t}$,

$$f_{at} = \sum_{j=1}^{4} \zeta_{j,t-1}\,\Gamma_{f,,j,a} + \delta_{f,at}, \qquad a2 \le a \le a6. \qquad (7)$$

In the present applications $\Gamma_{f,1,a}$ is a constant, $\Gamma_{f,2,a}$ adds a constant to f_{1t}, and $\Gamma_{f,3,a}$ and $\Gamma_{f,4,a}$ are second- and third order polynomials with zero derivatives at a = a4. The standard deviation of $\delta_{f,at}$ is modelled in the same way as $\sigma_{c,a}$ in equation (6). There are also arrangements to account for exceptional changes at a given time.

The state variables are defined

$$\zeta_{j,t} = \psi_{j,t-1} + \delta_{\zeta jt}, \qquad (8)$$

$$\psi_{j,t} = \psi_{j,t-1} + \delta_{\psi jt}. \qquad (9)$$

The residuals $\delta_{\psi jt}$ produce random walk variations. The transitory residuals $\delta_{\zeta t}$, multiplied by respective $\Gamma_{f,j,a}$, can be regarded as a modification of the variation with age and correlation structure of the residuals in equation (7).

The catchability is modelled in a similar way:

$$q_{at} = \sum_{j=1}^{4} \xi_{j,t-1}\Gamma_{i,j,a}, \qquad a1 \le a \le a5, \qquad (10)$$

where $\Gamma_{i,3,a}$ and $\Gamma_{i,4,a}$ have zero derivatives at a = a3 and the state variables are defined as

$$\xi_{jt} = \chi_{j,t-1} + \delta_{\xi jt}, \qquad (11)$$

$$\chi_{1t} = \chi_{1,t-1} + \theta_{\chi 1} + \delta_{\chi 1t}, \qquad (12)$$

$$\chi_{jt} = \chi_{j,t-1} + \delta_{\chi jt}, \qquad j > 1$$

No additional residuals are included in equation (10) because it is impossible to estimate them separately from the residuals in equations (3) and (5). In the present applications, the $\Gamma_{i,j,a}$ functions are defined in the same way as $\Gamma_{f,j,a}$, with zero derivatives at a3. A non-zero value of the parameter $\theta_{\chi 1}$ produces a linear trend in catchability. The Γ- functions employed in the assessment of Icelandic summer spawning herring are presented below:

A	□F,1,A	□F,2,A	□F,3,A	□F,4,A
3	1.000	1.000	0.780	0.368
4	1.000	-0.111	0.420	-0.277
5	1.000	-0.111	0.140	-0.416
6	1.000	-0.111	-0.060	-0.258
7	1.000	-0.111	-0.180	-0.010
8	1.000	-0.111	-0.220	0.118
9	1.000	-0.111	-0.220	0.118
10	1.000	-0.111	-0.220	0.118
11	1.000	-0.111	-0.220	0.118

A	□I,1,A	□I,2,A	□I,3,A	□I,4,A
2	1.000	1.000	0.766	0.421
3	1.000	-0.143	0.328	-0.516
4	1.000	-0.143	0.016	-0.502
5	1.000	-0.143	-0.172	-0.089
6	1.000	-0.143	-0.234	0.171
7	1.000	-0.143	-0.234	0.171
8	1.000	-0.143	-0.234	0.171
9	1.000	-0.143	-0.234	0.171

It is much more difficult to estimate the rate of unobserved mortality, M_{at}, than the fishing mortality from catch-at-age- and survey data. Actual stock assessment is often based on the assumption of a predetermined constant value of M. The most general model that we have considered is

$$m_{at} = m_0 + \mu_t + \delta_{m,at}, \qquad (13)$$

$$\mu_t = \nu_{t-1} + \delta_{\mu t},$$

$$\nu_t = \nu_{t-1} + \delta_{\nu t},$$

with standard deviations σ_m, σ_μ and σ_ν. It is generally not possible to estimate simultaneously the variance of $\delta_{m,at}$ and $\delta_{n,at}$. But if $\delta_{m,at}$ is estimated, corresponding variance is included in equation (4).

The function ϕ_a, producing stock-dependent relationship with the index if it differs from 1, is also produced by a linear combination of $\Gamma_{i,j,a}$:

$$\phi_a = \sum_{j=1}^{4} \theta_{\phi,j}\,\Gamma_{i,j,a}. \qquad (14)$$

In order to set off the Kalman filter algorithm, initial values of the state variables and their covariance matrices must be provided. In linear problems this is easily achieved by arbitrary values of the state variables and very large variances. After a number of steps, depending on the number of observed series and state variables, values with covariance matrices corresponding to the actual accuracy have emerged. The likelihood function for estimating the parameters is obtained from subsequent prediction errors of the residuals. (Harvey, 1989).

In non-linear problems, where the state variables are used to calculate the covariance matrices, their initial values must not be too far from reasonable values. In the present case, initial stock values are obtained by virtual population (VP) analysis. Initial values of other state variables are estimated as parameters and the VP run is also used to select suitable initial values for the estimation of these parameters. Reasonable, rather than extremely large, values are selected for the initial covariance matrices.

Estimated parameters determine initial catchability and selectivity, stock dependence, magnitude and character of the variations of the functions ψ and ζ and the magnitude of the various residuals. The accuracy of these parameters is obtained by the Hessian matrix and the accuracy increases with the length of the series in accordance with established likelihood theory. The first two years are not included in the likelihood function because of the initialization of the state variables which implies that the covariances may not provide a good assessment of the accuracy of the state variables. Stocks, fishing mortality rates and other state variables are estimated by the Kalman filter and the smoothing algorithm (Harvey, 1989). The Kalman filter provides the covariance matrix of estimated state variables. These are calculated, assuming estimated variances and other parameters to be correct. An adjustment, taking into account the inaccuracy in the parameters, obtained from the Hessian matrix, is calculated for the estimates in the final year as described by Ansley and Kohn (1986).

It is not possible to estimate all parameters in the present models with the available data. Many must be assigned predetermined values, often zero. Some parameters are almost always important but others are useful with some data sets and insignificant in others. Commonly estimates of two or more parameters are strongly correlated so that only one can be estimated significantly. In so far as the quantity and quality of data allows, we follow the concept, familiar in econometrics, of "general to specific" in model selection without, however, introducing any automatic procedure for this purpose, (Hendry and Krolzig, 2005).

The calculations with the Kalman filter proceed forward in time. For each year the present estimates of the state variables are used to predict next year's variables and the values of catch-at-age and survey indices. The difference between actual observations and these predictions constitute the observed residuals in this analysis. The likelihood function is calculated from the residuals and their covariance matrices.

In the estimation of the state variables in year t, the Kalman filter uses information in that year and previous years but not subsequent observations. It is therefore only in the last year that the Kalman filter uses all information in the data for estimation of the state variables. For earlier years this is achieved by an algorithm called smoothing, proceeding backward from the last year (Harvey, 1989). These are the estimates usually presented. Corresponding covariance matrices can also be obtained, but unlike the estimates of the state variables, these estimates are unreliable here. This is because of the difficulty in distinguishing between measurement errors and other random elements. Their relative magnitudes have a great effect upon the estimated accuracy of the earlier state variables in the smoothing procedure but less in the Kalman filter. I suspect that even when the likelihood function appears to produce tolerable estimates of both kinds of variations, they are susceptible to misspecifications and the adjustment from Ansley and Kohn (1986) does not deal with that.

The observed residuals do not directly represent any of the residuals defined in the model. They are standardized by dividing by the calculated standard deviation of respective residual into the observed value and first order serial correlation coefficients with respect to age, time and cohort calculated. They are denoted by r_a, r_t and r_{coh} in the results. The estimation procedure requires that there is no serial correlation in the data so that significant values of r_t and r_{coh} are an indication of misspecification. On the other hand, correlations within each age are expected and modelled. Large values of r_a are therefore not an indication of misspecification. With independent observations, the distribution of calculated serial correlation coefficients when the true value is zero is approximately normal with variance=(number of observations)$^{-1}$. In the present case this value is somewhat too low because of the correlation with age. Tests for normality, based on 3rd and 4th moments, are denoted by γ_1 and γ_2 and are N(0;1) when the residuals are normally distributed. Moderate departure from that assumption is harmless for the estimation. The variances of the standardized residuals are calculated for each year and age, both for survey and catch-at-age, and examined in order to detect abnormally large values, calling for changes in specification, but these statistics are not presented.

The present selection of time-series models for catch-at-age analysis is strongly affected by the fact that the series are often only about 20 years long and sometimes shorter. The non-stationary random walk model would hardly be a realistic model of long-term behaviour of fishing mortality rates or catchability. But it is very flexible and probably fairly adequate to capture the main variations, developing over a time-span of this length. Notice that a first order autoregressive model requires the same number of parameters as our random walk + transitory variations.

The Kalman filter is designed for linear relationships. The present application employs linear approximations of non-linear relationships in order to fit into the Kalman filter framework. This introduces some bias in the estimation of parameters, state variables and covariance matrices. The magnitude of this is not easily tractable by analytical methods, but an obvious way to investigate it is to generate data in accordance with the estimated models, estimate them and compare the results with the known parameters and state variables. Preliminary unpublished results of such analysis indicate that the bias is much smaller than errors resulting from the random elements.

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Predictions of whole body weight of Icelandic summer-spawning herring

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Abstract

The main objective of the paper is to verify the different models in predicting the weight-at-age for Icelandic summer-spawning herring and determine if it could be done more accurately than done in recent years in the stock assessment. Exploring the weight-at-age matrix used in assessment of the stock over the years 1986 to 2009 and age groups 2 to 12+, the most appropriate model was considered the one that accounts for the weight of the year class in the year before (W_{y+1}-W_y=$f(W_y)$). That model was considered to have advantages over the presently used three years means to predict the weight, and it is recommended to use that in projection of the stock in the coming years.

Introduction

In the stock prognosis in past years' assessments of Icelandic summer-spawning herring, the predicted weight-at-age has been set to the mean weight of the age group over the previous three years (ICES, 2010). Some uncertainties about this procedure have evoked in recent assessments (e.g. Guðmundsdóttir and Óskarsson, 2008; ICES, 2008). Furthermore, the body condition, and the growth rate, of the stock have been shown to be related to stock size, which indicate a density-dependent growth (Óskarsson, 2008). Considering that, the objective here is to verify the different models in predicting the weight-at-age and determine if it could be done more accurately than done in recent years and possibly by using available biological knowledge.

Material and methods

The data used in this exercise is the weight-at-age matrix used in assessment of the stock over the years 1986 to 2009 and age groups 2 to 12+ (ICES, 2010). These data are actually the stock weights as represented by the catch samples. Results of the analytical assessment in 2010 provide the number-at-age for the age groups 3 to 12+ (N_{age3+}) over these years (ICES, 2010). These weight data represents the observed weights and are used alone or with stock related data to predict the weights-at-age in three different ways:

i) The predicted weight at equals the mean weight of the age group over the previous three years (like done in recent years' assessments).

ii) The weights are predicted from the number of herring in the stock at age 3+.

iii) The year classes are followed and their weight gain over a year is modeled (W_{y+1}–W_y=$f(W_y)$) and used to predict the weight-at-age.

The relationships between observed and predicted weights for all age groups obtained from these three methods were then used to select the most appropriate methods in predicting the weight-at-age for the stock.

When testing for a density-dependency, the most appropriate measure of stock size is biomass, as for example used by Óskarsson (2008). However, the biomass requires information about weights and is therefore not applicable for predicting mean weights. Instead, N_{age3+} of the stock was used. Preliminary examination indicated that N_{age3+} gave similar fit to the weights as the biomass, which supports its use.

Results and discussions

The predictability power of the currently used method to predict the mean weight of the stock, as mean weight over the three previous years, was explored by comparing the predicted weights to the observed weights (Figure 1) for the period 1986 to 2009. The comparison shows that the predictability power is poor for age 5 and older. The linear relationships between observed and predicted weights were only significant (at α=.05.) for age 3 and 4 (Figure 1).

Giving that body condition, and the growth rate, of the stock have been shown to be density-dependent (Óskarsson, 2008), the observed weights were fitted to N_{age3+} (Figure 2). The relationships were only positively significant for age groups 3-5 at α=.05. Thus, the weight for these three age classes (age 3–5) can be predicted from age and N_{age3+} (Figure 3) by using this single obtained relationship:

(1) $W = -333.0 + 188.3 \times \log_2(age) + 35.88 \times \log_2(N_{age3+})$ (n=72, r^2=0.891, p<<0.001).

The relationships between observed and fitted weights as obtained from this relationship are shown in Figure 3. It is obvious that this model is an improvement in predicting the weights relative to the currently used method (Figure 1), particularly for age group 5.

The third method to predict the weight was modeling the inter-annual weight gain by follow the mean weight of the same year class in the year y and y+1 for all year classes from 1979 to 2005 at age 2 to 10.The data (Figure 4) were fitted both with a modified von Bertalanffy growth functions that estimate changes in weight instead of length and a linear regression. The von Bertalanffy growth function was on this form:

(2) $$W_{y+1} - W_y = \frac{dW}{dt} = K\left(W_\infty^{1/3} \times W^{2/3} - W\right).$$

Two parameters were estimated with the data, K=1.130 (corresponds to Weight=K×Length[3]) and W_∞=371.8. The behaviour of the residuals from the observed versus predicted weight was not as desired, especially for age (Figure 5). The fitted linear model to the data became:

(3) $$W_{y+1} - W_y = \frac{dW}{dt} = -0.2229 \times W_y + 90.27$$ (r^2=0.596, n=258, p<<0.001).

The residuals from the linear model (Figure 6) behaved better than from the von Bertalanffy growth function with no signs of systematic trends over years, year classes or age groups. Accordingly, the linear model was selected over the von Bertalanffy growth function and explored how well it did in predicting the weight (Figure 7).

As can be seen in Figures 3 and 7, there were not 1:1 relationships between observed and predicted weights. The reason is that each relationship was obtained across three and eight age groups, respectively. The relationships become, accordingly, close to 1:1 when all the three age groups are combined. That does however, not affect the predicted values.

Concluding remarks

The weight-at-age of 3 to 5 years old Icelandic summer-spawning herring can be predicted more accurately than with the presently used approach by two alternative models (Equations 1 and 3). The question is then, which of these two models should be selected. In favour of Equation 3, its predictions are generally fitting better to the observed weights than the predictions from Equation 1, and that kind of model has been used for the stock previously (ICES, 1993). Using Equation 1 is supported by the observation of Óskarsson (2008) of density-dependent growth and condition of the stock. However, he observed also a strong auto-correlation in the data that is reflected indirectly in Equation 3. Consequently, it is suggested using Equation 3 to predict weight-at-age for all age groups in the stock prognosis. When applying model that utilizes the weight from the previous year to predict weight in one year (e.g. Equation 3), then the density-dependency is incorporated indirectly to the approach since changes in stock number or biomass are normally not huge between two adjoining years.

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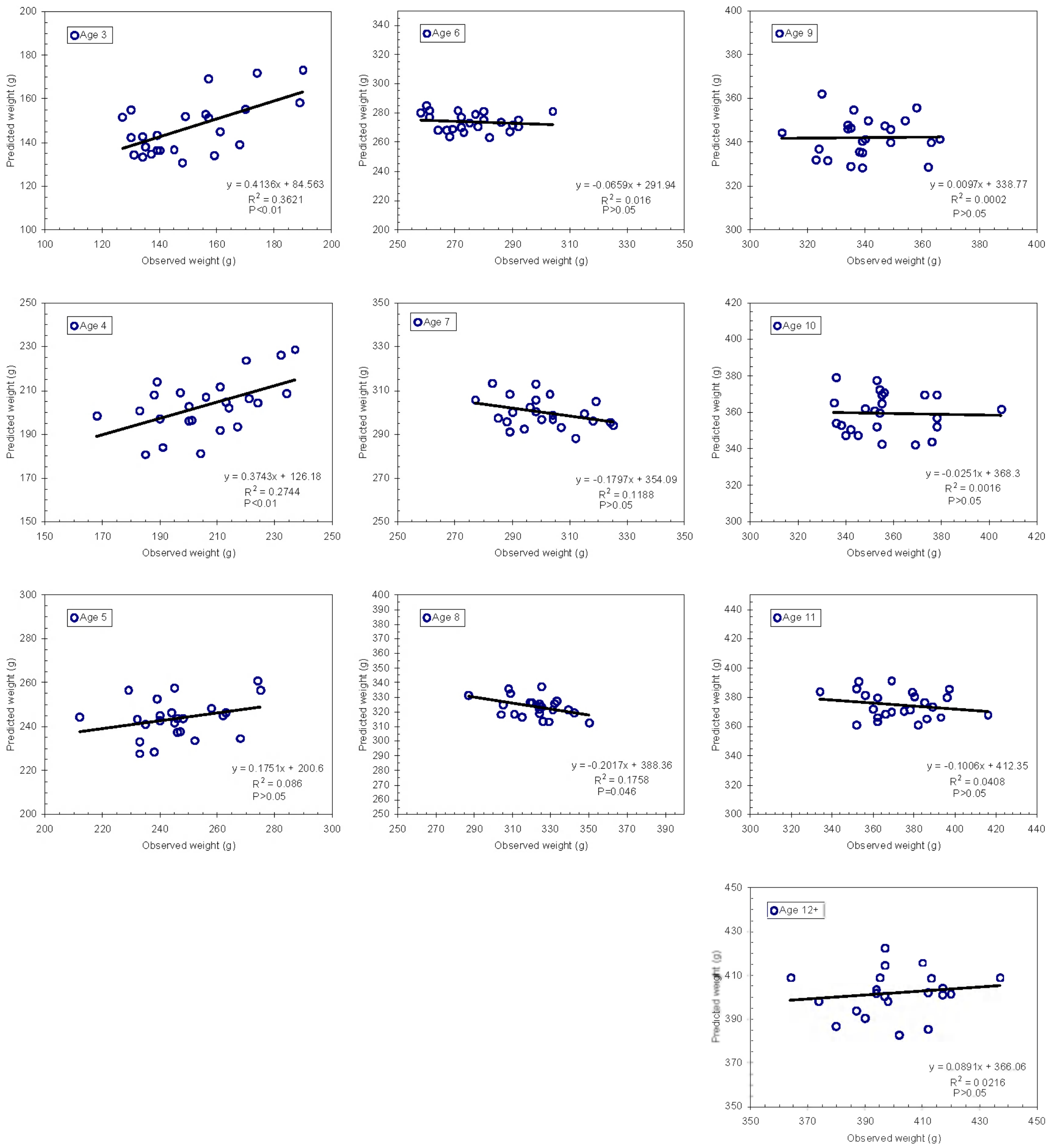

Figure 1. The linear relationships between observed weight for age groups 3–12 (12 a plus group) of Icelandic summer-spawning herring during 1986 to 2009 and predicted weight as the mean weight of previous three years of each age group.

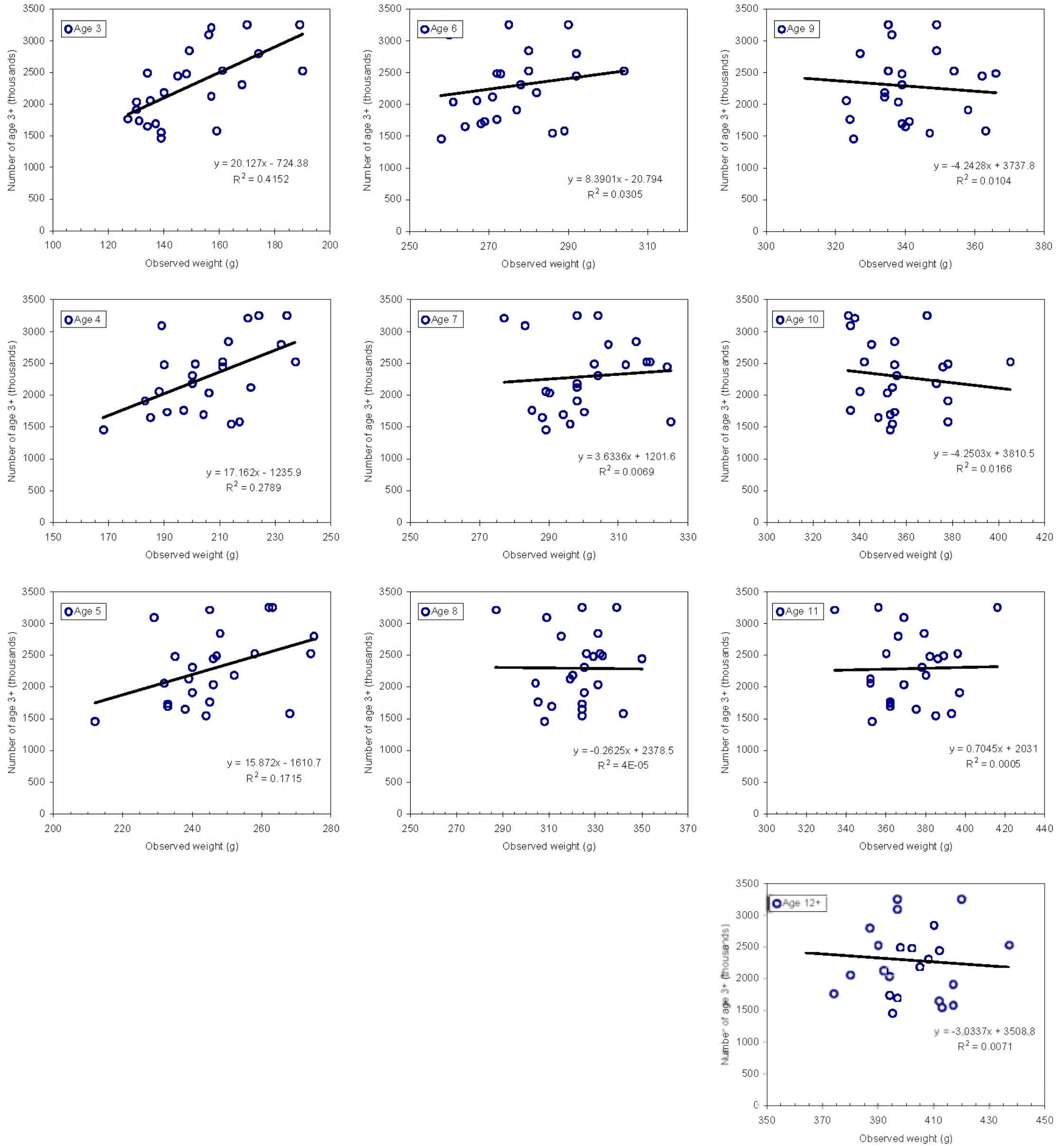

Figure 2. The linear relationships between observed weight for age groups 3–12 (12 a plus group) of Icelandic summer-spawning herring during 1986 to 2009 and number of age 3+ in the stock (in thousands) on January 1st in the same year.

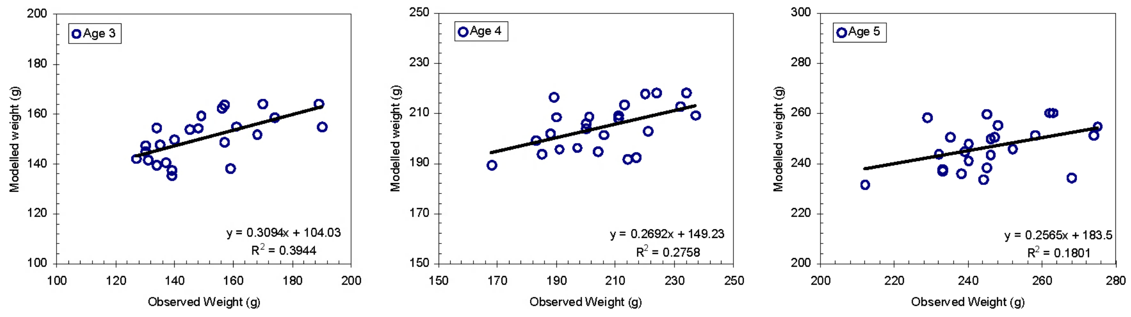

Figure 3. The linear relationships between observed weight for age groups 3–5 of Icelandic summer-spawning herring during 1986 to 2009 and modelled weight-at-age according to number at age 3+ in the stock (see Equation 1).

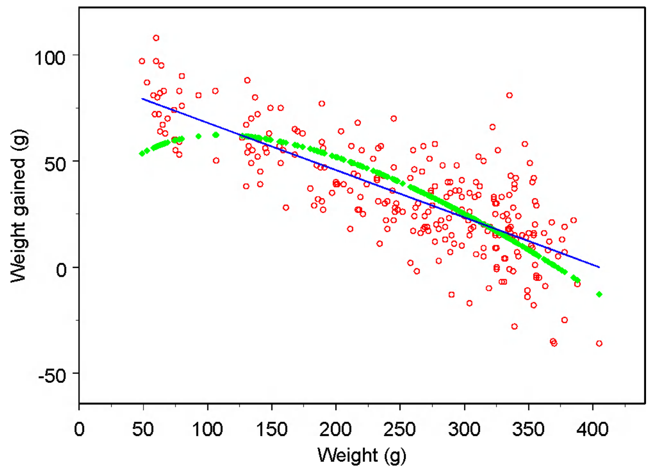

Figure 4. The relationship between weight in year y (W_y) against weight gain (W_{y+1}-W_y) when following the same year class of Icelandic summer-spawning herring. The fitted linear regression (blue) and a modified von Bertalanffy growth functions (green) are also shown (see in text).

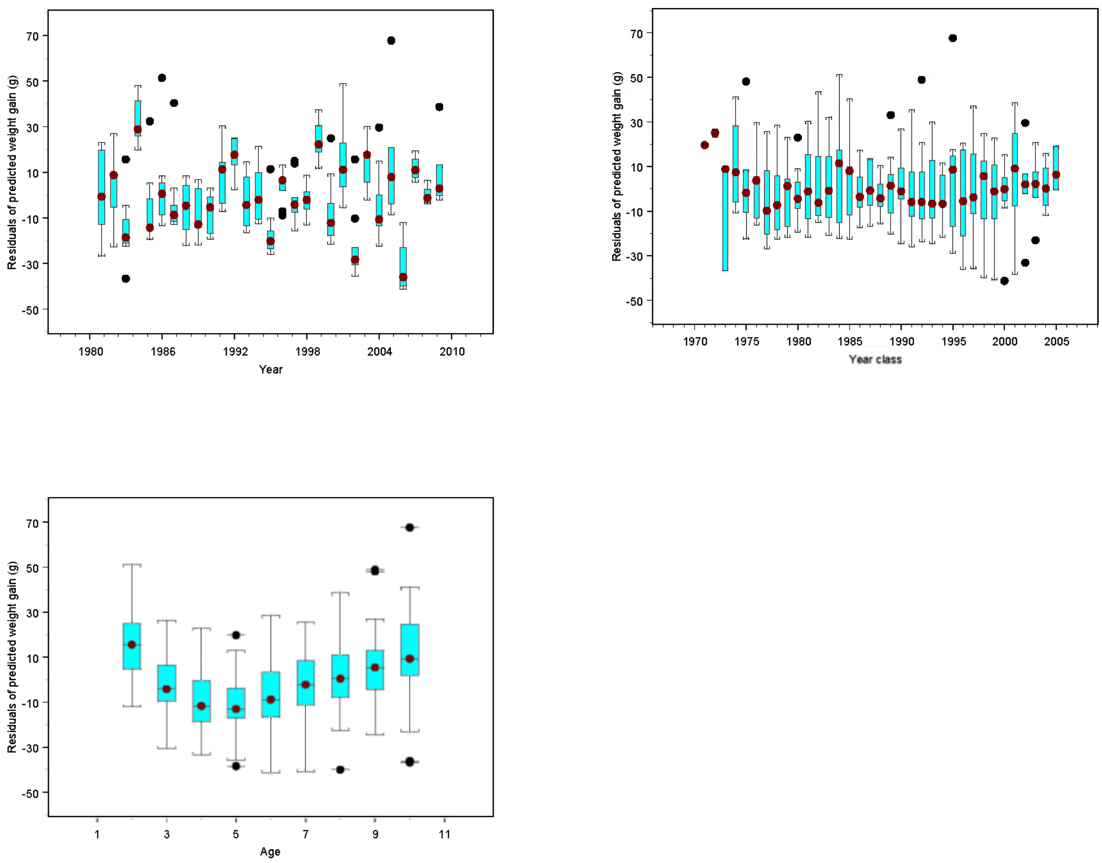

Figure 5. Boxplots of the residuals from the observed versus predicted weight of Icelandic summer-spawning herring from the modified von Bertalanffy growth function (Equation 2) against year (left, top), year class (right, top) and age (left, bottom).

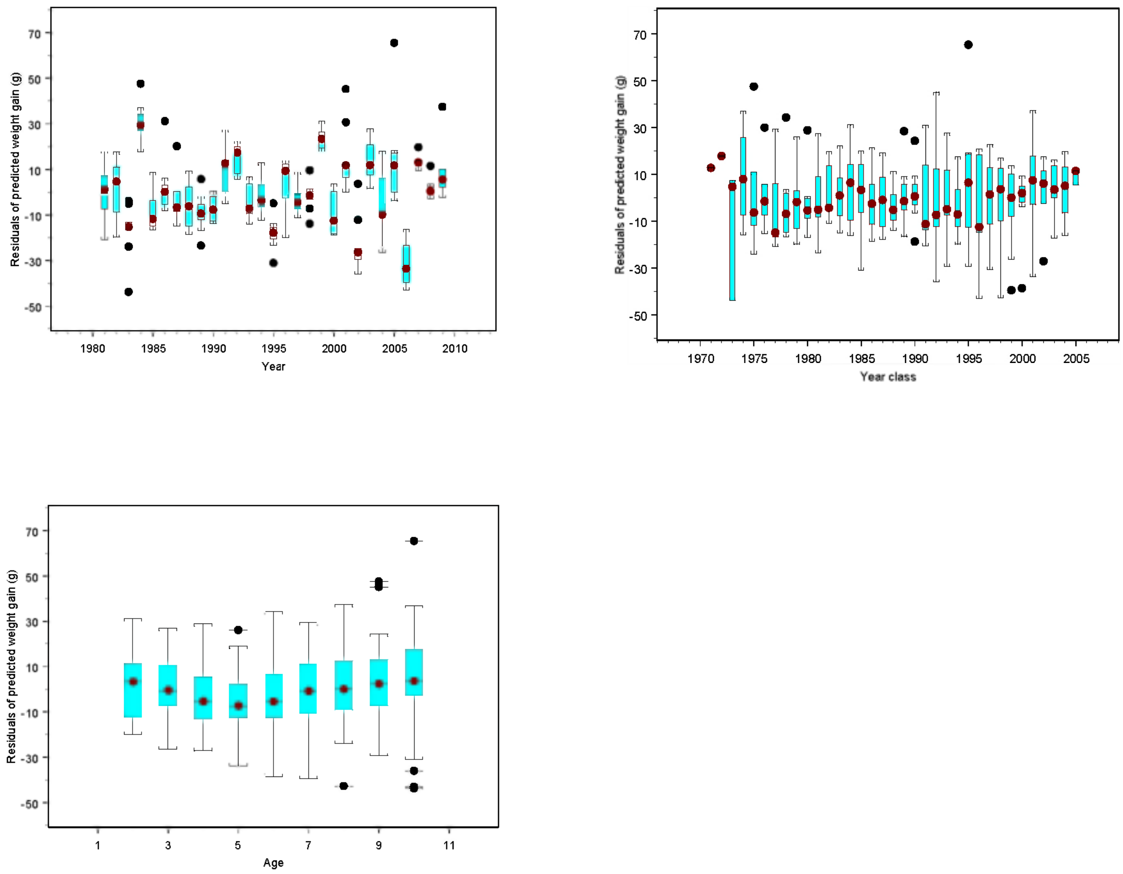

Figure 6. Boxplots of the residuals from the observed versus predicted weight of Icelandic summer-spawning herring from a linear regression (Equation 3) against year (left, top), year class (right, top) and age (left, bottom).

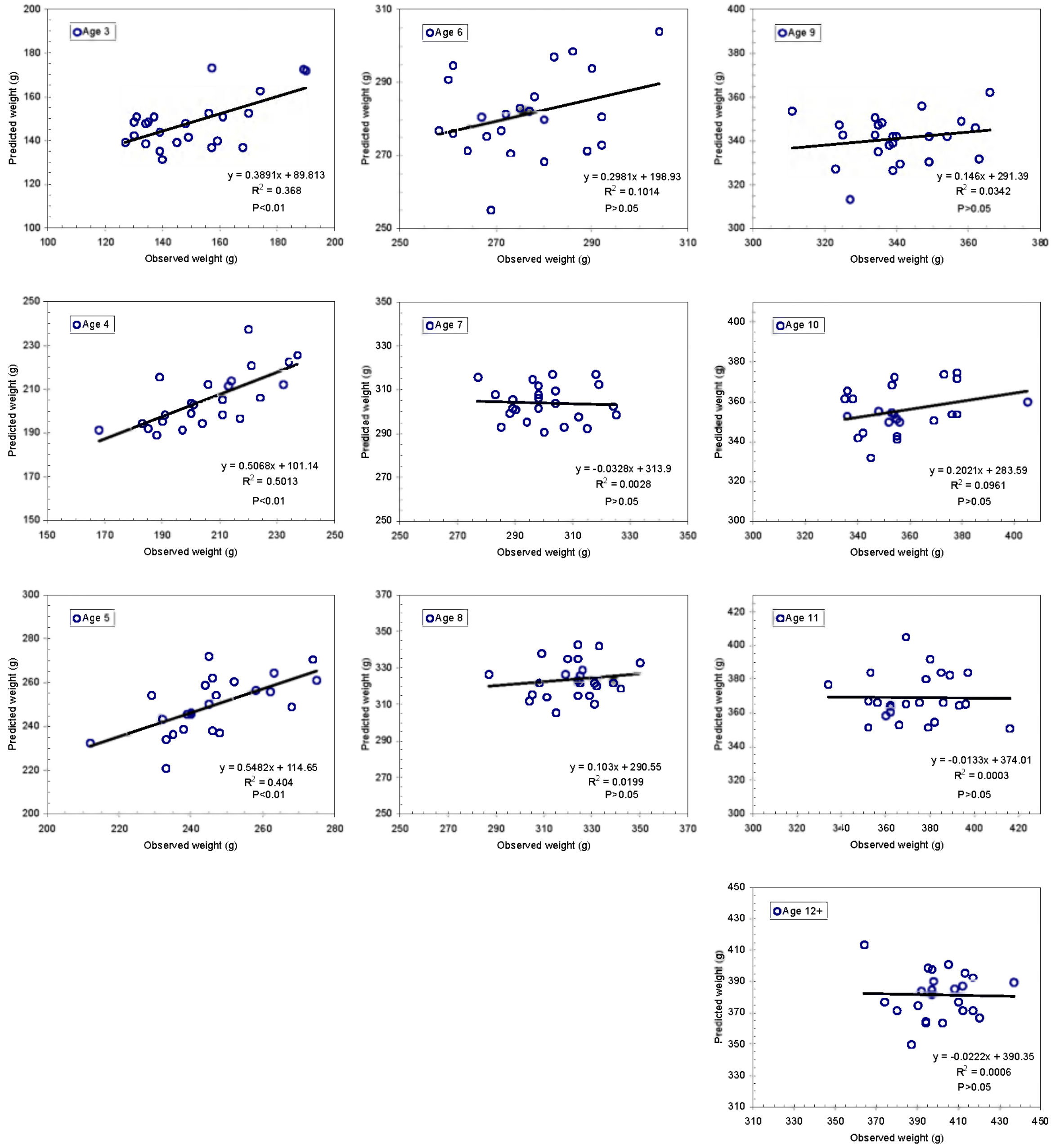

Figure 7. The linear relationships between observed weight for age groups 3 to 12+ of Icelandic summer-spawning herring during 1986 to 2009 and modelled weight-at-age according to the weight of the year class in the year before (see Equation 3).

Stock assessment of Icelandic summer-spawning herring/Analytical assessment with Colraine

WD 7, by Arni Magnusson, 25 January 2011 see next page

Stock assessment of Icelandic summer-spawning herring

Arni Magnusson

25 January 2011

Abstract

This is the first Coleraine assessment of Icelandic herring, using input data starting in 1987 and ending in 2008, to exclude the ongoing period of *Ichthyophonus* infection. Point estimates of interest include spawning biomass $B_{2009} = 563$ thousand t, depletion level $B_{2009}/B_0 = 0.22$, and current surplus production 92 thousand t. The 95% confidence interval of these and other quantities is presented, based on MCMC analysis.

Contents

1 Introduction

1.1 Coleraine assessment

During a recent TAC meeting at Hafro, it was decided to assess the Icelandic summer-spawning herring stock using the Coleraine statistical catch-at-age model (Hilborn et al. 2003), in addition to the VPA and state-space models that have been used in previous herring assessments. The main objectives are to (1) provide a model run that can be compared with the other models to confront model uncertainty, and (2) evaluate the general usefulness of Coleraine as a software platform to assess Hafro stocks.

1.2 Biology, fishery, data

The biology, fishery, and available data for the Icelandic summer-spawning herring are described in other working documents. The ongoing *Ichthyophonus* infection is of central importance, as it undermines common assumptions used stock assessment models, such as constant natural mortality rate M. Instead of explicitly modelling the consequences of the *Ichthyophonus* infection, the assessment data are limited to the years up to and including 2008, before the infection had a major effect on the stock.

Early assessment data are also truncated, starting the model in 1987 to make the results directly comparable with the VPA and state-space model runs. Furthermore, age 2 is excluded from the acoustic survey data. These decisions, to exclude all data from 1975 to 1986, and to exclude age 2 from the survey data, are discussed and examined in other working documents.

2 Data

The main data used in this assessment (Table 1) are annual landings (Fig. 1), annual biomass index from the acoustic survey (Fig. 2), commercial catch at age (Fig. 3), and survey catch at age (Fig. 4).

Table 1. Data overview.

Data	Years	How many
Landings	1987–2008	22
Commercial catch at age	1987–2008	22
Survey catch at age	1987–1993, 1995-2008	21
Survey biomass index	1987–1993, 1995-2008	21

2.1 Landings

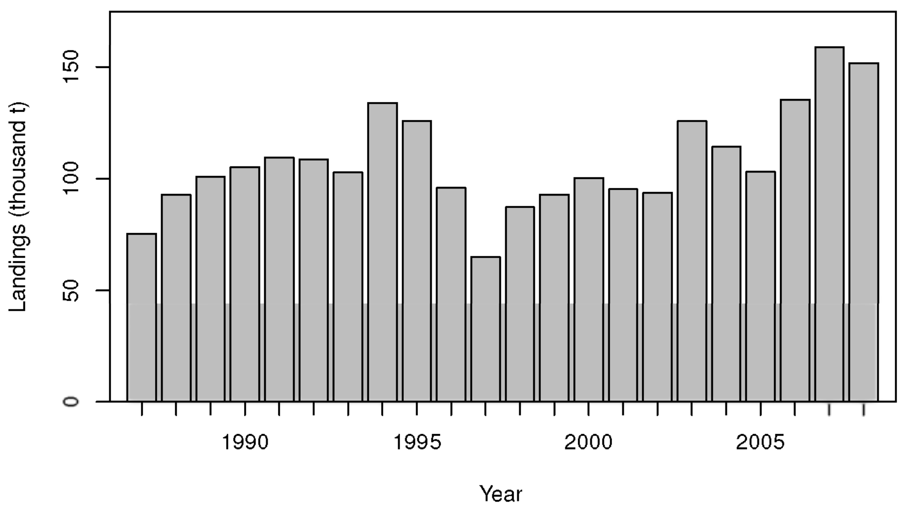

Figure 1. Landings.

2.2 Survey biomass index

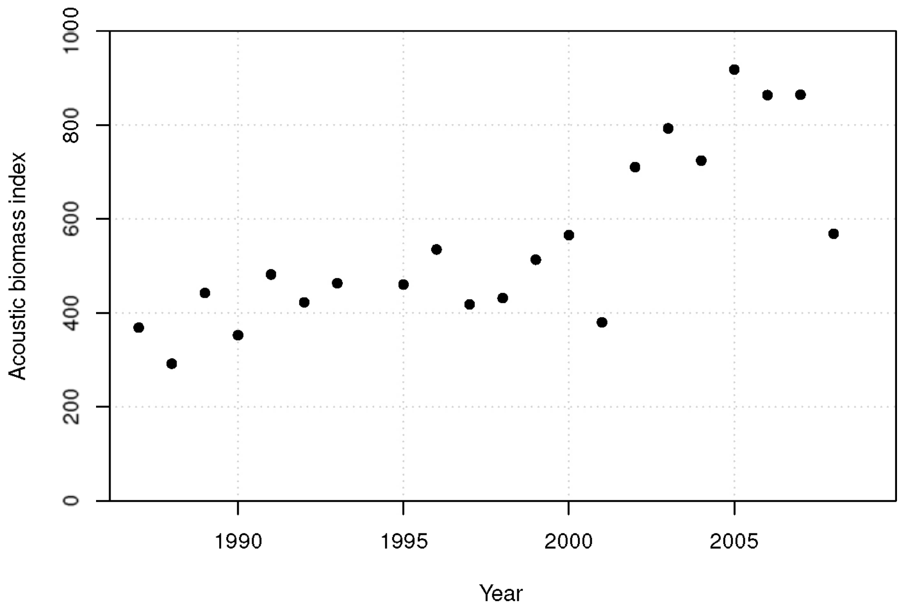

Figure 2. Survey biomass index.

2.3 Commercial catch at age

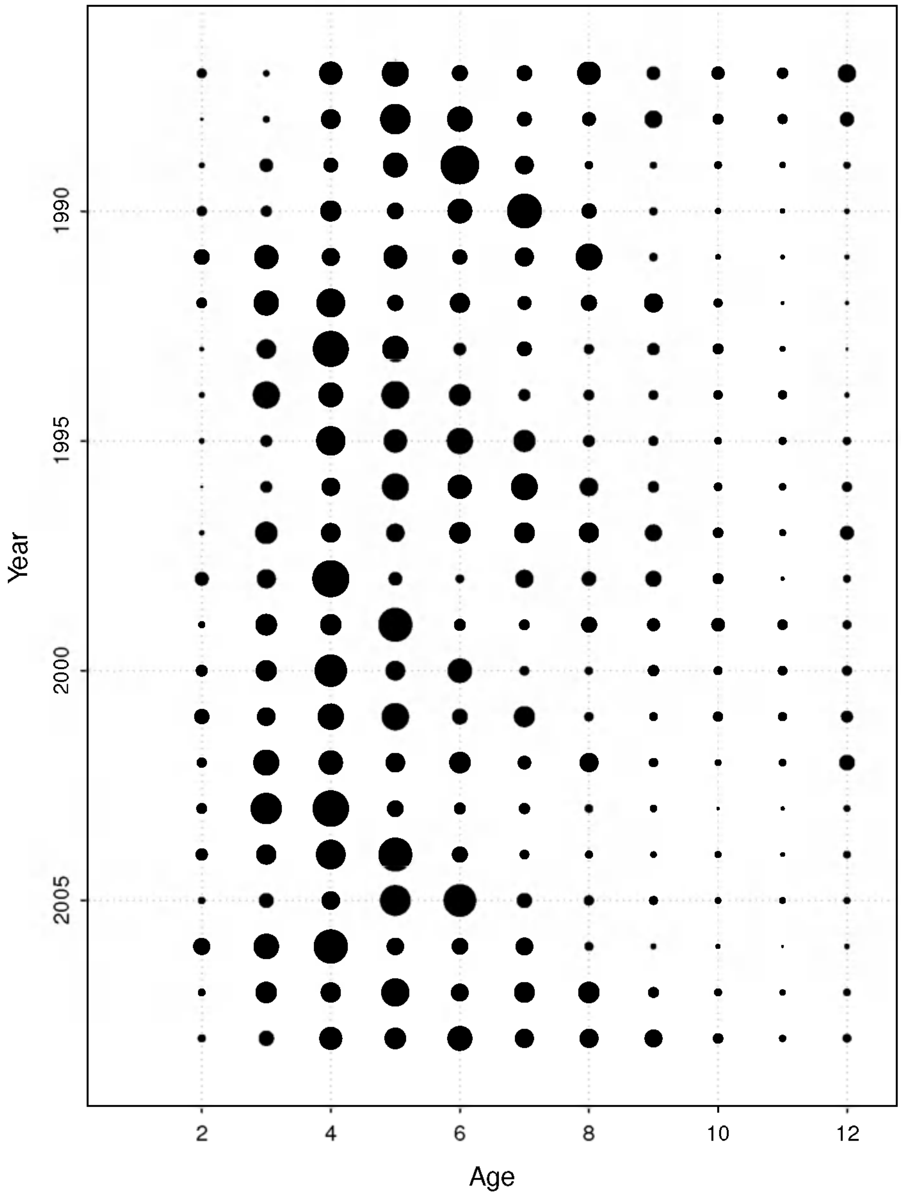

Figure 3. Commercial catch at age. Circles show relative frequency within a year.

2.4 Survey catch at age

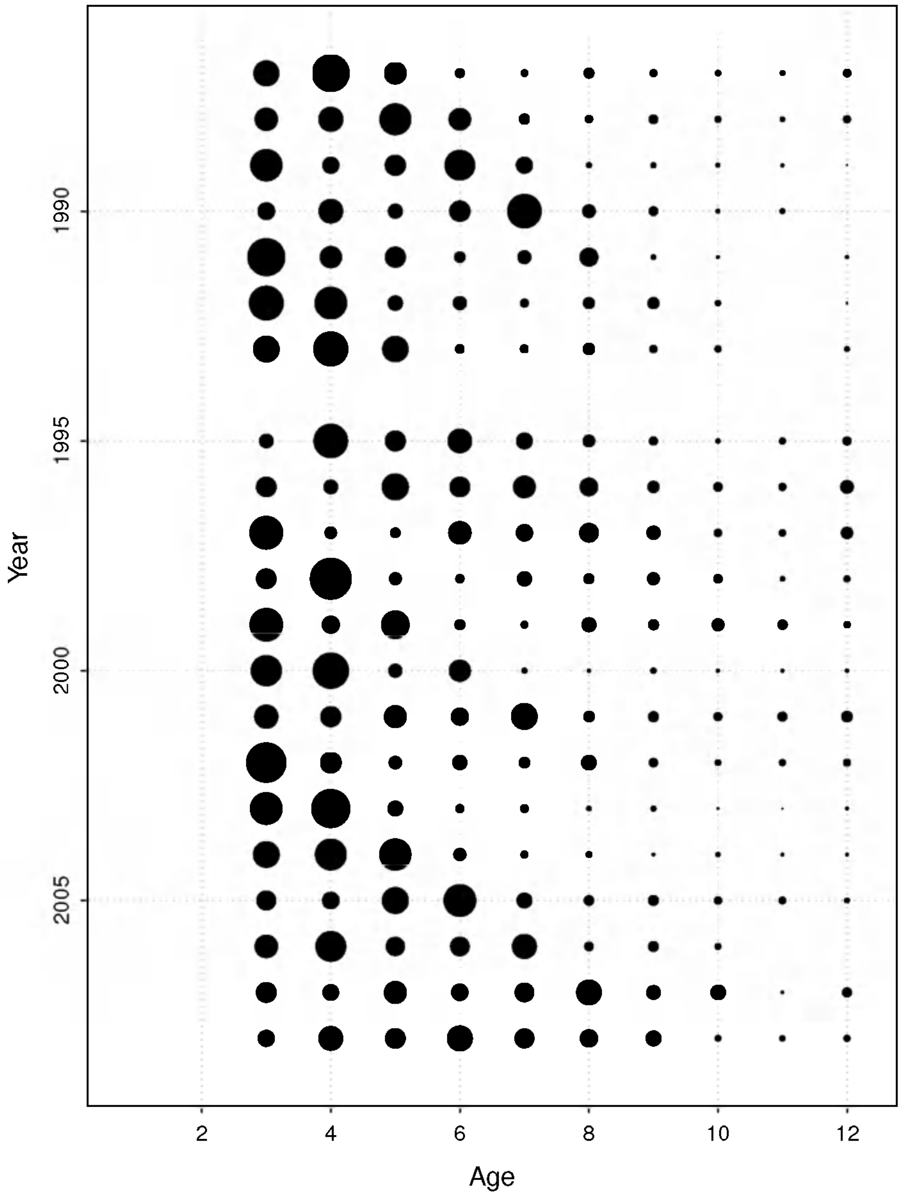

Figure 4. Survey catch at age. Circles show relative frequency within a year.

3 Model

Coleraine (Hilborn et al. 2003) is a versatile environment for single-species statistical catch-at-age modelling. It can incorporate a combination of catch at age, catch at length, and abundance indices from different fisheries and surveys, allowing for missing years. Data and parameters can be sex- and gear-specific. Future projections can be used to evaluate a range of harvest policies. The model is implemented in AD Model Builder (ADMB Project 2008), supporting maximum likelihood or Bayesian estimation, using the delta method and/or Bayesian MCMC to analyze the uncertainty.

Optional software for working with Coleraine include an Excel spreadsheet interface and two R packages, 'scape' and 'scapeMCMC', for plotting and diagnosing model fits and MCMC output (Magnusson 2005). Several variations of simple age-based Coleraine models have been described and analyzed in detail by Magnusson and Hilborn (2007), while diverse examples of sex- and gear-specific age- and length-based model output can be found in Magnusson (2005).

The model used in this assessment is a simple age-based Coleraine model. Natural mortality rate is assumed to be $M = 0.1$, age 12 is a plus group, and recruitment is estimated as annual deviates from a Beverton-Holt line with steepness $h = 0.9$ and variability $\sigma_R = 0.6$. Selectivity is constant between years and landings are assumed to be known without error. All parameters are assigned wide bounds that are used as flat priors in the Bayesian uncertainty analysis, where 1 000 draws were saved out of 1 000 000 MCMC iterations.

3.1 Dynamics

The population dynamics are governed by the equation:

$$N_{t+1,a+1} = N_{t,a}\, e^{-M}(1 - {}_C S_a u_t) \tag{1}$$

where $N_{t,a}$ is population size at time t and age a, M is the rate of natural mortality, ${}_C S$ is the selectivity of the commercial fishery, and u is harvest rate. The oldest age group, age A, is treated as a plus group:

$$N_{t+1,A} = N_{t,A-1}\, e^{-M}(1 - {}_C S_{A-1} u_t) \; + \; N_{t,A}\, e^{-M}(1 - {}_C S_A u_t) \tag{2}$$

Selectivity is asymptotic, shaped like a normal curve on the left:

$$S_a = \begin{cases} \exp\left(\dfrac{-(a - S_{\text{full}})^2}{\exp(S_{\text{left}})}\right), & a \leq S_{\text{full}} \\ 1, & a > S_{\text{full}} \end{cases} \tag{3}$$

where S_{full} is the age at full selectivity and S_{left} describes the left-hand slope of the curve. Harvest rate is defined as the fraction removed from the vulnerable biomass in the middle of the fishing year,

$$u_t = Y_t / V_t \tag{4}$$

where Y is catch, vulnerable biomass is

$$V_t = \sum_a ({}_C S_a N_{t,a}\, w_{t,a}) e^{-M/2} \tag{5}$$

and w is body weight.

The population size at the start of the first year is

$$N_{1,1} = R_0 R_{\text{init}} \times \exp({}_R\varepsilon_{1,1} - \sigma_R^2/2)$$

$$N_{1,a} = R_0\, R_{\text{init}}\, e^{-(a-1)M} \prod_{i=1}^{a-1} (1 - {}_C S_i u_{\text{init}}) \times \exp({}_R\varepsilon_{1,a} - \sigma_R^2/2)$$

$$N_{1,A} = R_0\, R_{\text{init}}\, e^{-(A-1)M} \prod_{i=1}^{A-1} (1 - {}_C S_i u_{\text{init}}) \,/\, [1 - e^{-M}(1 - {}_C S_A u_{\text{init}})] \times R_{\text{plus}} \qquad (6)$$

for one-year-olds, intermediate ages, and the plus group, where R_0 is the average virgin recruitment. Recruitment is stochastic around a Beverton-Holt stock-recruitment function, reparametrized according to Francis (1992):

$$N_{t+1,1} = \frac{4hR_0(B_t/B_0)}{1-h+(5h-1)(B_t/B_0)} \times \exp({}_R\varepsilon_{t,1} - \sigma_R^2/2) \qquad (7)$$

where $B_t = \sum_a N_{t,a} \Phi_{t,a} w_{t,a}$ is spawning biomass,

$$B_0 = \sum_{a=1}^{A-1} R_0 e^{-(a-1)M} \Phi_a w_{1,a} + R_0\, e^{-(A-1)M} \Phi_A w_{1,A}/(1-e^{-M}) \qquad (8)$$

is average virgin spawning biomass, h is steepness of the stock-recruitment curve, and Φ is maturity at age.

3.2 Parameters

A total of 6 parameters are estimated (Table 2), in addition to 40 recruitment deviates. Ages 3–12 are are fully selected in the survey.

Table 2. Estimated parameters.

Parameter	Meaning
R_0	Average virgin recruitment
R_{init}	Initial population scaler
u_{init}	Initial harvest rate
${}_C S_{\text{full}}$	Age at full selectivity in the commercial fishery
${}_C S_{\text{left}}$	Left slope of commercial selectivity curve
q	Survey catchability coefficient

3.3 Estimation

The objective function for the parameter estimation is the sum of three components:

$$f = -\log L_I - \log L_C - \log L_S - \log L_R \qquad (9)$$

The survey biomass index likelihood component is lognormal:

$$-\log L_I = \sum_t \frac{(\log I_t - \log \hat{I}_t)^2}{2\sigma_I^2} \qquad (10)$$

where I and $\hat{I}$ are observed and fitted abundance indices,

$$\hat{I}_t = qV_t \tag{11}$$

and σ_I is the standard error of the log residuals, one value across all years.

Catch-at-age data are provided to the model in the form of proportions at age. The robust normal likelihood for proportions (Fournier et al. 1990) is assumed for the commercial catch-at-age data,

$$-\log L_C = -\sum_t \sum_a \log\left[\exp\left(\frac{({}_CP_{t,a} - {}_C\hat{P}_{t,a})^2}{2\left[{}_CP_{t,a}(1 - {}_CP_{t,a}) + 0.1/A\right]{}_Cn_t^{-1}}\right) + 0.01\right] \tag{12}$$

as well as the survey catch-at-age data:

$$-\log L_S = -\sum_t \sum_a \log\left[\exp\left(\frac{({}_SP_{t,a} - {}_S\hat{P}_{t,a})^2}{2\left[{}_SP_{t,a}(1 - {}_SP_{t,a}) + 0.1/A\right]{}_Sn_t^{-1}}\right) + 0.01\right] \tag{13}$$

where P and $\hat{P}$ are observed and fitted catch at age,

$$\hat{P}_{t,a} = \frac{S_a N_{t,a}}{\sum_a S_a N_{t,a}} \tag{14}$$

and n_t is the year-specific effective sample size.

