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Report of the Benchmark Workshop on Icelandic Stocks (WKICE)

26–30 January 2015

Copenhagen, Denmark

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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Contents

Executive summary

WKICE was set up to provide standards for assessing Greenland cod, Icelandic cod and Icelandic capelin.

Results from genetic investigations and tagging experiments suggest that the Atlantic cod (*Gadus morhua*) in Greenland waters is comprised primarily of three spawning stocks (Storr-Poulsen *et al*., 2003; Therkildsen *et al*., 2013):

1) West Greenland inshore;

2) West Greenland offshore; and

3) East Greenland offshore.

Until 2011, ICES advice was provided for all three stock components combined. Since 2012 separate advice has been given for the inshore stock component. WKICE evaluated the case for separating the two offshore components based on the tagging and genetic studies as well as advice from ICES SIMWG and concluded that they should be assessed separately.

For the inshore Greenland cod stock, none of the proposed analytical assessment approaches provided convincing results and were not considered appropriate to generating advice. However, the currently used approach (DLS on the survey) was also rejected and an alternative regression approach was approved by WKICE as the best available alternative to generate advice. It is based on a simple linear regression between survey indices and subsequent catches, but incorporates age-specific survey trends. Although it rests on some key assumptions, it provides a pragmatic way of generating advice incorporating precautionary considerations and a $U_{trigger}$ proxy.

The regression approach should however be considered an interim solution until an approach that utilizes the data to a fuller extent (i.e. a credible full stock assessment) is developed. Whatever approach is developed, it should consider the mixed-stock fishery and preferably incorporate new information on the degree of offshore input to the catches; both survey and commercial. WKICE also recommended that that alternative assessment models, other than those already tested, should be investigated to determine whether they perform better.

For the West Greenland offshore cod stock, all information from the fishery and surveys indicates that stock biomass continues to be low. The fishery has been closed for more than two decades and survey indices have been low. However, recent surveys have shown an increasing abundance of cod which is mainly composed of the 2009 year class. The presence of a single year class is not considered sufficient for advising an opening of the fishery.

No stock assessment can be undertaken for this stock, due to the lack of significant rebuilding since the stock collapsed in the late 1960s. The advisory process should consider this rebuilding process when generating advice in the near future. WKICE agreed that there was little further work that this benchmark meeting could usefully undertake at this time, but recommended that it continue to be monitored using the current German and Greenland surveys.

For the East Greenland offshore cod stock, several assessment models were presented, but none were approved as a basis for advice. Among the models presented, a separable model showed the most promise. However, it was not possible within the time frame of WKICE to explore the model fully, nor to develop alternative models.

In general, all models in combination with the survey results support an increasing trend in stock size.

As no analytical assessment was agreed for the East Greenland offshore cod, the DLS Method 3.2 approach incorporating survey indices was adopted. WKICE concluded that it is appropriate to apply the DLS approach, and that this should be done in a manner that takes observation error into account. However, WKICE believed that the DLS approach should only be considered an interim solution, pending development of an alternative analytical assessment approach. WKICE believes that the available data should be adequate for a full analytical stock assessment approach to be developed, and that assessment models incorporating a range of recommendations should be actively pursued. If a suitable model can be developed, an interim benchmark is recommended.

WKICE accepted the current Icelandic stock assessment, as described in the stock annex in this report, as a benchmark assessment. The assessment methodology and outputs have been relatively consistent since at least 2009, and the workshop judged the current assessment to be reliable and robust. The 2009 assessment produced projections to 2015 that are compatible with the results of the current assessment, although rebuilding is estimated to have occurred at a faster rate than that indicated by the 2009 projections.

The stock appears to have rebuilt from relatively low levels in the last 2–3 decades of the 20th century to levels corresponding to the 20% harvest control rule in recent years.

However, more work is needed on stock structure and migration patterns for the Icelandic cod and Greenland cod stocks, particularly if the distribution of the stocks alters as a result of climate change. Tagging studies, genetics studies and, to a lesser extent, morphology studies should be augmented to more fully address stock structure and catch composition issues.

For Icelandic capelin, WKICE agreed that for the final TAC advice a stochastic projection of the stock should be conducted starting from acoustic measurements, aiming at a TAC that is associated with $p(SSB < B_{lim}) < 5\%$. The preliminary TAC will be based on the autumn acoustic surveys following a graphical method developed by WKICE.

WKICE accepted the assessment methodology for Icelandic capelin, as described in the stock annex in this report, as a benchmark assessment. While it appears that the stock is currently lower than historical levels, it is estimated to be well above B_{lim}.

WKICE participated in a joint session with WKARCTIC where work presented for the Barents Sea capelin stressed the importance of capelin as a keystone species in the ecosystem. This is likely to also be true for Icelandic capelin. WKICE therefore recommended that studies of optimal harvesting of IGJM capelin should be conducted and presented to the NWWG. The NWWG should also initiate a review of the role of capelin in the Icelandic Sea ecosystem, and in particular whether the population size and growth of capelin predators shows a response to changes in capelin abundance.

Finally, further work on the new framework for setting the advice is needed, including detailed examination of the series of historical bootstrap estimates and additional tests of the predation model for cod, haddock and saithe, based on the groundfish survey in March (IGFS) data.

1 Introduction

WKICE met at ICES HQ from 26 to 30 January 2015 to address the following terms of reference.

A **Benchmark Workshop on Icelandic Stocks** (WKICE), chaired by External Chair Pamela Mace, New Zealand and ICES Chair Gudmundur Thordarsen, Iceland, and attended by two invited external experts Paul Spencer, US and Hans Lassen, Denmark will be established and work 25–26 November 2014 in Reykjavik, Iceland for data compilation and at ICES Headquarters for a five day Benchmark meeting 26–30 January 2015 back to back with WKARCT to:

a) Evaluate the appropriateness of data and methods to determine stock status and investigate methods for short-term outlook taking agreed or proposed management plans into account for the stocks listed in the text table below. The evaluation shall include consideration of:

   i) Stock identity and migration issues;

   ii) Life-history data;

   iii) Fishery-dependent and fishery-independent data;

   iv) Further inclusion of environmental drivers, multispecies information, and ecosystem impacts for stock dynamics in the assessments and outlook.

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

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

c) Evaluate the possible implications for biological reference points, when new standard analyses methods are proposed. Propose new MSY reference points taking into account the WKFRAME2, results and the introduction to the ICES advice (section 1.2), and WKMSYREF3.

d) Develop recommendations for future improving of the assessment methodology and data collection;

e) As part of the evaluation:

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

   ii) Following the DCWK, produce working documents to be reviewed during the Benchmark meeting at least seven days prior to the meeting.

The Workshop was preceded by a Data Collection Workshop 25–26 of November 2014 in Reykjavik, Iceland.

STOCKS	STOCK LEADER
Cod-iceg	Einar Hjörleifsson
Cod-in/offgrl	Anja Retzel and Rasmus Hedeholm
Cap-icel	Asta Gudmundsdottir

The participants are listed in Annex 2.

2 Stock structure of Greenland cod

2.1 Introduction

Results from genetic investigations (Therkildsen *et al.*, 2013) and tagging experiments (Storr-Poulsen *et al.*, 2003) suggest that the Atlantic cod (*Gadus morhua*) in Greenland waters is comprised primarily of three spawning stocks (Storr-Poulsen *et al.*, 2003; Therkildsen *et al.*, 2013):

1) West Greenland inshore;

2) West Greenland offshore; and

3) East Greenland/Iceland.

Due to limited sample sizes in the genetic studies, these delineations are based primarily on results from the tagging studies (see also WD#12 from the 2012 NWWG meeting).

The stock that contributed to the very large fishery in the 1960s was mainly the West Greenland offshore stock (Bonanomi *et al.*, 2014) which collapsed in the late 1960s and to this day has not recovered (ICES, 2014a). From the 1970s to the 1990s, low levels of fishing in offshore West Greenland were primarily supported by the immigration of two large year classes from the East Greenland or /Icelandic stocks. The offshore fishery recommenced in 2005 mainly in East Greenland and is composed of the East Greenland and /Iceland stocks.

Until 2011, ICES advice was provided for all three stock components combined. Since 2012 separate advice has been given for the inshore stock component, with the ICES SIMWG supporting this separation (ICES, 2012). To assess whether or not the offshore cod should be advised on and managed according to two separate offshore stock components a request was sent by NWWG to SIMWG to evaluate the scientific investigations (tagging and genetic studies and general demography) of the offshore cod stock components.

The conclusions of SIMWG were:

"*SIMWG finds that there is a valid scientific basis supporting the presence of distinct eastern and western spawning populations of offshore cod stocks in Greenland waters. SIMWG recommends that ICES recognize the mixed-stock nature of the Atlantic cod fishery in offshore Greenlandic waters and the associated risks of managing the mixture as a single unit in their advice. Stock composition analysis would improve the scientific basis of advice and permit assessment and management of eastern and western spawning populations as distinct stocks*." (ICES, 2014b).

2.2 Discussion

The distribution pattern of the East Greenland stock is complex as it moves around Greenland according to age. Juveniles (age 0–3 years) are mainly found in West Greenland and as young cod (age 4–6 years) they are mainly found in South Greenland. As they become mature at age 6 they start to migrate to the spawning grounds in East Greenland north of 63°N, and to some extent to Icelandic spawning grounds.

Tagging data show that when fish are maturing (>40 cm) they will primarily stay in West Greenland waters when tagged north of NAFO 1F, while fish tagged in NAFO 1F or East Greenland only move east or stay (Storr-Paulsen *et al.*, 2003). Hence, the distinct spawning stocks are maintained and seem to be spatially separated at roughly the NAFO 1F northern limit which corresponds to 60°45N. This may not be applicable historically, but in the current situation with a very low West Greenland offshore stock size, it seems the most appropriate division of the stocks. A similar conclusion can be made based on the distribution of year classes. Currently, the West Greenland stock biomass is so low that the majority of the fish found in West Greenland are of East Greenland or/ Iceland origin, and consequently, when these fish approach maturity they migrate out of West Greenland waters. As a result, almost all fish age 4 and older are in either NAFO 1F or ICES XIVb, whereas juveniles are found in NAFO areas 1A–1E.

Considering the available data on stock structure of the offshore cod in Greenland, WKICE agreed that the offshore cod in Greenland should be separated into two areas, with the West Greenland offshore stock comprising NAFO Divisions 1A–1E (West Greenland north of 60°45N), and the East Greenland stock comprising ICES Division XIVb in East Greenland and NAFO Division 1F (Southwest Greenland south of 60°45N). There are, however, implications to this area management as the juveniles of the East Greenland stock are missing in the survey series when the nursing area north of 60°45N is left out of the calculations. Likewise when the West Greenland stock is recovering, stock composition analysis will be necessary in order to minimize the effect of the spatial overlap of juveniles, in particular, of the East Greenland stock. However when the cod become fishable (age 4+) the two stocks seem to be spatially separated and it is therefore valid to manage them according to the areas specified here.

2.3 References

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3 Offshore cod in West Greenland (NAFO Divisions 1A–1E)

This stock is new in the ICES context. Previously the offshore East and West Greenland cod stocks were assessed combined, but during this benchmark it was decided to assess the two areas separately based on information on stock identification and stock dynamics (see Section 3). The stock area for this cod stock is defined as NAFO Divisions 1A–1E, e.g. not including the southwest Greenland area in Division 1F. Division 1F is considered part of the East Greenland cod stock distribution area.

3.1 Description of the fishery

3.1.1 Historical fishery

The offshore fishery in the last century took off in 1924 when Norwegian fishers discovered dense concentrations of cod on Fylla Bank in NAFO Division 1D. The West Greenland offshore fishery rapidly expanded to reach 120 000 t in 1931; a level that remained for a decade (Horsted, 2000). During World War II landings decreased by $^1/_3$ as only Greenland and Portugal participated in the fishery. During a period from the mid-1950s to 1960 the total annual landings taken offshore averaged about 270 000 t. In 1962 the offshore landings culminated with landings of 400 000 t. After this historic high, landings decreased sharply by 90% to 25 000 t in 1976 and even further down to 15 000 t in 1980. Annual catch level of 40 000 t was only exceeded in the periods 1977–1979 (where unreported catches of up to 50 000 t where believe to take place, Horsted, 2000) and 1988–1990 due to the occurrence of a few strong year classes. During 1989–1992 the fishery, which almost exclusively depended on one YC (1984 YC) shifted from West to East Greenland. The entire offshore fishery completely collapsed in 1993 (Figure 3.1.1).

No directed offshore fishery was allowed for the period 1993–2005, except for some minor allocations to Norway and the Faroe Islands.

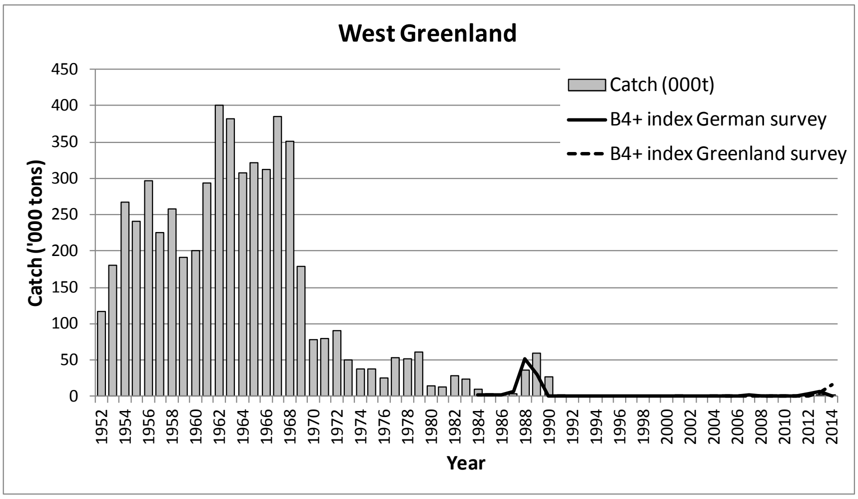

Figure 3.1.1. Landings, German survey B4+ biomass and Greenland survey B4+ biomass in the management areas in West Greenland (NAFO Divisions 1A–1E).

3.1.2 The present fishery

Vessels in the offshore fisheries are vessels above 75BT/120BTand restricted to the area more than 3 nm off the baseline. The vessels require a licence that stipulates a unique vessel quota. Trawl is the dominating gear but longlining also occurs especially in recent years; longlining is becoming more abundant and constituted almost half of the total catch in 2013.

Since 2005 directed cod fishery was introduced but catches was insignificant with only 550 t in 2008. In 2009 and 2010 fishery was closed in West Greenland. The measures introduced since 2009 had the objective to rebuild the stock in West Greenland by minimizing exploitation of the young fish and potential spawning fish.

In 2011 a management plan was implemented that allowed a small experimental fishery of 5000 tons per year in the period 2011–2013 in all offshore areas in Greenland (both West and East). This management plan was replaced for the period 2014–2016 where annual quota was set at 10 000 tons as experimental fishery in South and East Greenland, whereas West Greenland north of N60°45′ (corresponding to NAFO Divisions 1A–1E) was closed for fishery.

Catches have been insignificant in 2011–2013, when fishing was allowed in West Greenland offshore areas.

3.2 Biological information

3.2.1 Surveys

At present, two offshore trawl surveys provide the core information relevant to stock assessment purposes.

3.2.1.1 Greenland Shrimp and Fish survey GRL-GFS

Since 1992, GINR has conducted an annual stratified random bottom-trawl survey at West Greenland. The Greenland survey covers depth from 0–600 m and covers the area south of N72°00′ in West Greenland. From 2008 East Greenland was included in the survey and covers the area south of N67°00′ in East Greenland. Since 2005 an increasing number of hauls have been allocated to the southern areas in West Greenland (including Division 1F) as greater amount of cod have been found there. The numbers of annual trawl hauls have varied between 187 and 299 in West Greenland. The survey design, in respect to area coverage, trawl type and its rigging has been unchanged since 2005, i.e. coinciding with the period where significant cod year classes have been seen. The years prior to 2005 experienced a number of survey development that are detailed in the stock annex. The survey provides catch and weight-at-age.

3.2.1.2 Trawl survey by Germany (West and East Greenland)

The survey commenced in 1982 and was designed for the assessment of cod. The survey covers both East (area south of N67°00′) and West Greenland (area south of N67°00′). Up to 2012, the surveyed area ranged from 0–400 m depth divided into seven geographical strata and two depth zones, 0–200 m and 200–400 m. Numbers of hauls in West Greenland (excluding NAFO 1F) were initially ca. 90 per year but were reduced from the early 1990s to 30–40 per year. In 2013, the survey was re-stratified, with four strata in West Greenland resembling NAFO division structure, and five strata in East Greenland for the depth intervals 0–200 m and 200–400 m. The survey provides catch and weight-at-age.

3.2.1.3 Pilot Trawl survey by Greenland (West Greenland banks)

A random stratified bottom-trawl survey was conducted in 2013 from May 20 to July 3, during the main spawning event and on the traditionally main offshore west spawning areas in order to detect spawning on the banks. On Dana Banke, Fiskenæs Banke, Fyllas Banke, Lille Hellefiske Banke and Store Hellefiske Banke covering N62°66′–N68°07′ and depth 80–130 m. Out of 34 stations, very little amount of cod was registered (max 2.7 kg on 1 station, Figure 3.2.1). Hence no greater amount of spawning in western offshore areas is currently considered present.

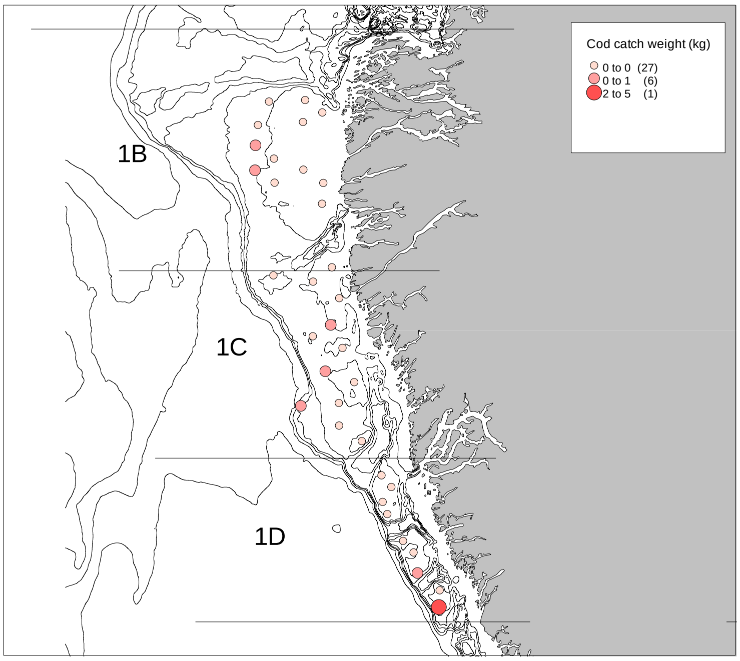

Figure 3.2.1. Cod catches during cod spring survey in 2013 with RV Sana.

3.3 Stock structure

See Section 2 for a detailed description of stock structure for the entire Greenland cod complex and stock delineation.

Recently a minor amount of spawning from the western offshore component is believed to take place. In the 1940s to 1960s spawning from this stock were considerable and were likely the main contributor to the stock. However a substantial part of the offspring from the East Greenland and occasionally Icelandic component is assumed to settle along the west coast of Greenland and subsequently start a migration back when reaching the age of 5–6 years. The larval drifts from Iceland are believed to occur irregularly (Buch *et al.*, 1994; Schopka, 1994; Wieland and Hovgård, 2002).

Tagging information show that cod in the fjords are resident and do occasionally migrate to the adjacent coastal areas (Hansen, 1949; Hovgård and Christensen, 1990; Storr-Paulsen *et al.*, 2004). Likewise, bank cod are predominantly resident and migrate to a lesser extent into the coastal areas. In contrast cod tagged in the coastal areas are found distributed over all the three habitats. Hence, tagging indicate that the offshore and inshore cod are generally separated but that the coastal area is a mixing zone.

3.4 Assessment

With virtually no fishery conducted in West Greenland since 1990 (fishery on the 1984 cohort) and low survey indices in the recent two decades, the stock is still considered to be at a very low level. Survey indices from both the Greenland and the German survey have increased since 2012–2013. An analytical assessment was not considered given this lack of observations (catches, survey indices). The management objective of having established a spawning–stock biomass that gives rise to robust recruitment is still not considered reached and therefore the survey trends are not suggested to be used as indicative for biomass trends for catch prognoses.

3.5 Reference points

None defined.

3.6 Conclusions

Previously this stock was assessed in combination with cod in East Greenland. This benchmark, WKICE, determined that cod in the West Greenland offshore area should be assessed as a separate biological entity. Although this entity has been determined to be the most appropriate biological unit, it is recognized that inshore cod in West Greenland mixes with this stock in coastal waters and also that cod from both East Greenland and Iceland occasionally recruit to the West Greenland offshore stock. However when the East Greenland/Icelandic stock matures at the age of 5–6 years they migrate out of the area and to the spawning grounds in East Greenland and Iceland.

All information from the fishery and surveys indicate that stock biomass continues to be low. The fishery has been closed for more than two decades and survey indices have been low. However, recent surveys have shown an increasing abundance of cod which is mainly composed of the 2009 year class. The presence of a single year class is not considered sufficient for advising an opening of the fishery.

No stock assessment can be undertaken for this stock, due to the lack of significant rebuilding since the stock collapsed in the late 1960s. The advisory process should consider this rebuilding process when generating advice in the near future. WKICE agreed that there was little further work that this benchmark meeting could usefully undertake. A catch curve analysis undertaken during the meeting provided little additional insight, due primarily to low sample sizes.

When and if the fishery is reopened, it may be necessary to allow for the fact that productivity could have declined. The consequence of a decline in productivity would be that a rebuild to previous levels may not be possible.

3.7 Recommendations for future work

The benchmark recommended that the West Greenland cod stock continues to be monitored using both German and Greenland surveys. If the abundance indices from these surveys continue to increase, it may be possible to reopen the fishery at some point in time, and to start collecting fishery information that can then be used in a stock assessment.

A rebuilt stock would be comprised of several strong year classes and would be capable of producing stable high recruitment. In order to detect whether this is occurring, the stock needs to be monitored at the time of spawning in spring and/or an egg/0-group survey should be performed. Currently surveys are only conducted in summer and autumn and sampling from other seasons is not possible as no fishery is allowed.

WKICE recommends continuing to monitor the West Greenland cod stock using both the German and Greenland surveys.

If the indices continue to increase, WKICE recommends development of a stock assessment model and estimation of appropriate reference points prior to reopening the fishery. This in turn will require investigation of the productivity of the stock relative to historical levels, as this will influence the level to which the stock is capable of rebuilding.

If the fishery is reopened, it will be imperative to obtain high quality information on stock structure and stock mixing on the fishing grounds. This need is likely to be ongoing (annual), particularly if the distributions of the stocks alter as a result of climate change. Tagging studies, genetics studies and, to a lesser extent, morphology studies should be augmented to more fully address stock structure and mixing issues. Attempts should be made to quantify the degree of mixing of the West Greenland cod stock with both inshore cod stocks and East Greenland/Iceland stocks.

3.8 References

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4 Greenland inshore cod

4.1 The fishery

Both historically and recently, the most important gear is poundnet (taking between 60% and 80% of the annual catches) anchored at shore and fishing the upper 20 m. Due to ice, poundnets are not used during November–April and jigs, longlines and gillnets are used instead. Trawling is not allowed within 3 nm off the coastal baseline.

The commercial fishery started in 1911 by opening cod trading at localities where cod seemed to occur regularly (Figure 4.1.1). The fishery expanded over the next decades through the development of a number of new trading places. Annual catches above 20 000 t were taken from 1955–1969 but declined to around 5000 t in the 1970s. In the 1980s catches fluctuated between 5000 and 35 000 t, partly driven by a few strong year classes (1979 and 1984) entering from the offshore stock (Horsted, 2000). From 1993 to 2001 catches were low; in the range of 500–2000 t. In the 2000s catches have gradually increased with a maximum catch in 2014 of 18 500 t. No licences were required until 2009 and until that time the fishery was not constrained by a TAC, although a minimum landing size of 40 cm was enforced.

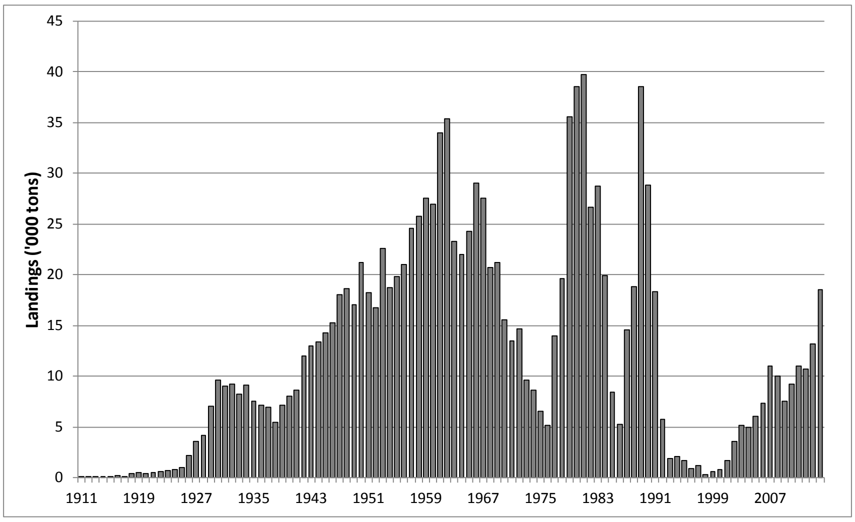

Figure 4.1. Inshore Greenland cod landings.

The fishery is carried out along the entire coastline of West Greenland from Disko Bay to Cape Farewell, with the majority of the catches (92%) being taken in Mid Greenland (Figure 4.1.2). The fishery has in recent years expanded north, and catches in this area are to a larger extent caught by longlines and gillnets as bycatch in the Greenland halibut fisheries. Fish caught with these gears are on average 10 cm larger than poundnet catches. In general mean length in the fishery has been increasing over the past ten years, and is currently 53 cm. All landings are reported, no discarding takes place and the data quality is considered high. Additionally, length measurements are taken continuously throughout the year covering the entire West coast.

Historical tagging data, demography and recent genetic studies have demonstrated that the inshore fishery is influenced by offshore dynamics. Hence, catches must be considered a mix of inshore cod, West Greenland offshore cod and East Greenland offshore cod. The proportional contribution has however never been quantified.

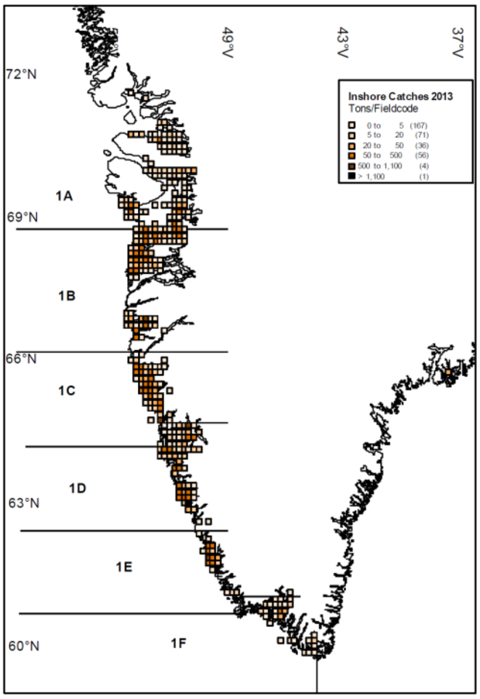

Figure 4.1.2. Distribution of the inshore cod fishery.

4.2 Biological information

Biological information is obtained from a gillnet survey targeting mainly juveniles. The survey was initially conducted every year since 1985. In 1999–2001 and 2007–2009 the coverage was poor, and these numbers are not used in assessments. The survey takes place in May–June in the two areas traditionally associated with large spawning aggregations. In addition, specific surveys on spawning locations are done occasionally. No survey targeting the adult part of the stock is currently performed.

Age readings are routinely done on both survey and commercially caught fish. Hence, catch-at-age data are available for commercial landings since 1976 and from 1985 for the survey.

Currently, spawning is believed to take place in multiple locations from Pamiut (62°N) to Sisimiut (68°N) with the densest aggregations in Nuuk (64°N) and Sisimiut. Spawning takes place from mid-March to late May. A shift in the maturity-at-age is believed to have happened around 2003 (Figure 4.2.1). This is coincident with a shift in the size-at-age, but no ultimate explanation for this pattern has been put forward. However, temperatures may have increased by as much as 1–2°C over the past decade (Ribergaard, 2014).

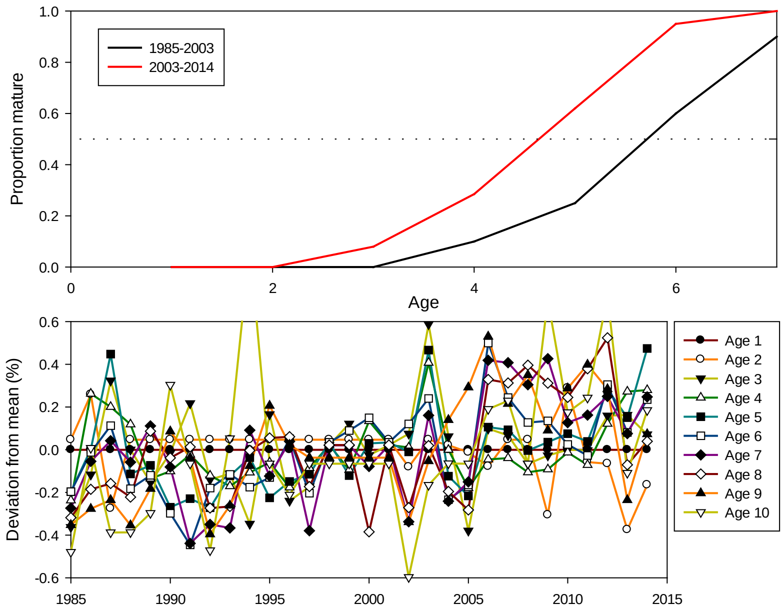

Figure 4.2.1. Top: maturity ogives for the periods 1985–2003 and 2003–2014. Bottom: relative changes in weight-at-age from 1985–2014.

4.3 Stock structure

See Section 2 for a detailed description of stock structure and stock delineation for the entire Greenland cod complex.

In 2012 the West Greenland inshore cod stock was split from the offshore stocks, and separate advice is now given for this stock. This division was based on tagging (Storr-Paulsen *et al.*, 2004), demography (ICES 2015) and genetic studies (Therkildsen *et al.*, 2013). Available studies do not indicate any stock structure within the inshore area (i.e. individual fjord stocks). However, tagging data indicate sedentary behaviour of individuals found in the bottom of the largest fjords.

The presence of a distinct inshore spawning population is well documented. The inshore stock does however mix with the offshore stock especially in the coastal regions in autumn. There is currently no easy way to separate the stocks in the catches, but a thorough genetic screening would be an option.

4.4 Assessment

In 2012 the advice for this stock was based on recent catches. In 2013–2014 the Data Limited Stock approach (DLS, method 3.2) was used with the survey and recent catches as input. The use of the DLS approach was heavily criticized at WKICE for several reasons. First, it does not fully utilize all of the available data. Most importantly, using a recruitment index can create a situation where the fishable biomass increases (above average year classes) but the survey decreases (below average year classes). Accordingly, the TAC advice could decrease although the overall stock size is improving. Most recently, this applies to the very large 2009 year class. The opposite situation of high recruitment but a low SSB could also occur, which could result in TAC advice that is risky and will lead to stock decline. Finally, the use of the DLS approach means that the advice depends on catches and when the advice is not followed (as is the case for this stock) higher catches will produce higher advice.

During WKICE several modelling scenarios were presented as alternative approaches to generate advice. All suffered from shortcomings, but also provided insight into stock dynamics. Each is briefly mentioned below and all are described in detail in the relevant working documents.

4.4.1 Statistical catch-at-age (Coleraine); WD#06

The statistical catch-at-age model was implemented in Coleraine. The input data were surveys, landings, catch-at-age (survey and commercial) and a maturity ogive. The maturity was fixed, and an average of the 1985–2003 and 2003–2014 ogives was used. M was fixed at 0.25.

Several different overall scenarios were set up, including shortened time-series, removal of certain year classes, and estimation of missing survey years. Of these, using the whole time-series with no survey estimates in missing years showed the most promise. Within these limits several exploratory runs were performed. The overall fit to the model was reasonable, but the model did not converge, and was therefore rejected by WKICE.

4.4.2 VPA ADPAT; WD#09

The input data were landings, commercial catch-at-age and the survey index. The maturity ogive and natural mortality (M) were year specific, which could not be accommodated in the Coleraine model. However, the model was sensitive to assumptions and exhibited strong retrospective patterns, particularly for F. It was therefore rejected by WKICE.

4.4.3 Regression approach

None of the model runs prepared prior to the meeting produced credible results that could be used for generating advice. As a consequence, a new approach was developed during the meeting. The survey index of 3–8 year olds in a given year was related to the catch in the next year (Figure 4.4.1) via linear regression. The advice will then be based on the survey index and the regression line, multiplied by a scaling factor. The validity of this approach rests on a number of assumptions. First of all, it is assumed that the fishery has been at a stable sustainable level (ideally the same across years). Based on preliminary model outputs and catch curves (see below) this seems to be a reasonable assumption, at least in the last 15 years. Some years in the 1980s did not follow the overall trend, and were most likely subjected to a very high fishing intensity and a very high offshore input to the fishery, and these years were excluded from the analyses. The fish enter the fishery at age 4. Accordingly the survey index of ages 3–8 was used to generate advice although age 2 fish are abundant in the survey.

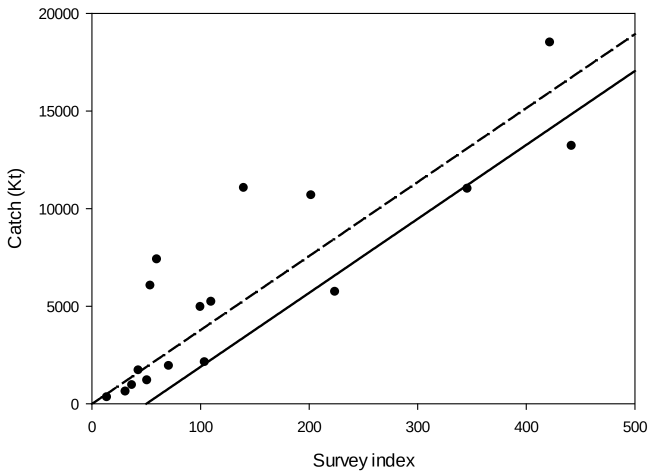

Figure 4.4.1. Survey index of 3–8 year olds vs. the catch the following year. r2 = 0.76. Based on data from 1991–2014.

A similar approach was also tried using survey biomass instead of numbers, but the results were almost identical. Given that this approach is based on uncertain data, a precautionary approach should be taken. Therefore, rather than having the regression pass through the origin, the intercept is set at a survey index value of 50. The resulting liner regression slope is 37.9. Consequently, the advice is generated as follows:

$$C_{y+1}=37.9 * (U_{3\text{-}8y} - U_{trigger}) \quad (1)$$

where $U_{3\text{-}8y}$ is the combined survey value for ages 3–8 and $U_{trigger}$ is 50.

4.5 Reference points

None of the estimated reference points from the various approaches were approved by the benchmark as a basis for advice. They are used indirectly as they justify one of the assumptions of the chosen approach: that the fishery has been conducted at a sustainable level. Hence, they are presented here.

The selectivity curve for commercial fishery estimated from the Coleraine base run was used as a proxy of F for input to a Yield-per-recruit and Spawning Biomass per recruit analysis from which reference point estimates were derived (Hedeholm and Post, 2015d; Table 4.5.1). The catch curves estimated that recent cohorts were fished at approximately 0.6–0.7 (Figure 4.5.1), which is higher than reference points estimates and could suggest that the stock is being overfished. However, the catch curves fail to incorporate two issues: 1) there is an unquantified migration of older offshore fish out of the area, and 2) the dominant fishing gear (poundnet) is size selective with older fish being less likely to be caught. Lack of consideration of both of these factors will result in inflated estimates of F.

Table 4.5.1. Reference points from YPR analysis.

Reference point	Estimate
$F_{0.1}$	0.32
F_{MAX}	0.53
$F_{40\%}$	0.37
$F_{35\%}$	0.42
$F_{30\%}$	0.50

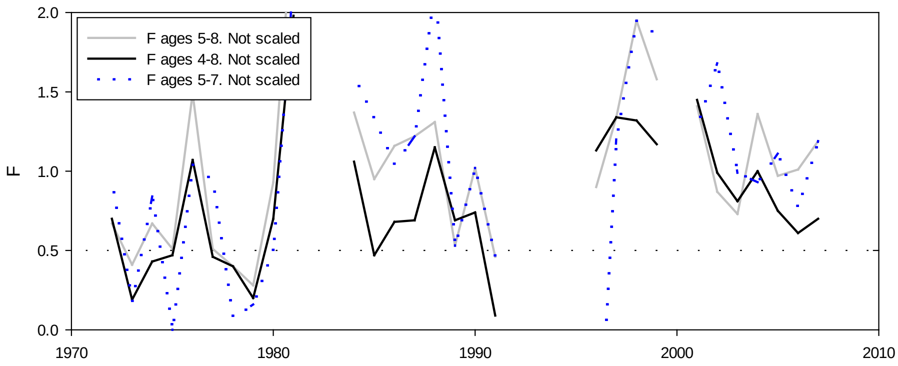

Figure 4.5.1. Catch curves using different age ranges for calculating F.

4.6 Conclusions

There are almost complete time-series for both survey and commercial catch-at-age for this stock from 1985–2014. However, the data are highly variable and the internal consistency is low. As a consequence, none of the proposed analytical assessment approaches provided convincing results and were not considered appropriate to generating advice. However, the currently used approach (DLS on the survey) was also rejected and an alternative regression approach was approved by WKICE as the best available alternative to generate advice. It is based on a simple linear regression between survey indices and subsequent catches, but incorporates age-specific survey trends. Although it rests on some key assumptions, it provides a pragmatic way of generating advice incorporating precautionary considerations and a $U_{trigger}$ proxy. The regression approach should however be considered an interim solution until an approach that utilizes the data to a fuller extent (i.e. a credible full stock assessment) is developed. Whatever approach is developed, it should consider the mixed-stock fishery and preferably incorporate new information on the degree of offshore input to the catches, both survey and commercial.

4.7 Recommendations

The benchmark recommended that alternative assessment models, other than the Coleraine and VPA-ADAPT models already tested, should be investigated to determine whether they perform better. Candidate models include Stock Synthesis 3, CASAL and SAM.

The method developed by WKICE for providing TAC advice could also be further investigated and refined. For example, simulation models should be developed to examine how well it might work in practice under various scenarios.

A key assumption in the method for providing TAC advice is that recent fishing mortalities are not only sustainable, but are also appropriate to ensuring that stock size and catch rates are at near-optimal levels. This assumption should be further investigated; for example, by examining estimates of fishing mortality from alternative stock assessment models, and continuing to monitor stock trends as data accumulate.

The potential for developing a survey that samples the full population (rather than focusing on recruits) should be investigated; for example, by initiating a multispecies trawl survey, or a gillnet survey with larger mesh size.

More work is needed on stock structure and migration patterns for the Icelandic cod and Greenland cod stocks, particularly if the distribution of the stocks alters as a result of climate change. Tagging studies, genetics studies and, to a lesser extent, morphology studies should be augmented to more fully address stock structure and catch composition issues.

4.8 References

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5 East Greenland cod (NAFO Division 1F and ICES Subarea XIVb)

This stock is new in the ICES context. Previously offshore cod in East and West Greenland were assessed in combination, but WKICE decided to assess the two areas separately based on information on stock identification and stock dynamics (see Section 2). The stock area for this cod stock is defined as NAFO Division 1F in Southwest Greenland and ICES Subdivision XIVb in East Greenland and the stock is simply referred to as the "East Greenland stock".

5.1 The fishery

5.1.1 Historical fishery

The fishery in East Greenland started in 1954 as a trawl fishery. However, until 1971 a substantial part of the landings from West Greenland were reported as 'unknown NAFO area'. Parts of the "unknown catches" were likely caught in NAFO Division 1F and were allocated to this NAFO region according to the proportion of the landings in this NAFO division. Historical catches in East Greenland are shown in Figure 5.1.1. Landings of about 30–60 kt dominated until the early 1970s, followed by a decrease to 10–30 kt until the early 1990s supported by the large year classes in 1973 and 1984. For more than a decade catches were close to nil, and cod was only caught as bycatch in the redfish fishery until the mid-2000s. Since then a fishery has developed with catches of approximately 5000 t annually.

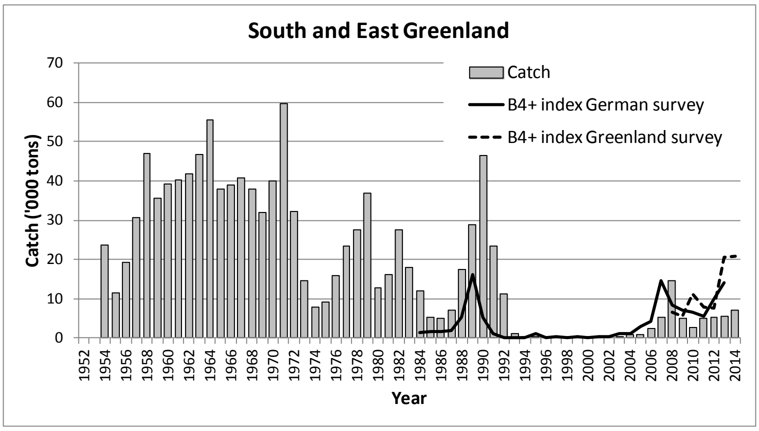

Figure 5.1.1. Landings, German survey B4+ biomass and Greenland survey B4+ biomass in the management areas in East Greenland (NAFO Division 1F and ICES Subdivision XIVb).

5.1.2 The current fishery

Vessels in the offshore fisheries are vessels above 75 BT/120 BT and are restricted to the area more than 3 nm off the coastal baseline. The vessels require a licence that stipulates a unique vessel quota. Trawl is the dominating gear but longlining also occurs and has in recent years become more prevalent, contributing almost half of the total catch in 2013 (Figure 5.1.2).

The East Greenland area has been subjected to several area closures in recent years. In 2008 fishing north of N63°00′ was not allowed in order to protect the potential spawning segments, especially on Kleine Banke. In 2009–2010 the delimitation was at

N62°00′ and additionally NAFO 1F was closed in 2010, primarily to protect the relatively strong incoming year classes.

In 2011 a management plan was implemented that allowed an experimental fishery of 5000 tons per year in the period 2011–2013 in all offshore areas in Greenland (both West and East). This management plan was replaced for the period 2014–2016 with an annual quota of 10 000 tons as an experimental fishery in South and East Greenland, and a closure for West Greenland north of N60°45′ (corresponding to NAFO Divisions 1A–1E).