Recruitment deviates are penalized under the assumption of lognormality:

$$-\log L_R = \sum_{a=2}^{A-1} \frac{{}_R\varepsilon_{1,a}^2}{2\sigma_R^2} + \sum_{t=2}^{t_{\max}-1} \frac{{}_R\varepsilon_{t,1}^2}{2\sigma_R^2} \tag{15}$$

The magnitude of the observation noise (σ_I, ${}_Cn_t$, ${}_Sn_t$) is estimated iteratively as

$$\hat{\sigma}_I = \sqrt{\frac{\sum(\log I_t - \log \hat{I}_t)^2}{T-1}} \tag{16}$$

for the abundance index, where T is the number of abundance index datapoints, and

$$\hat{n}_t = \frac{\sum_a \hat{P}_{t,a}(1 - \hat{P}_{t,a})}{\sum_a (P_{t,a} - \hat{P}_{t,a})^2} \tag{17}$$

for commercial and survey catch at age (McAllister and Ianelli 1997).

3.4 Reference points

Depletion level is defined as the current biomass relative to the average virgin biomass, B_{2009}/B_0. MSY is the long-term average yield at a fixed harvest rate u_{MSY}, $B_{2009}/B_{\mathrm{MSY}}$ is the current biomass relative to the average biomass at u_{MSY}, and surplus production is defined as the last year's catch, plus the resulting change in vulnerable biomass. See Magnusson and Hilborn (2007) for a detailed description and analysis of these reference points.

4 Results

4.1 Key quantities

Table 3. Estimated key quantities with 95% confidence intervals.

Quantity	2.5%	Estimate	97.5%
Parameters			
R_0	696	955	1361
R_{init}	0.47	0.80	1.45
u_{init}	0.31	0.37	0.52
$_{C}S_{\text{full}}$	4.58	4.79	4.97
$_{C}S_{\text{left}}$	0.72	0.96	1.12
q	0.95×10^{-3}	1.08×10^{-3}	1.21×10^{-3}
Reference points			
B_{2009}	388	562	833
V_{2009}	377	545	806
u_{2008}	0.18	0.25	0.33
u_{MSY}	0.23	0.24	0.24
Depletion	0.15	0.22	0.34
MSY	90	123	175
B_{2009}/B_{MSY}	0.68	1.04	1.58
Surplus	60	92	151

Table 4. Estimates of observation noise.

Quantity	Estimate
σ_I	0.23
$_{C}n$	108
$_{S}n$	72

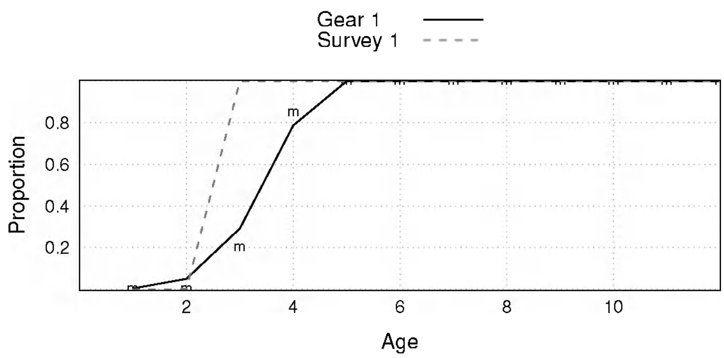

Figure 5. Selectivity and maturity (m).

4.2 Fit to data

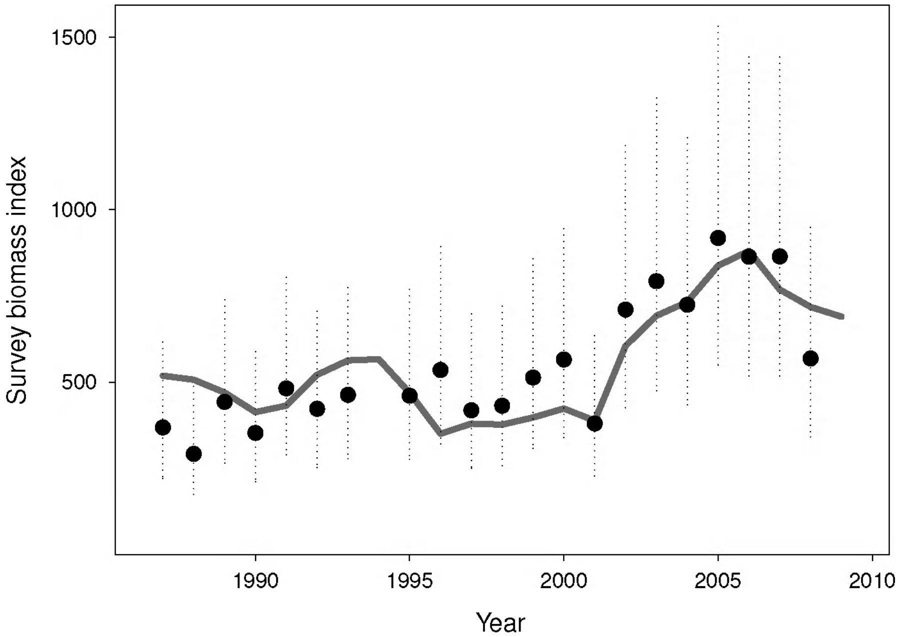

Figure 6. Model fit (line) to survey biomass index, shown with 95% error bars.

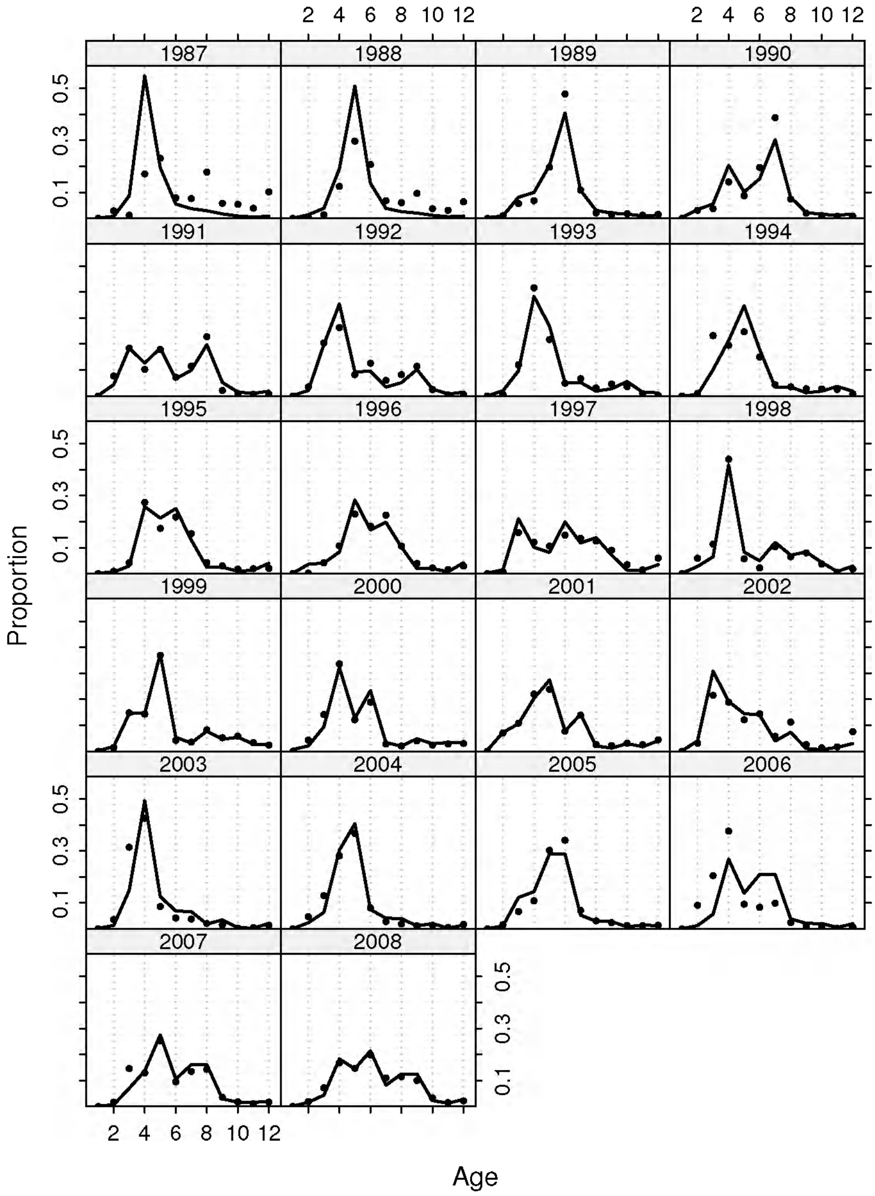

Figure 7. Model fit (line) to observed commercial catch at age (dots).

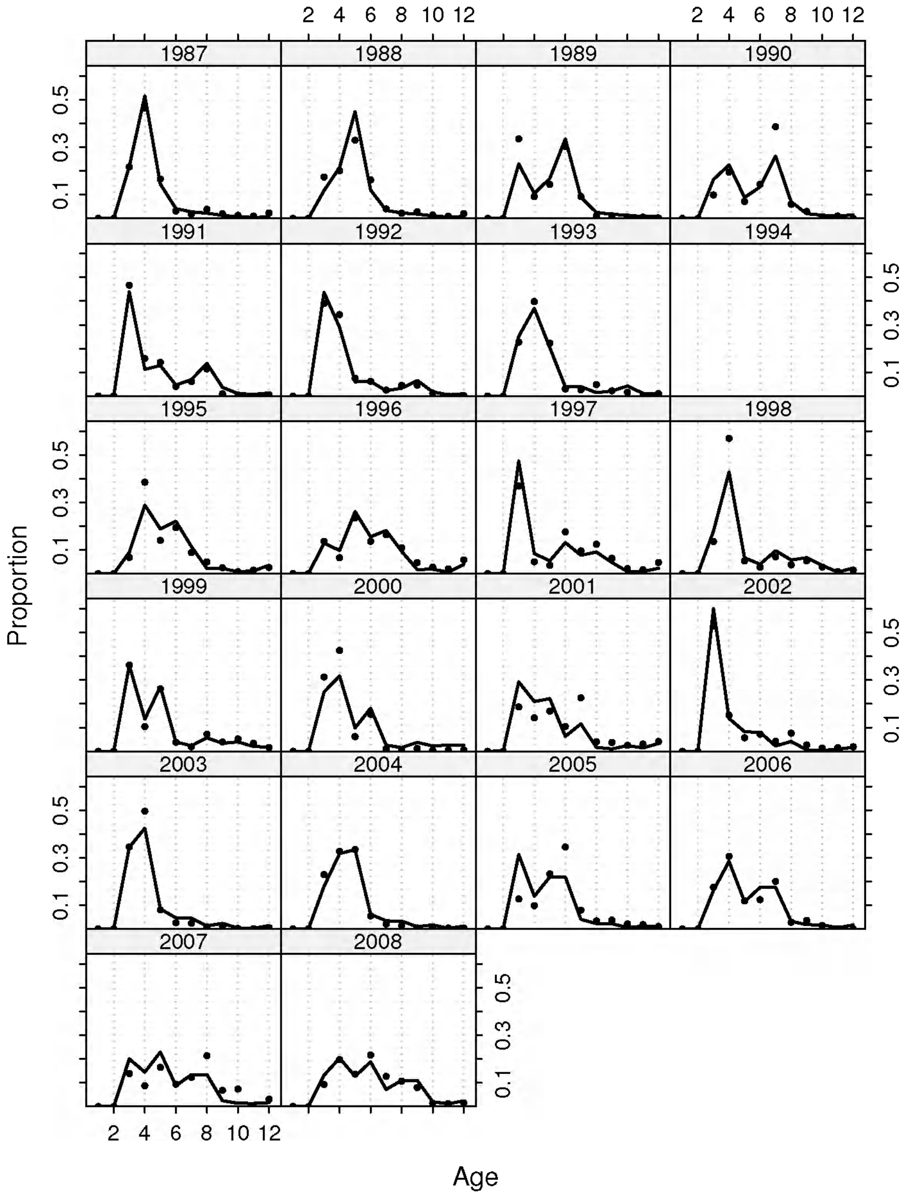

Figure 8. Model fit (line) to observed survey catch at age (dots).

4.3 Uncertainty

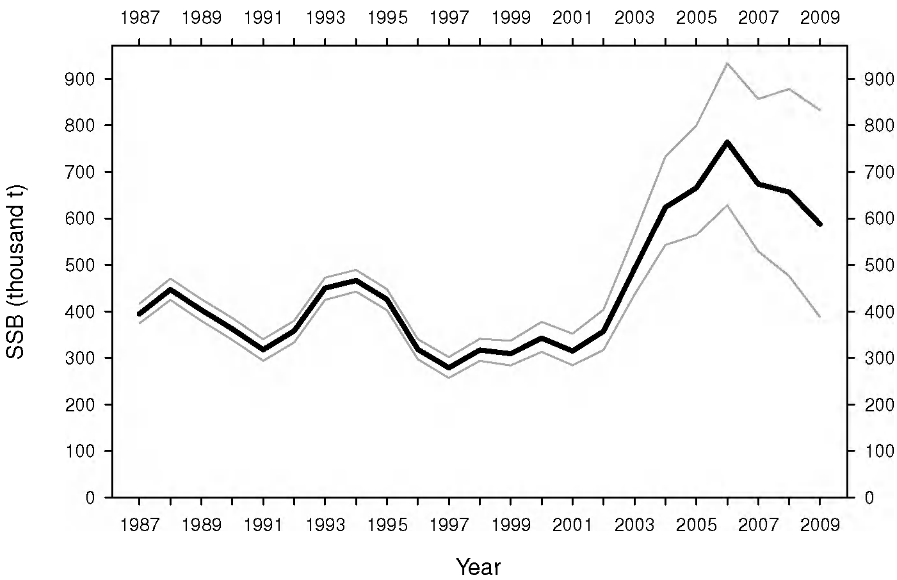

Figure 9. Spawning biomass with 95% confidence intervals.

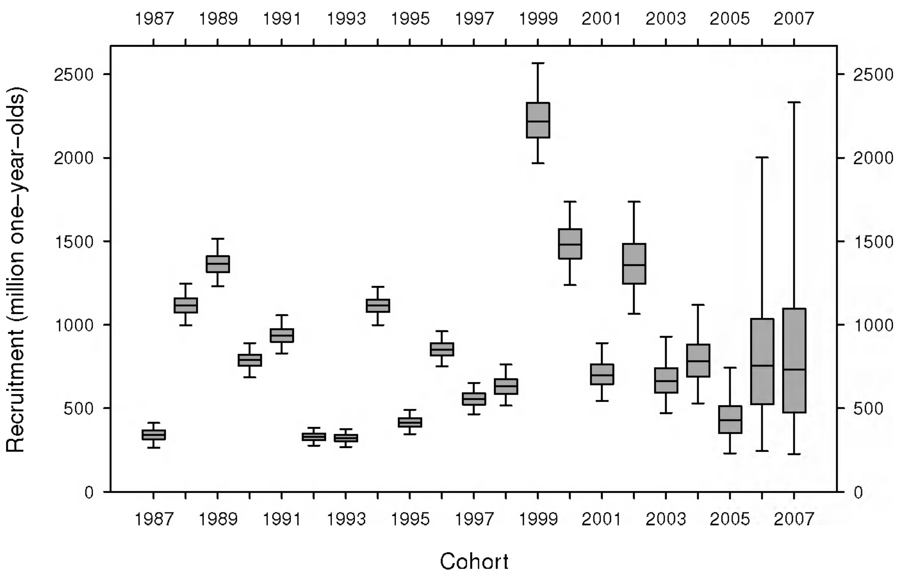

Figure 10. Recruitment with 50% and 95% confidence intervals.

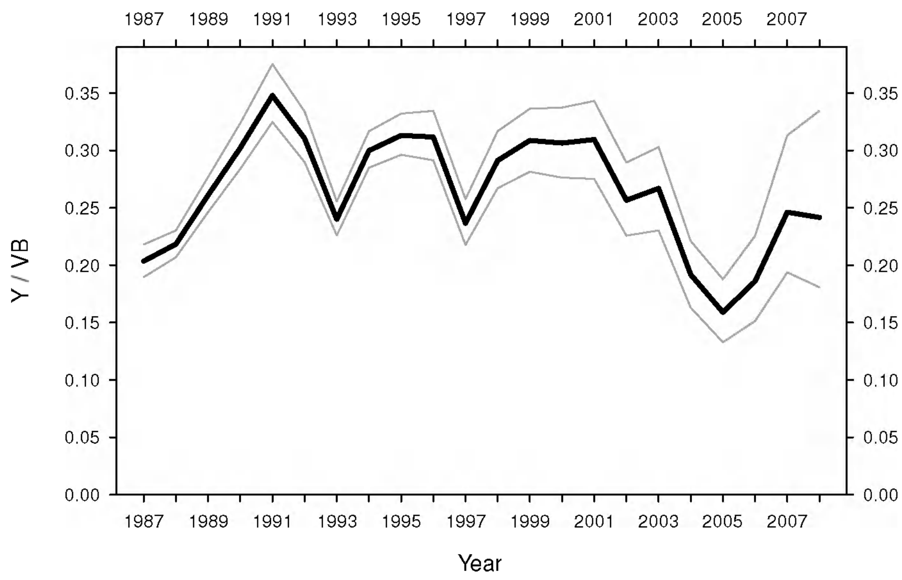

Figure 11. Harvest rate with 95% confidence intervals.

4.4 Retrospective analysis

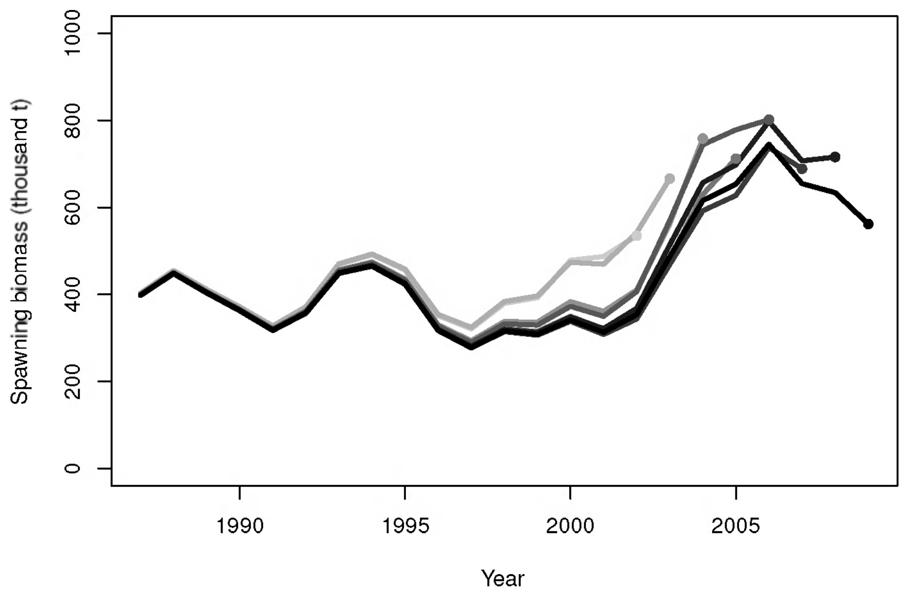

Figure 12. Retrospective analysis.

5 Discussion

Asta Gudmundsdottir has compared the results presented above to the VPA (main assessment model) and state-space (Gudmundur Gudmundsson) model runs. Despite considerably different statistical approaches and assumptions, the three models showed rather similar results overall. Thus, model uncertainty appears to somewhat less than the authors expected. Clearly, the main concern for current management of the Icelandic herring fishery is the ongoing *Ichthyophonus* infection.

Coleraine has been used in previous Icelandic cod (ICES 2001, ICES 2002, ICES 2003) and silver smelt (ICES 2010) assessments. The scientific contribution of this herring assessment is both providing a comparison model run to check model uncertainty against the VPA and state-space models, and also an exploration of uncertainty and reference points.

One of the benefits of a statistical catch-at-age model, compared to VPA, is a framework to evaluate uncertainty about estimated and derived quantities in a statistically sound and straightforward way. Coleraine, like other AD Model Builder applications, has built-in capability to evaluate uncertainty, using either the delta method or MCMC. The MCMC option, used in this herring assessment, takes more computational work than the delta method, but is more robust to non-Gaussian error structure.

Reference points were explored briefly in this assessment (Table 3). Further exploration would be worthwhile, under the assumption that the herring population will return to previous stock dynamics after recovering from the *Ichthyophonus* infection. The reference points describe the stock status before the infection, and lead to questions about sustainable harvest levels. It is worth noting that the uncertainty about the reference point u_{MSY} (optimal long-term harvest rate) is not properly analyzed in this simple assessment, where u_{MSY} is defined as a function of M, h, ${}_CS_{\mathrm{full}}$, ${}_CS_{\mathrm{left}}$, and body growth, but most of these quantities were fixed. More ambitious approaches to harvest control rule evaluation are likely to be discussed in the benchmark working group.

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Evaluation of the survey indices from the autumn/winter surveys of Icelandic summer-spawning herring

ICES, WKBENCH 2011, WD Her-Vasu No. 8

by Guðmundur J. Óskarsson

Abstract

There has been a suspicion that the age composition in the acoustic surveys of Icelandic summer-spawning herring might be inadequately determined for some years as results of insufficient biological sampling in the survey. The survey indices from the years 1986 to 2010 are therefore validated here by comparing them to the catch composition the same year and determine if the survey indices needs to, and then can, be revisited and recalculated with for example more adequate biological samples originating from the commercial catch. The analyses revealed that all the major discrepancies between the proportion of the age groups in the catch and in the survey could be explained by the nature and location of the fishery and/or different spatial and temporal distribution of the fishery and the acoustic surveys. Thus, there is neither reason nor justification to revisit the acoustic measurements and recalculate the indices with for example different biological samples.

Introduction

As for many other herring stocks, the survey indices from the acoustic measurements are used as tuning-series in the analytical assessment of the stock. There has been a suspicion that the age composition in the acoustic surveys might be inadequately determined as results of an occasional insufficient biological sampling in the survey. It can lead to a discrepancy between the observed age composition of the stock as represented by the catch samples and as represented by the acoustic surveys. A likely consequence of such a discrepancy is that the strength of the year classes in the assessment models are determined inaccurately and it can cause unwanted retrospective patterns in the results. The age composition in the survey indices are based on length distributions and age-at-length keys from the surveys themselves. The age-at-length keys are normally not different from the keys that are obtained from the catch samples the same year while the length distribution can be different. It can be normal that the length distribution from a survey and catch samples the same year vary since the survey is assumed to cover the whole distribution area of the stock while the fishery can be concentrated in a single or few subareas. Thus the objective here is to validate the survey indices from the years 1986 to 2010, by comparing it to the catch composition the same year and determine if the survey indices needs to, and then can, be revisited and recalculated with for example more adequate biological samples originating from the commercial catch.

Methods and results

The age distributions from the survey and the catch data were compared and discrepancy between determined, and thereby verified if the age composition in the acoustic surveys might be inadequately determined because the biological sampling in the being insufficient. It involved that for each year the proportion of the different age groups was calculated for the survey data and the catch data and the difference determined as this equation indicates:

$$N_{catch,age\,x} \times \left(\sum^{age} N_{catch} \right)^{-1} - N_{survey,age\,x} \times \left(\sum^{age} N_{survey} \right)^{-1}$$

The survey and the catch data are the same as used in the analytical assessment of the stock and are provided in the assessment reports (e.g. ICES, 2010). The age groups (x) included in the calculations were age 4 to 9 (Figure 1) and age 5 to 9 (Figure 2).

Results and discussions

The data were analyzed both for age groups 4 to 9 (Figure 1) and age 5 to 9 (Figure 2). Figure 1 shows that proportion of age 4 is usually higher in the survey than in the catches. This can most likely be explained by that the fishery is targeting larger herring. There are some exceptions to this, for example in 2006 and 2007 where the fleet had problems in finding large herring and fished instead a large amount of younger herring off the south coast, particularly age 4 in 2006 and age 4 and 5 in 2007 (ICES, 2007; 2008). Because the relative difference is largest in the age groups that are entering the fishery, i.e. age 4, the analyses were also limited to age groups 5 to 9 (Figure 2). The maximum difference between the proportions was less than 0.1 in 14 years out of total 21 years. Further attention was given to years where the maximum difference was >0.1 to determine what caused the differences.

In 1987 and 1988 the differences between the proportions in the catch and surveys was up to 24% (Figure 2). The reason for this difference is that the fishery took mainly place off the east coast that lies the furthest north where old part of the stock was found (> age 6), while for example age groups 3 to 5 were measured in considerable amount off the southeast coast in 1987 were no fishery took place (MRI, 1988). Thus the fishing pattern in these two years was atypical and different from previous years (ICES, 1989) and explains the low proportions of age 5, and consequently higher proportions of older ages, in the catch in comparison to the acoustic measurements.

During the years 1991 and 1992, the herring fishing fleet was mainly fishing off the southeast coast of Iceland (ICES, 1993; 1994). The proportion of young fish was high in the catches so area closures were frequent, particularly in 1991. It means that the fleet was forced to fish in different areas most likely with the consequences that age composition of the catches was skewed towards older fish relative to the age composition seen from the acoustic surveys, which took place in the same areas during the middle of the fishing seasons. That explains the higher proportion of age groups 5 as seen in the survey (Figure 2). The 1983 year class (at age 8 in 1991) appeared to show the highest discrepancy of the older age groups, but that can be expected since it was much larger (2–3 times) than the adjoining year classes.

In 1993, there was a completely temporal disharmony between the acoustic measurements undertaken in January and the fishery, which took mainly place in October and November with almost no fishery in January (ICES, 1995). It means that the acoustic measurement that was based on nine biological samples (ICES, 2008) cannot be recalculated with more samples originating the fishery. Thus, this apparent discrepancy in the age compositions in 1993 as represented by the catch data and the acoustic data (Figure 2) must be accepted as the best available estimates.

In 2000, the 1994 year class (at age 6; Figure 2) was in higher proportion in the acoustic measurements than in the catches. Around 70% of the catches that season were taken of the east coast while only 11% of the adult part of the stock was measured there acoustically (ICES, 2001). Thus, most of the stock was measured acoustically of the west coast where the 1994 year class was abundant. The stock began to utilize the areas west of Iceland for overwintering from 1995 and on. What initiated these changes has been suggested to be linked to occurrence of the 1993 and the relative big 1994 year classes there, which adopted presumably a new migration pattern (Óskarsson *et al.*, 2009). Thus, considering the fishing pattern with the most fishery off the east coast and that the relative abundance of the 1994 year class was less off the east coast than off the west coast, this observed discrepancy (Figure 2) can be expected and cannot been rejected.

The discrepancy between the proportions in 2003 is probably related to the fact that the 63% of the catch was taken off the east where only 28% of the stock was located according to the acoustic measurements, beside that the amount of older herring measured was considered small (MRI, 2004). Thus this observed discrepancy in 2003 (Figure 2) seems to be reasonable.

Considering that all the major discrepancies between the proportion of the age groups in the catch and in the survey can be explained by either the nature and location of the fishery or different spatial and temporal distribution of the fishery and the acoustic surveys, there is neither reason nor justification to revisit the acoustic measurements and recalculate the indices with for example different samples.

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Figure 1. The difference of proportion of number at age for age groups 4 to 9 of Icelandic summer-spawning herring between the number in commercial catch and number in the survey during 1986 to 2010 where positive residuals represent relative higher proportion in the catch.

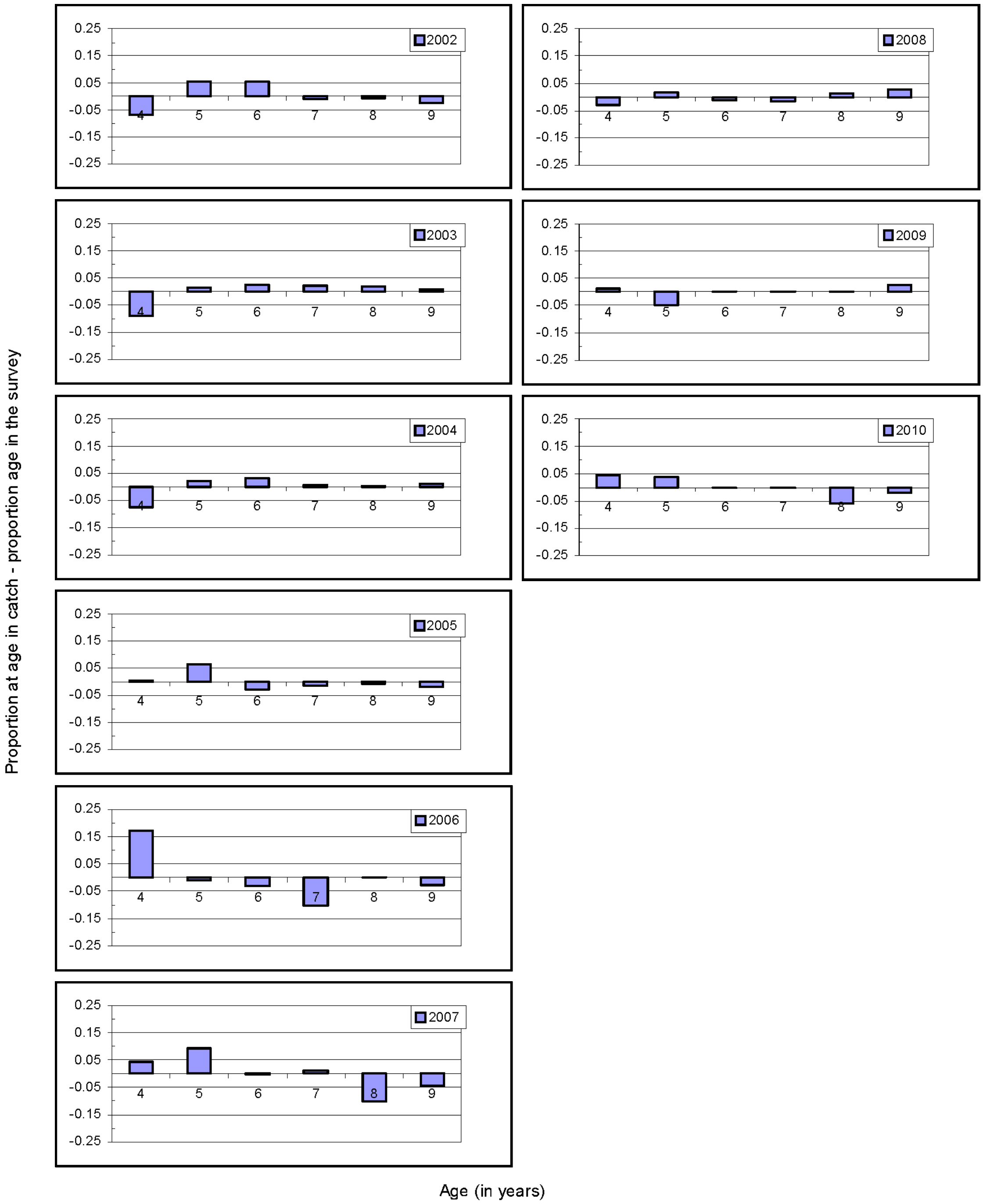

Figure 1. Continued.

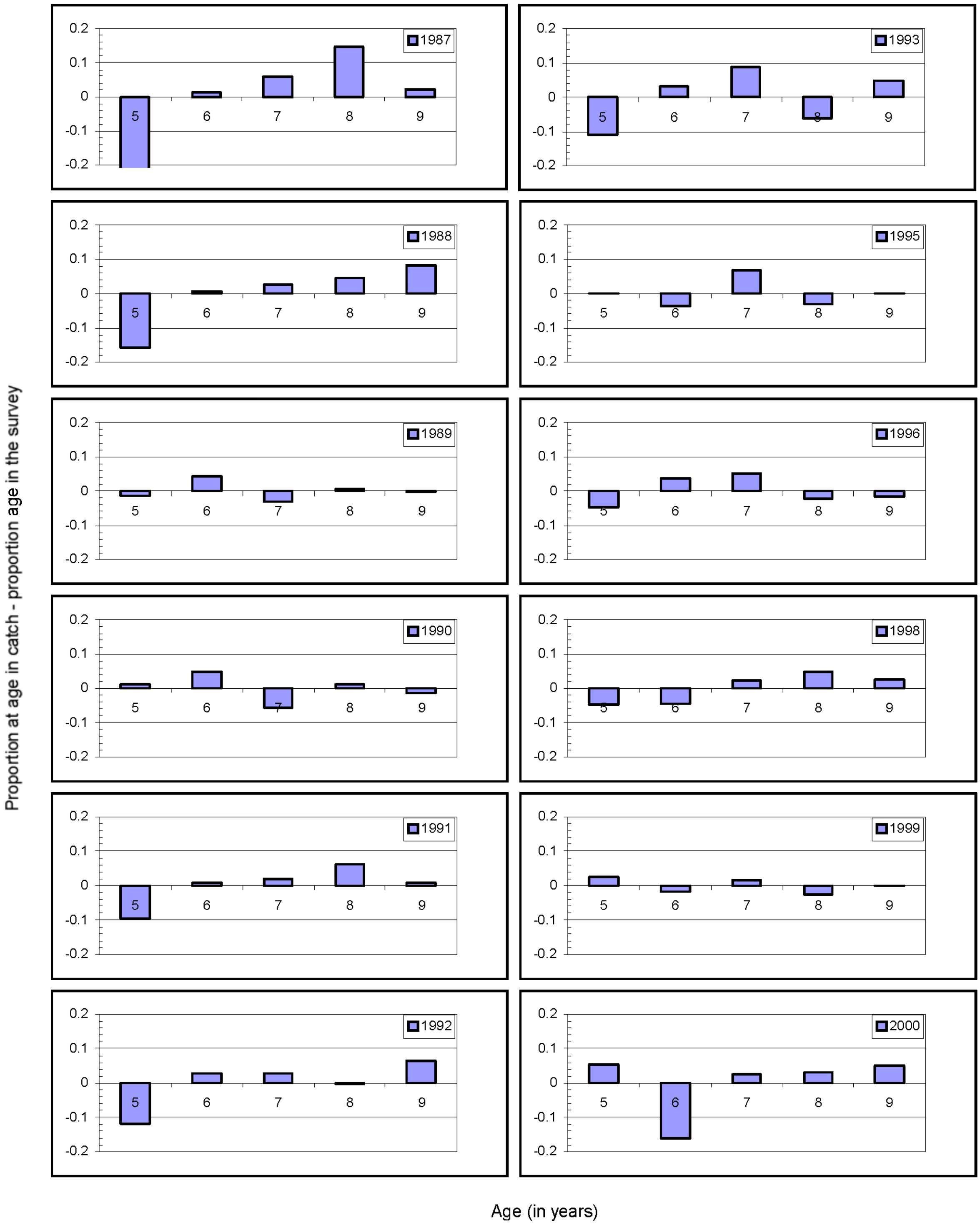

Figure 2. The difference of proportion of number at age for age groups 5 to 9 of Icelandic summer-spawning herring between the number in commercial catch and number in the survey during 1986 to 2010 where positive residuals represent relative higher proportion in the catch.

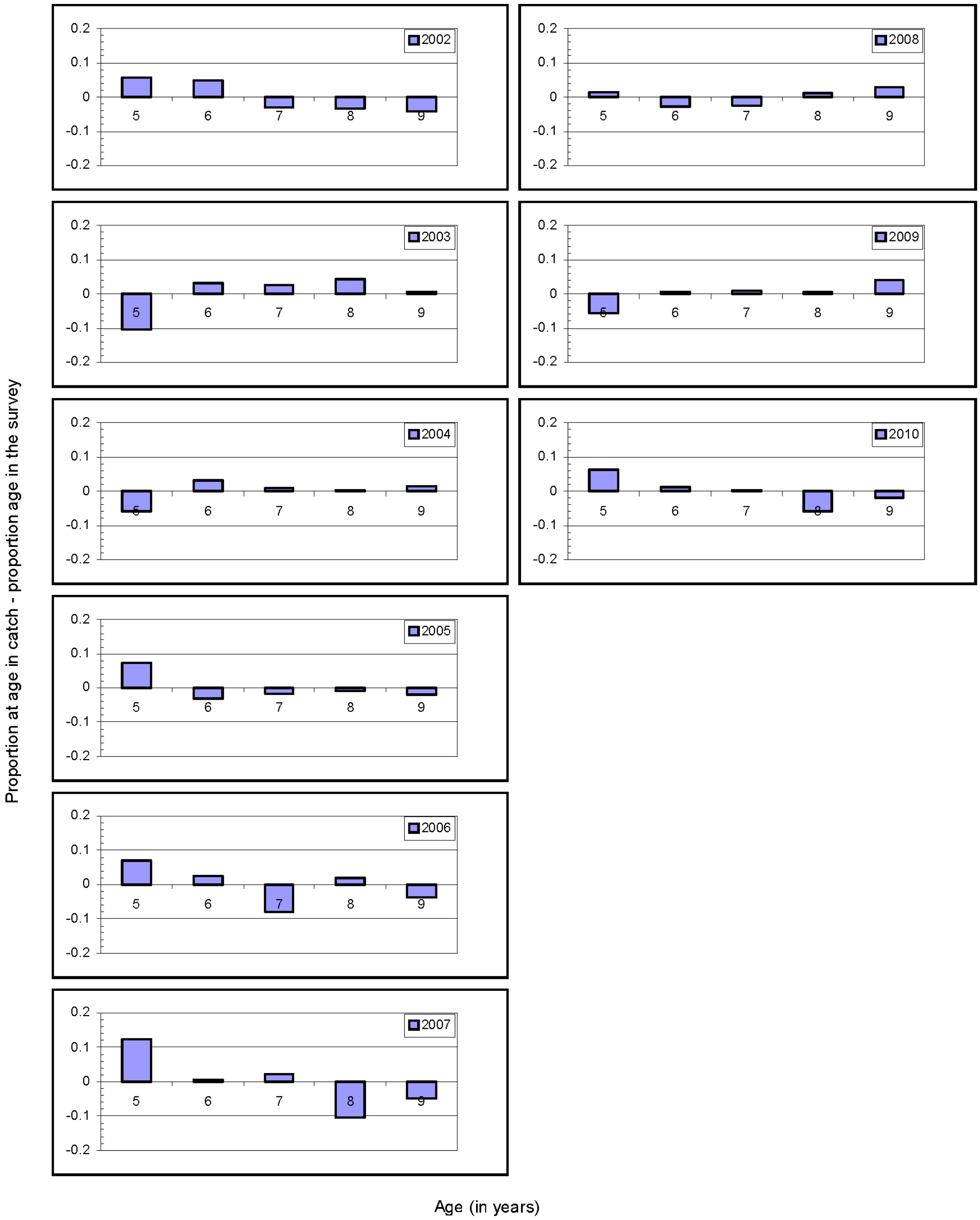

Figure 2. Continued.

Stock: Haddock in Subareas I and II (Northeast Arctic)

Inclusion of cod predation on haddock in the NEA haddock assessment

WKBENCH WD_ had_arct_1, by Bjarte Bogstad, IMR, Bergen, Norway

Since 1995, predation by cod on haddock has been included in the assessment of NEA haddock. This has been done for the years 1984 and onwards, where data on predation are available.

The amount of haddock consumed by cod is calculated using the methodology described by Bogstad and Mehl (1997). The calculations are based on data from the joint PINRO-IMR stomach content data base (Dolgov *et al.*, 2007) and stomach evacuation rates from experiments (dos Santos and Jobling, 1995).The consumption is calculated separately for each cod age group (1–9+) and separately for three areas and for the first and second half of the year. The amount consumed is calculated by prey species and length group. Age–length keys from surveys are used to transform these to number consumed by prey age group. The number of haddock consumed by age group and year is then included in the VPA as an additional catch (ICES, 2010). The estimated M2 values for ages 1–3 are fairly high (Figure 1). The M2 values for ages 4–6 are in almost all cases below 0.1. The M2 and N values for ages 1 and 2 are missing from the report.

Note that an historic average of M2 values is used for ages 3–6 before 1984. Data on frequency of occurrence from Russian stomach content data are available back to 1947 (Yaragina and Dolgov, 2009), and those could be utilized in order to calculate the historic abundance of ages 1 and 2.

Predation by cod on cod (cannibalism) is also included in the cod assessment, and it was concluded that including cannibalism improves the assessment. Also, variability in cod cannibalism has been studied in more detail by Yaragina *et al.* (2009). For cod predation on haddock there is little work done, although the Master thesis by Torvanger (2008) provides some information.

Figure 2–4 shows that the VPA with predation by cod included fits well to the survey indices from the Norwegian (2000–2005 and 2007 joint Norwegian/Russian) bottom-trawl survey in the winter. The analysis is limited to the years 1994–2007, because a change in spatial coverage as well as survey gear took place in 1994, and these changes significantly affected the indices for the younger age groups (Jakobsen *et al.*, 1997). There are several sources of uncertainty in the stomach content data (stomach sampling coverage, species and size identification of prey, age–length keys for prey) and also uncertainty related to the calculation of consumption from the stomach content data, so this good fit is encouraging.

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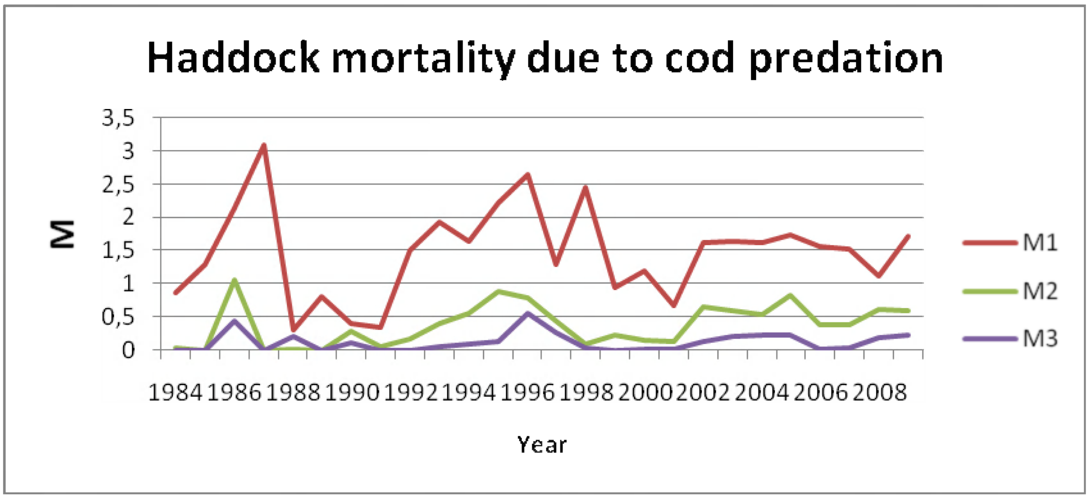

Figure 1. Haddock mortality due to predation by cod.

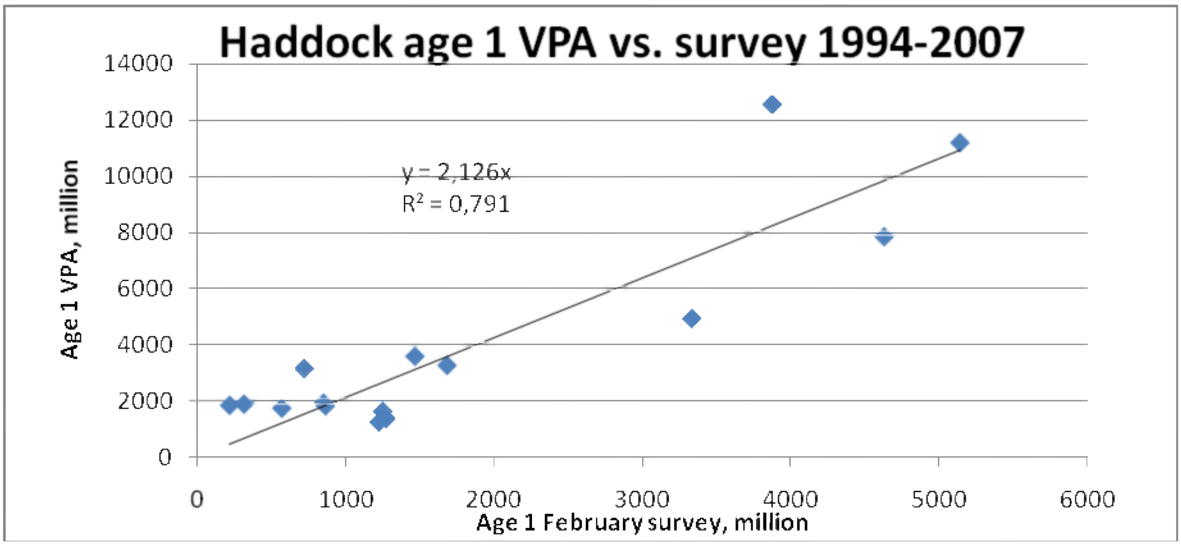

Figure 2. Haddock age 1 VPA vs. bottom-trawl survey indices for the period 1994–2007.

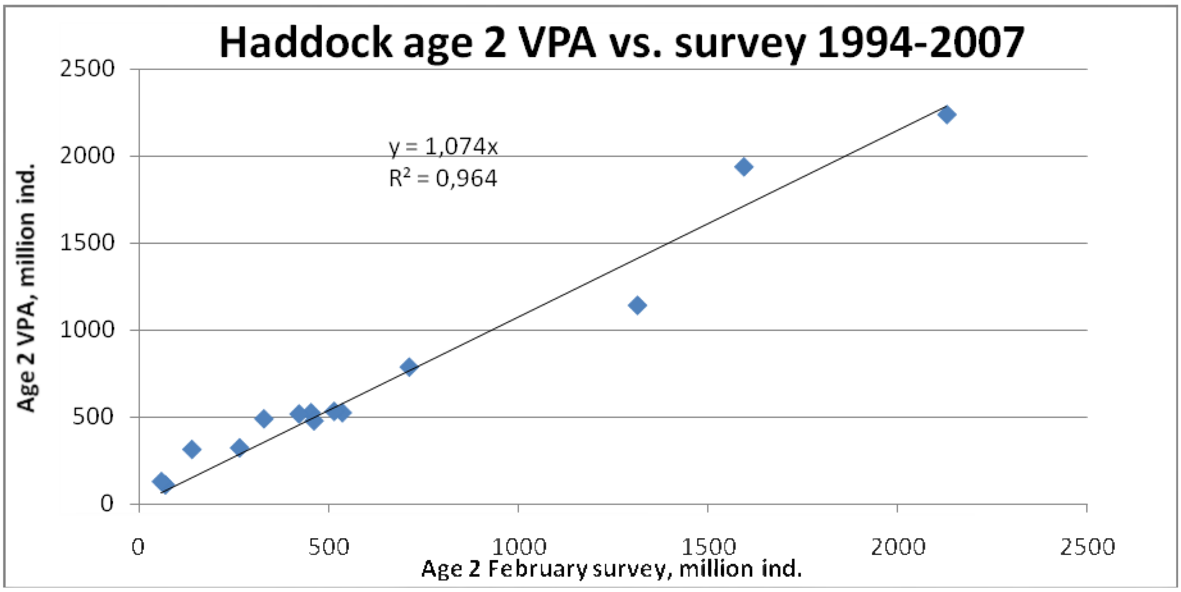

Figure 3. Haddock age 2 VPA vs. bottom-trawl survey indices for the period 1994–2007.

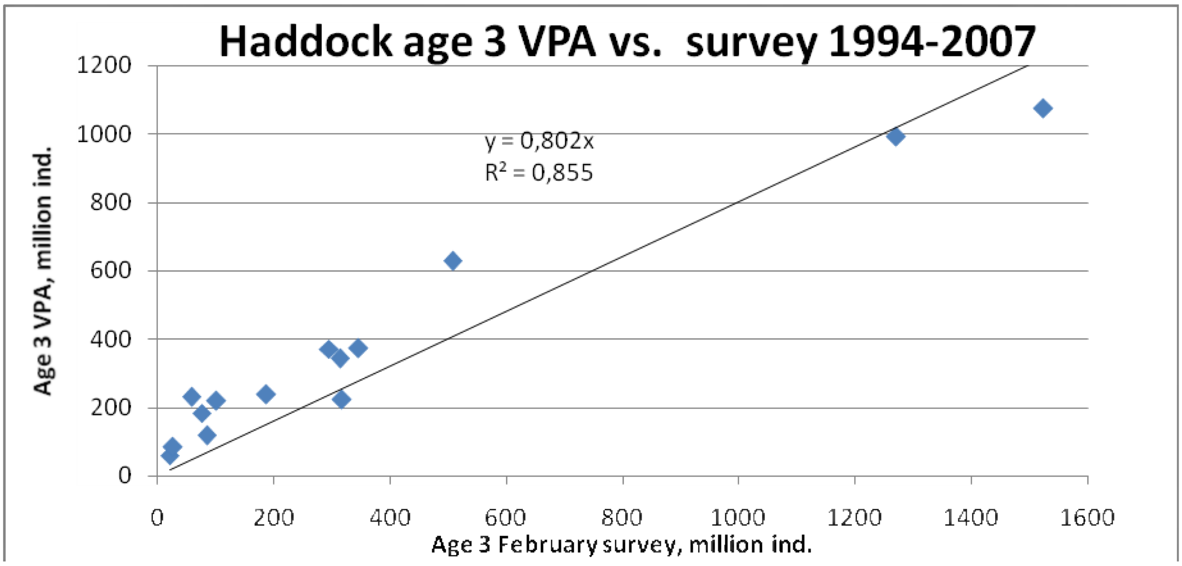

Figure 4. Haddock age 3 VPA vs. bottom-trawl survey indices for the period 1994–2007.

Are there differences in length-at-age and weight-at-age of haddock between Norwegian and Russian survey data?

WD # 2 to WKBENCH 2011. by Harald Gjøsæter, IMR.

Background

In the AFWG 2010 report the use of stock weights is described as follows:

"Stock weights (Table 4.6) used from 1985 to 2009 are averages of values derived from Russian surveys in autumn (mostly October–December) and Norwegian surveys in January-March the following year (Table B6). These averages are assumed to give representative values for the beginning of the year. In 2006 the Working group decided to model the stock weight-at-age data in order to remove some of the sampling variability in the estimates. The weight-at-age is modelled as follows: Mean length at age is modelled using a von Bertalanffy model with L_∞ and T_0 parameters estimated over the whole time-series and a separate K parameter for each year class. Weight-at-age is estimated from a length–weight relationship using the smoothed (modelled) length-at-age. Estimates were produced separately for the Russian autumn survey and the joint winter survey and were later combined as plain average."

The decision made in 2006 to model weights from length instead of using measured weights directly, was made to avoid random sampling variability in weight data.

Comparing table B5 (length) and B6 (weight) in the 2010 AFWG report give rise to suspicion whether there could be systematic differences between length-at-age and weight-at-age data from the Russian late autumn survey and the Norwegian (or joint) survey in February.

Comparing lengths and weights from the surveys

To study this in some more detail, the data in table B5 and B6 were compared in a systematic manner. Since the haddock age is shifted by one year at 1 January, the basis for comparison was age X in the Russian survey in November year Y, and age X+1 in the Norwegian survey in February year Y+1. Absolute and relative difference between length- and weight-at-age for such pairs of data were calculated and plotted as time series and summarized over years for age-groups. The results are shown in Figure 1 and Figure 2.

Paired two-sample t-tests were made for each of the age groups, with the 0-hypothesis that there is no difference between recorded length- and weight-at-age in the two surveys. Those years where observations were lacking in one or both data series were left out of the analyses. The results are shown in Table 1 and Table 2. For all age groups except the 1- and 2-year-olds (length) and 2-year-olds (weight), there are significant (at the 5% level) differences between the Norwegian and the Russian surveys. For age groups larger than 4, the recorded lengths and weights from the Russian survey are larger than those from the Norwegian survey. For the younger age groups, the lengths or weights are either equal or the Norwegian lengths or weights are larger.

Figure 3 and 4 show modelled and observed weights (in the February survey) respectively.

What are the reasons for these systematic differences?

There could be various reasons for the observed differences and it is difficult to pinpoint the most prominent reasons. For the younger age groups, trawl selectivity might be an issue. Plotting survey indices by year class for the Russian and Norwegian surveys reveals that the youngest age groups are probably underrepresented. If this is a trawl selectivity problem, lengths (and weights) will be underestimated for the younger age groups, and if this is a bigger problem in the Norwegian survey than in the Russian survey, this might explain that lengths and weights from the Norwegian survey are larger for the youngest age groups.

For age groups four and older, the Russian lengths and weights are larger than the Norwegian observations. Two reasons could possibly explain this: first, there could be a sampling problem caused by behavioural changes of haddock from autumn to winter and second, there could be systematic differences in the interpretation of age readings between the institutes.

If, for instance, maturing fish move out of the February survey area to spawn somewhere else, and if the longest and heaviest fish in each age group have a higher probability of being mature, then these fish could be underrepresented in the Norwegian survey while being caught in the Russian survey.

Haddock otoliths have been exchanged and the interpretation compared among age readers at PINRO and IMR for about 15 years. The reports from such otolith workshops show that the amount of discrepancy between Norwegian and Russian age readers has decreased during that period, from 12–35% during the late 1990s to 5–15% during recent years. The reports do not show how the discrepancy is distributed to random variation and systematic variation (bias). However, in the report from the meeting in May 2009 in Bergen, it is stated: "The main reason of discrepancies between PINRO and IMR readers is different interpretation of the otolith summer structures in the first and second year of the haddock life due to false zones. PINRO identified false zones and, while IMR interpreted them to be annual structures." This remark pertains to a specific reading exercise and it is unclear whether this is a common observation. The Norwegian lead haddock age reading expert cannot confirm this to be the case. If this is a common phenomenon (implying that fish older than 1–2 years are given a higher age by Norwegian age readers) that would explain (at least part of) the observed differences in length-at-age and weight-at-age in the material from the surveys.

To gather more circumstantial evidence for or against the theory that the differences might stem from differences in age reading, the weight-at-age in the catches was analysed. The weight-at-age in catch data from Norway and Russia divided on ICES areas I, IIa and IIb, re-analysed during the WKHAD meeting in 2006 for the period 1980–2006 was compared. The plots of weight-at-age confirm the findings from the survey data in that younger fish (typically up to 3–4 years) from all areas were generally lighter in the Russian data than in the Norwegian data, while for older fish the Russian data had in general heavier fish. This strengthens the theory that biased age readings might be responsible for at least parts of the observed differences.

What is gained by modelling stock weights compared to using observed weights?

The analysis of variation in lengths and weights from the Norwegian and Russian surveys shows that the variability is comparable for lengths and for weights and that they both are significantly different in the two survey-series for most age groups. Inferring weights from lengths by use of a von Bertalanffy growth equation seems attractive if the precision of weight measurements is questioned while the precision of length measurements is not. It does not help to overcome the observed differences between the two surveys used for establishing the growth equations, whether those differences are caused by various sampling problems or by for instance age reading problems.

Concluding remarks

It may be concluded that the modelling exercise could be continued, but work should be undertaken to understand the reasons for the systematic differences between the November survey and the February survey. If the reasons for the difference could be revealed, it might seem preferable to base the stock weights on one of the surveys instead of averaging the measurements (or the model output) from each of the surveys.

Further, since the same type of difference is also revealed in the catch data, work should be undertaken to analyse in more detail the reason for these discrepancies. (The analysis also showed that in one particular year (2003) there are so large differences in weight-at-age data between Norway and Russia that they probably stem from some erratic calculations.) Potentially, the differences found could introduce errors at various input data to the sequential population analysis models used for haddock stock assessment. Whether these errors are large enough to warrant re-analysis of age material back in time is not considered here, but this should be further investigated.

Table 1. Paired two-sample t-tests of differences between length-at-age for each of the age groups. Age group 1 means age group 0 in late autumn compared with age group 1 in February the year after. Those tests marked with yellow are significant at the 5% level.

Age group	No of pairs	Mean Norw	Mean Russian	t-value	P(T<t)
1	10	16.5	14.9	1.8500	0.0974
2	26	22.9	22.8	0.1916	0.8496
3	26	30.7	29.8	2.2156	0.0361
4	26	38.7	37.6	2.4757	0.0204
5	24	45.6	46.7	-2.1248	0.0437
6	23	50.1	52.3	-3.7796	0.0010
7	22	54.1	56.6	-4.5584	0.0002

Table 2. Paired two-sample t-tests of differences between weight-at-age for each of the age groups. Age group 1 means age group 0 in late autumn compared with age group 1 in February the year after. Those tests marked with yellow are significant at the 5% level.

Age group	No of pairs	Mean Norw	Mean Russian	t-value	P(T<t)
1	10	29.2	26.1	2.290	0.0478
2	26	106.1	106.7	-0.200	0.8432
3	26	280.8	249.0	2.598	0.0155
4	26	585.7	527.8	2.907	0.0075
5	24	913.2	985.1	-2.280	0.0322
6	23	1293.4	1422.6	-3.034	0.0061
7	22	1622.4	1826.0	-4.315	0.0003

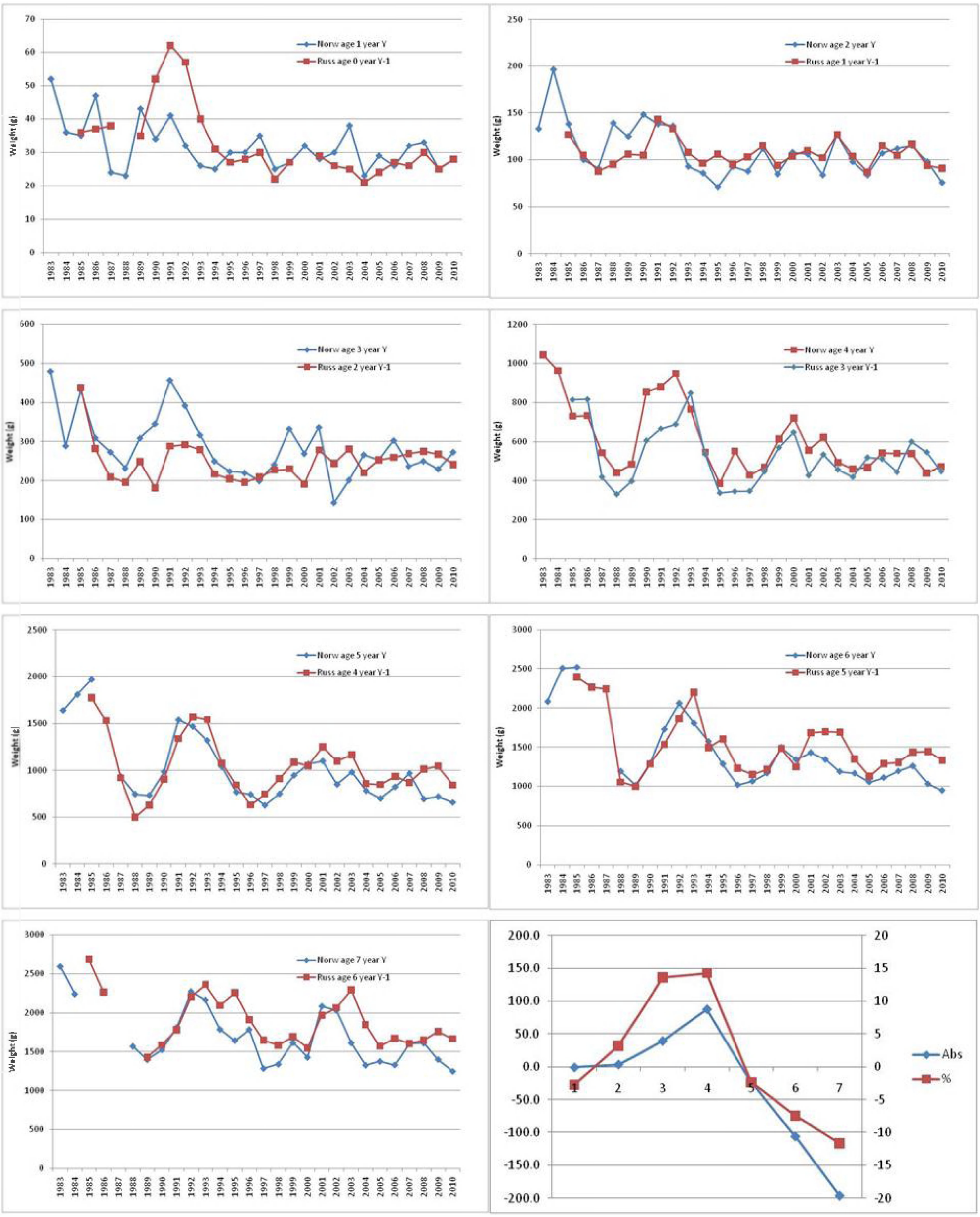

Figure 1. Comparison of weight-at-age in Norwegian and Russian surveys. Lower right panel shows mean weight difference for each age group.

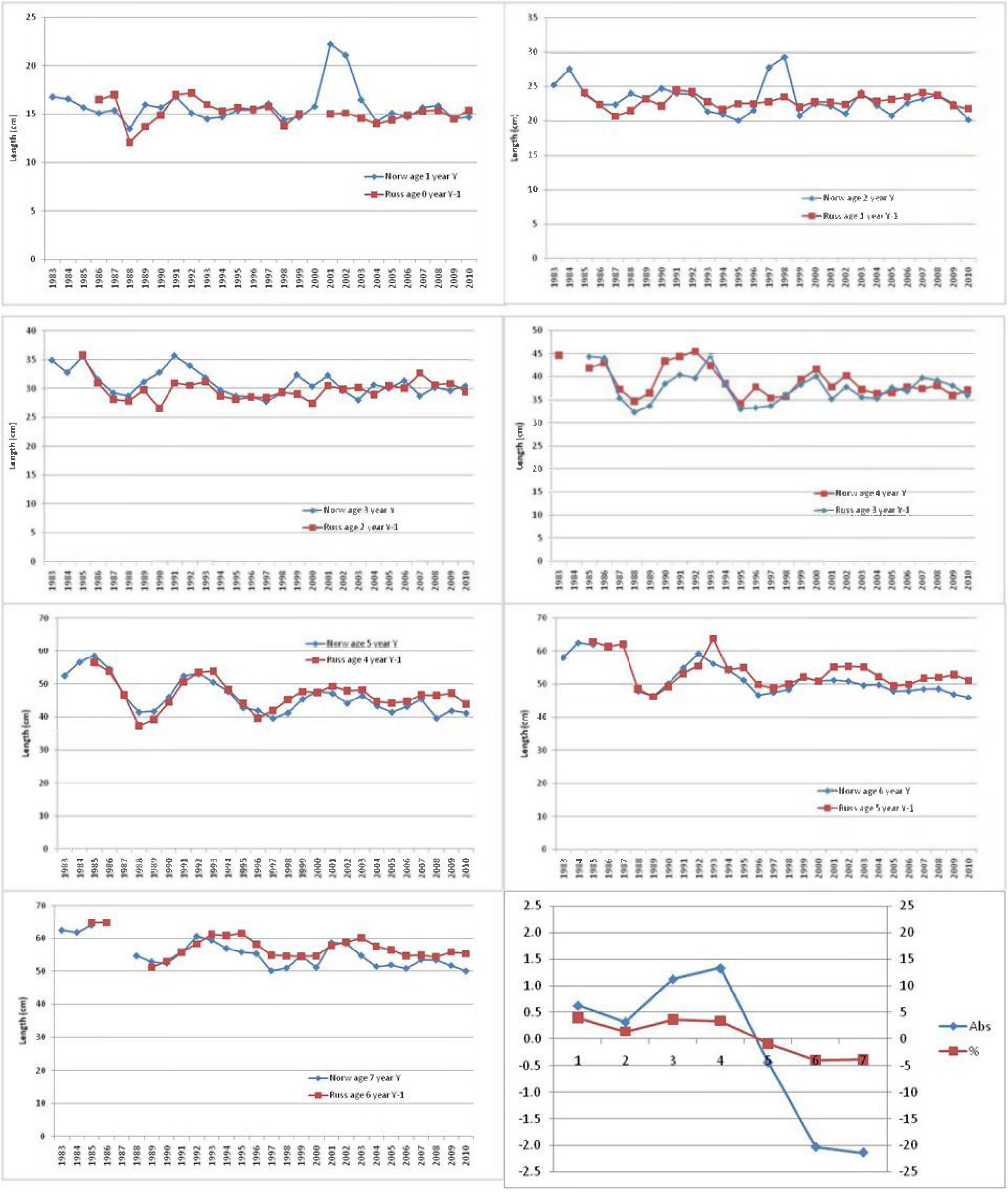

Figure 2. Comparison of length-at-age in Norwegian and Russian surveys. Lower right panel shows mean length difference for each age group.

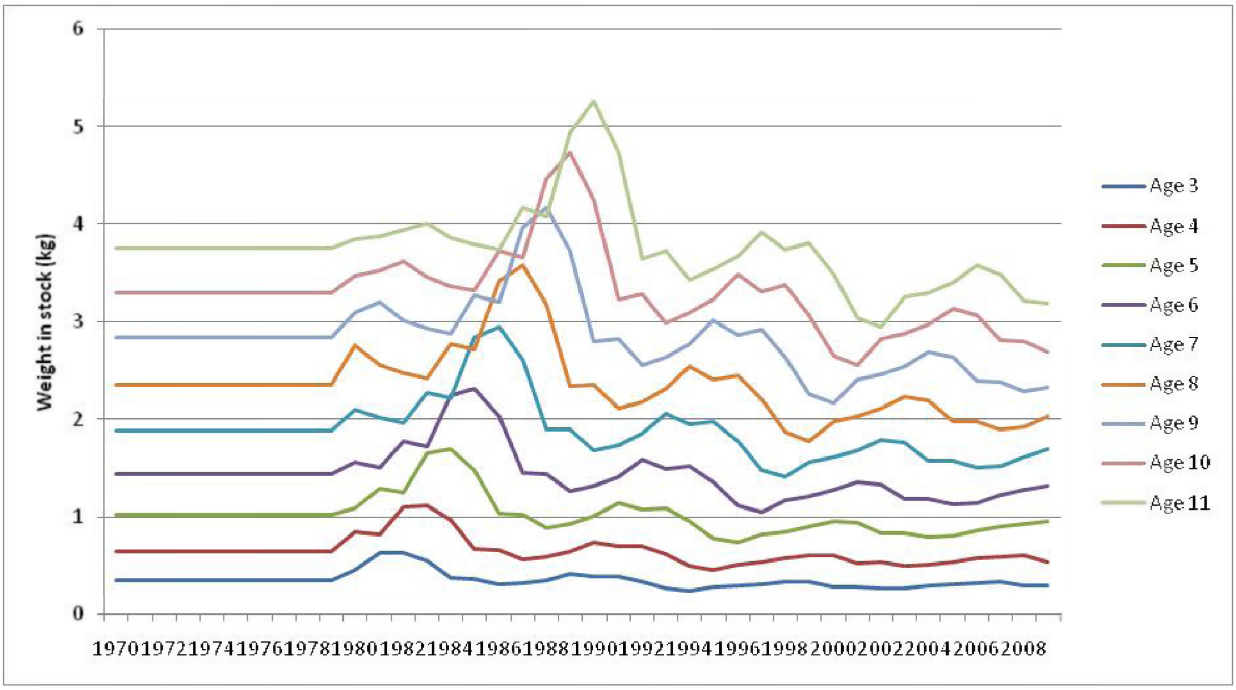

Figure 3. Modelled stock weights used in the assessment. Constant weight-at-age was used up to 1980.

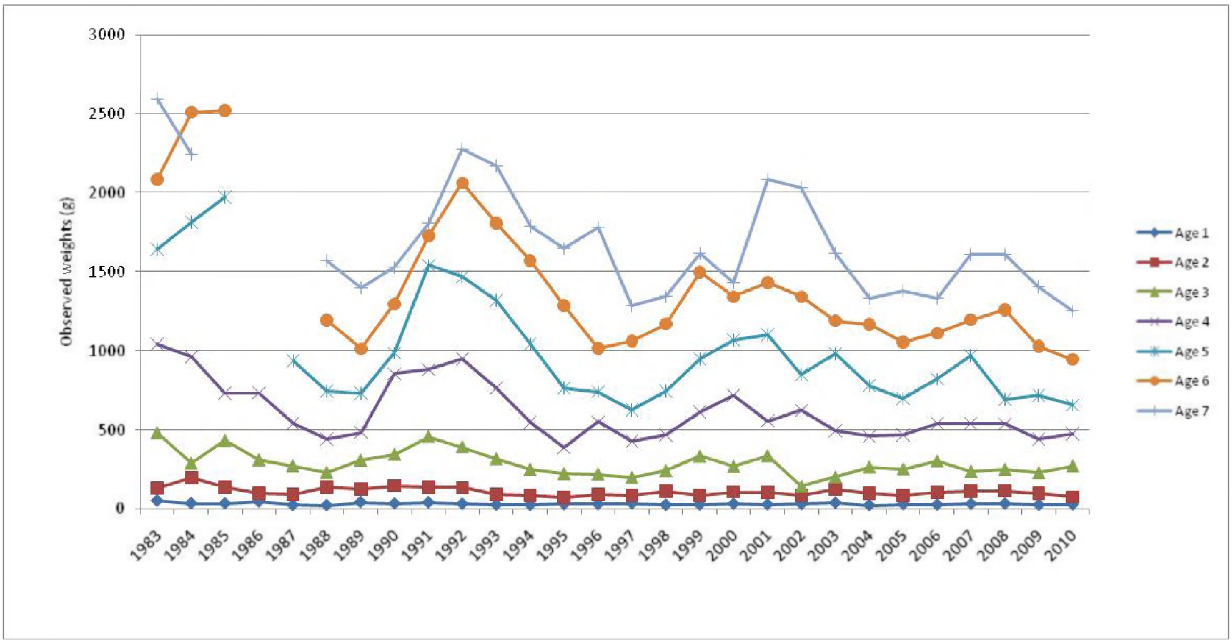

Figure 4. Observed weight-at-age in the Norwegian winter survey.

Recruitment prediction for NEA haddock

by Gjert E. Dingsør

Introduction

Recruitment of Northeast Arctic haddock is highly variable and stock-recruitment models do not give any reliable predictions of future recruitment. The traditional procedure to predict recruitment at age-3 has been to use the RCT3 program, where the predictions are based on only survey indices. However, we know that external factors (e.g. cod predation) influence survival and regression models including external factors are used by AFWG to predict recruitment at age-3 for NEA cod (ICES, 2010). In this work I wanted to investigate if it is possible to improve age-3 predictions with the use of regression models.

Several approaches to regression validation are available. Regression R-squared can give misleading and overly optimistic view of accuracy of prediction when the model is applied outside the calibration period. Split-validation or cross-validation are often recommended. In split-validation, the time series is split in two and the model is calibrated using one fraction and validated using the other fraction. With relatively short time series, cross-validation may be a better choice. In cross-validation, one leaves out n observations, calibrates the model, and predicts the years left out. This procedure is repeated several times leaving out different subsets, the standard error of prediction can then be estimated. In this work I have applied leave-one-out cross-validation.

Methods

The different abundance indices available for haddock at age 0–3 (Table 1) were used together with temperature and cod/capelin ratio to construct recruitment models. Temperature was included under the assumption that survival is better at high temperatures and cod/capelin ratio was included under the assumption that the predation pressure from cod is higher when this ratio increases, i.e. decreased survival. A Generalized Linear Modelling approach was used and the selection of variables in the final models were determined by a backward selection strategy based on Akaike information criterion (AIC) and statistical significance of terms. The GLM models where calibrated by the 1983–2004 year-classes, the last five year classes were not used in the calibration to reduce the influence of tuning processes in XSA.

Table 1. Variables used in fitting of the regression models.

ABREVIATION	DEFINITION
had3vpa	Number-at-age-3 from XSA (AFWG 2010)
hadB1–3	Abundance indices from Norwegian trawl survey, ages 1–3
hadA1–3	Abundance indices from Norwegian acoustic survey, ages 1–3
hadR1–3	Abundance indices from Russian trawl survey, ages 0–2
had0	0-group abundance index from Joint survey
kolaAMlx	Annual mean temperature lagged x years, Kola section
CCRlx	Cod/capelin ratio lagged x years

The regression models compared in this work are the following:

Models that can predict numbers at age-3 in year t, t+1 and t+2:

log(had3vpa) ~ kolaAMl2 +log(hadB1) + log(CCRl2)

log(had3vpa) ~ kolaAMl2 + log(hadA1) + log(CCRl2)

log(had3vpa) ~ log(hadR0) + log(CCRl2)

log(had3vpa) ~ log(had0) + log(CCRl2)

Models that can predict numbers at age-3 in year t and t+1:

log(had3vpa) ~ log(hadB2) + log(CCRl1)

log(had3vpa) ~ log(hadA2) + log(CCRl1)

log(had3vpa) ~ log(hadR1) + log(CCRl1)

Models that can predict numbers at age-3 in year t:

log(had3vpa) ~ log(hadB3)

log(had3vpa) ~ log(hadA3)

log(had3vpa) ~ log(hadR2)

All of these models were compared to RCT3 predictions. RCT3 can predict number at age-3 in year t, t+1, and t+2.

Regression validation statistics:

Sum of squares of validation errors:

$$SSE_v = \sum_{i=1}^{n_v} (e_{(i)})^2 \qquad (1)$$

where $e_{(i)} = y_i - \hat{y}_{(i)}$, i.e. sum of difference between observed and predicted values in year *i*. The notation (*i*) indicates that the data for year *i* was not used in the fitting of the model. In this case, SSE is equivalent to leave-one-out cross-validation. A measure of the average size of the prediction error for the validation period is then the square root of the mean squared error of validation:

$$RMSE_v = \sqrt{\frac{1}{n_v}\sum_{n_v} SSE_v} \qquad (2)$$

Reduction of error:

$$\mathrm{RE} = 1 - \frac{\mathrm{SSE_v}}{\mathrm{SSE_{null}}} \qquad (3)$$

where

$$SSE_{null} = \sum_{i=1}^{n_v} (y_i \quad \bar{y}_c)^2 \qquad (4)$$

RE measures the skill of a regression model, defined as its accuracy relative to a prediction based on no knowledge. Similar to R^2, the closer RE is to 1, the better is the model performing. However it is important to note that RE is more conservative than the traditional R^2 based on residual sum of squares.

The $RMSE_v$ does also allow for estimation of prediction confidence intervals given by the pointwise estimate $\pm$ 2*$RMSE_v$.

The models are also compared using AIC, penalizing additional terms.

Results and discussion

The results indicate that RCT3 does a fairly good job at predicting recruitment at age-3 (Tables 2 and 3, and Figure 1), but it is possible to make better predictions with relatively simple models, which take into account predation from cod and temperature differences. All models produce similar predictions (Table 3 and Figure 1). However, the confidence intervals are wide and widest for the t+2 predictions (Figures 2–4). The RCT3 predictions for t+2 are consistently lower than the predictions from the other models (Figure 1), probably caused by the shrinkage towards mean recruitment.

The cod/capelin ratio show a consistent, negative effect in the t+1 and t+2 models (Table 2) and diagnostic plots indicate that this effect is more important than the positive temperature effect. Temperature is only significant for the t+2 predictions. However, it is possible that temperature estimates from one of the more western sections would give a better fit since haddock have a south-western distribution in the Barents Sea.

To reduce the influence of possible outliers in survey indices, one may argue that it is advisable to use the mean of different and independent predictions. This is done for recruitment modelling of NEA cod and seems to be a good idea for NEA haddock, as well. Note that the predictions are not strictly independent since they use some of the same input variables and the acoustic estimates use age–length keys from the bottom-trawl stations. This may bias the estimates, but the influence is likely to be minor.

Conclusion

All models have a tendency to underestimate the largest year classes, but this is not a bad property in a precautionary management regime. It is more severe if they tend to overestimate poor year classes. All models produce fairly good predictions and the new models seem to be more precise than the RCT3 predictions, especially for year t+2. However, it is debatable if it is worth taking the 'risk' of introducing more uncertain variables into the prediction of haddock at age-3. NEA haddock as a one-year HCR and estimates two years ahead has little effect on the advice given. Thus, it is recommended that the use of RCT3 is continued and is the main source of predicted values. However, the other models are useful for support and may give us early indications of arising problems due to increased predation from cod.

Table 2. Comparison of regression models. AIC: Akaike information criterion; RMSE$_v$: root mean squared error of validation; RE: reduction of error (leave-one-out cross validation); R^2: deviance explained (calibration period). Best models in bold.

Model	Formulation	AIC	RMSEv	RE	R2
HAD1B	**log(had3vpa) ~ 7.08 + 0.52*kolaAMI2 + 0.45*log(hadB1) - 0.23*log(CCRI2)**	**21.19**	**0.39**	**0.80**	**0.87**
HAD1A	log(had3vpa) ~ 7.66 + 0.50*kolaAMI2 + 0.39*log(hadA1) - 0.25*log(CCRI2)	28.39	0.45	0.74	0.82
HAD0R	log(had3vpa) ~ 11.42 + 0.43*log(hadR0) - 0.23*log(CCRI2)	27.92	0.44	0.75	0.81
HAD0G	log(had3vpa) ~ 9.26 + 0.44*log(had0) - 0.39*log(CCRI2)	38.16	0.54	0.61	0.70
HAD2B	**log(had3vpa) ~ 8.95 + 0.60*log(hadB2) - 0.20*log(CCRI1)**	**4.99**	**0.27**	**0.91**	**0.93**
HAD2A	log(had3vpa) ~ 9.64 + 0.51*log(hadA2) - 0.15*log(CCRI1)	17.77	0.36	0.83	0.88
HAD1R	log(had3vpa) ~ 10.94 + 0.56*log(hadR1) - 0.13*log(CCRI1)	10.75	0.31	0.87	0.91
HAD3B	log(had3vpa) ~ 9.10 + 0.64*log(hadB3)	18.05	0.36	0.83	0.87
HAD3A	**log(had3vpa) ~ 9.39 + 0.62*log(hadA3)**	**1.32**	**0.25**	**0.92**	**0.94**
HAD2R	log(had3vpa) ~ 10.47 + 0.62*log(hadR2)	6.10	0.26	0.91	0.92
RCT3		NA	0.23*	NA	0.72

*Note: RMSE for RCT3 is based on sum of squares of residuals and is expected to be smaller than RMSE$_v$ based on leave-one-out cross validation.

Table 3. Predicted year-class strength at age-3 of the five last year-classes.

Model\Yearclass	2005	2006	2007	2008	2009
HAD1B	593	597	301	246	371
HAD1A	457	558	391	330	434
HAD0R	438	465	218	199	242
HAD0G	733	565	393	365	672
Mean (HAD1B, HAD1A, HAD0R)	496	540	303	258	349
HAD2B	602	813	256	129	
HAD2A	449	723	256	142	
HAD1R	638	715	241	102	
Mean (HAD2B, HAD2A, HAD1R)	563	750	251	124	
HAD3B	949	845	171		
HAD3A	705	873	253		
HAD2R	970	1021	194		
Mean (HAD3B, HAD3A, HAD2R)	874	913	206		
RCT3 (t+2)	521	427	192	146	303
RCT3 (t+1)	658	776	206	101	
RCT3 (t)	892	1052	212		
VPA (2010)	1029	812			

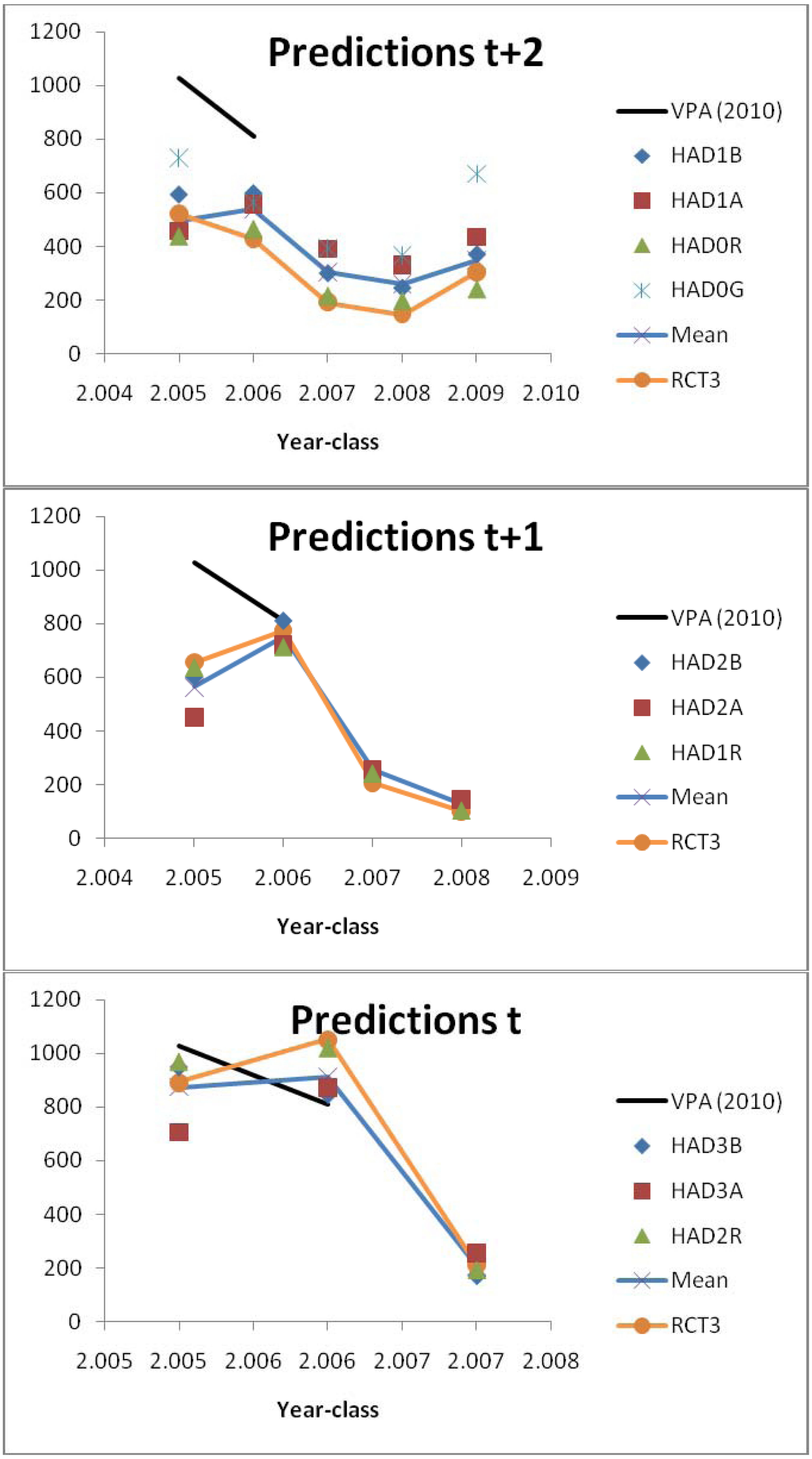

Figure 1. Predicted year-class strength at age-3 of the five last year-classes.

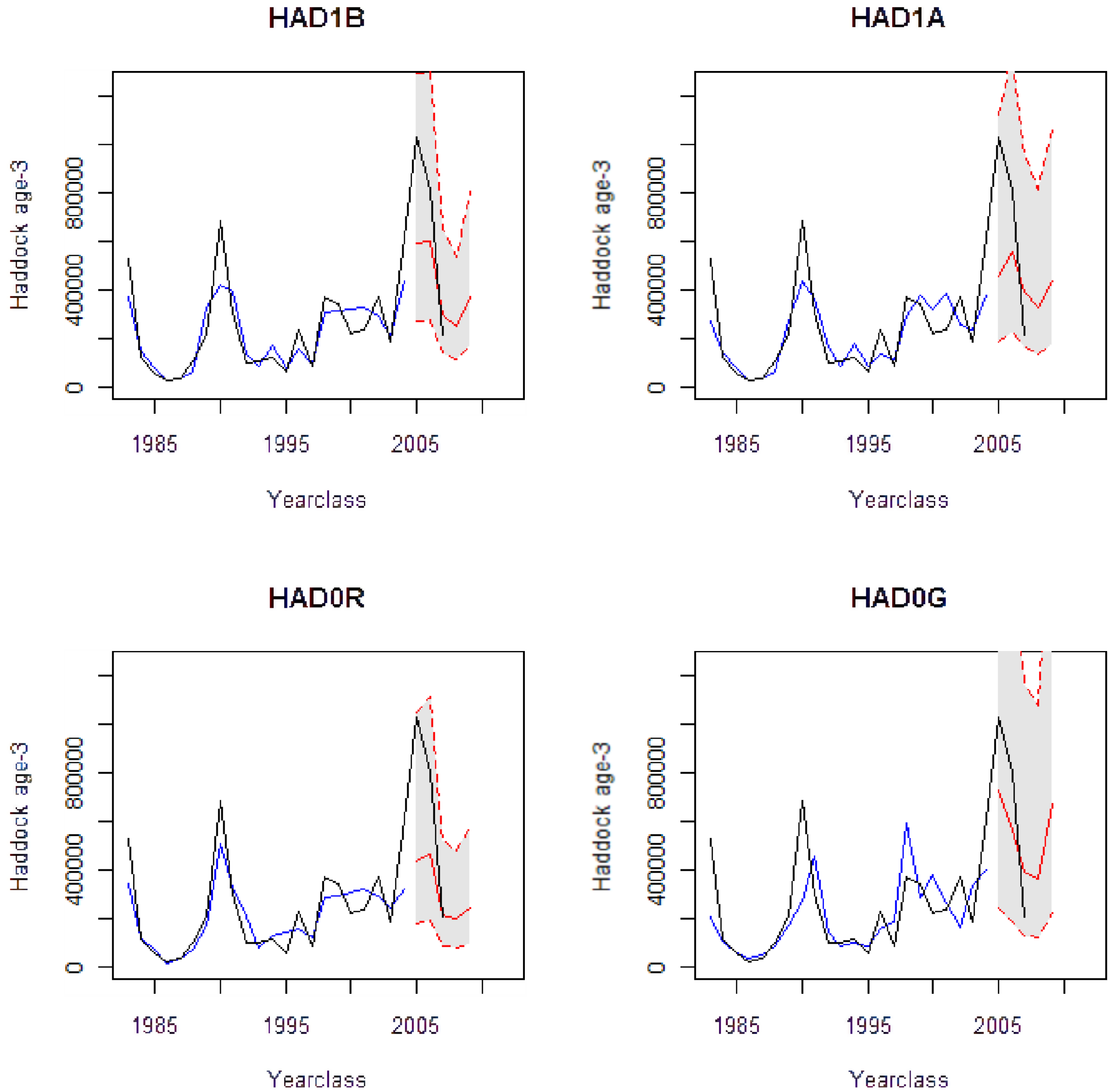

Figure 2. Models able to predict two years ahead. Calibrated on year classes 1983–2004 (black line), fitted model (blue line) and predicted year classes 2005–2009 (red line with confidence interval, shaded area).

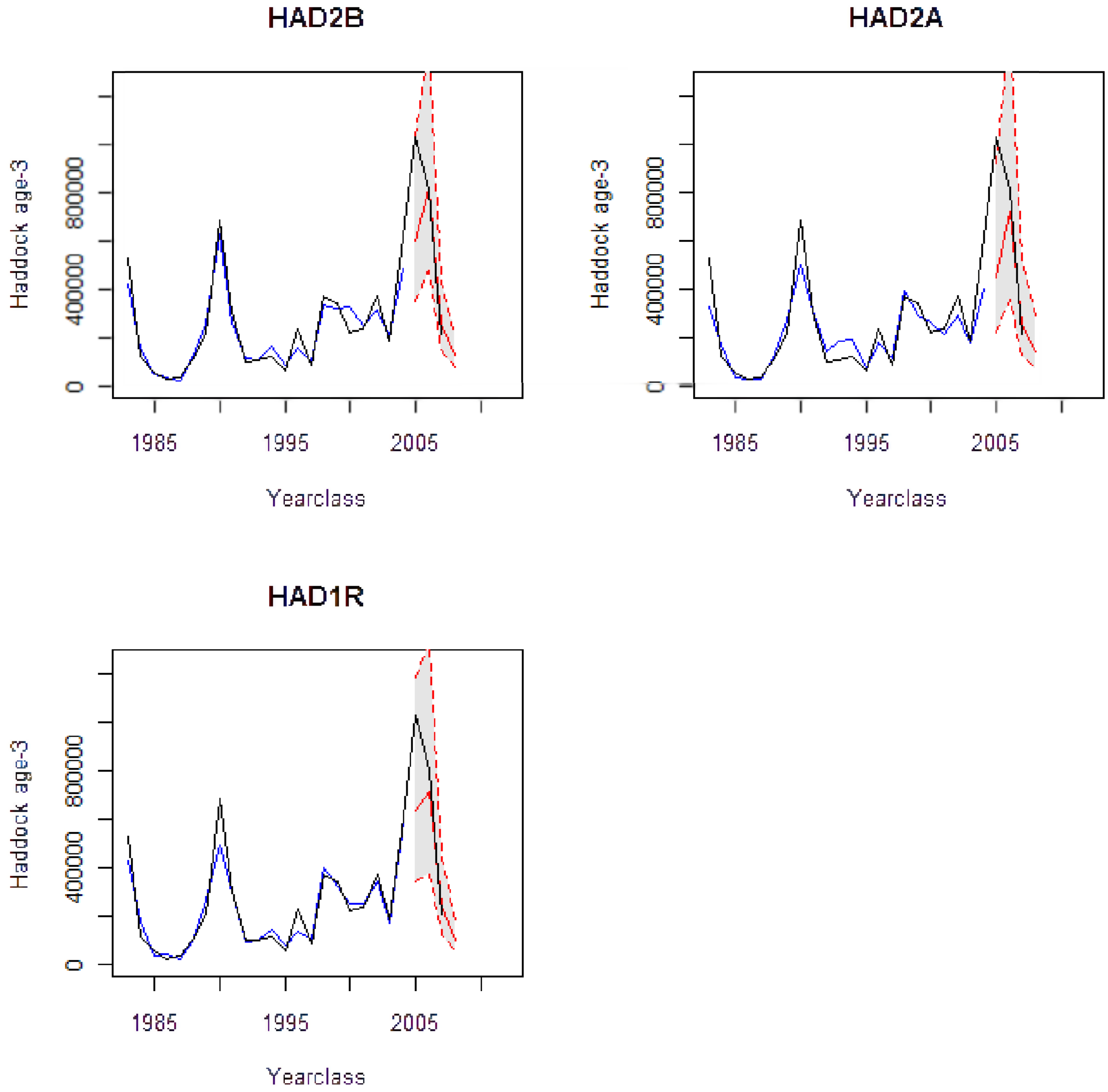

Figure 3. Models able to predict one year ahead. Calibrated on year classes 1983–2004 (black line), fitted model (blue line) and predicted year classes 2005–2008 (red line with confidence interval, shaded area).

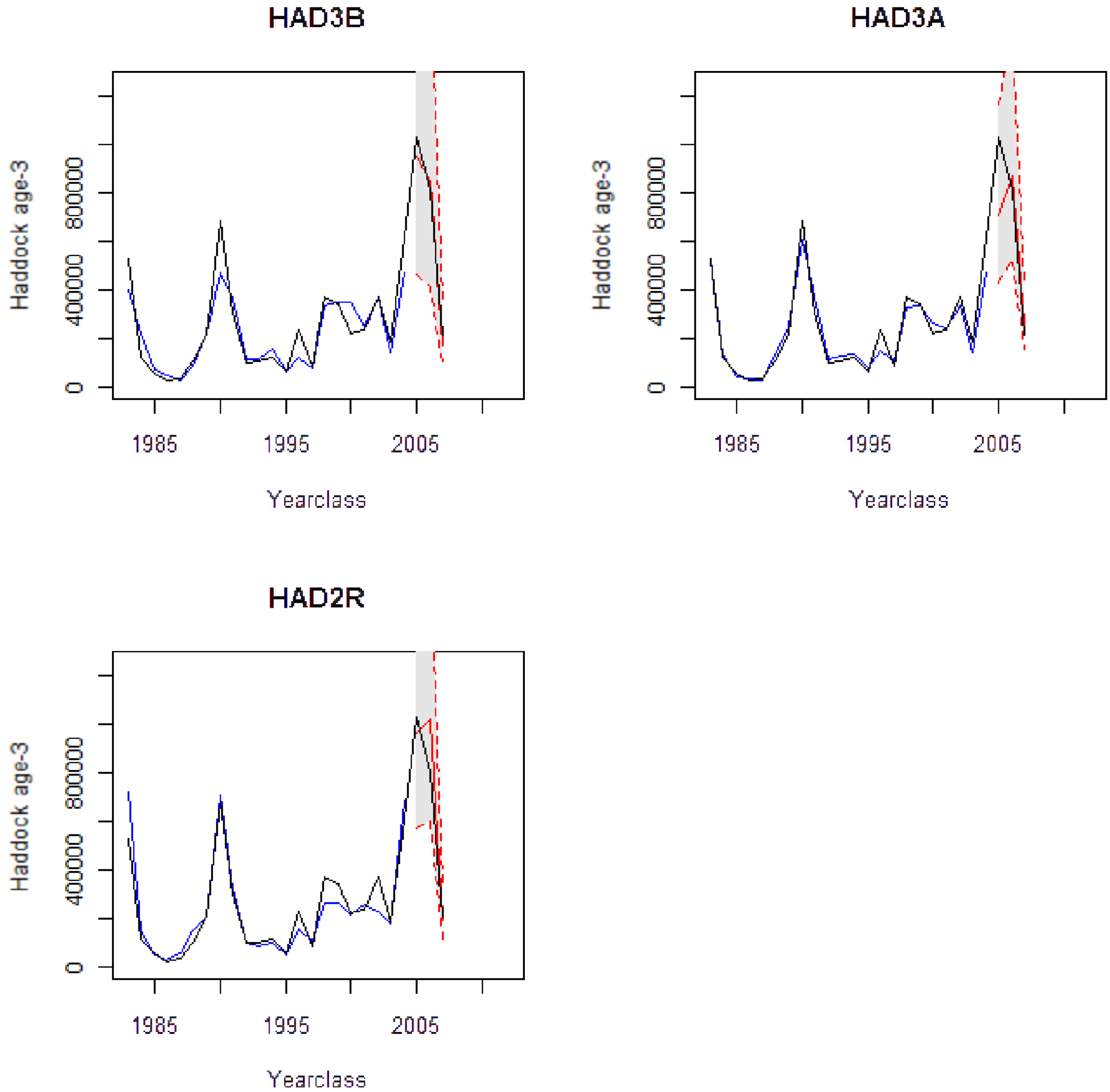

Figure 4. Models able to predict present year. Calibrated on year classes 1983–2004 (black line), fitted model (blue line) and predicted year classes 2005–2007 (red line with confidence interval, shaded area).

References

ICES. 2010. Report of the Arctic Fisheries Working Group (AFWG), 22–28 April 2010, Lisbon, Portugal (WEBEX). ICES CM 2010/ACOM:05.

XSA model settings for North-east Arctic haddock

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Introduction

Currently NEA haddock assessed by AFWG using XSA model (ICES, 2011). Different alternative models and methods were tried by the Working Group but XSA were chosen as main method so far. During preparation to the benchmark meeting it was studied if the currently used by AFWG XSA setting gives a best estimate of haddock stock size. Data available for XSA tuning of NEA haddock and model configuration (different XSA parameters) were studied in order to improve quality of assessment.

Data for XSA tuning

There are six indices available for estimation of NEA haddock abundance calculated on base of three surveys (see table below).

Surveys available for tuning of XSA model.

Survey	Index	XSA fleet name *	First year	Last year
Russian trawl acoustic survey in the Barents Sea and adjacent waters in November–December	Bottom-trawl index (numbers per hour trawling)	FLT01: Russian BT	1983	2009
	Acoustic index	FLT011: Russian acoustic	1995	2009
	Acoustic index (old method)	Not used	1985	2009
Norwegian/Joint trawl acoustic surveys in the Barents Sea in January–March	Acoustic index	FLT02: Norwegian acoustic	1981	2009
	Bottom-trawl index (absolute abundance)	FLT04: Norwegian BT	1981	2009
Joint Ecosystem survey of the Barents Sea in August–September	Bottom-trawl index (absolute abundance)	FLT007: Ecosystem	2004	2009

*** Shaded fleets not used in AFWG current assessment**.

All indexes were examined on internal consistency (Tables 1–5, Figures 1–5). Those age groups that have a reasonably good correlation with consequent age groups were chosen for XSA tuning. One index (Russian acoustic index (old method)) showed a high level of noise, low correlations for all ages (Table 6, Figure 6) and has been exclude from further analysis. For other five indexes the particular age groups with reasonably high correlations were chosen for 1st XSA trial run (see table below).

Indexes chosen for tuning of XSA model for NEA haddock.

Fleets	First year	Last year	First age	Last age	Alpha	Beta
FLT01: Russian BT	1990	2009	1	8	.900	1.000
FLT02: Norwegian acoustic	1990	2009	1	7	.990	1.000
FLT04: Norwegian BT	1990	2009	1	8	.990	1.000
FLT007: Ecosystem	2004	2009	1	8	.650	.750
FLT011: Russian acoustic	1990	2009	2	7	.900	1.000

*** Shaded fleets/age groups are not used in AFWG current assessment.**

AFWG decided not to use survey data before 1990 and we follow this conclusion without further exploration. Compare to last AFWG haddock assessment in tuning data there are following differences:

- two fleets added: FLT011 and FLT007;
- for fleet FLT01 age group 8 is added.

Catch-at-age data

Catch-at-age data were also studied in order to check if more abundant year classes could be followed in this matrix (Table 7, Figure 7). There are reasonably good correlation found between catch-at-age data for consequent ages (Figure 7).

AFWG use in NEA haddock assessment data on Barents Sea cod consumption estimates. Numbers of haddock consumed by cod are included in catch-at-age matrix on XSA 1st run. After that estimated fishing mortality (Fs) are divided on "true" Fs and M (natural mortality). We try to check advantages of such an approach. Surveys are supposed reflect year-class strength for younger ages more accurate compare to catch data. So survey indexes should have higher correlation with catch-at-age matrix with cod consumption data included. It was confirmed by analysis for two surveys (Figure 8–11). Other surveys not studied but results expected to be the same. Inclusion of numbers of haddock consumed by cod allows to estimate abundance of haddock at age 1 and 2, and also it allows to use surveys at these ages in XSA tuning. So it was concluded to adopt AFWG practice to include cod consumption data in assessment.

XSA parameters

It was decided to keep default values for following parameters:

Regression type = C

Minimum of five points used for regression

Prior weighting not applied

Minimum standard error for population

estimates derived from each fleet = .300

Regarding last one it should be mentioned that it is particularly important to have such a limit now, when we include Ecosystem survey index, as it has extremely low error because of few points in time-series.

Possible alternative values for other parameters were studied.

Q parameters

Based on results of first exploratory run (run 1 in table below) it was found that there no reasons to assume q independent of age for any ages (Figure 12). The last age in surveys data is 8, so XSA parameter "**Catchability independent of age for ages >= 9**" was taken in final run.

	Surveys (ages)	1st age for q independent of stock size	1st age for q independent of age	P shrinkage ages	P shrinkage to	F shrinkage to	shrinkage s.e.	Time Weighting Power/years
AFWG-2010	FLT01 (1 and 3–7) FLT02 (1 and 3–7) FLT04 (1 and 3–8)	7	9	1(3)–6	final 5 years	final 5 years and 3 oldest ages	0.5	3/20
run 1	FLT01 (1–8) FLT02 (1–7) FLT04 (1–8) FLT007 (1–8) FLT011 (2–7)	9	9	1–8	final 5 years	final 5 years and 3 oldest ages	0.5	3/20
run 2	FLT01 (1–8) FLT02 (1–7) FLT04 (1–8) FLT007 (1–8)	9	9	1–8	final 5 years	final 5 years and 3 oldest ages	0.5	3/20
run 3	FLT01 (1–8) FLT02 (1–7) FLT04 (1–8) FLT007 (1–8)	9	9	No	No	final 5 years and 3 oldest ages	0.5	3/20
run 4	FLT01 (1–8) FLT02 (1–7) FLT04 (1–8) FLT007 (1–8)	9	9	1–8	final 5 years	final 5 years and 3 oldest ages	1.0 and 1.5	3/20
run 5	FLT01 (1–8) FLT02 (1–7) FLT04 (1–8) FLT007 (1–8)	9	9	1–8	final 3 years	final 3 years and 3 oldest ages	0.5	3/20

	Surveys (ages)	1st age for q independent of stock size	1st age for q independent of age	P shrinkage ages	P shrinkage to	F shrinkage to	Shrinkage s.e.	Time Weighting Power/years
run 6	FLT01 (1–8) FLT02 (1–7) FLT04 (1–8) FLT007 (1–8)	9	9	1–8	final 5 years	final 5 years and 3 oldest ages	0.5	3/10
run 7	FLT01 (1–8) FLT02 (1–7) FLT04 (1–8) FLT007 (1–8)	9	9	1–8	final 5 years	final 5 years and 3 oldest ages	1.5	3/10
Final run	FLT01 (1–8) FLT02 (1–7) FLT04 (1–8) FLT007 (1–8)	9	9	1–8	final 5 years	final 5 years and 3 oldest ages	1.5	3/20

XSA parameter "**Catchability independent of stock size**"

Based on analysis of relationship between survey indexes and catch-at-age data it was mentioned that power function is more suitable for most ages (Figure 13–15). Using linear relationship in XSA could lead to overestimation of more abundant year classes and underestimation of low abundant ones. So another q parameter could be set to **"Catchability independent of stock size ages <9"**.

Results of XSA diagnostic from first exploratory run (run 1) confirm this conclusion (Table 8).

Survey choice

First trial run (run 1) was done taking five chosen surveys into account. Two of them were not used in assessment previously: Joint ecosystem survey and Russian acoustic survey. All XSA parameters were close to last AFWG except **"Catchability independent of stock size ages"**.

In run 1 Log catchability residuals for all surveys were in general lower than in AFWG final run (Figures 16 and 17). On the other hand Russian acoustic survey (FLT011) residuals demonstrate strong year effect particularly in most recent years (Figure 16). Such a high year effect could be explained by changes of area coverage (ICES, 2011) what were not taking into account in survey index calculation. It was decided to exclude this survey from further analysis and study it again during the next benchmark after appropriate adjustment. Next XSA run (run2) without Fleet011 showed slightly lower residuals for all surveys, especially for Ecosystem survey and younger ages.

The differences of **run 2** compare to last AFWG final run are:

- Ecosystem survey added;
- ages 1 and 2 in all surveys are included in tuning;
- age 8 in Fleet01 is added in tuning;
- catchability of all surveys taken as depended of stock size for ages 7 and 8.

Nevertheless all these changes have a rather minor effect on results of assessment. SSB estimates very close in these two cases, while R at age 3 estimates 13% higher in run 2 compare to AFWG run (Figure 18).

Shrinkage

On the next step different options for XSA shrinkage parameters were studied. NEA haddock stock demonstrate a fast grow in most recent years. Fishing mortality is decreasing subsequently. In such a type of stock dynamic it is difficult to support using high weight (low assumed error) both for P and F shrinkage. P shrinkage weight is not regulated in XSA (it is proportional to inverse variance (s.e.) of population abundance in appropriate age). So it was tried not to use P shrinkage as far as different values of XSA parameter **"shrinkage s.e."**

In run 3 P shrinkage were not used, It cased visible increase at stock size (SSB increased on 8% in 2009, while R at age 3 increased on 27%). Retrospective run was visibly worse compare to AFWG-2010 final run (Figure 19).

Decrease of shrinkage weight by setting s.e.=1.0 (run 4) cased small increase in SSB and 10% increase in R at age 3 abundance in year 2009. The difference in previous years was negligible. Nevertheless results of retrospective run with XSA settings from run 4 were considerably different compare to AFWG 2010 final run. The SSB and F retro patterns improved for most recent years but deviations of estimates in historical period become much worse (Figure 20).

Further decrease of shrinkage weight by setting s.e.=1.5 cause similar but stronger effect (Figure 21).

In situation of rapid increase of stock abundance it is deemed to be reasonable to decrease numbers of years used in shrinkage. Run 5 was done to test this option. Decreasing of number of years to three demonstrate retro pattern for SSB and F similar but slightly worse compare to AFWG 2010 final run (Figure 22). Decreasing of number of last ages used in shrinkage from 3 to 2 caused similar effect.

It was concluded to keep these parameters of shrinkage the same as those used on AFWG-2010: **Survivor estimates shrunk towards the mean F of the final five years or the three oldest ages**.

Tapered time weighting

It have been tasted (run 6) to use shorter time window (ten years) which gave worse retro for SSB and F compare to AFWG (Figure 23). On the other hand combine effect of low shrinkage weight (s.e.=1.5) which improve retro pattern in most recent years and ten years window (run 7) allows to get improved retro pattern on all period of time (Figure 24). Nevertheless last variant make worse survey regression statistic (Figure 25). Survey estimates become less stable and this could create new retro problem in future.

Based on all exploratory runs a new set of XSA parameters were proposed (final run). It is still necessary to do further analysis and discourse retro problem in light of shrinkage and time window influence before final values for these parameters will be decided. If we will decide to keep shrinkage and time window parameters be the same as on last AFWG the final proposal for XSA parameter set will be those belong to run 2. Compare to AFWG 2010 such a run using new parameters gives rather minor changes in current stock status (Figure 18). R at age 3 estimates 13% higher, SSB close to AFWG final run.

References

ICES. 2011. Report of the Arctic Fisheries Working Group (AFWG), 22–28 April 2010, Lisbon, Portugal (WEBEX). ICES CM 2010/ACOM:05. 664 pp.

Table 1. Northeast Arctic haddock.

Russian trawl acoustic survey in the Barents Sea and adjacent waters in November–December.

Bottom-trawl index (numbers per hour trawling) - FLT01.

Year/age	0	1	2	3	4	5	6	7	8	9	10+
1983	29,8	59,2	9,5	0,5	0,4	0	0	0	0	0	0,8
1984	6,4	58,6	58,4	1,5	0,2	0,1	0	0	0	0	0,3
1985	3	14,4	134,3	90	0,4	0,1	0,1	0	0	0	0,2
1986	0,2	1,4	10,7	36,3	16,4	0,1	0	0	0	0	0
1987	0,3	0,9	1,7	8,3	22,5	5,7	0	0	0	0	0
1988	1,3	0,3	0,7	1,7	4	7,6	0,8	0	0	0	0
1989	2,2	1,8	2,4	0,4	1,4	4,1	8,1	1,1	0,1	0	0
1990	44,8	14,3	10,6	7,3	4,2	7,3	7,4	5,7	0,3	0,1	0
1991	16,7	42,9	17,6	6,2	0,9	0,3	0,6	1,8	1,5	0,2	0
1992	16,4	28,2	128,6	34,6	5	0,4	0,6	0,9	0,8	0,1	0
1993	3,5	4,8	35,7	198,5	35,6	4,8	0,8	0,4	0,4	0	0
1994	9,1	4,9	5,8	44,2	101,4	11,6	1,5	0,1	0,1	0,5	0
1995	6,4	7,2	4,2	3,1	12,3	37	4	0,5	0,1	0,3	0
1996	6	2,3	5,7	2,8	4,9	36,2	33,4	2,9	0,3	0,3	0
1997	1,8	4,6	1,9	3,2	3,2	1	2,7	1	0,8	0	0
1998	10,7	2,9	11,5	3,8	4,6	0,8	0,5	1,5	0,5	0	0
1999	11,7	28,9	6,1	19,6	3,9	3,7	0,8	0,3	0,7	0,7	0
2000	15,1	20,7	26,2	6	10,9	2,6	1,1	0,2	0,1	0,4	0
2001	20,8	14,9	26,1	33,4	4	6,5	1,1	0,4	0,1	0,3	0
2002	33,2	19,3	18,9	39,9	45	4,7	2,4	0,4	0,1	0,2	0
2003	19,8	32,8	25,1	22,1	29,9	23,1	3,4	1,6	0,2	0,1	0
2004	50	11	20,6	11,3	9,4	10,7	8,7	0,5	0,4	0,2	0
2005	62	79,2	13,6	24	8,6	4,8	5,7	2,4	0,1	0,2	0
2006	53,4	79,2	122,7	11,3	11,9	5,7	2,6	2,4	1,1	0,2	0
2007	6,5	83,9	214,2	83,8	7,3	13,7	3,8	1,4	1,1	0,4	0
2008	5,7	12,7	232,7	255,7	105,1	12,4	11,1	1,7	0,7	0,4	0
2009	10	2,9	15,8	164,7	170,4	63,1	5,7	3,2	0,5	0,4	0

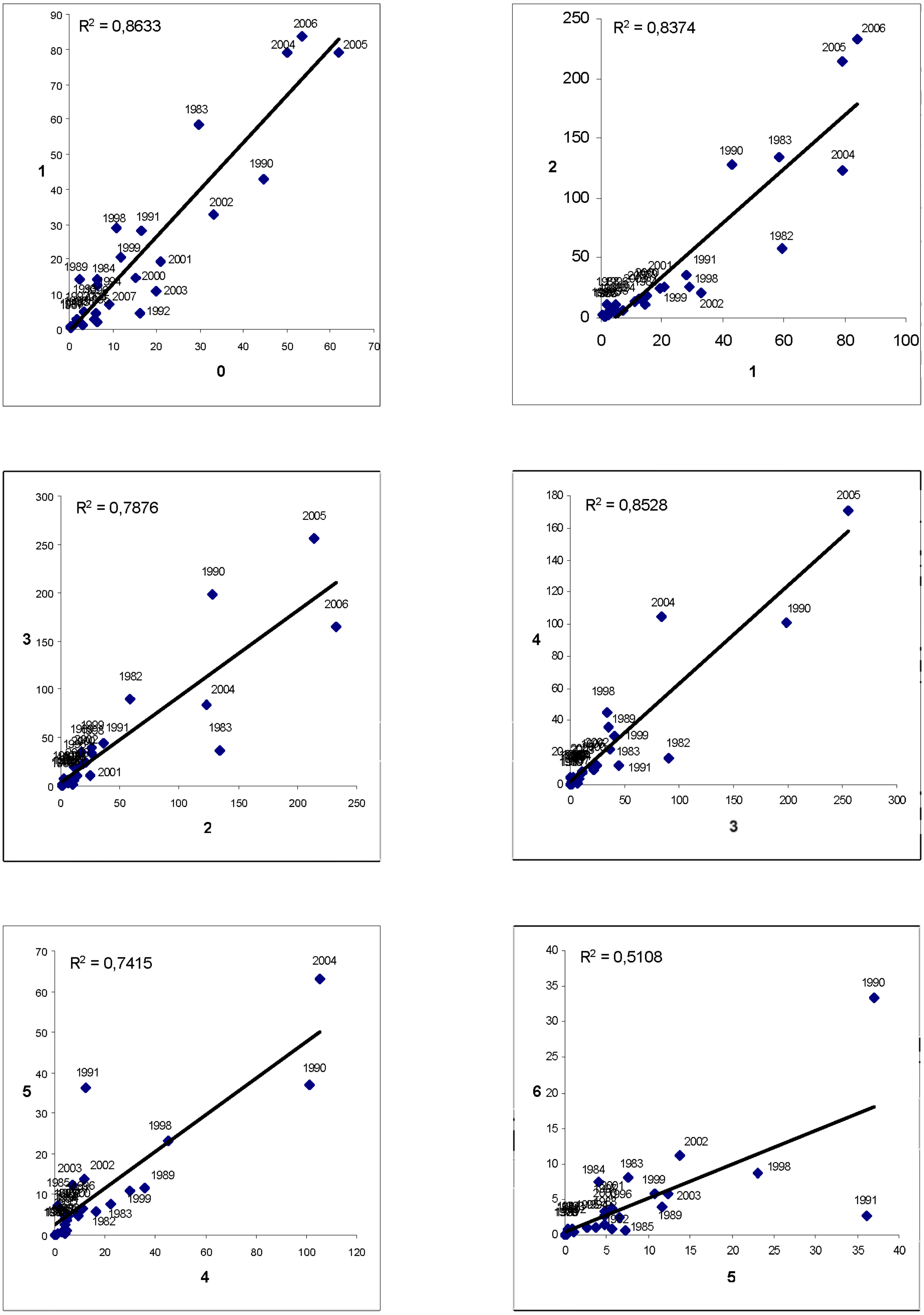


Figure 1. Relationship between year-class strength estimates for consequent age groups in Russian bottom-trawl acoustic survey (XSA Fleet01). Points are marked by year class/generation.