Historically several countries took part in the fishery but recently catches have been taken primarily by Greenland, followed by Germany/UK (EU) and Norway. The fishery is conducted in three main areas: on the shelf edge on Dohrn Bank (approximately 65°30N in East Greenland), between Kleine Banke and Skjoldungen Bank (approximately 62°30N–64°30N in East Greenland) and in Julianehaabs Bight in Southwest Greenland (approximately 60°00N) with the catches taken on Dorhn Bank being dominated by trawlers and those in Julianehaabs Bight being dominated by longliners (Figure 5.1.2).

Length measurements and otoliths for age determination are obtained from sampling onboard the fishing vessels. Hence, catch-at-age data are available for 1973–1995 and 2005–present for the fishery (ICES, 2015).

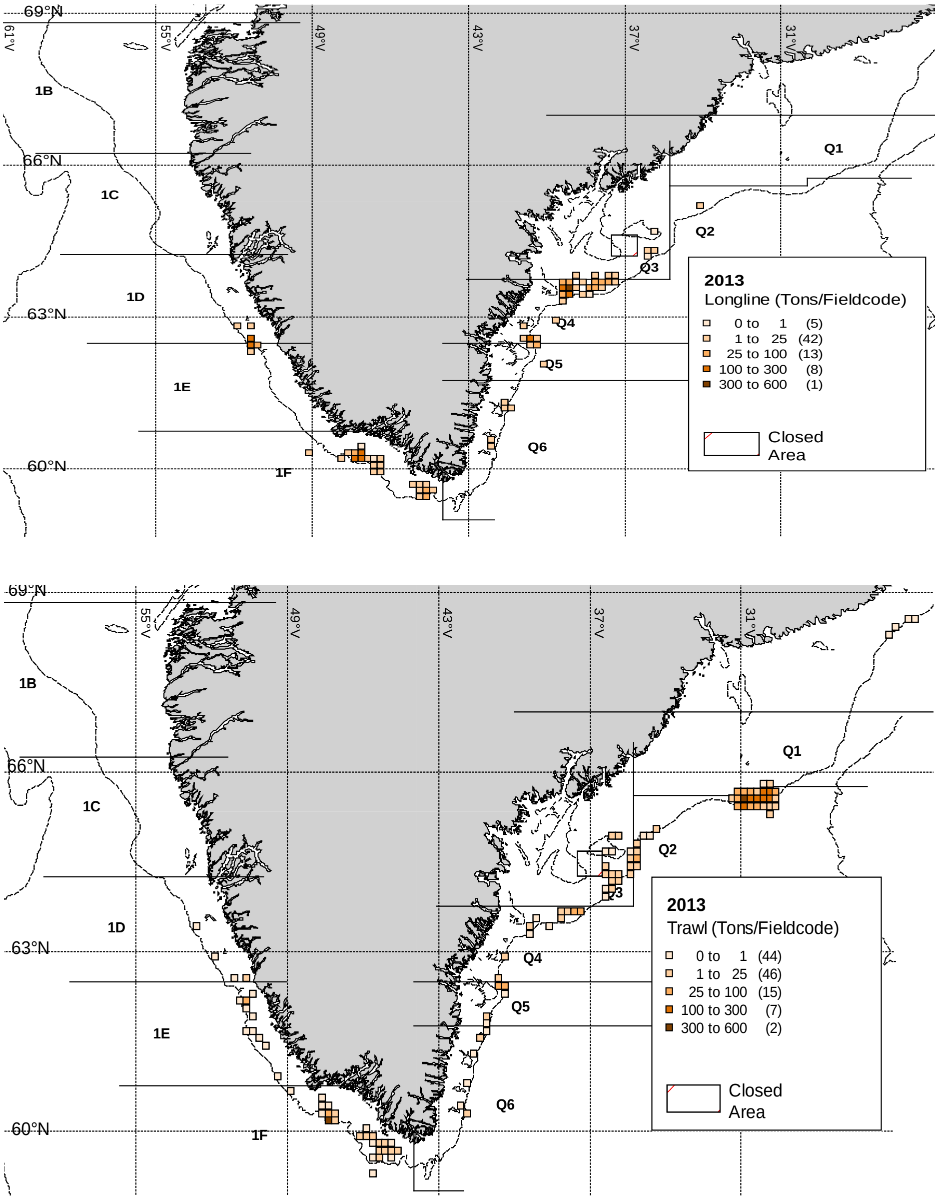

Figure 6.1.2. Distribution of the longline and trawl fisheries in Greenland 2013.

5.2 Biological information

5.2.1 Surveys

Two offshore trawl surveys and information on catch composition (length and age) from the fisheries provide the core information relevant to stock assessment purposes.

5.2.1.1 Greenland Shrimp and Fish survey GRL-GFS

Since 1992, GINR has conducted an annual stratified random bottom-trawl survey in West Greenland. The Greenland survey covers depth from 0–600 m and covers the area south of N72°00′ in West Greenland. From 2008 East Greenland was included in the survey and covers the area south of N67°00′ in East Greenland. Approximately 125 hauls are taken each year in NAFO Division 1F and East Greenland. The survey provides catch and weights-at-age.

5.2.1.2 Trawl survey by Germany (Ger(GRL)-GFS-Q4)

The German survey has been conducted since 1982. The survey covers both East (area south of N67°00′) and West Greenland (area south of N67°00′). Up to 2012, the surveyed area ranged from 0–400 m depth divided into seven geographical strata and two depth zones, 0–200 m and 200–400 m. Numbers of hauls were initially ca. 110 per year but were reduced from the early 1990s to 50–60 per year. In 2013, the survey was re-stratified, with four strata in West Greenland resembling the NAFO division structure, and five strata in East Greenland for the depth intervals 0–200 m and 200–400 m. The survey provides catch and weights-at-age.

5.2.2 Spawning

The recent offshore fishery has shown dense concentrations of large spawning cod off East Greenland from at least 2004, and in 2007 spawning was well documented from catches from Greenlandic trawlers in April–May. In addition an Icelandic survey in April–May 2009 in East Greenland found dense concentrations of spawning cod north of 62° at the banks between "Skjoldungen" (62°30′) and "Kleine Bank" (64°30′). The major contribution to the spawning biomass was made by the 2003 YC. Length at 50% maturity was approximately 60 cm. In years when very large year classes are seen in both the fishery and the survey the fish most likely originate in Iceland waters. This has been corroborated by an 0-group survey that documented the inflow of both the 1973 and 1984 year classes to Greenland waters (Helgasson *et al.*, 1987; Ástorsson *et al.*, 1994). The 0-group survey no longer exists and therefore the recent large year classes (2003 and 2009) have not been observed as inflow from Iceland as 0-groups.

5.2.3 Sampling the fishery

With the implementation of the management plan in 2011 that introduced the cod fishery as an experimental fishery, the vessels were required to provide information on length and age from their catches. The vessels themselves have since 2011 provided samples of whole cod and daily length measurements of the catch and daily collections of otoliths from the catch.

5.3 Stock structure

See Section 2 for a detailed description of stock structure and stock delineation for the entire Greenland cod complex.

Eggs and larvae from East Greenland and occasionally Iceland drift to West Greenland waters to settle and return for spawning at age 5–6 (Figure 5.3.1). Ages 1–4 are therefore predominantly found in West Greenland, whereas ages 4–6 are predominantly found in South Greenland, but ages 6 and older are almost exclusively found in East Greenland (excluding NAFO 1F). This is even more pronounced due to the current low stock size of the West Greenland stock.

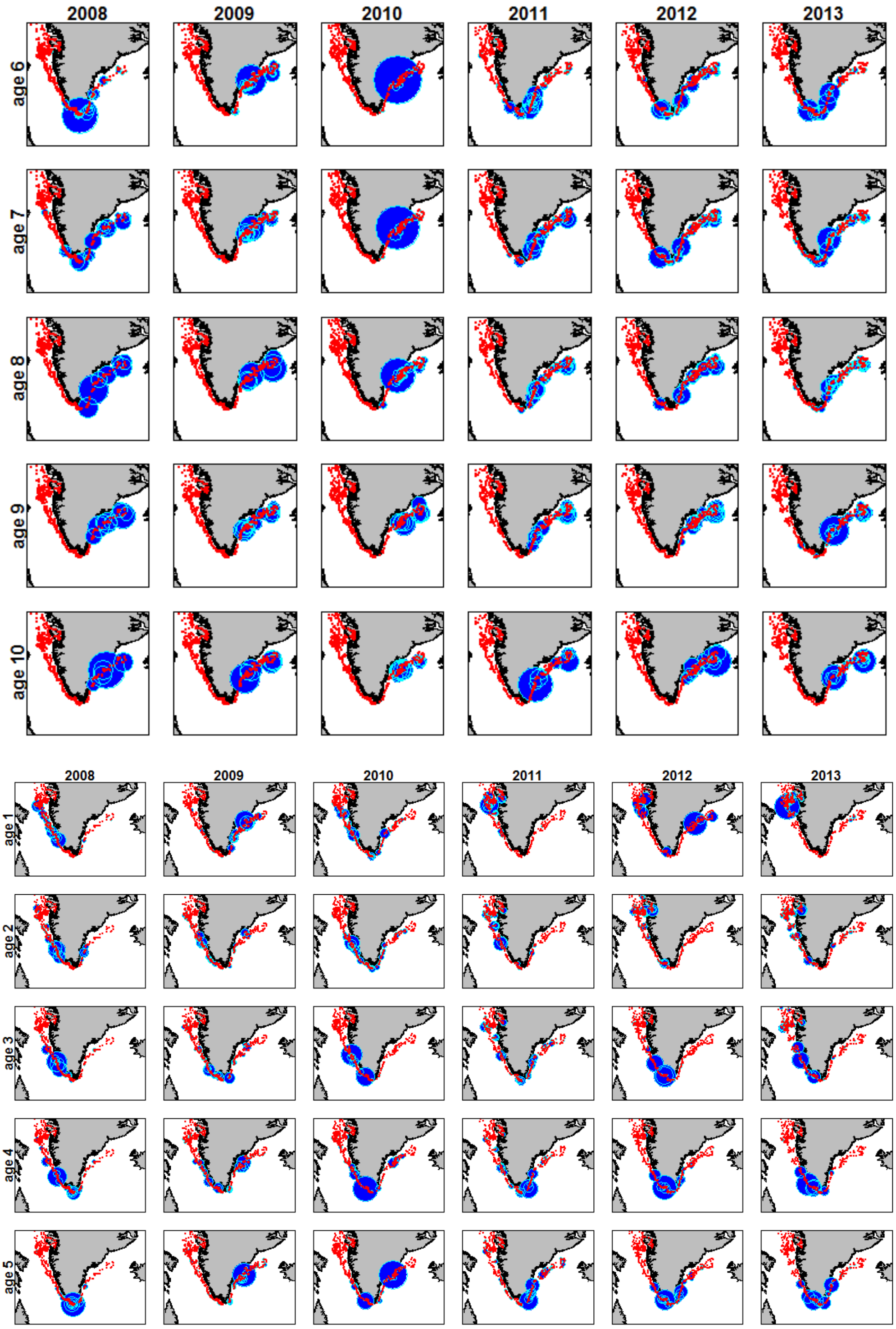

Figure 6.3.1. Abundance (%) of ages 1–10 in the years 2008–2013 from the Greenland survey. The size of blue circles denotes the percentage of the cohort in the given year, where each square equals 100%. Red circles are trawl stations.

5.4 Assessment

5.4.1 Separable model (WD 19)

A Shepherd-Nicholson separable model using the catch data and the German survey indices for ages 1–10 from NAO-Division 1F and ICES Area XIV was formulated and explored during the workshop. Immigration / emigration was estimated in four cases: one for the 1973 year class, two for the 1984 year class, and one for the 2003 year class. While some of the results were promising, questions arose about the way the survey indices had been calculated and the large differences in mean weights-at-age in the German and Greenland surveys. No conclusions about stock status are presented here as there was insufficient time to include all sources of information (e.g. the Greenland survey) and to develop the model to a point where it could be recommended as a basis for advice.

5.4.2 Smoothing of the surveys

A random effects survey smoother was applied to the estimates of biomass from the Greenland and German trawl surveys. The underlying survey biomass is modelled with a random walk with process errors, and the observations of survey biomass estimates are estimated with observation errors:

$$z_t = z_{t-1} + a_t$$

$$y_t = z_t + e_t$$

where z_t is the natural log of true survey biomass at time t, y_t is the natural log of estimated survey biomass, and a_t and e_t are process and observation errors, respectively, modelled with normal distributions. The empirical standard deviations of the survey biomass estimates are used for the time-series of standard deviations of e_t. The process error standard deviation is constant and estimated as a parameter in the model. Finally, estimates of a_t from year to year (i.e. the step changes in the true biomass) are modelled as random effects, leaving only the process error variance as a free parameter.

The data provided for the Greenland survey included the coefficient of variation (CV) of the survey estimates, which were then converted to the standard deviations. The German data, however, reported the uncertainty in the estimates as a function of the confidence intervals. Because the units of these uncertainty measures were unclear, a scaled version of the original units was used as the survey CVs. The CVs for the Greenland survey ranged between 0.2 and 0.54, whereas the CVs used for the German survey ranged between 0.27 and 1.2.

The smoothed fits to the survey time-series each indicate increasing biomass in recent years (Figure 5.4.1). High variability occurs in the point estimates of survey biomass for the German survey, with a CV of 1.18, which exceeds the scaled observation error CVs for all but one year. The high variability of the point estimates can be observed in the period from 2000–2007 in which biomass increased by approximately two orders of magnitude from 1608 t to 114 240 t. The high variability of the point estimates relative to the CVs of the survey biomass estimates results in a high estimate of process error standard deviation of 0.67, with the smoothed line tracking the point estimates fairly closely with the exception of years of high spikes in survey biomass estimates relative to adjacent years (1989, 1995, 2007, and 2014).

The Greenland survey begins in 2008 and covers a period of relatively high biomass, thus showing less variability of the point estimates of survey biomass. The estimated process error standard deviation from the random effects model was 0.34. The smoothed time-series provide a consistent scale and trend of biomass in recent years (Figure 5.4.2), with smoothed estimates of 2014 biomass of 163 030 t and 169 195 t in the German and Greenland surveys, respectively.

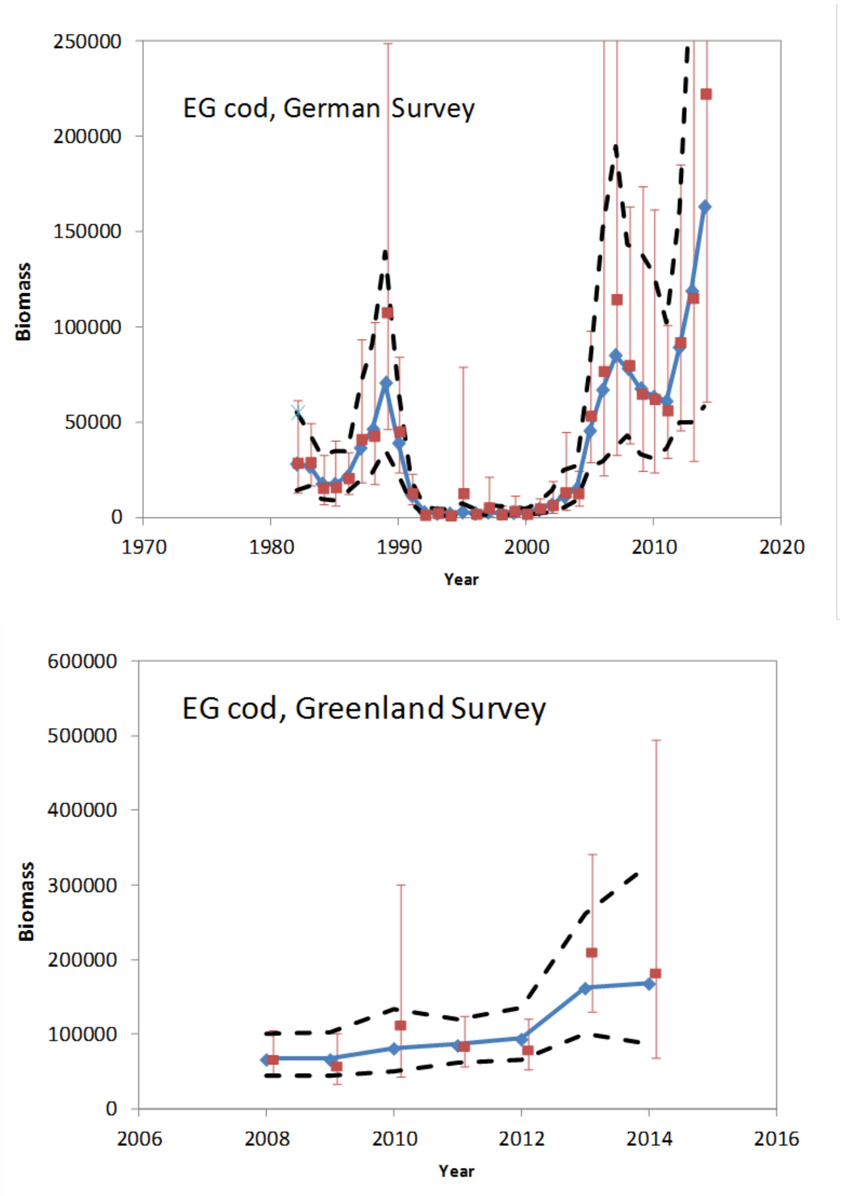

Figure 5.4.1. Smoothed estimates of survey biomass (blue line) for east Greenland cod from the German and Greenland surveys. The survey biomass estimates with 95% confidence intervals are shown in red, and the 95% confidence intervals of the smoothed estimates are shown with the dashed lines.

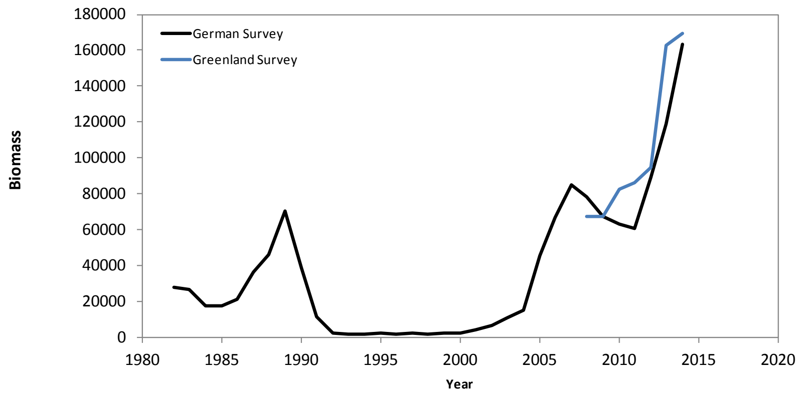

Figure 5.4.2. Smoothed estimates of survey biomass for east Greenland cod from the German (black line) and Greenland (blue line) surveys.

5.4.3 Stock production model (WD18)

A stock production model implemented in an ASPIC framework provided by the NOAA fisheries toolbox was developed to explore reference points and gain insight into stock dynamics. As data the German survey B4+ biomass indices from 1982–2014, landings from 1982–2014 and cpue from 1982–2014 were used. The model continually hit parameter boundaries and WKICE did not consider some of the parameter estimates to be credible. Therefore the approach was not accepted as a basis for providing advice.

5.4.4 DLS approach (method 3.2)

WKICE did not believe that any of the analytical methods presented are currently adequate to form a basis for ICES advice. A number of questions related to the derivation of the indices were raised and were unable to be addressed during the meeting. However, the German and Greenland surveys were believed to more or less reflect relative stock trends, especially when considering their congruence in the period of overlap (2008–2014). Therefore survey indices should be incorporated into ICES advice. One way of doing that is to use the indices in a DLS framework (ICES, 2012, Method 3.2) where survey trends are multiplied by the commercial catches. A thorough scrutiny of the survey uncertainties was not performed during WKICE, but future work would help to decide how much weighting should be put on the different surveys and whether smoothing of the indices is beneficial (considering the very high residual, see Random smoother effect Section 5.4.2). For producing catch advice, it was decided to use Method 3.2 with the following equation:

$$C_{y+1} = C_y \left(\frac{\sum_{i=y-x}^{y-1} I_i / x}{\sum_{i=y-z}^{y-x-1} I_i / (z - z)} \right)$$

where C_{y+1} is the catch advice for the next year (in this case 2016), C_{y-1} is the average catch of the last three years (in this case 2012–2014), I = Survey index value for B4+, x equals 2 and z is 5.

WKICE also agreed that an uncertainty cap or "change limit" of +-20% change in C_{y+1} if C_{y+1} from the equation is 20% greater or less than C_{y-1} should be applied to address uncertainty or noise in the data and its potential influence on the catch advice.

However, WKICE also agreed that this DLS approach should be replaced as soon as possible with an analytical stock assessment that more fully utilizes all of the available data, assuming a credible assessment can be developed.

5.5 Reference points

None defined.

5.6 Conclusions

Previously this stock was assessed in combination with the West Greenland offshore stock. WKICE determined that cod in the South (NAFO 1F) and East Greenland offshore (ICES XIVb) areas should be assessed as a separate biological entity. Although this entity has been determined to be the most appropriate biological unit, it is recognized that the primary nursery area of the juveniles of this stock is in West Greenland. However when the East Greenland/Icelandic stock starts to mature at the age of 5–6, they migrate out of West Greenland and to the spawning grounds in East Greenland and to some extent Iceland.

Several assessment models were presented, but none were approved as a basis for advice. Among the models presented, a separable model showed the most promise (WD 19). However, the model used is not currently a standard ICES model and none of the external reviewers were familiar with it. It was not possible within the time frame of WKICE to explore the model fully, nor to develop alternative models. In general, all models in combination with the survey results support an increasing trend in stock size.