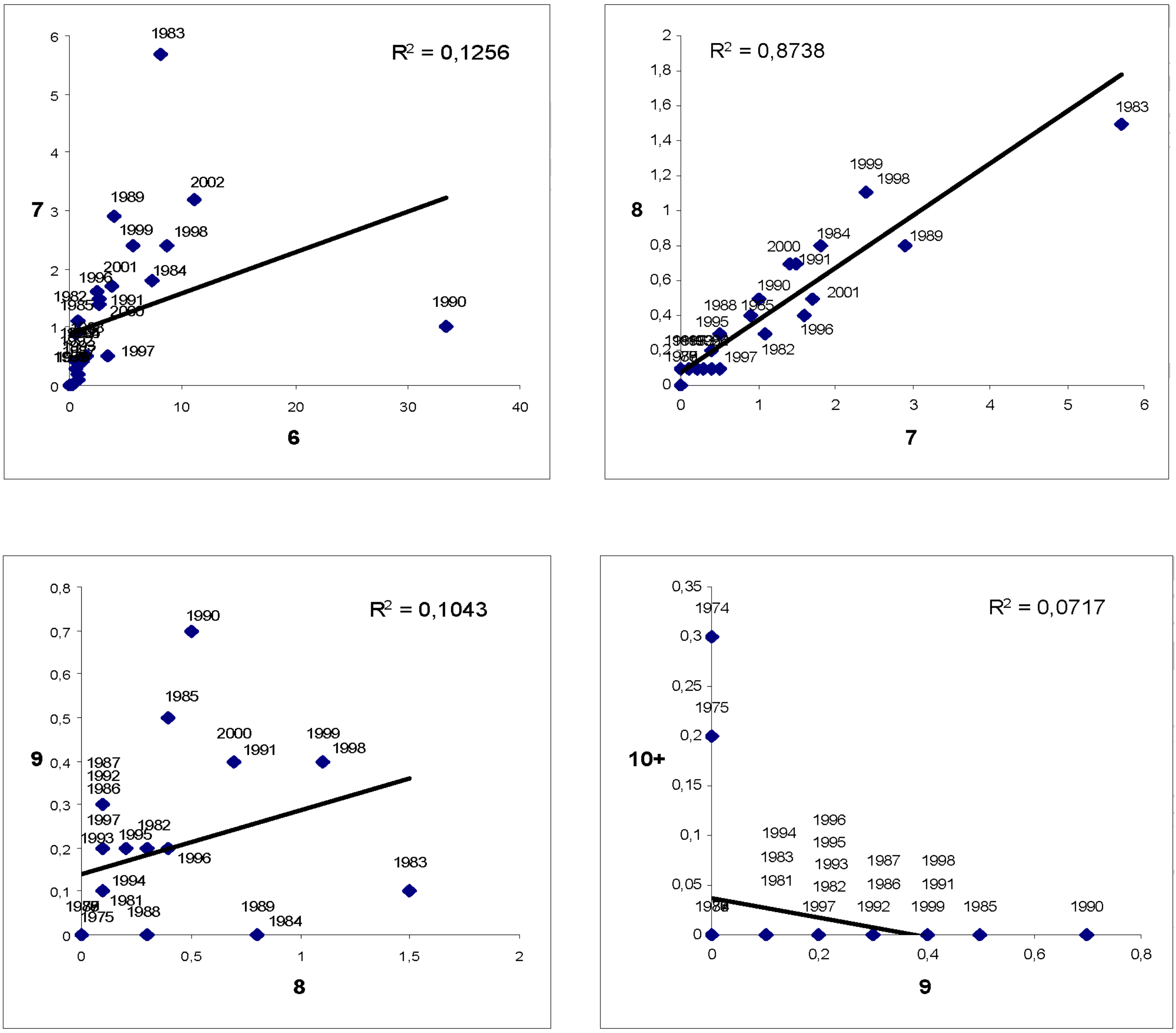


Figure 1. (Continued). Relationship between year-class strength estimates for consequent age groups in Russian bottom-trawl acoustic survey (XSA Fleet01). Points are marked by year class/generation.

Table 2. Northeast Arctic haddock.

Norwegian/Joint trawl acoustic surveys in the Barents Sea in January–March.

Acoustic index - FLT02 (stock numbers in millions).

Year	1	2	3	4	5	6	7	8	9	10
1981	7	14	5	21	60	18	1	0	0	0
1982	9	2	3	4	4	10	6	0	0	0
1983	0	5	2	3	1	1	4	2	0	0
1984	1685	173	6	2	1	0	0	0	0	0
1985	1530	776	215	5	0	0	0	0	0	0
1986	556	266	452	189	0	0	0	0	0	0
1987	85	17	49	171	50	0	0	0	0	0
1988	18	4	8	23	46	7	0	0	0	0
1989	52	5	6	11	20	21	2	0	0	0
1990	270	35	3	3	4	7	11	2	0	0
1991	1890	252	45	8	3	3	3	6	0	0
1992	1135	868	134	23	2	0	0	1	2	0
1993	947	626	563	130	13	0	0	0	0	3
1994	562	193	255	631	111	12	0	0	0	0
1995	1379	285	36	111	387	42	2	0	0	0
1996	249	229	44	31	76	151	8	0	0	0
1997	693	24	51	17	12	43	43	2	0	0
1998	220	122	20	28	12	5	13	16	1	0
1999	856	46	57	13	14	4	1	2	2	0
2000	1024	509	32	65	19	11	2	1	2	0
2001	976	316	210	23	22	1	1	0	0	1
2002	2062	282	216	149	14	12	1	0	0	1
2003	2394	279	145	198	169	17	5	0	0	1
2004	752	474	127	76	76	66	7	2	0	0
2005	3364	209	219	102	36	40	9	0	0	0
2006	2767	804	54	86	30	12	9	2	0	0
2007	3197	868	379	54	88	22	6	5	2	0
2008	1266,6	1835	723	252	57	74	10	6	0	1
2009	849	246,3	1021,7	773	402,1	31,3	14,9	1,6	0,13	0,53
2010	2035,8	81,8	138	593	557,4	191,4	10,3	2,9	0,68	0,72

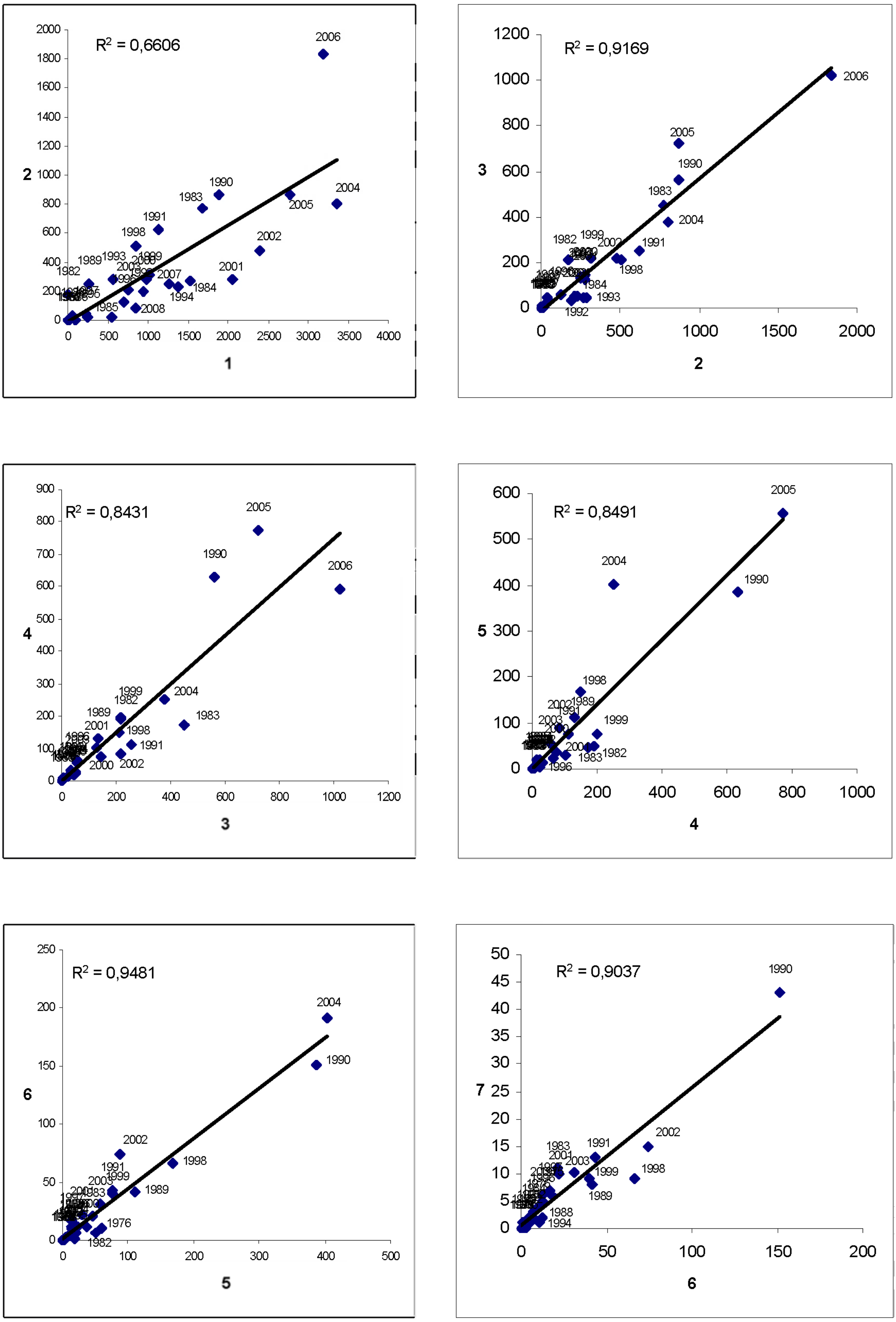


Figure 2. Relationship between year-class strength estimates for consequent age groups in Norwegian/Joint trawl acoustic surveys in the Barents Sea in January–March (XSA FLT02: acoustic index). Points are marked by year class/generation.

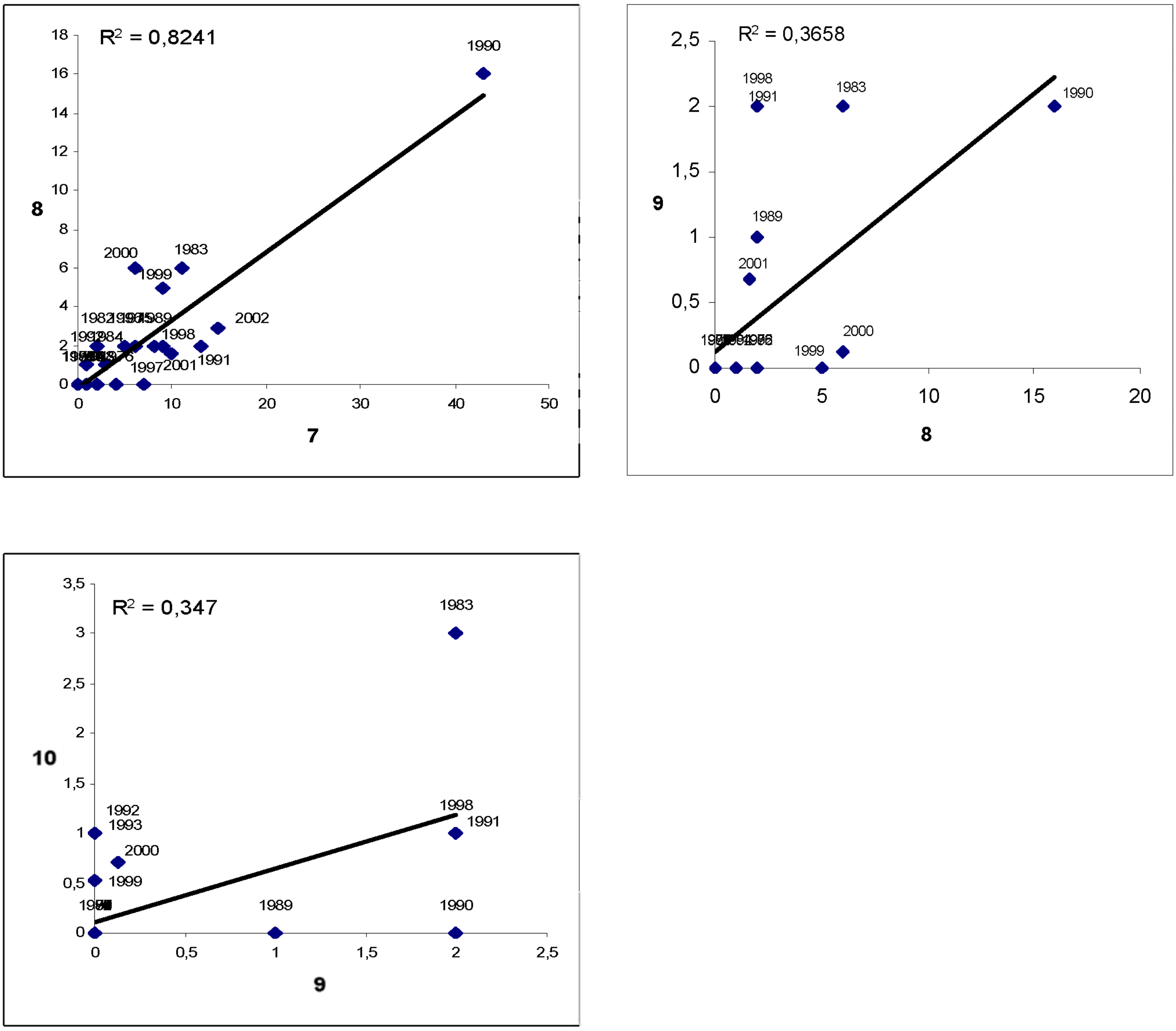


Figure 2. (Continued). Relationship between year-class strength estimates for consequent age groups in Norwegian/Joint trawl acoustic surveys in the Barents Sea in January–March (XSA FLT02: acoustic index). Points are marked by year class/generation.

Table 3. Northeast Arctic haddock.

Norwegian/Joint trawl acoustic surveys in the Barents Sea in January–March.

Bottom trawl index - FLT04.

Year	1	2	3	4	5	6	7	8	9	10+
1981	3,1	7,3	2,3	7,8	1,8	5,3	0,5	0,2	0	0
1982	3,9	1,5	1,7	1,8	1,9	4,8	2,4	0,2	0	0
1983	2919,3	4,8	3,1	2,4	0,9	1,9	2,5	0,7	0	0
1984	3832,6	514,6	18,9	1,5	0,8	0,2	0,1	0,4	0,1	0
1985	1901,1	1593,8	475,9	14,7	0,5	0,5	0,1	0,1	0,4	0,3
1986	665	370,3	384,6	110,8	0,6	0,2	0,1	0,1	0,1	0,1
1987	163,8	79,9	154,4	290,2	52,9	0	0	0	0	0,3
1988	35,4	15,3	25,3	68,9	116,4	13,8	0,1	0	0	0
1989	81,2	9,5	14,1	21,6	34	32,7	3,4	0,1	0	0
1990	644,1	54,6	4,5	3,4	5	9,2	11,8	1,8	0	0
1991	2006	300,3	33,4	5,1	4,2	2,7	1,7	4,2	0	0
1992	1659,4	1375,5	150,5	24,4	2,1	0,6	0,7	1,6	2,3	0
1993	727,9	599	507,7	105,6	10,5	0,6	0,4	0,3	0,4	1,1
1994	603,2	228	339,5	436,6	49,7	3,4	0,2	0,1	0,2	0,6
1995	1463,6	179,3	53,6	171,1	339,5	34,5	2,8	0	0,1	0
1996	309,5	263,6	52,5	48,1	148,6	252,8	11,6	0,9	0	0,1
1997	1268	67,9	86,1	28	19,4	46,7	62,2	3,5	0,1	0
1998	212,9	137,9	22,7	33,2	13,2	3,4	8	8,1	0,7	0,1
1999	1244,9	57,6	59,8	12,2	10,2	2,8	1	1,7	1,1	0
2000	847,2	452,2	27,2	35,4	8,4	4	0,8	0,3	0,7	0,2
2001	1220,5	460,3	296	29,3	25,1	1,7	0,9	0,1	0,1	0,3
2002	1680,3	534,7	314,7	185,3	17,6	8,2	0,8	0,3	0	0,3
2003	3332,1	513,1	317,4	182	73,6	5,5	2,3	0,2	0,1	0,2
2004	715,9	711,2	188,1	102,7	80,4	46,2	5,9	1,1	0,2	0,1
2005	4630,2	420,4	346,5	133,3	66,8	52,2	12,3	0,6	0,2	0
2006	5141,3	1313,1	77,4	140,5	48,2	19,6	15,2	3,1	0,1	0,3
2007	3874,4	1593,8	507,7	66	86	23,3	7,5	3,7	1,4	0,2
2008	860,2	2129,4	1522,4	600,9	86,8	48,9	6,27	2,51	0,82	0,13
2009	564,7	328	1270,4	773,2	365,4	38,5	10,6	1,4	0,1	0,3
2010	1619,5	111,2	102,8	508,6	479,6	131,2	7	1	0,6	0,6

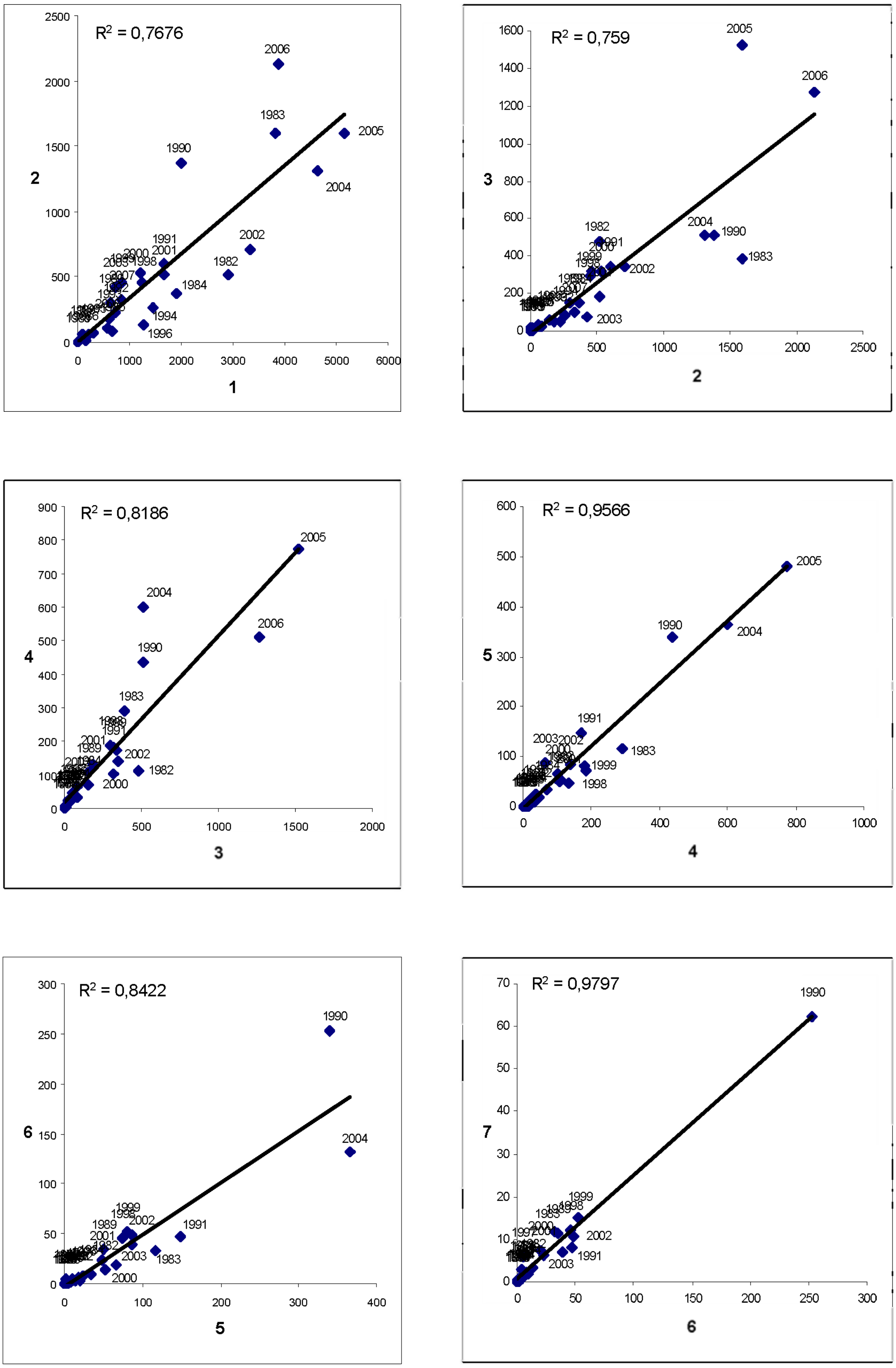


Figure 3. Relationship between year-class strength estimates for consequent age groups in Norwegian/Joint trawl acoustic surveys in the Barents Sea in January–March (XSA FLT04: bottom trawl index). Points are marked by year class/generation.

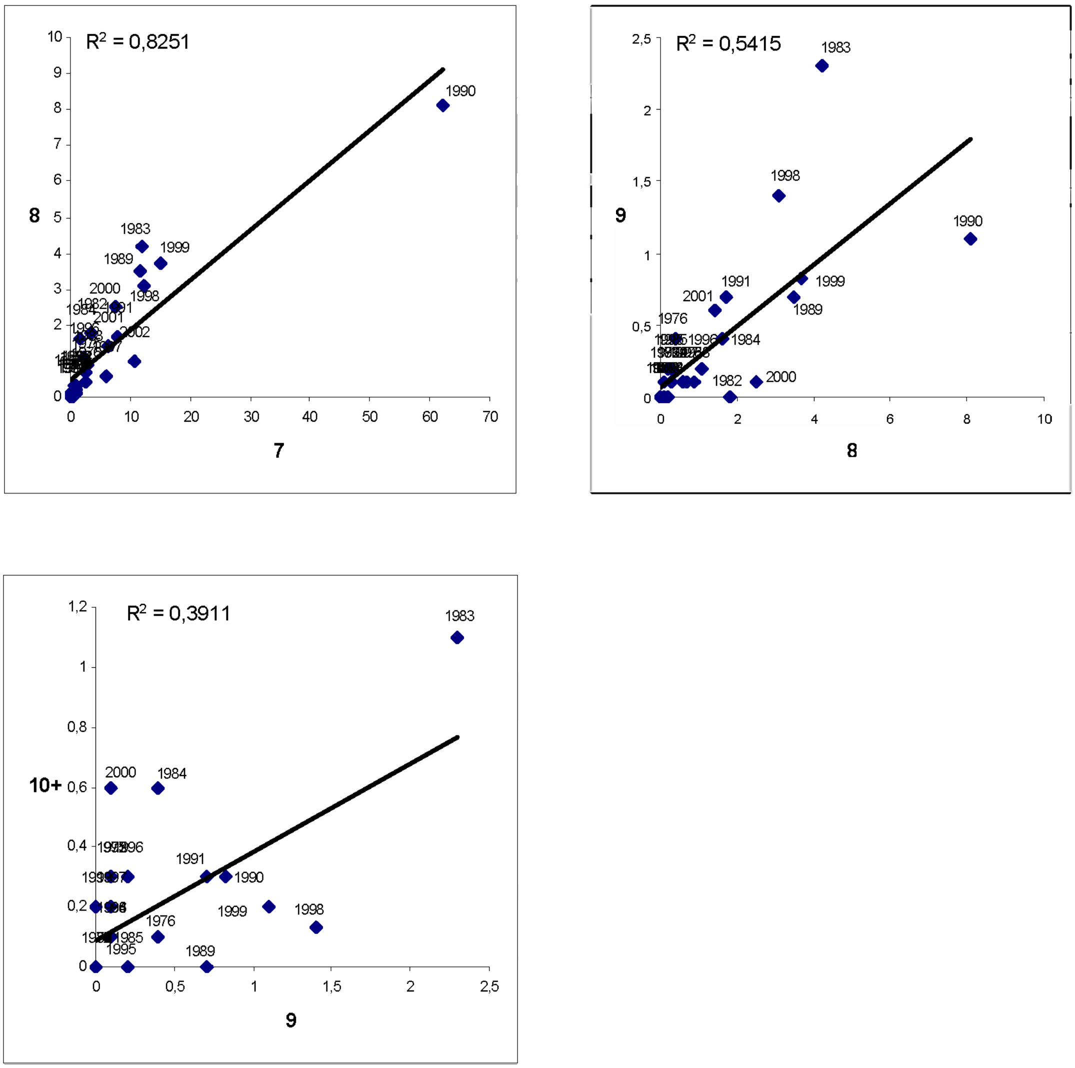


Figure 3. (Continued). Relationship between year-class strength estimates for consequent age groups in Norwegian/Joint trawl acoustic surveys in the Barents Sea in January–March (XSA FLT04: bottom trawl index). Points are marked by year class/generation.

Table 4. Northeast Arctic haddock.

Joint Ecosystem survey of the Barents Sea in August–September.

Bottom-trawl index - FLT007.

Year	1	2	3	4	5	6	7	8
2004	189	269	123	70	69	31	3	2
2005	627	114	323	89	29	31	15	0
2006	2152	1068	151	143	43	18	16	6
2007	995	1827	1287	89	94	19	6	7
2008	322	1293	1155	406	43	36	5	3
2009	136	143	649	617	306	21	7	1

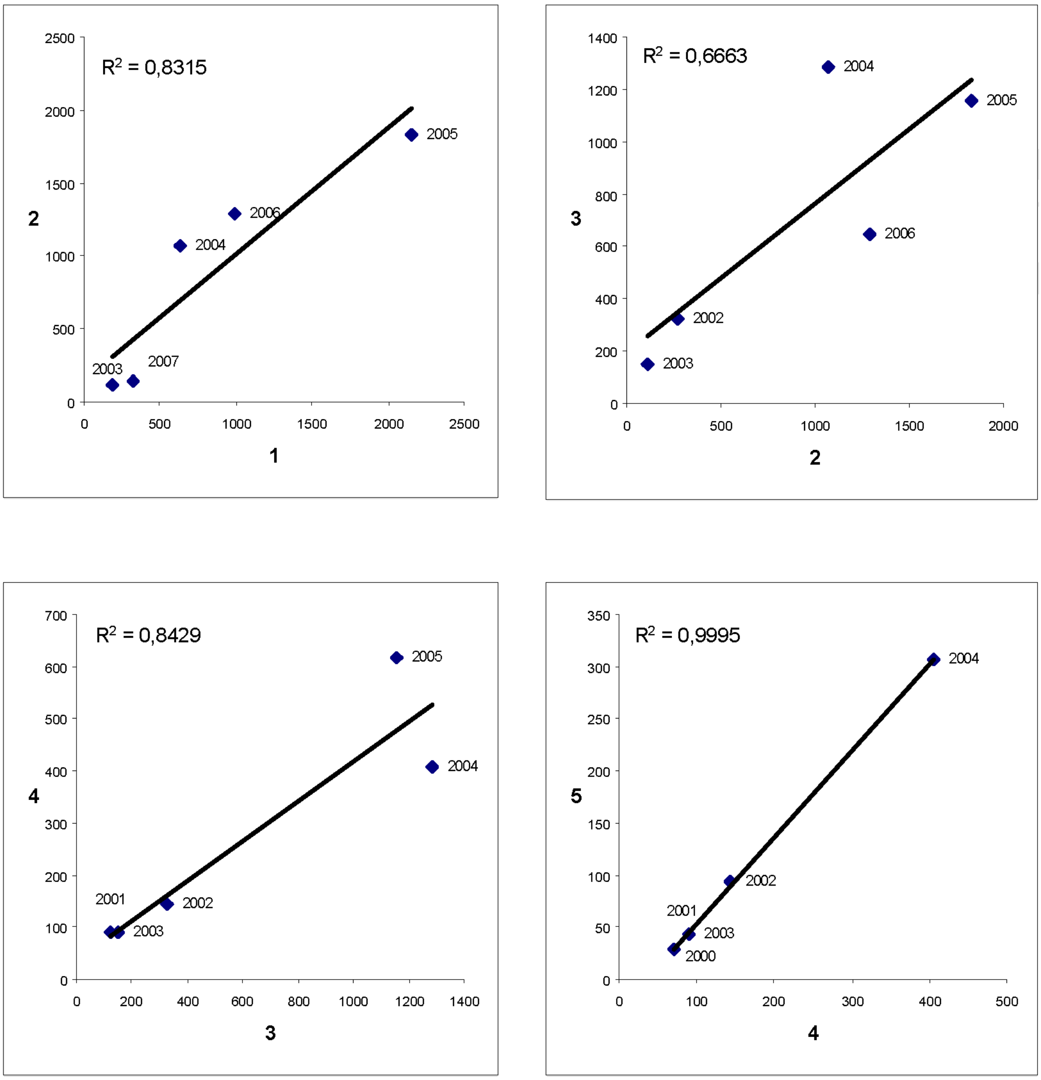
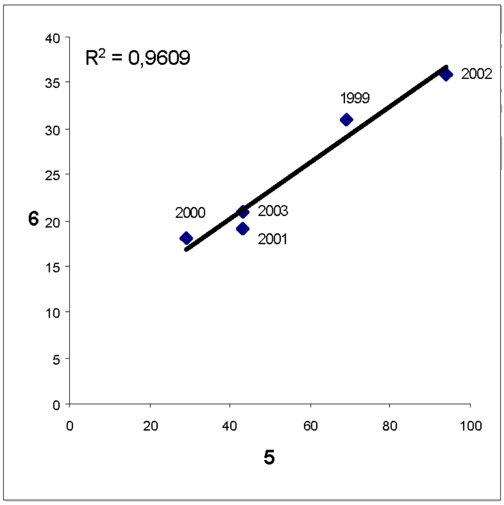
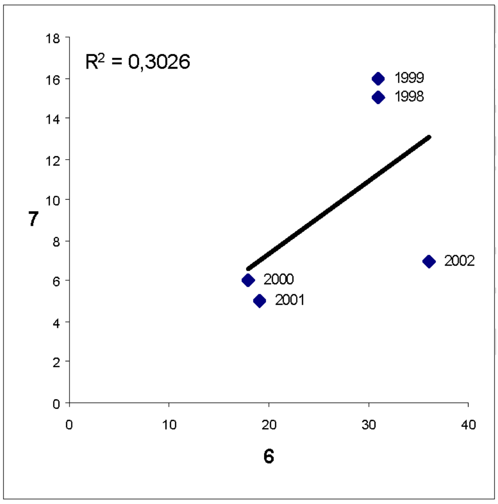


Figure 4. Relationship between year-class strength estimates for consequent age groups in Joint Ecosystem survey. (XSA FLT007: bottom-trawl index). Points are marked by year class/generation.





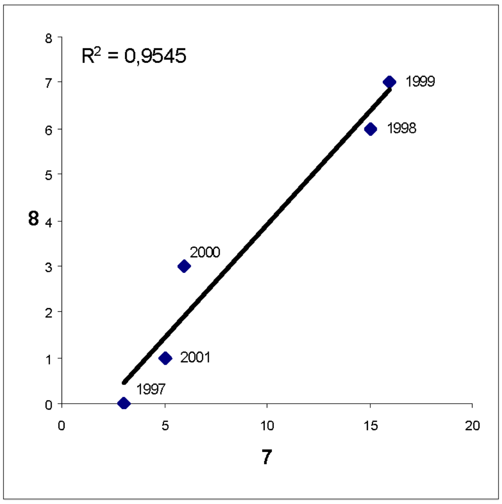


Figure 4. (Continued). Relationship between year-class strength estimates for consequent age groups in Joint Ecosystem survey. (XSA FLT007: bottom-trawl index). Points are marked by year class/generation.

Table 5. Northeast Arctic haddock.

Russian trawl acoustic survey in the Barents Sea and adjacent waters in November–December.

Acoustic index - FLT011 (new method).

Year	0	1	2	3	4	5	6	7	8	9	10+
1995	163	170	79	71	230	404	41	5	1	1	2
1996	992	245	291	91	63	206	187	17	1	0	0
1997	185	104	21	121	94	48	47	31	20	0	0
1998	257	44	83	20	20	6	2	7	2	0	0
1999	632	499	60	123	14	16	4	1	4	1	0
2000	524	395	287	54	57	14	6	1	1	1	1
2001	491	160	227	221	19	35	5	2	1	1	1
2002	1045	209	139	268	239	27	17	2	1	0	1
2003	1168	473	217	116	134	94	14	6	1	0	0
2004	8529	1141	342	116	54	55	44	3	4	1	1
2005	17782	2903	123	205	62	33	38	16	1	1	0
2006	9396	1286	308	30	31	10	0	5	5	4	1
2007	812	1473	2226	745	53	75	22	8	7	2	1
2008	245	203	2134	1947	728	88	83	13	6	4	2
2009	1650	204	243	1455	1258	485	46	30	4	2	1

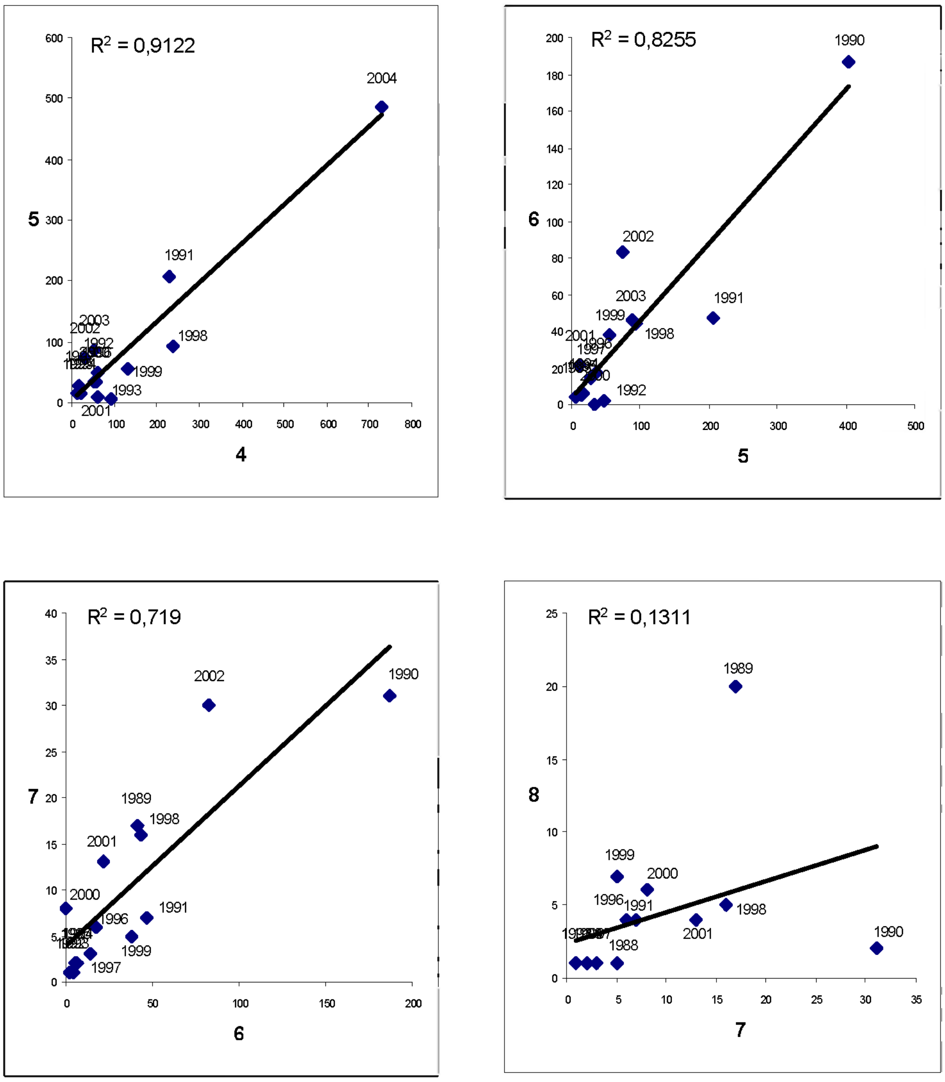


Figure 5. Relationship between year-class strength estimates for consequent age groups in Russian bottom-trawl acoustic survey (Acoustic index "new method" - XSA Fleet011). Points are marked by year class/generation.

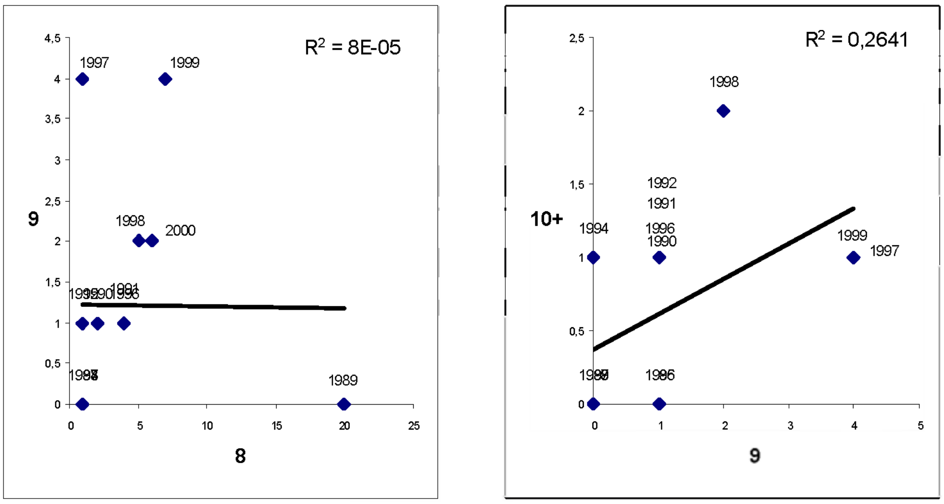


Figure 5. (Continued). Relationship between year-class strength estimates for consequent age groups in Russian bottom-trawl acoustic survey (Acoustic index "new method" - XSA Fleet011). Points are marked by year class/generation.

Table 6. Northeast Arctic haddock.

Russian trawl acoustic survey in the Barents Sea and adjacent waters in November–December.

Acoustic index (old method).

Year	0	1	2	3	4	5	6	7	8	9+
1985	194	434	1468	636	3	1	0	0	0	1
1986	34	37	208	917	910	2	0	0	0	0
1987	6	16	29	62	197	61	0	0	0	12
1988	2	1	3	18	83	301	46	0	0	0
1989	41	32	94	2	14	35	67	9	1	0
1990	594	176	75	28	17	23	43	44	4	1
1991	240	368	143	65	11	4	7	21	17	2
1992	199	245	758	218	35	3	4	7	6	0
1993	20	26	199	1076	228	31	5	2	3	5
1994	118	51	39	252	591	76	9	0	1	4
1995	38	40	18	18	77	225	23	3	1	1
1996	281	44	148	93	69	280	242	19	3	2
1997	70	138	41	207	82	48	41	25	20	0
1998	107	27	82	22	25	7	3	9	3	0
1999	222	330	43	129	25	29	7	3	7	2
000	246	292	238	49	86	23	9	2	1	4
2001	256	122	200	229	24	45	7	3	1	2
2002	868	811	581	447	237	329	49	20	12	10
2003	352	310	189	124	161	124	19	9	1	1
2004	3164	472	421	176	143	154	151	10	21	5
2005	7156	2521	271	476	172	114	154	79	5	7
2006	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0
2008	106	172	1960	1911	783	99	96	15	7	5
2009	302	28	126	943	1050	445	40	20	3	2

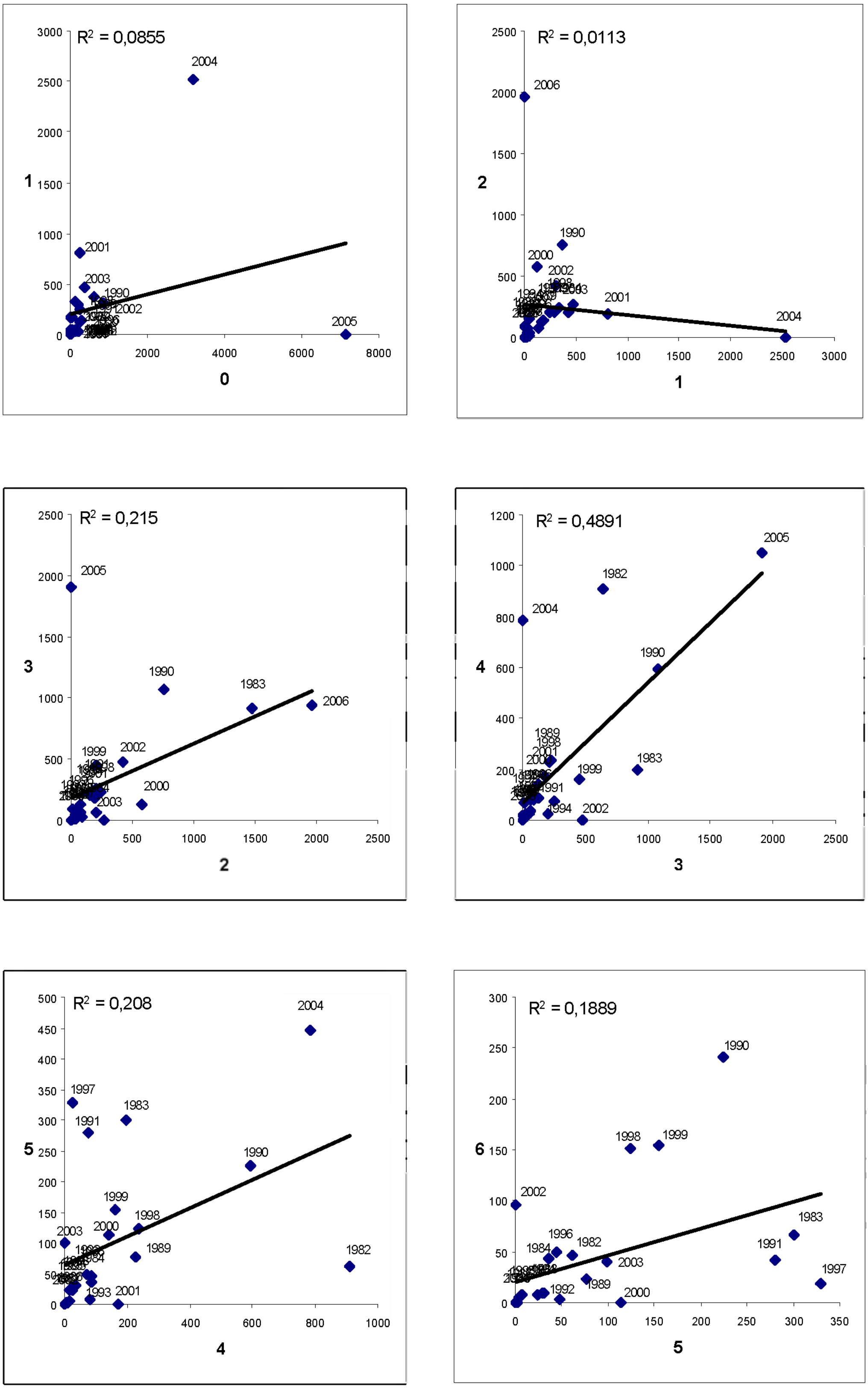


Figure 6. Relationship between year-class strength estimates for consequent age groups in Russian bottom-trawl acoustic survey (Acoustic index "old method"). Points are marked by year class/generation.

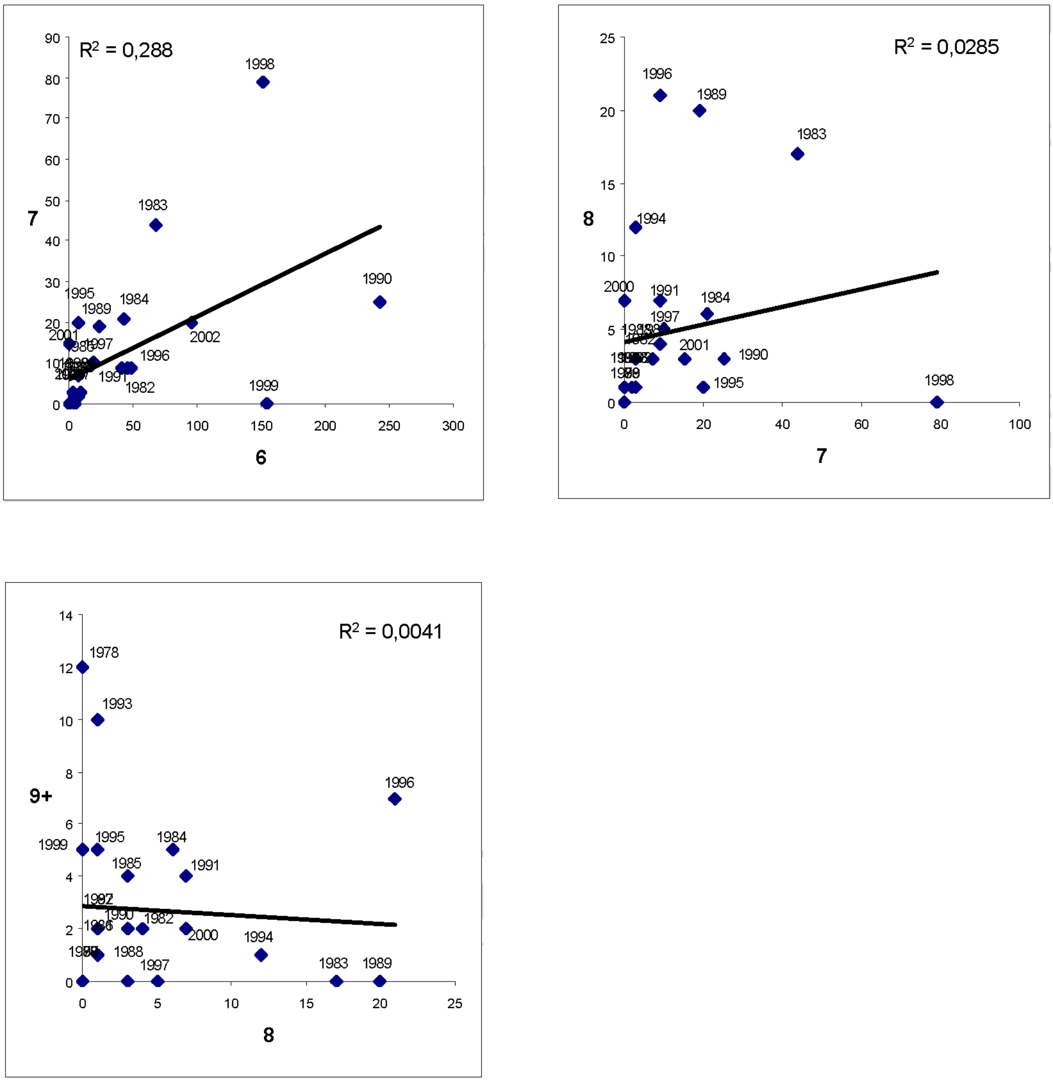


Figure 6. (Continued). Relationship between year-class strength estimates for consequent age groups in Russian bottom-trawl acoustic survey (Acoustic index "old method"). Points are marked by year class/generation.

Table 7. Northeast Arctic haddock.

Catch-at-age data together with cod consumption estimates (AFWG XSA 1st run file "canump").

Year	1	2	3	4	5	6	7	8	9	10	11
1984	980 752	15 442	1347	1019	1899	657	950	2619	352	87	77
1985	1 206 223	8120	29 624	1695	564	1009	943	886	1763	588	281
1986	566 946	245 619	191 206	68 429	1565	783	896	393	702	1144	987
1987	768 414	83	5031	87 170	64 556	960	597	376	212	230	738
1988	17 169	647	10 583	12 478	48 115	20 429	397	178	74	88	446
1989	231 357	221	2157	4986	16 071	25 313	3198	147	1	28	177
1990	144 024	38 341	4681	2580	2142	4046	6221	840	134	42	71
1991	457 829	14 762	4421	3564	2416	3299	4633	3953	461	83	54
1992	2 112 408	153 992	12 656	11 567	4099	2642	2894	3327	3498	486	84
1993	1 377 069	165 972	50 334	22 877	16 601	4103	1747	1886	2105	1965	323
1994	1 412 856	80 830	28 338	55 501	37 258	13 275	2057	903	1453	2769	2110
1995	2 900 754	163 748	13 965	45 871	102 528	19 485	6417	746	361	770	1576
1996	1 594 130	161 838	41 830	12 277	39 112	77 024	13 426	2944	573	365	1897
1997	906 606	35 582	27 756	7361	13 386	33 361	49 478	5636	778	245	748
1998	1 535 302	29 724	3673	14 210	9763	8633	13 801	19 469	2113	330	490
1999	898 259	23 922	17 166	8039	15 365	6073	4466	6355	6204	647	446
2000	1 216 456	65 713	3611	31 131	6683	5228	2406	1657	1570	1744	437
2001	553 375	54 368	17 891	5308	32 049	5279	2941	1137	1161	1169	1204
2002	2 377 170	229 664	45 157	48 757	11 478	22 165	2602	1602	482	448	1029
2003	3 616 232	220 097	45 633	43 776	57 633	11 736	14 541	1637	2178	858	1219
2004	2 299 635	300 487	51 411	30 036	43 763	41 226	4939	4914	598	1252	901
2005	5 856 774	266 315	78 759	31 292	26 391	38 271	24 461	2393	2997	990	1524
2006	8 012 771	338 268	7828	39 438	28 802	15 547	16 023	8567	1259	1298	718
2007	8 917 615	565 692	52 745	17 620	48 644	18 860	10 642	7889	2570	678	988
2008	1 118 533	927 748	190 027	67 686	27 522	34 259	9145	4520	2846	1181	654
2009	1 296 085	202 534	206 922	94 104	69 557	15 390	15 382	3800	1669	887	960

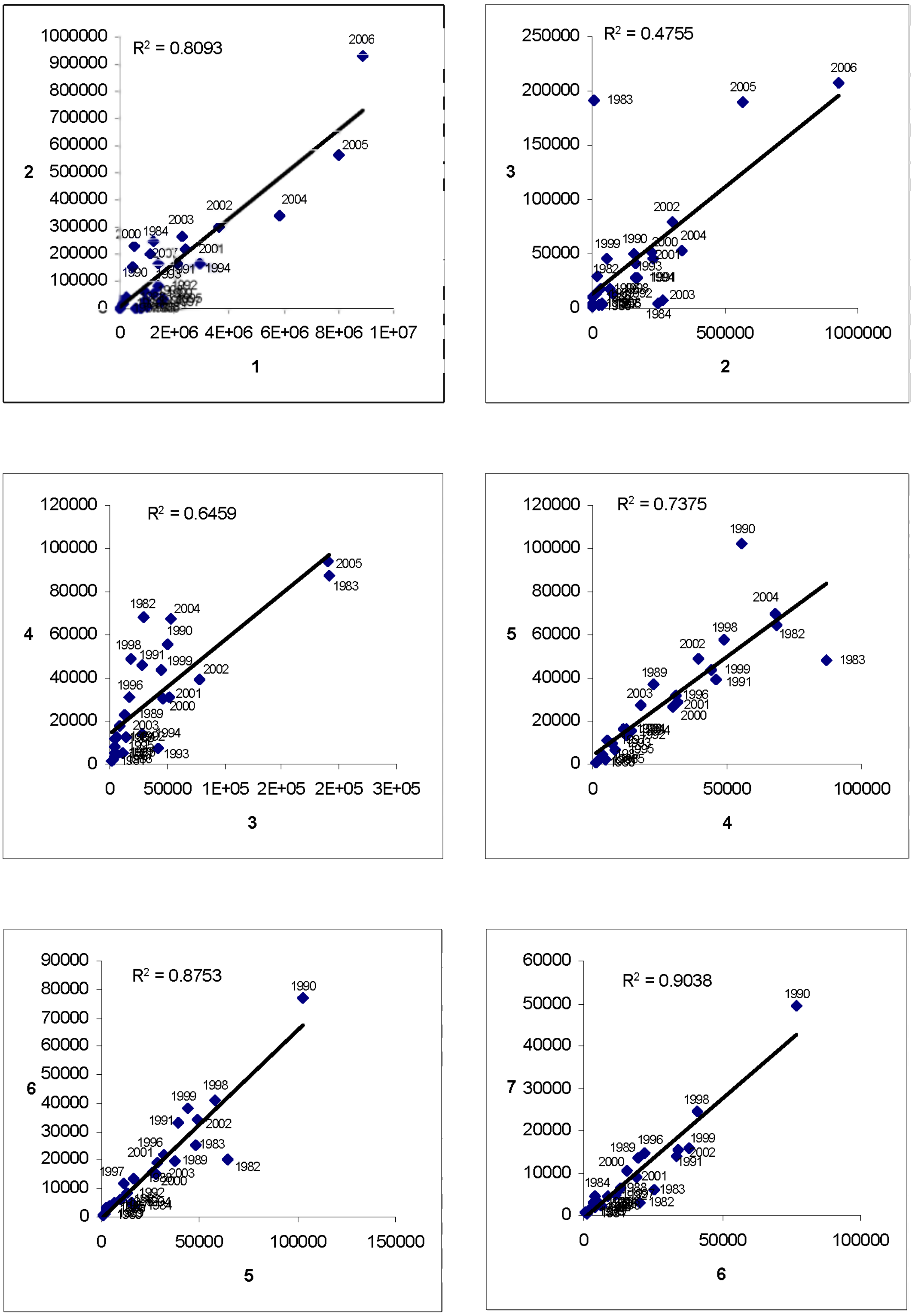


Figure 7. Relationship between year-class strength estimates for consequent age groups in catch-at-age data together with cod consumption estimates (XSA file canump). Points are marked by year class/generation.