As no analytical assessment was agreed for the East Greenland offshore cod, the DLS Method 3.2 approach incorporating survey indices was adopted. The DLS method applied to the smoothed survey biomass estimates offers the advantage of attempting to remove the survey observation errors. In contrast, using the observed survey biomass estimates as the "true" biomass would not recognize the existence of observation errors, which could lead to errors in the estimated trend of the survey index (particularly observation errors in the most recent two years). The sharp increase in the 2014 estimate for the German survey is thought to be at least partly due to observation error, and the random effects smoother appropriately discounts this datapoint relative to using the point estimates directly. WKICE concluded that it is appropriate to apply the DLS approach, and that this should be dome in a manner that takes observation error into account. The random effects smoother is currently the best available approach, but alternatives could also be investigated. Further refinements to the approach can be obtained by more precisely quantifying the observation error CVs in the German survey.

5.7 Recommendations

The Greenland and German trawl surveys are fundamental to the assessment of cod in East Greenland. The two surveys provide similar signals and similar age compositions but the mean weights-at-age differ considerably. Recommendations regarding survey data are given below.

1) The cause for the difference in the mean weights-at-age between the German survey and the commercial catch should be identified. The Greenland survey weights-at-age correspond well to the weights in the catches, but both are lower than the German survey weights-at-age. The catch-at-age patterns in the German and Greenland survey ages appear to be consistent, and the German and Greenland laboratories should work to formally standardize their age-reading methods.
2) The spatial distribution of the survey tows should be further examined to identify unusually high tows that may affect the survey biomass estimates. Additionally, a spatial analysis of the survey catch by age would indicate whether the size-at-age varied spatially, which could reflect variability of the influx of fish returning from the West Greenland area.
3) The standardization of the German trawl survey should be carefully reviewed and factors such as vessel and gear type should be explicitly included in the analysis, if this is not already the case. Expressing the variability as either a standard deviation or coefficient of variation would allow this survey data to be more easily incorporated into population models.
4) The possibility of conducting a 0-group survey to provide a preliminary estimate of year-class strength and the magnitude of any influx of early life-history stages from Iceland should be investigated.

Model explorations conducted at the Benchmark meeting indicated the importance of the contrast in abundance in the early period (1982–1991) for estimating survey catchability, and suggested that the estimated emigration of the 2003 year class (in 2009) to Iceland was of comparable magnitude to the estimated immigration from the Icelandic cod assessment. The Benchmark group was inconclusive on how best to use the survey data in the assessment (e.g. relative weighting of the two survey indices, use of the mean weight data) and offers the following recommendations for work that should lead to a useful assessment model.

1) The feasibility and utility of developing a combined assessment model for Icelandic and East Greenland cod stocks should be investigated. The available genetic data suggest some connectivity between the Icelandic and Greenland areas, and tagging data indicate connectivity between the East Greenland cod stock and the Icelandic cod stock, mainly by means of drift/migrations of large year classes that return to Iceland for spawning, but likely also for adults during the feeding season. Such migrations can affect the separate models in each of these areas. The assessment model(s) (either two single models or a combined model) should account for these migrations. There is a need to evaluate whether combining the fishery and survey data from these two interrelated areas into a combined assessment model is likely to provide an improvement over the current approach to addressing emigration/immigration within the two separate models.
2) Prior to formulating a combined East Greenland and Icelandic cod model, further targeted work using both genetics and tagging is likely to be required to gain additional insight into stock structure and migration patterns. Tagging data may identify years in which large drift/migrations occurred between the East Greenland and Icelandic areas, and may facilitate the goal of estimating age-specific migration rates between areas. Because of the complex nature of spatial genetic structure, this evaluation

should also consider the linkages between these two stocks and West Greenland.

3) In the development of age-structured models, fit the proportions of catch-at-age instead of the catch numbers-at-age, with the catch biomass providing the scale of the removals. Variability of the observation errors of the estimated catch can be addressed by allowing the catch CV to vary across the years of the time-series. The catch (and survey) data in the early portion of the time-series appears to provide information on the scale of the abundance (i.e. survey catchability) and should not be removed from the model.

4) For age-structured modelling, caution should be exercised when considering dropping or shortening survey time-series. A rationale offered for dropping the early years of the German survey time-series was that environmental conditions and fishing mortality rates may have changed. However, well-designed surveys should provide credible estimates of abundance over a range of abundance levels and environmental conditions. It may be possible that the availability of the stock to the survey, or the availability of the Iceland stock to the survey, has varied over time, and this should be investigated (see recommendation above on examining the spatial pattern of the survey catch data).

WKICE was reluctant to recommend adoption of DLS Method 3.2, and simple calculations (not reported here) suggested the method may not work well in some situations and should only be considered an interim solution. The recommendation was made only because there was insufficient time to develop an alternative analytical assessment approach. WKICE believes that the available data should be adequate for a full analytical stock assessment approach to be developed, and that assessment models incorporating the above recommendations should be actively pursued. If a suitable model can be developed, an interim benchmark is recommended.

5.8 References

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6 Icelandic cod

6.1 The fishery

Annual estimates of landings of cod from Icelandic waters are available since 1905. The bottom-trawl and longline fisheries are the most important. In the former the largest part of the catch is confined to the outer continental shelf, while the latter is on the shelf proper. The landings estimates in the last two decades are based on a full census and area misreporting is believed to be minimal. Discarding of fish of economic value is banned in Icelandic waters. Estimates of annual cod discards (Ólafur Pálsson *et al.*, 2010) since 2001 are in the range of 1.4–4.3% of the numbers landed and 0.4–1.8% of the weight landed. Mean annual discards of cod over the period 2001–2008 were around 2 kt, or just over 1% of landings. In 2008 estimates of cod discards amounted to 1.1 kt, 0.8% of landings, the third lowest value in the period 2001–2008. The method used for deriving these estimates assumes that discarding only occurs as highgrading. Various management rules, such as quick area closures if more than 25% of the catches in hauls are less than 55 cm, temporary transfer of ITQ among boats, and an allowance to land smaller fish outside the ITQ account systems are in place. The intent of these measures is in part to minimize discarding.

The control of the catches, since the 1991/1992 fishing year, has in principle been an ITQ based TAC system, although some specific measures for the smaller vessels (<15 m) have remained in place. A harvest control rule has been the basis of the decision for the total TAC since 1993. The rule has undergone some amendments over time but has from the start been based on a multiplier of the reference biomass, defined as the estimated biomass of fish four years and older. Until the 2007/2008 fishing year the multiplier was 0.25 but has since been of the following form:

$$TAC_{y+1} = min\left\{1, \frac{SSB_y}{SSB_{Trigger}}\right\} \times \frac{0.20 \times B_{4+,y} + TAC_y}{2}$$

The ratio of the landings relative to the catch dictated by the harvest control rule in place at any time shows that there has been an overshoot in the landings (mean around 8% for the period since 1993). This can be largely attributed to various socio-economic measures that were mostly foreseeable and predictable at the time of the decision-making. In the last couple of years a system has been set in place that is supposed to take account of these overshoots but its effect is still not visible.

6.2 Biological information

The data that are input to the current assessment are:

- Catch-at-age from 1955 onwards, age 3–14;
- Catch weight-at-age over the same period;
- Spring survey indices from 1985 onwards, age 1–10 (approximately 550 stations);
- Fall survey indices from 1996 onwards, age 1–10 (approximately 320 stations);

- Weight-at-age and maturity-at-age in the spawning stock are derived from the spring survey estimates except in ten years and older, where catch weights are used.

Natural mortality is set to 0.2 for all groups.

6.3 Stock structure

The Icelandic cod stock is distributed all around Iceland, and in the assessment landings of cod within Icelandic EEZ waters are assumed to be a single homogeneous unit. Spawning takes place in late winter mainly off the southwest coast but smaller, variable regional spawning components have also been observed all around Iceland. The conventional wisdom has been that pelagic eggs and larvae from the main spawning grounds off the southwest coast drift clockwise northwards and eastward along the island to the main nursery grounds off the north coast. The mature stock migrates from the spawning grounds to feeding grounds to deeper waters in the northwest and southeast or within the shallow water realm of the continental shelf proper.

A larval drift to Greenland waters has been recorded in some years and substantial immigrations of mature cod from Greenland which are considered to be of Icelandic origin have been observed in some periods. This pattern was considered to be quite prevalent prior to 1970, when conditions in Greenlandic waters were favourable for cod productivity. Periodic immigrations have been estimated in the assessment from anomalies in the catch-at-age matrix, with the timing of such events being based on additional qualitative judgment from tagging, 0-group surveys and weights-at-age. The most recent of such migrations was from the 1984 year class in 1990, with the number estimated being around 30 million. Recent tagging experiments as well as an unexplained decline in survey indices in West Greenlandic waters indicate that part of the 2003 and to some extent the 2002 year classes may have migrated from Greenland to Icelandic waters. In the current assessment the immigration at age 6 in 2009 is estimated to be around 9.7 million.

A slight but significant genetic difference has been observed between the cod spawning in the northern waters vs. cod spawning in the southern waters (Pampoulie *et al.*, 2007). There are indications that different behavioural types (shallow vs. deep migration) may be found within cod spawning in the same areas (Pampoulie *et al.*, 2008). In addition genetic comparisons of cod samples in Greenlandic waters indicate that there is genetic affinity of mature cod in Icelandic and Greenlandic waters, particularly in the eastern and southwestern areas. The research show that management measurements operating on a finer or larger scale than is currently in place may be warranted. However, robust methods for splitting up or combining catch-at-age and survey at age among areas have yet to be investigated.

Extensive tagging experiments spanning with some hiatuses over the last 100 years indicate that significant emigration of adult cod from Iceland to other areas may be rare. In recent years it has been observed that cod tagged in Iceland has been recaptured inside Faroese waters on the Faroese ridge proper. Anecdotal information from the fishing industry indicates that there may also be some exchange of cod across the Denmark Strait. These migrations may be of different nature than the hypothesized net "life-history" immigration of cod described above.

6.4 Assessment

The current assessment is based on a forward running statistical catch-at-age model (adcam, sometimes also referred to as cam) where fishing mortality-at-age is allowed to change gradually in time (random walk).

In the equation linking stock in numbers and survey indices:

$$U_{ay} = q_a N_{ay}^{\beta_a}$$

the β is estimated for age groups 1 to 5.

The dynamics of cod based on this assessment (Figure 6.4.1) can be summarized as follows: the spawning stock of Icelandic cod is increasing and is higher than has been observed over the last four decades. Fishing mortality has declined significantly in the last decade and is currently close to an historical low. Year classes since 1985 are estimated to have been relatively stable but with the mean around 35% lower than that observed for year classes from 1953 to 1984. The increase in stock size in the last decades can most likely be attributed to the reduction in fishing mortality as intended with the establishment of the HCR.

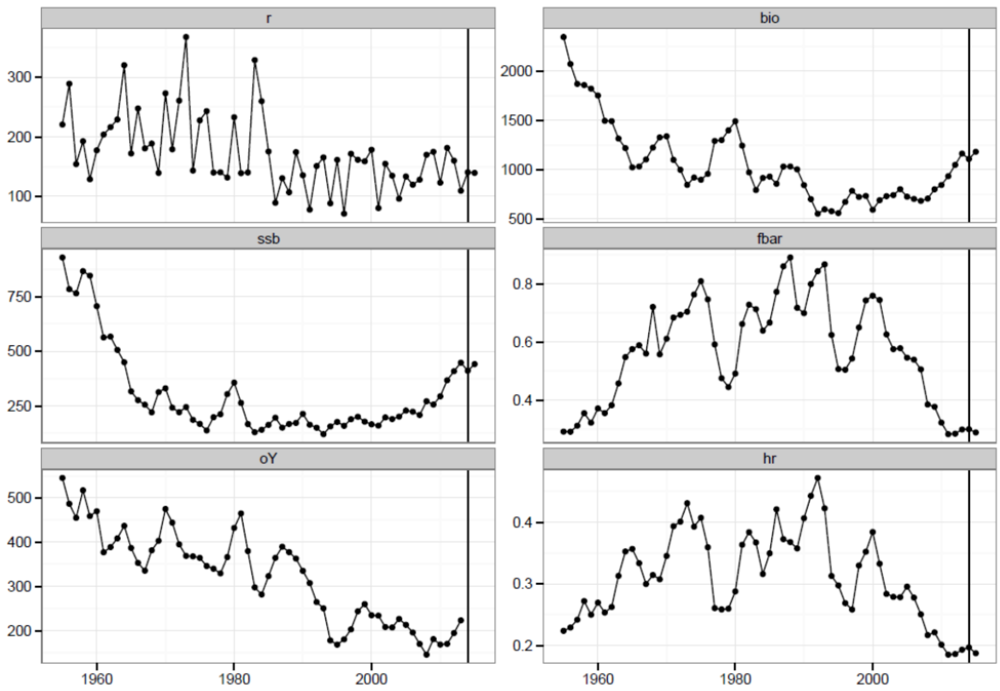

Figure 6.4.1. Assessment summary of the base run (adcam, both spring and fall surveys).

The survey residuals are within a reasonable range (Figure 6.4.2), although residuals tend to be mostly negative for spring survey indices for ages 2 to 5 in recent years. A retrospective analysis based on the current framework (Figures 6.4.3 and 6.4.4) indicates a slight overestimation of reference biomass and underestimation of fishing mortalities over the last decade. The inference made from these patterns should however be weighed against the estimated low current fishing mortality, which results in older data still having an influence on the terminal estimates. In other words, convergence is slow when fishing mortality is low.

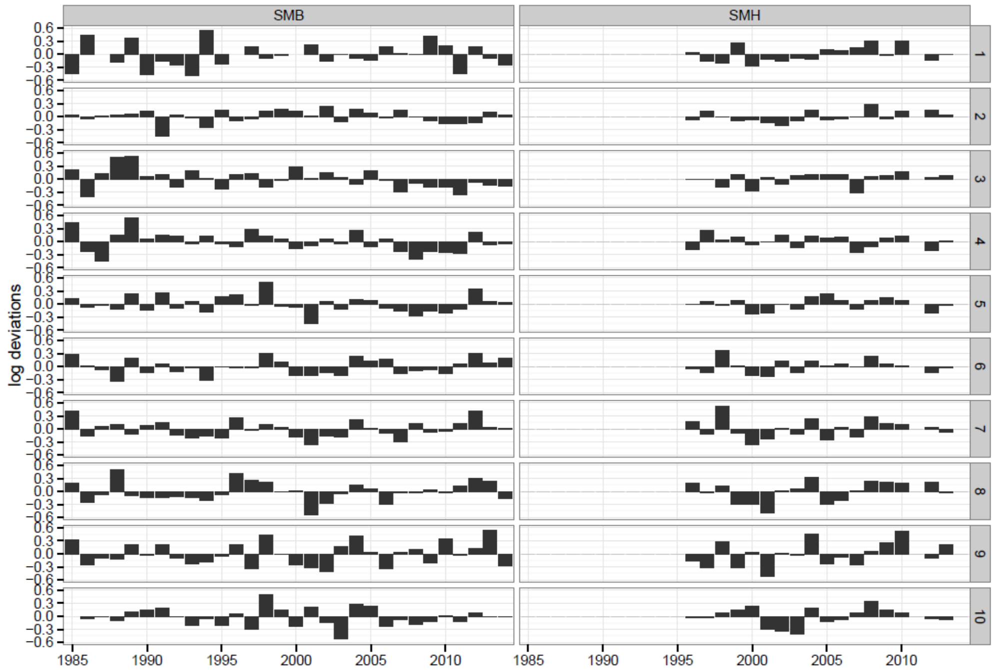

Figure 6.4.2. Spring (left) and fall (right) survey residuals by age from the base run (adcam, both spring and fall surveys).

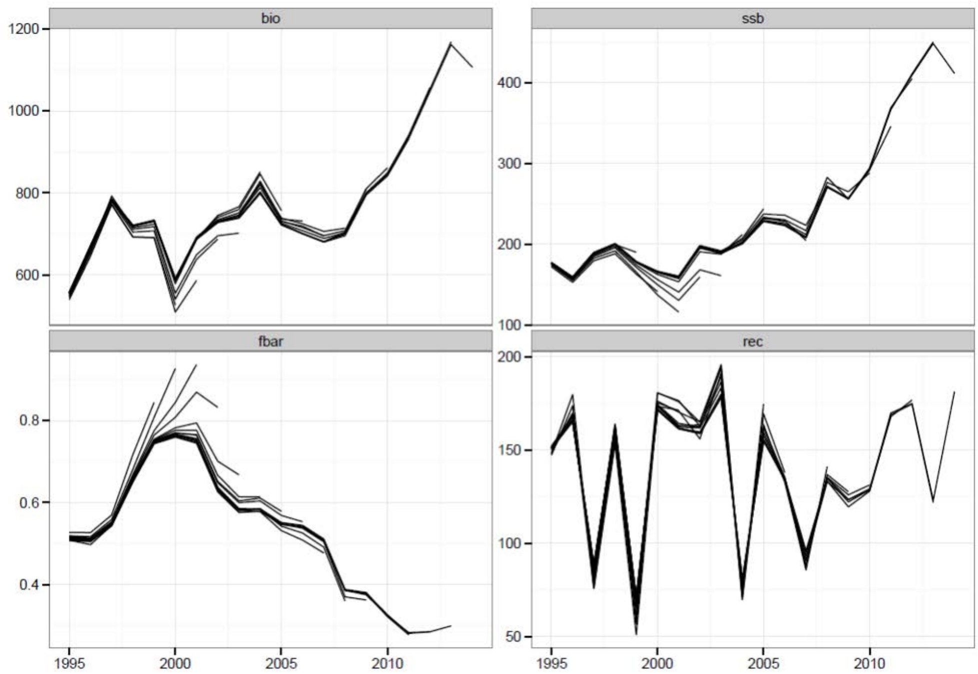

Figure 6.4.3. Retrospective pattern of the base run (adcam, both spring and fall surveys).

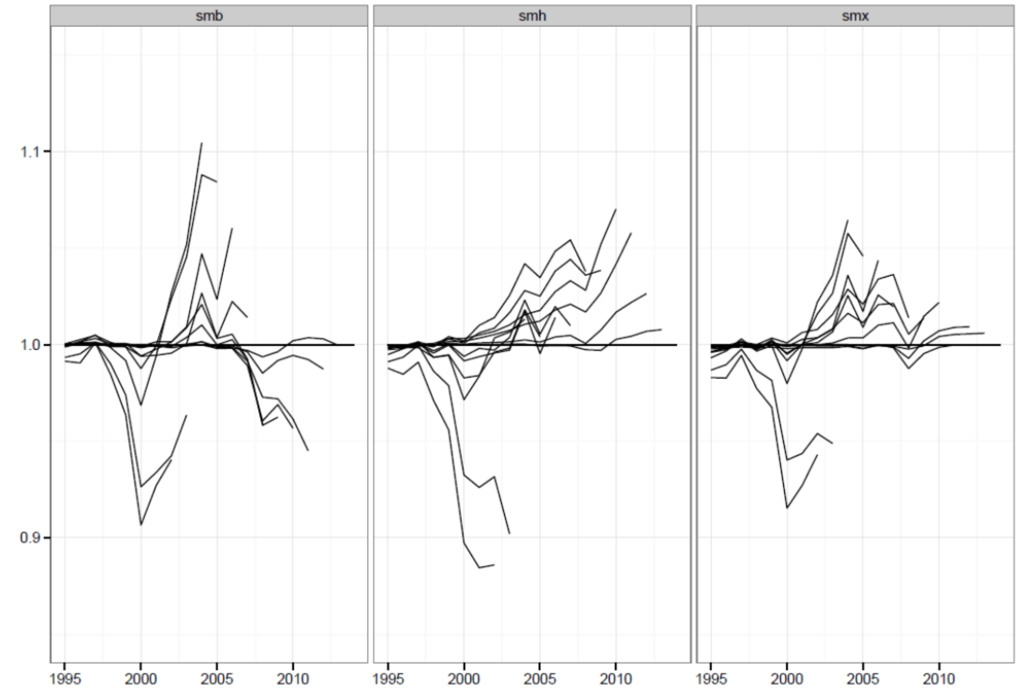

Figure 6.4.4. Retrospective pattern in the reference biomass based on adcam runs tuned with the spring survey only (smb, left panel), fall survey only (smh, middle panel) and both surveys (smx, the base run, right panel).

As has been observed in recent years the assessment based on the adcam module tuning with the fall survey only gives around 10% higher reference biomass than when both surveys are used, while tuning with the spring survey results in around 10% lower reference biomass (Figures 6.4.5 and 6.4.6). There are hence some conflicts with respect to the extent of the increase in the biomass and reduction in fishing mortality in recent years between the two survey input sources. A retrospective analysis based on using only one survey at a time in the tuning (Figure 6.4.4) did not indicate that there is an improvement over the current model setting (both surveys).

Models where the catch/fishing mortality is not modelled (adapt type of vpa) and where the fishing pattern is not considered to change each year (separable) have been routinely run for comparative purpose (Figures 6.4.5 and 6.4.6). Within these two alternative frameworks, the observation with respect to different survey fleets on the biomass estimates is the same as observed in adcam: i.e. the fall survey generally provides higher biomass estimates than the spring survey. The adapt framework often results in higher biomass estimates than does the separable model, while current model framework (adcam) falls somewhere in the middle.

In addition to the above models, XSA and SAM were run using both survey indices as tuning fleets. They resulted in somewhat higher estimates of reference biomass than the current framework (Figures 6.4.5 and 6.4.6).

In summary, with the exception of the adapt tuned with the fall survey and XSA tuned with both surveys, the model configurations trialled give reference biomass estimates in 2014 that are within +/-10% of the estimates from the base run. It therefore appears that different model assumptions have only a minor impact on the assessment results.

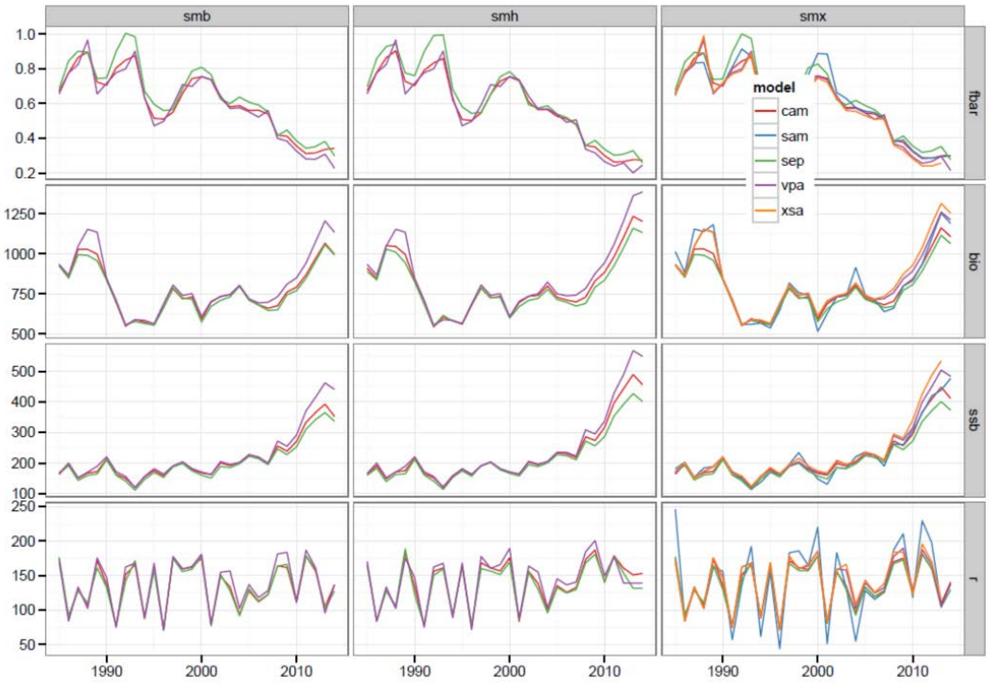

Figure 6.4.5. Comparison of alternative model runs tuned with the spring survey only (smb, left panel), fall survey only (smh, middle panel) and both surveys (smx, right panel). Model acronyms are explained in the text.

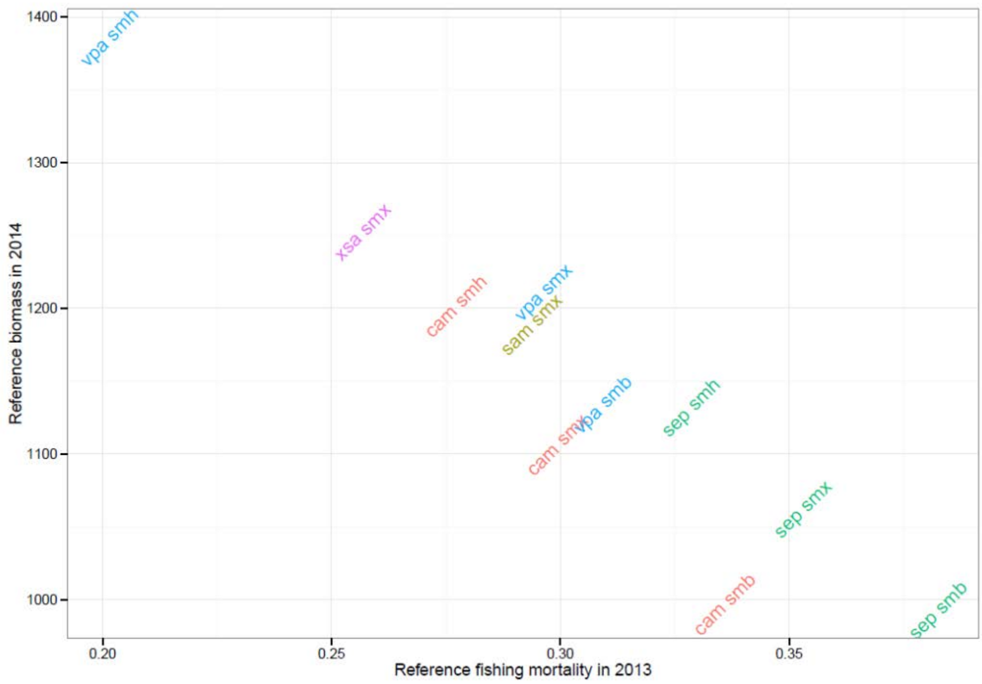

Figure 6.4.6. Terminal estimate of fishing mortality in 2013 and reference biomass in 2014 using alternative model setups and tuning fleets: Spring survey only (smb), fall survey only (smh) and both surveys (smx).

The data have also been annually explored in the TSA framework (not presented at this meeting). The results given conventional assumptions of fixed catchability are in line with the estimates above. The conclusion from an exploratory analysis on potential changes in catchability in the surveys (NWWG 2014) were: "Significant estimates of linear trend or random walk in survey catchability are an important warning that results, based on the assumption that no permanent or long-term variations are present in the survey catchability are unreliable. But they are not a strong evidence of the assumption that linear trend or random walk are a good model of the actual process."

In addition to some conflict in the survey signals, the year classes seem to be declining at a somewhat faster rate in the fisheries than in the surveys. This can be demonstrated when the tuning is conducted only using age groups 1–4 (Figure 6.4.7).

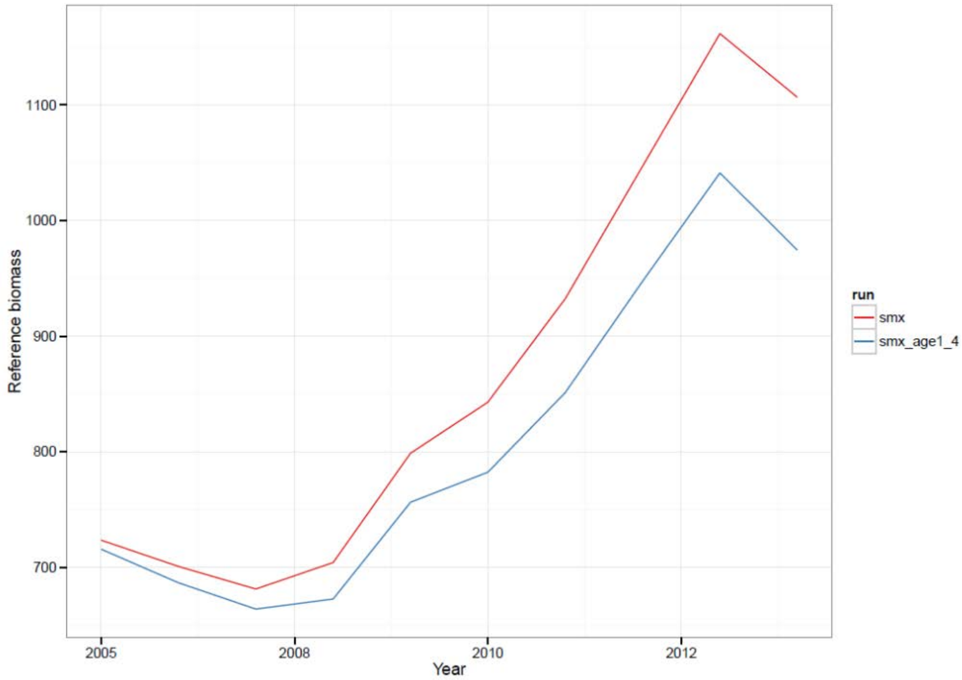

Figure 6.4.7. Comparison of the reference biomass estimates from the base run (adcam smx, survey age 1–10) and a run based on restricting survey indices to age 1–4 (smx_age1_4).

The decline in fishing mortality in recent years means that older data still have an influence on the estimates in the most recent years and convergence of the assessment model is slow. It is hence unclear at this moment which modelling configurations most likely represent the true state of nature. It must be kept in mind that in the HCR evaluations, differences in assessment results as shown above were accounted for by setting the assessment error coefficient of variation to 0.15 and the first order autocorrelation to 0.45.

Prior to 2004 the weights-at-age in the catches in the assessment and the advisory year were based on a model using weights-at-age in the previous year from the same cohort as well as the estimated capelin biomass. Since then the predicted catch weight for age groups 4–9 in the assessment year (y) have been based on a simple linear regression of the relationship between survey weights-at-age in the year prior to the advisory year (y-1):

$$cW_{a,y-1} = \alpha + \beta \times sW_{a,y-1}$$

The parameters are then used to predict the catch weights in the assessment year using available survey weights-at-age in the assessment year:

$$cW_{a,y} = \alpha + \beta \times sW_{a,y}$$

These catch weights-at-age are then used to calculate the reference biomass (B4+) in the assessment year, the latter being used in the HCR to dictate the TAC.

The relationship between capelin biomass and catch weights was briefly revisited during the benchmark. Although a correlation between cod weights and capelin biomass is evident, it was concluded that adding capelin biomass as a co-parameter in the prediction would likely not improve the current method.

6.4.1 HCR evaluation revisited

The 20% multiplier in the HCR has been in place since 2009. When evaluated in 2009 (ICES, 2009) it was expected that the stock would increase substantially until 2015 (Figure 6.4.8). According to the 2014 assessment the biomass increased somewhat faster than expected, given the available measurements of the incoming recruits. In part this is due to higher mean weights-at-age. Additional year classes that have become available since 2009 are also somewhat larger than those projected. All in all the development is within the expected range anticipated in the 2009 simulations.

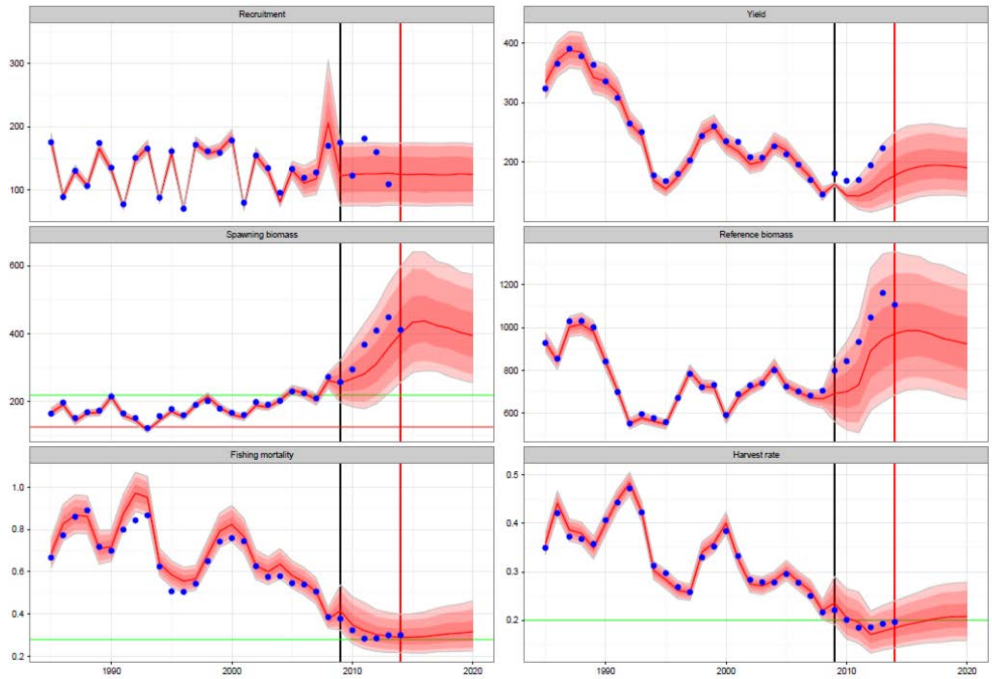

Figure 6.4.8. Comparison of the expected stock dynamics conducted in 2009 based on a 20% multiplier in the HCR (red colours, outer ribbons show the upper and lower 5%) and the dynamics estimated in the 2014 assessment (blue colours).

The evaluation framework used in 2009 was revisited at the benchmark. The only difference was the additional stock–recruitment data and mean weights-at-age used in the forward simulations. For the latter, values in 2009 were based on the recent averages, which were then at an historical low. Since then the weights-at-age have increased and the more recent values are used. The simulation was run forward from 2014 for 50 years, with the long-term metrics being based on the results from the last ten terminal years where starting values in 2014 have little influence on results.

The harvest rate in the HCR that resulted in maximum sustainable yield was 0.22 while the harvest rate that resulted in less than 5% probability of going below $B_{trigger}$ was 0.21 (Figure 6.4.9). The current analysis confirms the conclusion from 2009 that the HCR is in accordance with the precautionary approach (low probability of going below B_{lim} and $B_{trigger}$) and that the ICES MSY approach is appropriate.

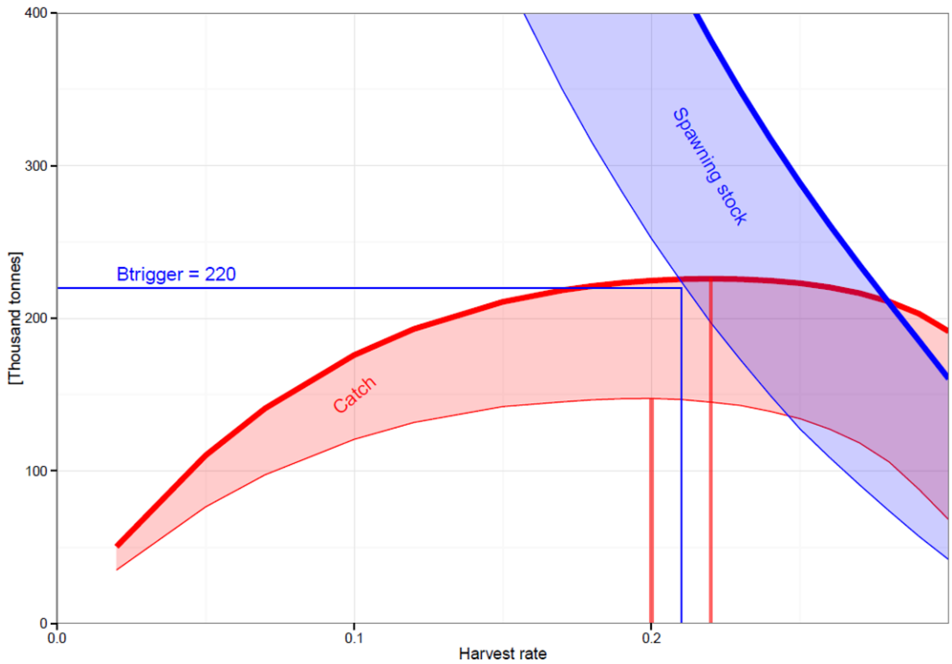

Figure 6.4.9. Equilibrium results from the harvest control rule evaluation conducted in 2015. Catch (red colours) and spawning–stock biomass (blue colours) at equilibrium as a function of harvest rate. The thick lines refer to the mean and the thin lines to the lower 5th quantile.

6.5 Reference points

Only B_{lim} (125 kt) is defined as a reference point for this stock. The basis is B_{loss}, the hypothesis being that a recruitment shift occurred in the 1980s. If that hypothesis is false the $B_{trigger}$ that is in the HCR (220 kt) could be considered as an alternative candidate for B_{lim}. The basis for this would be that at lower values of spawning–stock biomass, recruitment has been less than the long-term mean more frequently than it has been above it. In recent years the spawning–stock biomass has increased substantially but recruitment above the long-term mean has yet to be observed.

Given that the HCR in place is in conformity with the precautionary approach and that it results in maximum sustainable yield (MSY), setting additional reference points (F_{lim}, B_{pa}, B_{lim}, F_{MSY}) is not warranted.

6.6 Conclusions

WKICE accepted the current Icelandic stock assessment, as described in the stock annex in this report, as a benchmark assessment. The assessment methodology and outputs have been relatively consistent since at least 2009, and the workshop judged the current assessment to be reliable and robust. The 2009 assessment produced projections to 2015 that are compatible with the results of the current assessment, although rebuilding is estimated to have occurred at a faster rate than that indicated by the 2009 projections.

The stock appears to have rebuilt from relatively low levels in the last 2–3 decades of the 20th century to levels corresponding to the 20% harvest control rule in recent years.

6.7 Recommendations

The potential for combining East Greenland and Icelandic cod into a single assessment (i.e. treating them as a single stock) should be explored to determine whether such a model can produce a more robust and credible assessment of overall trends in biomass and fishing mortality, as well as current and past stock status. If possible, migrations of the stock between Iceland and East Greenland should also be modelled.

More work is needed on stock structure and migration patterns for Icelandic cod and the Greenland cod stocks, particularly if the distribution of the stocks alters as a result of climate change. Tagging studies, genetics studies and, to a lesser extent, morphology studies should be augmented to more fully address stock structure issues.

Considerable advances were made at the benchmark meeting in regards to estimating the consumption of capelin by cod and the effect this has on the spawning stock of capelin. Addressing the effects of this should also be investigated for the cod stock. Previous studies have shown a correlation between the size of the capelin stock and mean weight-at-age of cod. This relationship broke down few years ago but further analysis on available data should be conducted to further estimate the availability of capelin to cod and the effect this has on the condition of the cod stock.

Mean recruitment after 1984 is considerably lower than before 1984 although the SSB has increased in recent years. Exploring the effects of ecological drivers such as changes in hydrography or predation on juveniles might shed some light on the changes in recruitment.

In terms of the actual assessment of cod in Iceland, the main thing that needs to be explored is the discrepancy over time in the two surveys used for tuning. Addressing this issue will become more important if this discrepancy continues to increase and affects the assessment uncertainty.

6.8 References

ICES. 2009b. Report of the Ad hoc Group on Icelandic Cod HCR Evaluation (AGICOD), 24–26 November 2009 ICES, Copenhagen, Denmark. ICES CM 2009\ACOM:56. 89 pp.

7 Capelin in the Iceland–East Greenland–Jan Mayen area (IGJM)

Since the early 1990s the same model for setting an initial, preliminary TAC has been used based on projection of survey estimates of immature abundance from the autumn survey in the previous year. The method for setting the final TAC has also been unchanged based on estimates of abundance of mature capelin from the January survey. Neither method was endorsed by WKSHORT 2009, mainly because the value of M (natural mortality) used in the assessment calculations (0.035 per month) was considered too low. In addition WKSHORT 2009 recommended using bootstrapping to estimate the confidence intervals on the acoustic survey estimates. Prior to WKICE a new advice framework based on a stochastic approach was developed.

7.1 The fishery

In the mid-1960s a purse-seine fishery began on capelin and soon expanded to a large-scale fishery. During its first eight years, the fishery was conducted in February and March on schools of prespawning fish on or close to the spawning grounds south and west of Iceland. In January 1973 a successful capelin fishery began in deep waters near the shelf break east of Iceland. In 1976 a summer capelin fishery began in the Iceland Sea. This fishery became multinational with vessels from Iceland, Norway, Faroes and Denmark. The pelagic trawl was introduced to the fishery in the mid-1990s.

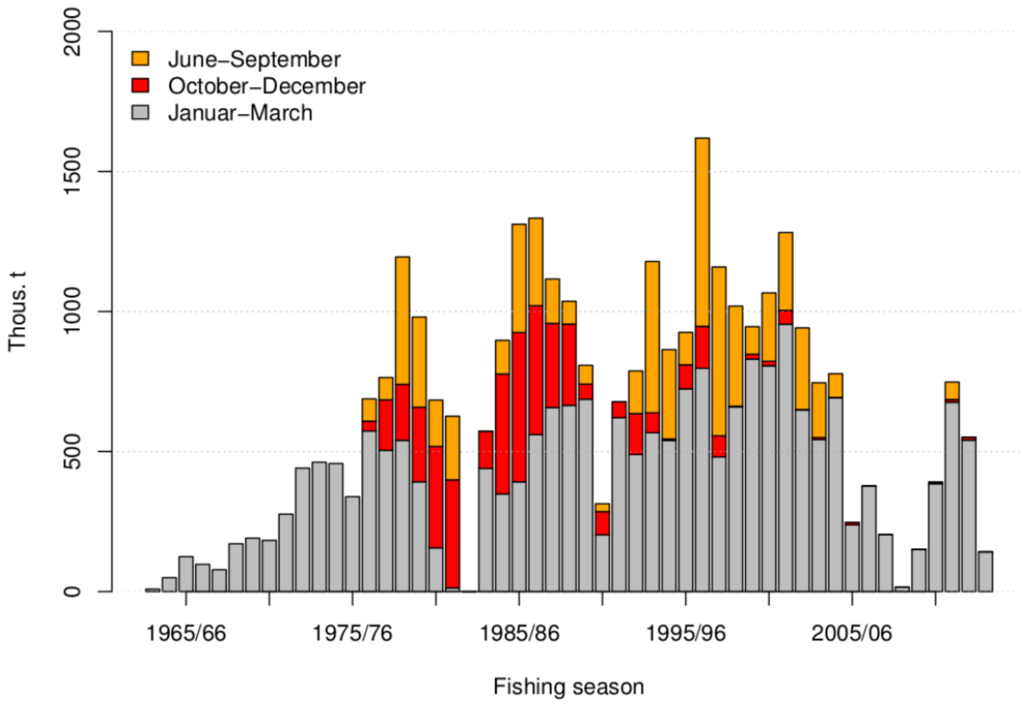

Figure 7.1.1. Total catch (in thousand tonnes) of the Icelandic capelin since 1963/1964 by fishing season.

A fishery during winter (January–March) has taken place in all years, with the exception of the winter of 1982 and the 1982/1983 and 2008/2009 fishing seasons, when a moratorium was in effect (Figure 7.1.1). Until the late 1980s the fishery in October–

December was much more pronounced than the fishery in June–September, whereas it was the opposite in the 1990s. During the 1990s the fishery in autumn was at low levels and practically no autumn fishery has taken place since 2000. Since the mid-2000s, a preliminary quota allowing for a summer fishery has only been set twice and the resulting fishery has been at a low level.