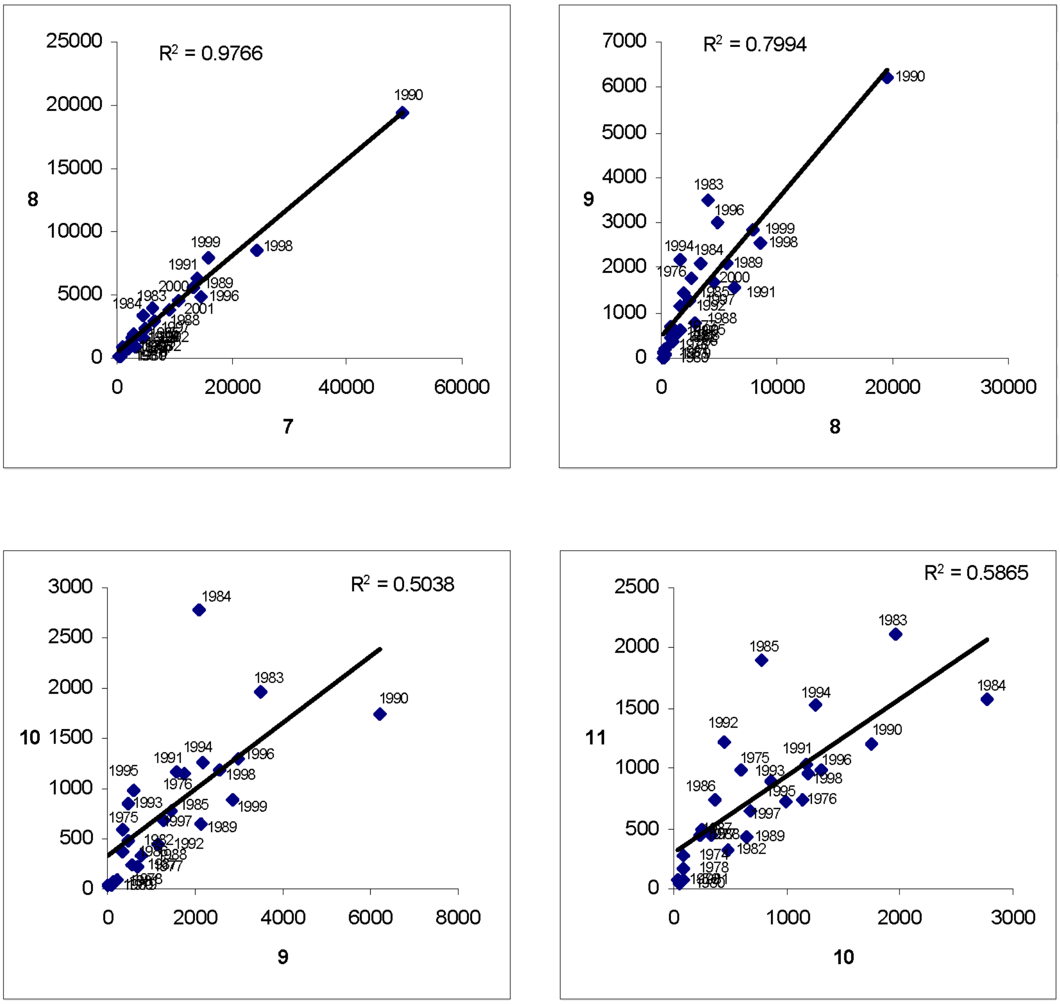


Figure 7. (Continued). Relationship between year-class strength estimates for consequent age groups in catch-at-age data together with cod consumption estimates (XSA file canump). Points are marked by year class/generation.

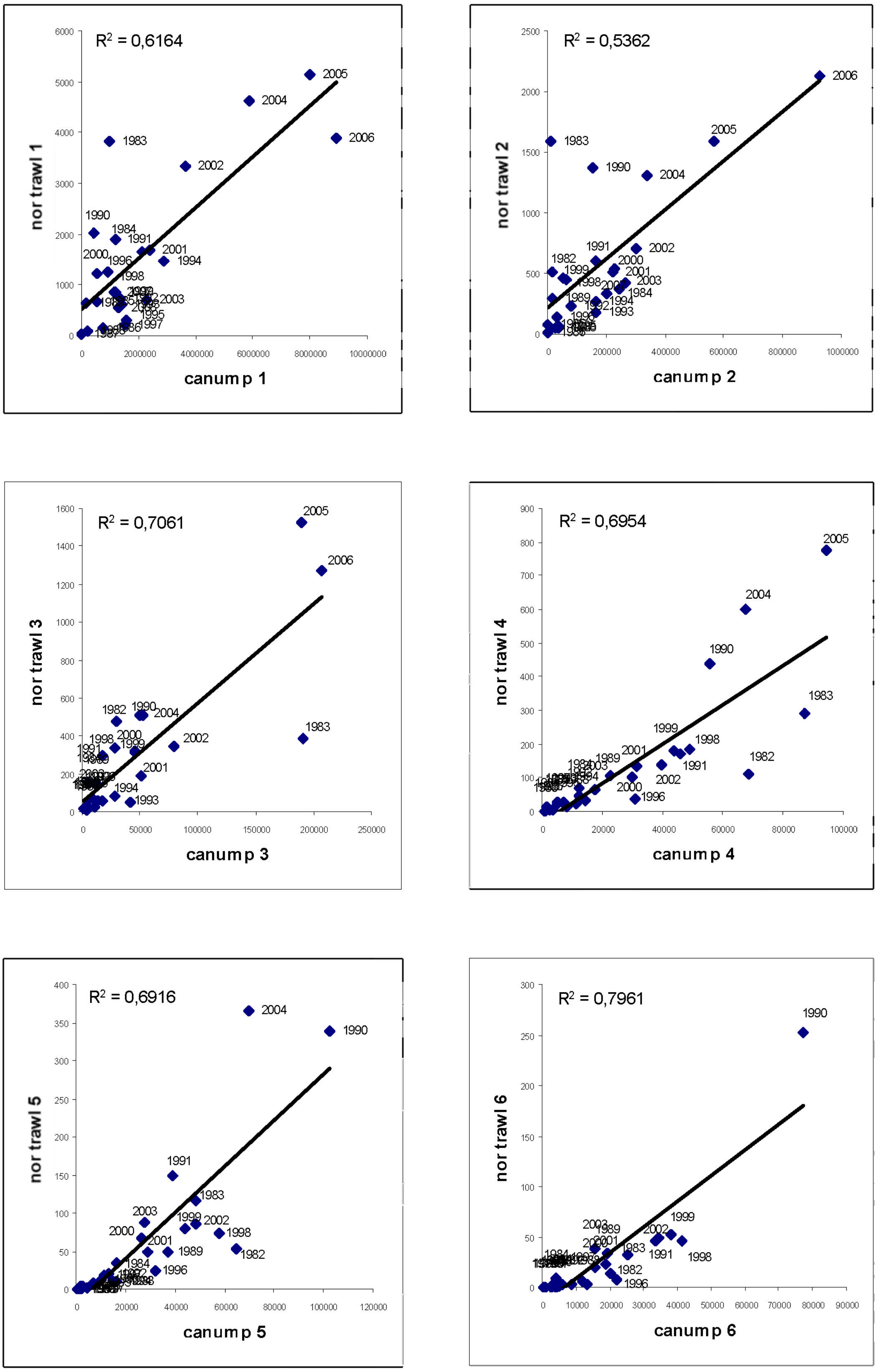


Figure 8. Relationship between year-class strength estimates by catch-at-age data (cod consumption included) and Norwegian/Joint trawl acoustic survey (bottom-trawl index – Fleet04). Points are marked by year class/generation.

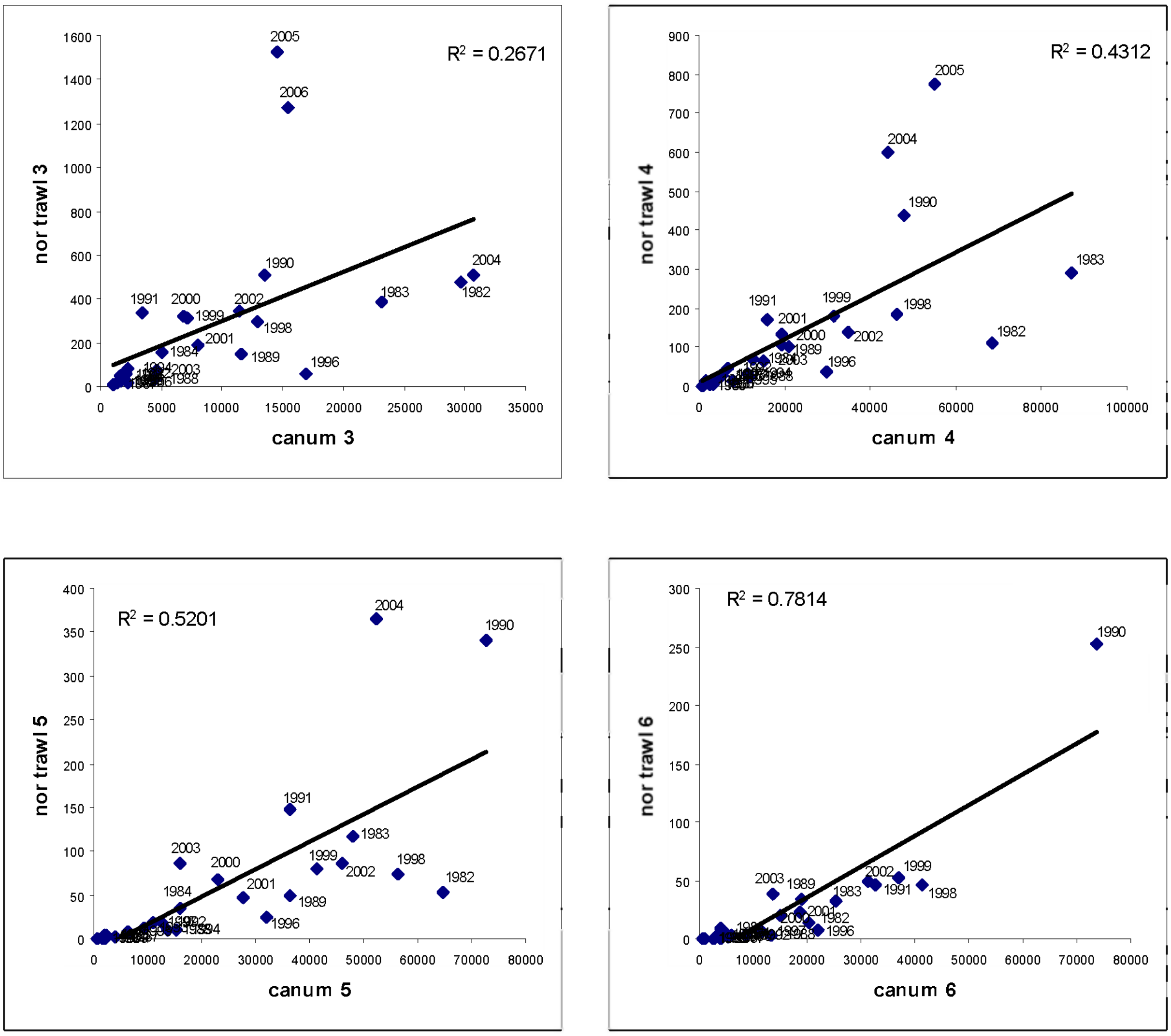


Figure 9. Relationship between year-class strength estimates by catch-at-age data (cod consumption NOT included) and Norwegian/Joint trawl acoustic survey (bottom-trawl index – Fleet04). Points are marked by year class/generation.

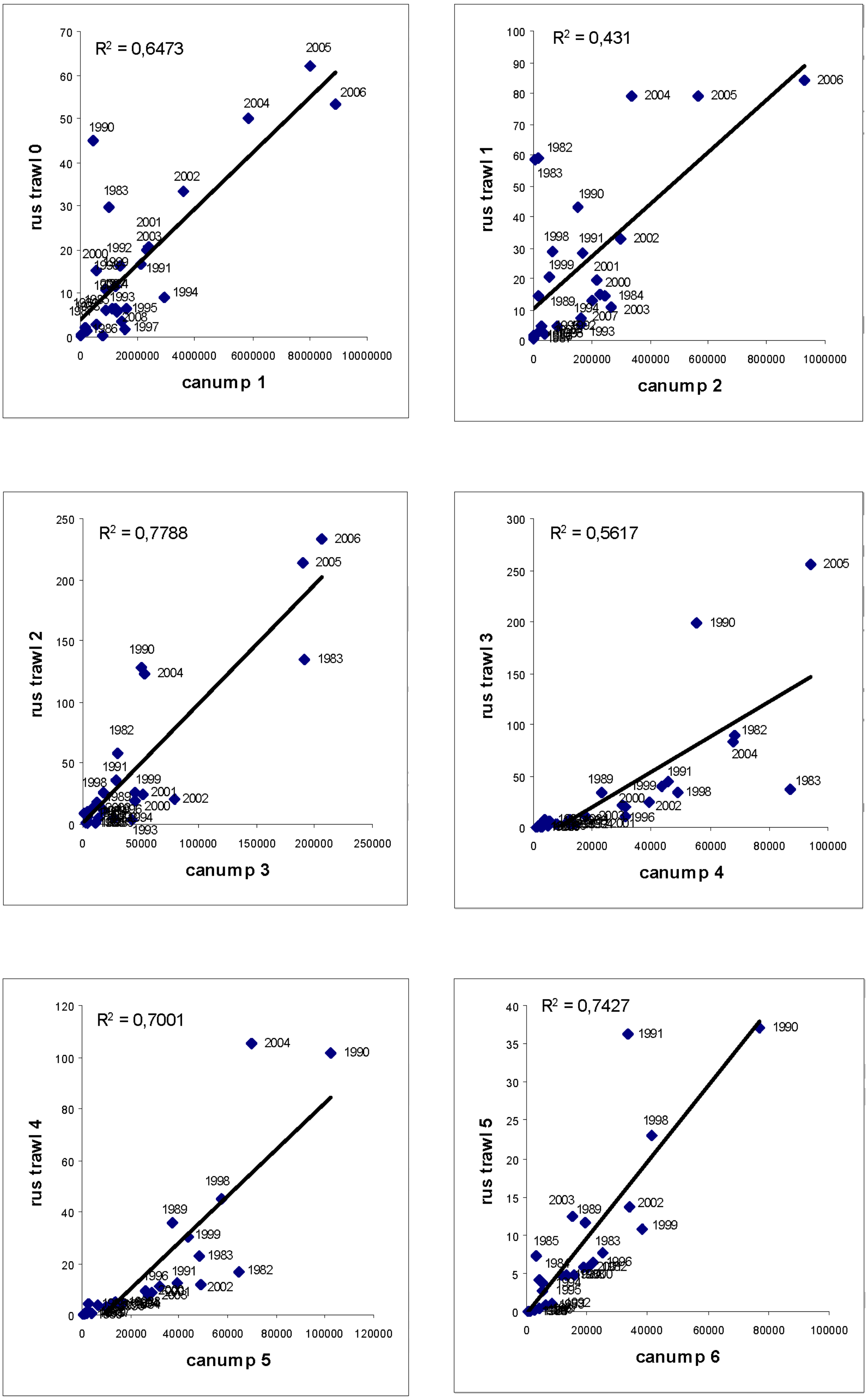


Figure 10. Relationship between year-class strength estimates by catch-at-age data (cod consumption included) and Russian trawl acoustic survey (bottom-trawl index – Fleet01). Points are marked by year class/generation.

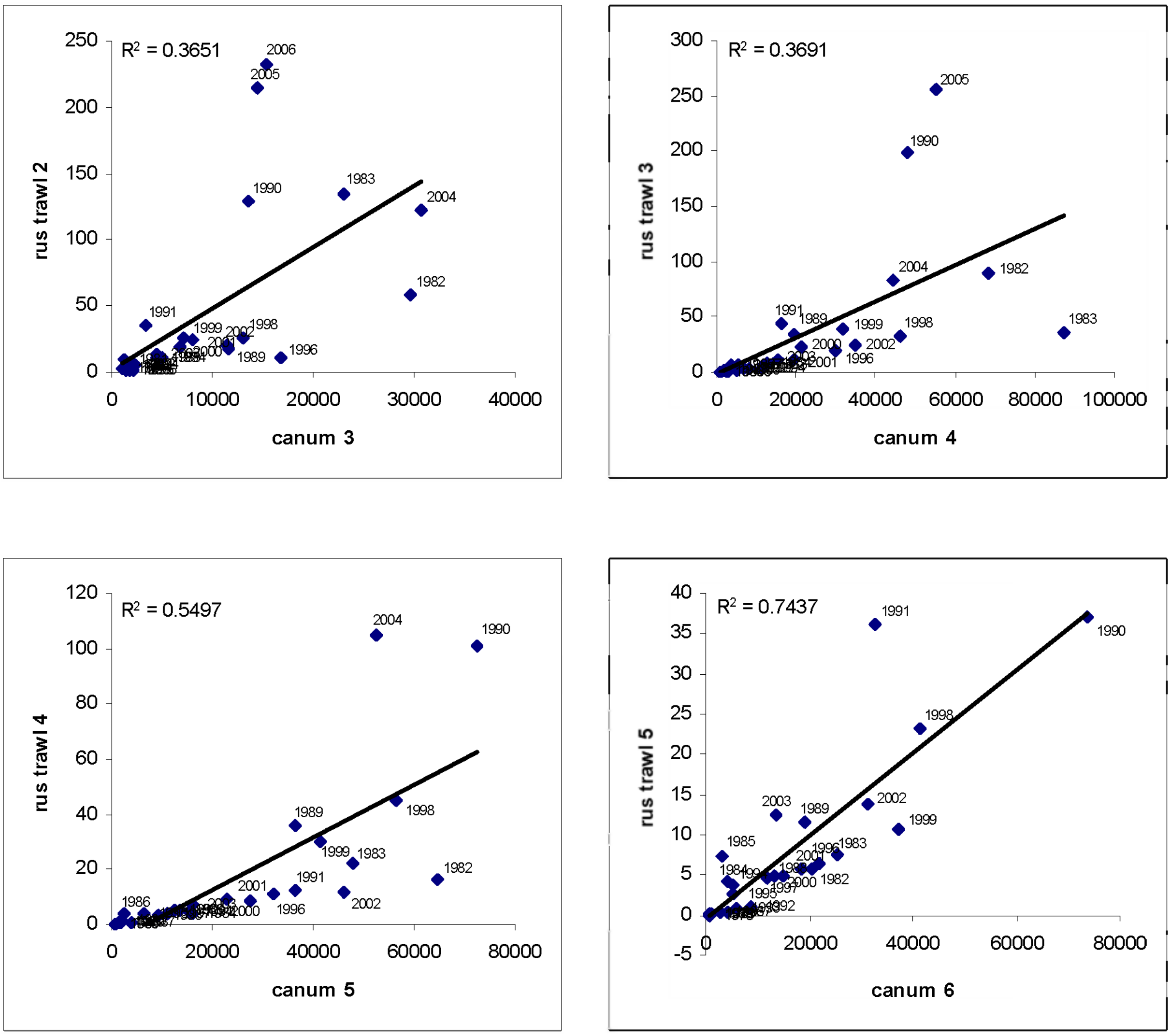


Figure 11. Relationship between year-class strength estimates by catch-at-age data (cod consumption NOT included) and Russian trawl acoustic survey (bottom-trawl index – Fleet01). Points are marked by year class/generation.

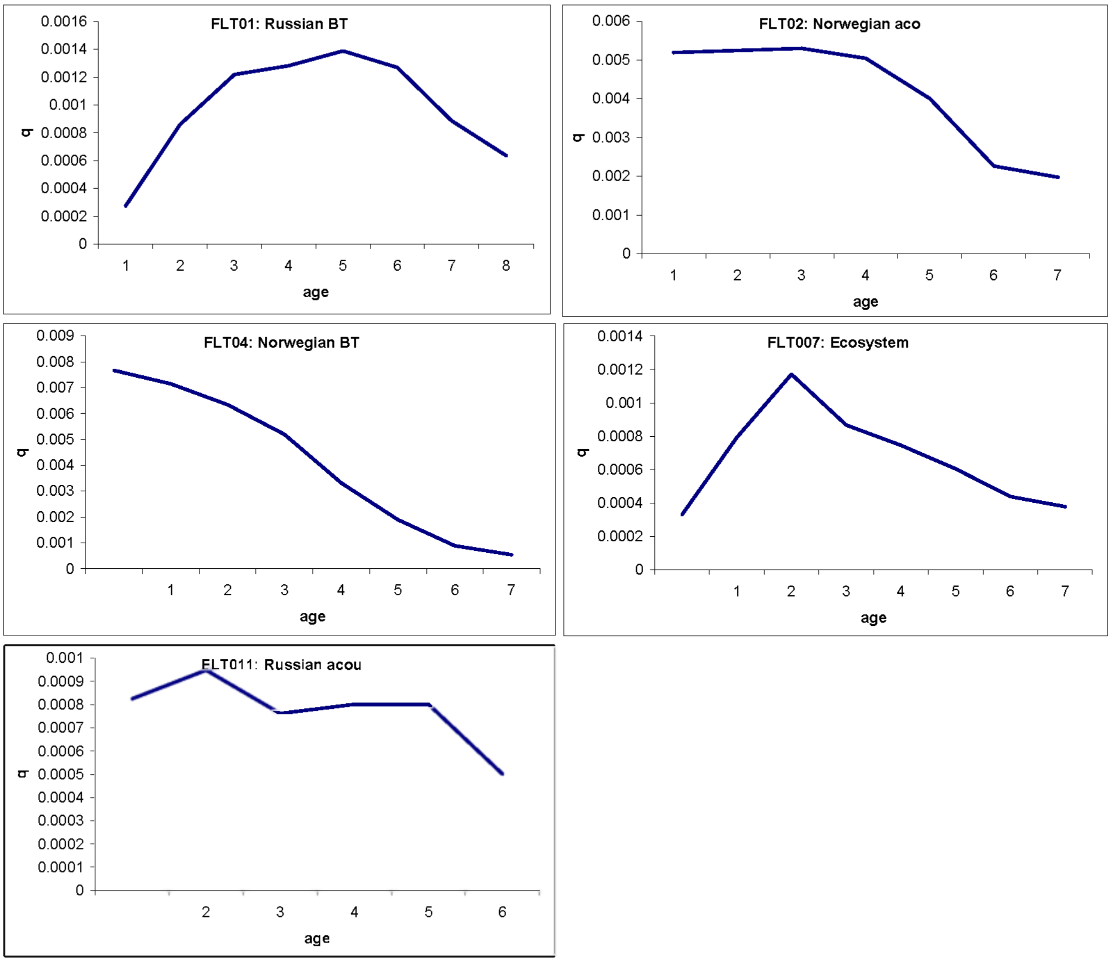


Figure 12. NEA haddock. Catchability for different surveys (exp(-Log q), XSA run 1 see text).

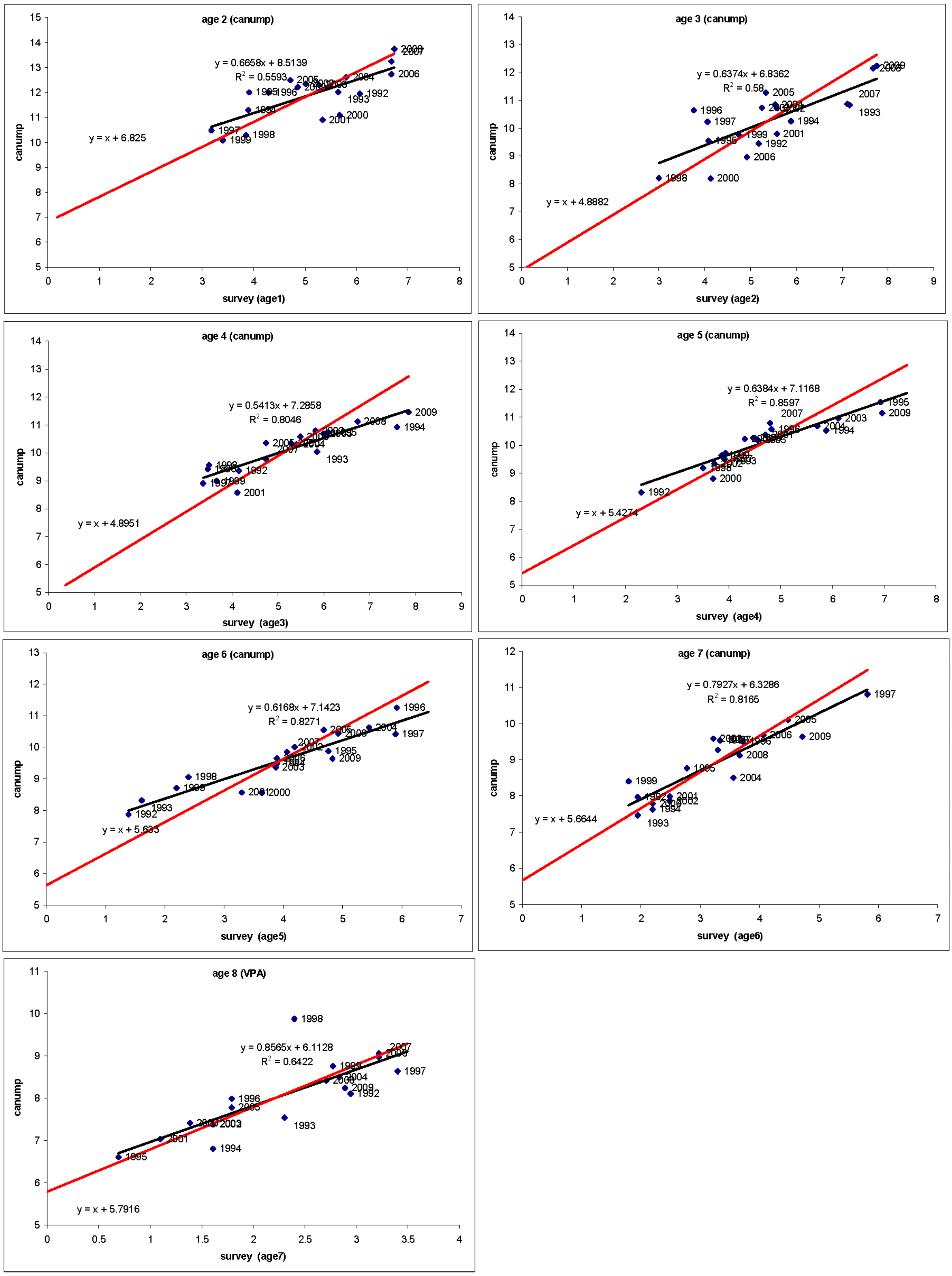


Figure 13. Relationship between year-class strength estimates by Russian bottom-trawl acoustic survey (bottom-trawl index - XSA Fleet01). Data log transformed. Black line is linear trend, red line is liner trend with slope = 1. Points are marked by year when catch was taken.

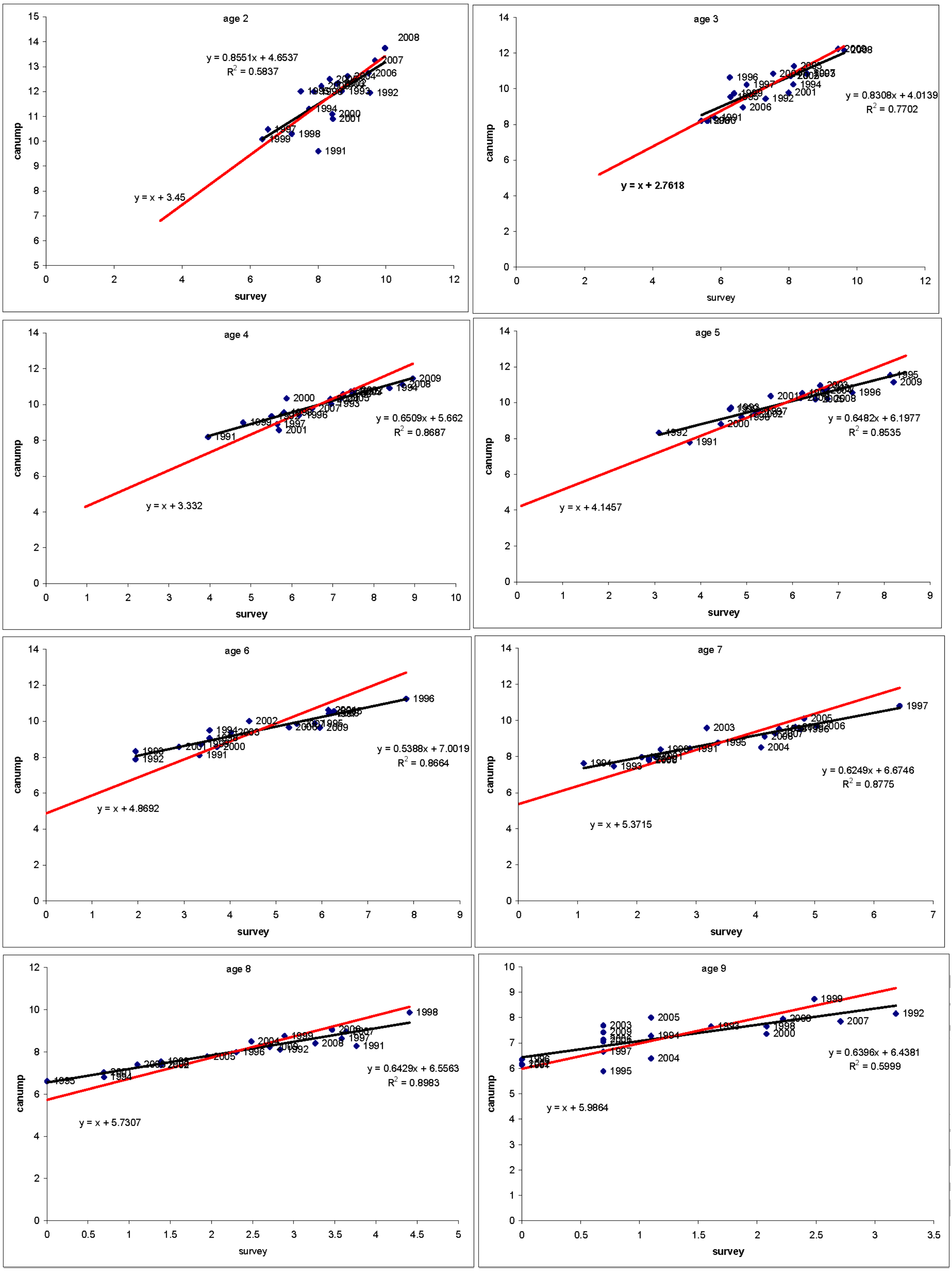


Figure 14. Relationship between year-class strength estimates by Norwegian/Joint trawl acoustic surveys (bottom-trawl index - XSA FLT04). Data log transformed. Black line is linear trend, red line is liner trend with slope = 1. Points are marked by year when catch was taken.

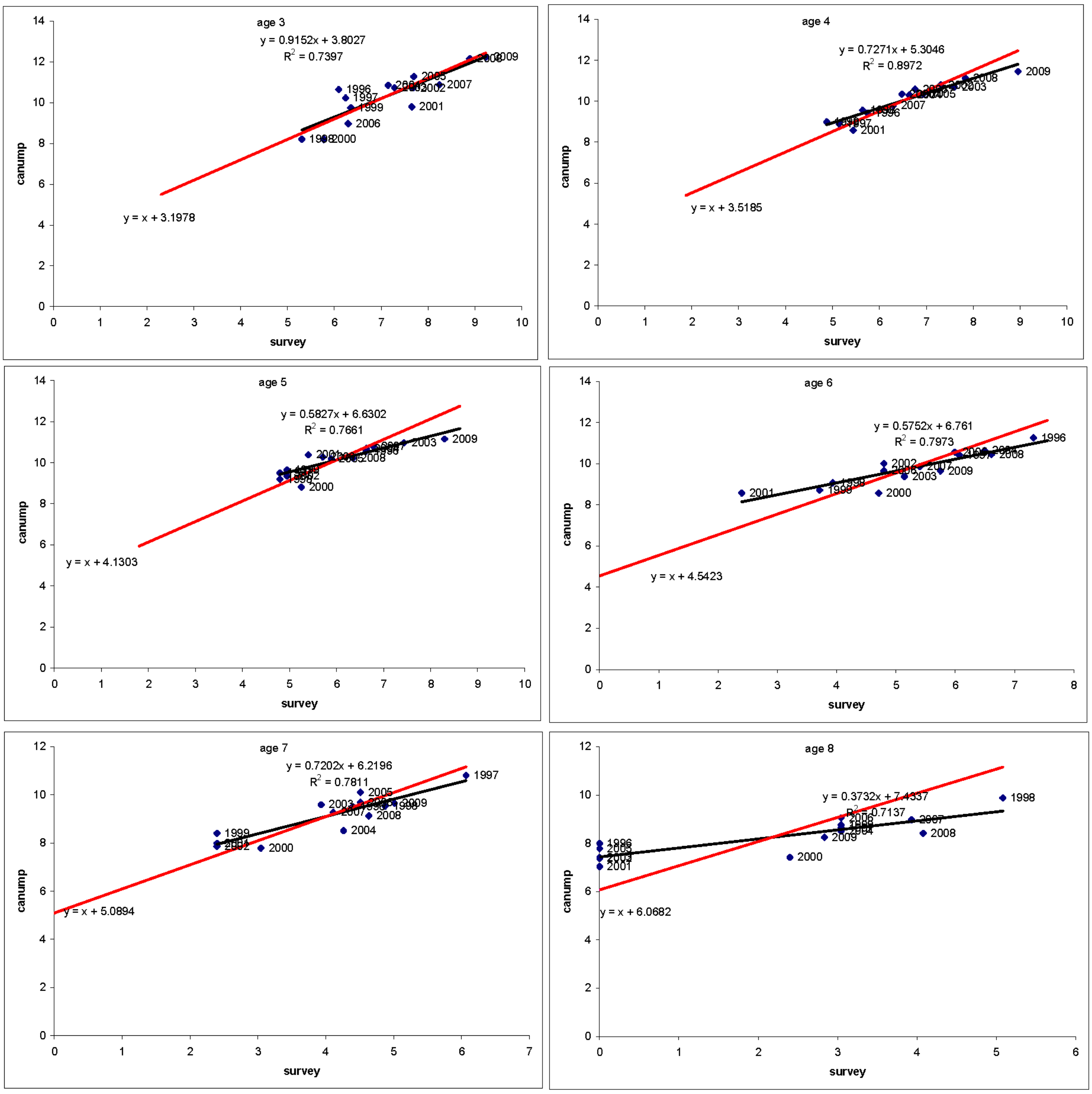


Figure 15. Relationship between year-class strength estimates by Norwegian/Joint trawl acoustic surveys (acoustic index - XSA FLT02). Data log transformed. Black line is linear trend, red line is liner trend with slope = 1. Points are marked by year when catch was taken.

Table 8. Northeast Arctic haddock. Some results of some diagnostic from XSA run 1 (see text).

	FLT01: Russian BT		FLT02: Norwegian aco		FLT04: Norwegian BT		FLT007: Ecosystem		FLT011: Russian acou	
Age	Slope	t-value	Slope	t-value	Slope	t-value	Slope	t-value	Slope	t-value
1	0.75	1.887	0.88	0.967	0.85	1.604	0.92	0.398	0.71	2.263
2	0.63	4.864	0.76	3.151	0.68	3.367	0.6	3.59	0.68	2.37
3	0.64	4.866	0.73	3.978	0.73	2.934	0.81	0.92	0.71	1.507
4	0.68	3.145	0.69	2.982	0.71	2.648	0.82	4.126	0.73	1.285
5	0.69	2.343	0.59	2.923	0.56	4.197	0.64	3.413	0.6	2.791
6	0.72	1.809	0.68	1.756	0.58	2.875	0.96	0.174	0.59	2.235
7	0.73	1.401	0.85	0.418	0.52	3.585	0.62	2.028	0.71	2.263
8	0.71	1.079					0.23	2.796		

* Shaded cells show statistically significant difference from linear model (t>2, so power model is better for with ages).

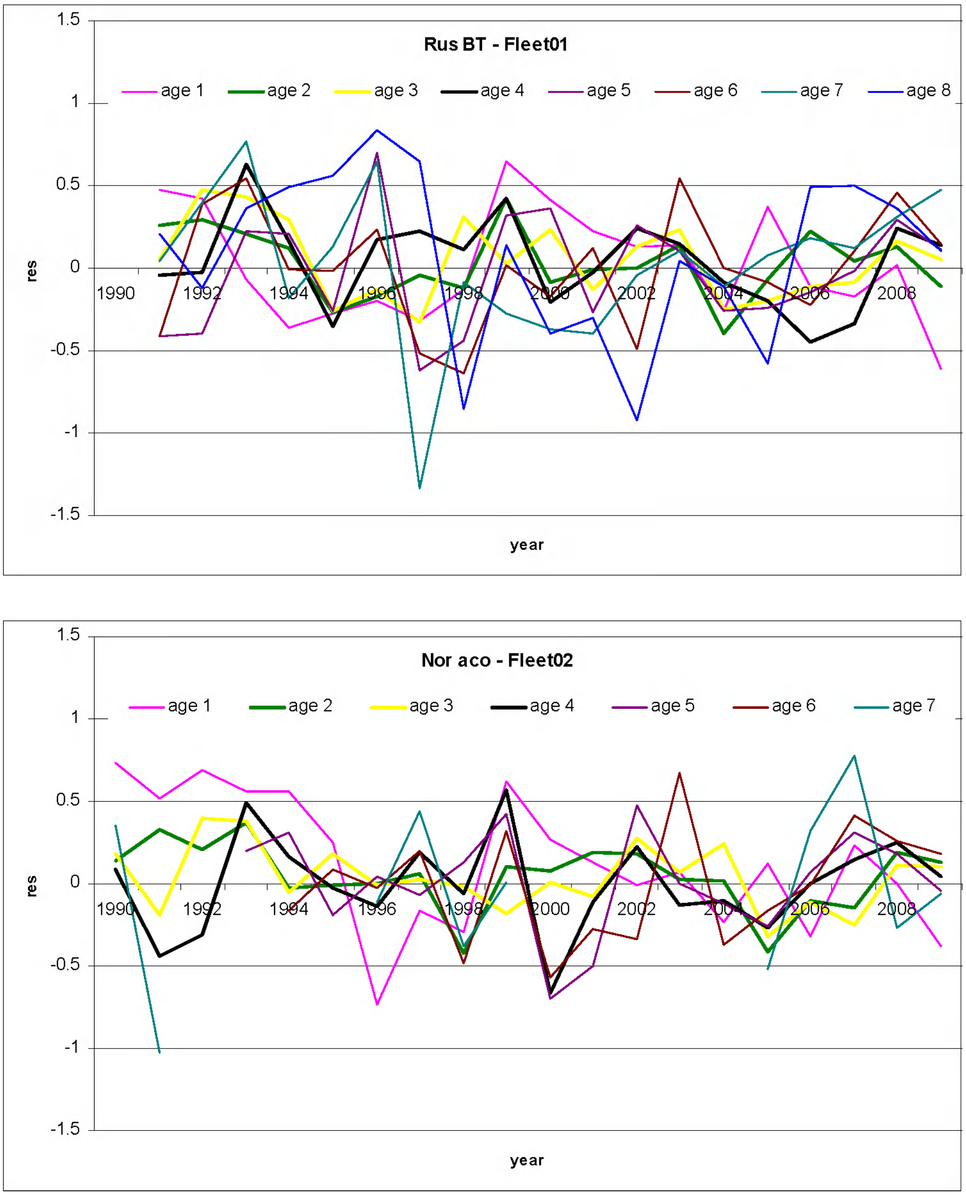
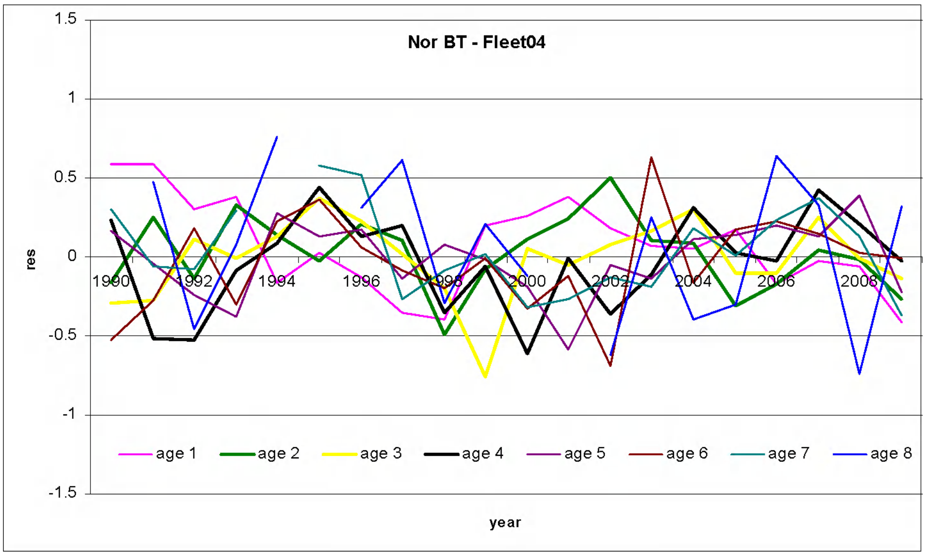
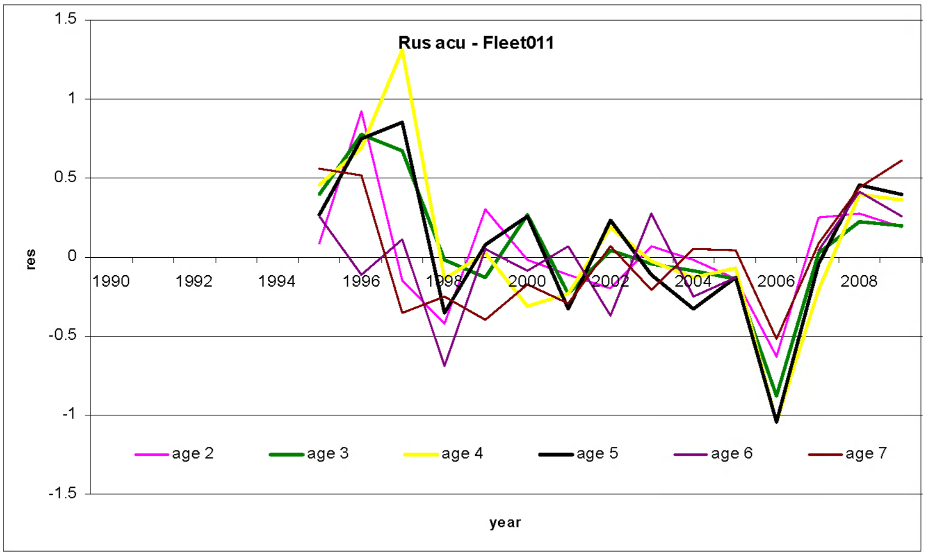


Figure 16. Northeast Arctic haddock. Surveys residuals from XSA diagnostic (run 1, see text).





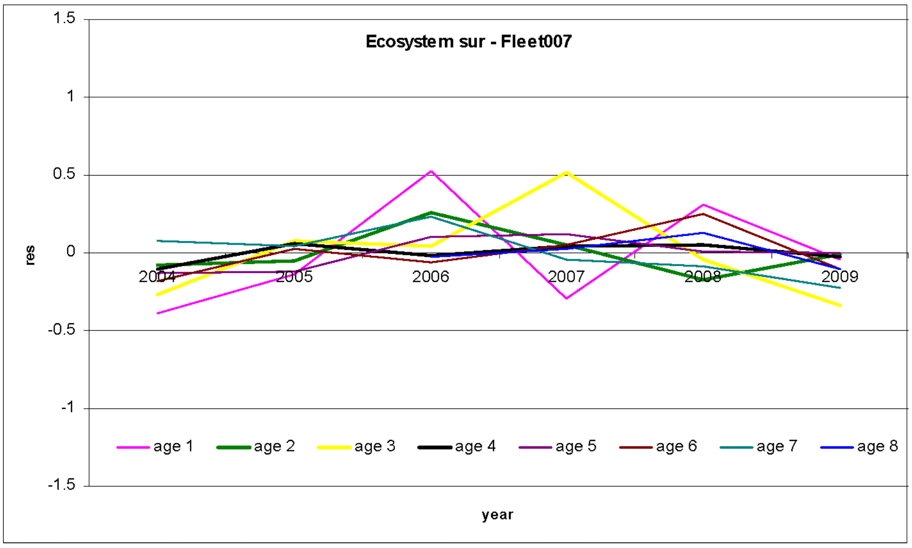


Figure 16. (Continued). Northeast Arctic haddock. Surveys residuals from XSA diagnostic (run 1, see text).

Figure 17. Northeast Arctic haddock. Surveys residuals from XSA diagnostic (AFWG 2010 predation run).

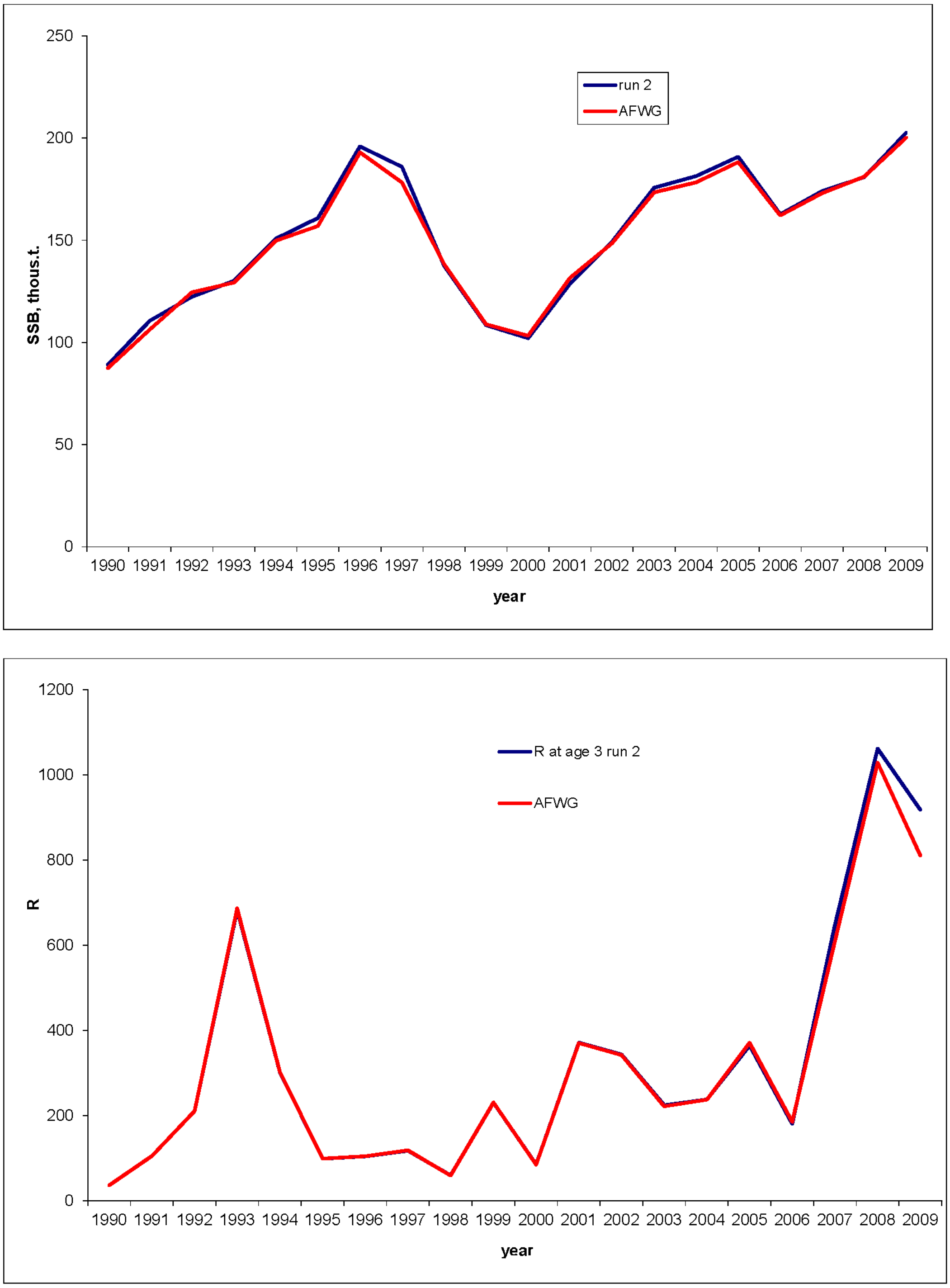


Figure 18. Northeast Arctic haddock. Comparison of XSA results run 2 (see text) with AFWG 2010 final run.

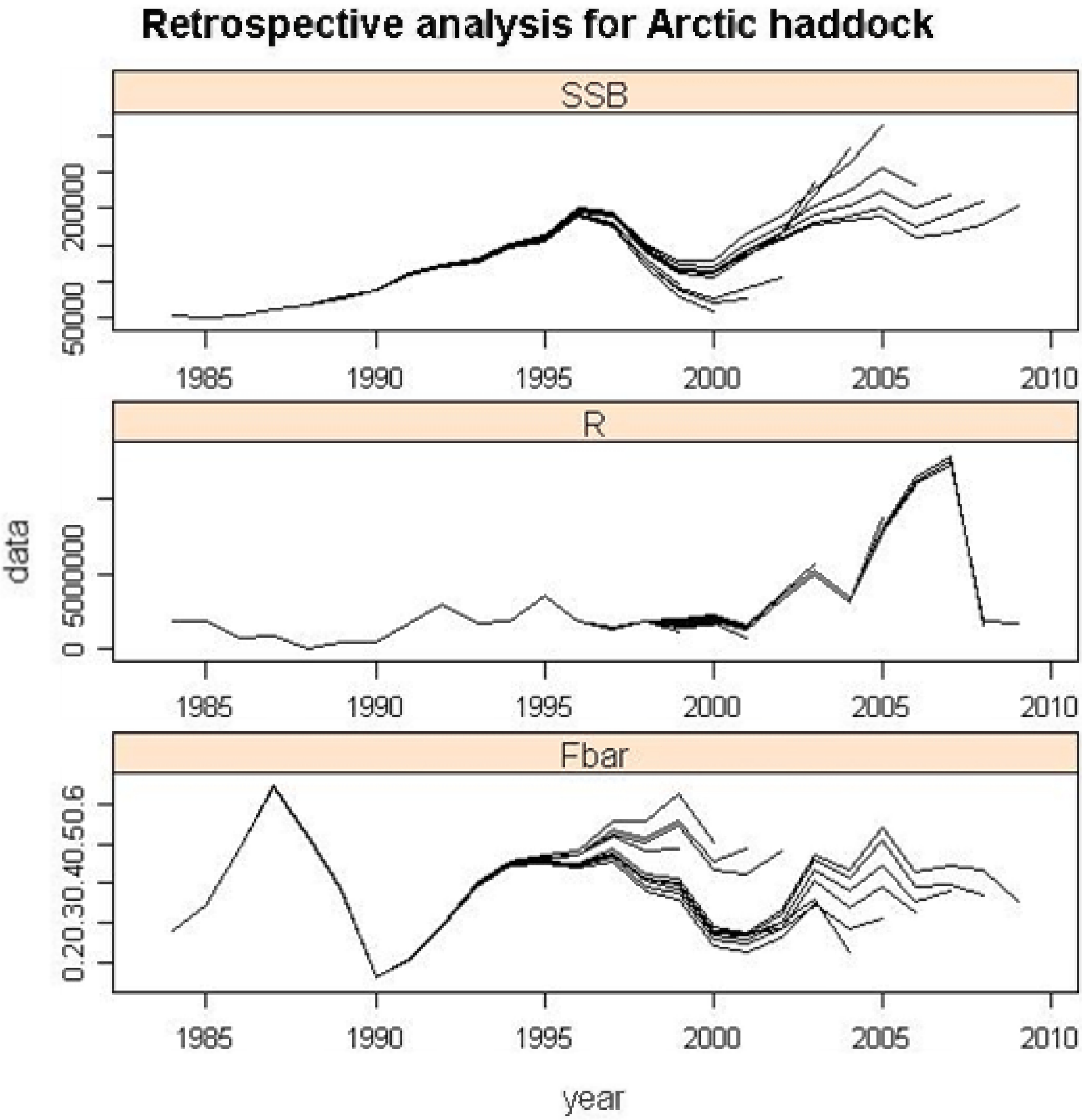


Figure 19. Northeast Arctic haddock. Results of retrospective runs with XSA settings from run 3 (No P-shrinkage).

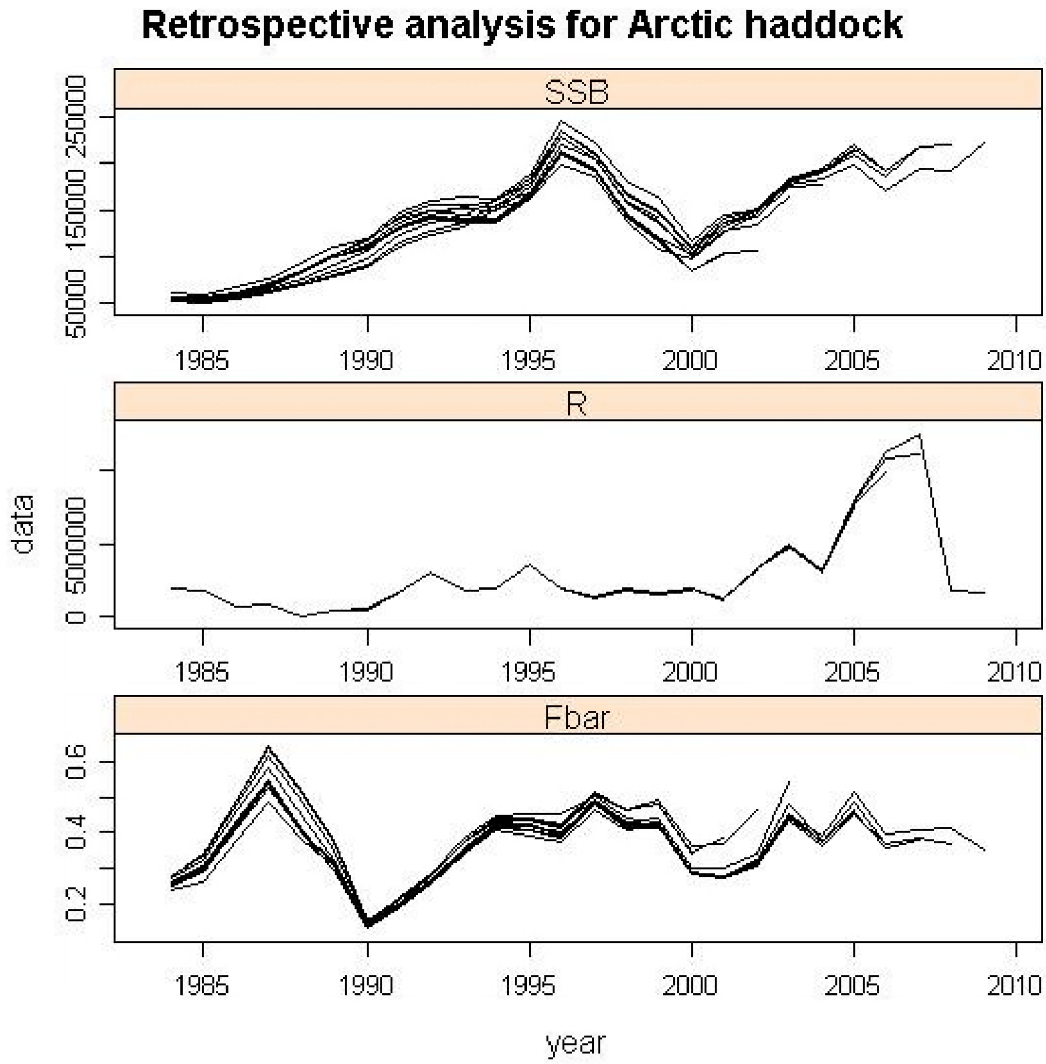


Figure 20. Northeast Arctic haddock. Results of retrospective runs with XSA settings from run 4 (with P and F shrinkage; s.e. for F shrinkage = 1.0).

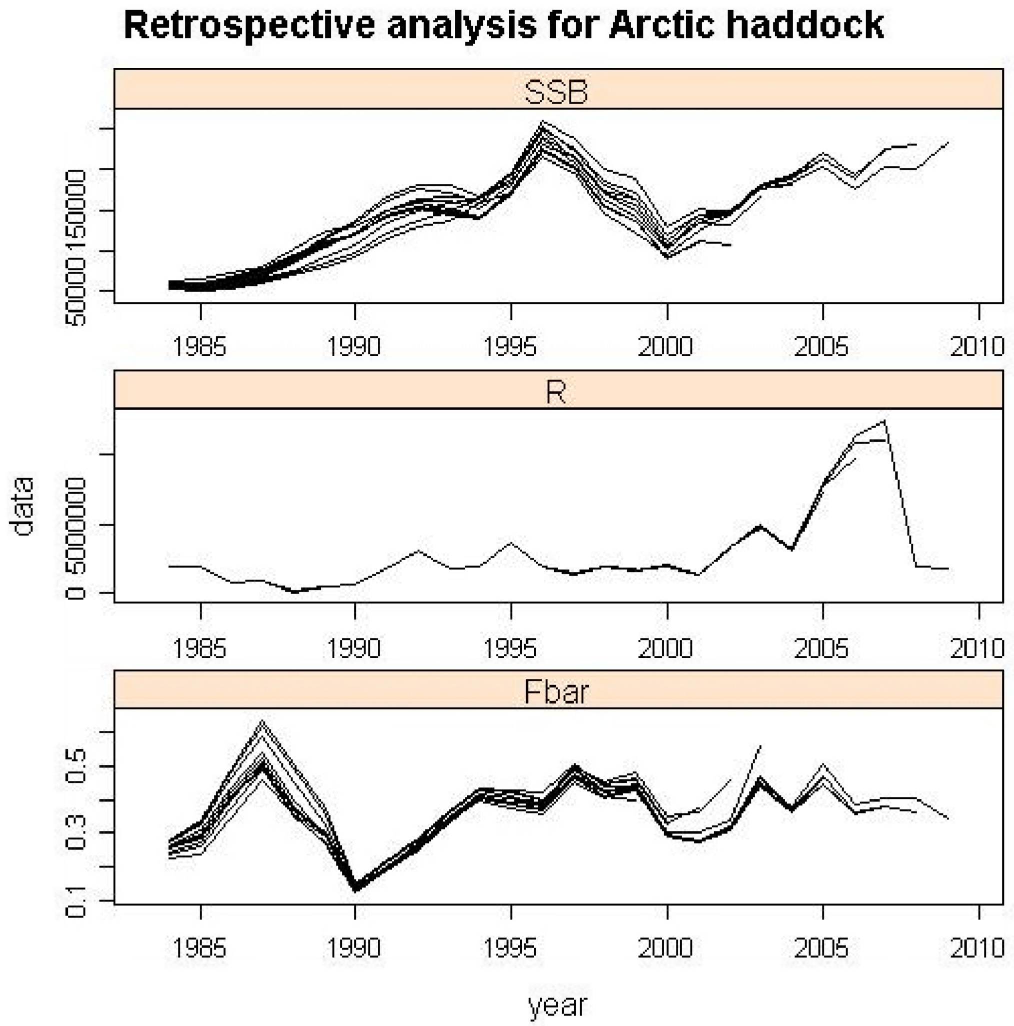


Figure 21. Northeast Arctic haddock. Results of retrospective runs with XSA settings from run 4 (with P and F shrinkage; s.e. for F shrinkage = 1.5).

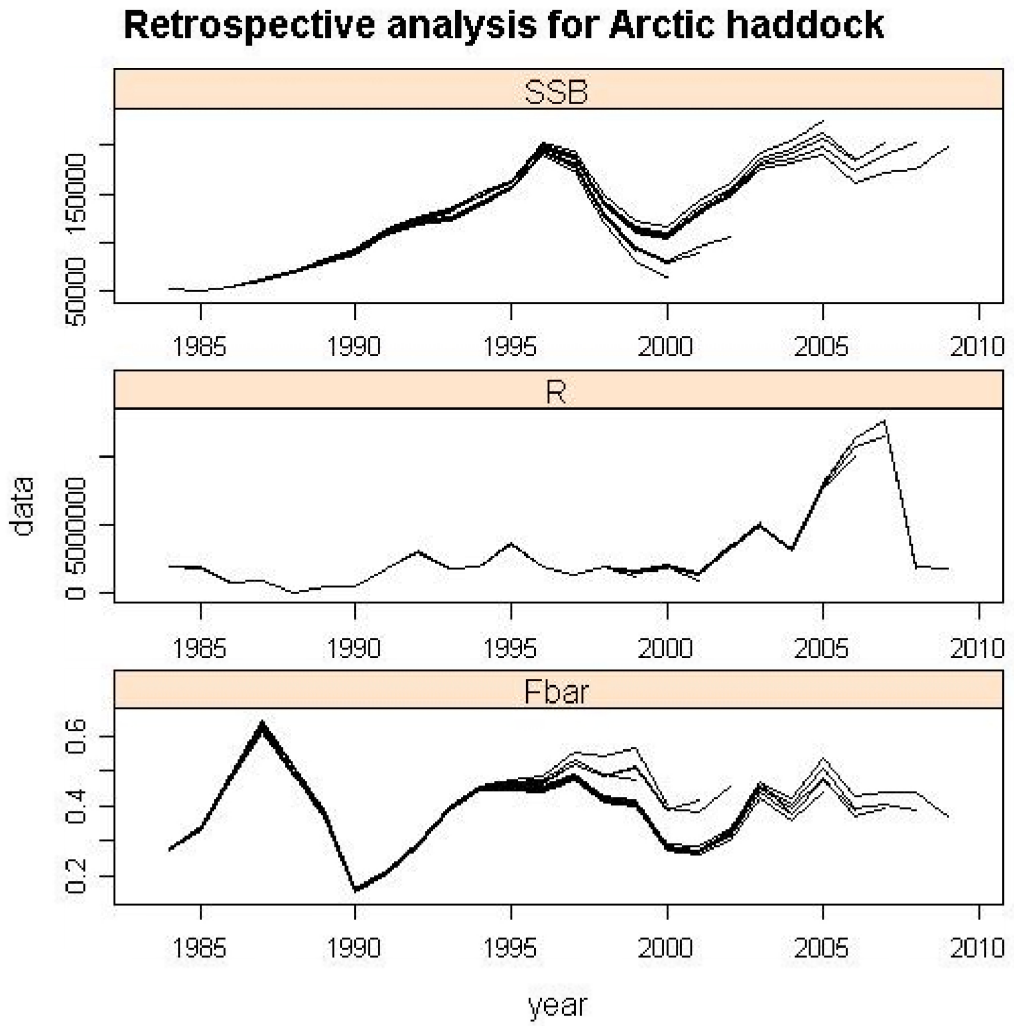


Figure 22. Northeast Arctic haddock. Results of retrospective runs with XSA settings from run 5 (with P and F shrinkage; s.e. for F shrinkage = 0.5, shrinkage used for last 3 years and last 3 ages).

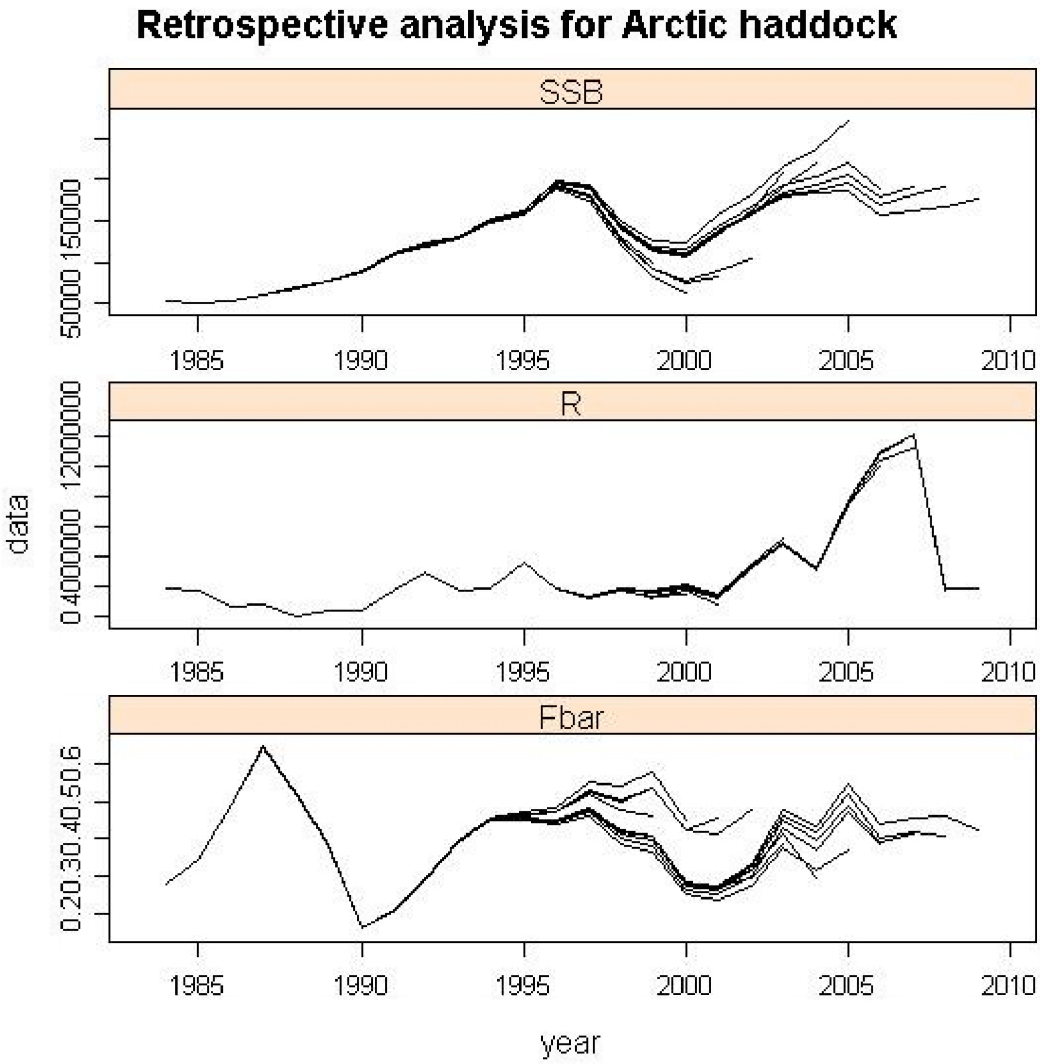


Figure 23. Northeast Arctic haddock. Results of retrospective runs with XSA settings from run 6 (with time window for down weighting old data = 10 years with power 3).

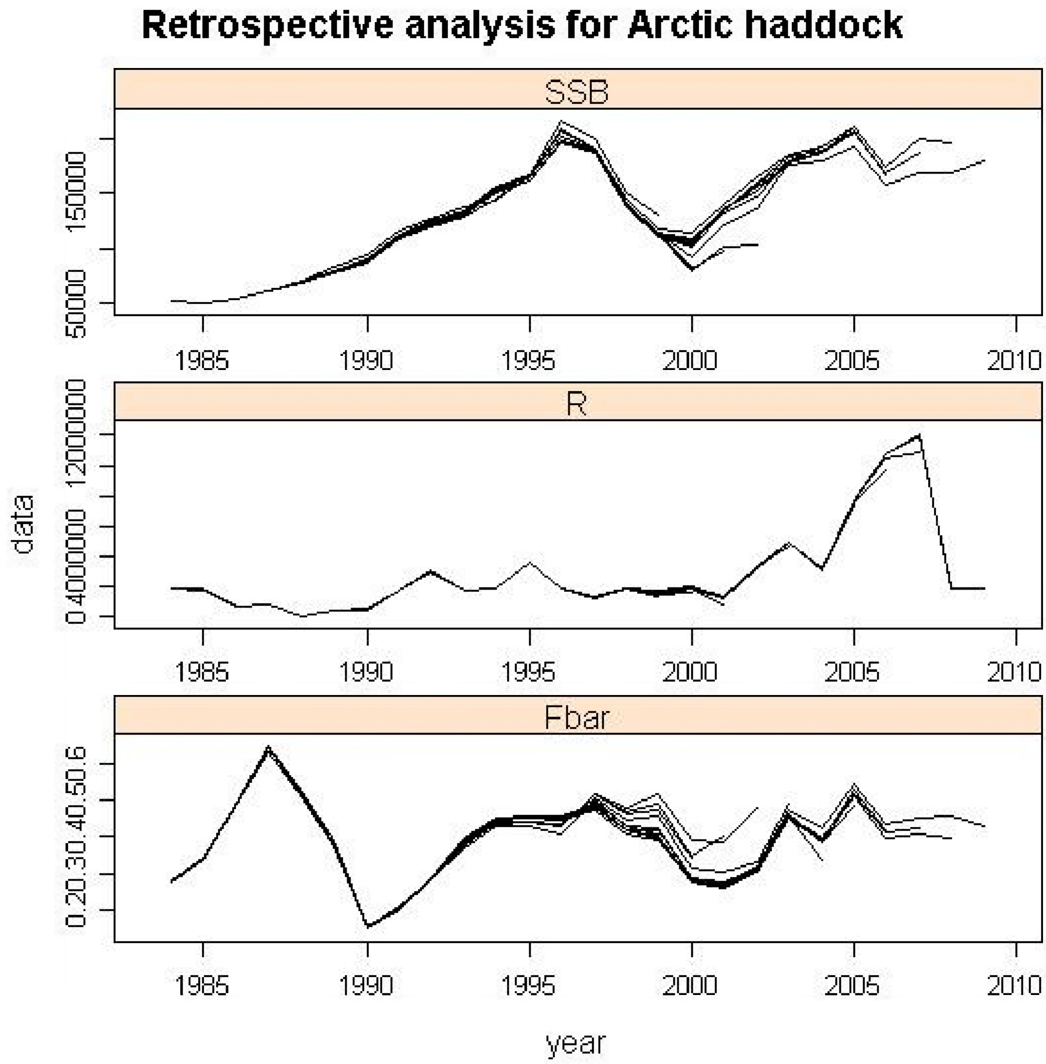


Figure 24. Northeast Arctic haddock. Results of retrospective runs with XSA settings from run 7 (with time window for down weighting old data = 10 years with power 3 and s.e. for shrinkage = 1.5).

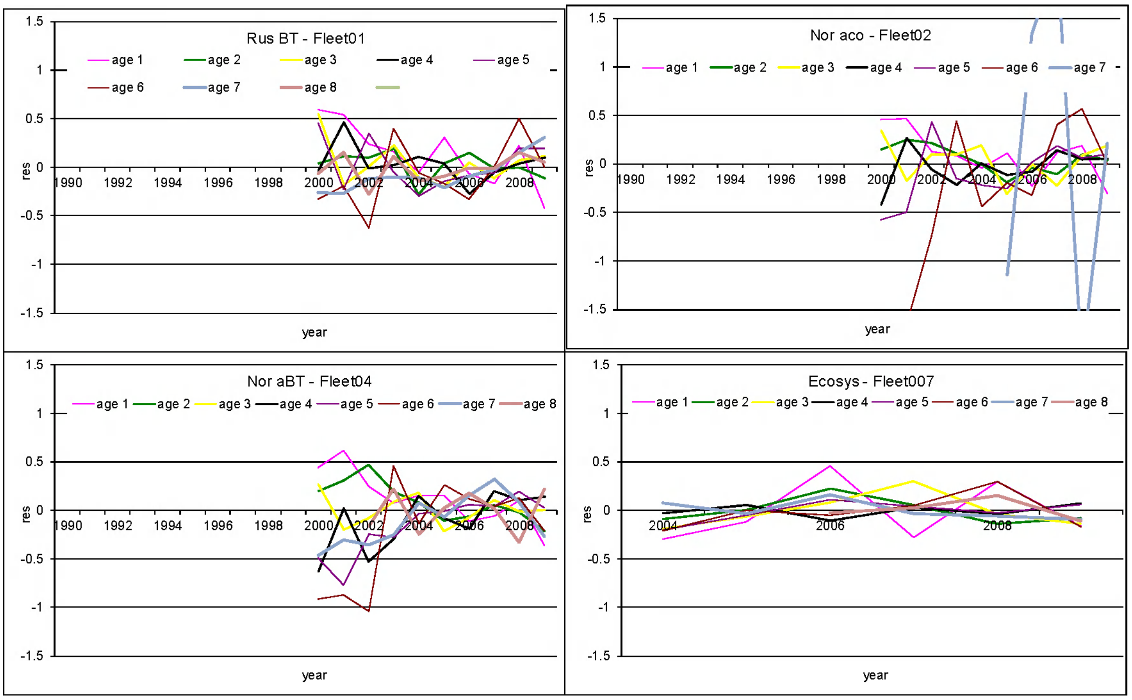


Figure 25. Northeast Arctic haddock. Surveys residuals from XSA diagnostic (run 7).

Data availability and critical gaps in knowledge in estimation of catch-at-age for three stocks in the Norwegian Northeast Arctic fishery

by Åge Fotland, Institute of Marine Research (IMR), Bergen, Norway.

Biological samples for estimation of Norwegian catch-at-age for NeA cod, NeA haddock and NeA saithe in 2008 and 2009

In the time period since 2002 the Norwegian biological samples from commercial fishery for these three stocks have been quite stable. The sources are listed in Table 1.

Table 1. Appropriate commercial biological samples used in assessment for catches-at-age.

Source	Year range	Coverage	Comments
Ambulant sampling	1980–2009[3]	ICES Subareas I and II[4]	"Amigo" and "Falkungen"
Coastguard	1992–last data year	ICES Subareas I and II[5]	
Fishery Directorate Surveillance fleet	1980–last data year	ICES Subareas I and II	Some samples are from shrimp trawl
Reference fleet	2002–last data year	ICES Subareas I and II	
Coast reference fleet	2005–last data year	Coast near areas	
Møreforsking	1994–last data year	Coast near areas in the southern part	

2008 is the last year, where all sources are available for all seasons. There could be some effects on estimation of catches-at-age when changes in sampling strategy have been shifted in 2009. Some area and gear group distributions are looked into in ICES Subareas I, IIa and IIb.

These gear groups are:

NeA cod	NeA haddock	NeA saithe
Line	Line	Gillnet
Gillnet	Trawl	Purse seine
Trawl	"Others"	Trawl
"Others"		"Others"

The Norwegian statistical areas in the ICES Subareas I and II are shown in Appendix A. Gears and coding of the gear groups is set up in Table 2.

[3] This sampling regime was ended in Q3 in 2009.

[4] North of Lofoten 4 6-weeks time periods each Year.

[5] Including sampling from the Loop Hole and Loop Ocean.

Table 2. Gear groups and their codes.

Code	Name
31	Trawl
32	Shrimp trawl
36	Danish seine
37	Puse seine
41	Gillnet
43	Others
51	Line
52	Handline

The program used to estimate catches-at-age; is ECA a Bayesian hierarchical model that have been developed to estimate the catch-at-age of fish, using data on weight, age, length and age-given-length, (Hirst and Aanes, 2004).

Table 3.1. NeA cod, summary samples with length, by area.

By area:	Norwegian statistical regions by Fishery Directorate									
	0	2	3	4	5	6	7	12	20	Total
Ambulant sampl.	0	0	0	1	1	0	0	0	0	2
Coast ref. fleet	3	0	2	6	6	0	0	0	0	17
Surveillance fleet	20	86	69	78	98	0	0	39	73	463
Reference fleet	26	72	61	103	89	0	0	236	385	972
Total	49	158	132	188	194	0	0	275	458	1454

Table 3.2. NeA cod, summary samples with length, by gear groups.

By gear:	Gear groups					
	31	32	41	51	52	Total
Ambulant sampl.	1	0	1	0	0	2
Coast ref. fleet	0	1	16	0	0	17
Surveillance fleet	222	176	0	65	0	463
Reference fleet	246	22	99	605	0	972
Total	469	199	116	670	0	1454

Table 3.3. NeA cod, summary samples with age, by area.

By area:	Norwegian statistical regions by Fishery Directorate									
	0	2	3	4	5	6	7	12	20	Total
Ambulant sampl.	31	0	62	43	41	0	0	0	0	177
Coast ref. fleet	2	0	5	11	6	0	0	0	0	24
Surveillance fleet	0	0	0	3	3	0	0	0	0	6
Reference fleet	9	16	19	17	19	0	0	39	74	193
Total	42	16	86	74	69	0	0	39	74	400

Table 3.4. NeA cod, summary samples with age, by gear groups.

By gear:	Gear groups					
	31	32	41	51	52	Total
Ambulant sampl.	3	30	76	58	10	177
Coast ref. fleet	0	2	20	2	0	24
Surveillance fleet	0	6	0	0	0	6
Reference fleet	55	12	21	105	0	193
Total	58	50	117	165	10	400

Table 3.5. NeA cod, summary samples with weight, by area.

By area:	Norwegian statistical regions by Fishery Directorate									
	0	2	3	4	5	6	7	12	20	Total
Ambulant sampl.	31	0	62	43	41	0	0	0	0	177
Coast ref. fleet	0	0	3	2	3	0	0	0	0	8
Surveillance fleet	0	0	0	0	3	0	0	0	0	3
Reference fleet	9	16	19	17	19	0	0	39	74	193
Total	40	16	84	62	66	0	0	39	74	381

Table 3.6. NeA cod, summary samples with weight, by gear groups.

By gear:	Gear groups					
	31	32	41	51	52	Total
Ambulant sampl.	3	30	76	58	10	177
Coast ref. fleet	0	0	8	0	0	8
Surveillance fleet	0	3	0	0	0	3
Reference fleet	55	12	21	105	0	193
Total	58	45	105	163	10	381

Table 4.1. NeA haddock, summary samples with length, by area.

By area:	Norwegian statistical regions by Fishery Directorate								
	0	3	4	5	6	7	12	20	Total
Ambulant sampl.	0	1	0	0	0	0	0	0	1
Coast ref. fleet	3	1	0	1	0	0	0	0	5
Møreforsking	0	0	0	0	0	0	0	0	0
Surveillance fleet	15	82	68	92	24	14	38	48	381
Reference fleet	25	126	99	181	177	107	205	317	1237
Total	43	210	167	274	201	121	243	365	1624

Table 4.2. NeA haddock, summary samples with length, by gear groups.

By gear:	Gear groups				
	31	36	41	51	Total
Ambulant sampl.	0	0	0	1	1
Coast ref. fleet	0	0	4	1	5
Møreforsking	0	0	0	0	0
Surveillance fleet	238	69	0	74	381
Reference fleet	309	20	142	766	1237
Total	547	89	146	842	1624

Table 4.3. NeA haddock, summary samples with age, by area.

By area:	Norwegian statistical regions by Fishery Directorate								
	0	3	4	5	6	7	12	20	Total
Ambulant sampl.	8	39	18	29	0	0	0	0	94
Coast ref. fleet	0	1	0	0	0	1	0	0	2
Møreforsking	0	0	0	0	0	6	0	0	6
Surveillance fleet	0	1	0	0	0	0	0	0	1
Reference fleet	6	27	13	32	25	19	39	51	212
Total	14	68	31	61	25	26	39	51	315

Table 4.4. NeA haddock, summary samples with age, by gear groups.

By gear:	Gear groups				
	31	36	41	51	Total
Ambulant sampl.	3	29	6	56	94
Coast ref. fleet	0	0	1	1	2
Møreforsking	6	0	0	0	6
Surveillance fleet	0	0	0	1	1
Reference fleet	50	3	14	145	212
Total	59	32	21	203	315

Table 4.5. NeA haddock, summary samples with weight, by area.

By area:	Norwegian statistical regions by Fishery Directorate								
	0	3	4	5	6	7	12	20	Total
Ambulant sampl.	8	39	18	29	0	0	0	0	94
Coast ref. fleet	0	0	0	0	0	0	0	0	0
Møreforsking	0	0	0	0	0	6	0	0	6
Surveillance fleet	0	0	0	0	0	0	0	0	0
Reference fleet	6	27	13	32	25	18	39	51	211
Total	14	66	31	61	25	24	39	51	311

Table 4.6. NeA haddock, summary samples with weight, by gear groups.

By gear:	Gear groups				
	31	36	41	51	Total

Ambulant sampl.	3	29	6	56	94
Coast ref. fleet	0	0	0	0	0
Møreforsking	6	0	0	0	6
Surveillance fleet	0	0	0	0	0
Reference fleet	49	3	14	145	211
Total	58	32	20	201	311

Table 5.1. NeA saithe, summary samples with length, by area.

By area:	Norwegian statistical regions by Fishery Directorate						
	0	3	4	5	6	7	Total
Ambulant sampl.	0	0	0	0	0	0	0
Coast ref. fleet	2	0	0	1	0	3	6
Møreforsking	0	0	0	0	0	0	0
Surveillance fleet	19	47	86	85	25	14	276
Reference fleet	32	30	182	198	142	151	735
Total	53	77	268	284	167	168	1017

Table 5.2. NeA saithe, summary samples with length, by gear groups.

By gear:	Gear groups				
	31	37	41	51	Total
Ambulant sampl.	0	0	0	0	0
Coast ref. fleet	0	0	6	0	6
Møreforsking	0	0	0	0	0
Surveillance fleet	203	13	0	60	276
Reference fleet	209	8	156	362	735
Total	412	21	162	422	1017

Table 5.3. NeA saithe, summary samples with age, by area.

By area:	Norwegian statistical regions by Fishery Directorate						
	0	3	4	5	6	7	Total
Ambulant sampl.	6	13	16	24	0	0	59
Coast ref. fleet	0	0	0	0	0	1	1
Møreforsking	0	0	0	1	0	7	8
Surveillance fleet	0	0	0	0	0	0	0
Reference fleet	3	5	34	18	13	20	93
Total	9	18	50	43	13	28	161

Table 5.4. NeA saithe, summary samples with age, by gear groups.

By gear:	Gear groups				
	31	37	41	51	Total
Ambulant sampl.	2	12	30	15	59
Coast ref. fleet	0	0	1	0	1
Møreforsking	6	0	2	0	8
Surveillance fleet	0	0	0	0	0
Reference fleet	46	23	22	2	93
Total	54	35	55	17	161

Table 5.5. NeA saithe, summary samples with weight, by area.

By area:	Norwegian statistical regions by Fishery Directorate						
	0	3	4	5	6	7	Total
Ambulant sampl.	4	6	9	12	0	0	31
Coast ref. fleet	0	0	0	0	0	0	0
Møreforsking	0	0	0	1	0	7	8
Surveillance fleet	0	0	0	0	0	0	0
Reference fleet	3	5	34	18	13	19	92
Total	7	11	43	31	13	26	131

Table 5.6. NeA saithe, summary samples with weight, by gear groups.

By gear:	Gear groups				
	31	37	41	51	Total
Ambulant sampl.	0	12	12	7	31
Coast ref. fleet	0	0	0	0	0
Møreforsking	6	0	2	0	8
Surveillance fleet	0	0	0	0	0
Reference fleet	45	23	22	2	92
Total	51	35	36	9	131

A more detailed grouping of gear groups in the NeA saithe assessment are not possible due to lack of samples, (Tables 6.1–6.3). For Gear groups line and handline there are few samples and for gear groups Danish seine, purse seine and gillnet the samples for some quarters are missing. Although there are 35 samples with age and weight from purse seine fishery, there are none in regions 0, 5, 6 and 7. There are two samples with length (4, and 32 fishes) in the same regions. The purse seine catches in the respective regions are 312, 473, 880 and 6430 tonnes. All samples from Danish seine are from the Ambulant sampling regime, marked with deep red colour. For shrimp trawl and "others" there are none samples. The catches are only 26 and 72 tonnes respectively.

Table 6.1. NeA saithe, summary samples with length, by area, used in assessment.

By gear:	Gear groups								
	31	32	36	37	41	43	51	52	Total

Ambulant sampl.	0	0	0	0	0	0	0	0	0
Coast ref. fleet	0	0	0	0	6	0	0	0	6
Møreforsking	0	0	0	0	0	0	0	0	0
Surveillance fleet	203	0	51	13	0	0	9	0	276
Reference fleet	209	0	18	8	156	0	344	0	735
Total	412	0	69	21	162	0	353	0	1017
Total catch by gear:	72 504	26	8359	39 405	36 951	72	2855	5826	165 998

Table 6.2. NeA saithe, summary samples with age, by area, used in assessment.

By gear:	Gear groups								
	31	32	36	37	41	43	51	52	Total
Ambulant sampl.	2	0	13	12	30	0	1	1	59
Coast ref. fleet	0	0	0	0	1	0	0	0	1
Møreforsking	6	0	0	0	2	0	0	0	8
Surveillance fleet	0	0	0	0	0	0	0	0	0
Reference fleet	46	0	0	23	22	0	2	0	93
Total	54	0	13	35	55	0	3	1	161
Total catch by gear:	72 504	26	8359	39 405	36 951	72	2855	5826	165 998

Table 6.3. NeA saithe, summary samples with weight, by area, used in assessment.

By gear:	Gear groups								
	31	32	36	37	41	43	51	52	Total
Ambulant sampl.	0	0	5	12	12	0	1	1	31
Coast ref. fleet	0	0	0	0	0	0	0	0	0
Møreforsking	6	0	0	0	2	0	0	0	8
Surveillance fleet	0	0	0	0	0	0	0	0	0
Reference fleet	45	0	0	23	22	0	2	0	92
Total	51	0	5	35	36	0	3	1	131
Total catch by gear:	72 504	26	8359	39 405	36 951	72	2855	5826	165 998

A more detailed grouping of gear groups in the NeA saithe assessment is not possible due to lack of samples, (Tables 7.1–8.3). There are changes in sampling density by season. For age samples the percent samples by Quarters are:

67%	29%	3%	1%

For weight samples the corresponding samples by Quarters are:

63%	20%	2%	1%

For shrimp trawl and others there are none samples. The catches are only 0 and 6 tonnes respectively.

Table 7.1. NeA saithe, summary samples with length, by area, used in assessment.

By gear:	Gear groups								
	31	32	36	37	41	43	51	52	Total
Ambulant sampl.	0	0	0	0	0	0	0	0	0
Coast ref. fleet	0	0	0	0	27	0	0	0	27
Coastguard	65	0	11	6	5	0	4	0	91
Møreforsking	3	0	0	0	0	0	0	0	3
Surveillance fleet	266	0	33	24	0	0	2	0	325
Reference fleet	205	0	5	6	140	0	252	0	608
Total	539	0	49	36	172	0	258	0	1054
Total catch by gear:	63 740	0	5322	35 512	33 018	6	1555	5183	144 337

Table 7.2. NeA saithe, summary samples with age, by area, used in assessment.

By gear:	Gear groups								
	31	32	36	37	41	43	51	52	Total
Ambulant sampl.	1	0	7	4	6	0	1	0	19
Coast ref. fleet	0	0	0	0	0	0	0	0	0
Coastguard	1	0	0	0	0	0	0	0	1
Møreforsking	2	0	0	0	2	0	0	0	4
Surveillance fleet	0	0	0	0	0	0	0	0	0
Reference fleet	30	0	2	0	21	0	10	0	63
Total	34	0	9	4	29	0	11	0	87
Total catch by gear:	63 740	0	5322	35 512	33 018	6	1555	5183	144 337

Table 7.3. NeA saithe, summary samples with weight, by area, used in assessment.

By gear:	Gear groups								
	31	32	36	37	41	43	51	52	Total
Ambulant sampl.	0	0	1	4	2	0	1	0	8
Coast ref. fleet	0	0	0	0	0	0	0	0	0
Coastguard	0	0	0	0	0	0	0	0	0
Møreforsking	2	0	0	0	2	0	0	0	4
Surveillance fleet	0	0	0	0	0	0	0	0	0
Reference fleet	30	0	2	0	21	0	10	0	63
Total	32	0	3	4	25	0	11	0	75
Total catch by gear:	63 740	0	5322	35 512	33 018	6	1555	5183	144 337

Table 8.1. NeA saithe, summary samples with length, by season, used in assessment.

By Season	Quarters				
	1	2	3	4	Total
Ambulant sampl.	0	0	0	0	0
Coast ref. fleet	11	1	4	11	27
Coastguard	50	25	8	8	91
Møreforsking	0	1	1	1	3
Surveillance fleet	146	116	17	46	325
Reference fleet	360	130	57	61	608
Total	567	273	87	127	1054
Total catch by season:	55 516	29 341	34 414	25 065	144 337

Table 8.2. NeA saithe, summary samples with age, by season, used in assessment.

By Season	Quarters				
	1	2	3	4	Total
Ambulant sampl.	6	13	0	0	19
Coast ref. fleet	0	0	0	0	0
Coastguard	0	0	1	0	1
Møreforsking	3	1	0	0	4
Surveillance fleet	0	0	0	0	0
Reference fleet	49	11	2	1	63
Total	58	25	3	1	87
Total catch by season:	55 516	29 341	34 414	25 065	144 337

Table 8.3. NeA saithe, summary samples with weight, by season, used in assessment

By Season	Quarters				
	1	2	3	4	Total
Ambulant sampl.	3	5	0	0	8
Coast ref. fleet	0	0	0	0	0
Coastguard	0	0	0	0	0
Møreforsking	3	1	0	0	4
Surveillance fleet	0	0	0	0	0
Reference fleet	49	11	2	1	63
Total	55	17	2	1	75
Total catch by season:	55 516	29 341	34 414	25 065	144 337

In Figures 1.1–1.16 catch-at-age and uncertainty at age for NeA cod are shown and in the same detailed level when the ambulant sampling regime is omitted. For the most abundant age groups the mean catch-at-age is quite alike but the confidence interval is narrower when all sample sources are included. For age groups up to 4 the uncertainty increases as for age groups above age 10. More uncertainty is seen for gillnet where the ambulant sampling covers about 70% of the weight samples.

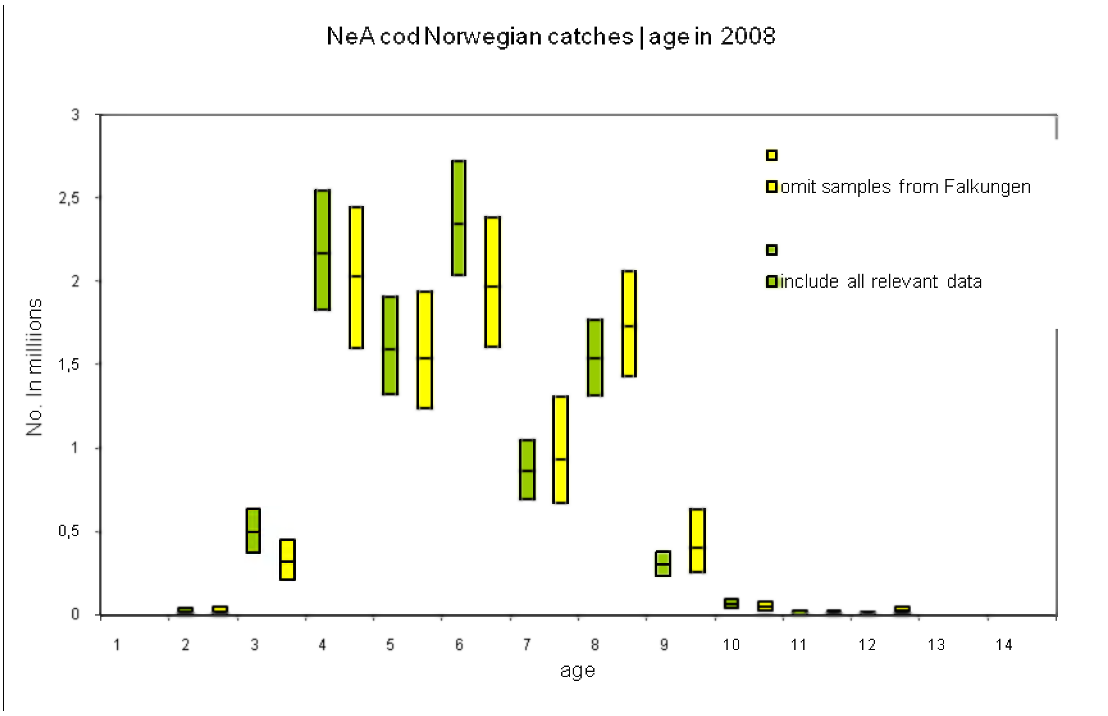


Figure 1.1. Catch-at-age for NeA cod 2008_allgears_Area_I.

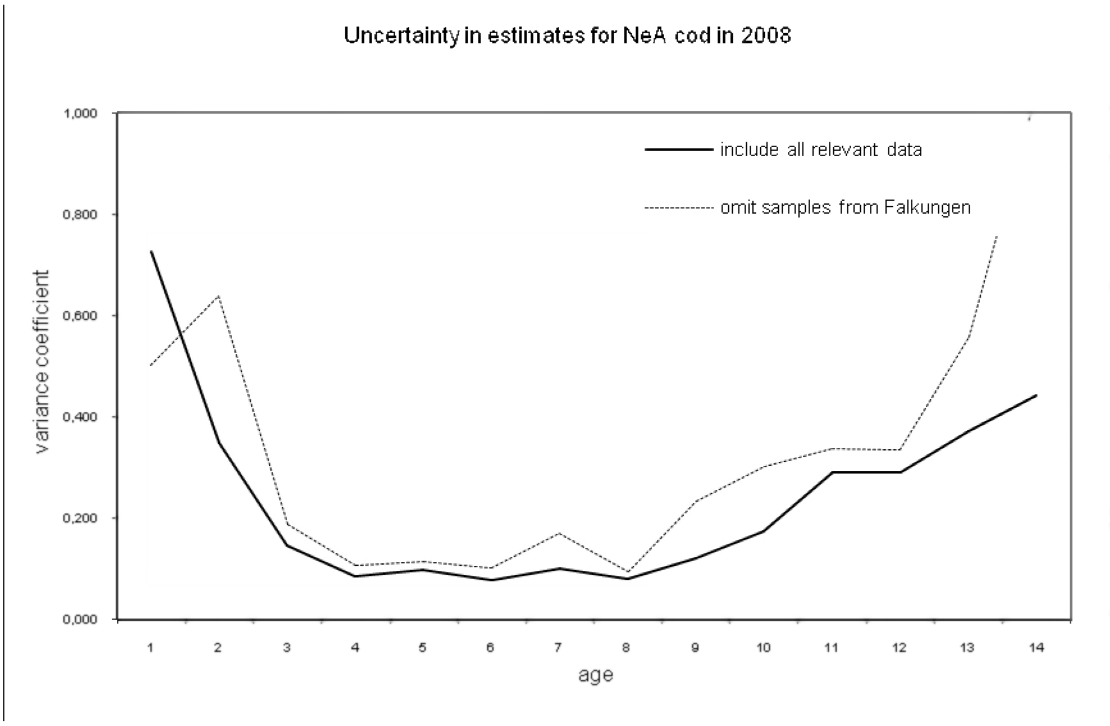


Figure 1.2. Variance coefficients for NeA cod 2008_allgears_Area_I.

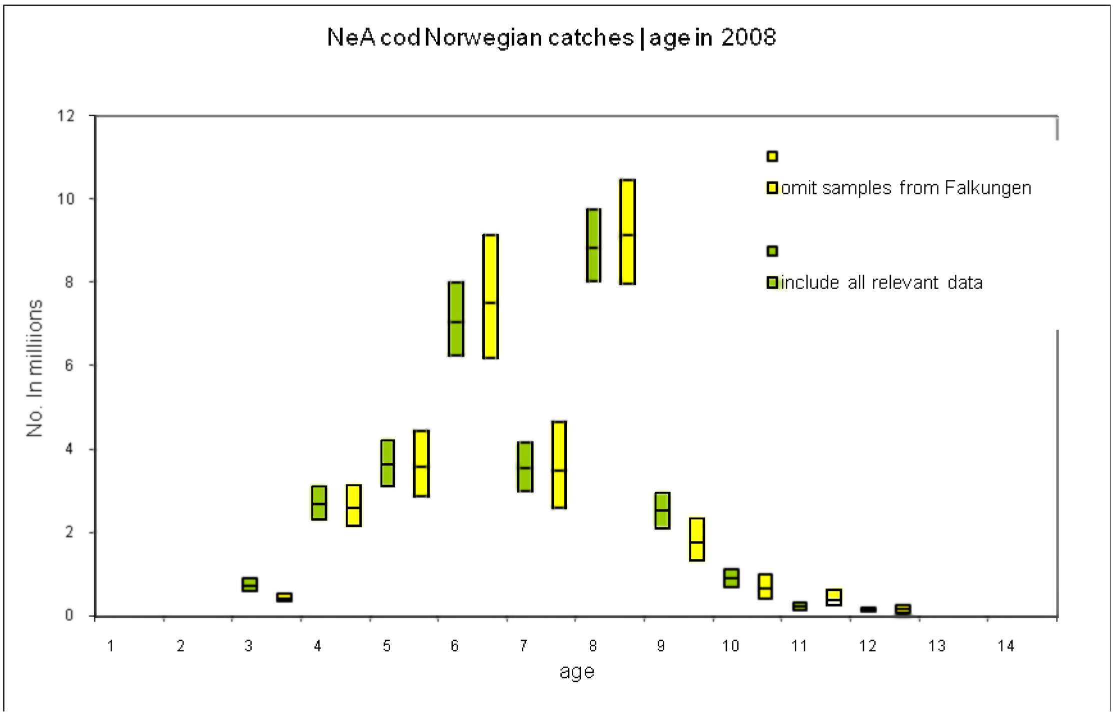


Figure 1.3. Catch-at-age for NeA cod 2008_allgears_Area_IIa.

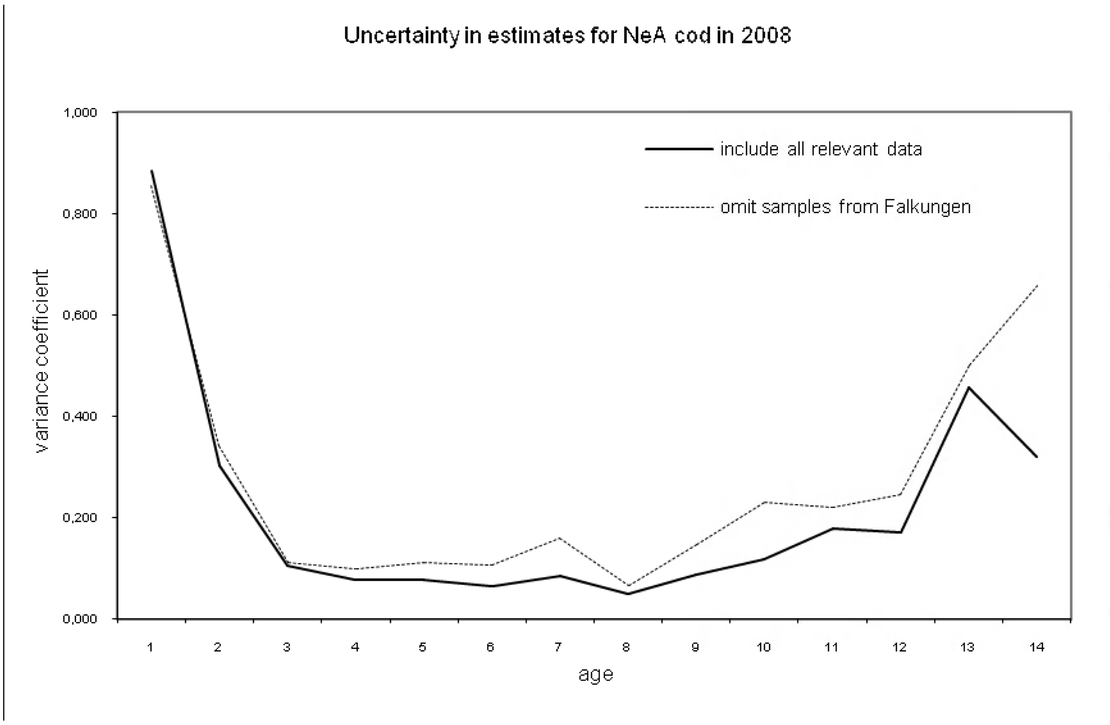


Figure 1.4. Variance coefficients for NeA cod 2008_allgears_Area_IIa.

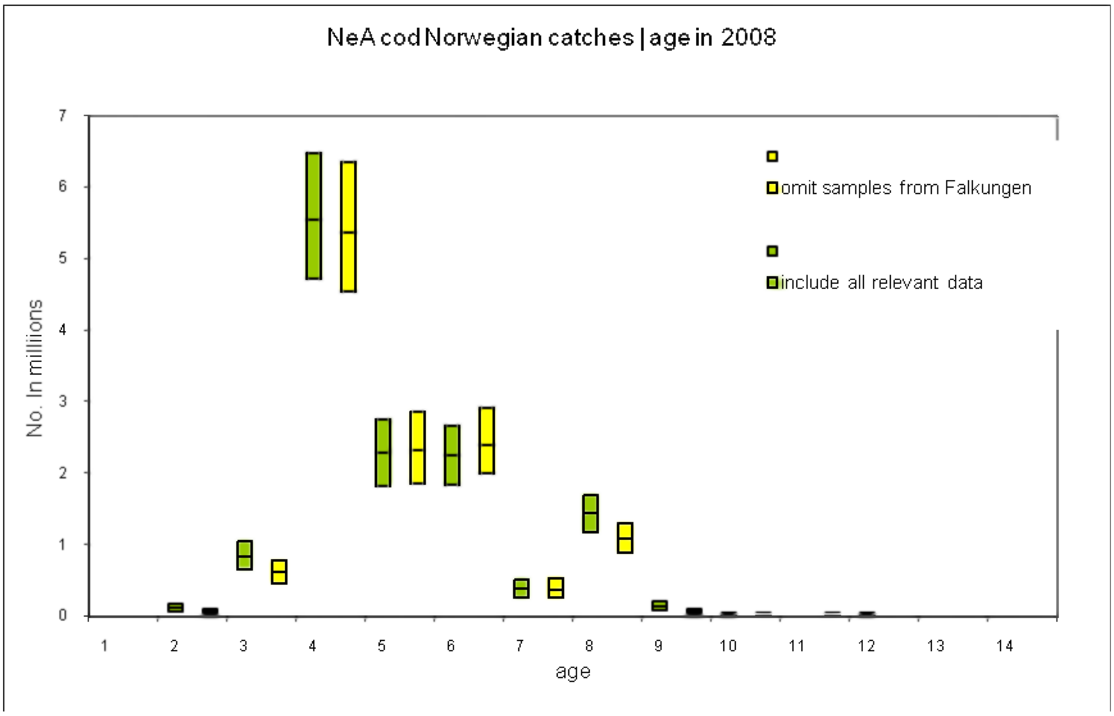


Figure 1.5. Catch-at-age for NeA cod 2008_allgears_Area_IIb.

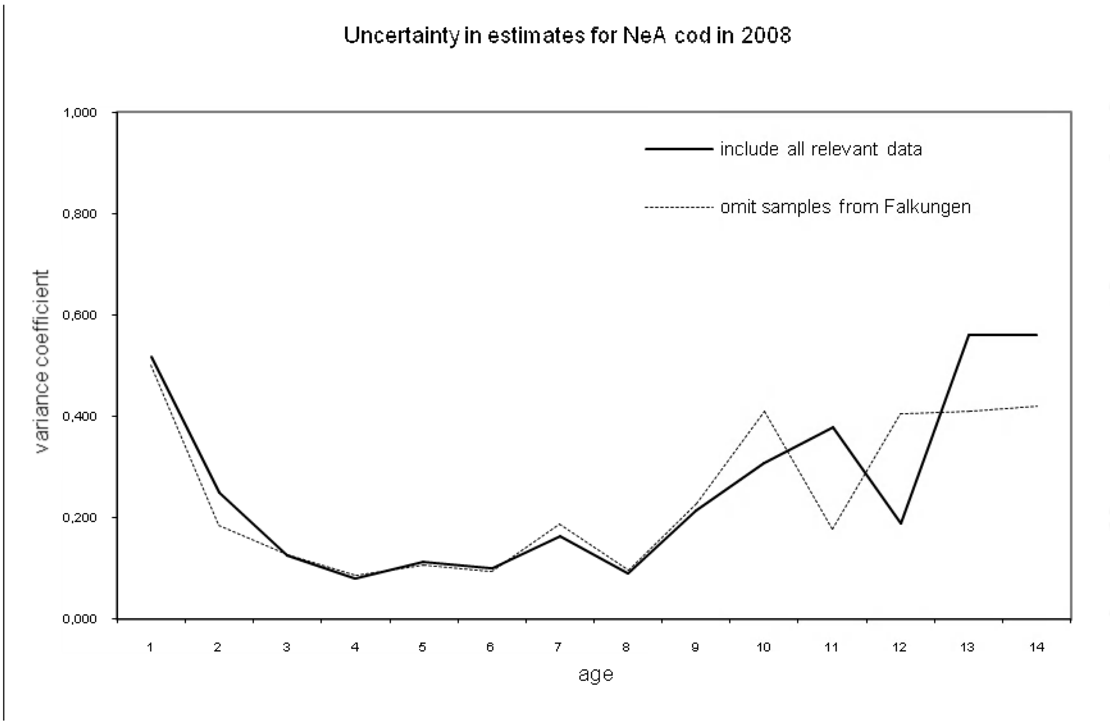


Figure 1.6. Variance coefficients for NeA cod 2008_allgears_Area_IIb.

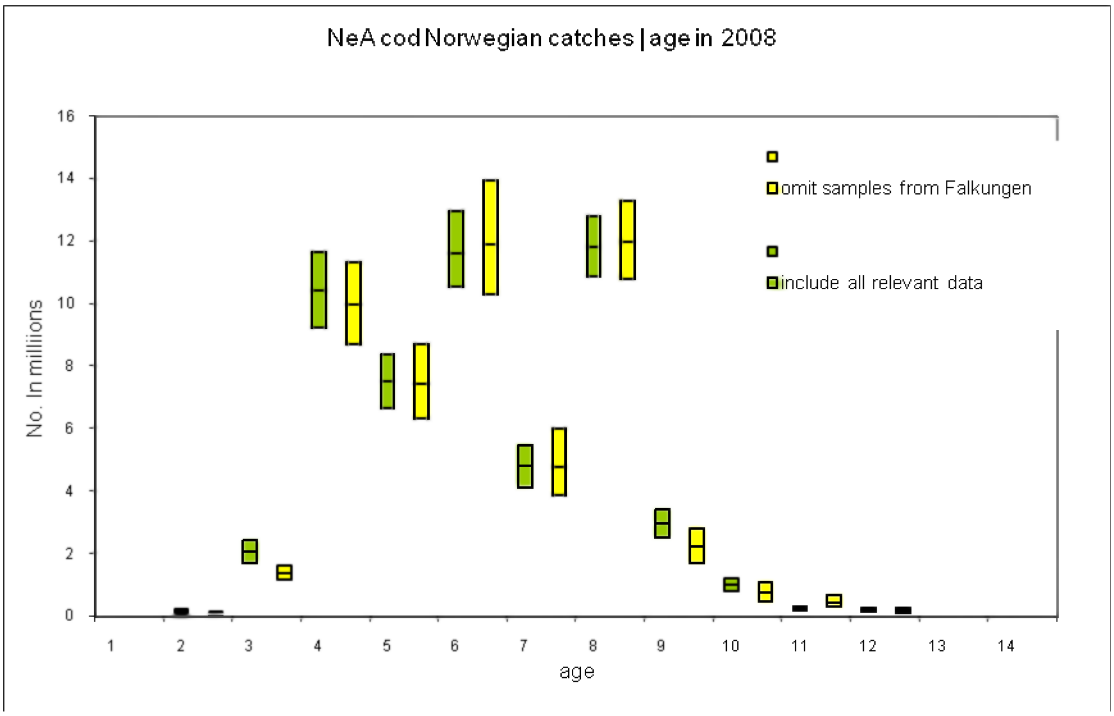


Figure 1.7. Catch-at-age for NeA cod 2008_allgears_total area.