The fishing season has extended from June 20 to the end of the following March since the mid-1990s. However, when stock size has been estimated to be low the fishing season has started later, in October/November after an autumn survey, or even in January/February following a winter survey.

7.2 Biological information

The timeline of life-history and survey events for a cohort of capelin can be summarised as follows (also see the schematic in Figure 7.2.1):

- Year 0
  - Spring: Hatches from egg.
- Year 1
  - Autumn: Measured as immature.
- Year 2
  - Summer: The bulk of the cohort is still immature but about to start maturation. The feeding migration begins.
  - Autumn: September–October survey, the majority of the cohort is mature, but some may still be immature (delayed spawners).
- Year 3
  - Winter: The bulk of the cohort migrate to spawn. The final TAC is issued in-season, based mainly on acoustic estimates of this cohort.
  - Spring: Spawning and subsequent mortality.
  - Autumn: The rest (minority) of the cohort (that did not spawn in spring) is measured acoustically.
- Year 4
  - Winter: The rest of the cohort is measured acoustically when migrating to the spawning grounds.
  - Spring: Spawns and dies.

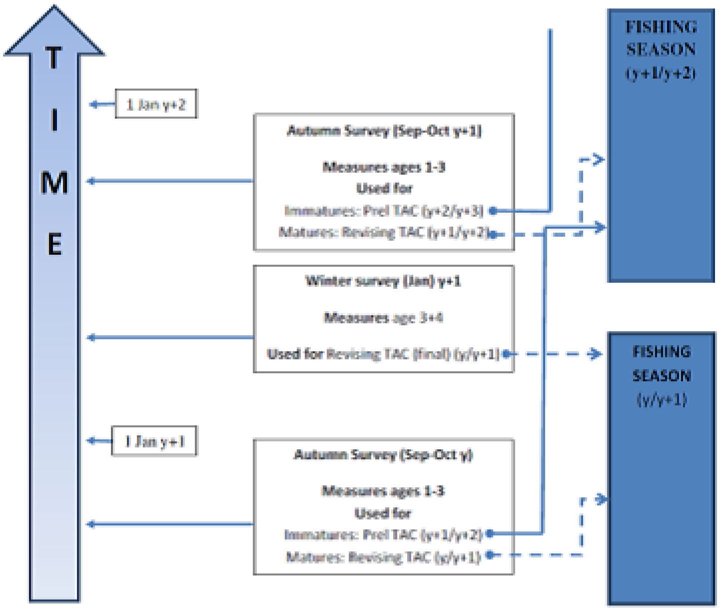

Figure 7.2.1. Timeline for surveys and their use in TAC setting. Solid line on the left side of the diagram marks the time when the survey takes places and the place of 1 January on this timeline. The solid line on the right hand side of the diagram marks the setting of the preliminary TAC while the dashed lines mark revisions of the TAC.

7.3 Stock structure

Capelin is a small pelagic schooling fish. It is a cold-water species that inhabits arctic and subarctic waters in the North Atlantic and North Pacific. Capelin in the Iceland-East Greenland-Jan Mayen area is considered to be a separate stock.

7.4 Assessment

The stock has been assessed using acoustic surveys since 1979, as described in the IGJM capelin stock annex.

WKICE adopted the stochastic HCR described below. This HCR was adapted from the one for Barents Sea capelin. A new methodology for setting an initial/preliminary quota was also developed during the benchmark meeting.

The application of the new HCRs following acoustic assessment surveys are given below:

Following the acoustic survey in winter (January–February)

Bootstrap replicates of survey estimates of SSB are combined with data on the predicted predator stocks from NWWG the previous year (cod Va, haddock Va, saithe Va). Predator distributions are sampled from observed distributions in the March survey. The estimates are fed into a predation model run with varying catches until spawning in late March. The **final TAC** is set at the catch giving p(SSB $<B_{lim} = 150$ kt) <0.05.

Following the acoustic survey in autumn (September–October):

a) For the mature/maturing part of the stock (for the current/coming season)

Bootstrap replicates of the survey estimates of SSB, are combined with updated assumptions about predator growth and mortality. Additional uncertainty is included due to variable mortality. The estimates are fed into the predation model with same supporting data as that applied to the winter survey results. The **intermediate TAC** is set at the catch giving p(SSB <B_{lim} = 150 kt) <0.05.

b) Based on estimates for the immature part of the stock (for the next fishing season)

A proposal was made to WKICE for a simple approach for setting the initial TAC, based on a plot of immature capelin against fishable biomass with estimated uncertainties added (WD 16). It was rejected by WKICE and instead the following proposal for setting **the initial/preliminary TAC** for the next fishing season was developed during the meeting and then adopted:

Estimating the predicted final TAC was, similar to the method used up until now, based upon a regression enabling the prediction of the final TAC that will lead to p(SSB <B_{lim} = 150 kt) <0.05. This was done by:

1) bootstrapping the historical January acoustic estimate and finding the 95% lower confident limit;

2) adding catches taken before the January survey;

3) subtracting 300 kt (B_{lim}=150 kt and an allowance of 150 kt for predation, set at the average model estimate from survey to spawning); and

4) setting up a regression model with this value vs. acoustic indices of immature capelin (Figure 7.4.1). The slope of the regression line is 5.2.

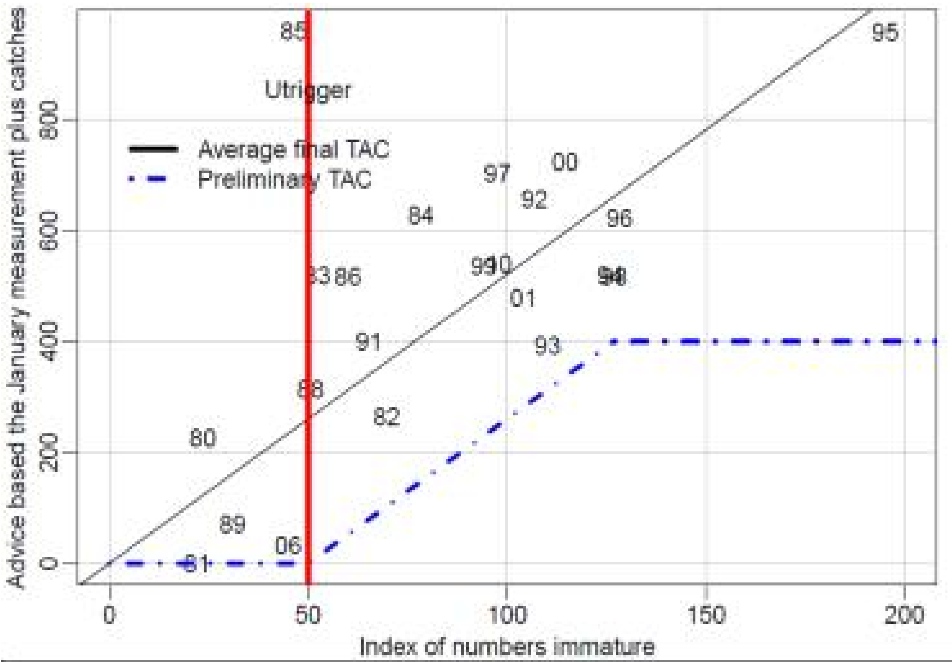

Figure 7.4.1. Indices of numbers of immature capelin from autumn surveys against advice (based on acoustic measurements in January plus catches taken before the measurements). The solid line is the 'Final TAC regression' representing the 'best' guess on the final TAC based on the survey result while the dashed line, taking a precautionary approach, shows the decision rule for advising the initial TAC.

The benchmark group proposed a method for setting the initial TAC. Two fixed points were defined: $U_{trigger}$ = 50 billion immature capelin and TAC_{MAX} = 400 kt for U >127 billion immature capelin. The agreed method for setting the initial/preliminary TAC was:

- TAC = 5.2x(U_{imm}–$U_{trigger}$) kt for U_{imm} in the range 50–127 billion.
- TAC = 0 if U_{imm} <50 billion.
- TAC = 400 kt if U_{imm} >127 billion.

The rationale for choosing these points is based on the analysis presented in Figure 7.4.1 and is as follows: $U_{trigger}$ was chosen to avoid the situation where low numbers of immature capelin have historically led to extremely low final TACs (the 81, 89 and 06 points in Figure 7.4.1). Adoption of a value of 50 billion immature capelin as $U_{trigger}$ also resulted in the line parallel with the Final TAC regression line bounding all observations. Excluding the largest observation (95), which is far higher than the rest of the observations, the upper bound is based on the highest observed immature indices and corresponds to about 127 billion immature capelin, which in turn corresponds to about 400 kt of January advice and catches. This upper bound is an extra measure of precaution in setting the initial TAC. The TAC will be adjusted upwards (or down, but this should be rare based on this rule) to the final TAC following the winter survey.

The final TAC will take account of both the autumn and winter surveys and the elapsed time between the surveys, downweighting the autumn results. Discrepancies (later surveys indicating a lower stock size) will be addressed on an as-needed basis in the application of the new methodology; e.g. if the winter survey gives a low estimate of stock size, but there is evidence that it may have missed the fish, it may be disregarded.

7.5 Reference points

Limit reference points have not been set previously for this stock, but a $B_{escapement}$ point of 400 kt has been used since 1979. WKICE endorsed setting a B_{lim} at B_{loss} (approximately 150 kt) based upon the observation that the recruitments that were generated around B_{loss} (cohorts 1990, 1981 and 1982) were of average strength and that average recruitment did not appear to decline at low SSB over the observed range.

The benchmark group suggests using 150 kt as B_{lim}.

7.6 Conclusions

The assessment method for the capelin stock was agreed as follows: for the final TAC advice a stochastic projection of the stock will be conducted starting from acoustic measurements, aiming at a TAC that is associated with p(SSB <B_{lim}) <5%. The preliminary TAC will be based on the autumn acoustic surveys following the method illustrated in Figure 7.4.1.

WKICE accepted the assessment methodology for IGJM capelin, as described in the stock annex in this report, as a benchmark assessment. While it appears that the stock is currently lower than historical levels, it is estimated to be well above B_{lim}.

7.7 Recommendations

Work presented for the Barents Sea capelin stresses the importance of capelin as a keystone species in the ecosystem, and also suggests that capelin should be fished as close to spawning as technically and economically possible. Similar considerations may apply to IGJM capelin. If shown to be applicable, this could reduce the importance of the initial TAC, as a new measurement of the fishable stock would be available before the start of the fisheries (although the initial TAC may still provide useful information to the industry, as an indicator of the likely magnitude of the final TAC). Therefore, WKICE recommends that:

- Studies of optimal harvesting of IGJM capelin should be conducted and presented to the NWWG. These estimates should take account of growth, mortality and gear selection in relation to the timing of the fishery.
- The NWWG should initiate a review of the role of capelin in the Icelandic Sea ecosystem and in particular whether the population size and growth of capelin predators shows a response to changes in capelin abundance.

Marine mammal abundance in the capelin distribution areas should be monitored, e.g. by including observers on autumn surveys. Such a program could indicate whether predation on capelin by whales in quarter 3 should be added to the TAC-framework.

Further work on the new framework for setting the advice is needed, including detailed examination of the series of historical bootstrap estimates and additional tests of the predation model by cod, haddock and saithe, based on the groundfish survey in March (IGFS) data.

The survey design should be studied further, and collaboration with industry that has been ongoing should be continued and further developed. Pairs of successful surveys should be identified and examined to determine the correspondence between September–October and following January–February surveys to potentially shed light on natural mortality, especially if supplemented with research on survey catchability and target strength. Within the winter season, repeat coverage and accompanying variance reduction can be used to investigate the advantage of the stochastic HCR as compared to the 'old rule'.

Coordinated collection of biological samples and logbook information from non-Icelandic vessels should be initiated, to ensure broader coverage of participants in the fishery.

Further work on survey stratification and comparison with alternative approaches to estimating uncertainty could also usefully be undertaken, e.g. using geostatistics.

The assessment and advice on the final TAC for capelin based on the January survey result is issued directly to the Coastal States by the Icelandic Marine Research Institute. This process is not internationally peer reviewed prior to the release of the advice. Among the reasons for using this process is the need for fast advice once the survey result is available. The ICES ACOM procedure is more time consuming, but it was pointed out that in similar cases of the Biscay anchovy and the North Sea sandeel, ACOM has established procedures that allow ICES to react quickly.

The terms of reference for WKICE were essentially limited to the quality of the assessment on which advice will be based, and WKICE accepted the methodology detailed in the stock annex. NWWG can review the basis for the advice after the fact, and ACOM can propose corrections to the process, if required.

The Coastal States may want to expand ICES involvement in providing the final capelin advice, but it is beyond the scope of WKICE to recommend how this might be accomplished.

Annex 1: Comments by the External Experts

General comments

The reviewers asked whether the benchmark process is generally adding value, and concluded that it is. Benchmarks are needed because assessment Working Groups are restricted from introducing new methodologies. While they may add considerably to the workload of participants, they represent an opportunity to address long-standing sources of uncertainty and to trial new methodologies. They also represent an opportunity for stakeholder input, due to the openness of the process.

However, in order to do justice to the stock assessments being benchmarked, it was agreed that that each benchmark should only consider 1–3 stocks, rather than 4–5 as sometimes occurs. WKICE attempted to benchmark five stocks.

To an extent, the number of stocks for which assessments can be thoroughly reviewed depends on the extent and completeness of the analyses completed prior to the meeting. In cases where stock assessments are robust and based on a range of relevant, non-conflicting data sources, the task of the benchmark is relatively straightforward. However, for stocks with relatively little preparation, or overarching gaps in data, the benchmark may only be able to progress the analyses to a limited extent and make recommendations for future work that can subsequently be used to progress the assessment further. One suggestion in this case is to request that the Benchmark Steering Group move some of the work, including aspects of methodology changes, into the assessment Working Groups, in order to be better prepared for the benchmarks. However, new methodologies should continue to be carefully benchmarked before they are introduced as a basis for advice. In general, the more work that can be completed prior to the benchmark and the more the detail that can be presented at the benchmark, the better for a thorough and robust review.

In WKICE, the amount of detail presented for each assessment and the amount of analysis done ahead of the meeting varied considerably between stocks, as detailed below. It is difficult for external reviewers who are unfamiliar with particular assessment approaches to fully evaluate assessments that are lacking in detail about the assumptions made. In addition, a considerable amount was spent waiting for a small number of participants to complete analyses within the meeting itself. The reviewers were, however, appreciative of the hard work of these analysts and of all participants both before and during the meeting.

Greenland cod

While the external experts were generally pleased with the progress made on the Greenland cod stocks during the Benchmark, it may have been possible to progress the assessments further (particularly for East Greenland cod) if the Greenland cod stock structure issue had been fully resolved prior to the meeting. The problem here appears to be a lack of clarity about which ICES group has the ultimate responsibility for approving changes to stock structure assumptions. Although "stock identity and migration issues" are identified in the Terms of Reference, it was noted that the ICES Stock Identification Methods Working Group (ICES SIMWG) had already reviewed this topic, and the extent to which the Benchmark review was being asked to further review this material (beyond the work of SIMWG) was unclear. Additionally, the roles of the data compilation group that meets prior to the benchmark, or ACOM itself, in determining stock structure were also unclear.

Apparently, the 3-stock structure (West Greenland inshore, West Greenland offshore and East Greenland offshore) has been the common assumption in the Northwest Working Group for about two years. However, the first presentation on Greenland cod concerned stock structure with a request for WKICE to endorse the 3-stock approach. This presentation was somewhat lacking in detail, and a more thorough presentation of the data and analyses reviewed by SIMWG would have achieved a fuller understanding of stock structure and the basis for the conclusions of SIMWG. For example, a post-meeting discussion (via e-mail) more thoroughly revealed the nature of the genetic and tagging data and was helpful in refining recommendations regarding the feasibility of developing a combined East Greenland and Icelandic cod assessment model. Preferably, this discussion would have occurred during the WKICE meeting. Based on the information that was presented, and some subsequent questions and discussions about methodology and conclusions, the external reviewers found the arguments for the 3-stock hypothesis compelling.

Icelandic cod

The Icelandic cod stock assessment appears to have been well-developed and relatively robust, with some form of harvest control rule in place since 1994 and the adcam stock assessment model in use since 2002. It was a surprise to the reviewers that it had not previously been benchmarked. The results presented were based on the 2014 assessment, which had already been accepted by the NWWG. The main uncertainty identified is that the catch-at-age data indicate a smaller stock size than does the survey data.

The external reviewers suggested that it would be useful to conduct a wider range of sensitivities. These should be conducted both within the adcam model by, for example, adjusting the relative weights of different datasets, and by implementing alternative age-structured models.

Icelandic–East Greenland–Jan Mayen capelin

The Arctic and the Iceland-Greenland groups met jointly to discuss the Barents Sea and Icelandic capelin assessments. While the meeting was very useful, such joint meetings would probably benefit if centred on predefined themes. This means that the approaches for the two stocks would be presented in parallel followed by a discussion of the theme. Also, the two groups should have prior access to each other's SharePoint sites and therefore allow the meeting participants a brief preview of all papers to be presented.

Joint topics that the Benchmark might have taken up include the methodology for B_{lim} setting and the interpretation of S–R diagrams, general survey techniques and projections of survey estimates to SSB.

While the fundamental population dynamics of the Jan Mayen and the Barents Sea stocks are similar, the differences in the data need to be fully appreciated. A major difference is the period over which the SSB should be projected: 8–9 months for the Barents Sea and 1–2 months for the Jan Mayen stock. This means that the mortality and growth taking place in the Barents Sea capelin stock between the survey and spawning is significant while in the Jan Mayen stock, growth and mortality approximately even out. The optimal research strategy in terms of providing ICES advice therefore differs between the two stocks. In general, predation mortalities and growth and how these are influenced by environmental variability are difficult to assess accurately. This creates high uncertainty in the projected estimates of SSB, although it is less of an issue for Jan Mayen capelin than it is for the Barents Sea. Changing the timing of the Barents Sea survey to shorten the projection period may be more robust and cost-effective than conducting research to estimate predation mortality and other factors over an 8–9 month period. For both cases improving the survey technique and survey design is useful but the overall improvement, reduction of the CV for the stock size estimate, would be small for the Barents Sea stock.

The surveys are in both cases characterized by hot spots (areas with high densities) and statistical techniques where the survey intensity is increased around such a hot spot should be considered. (Thompson and Seber, 1996). Alternatively, model-based estimates of survey abundance can be investigated using statistical distributions appropriate to populations with patchy spatial distributions (Thorson *et al*., 2011; 2012).

Overall conclusions

The external experts, Pamela Mace (External Chair), Paul Spencer and Hans Lassen accept the report as representing the consensus of the meeting and are also in agreement with the conclusions and the recommendations for future work.

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Annex 3: Stock Annex for Cod in offshore waters of NAFO Subarea 1A–1E (West Greenland offshore cod)

Stock	Cod in offshore waters of NAFO Subarea 1A, 1B, 1C, 1D and 1E (West Greenland offshore cod)
Working Group	Northwestern Working Group
Date	January 2015
Revised by	WKICE

A. General

A.1. Stock definition

ICES advice is given for three separate cod stocks in Greenland waters:

1) West Greenland offshore (NAFO 1A–1E)

2) East Greenland offshore (NAFO1F+ICES XIVb)

3) West Greenland inshore (NAFO 1A–1F) inside the 3 nm limit.

Tagging data from Greenland shows, that when fish are maturing (>40 cm) they will primarily stay in West Greenland waters when tagged north of NAFO 1F, while fish tagged in NAFO 1F or East Greenland only move east or stay (Stor-Paulsen *et al.*, 2003). Hence, the distinct spawning stocks are maintained and seem to be spatially separated at roughly the NAFO 1F northern limit which corresponds to 60°45N. This may not be historically stable, but in the current situation with a very low West Greenland offshore stock size, it seems the most appropriate division of the stocks. A similar conclusion can be made based on the distribution of year classes. Currently, the West Greenland stock biomass is so low, that the majority of the fish found in West Greenland are of East Greenland/Icelandic origin, and consequently, when these fish approach maturity, they migrate out of West Greenland waters. Consequently, fish age four and older are predominantly in either NAFO 1F or ICES XIVb, whereas juveniles are found in NAFO Areas 1A–1E, which is currently considered a nursing area for the East Greenland/Icelandic stock (Figure A.1.1).

Tagging information show that cod in the fjords in West Greenland are resident and do occasionally migrates to the adjacent coastal areas (Hansen, 1949; Hovgård and Christensen, 1990; Storr-Paulsen *et al.*, 2004). Likewise, bank cod in West Greenland are predominantly resident and migrate to a lesser extent into the coastal areas. In contrast cod tagged in the coastal areas are found distributed over all the three habitats. Hence, tagging indicate that the West Greenland offshore and inshore cod are generally separated but that the coastal area is a mixing zone.

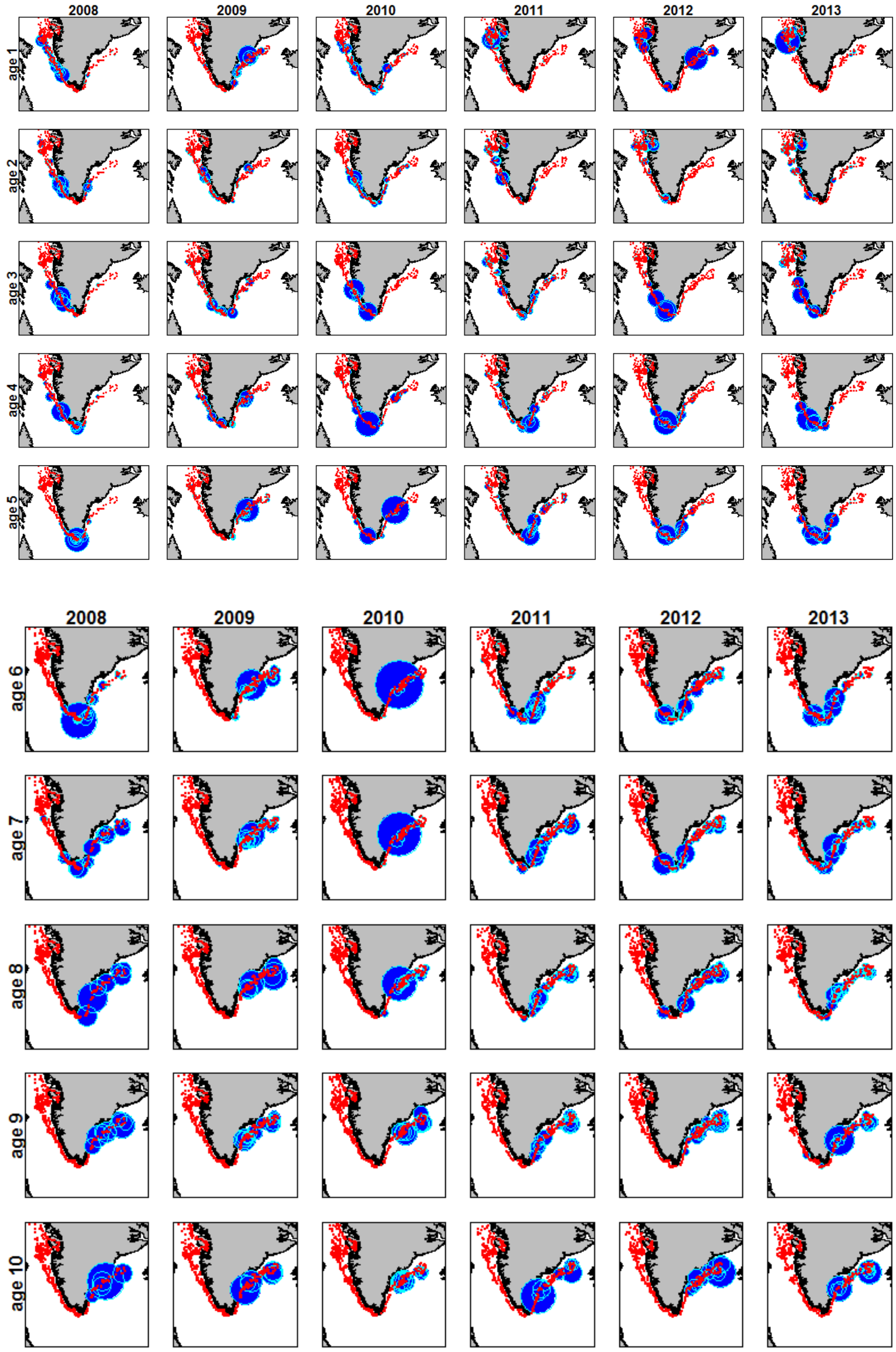

Figure A.1.1. Abundance (%) of ages 1–10 in the years 2008–2013 from the Greenland survey. The size of blue circles denotes the percentage of the cohort in the given year, where each square equals 100%. Red circles are trawl stations.

A.2. Fishery

A short historical review

The offshore fishery in the last century took off in 1924 when Norwegian fishers discovered dense concentrations of cod on Fylla Bank in NAFO Division 1D. The West Greenland offshore fishery rapidly expanded to reach 120 000 t in 1931; a level that remained for a decade (Horsted, 2000). During World War II landings decreased by 1/3 as only Greenland and Portugal participated in the fishery. Until 1951 landings are total West Greenland, including NAFO 1F, but from 1952 landing have been split per NAFO divisions. However, until 1971 a substantial part of the landings from West Greenland were reported as 'unknown NAFO area'. Parts of the "unknown catches" were allocated to each NAFO region according to the proportion of the landings in each NAFO division (ICES 2015).

During a period from the mid-1950s to 1960 the total annual landings taken offshore averaged about 270 000t. In 1962 the offshore landings culminated with landings of 400 000 t. After this historic high, landings decreased sharply by 90% to 25 000 t in 1976 and even further down to 15 000 t in 1980. Annual catch level of 40 000 t was only exceeded in the periods 1977–1979 (where unreported catches of up to 50 000 t where believe to take place, Horsted, 2000) and 1988–1990 due to the occurrence of a few strong year classes. During 1989–1992 the fishery, which almost exclusively depended on one YC (1984 YC) shifted from West to East Greenland. The entire offshore fishery completely collapsed in 1993 (Figure A.2.1).

No directed offshore fishery was allowed for the period 1993–2005, except for some minor allocations to Norway and the Faroe Islands.

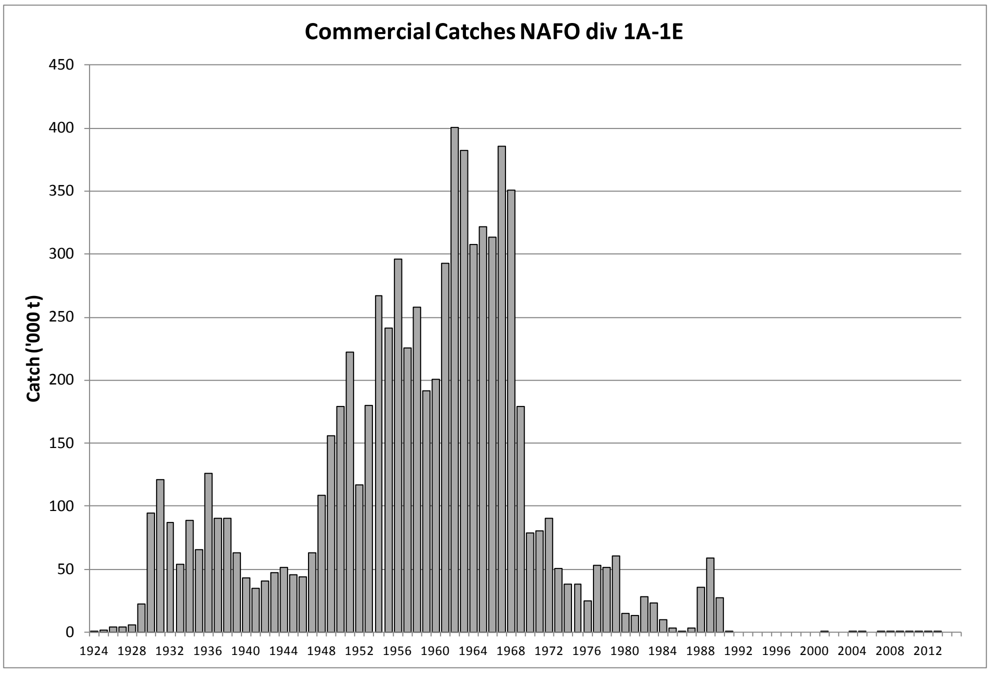

Figure A.2.1. Landings in the management area West Greenland (NAFO Division 1A–1E). Until 1951 1F is included.

The present fishery

Vessels in the offshore fisheries are vessels above 75BT/120BTand restricted to the area more than 3 nm off the baseline. The vessels require a licence that stipulates a unique vessel quota. Trawl and longline are the dominating gear.

Since 2005 directed cod fishery was introduced but catches was insignificant with only 550 t in 2008. In 2009 and 2010 fishery was closed in West Greenland. The measures introduced since 2009 had the objective to rebuild the stock in West Greenland by minimizing exploitation of the young fish and potential spawning fish.

In 2011 a management plan was implemented that allowed an experimental fishery of 5000 tons per year in the period 2011–2013 in all offshore areas in Greenland (both West and East). This management plan was replaced for the period 2014–2016 where annual quota was set at 10 000 tons as experimental fishery in South and East Greenland, whereas West Greenland north of N60°45′ (corresponding to NAFO Divisions 1A–1E) was closed for fishery.

A.3. Ecosystem aspects

Some studies indicate that cod recruitment in Greenland waters is significantly influenced by environmental factors like air and sea surface temperatures in the Dohrn Bank region during spawning, in addition with the zonal wind component in the region between Iceland and Greenland during the first summer (Stein and Borokov, 2004). In addition emergence and especially decline of the cod stock in Greenland waters can be linked to sea temperature leaving the stock vulnerable to overfishing in cold periods (Hovgård and Wieland, 2008).

When and if the fishery is reopened, it may be necessary to allow for the fact that productivity could have declined. The consequence of a decline in productivity would be that a rebuild to previous levels may not be possible.

B. Data

B.1. Commercial catch

The information on landings in weight are compiled and processed by the Greenland Fisheries License Control (GFLK). The offshore information is available on the haul-by-haul scale provided by logbooks. Sampling of length frequencies and information on age, weights and maturities are collected and compiled by the Greenland Institute of Natural Resources.

Due to recent very low catches, samples from the commercial fleet have been limited.

B.2. Biological data

Spawning

No spawning of significance has been documented on the banks in West Greenland. In 2013 a random stratified bottom-trawl survey was conducted during the main spawn event and on the traditionally main offshore west spawning areas in order to detect spawning on the banks. On Dana Banke, Fiskenæs Banke, Fyllas Banke, Lille Hellefiske Banke and Store Hellefiske Banke covering N62°66′–N68°07′ and depth between 80–130 m. Out of 34 stations, very little amount of cod was registered (maximum 2.7 kg at one station, Figure B.2.1). Hence no greater amount of spawning in western offshore areas is currently considered present.

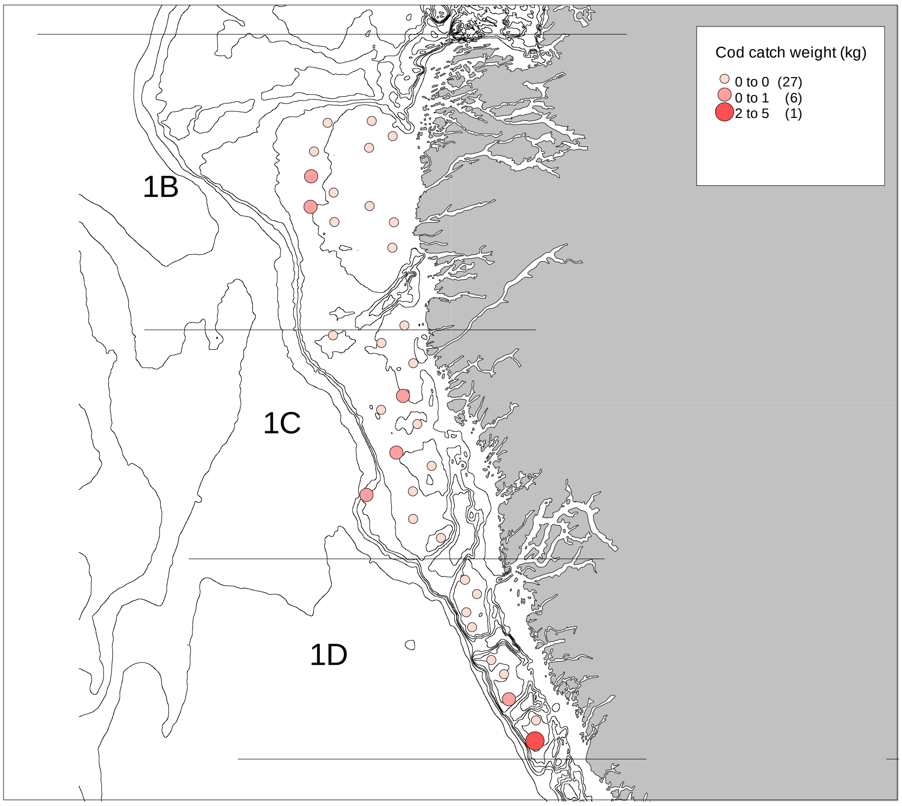

Figure B.2.1. Cod catches during cod spring survey in 2013 (May 20 to June 3) with RV Sana, covering N62°66′–N68°07′.

B.3. Surveys

At present, two offshore trawl surveys provide the core information relevant to stock assessment purposes.

Trawl survey by Greenland (Greenland Shrimp and Fish survey (GRL-GFS))

Since 1992, GINR has conducted an annual stratified random bottom-trawl survey at West Greenland. The Greenland survey covers depth from 0–600 m and covers the area south of N72°00′ in West Greenland. From 2008 East Greenland was included in the survey and covers the area south of N67°00′ in East Greenland. Approximately 125 hauls are taken each year in NAFO Division 1F and East Greenland. The survey provides catch and weight-at-age.

Survey area and stratification

NAFO Division 1A–1E: The stratification is based on designated 'Shrimp Areas' that is divided into depth zones of: 151–200, 201–300, 301–400 and 401–600 m, as based on depth contour lines. The depth zones 0–100 m and 100–150 m are delimited by the NAFO Subdivision boundaries. The "shrimp areas" are shown in Figure B.3.1 and their sizes are provided in Table B.3.1. After the split of the two offshore cod stock, the "Shrimp Area W7" that covers both NAFO Division 1E and 1F was re-measured in order to find out the area that constitutes this "shrimp area" in each NAFO division.

The survey trawl and its operation: The initially used trawl was a 3000/20-mesh "Skjervøy" trouser trawl, but was from 2005 replaced by a "Cosmos" trouser trawl. Calibration experiments with the two trawls were conducted in the main shrimp areas in 2004 and 2005 and a formal analysis of conversion factors were established for shrimp (Rosing and Wieland, 2005). The catch of cod in the calibration experiments was low. However a comparison of the catch efficiency towards cod indicates that the Cosmos trawl is ca. 1.5 times as efficient as the Skjervøy (Rosing and Wieland, 2005; ICES 2008). Tow duration has over the years been gradually reduced from 60 minutes to 30 and is from 2005 fixed at 15 minutes. Survey abundance and biomass is expressed per swept-area: Wingspread*towed distance, where wingspread is inferred from SCANMAR recordings and the towed distance is measured by GPS.

Table B.3.1. The survey area (km²) in the Greenland shrimp and fish survey.

West Greenland							
	Depthstrata						
Area	0-100	100-150	150-200	200-300	300-400	400-600	Total
W1	-	-	2873	6099	7520	816	17307
W2	-	-	1674	2612	1741	915	6941
W3	-	-	2122	4725	2085	2994	11926
W4	-	-	4119	1818	821	1961	8719
W5	-	-	3001	3648	1950	3021	11620
W6	-	-	1206	2006	1585	1234	6031
W7	-	-	2442	891	265	317	3915
W7 in 1E							
W7 in 1F							
W8	-	-	424	567	405	718	2114
W9	-	-	1711	938	516	430	3595
C0	-	-	-	903	2179	1154	4236
I1	-	-	407	1963	2441	1499	6310
I2	-	-	419	815	1085	1338	3658
U1	-	-	2486	4633	4785	5129	17033
U2	-	-	-	6710	8481	7994	23185
U3	-	-	2012	3017	1675	2710	9413
1A	3039	5220	-	-	-	-	8259
1B	11346	4966	-	-	-	-	16312
1C	4183	8169	-	-	-	-	12351
1D	4136	1538	-	-	-	-	5673
1E	494	2721	-	-	-	-	3215
1F	1497	5248	-	-	-	-	6745
All strata							188559

East Greenland				
Area	0001-0200	0201-0400	0401-0600	Total
Q1	217	35445	6975	42637
Q2	93	7657	1246	8996
Q3	3363	22547	9830	35740
Q4	1337	7770	2054	11161
Q5	469	2785	1819	5073
Q6	6307	6130	2063	14500
All strata				118107

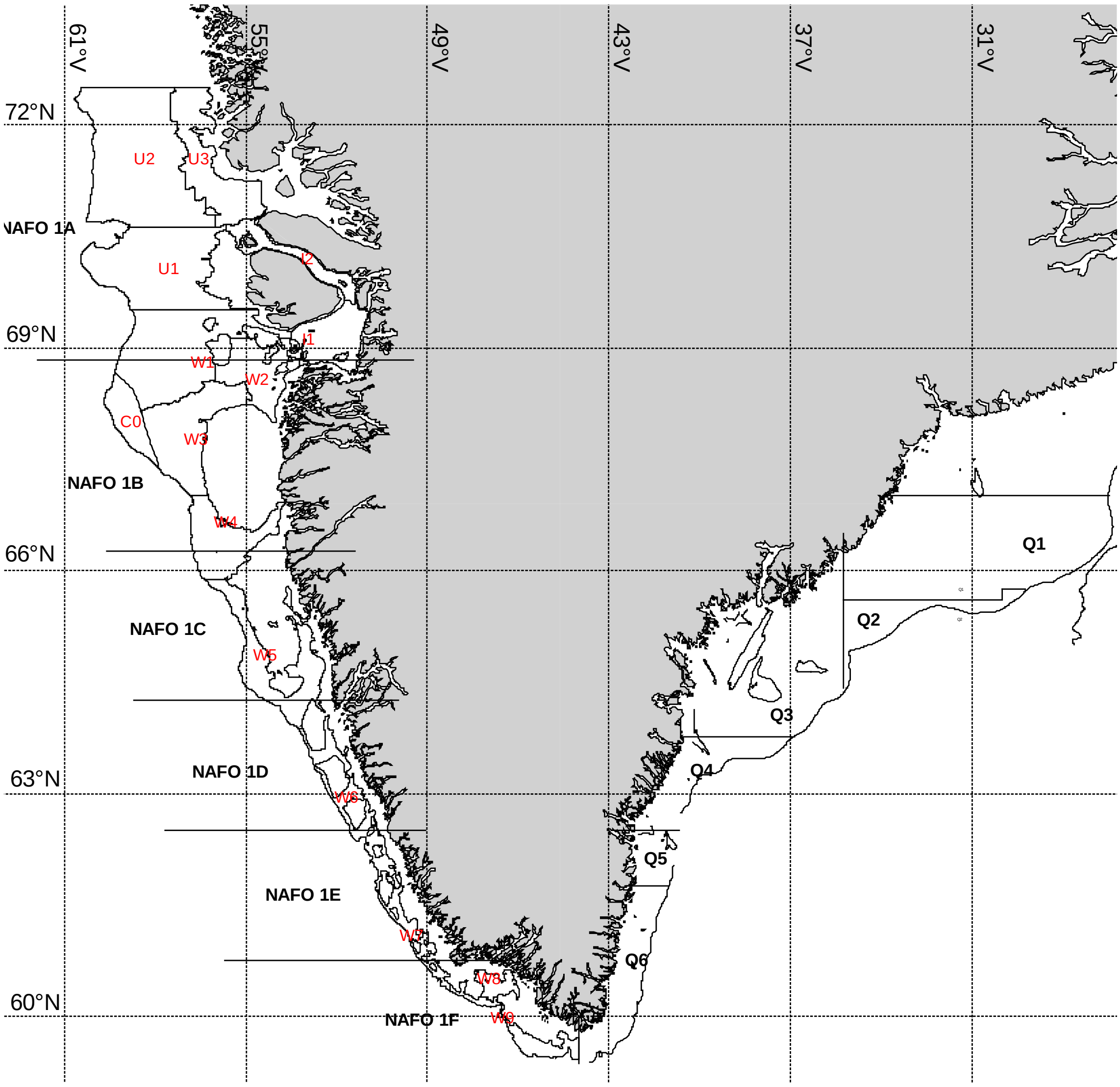

Figure B.3.1. The stratification areas used in the Greenland shrimp and fish survey. In West Greenland each strata is divided in depth strata of 150–200 m, 200–300 m, 300–400 m and 400–600 m. "Shallow" water strata of 0–100 m and 100–150 m are delimited by the 3 nm line (not shown) and the NAFO Divisions. In East Greenland each strata is divided in depth strata of 0–200 m, 200–400 m and 400–600 m. "Shallow" water strata of 0–200 m is delimited by the 3 nm line (not shown).

Trawl survey by Germany (German Greenland groundfish survey (Ger(GRL)-GFS-Q4))

The German survey has been conducted since 1982 and was designed for the assessment of cod. The survey covers both East (area south of N67°00′) and West Greenland (area south of N67°00′). Up to 2012, the surveyed area ranged from 0–400 m depth divided into seven geographical strata and two depth zones, 0–200 m and 200–400 m. Numbers of hauls were initially ca. 110 per year but were reduced from the early 1990s to 50–60 per year in South and East Greenland. In 2013, the survey was re-stratified, with four strata in West Greenland resembling NAFO division structure, and five strata in East Greenland for the depth intervals 0–200 m and 200–400 m (Table 3.2; Figure 3.2). For further information about the re-stratification see WD 25, ICES NWWG 2013.

The surveys were carried out by the research vessel (RV) WALTHER HERWIG II 1982–1993 (except in 1984 when RV ANTON DOHRN was used) and since 1994 by

RV WALTHER HERWIG III. The fishing gear used was a standardized 140-foot wide bottom trawl, composed of a net frame rigged with heavy groundgear due to the rough nature of the fishing grounds. A small mesh liner (10 mm) was used inside the codend. The horizontal distance between wingends was 25 m and the vertical net opening being 4 m at 300 m depth. In 1994 smaller Polyvalent doors (4.5 m^2, 1500 kg) were used for the first time in order to reduce net damages due to overspread caused by bigger doors (6 m^2, 1700 kg), which have been used earlier.

Up to 2008 strata with less than five hauls were excluded in the annual stock calculations. From 2009 all valid hauls have been included and biomass indices for the entire time-series have been corrected. For strata with less than five haul samples, GLM and quasi-likelihood estimates have been recalculated based on year and stratum effects from the time-series. In some years (notable 1992 and 1994) several strata were uncovered, implying that the survey was incomplete.