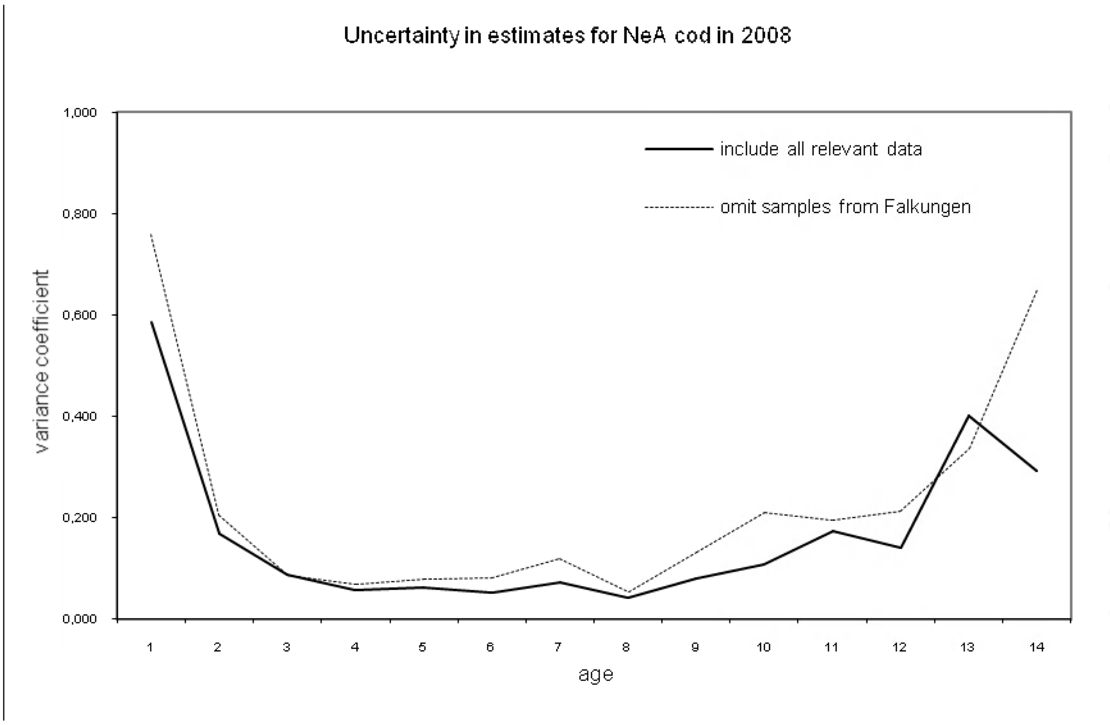


Figure 1.8. Variance coefficients for NeA cod 2008_allgears_total area.

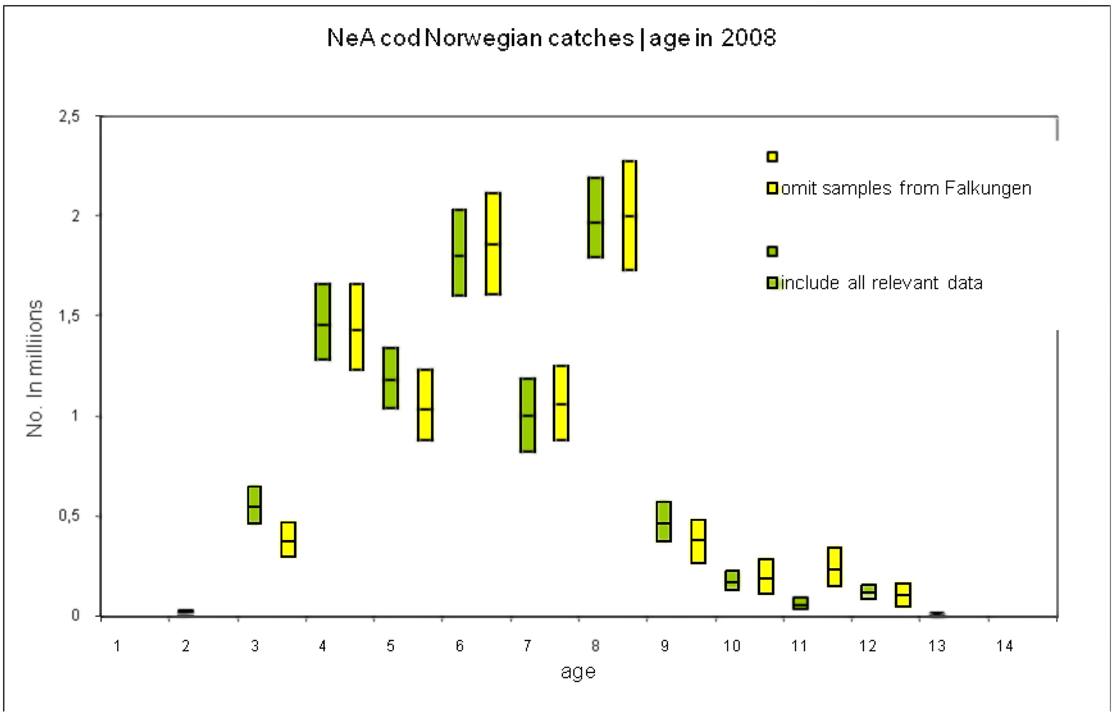


Figure 1.9. Catch-at-age for NeA cod 2008_line_total area.

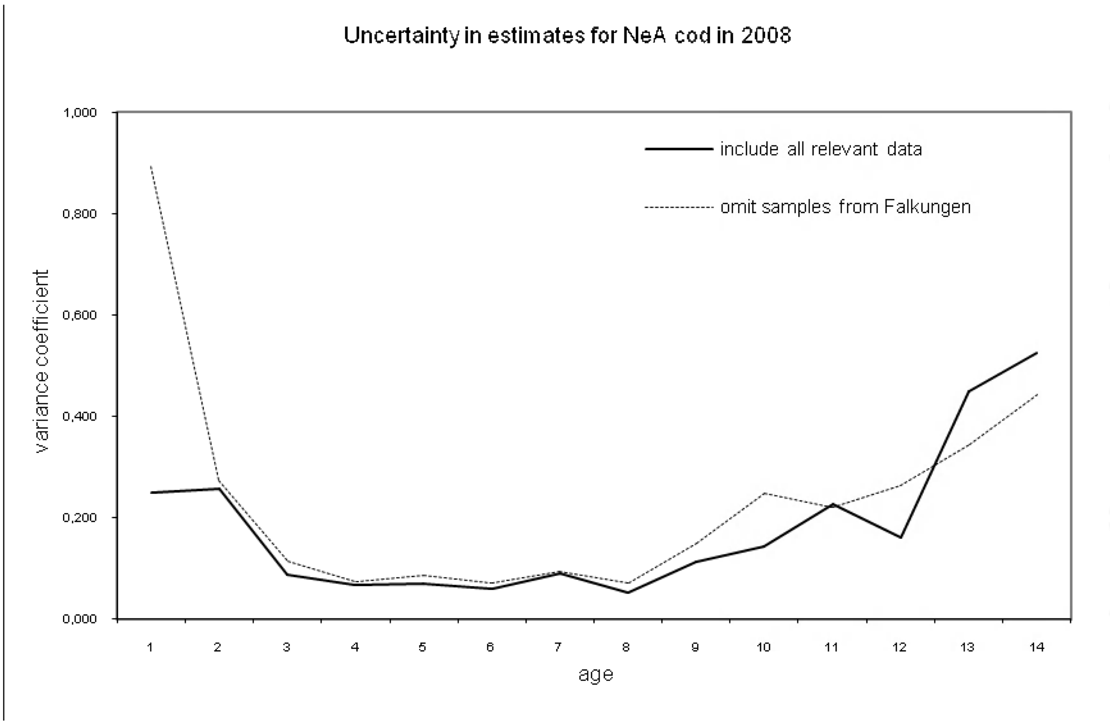


Figure 1.10. Variance coefficients for NeA cod 2008_line_total area.

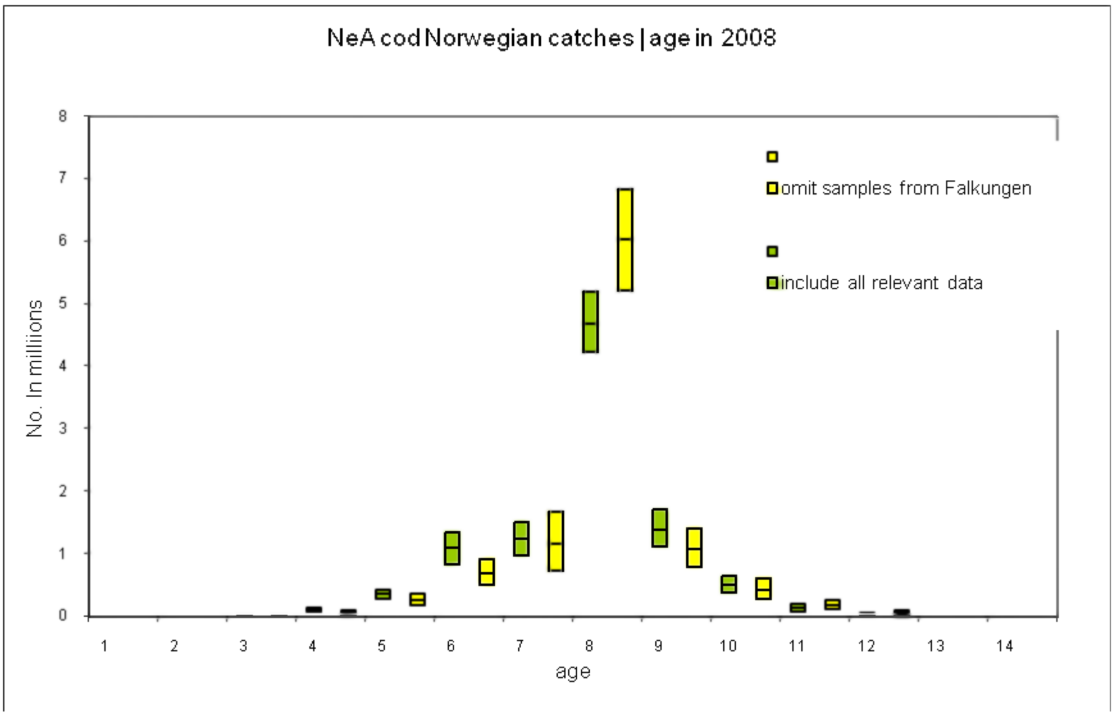


Figure 1.11. Catch-at-age for NeA cod 2008_gillnet_total area.

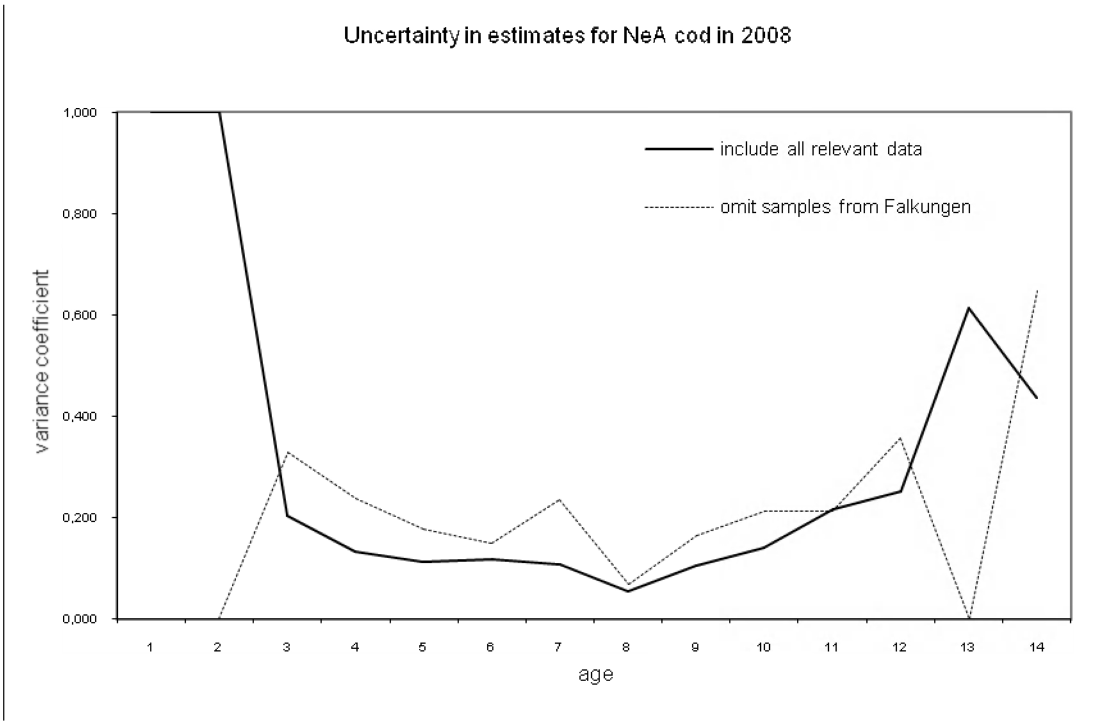


Figure 1.12. Variance coefficients for NeA cod 2008_gillnet_total area.

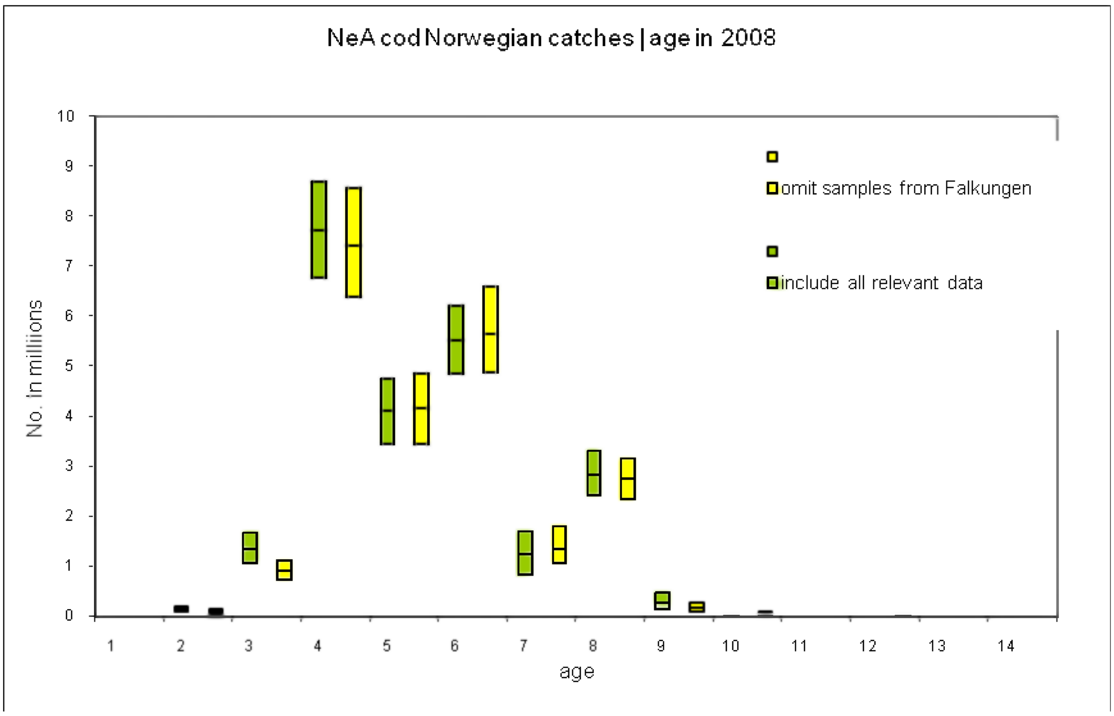


Figure 1.13. Catch-at-age for NeA cod 2008_trawl_total area.

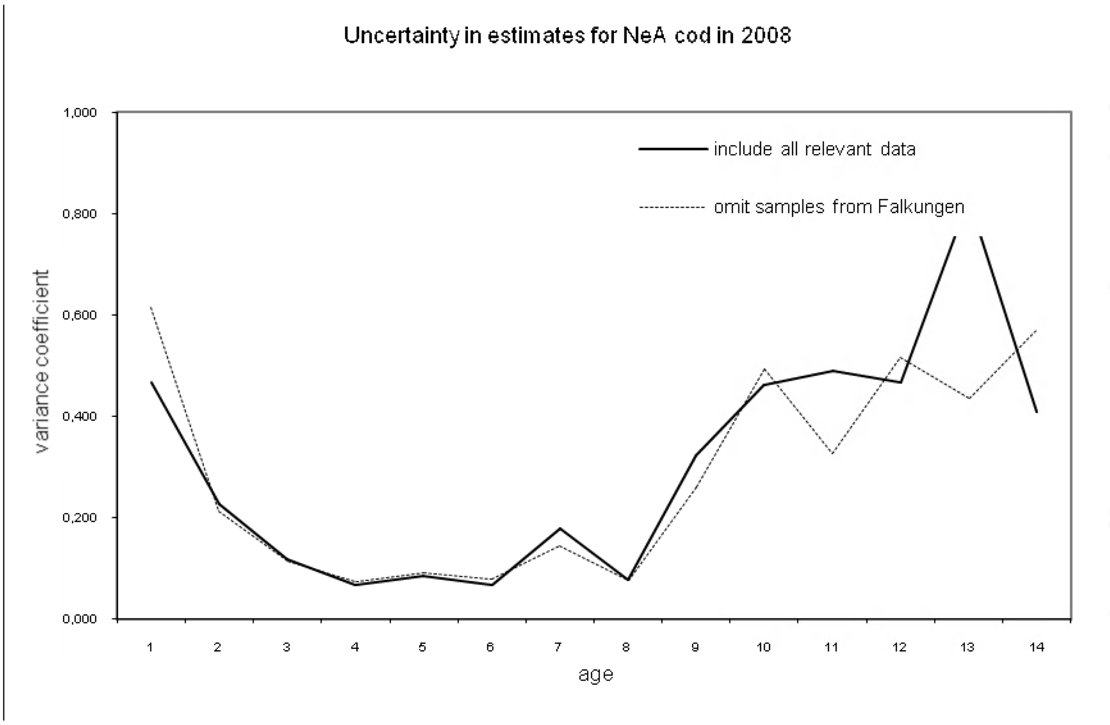


Figure 1.14. Variance coefficients for NeA cod 2008_trawl_total area.

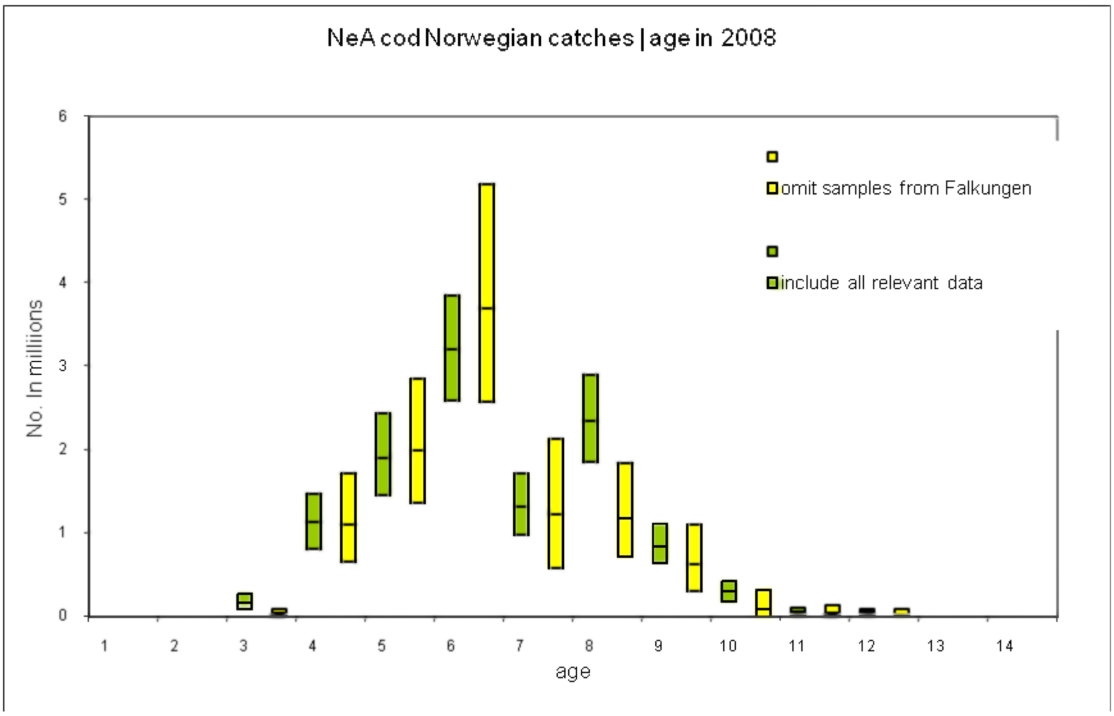


Figure 1.15. Catch-at-age for NeA cod 2008_others_total area.

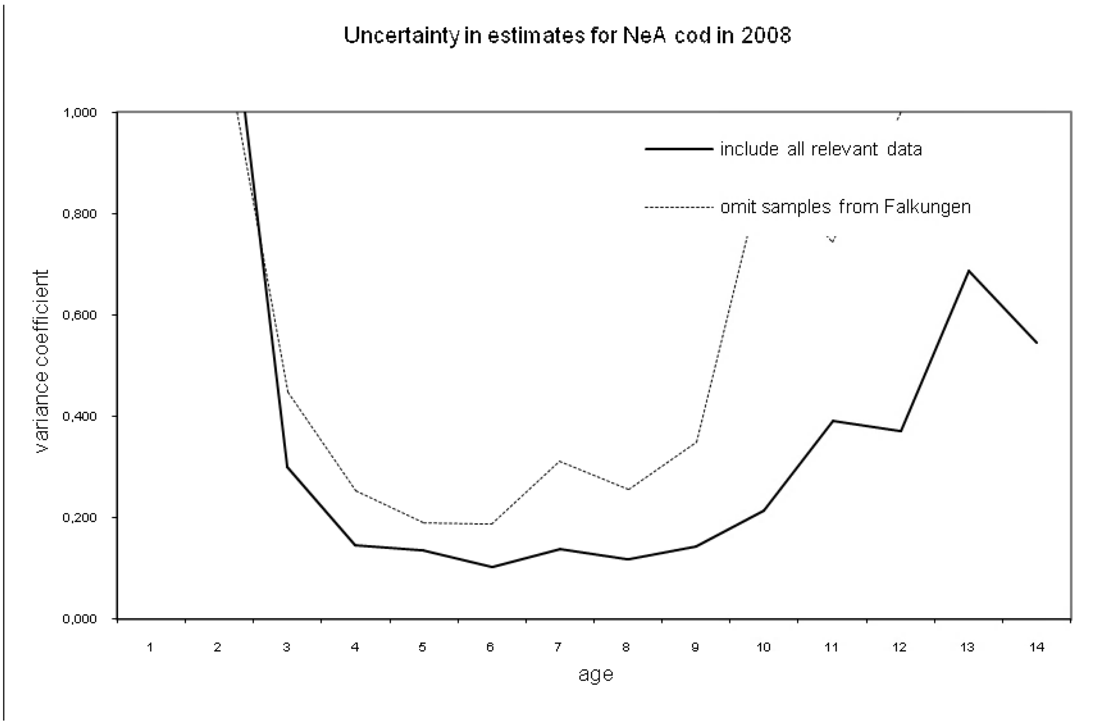


Figure 1.16. Variance coefficients for NeA cod 2008_others_total area.

In Figures 2.1–2.14 catch-at-age and uncertainty at age for NeA haddock are shown and in the same detailed level when the ambulant sampling regime is omitted. For the most abundant age groups the mean catch-at-age is quite alike but the confidence interval is wider when the ambulant sampling is excluded. For age groups up to 4 the uncertainty increases as for age groups above age 10. In general the confidence interval is wider for most age groups than for NeA cod. More uncertainty is seen for "others" (Danish seine, gillnet) where the ambulant sampling covers 90%, 20% respectively of the age samples.

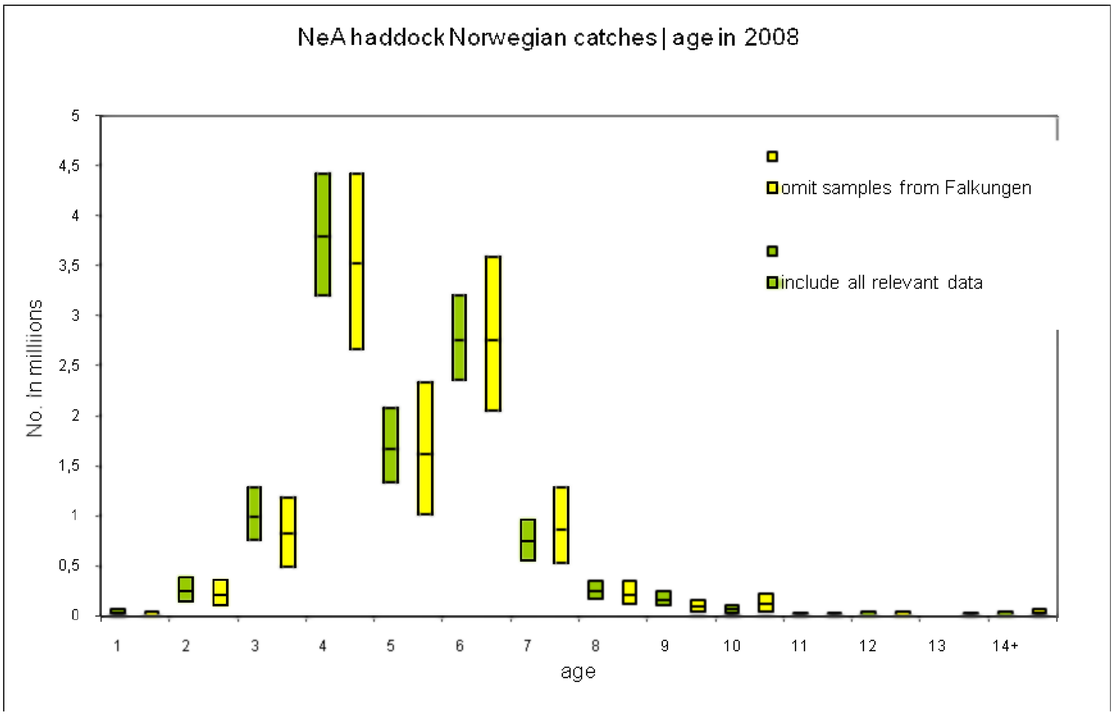


Figure 2.1. Catch-at-age for NeA haddock 2008_allgears_Area_I.

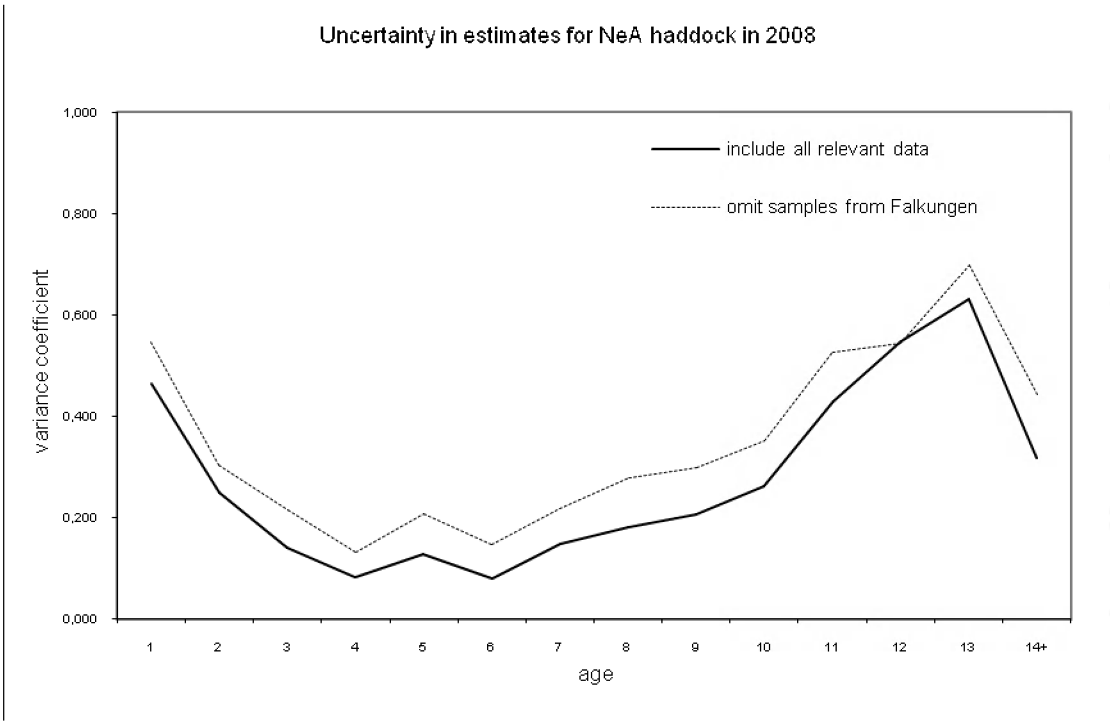


Figure 2.2. Variance coefficients for NeA haddock 2008_allgears_Area_I.

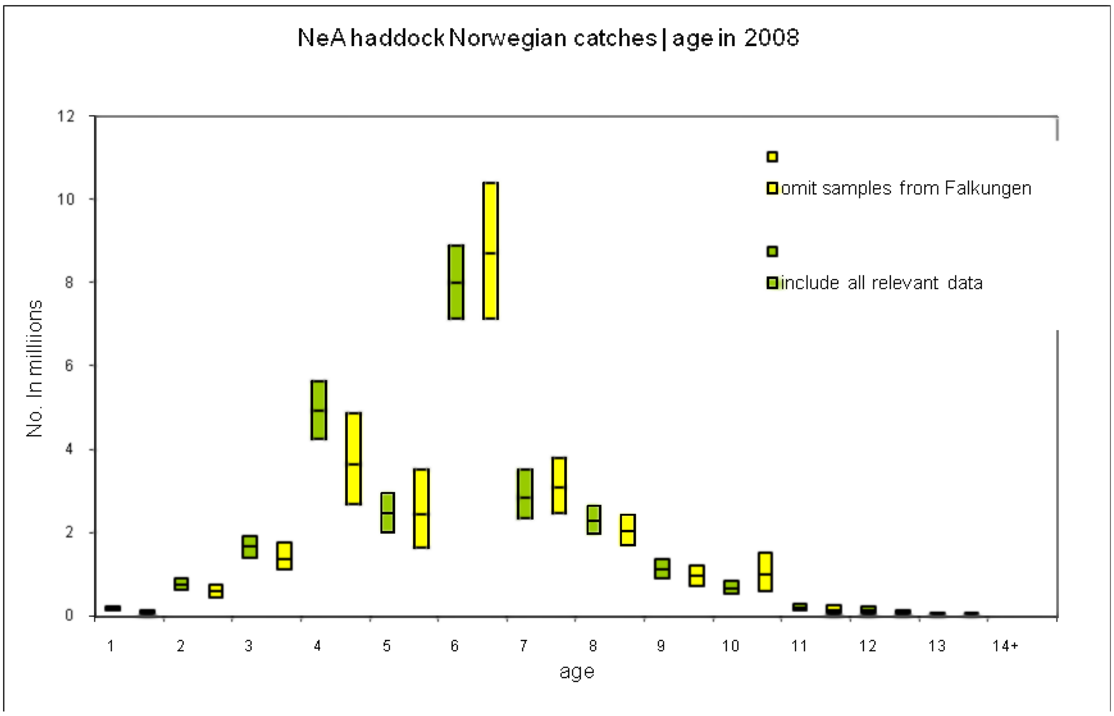


Figure 2.3. Catch-at-age for NeA haddock 2008_allgears_Area_IIa.

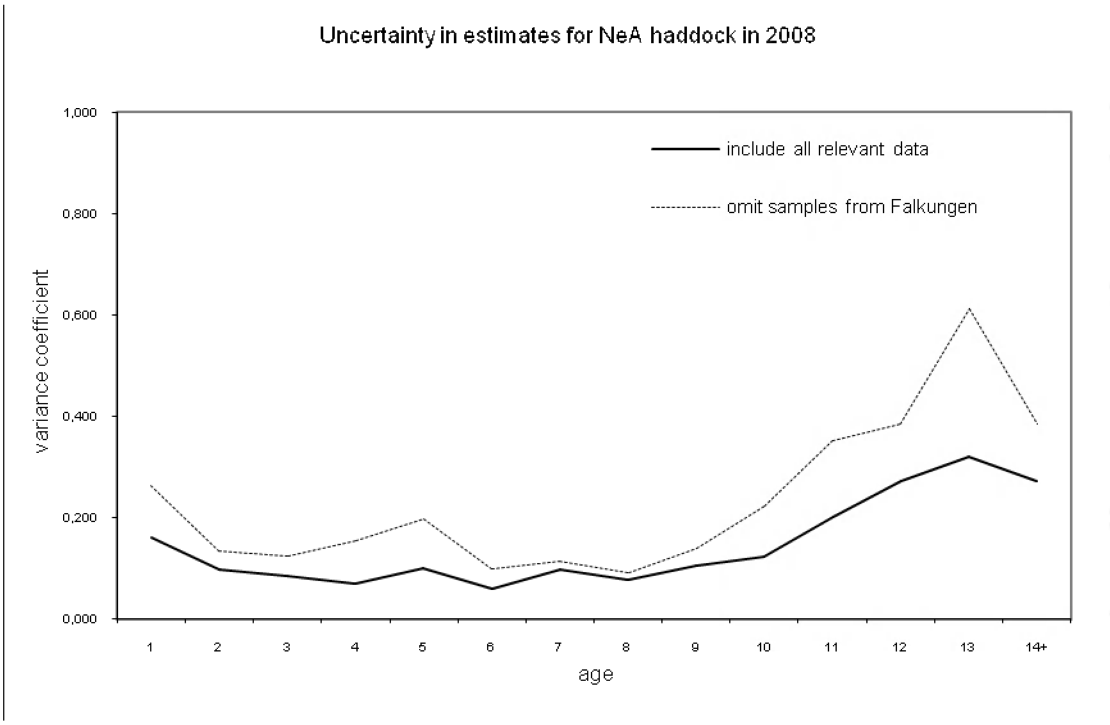


Figure 2.4. Variance coefficients for NeA haddock 2008_allgears_Area_IIa.

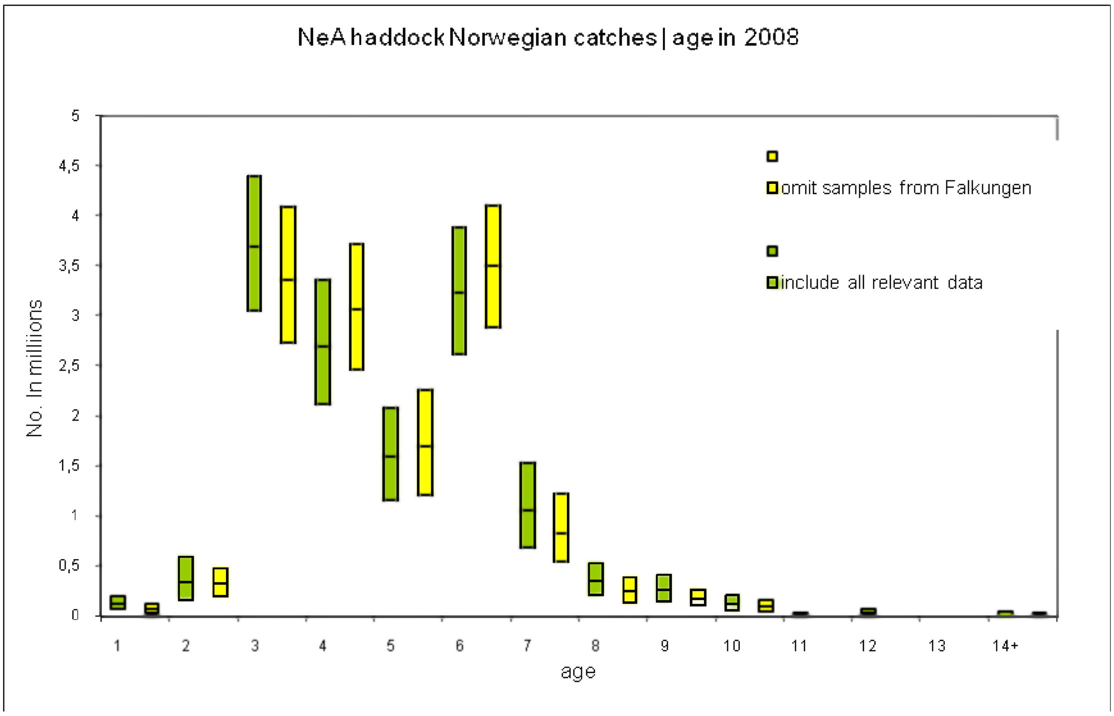


Figure 2.5. Catch-at-age for NeA haddock 2008_allgears_Area_IIb.

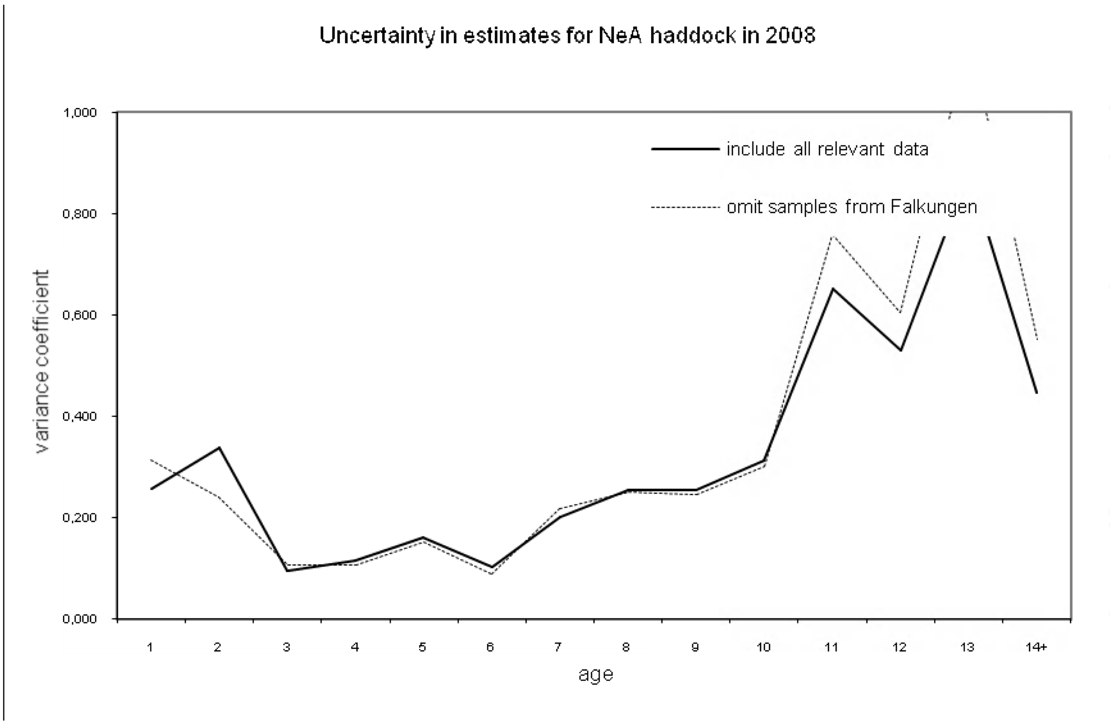


Figure 2.6. Variance coefficients for NeA haddock 2008_allgears_Area_IIb.

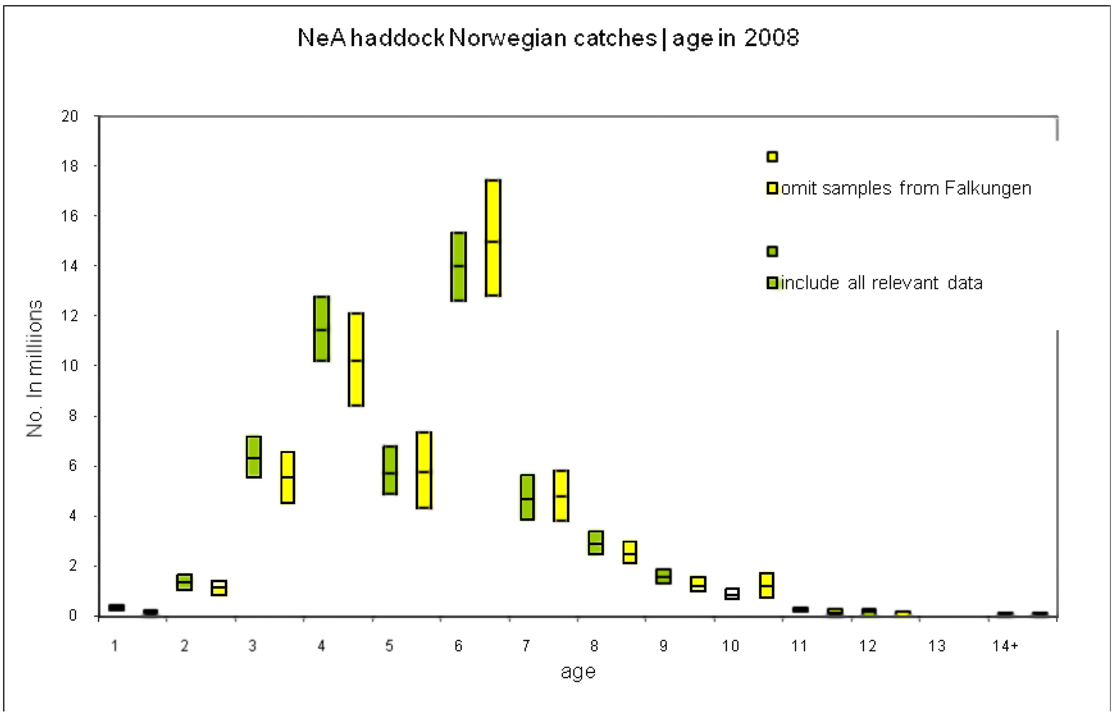


Figure 2.7. Catch-at-age for NeA haddock 2008_allgears_total area.

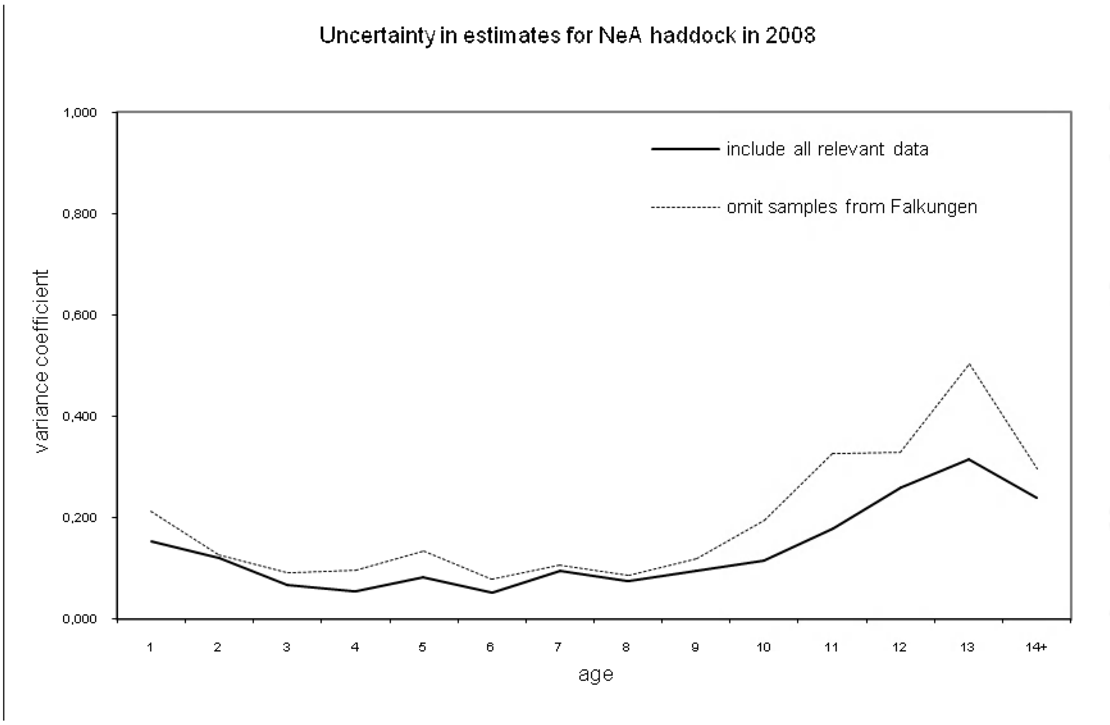


Figure 2.8. Variance coefficients for NeA haddock 2008_allgears_total area.

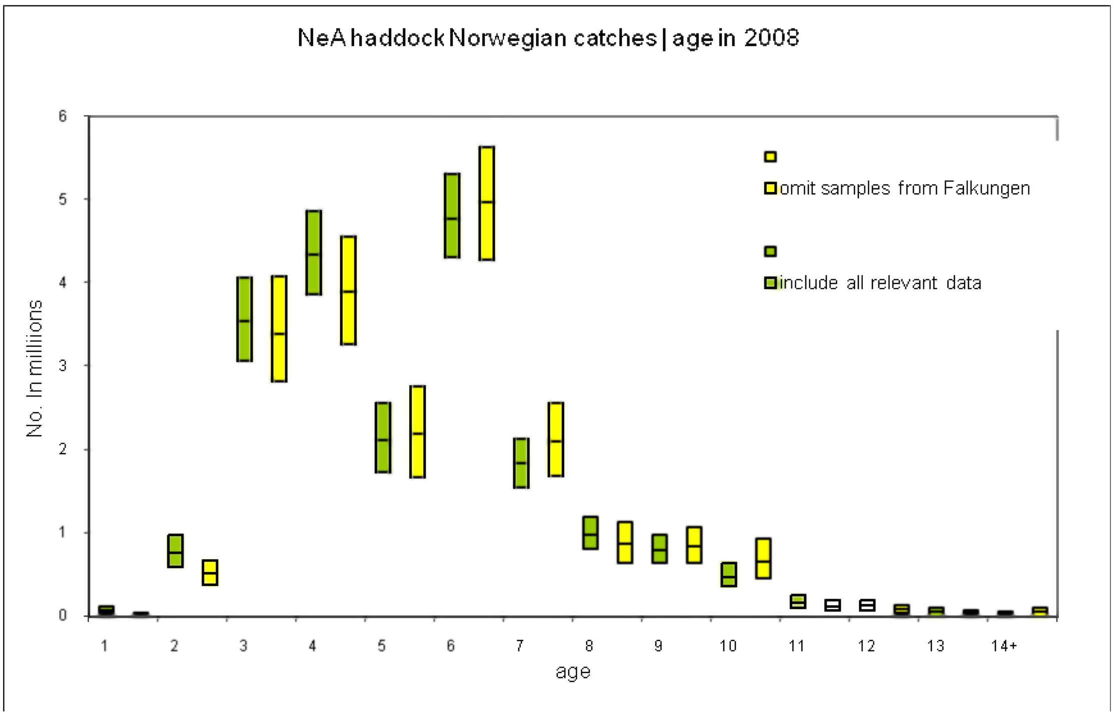


Figure 2.9. Catch-at-age for NeA haddock 2008_line_total area.

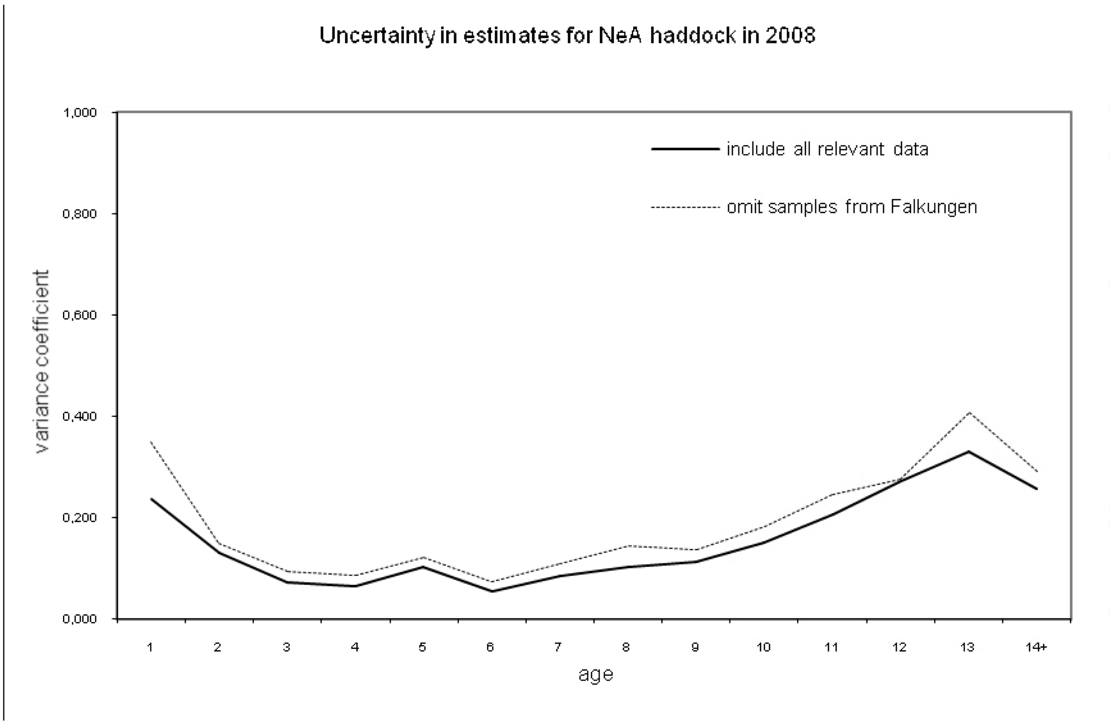


Figure 2.10. Variance coefficients for NeA haddock 2008_line_total area.

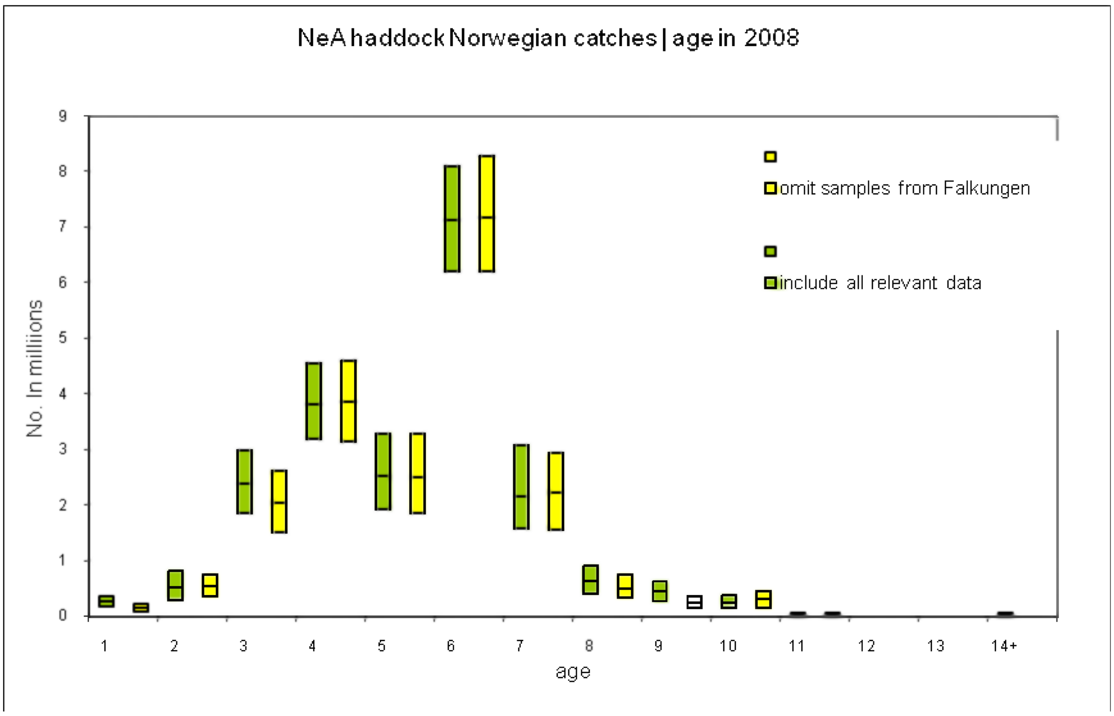


Figure 2.11. Catch-at-age for NeA haddock 2008_trawl_total area.

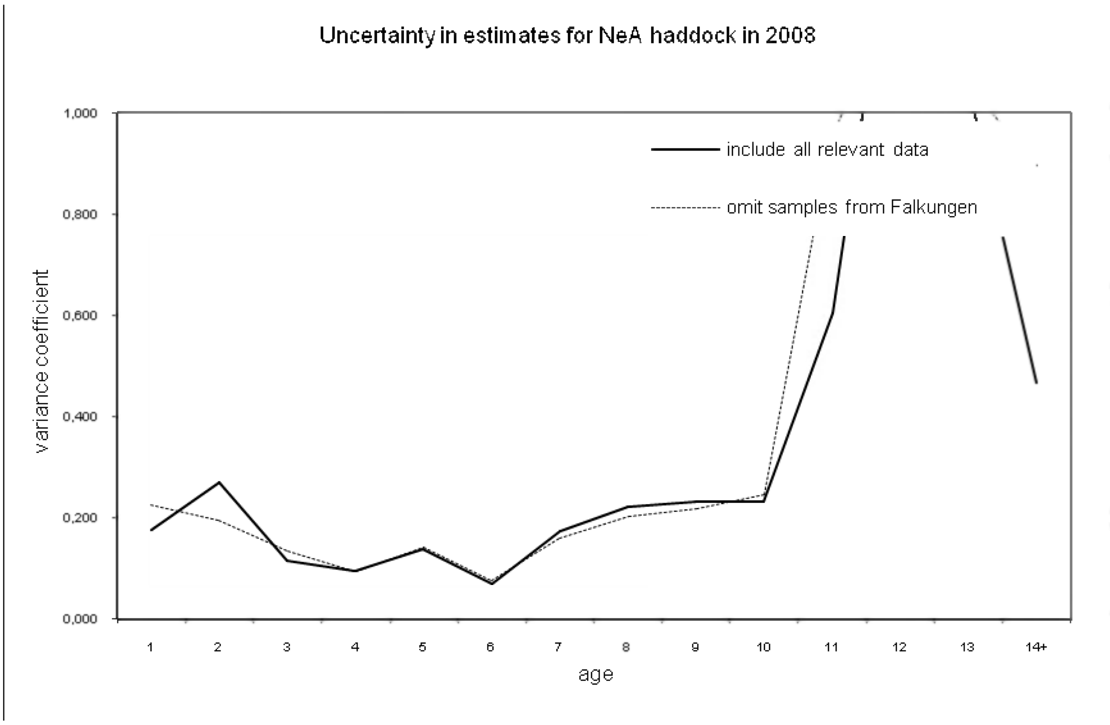


Figure 2.12. Variance coefficients for NeA haddock 2008_trawl_total area.

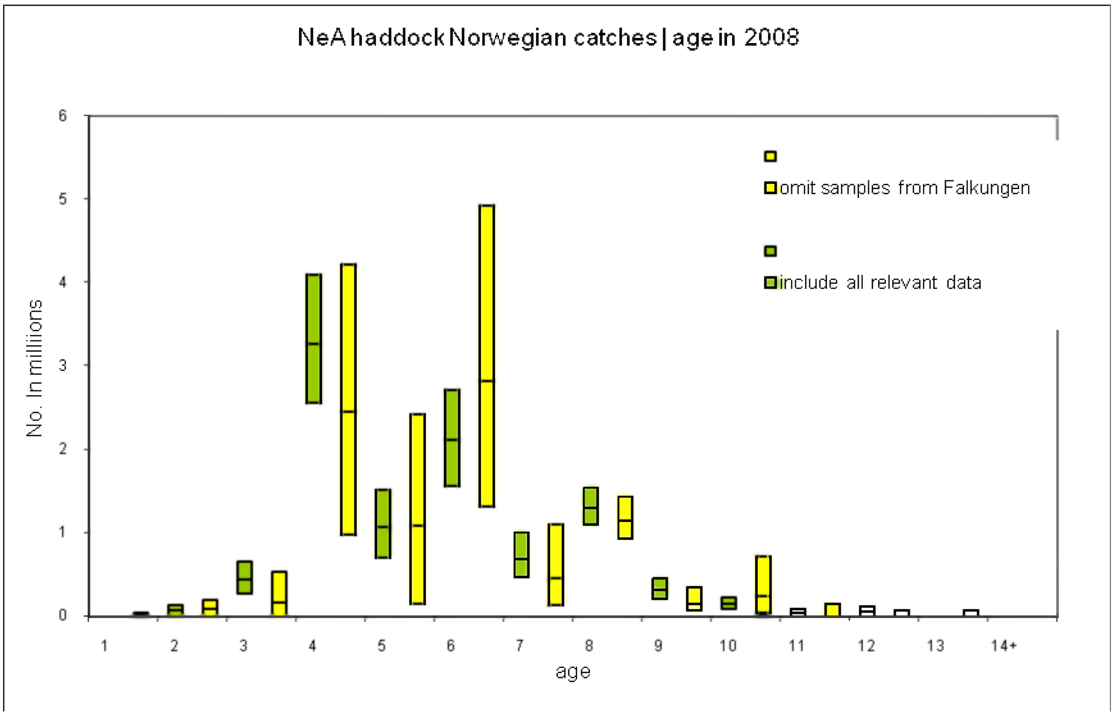


Figure 2.13. Catch-at-age for NeA haddock 2008_others_total area.

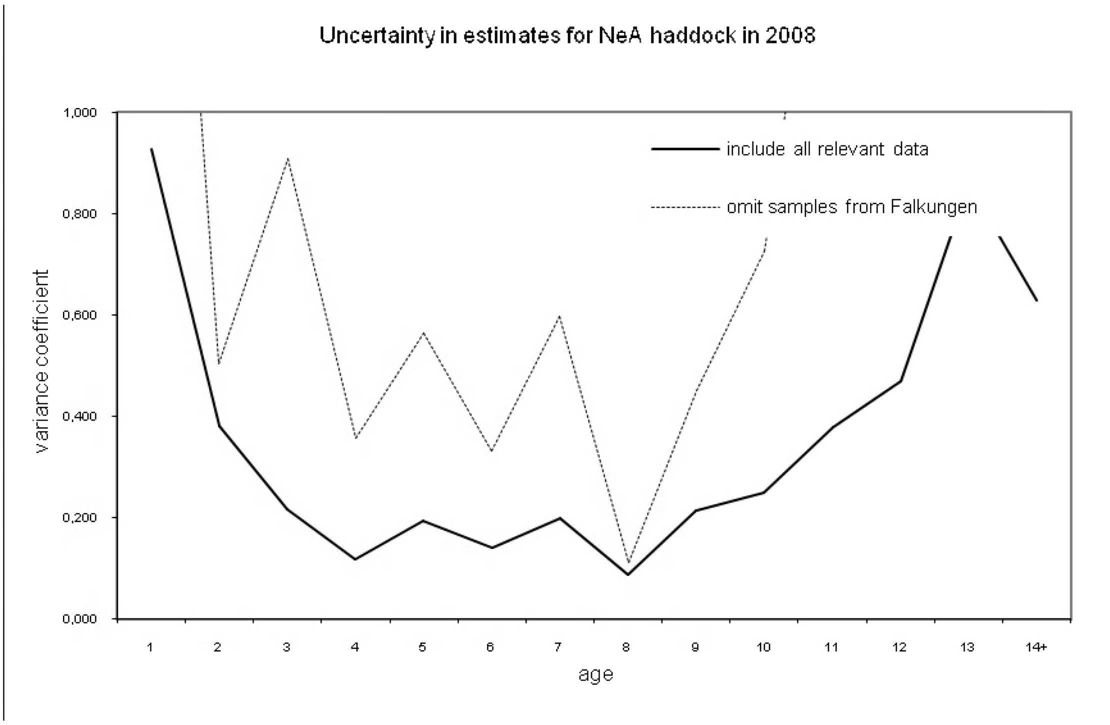


Figure 2.14. Variance coefficients for NeA haddock 2008_others_total area.

In Figures 3.1–3.16 catch-at-age and uncertainty at age for NeA saithe are shown and in the same detailed level when the ambulant sampling regime is omitted. For the most abundant age groups the mean catch-at-age is more alike but the confidence interval is wider when the ambulant sampling is excluded for all age groups. For age groups up to 3 the uncertainty increases as for age groups above age 8. In general the confidence interval is wider for most age groups than for NeA haddock. More uncertainty is seen for Gillnet and "others" (Danish seine, line) where the ambulant sampling covers respectively 50%, (100%, 88%) of the age samples.

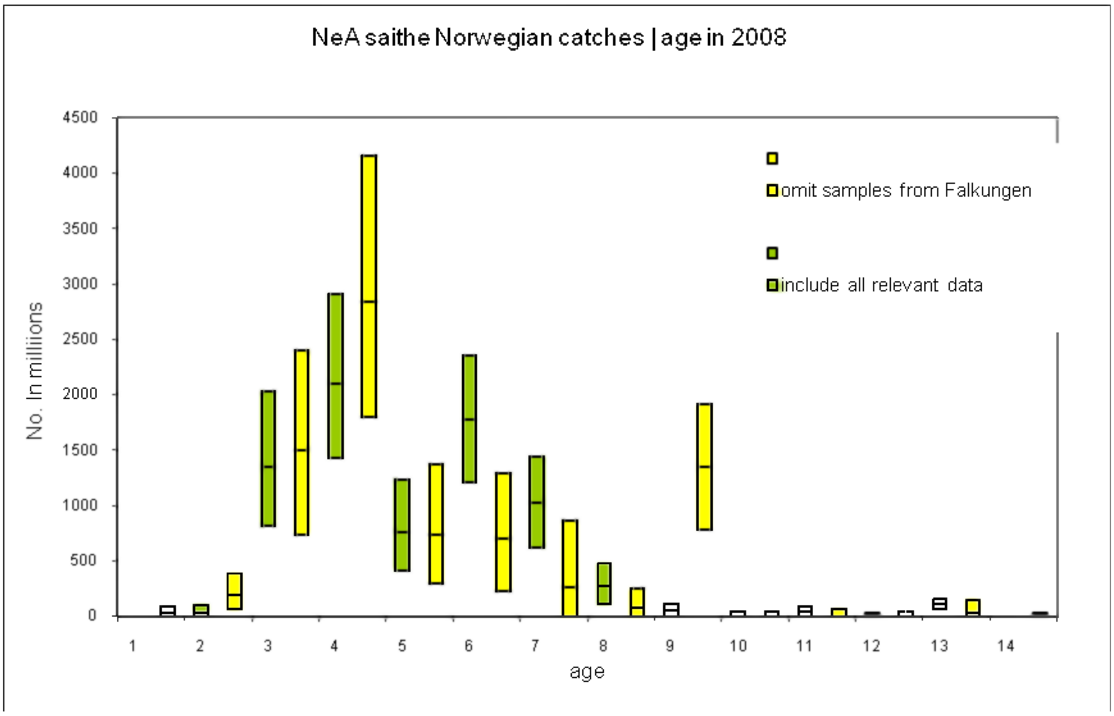


Figure 3.1. Catch-at-age for NeA saithe 2008_allgears_Area_I.

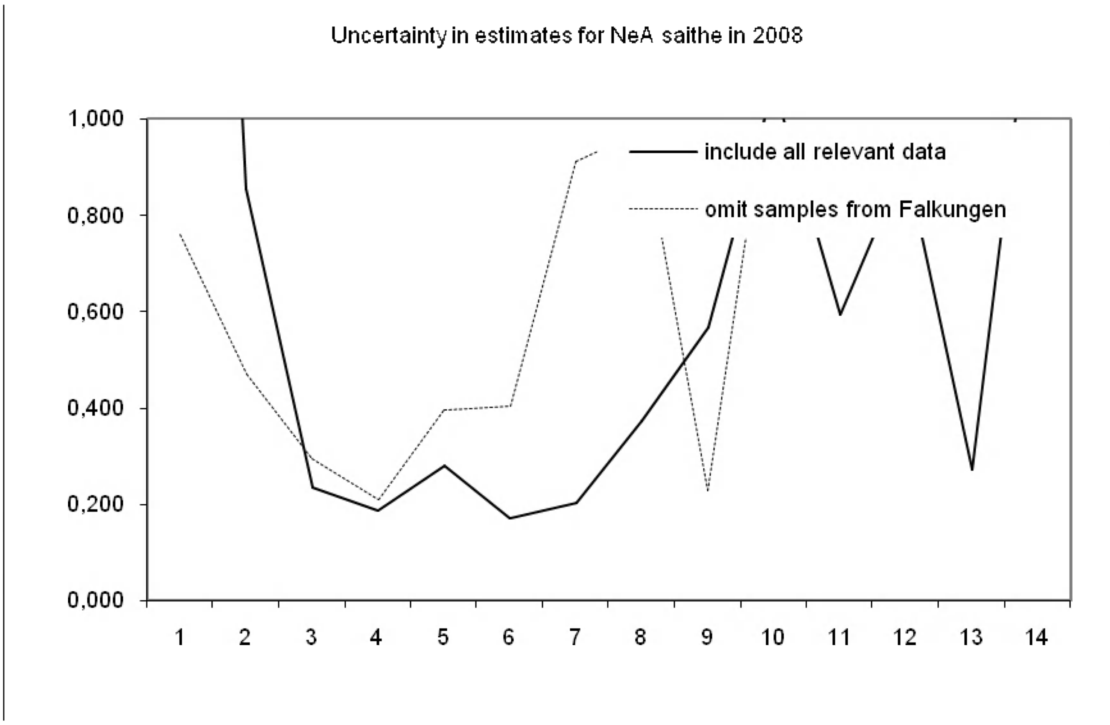


Figure 3.2. Variance coefficients for NeA saithe 2008_allgears_Area_I.

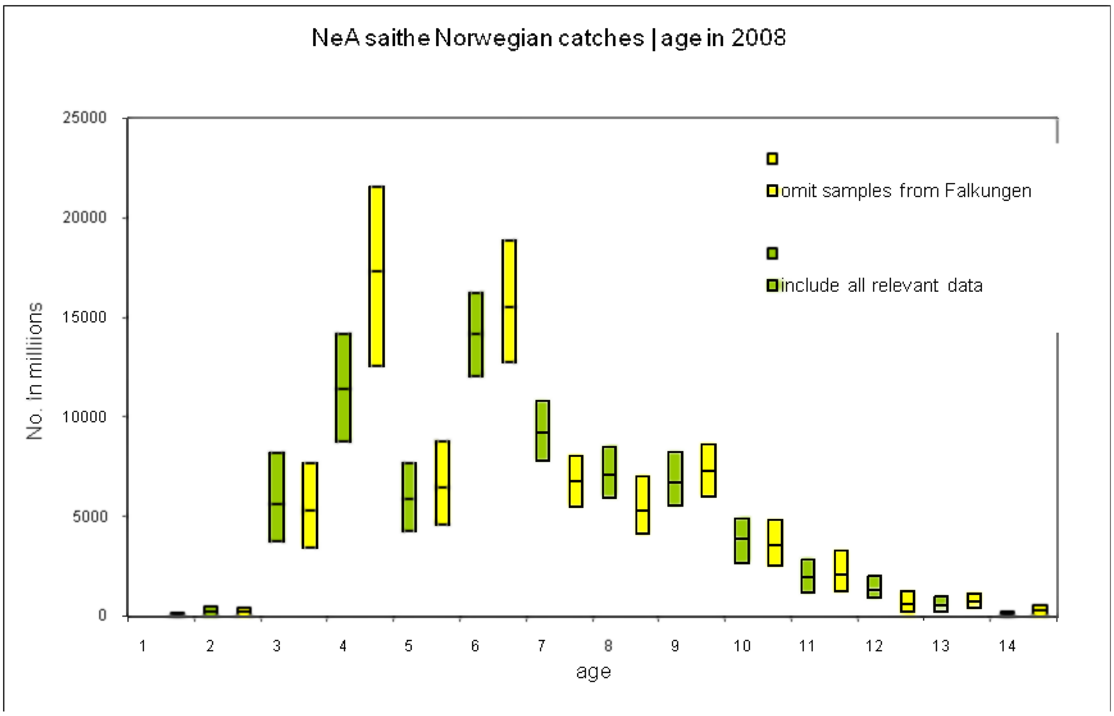


Figure 3.3. Catch-at-age for NeA saithe 2008_allgears_Area_IIa.

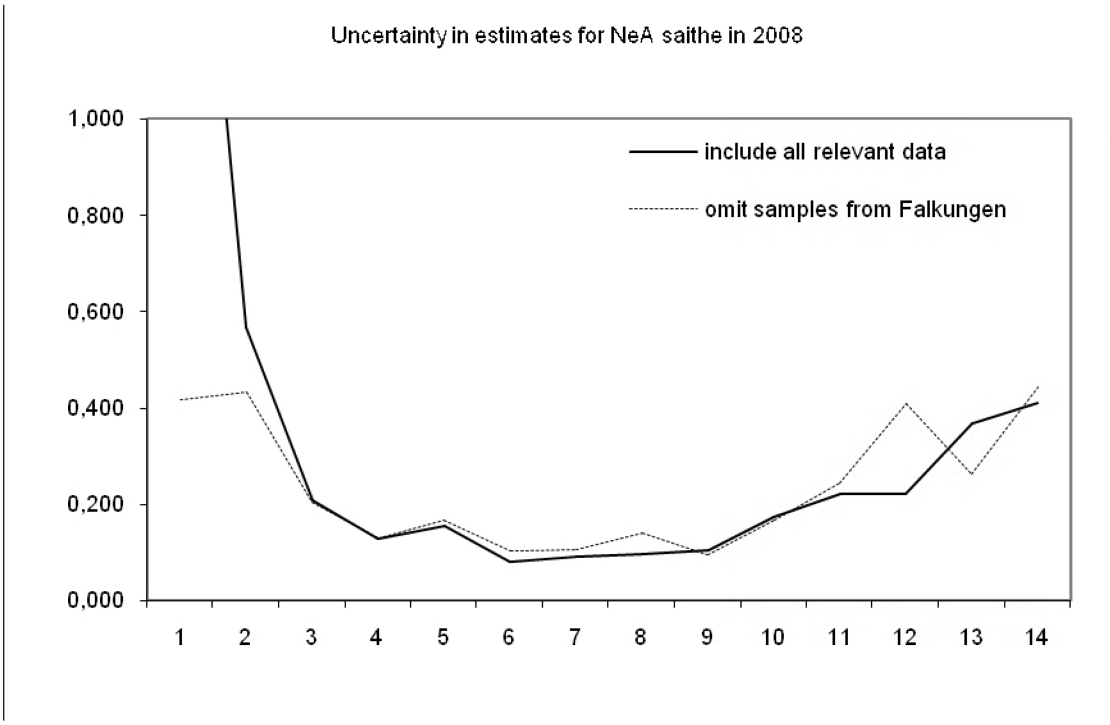


Figure 3.4. Variance coefficients for NeA saithe 2008_allgears_Area_IIa.

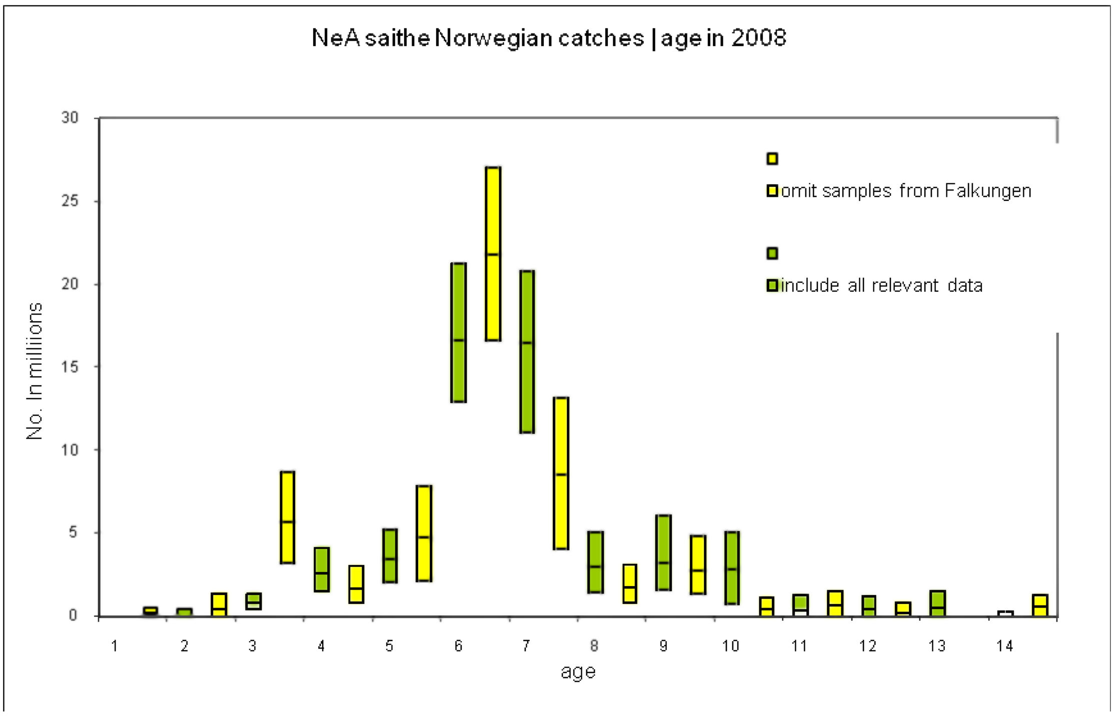


Figure 3.5. Catch-at-age for NeA saithe 2008_allgears_Area_IIb.

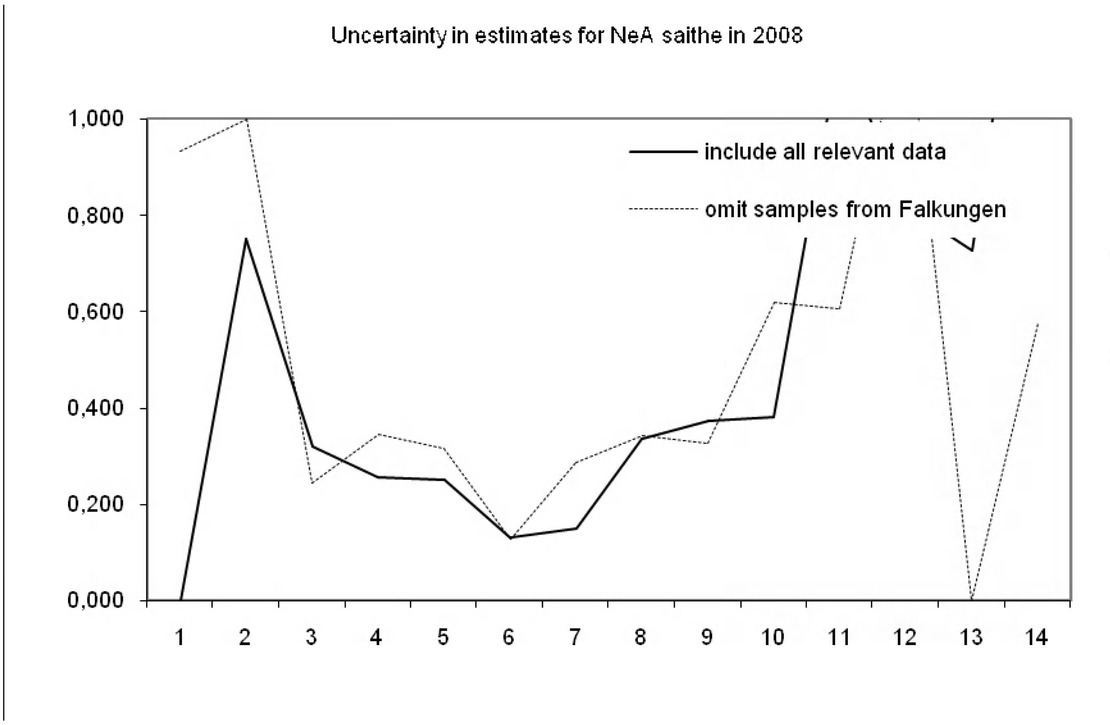


Figure 3.6. Variance coefficients for NeA saithe 2008_allgears_Area_IIb.

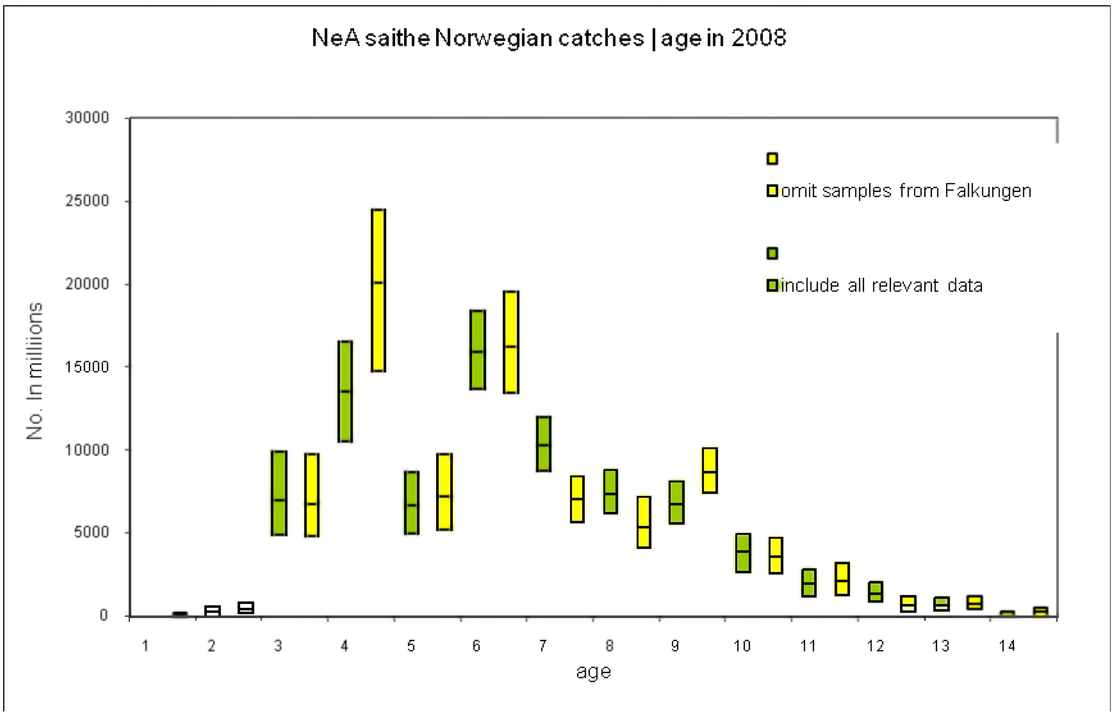


Figure 3.7. Catch-at-age for NeA saithe 2008_allgears_total area.

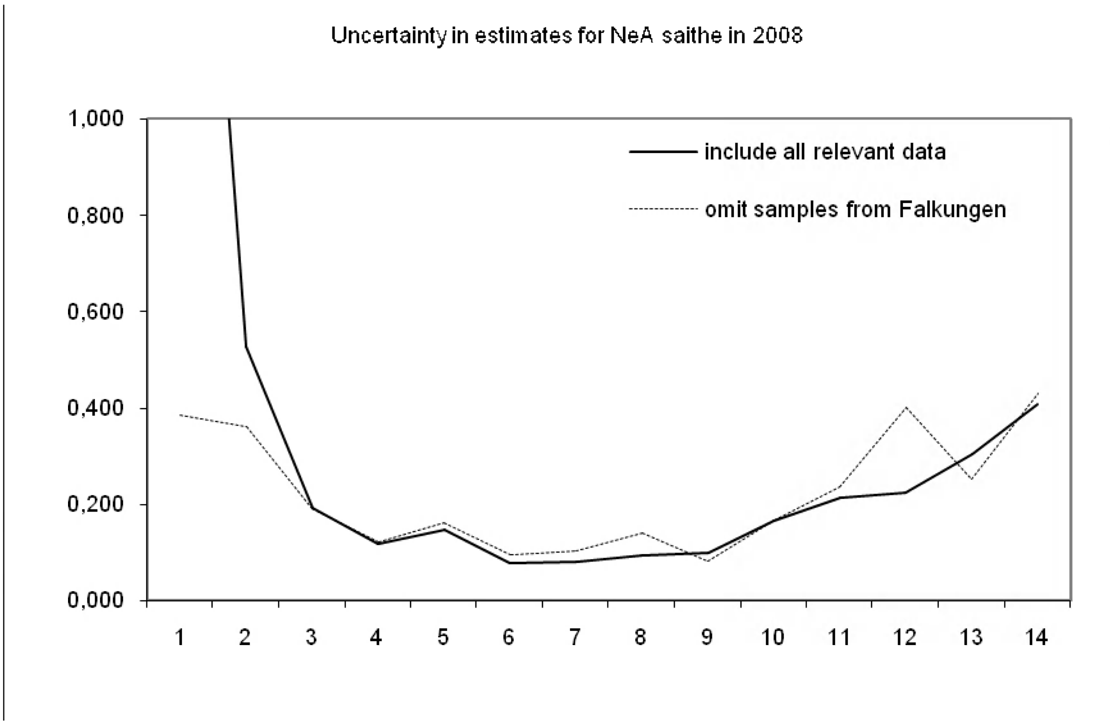


Figure 3.8. Variance coefficients for NeA saithe 2008_allgears_total area.

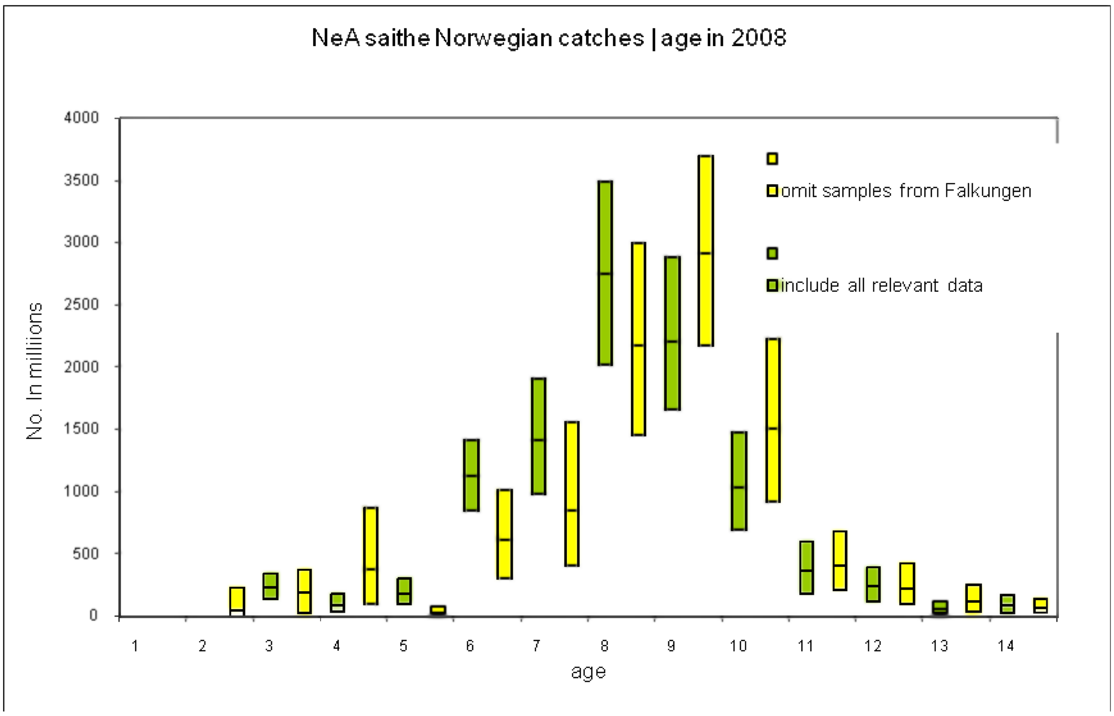


Figure 3.9. Catch-at-age for NeA saithe 2008_gillnet_total area.

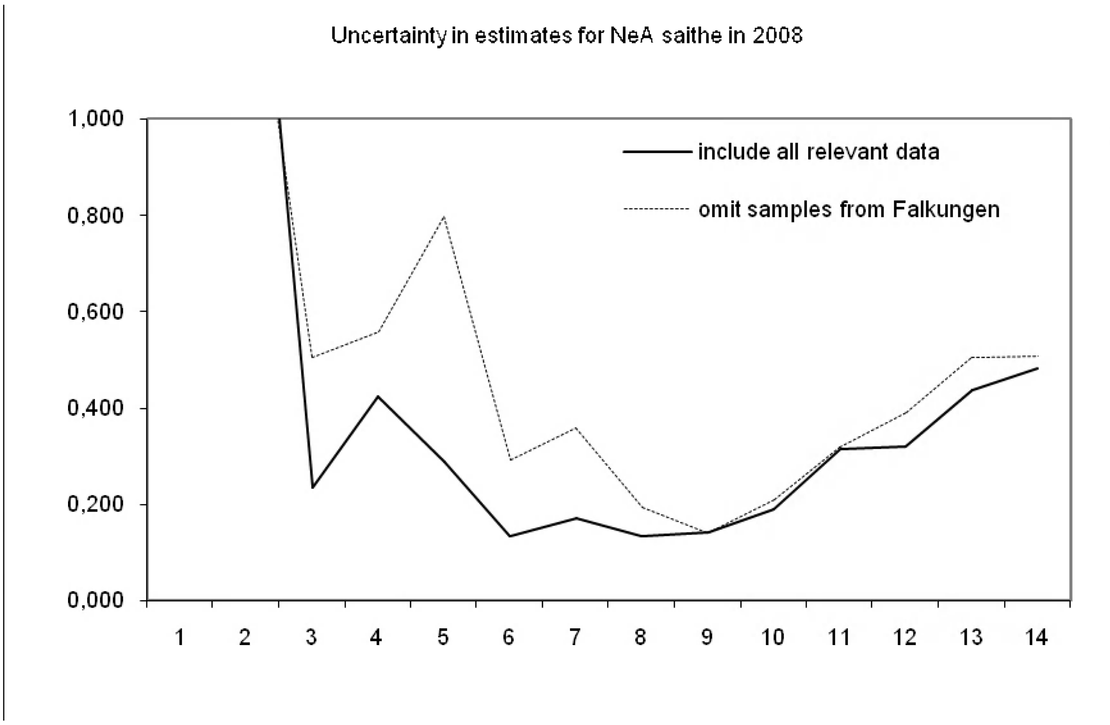


Figure 3.10. Variance coefficients for NeA saithe 2008_gillnet_total area.

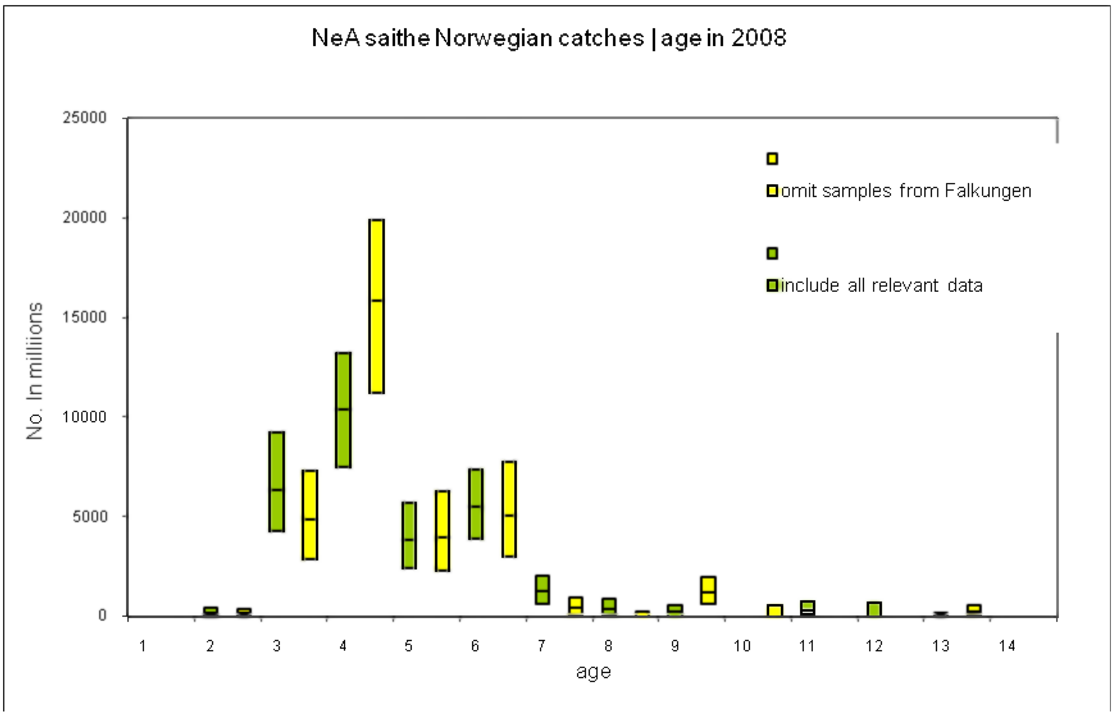


Figure 3.11. Catch-at-age for NeA saithe 2008_purse seine_total area.

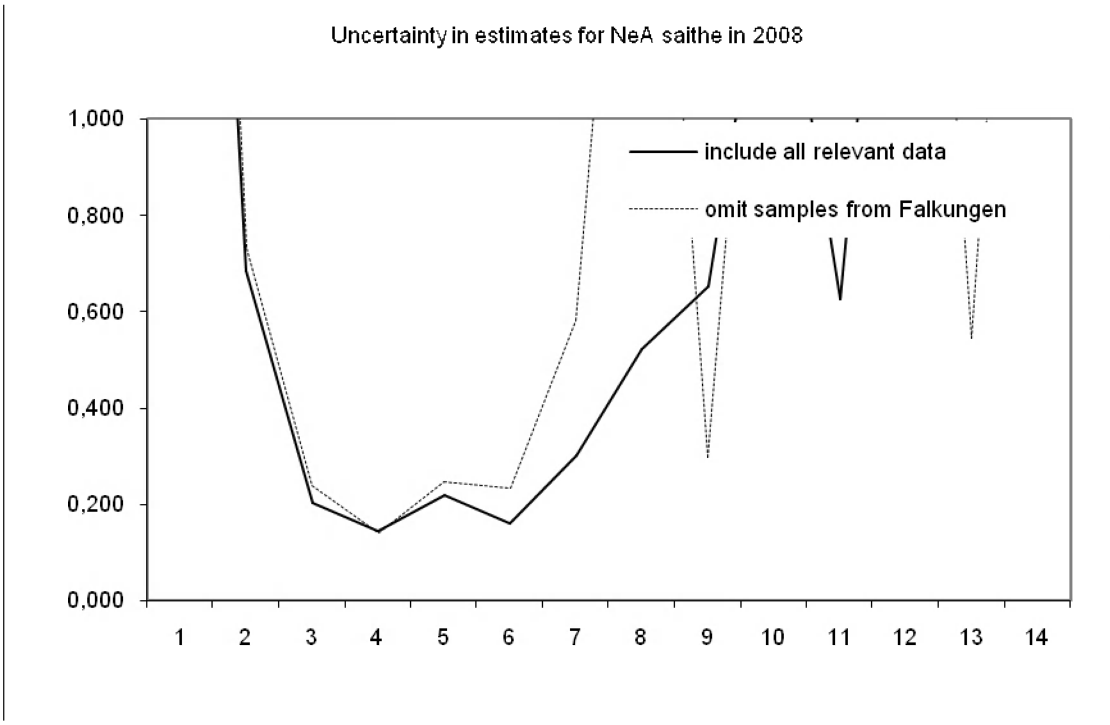


Figure 3.12. Variance coefficients for NeA saithe 2008_purse seine_total area.

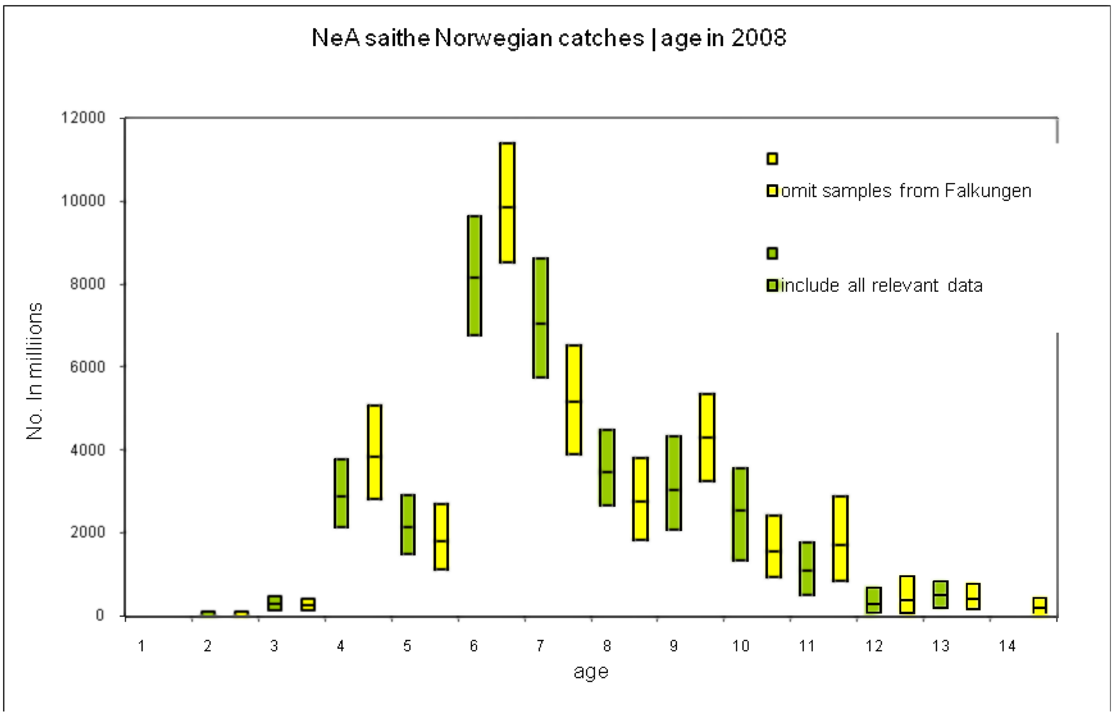


Figure 3.13. Catch-at-age for NeA saithe 2008_trawl_total area.

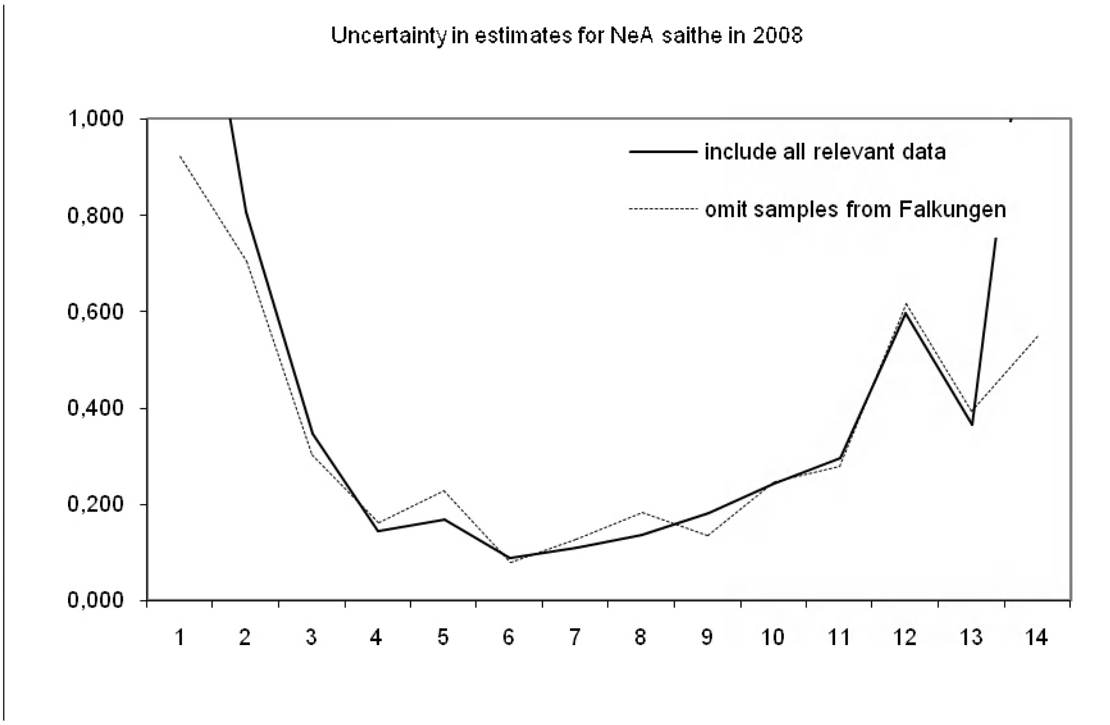


Figure 3.14. Variance coefficients for NeA saithe 2008_trawl_total area.

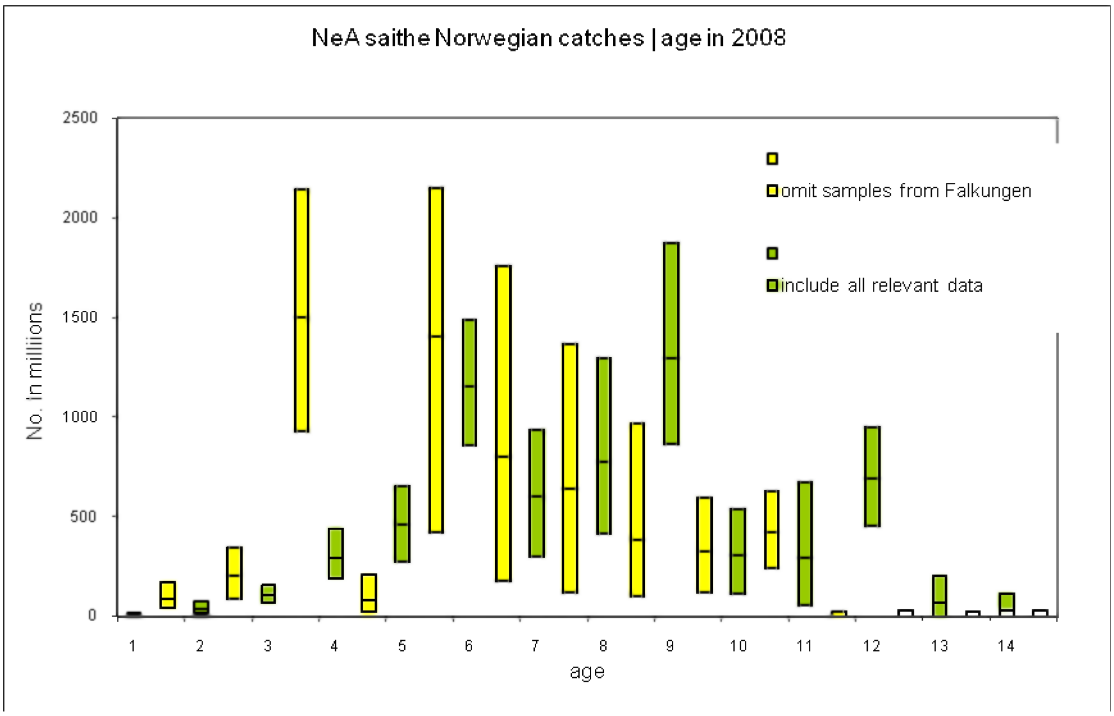


Figure 3.15. Catch-at-age for NeA saithe 2008_others_total area.

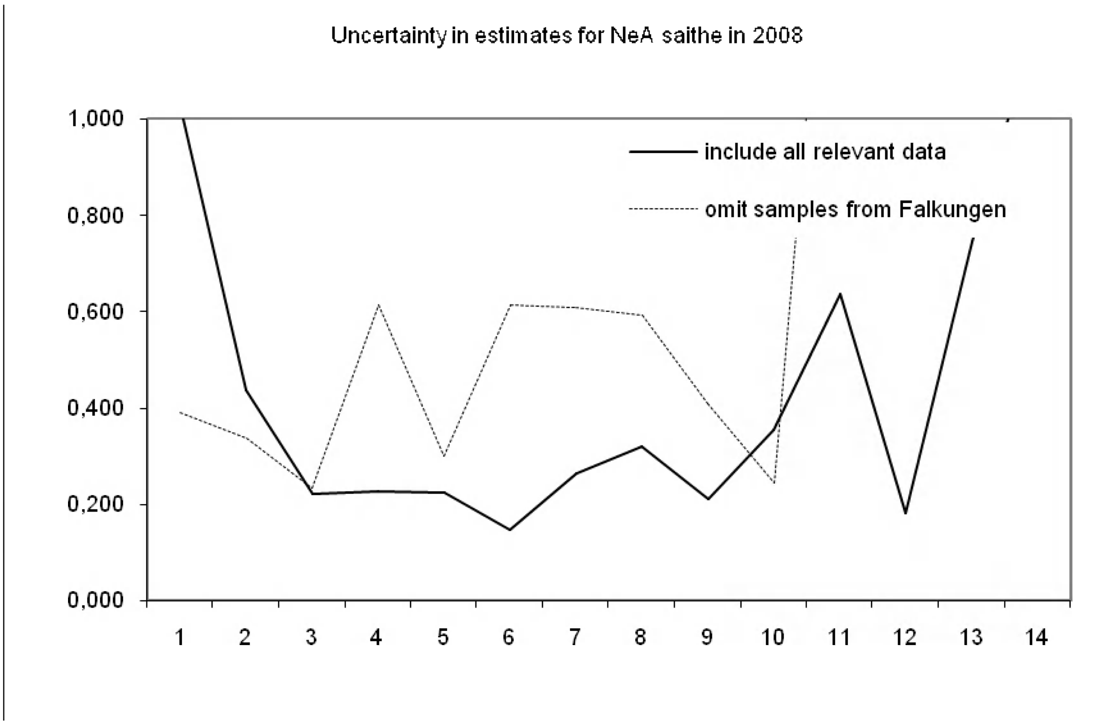


Figure 3.16. Variance coefficients for NeA saithe 2008_others_total area.

Acknowledgements

Summary

The purpose is to estimate catch-at-age in the Norwegian fishery by at least ICES division and proportion of sampling allocated to that ICES division over the proportion of landings in the same area.

i) Are there any important divisions that are not being sampled and

ii) Are there divisions that are being over sampled?

One should be able to redirect the effort so that in each division a proportional sampling effort is allocated.

ECA estimate catch-at-age for categories of cells. Each cell is a single or combination of area, gear and season. Since sample coverage has changed lately it will influence the capability to estimate distinct categories in favour of aggregated cells. Uncertainty in estimation will increase by that since aggregated cells consists of gears with different selection pattern, seasons with different growth and areas with different clusters of the stock.

References

ICES. WKROUND Report. 2010. ICES ADVISORY COMMITTEE. ICES CM 2010/ACOM:36. Report of the Benchmark Workshop on Roundfish. 9–16 February 2010, Copenhagen, Denmark. 183pp.

Hirst, D., Aanes, S., Storvik, G. and Tvete, I.F. 2004. Estimating catch at age from Market sampling data using a Bayesian hierarchical model. Journal of the Royal statistical society. Series c, applied statistics, 53: 1–14.

Appendix A

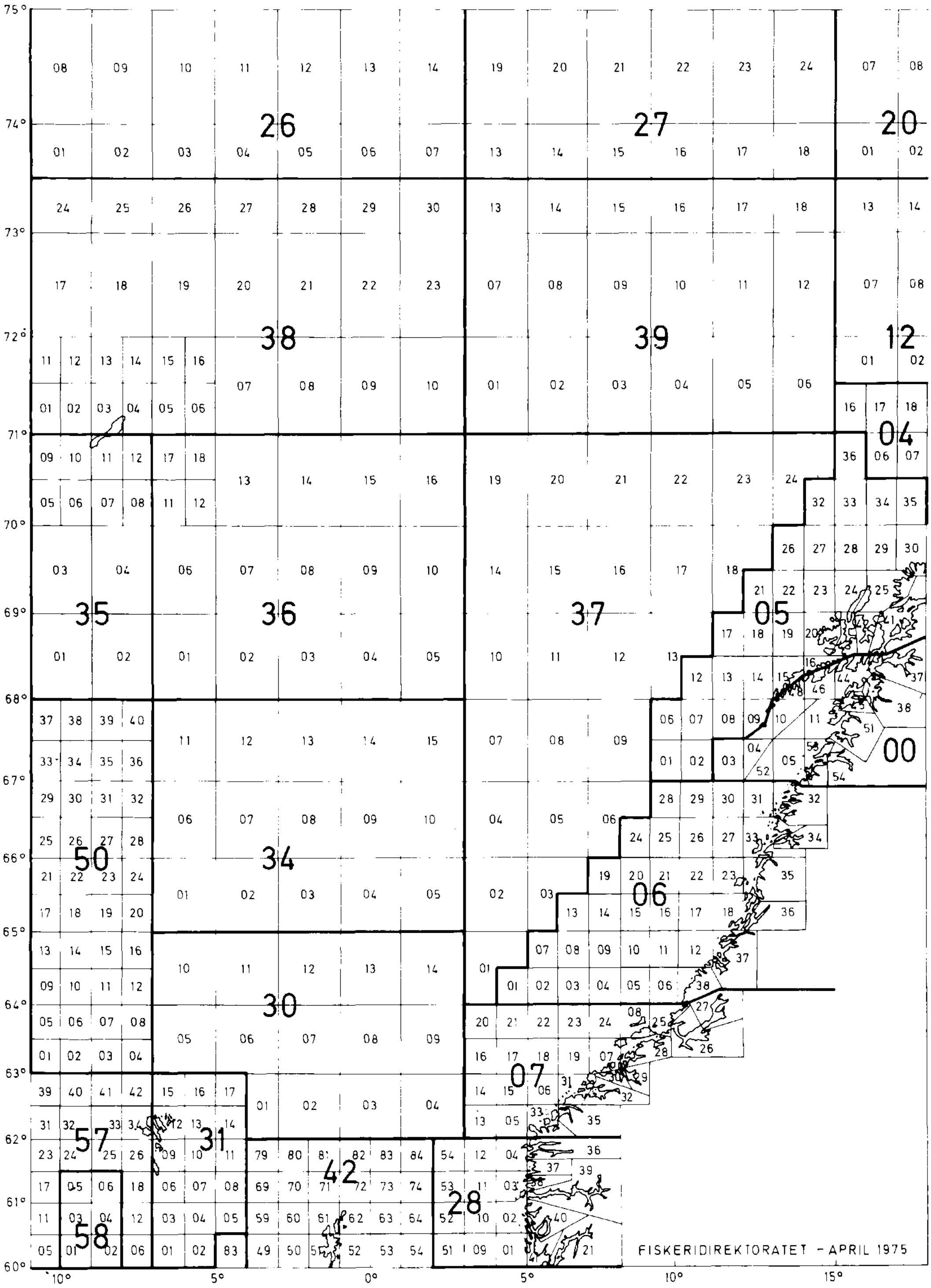


Figure 1. Norwegian statistical regions from Møre to Lofoten.

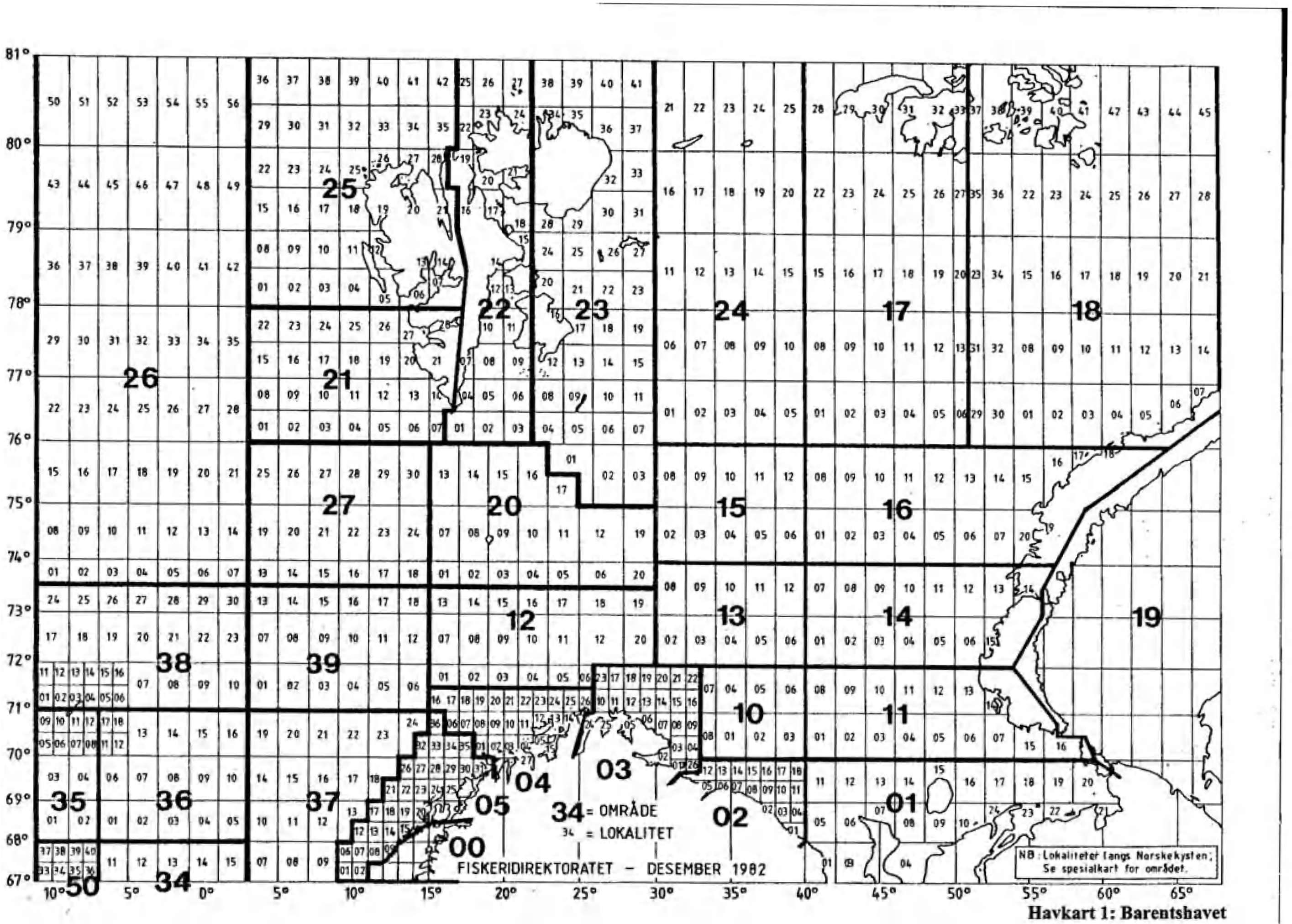


Figure 2. Norwegian statistical regions in the Barents Sea.