Table B.3.2. Stratification in the German groundfish survey in the Greenland survey area (nm^2). In West GLD stratification equals NAFO stratification, in East GLD based on assignment to ICES rectangles, therefore geographic boundaries given as ca-values.

	BOUNDARIES				DEPTH	AREA
Stratum	south	north	east	west	(m)	(nm2)
1.1	64°15'N	67°00'N	50°00'W	57°00'W	1–200	6805
1.2	64°15'N	67°00'N	50°00'W	57°00'W	201–400	1881
2.1	62°30'N	64°15'N	50°00'W	55°00'W	1–200	2350
2.2	62°30'N	64°15'N	50°00'W	55°00'W	201–400	1018
3.1	60°45'N	62°30'N	48°00'W	53°00'W	1–200	1938
3.2	60°45'N	62°30'N	48°00'W	53°00'W	201–400	742
4.1	59°00'N	60°45'N	44°00'W	50°00'W	1–200	2568
4.2	59°00'N	60°45'N	44°00'W	50°00'W	201–400	971
5&6.1	59°00'N	ca 63°50'N	40°00'W	44°00'W	1–200	1562
5&6.2	59°00'N	ca 63°50'N	40°00'W	44°00'W	201–400	2691
7.1	ca 63°50'N	66°00'N	ca 33°00'W	41°00'W	1–200	298
7.2	ca 63°50'N	66°00'N	ca 33°00'W	41°00'W	201–400	2919
8.1	ca 63°50'N	66°00'N	ca 33°00'W	41°00'W	1–200	49
8.2	ca 63°50'N	66°00'N	ca 33°00'W	41°00'W	201–400	3895
9.1	64°45'N	67°00'N	29°00'W	33°00'W	1–200	0
9.2	64°45'N	67°00'N	29°00'W	33°00'W	201–400	1946
Sum						31 607

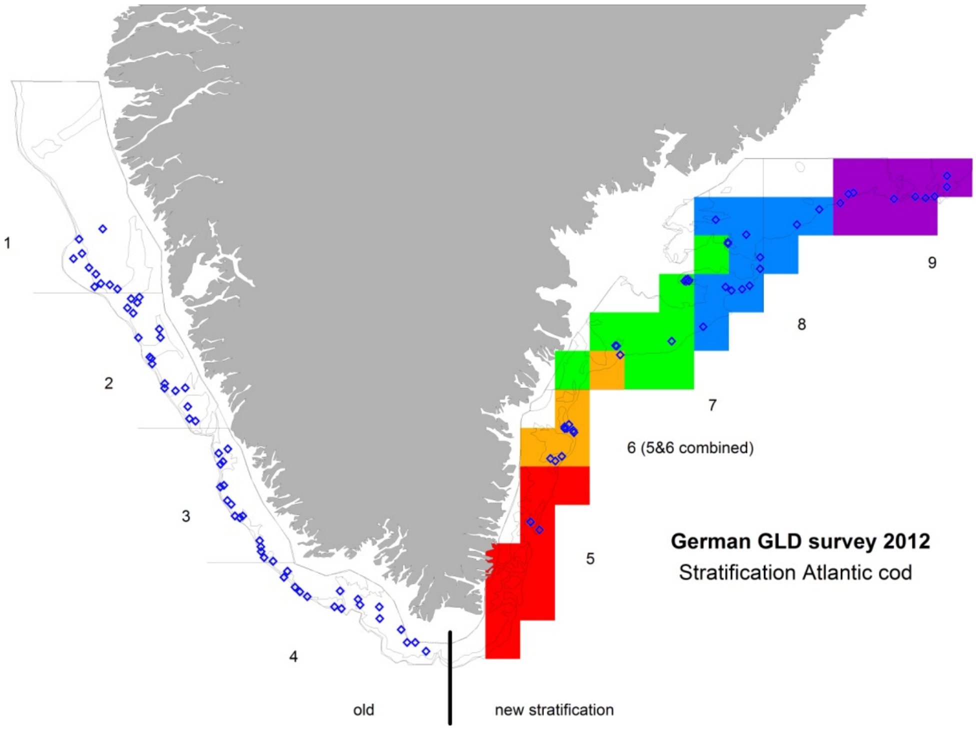

Figure B.3.2. The Stratification areas used in the German Greenland groundfish survey. Each stratum is divided into two depth zones, 0–200 m and 201–400 m.

B.4. Commercial cpue

Commercial cpue data are available. However, due to the limited fisheries in recent years they are of little use for stock assessment.

B.5. Other relevant data

NA.

C. Assessment: data and method

No stock assessment can be undertaken for this stock, due to the lack of significant rebuilding since the stock collapsed in the late 1960s. The advisory process should consider this rebuilding process when generating advice in the near future. WKICE agreed that there was little further work that this benchmark meeting could usefully undertake.

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Annex 4: Stock Annex for Cod in inshore waters of NAFO Subarea 1A–1F (Greenland cod)

Stock	Cod in inshore waters of NAFO Subarea 1A–1F (Greenland cod)
Working Group	Northwestern Working Group
Date	January 2015
Revised by	WKICE

A. General

A.1. Stock definition

ICES advice is given for three separate cod stocks in Greenland waters:

1) West Greenland offshore (NAFO 1A–1E)

2) East Greenland offshore (NAFO1F and ICES XIVb)

3) West Greenland inshore (NAFO 1A–1F) inside the 3 nm limit.

Inshore spawning cod is found in many fjords between 64 and 67°N in West Greenland (Hansen, 1949; Smidt, 1979; Buch *et al*., 1994). Recent summaries of the stock structure and developments includes: Buch *et al*. (1994), Wieland and Hovgård (2002), Storr-Paulsen *et al*. (2004), Wieland and Storr-Paulsen *(2005),* Hovgård and Wieland (2008), and Therkildsen *et al.* (2013).

Tagging information show that cod tagged in the fjords are predominately recaptured in the same fjord as tagged or in the adjacent coastal areas (Hansen (1949), Hovgård and Christensen (1990), Storr-Paulsen *et al.* (2004)). Tagged bank cod are predominately recaptured on the Banks and to a lesser extent in the coastal areas. In contrast, cod tagged in coastal areas are re-captured in all areas. Hence, the tagging experiments indicate that the offshore and inshore cod are generally separated but that the coastal area is a mixing zone, especially during the juvenile stages. A considerable number of tags are returned from Icelandic waters, especially from tagging in the coastal areas in Southwest Greenland (south of 61°N) and the banks in East and Southwest Greenland (ICES XIV, NAFO Division 1EF). Hence the genetic and tagging studies shows that inshore catches must be considered a mix of inshore cod, West Greenland offshore cod and East Greenland/Icelandic offshore cod. The proportional contribution has however never been quantified.

In 2012 the West Greenland inshore cod stock was split from the offshore stocks, and a separate advice has been given for this stock since.

A.2. Fishery

A short historical review

The inshore Greenland commercial cod fishery in West Greenland started in 1911 by opening the cod trading at localities where cod seemed to occur regularly. The fishery expanded over the next decades through a development of a number of new trading places. Annual catches above 20 000 t have been taken inshore during the period 1955–1969 but declined to around 5000 t in the 1970s. In the 1980s catches fluctuated between 5000 and 35 000 t, partly driven by a few strong year classes (1979 and 1984) entering from the offshore stock (Horsted, 2000). From 1993 to 2001 the inshore catches were low; in the range 500–2000 t. In the 2000s catches have gradually increased with maximum catches in 2007 and 2008 of 13 000 t. No licence was required until 2009 and the fishery has historically not been constrained by a TAC (for 2009 a TAC of 10 000 t was introduced) but a minimum landing size of 40 cm has been enforced. The most important gear has been pound-net (taking between 60% and 80% of the annual catches) anchored at shore and fishing the upper 20 m. Due to ice poundnets are not used during November–April but instead jigs, longlines and gillnets. Trawling is not allowed within 3 nm off the baseline. The fishery is carried out along the entire coastline of West Greenland from Disko Bay to Cap Farewell, with the majority of the catches being taken in mid-Greenland.

The present fishery

Coastal vessels in the inshore fishery are defined as vessels below 75BT/120BT. Inshore catches have since 00s increased with highest catches of 18 500 tons in 2014. In recent years the fishery has expanded north, and catches in this area are to a large extent caught as bycatch by longlines and gillnets in the Greenland halibut fishery. Fish caught with these gears are on average 10 cm larger than poundnet catches. In general the mean length in the fishery has been increasing over the past ten years, and is currently 53 cm. All landings are reported, no discarding is assumed to take place and the data quality is considered high. Additionally, length measurements are taken continuously throughout the year covering the entire West coast.

A.3. Ecosystem aspects

There is little bycatch in the poundnet or jig fishery. Additionally, fish below the minimum size are easily released from the pound and gillnets and are believed to survive. Poundnet selectivity means that fish ages six and older are not caught in proportion to the stock composition.

B. Data

B.1. Commercial catch

Information on landings in weight are compiled and processed by the Greenland Fisheries Licence Control (GFLK). Inshore catches are in addition documented by sale slips and from logbooks which have been mandatory since 2008 for vessels larger than 30 ft. However the quality of the logbook data has been low and in 2011 only 1000 t out of the total catch of 11 000 t were documented in logbooks. Sampling of length frequencies and information on age, weights and maturities are collected and compiled by the Greenland Institute of Natural Resources. In recent year's information from landing slips have been improved and from 2013 data based on these have been used to compile inshore catches instead of using total catches per factory as previously.

Sampling of the Greenland coastal fleet catches has always been impeded by the geographical conditions, i.e. the existence of many small landing sites separated along the 1000 km coast. Except for the Nuuk area, that is easily covered, samplings rely on dedicated sampling trips supplemented with ad hoc samplings. The sampling coverage was especially poor in the late 1990s when catches were very low (<1000 t annually) and length frequencies are missing in 1998 and 2001. The sampling coverage has improved since around 2004 through a formal cooperation with GFLK observers.

Currently, sampling is considered adequate to reliably describe the age composition of the catches.

Recent genetic studies have documented the presence of different stock in Greenland waters (see Section A1). Furthermore, results show that these stocks are present in catches in varying proportions in offshore regions, and something similar may apply to inshore landings. Hence, catches of the inshore stock may be overestimated but the proportions are unknown. This stock mixing also influence the recruitment index, as stock input from other regions may cause overestimation of recruitment.

B.2. Biological

Spawning

Spawning cod have been collected from 2008–2010 in order to investigate the extent of spawning. In addition a spawning survey was conducted in spring 2011 in order to investigate those fjords without samples of spawning cod. The results show that spawning occurs in the coastal zone and in the fjords and is especially pronounced between Sisimiut (NAFO 1B) and Paamiut (NAFO 1E).

B.3. Surveys

Inshore gillnet survey

The objective of the gillnet survey is to assess the abundance and distribution of pre recruit (age 2 and 3) cod in fjord areas in West Greenland. The survey has been conducted annually since 1985 covering three inshore areas along the cost of West Greenland: Sisimiut (NAFO Division 1B), Nuuk (NAFO Division 1D) and more occasionally Qaqortoq (NAFO Division 1F; Figure B.3.1).

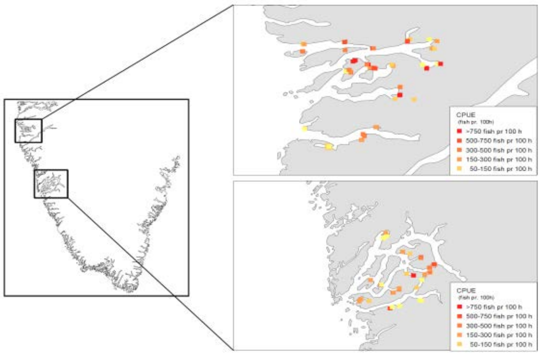

Figure B.3.1. Map with two fjord system most regularly surveyed in the West Greenland inshore gillnet survey. Data shown are 2013 results.

The survey uses gangs of gillnets with different mesh sizes (16.5, 18, 24, 28 and 33 mm, ½ mesh). 100–150 nets are set annually and are set perpendicular to the coast in order to keep depth constant. The survey effort is allocated evenly between the depth zones of 0–5 m, 5–10 m, 10–15 m and 15–20 m. The abundance index used in the survey is defined as 100*(# caught/net*hour).

The original net materials are no longer commercially available for the three smallest mesh sizes. From 2004 this has implied a change in twine thickness (particularly for the 24 mm mesh) that is expected to change the catchability of the nets.

Mesh-size (mm)	16.5	18.5	24	28	33
Old twine Ø (mm)	0.24	0.20	0.38	0.28	0.33
New twine Ø (mm)	0.20	0.22	0.25	0.28	0.33

The selection curve for the individual meshes is bimodal with cod being either gilled or snagged (Figure B.3.2; Hovgård, 1996a). For cod, as well as the bycatch of other species, the catchability depends on the twine thickness (Hovgård, 1996b). The effect of the potential change in catchability, associated with the change in net material, can be evaluated from parameters in Hovgård and Lassen (2000) that updates the selectivity estimates based on an improved version of the selection model (Hovgård *et al.*, 1999). The change in the catchability appears limited and confined to cod lengths between 20 and 27 cm.

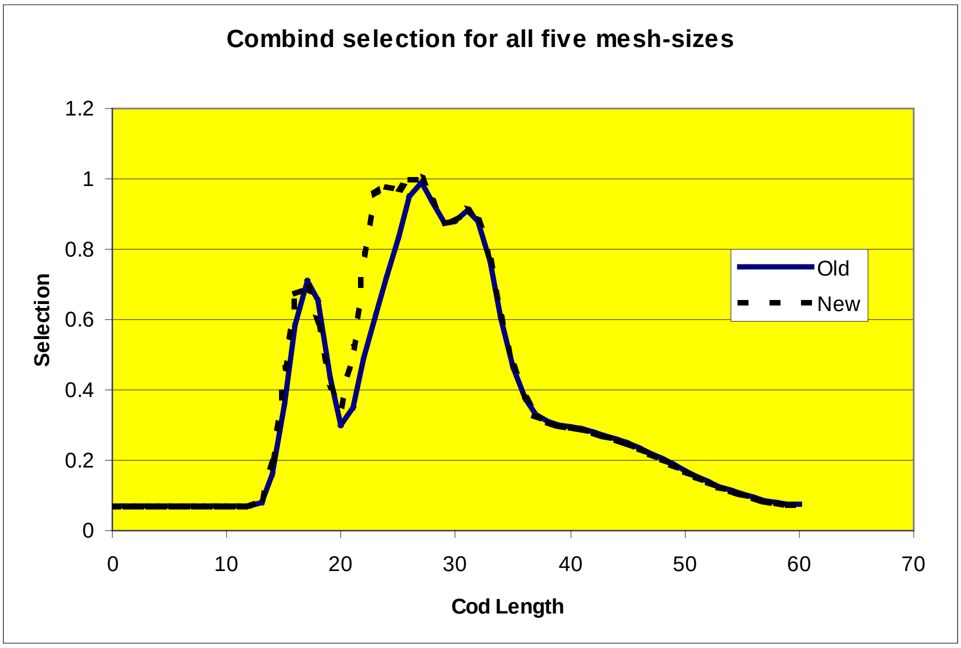

Figure B.3.2. Upper, mesh size description. Lower, combined selection for the gillnet survey. (Old) prior 2004, (New) from 2004 and onwards.

B.4. Commercial cpue

The cpue data quality depend very much on the gear used. Gillnet catches are usually bycatch. Jigs are only used from smaller boats that are not obligated to fill out logbooks. Finally, poundnet data are not useful in cpue calculations as nets are left in the water until they are full, and the information from the fishery does not allow for an evaluation of the fishing time.

Hence, commercial cpue are only available for a limited part of the fishery, and the data obtained are not considered as an indicator of stock size and cpue are not used in the assessment.

B.5. Other relevant data

NA.

C. Assessment: data and method

In 2012 the advice for this stock was based on recent catches. In 2013–2014 the Data Limited Stock approach (DLS, method 3.2) was used with the survey and recent catches as input. The use of the DLS approach was heavily criticized by the NWWG for several reasons. It does not in any way utilize the available data. Most importantly, using the recruitment index as it was, can create a situation where the fishable biomass increases (above average year classes) but the survey decreases (below average year classes). Accordingly, the TAC advice decreases although the stock was in an improving state. Most recently, this applies to the very large 2009 year class. The opposite situation of high recruitment but a low SSB could also be imagined, which will create problems. Finally, the use of the DLS approach entails that the advice depend on catches and when the advice is not followed (as is the case for this stock) higher catches will produce higher advice.

D. Short-term projection

Regression approach

None of the model runs presented at the WKICE benchmark or the current DLS procedure produced credible output useable for generating advice. As a consequence, a new approach was developed during the meeting. The survey index in a given year was related to the catch in the next year (Figure D.1.1). The advice is then based on the survey index multiplied by a factor. The validity of this approach rests on a number of assumptions. Among others, the fishery has been at a stable sustainable level (ideally the same across years). Based on the model outputs and catch curves (Hedeholm and Post, 2015) this seems to be a reasonable assumption, at least during the last 15 years. Some years in the 1980s did not follow the overall trend, and were most likely subjected to a very high fishing intensity and a very high offshore input to the fishery, and these years are therefore excluded from the regression analyses. The fish enter the fishery at age 4. Accordingly the survey index of ages 3–8 was used to generate advice although age 2 fish are abundant in the survey.

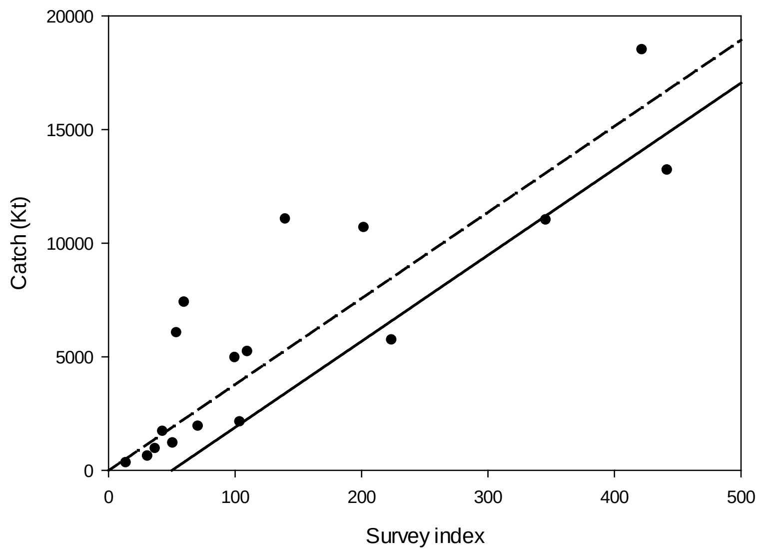

Figure D.1.1. Survey index of 3–8 year olds vs. the catch the following year. $r^2 = 0.76$. Based on data from 1991–2014.

Given that this approach is based on variable data a precautionary approach should be taken. So rather than having the regression pass through the origin, the intercept is set at a survey index value of 50. The resulting liner regression slope is 37.9. Consequently, the advice is generated as follows:

$$C_{y+1}=37.9 * (U_{3\text{–}8y}–U_{trigger}) \quad (1)$$

where $U_{3\text{–}8y}$ is the combined survey value for ages 3–8 and $U_{trigger}$ is 50.

E. Medium-term projections

NA.

F. Long-term projections

NA.

G. Biological reference points

	Type	Value	Technical basis
MSY	MSY $B_{trigger}$		Not defined
Approach	F_{MSY}		Not definedExplain
	B_{lim}		Not defined Explain
Precautionary	B_{PA}		Not defined Explain
Approach	F_{lim}		Not defined Explain
	F_{PA}		Not defined Explain
	$U_{Trigger}$	50	From the Gillnet survey (or whatever is the right name)

H. Other issues

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Therkildsen, N.O., Hemmer-Hansen, J., Hedeholm, R.B., Wisz, M.S., Pampoulie, C., Meldrup, D., Bonanomi, S., Retzel, A., Olsen, S.M., Nielsen, E.E. 2013. Spatiotemporal SNP analysis reveal pronounced biocomplexity at the northern range margin of Atlantic cod *Gadus morhua*. Evolutionary Applications. DOI 10.1111/eva. 12055.

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Annex 5: Stock Annex for Cod in offshore waters of NAFO Subarea 1F and ICES Area XIVb (East Greenland offshore cod)

Stock	Cod in offshore waters of NAFO Subarea 1F and IC ES Area XIVb (East Greenland offshore cod)
Working Group	Northwestern Working Group
Date	January 2015
Revised by	WKICE

A. General

A.1. Stock definition

ICES advice is given for three separate cod stocks in Greenland waters:

1) West Greenland offshore (NAFO 1A–1E)

2) East Greenland offshore (NAFO 1F and ICES XIVb)

3) West Greenland inshore (NAFO 1A–1F) inside the 3 nm limit.

Tagging data from Greenland show, that when fish are maturing (>40 cm) they will primarily stay in West Greenland waters when tagged north of NAFO 1F, while fish tagged in NAFO 1F or East Greenland only move east or stay (Stor-Paulsen *et al*. 2003). Hence, the distinct spawning stocks are maintained and seem to be spatially separated at roughly the NAFO 1F northern limit which corresponds to 60°45N. This may not be historically stable, but in the current situation with a very low West Greenland offshore stock size, it seems the most appropriate division of the stocks. A similar conclusion can be made based on the distribution of year classes. Currently, the West Greenland stock biomass is so low, that the majority of the fish found in West Greenland are of East Greenland/Icelandic origin, and consequently, when these fish approach maturity, they migrate out of West Greenland waters. Consequently, fish age four and older are predominantly in either NAFO 1F or ICES XIVb, whereas juveniles are found in NAFO Areas 1A–1E, which is currently considered a nursing area for the East Greenland/Iceland stock (Figure A.1.1).

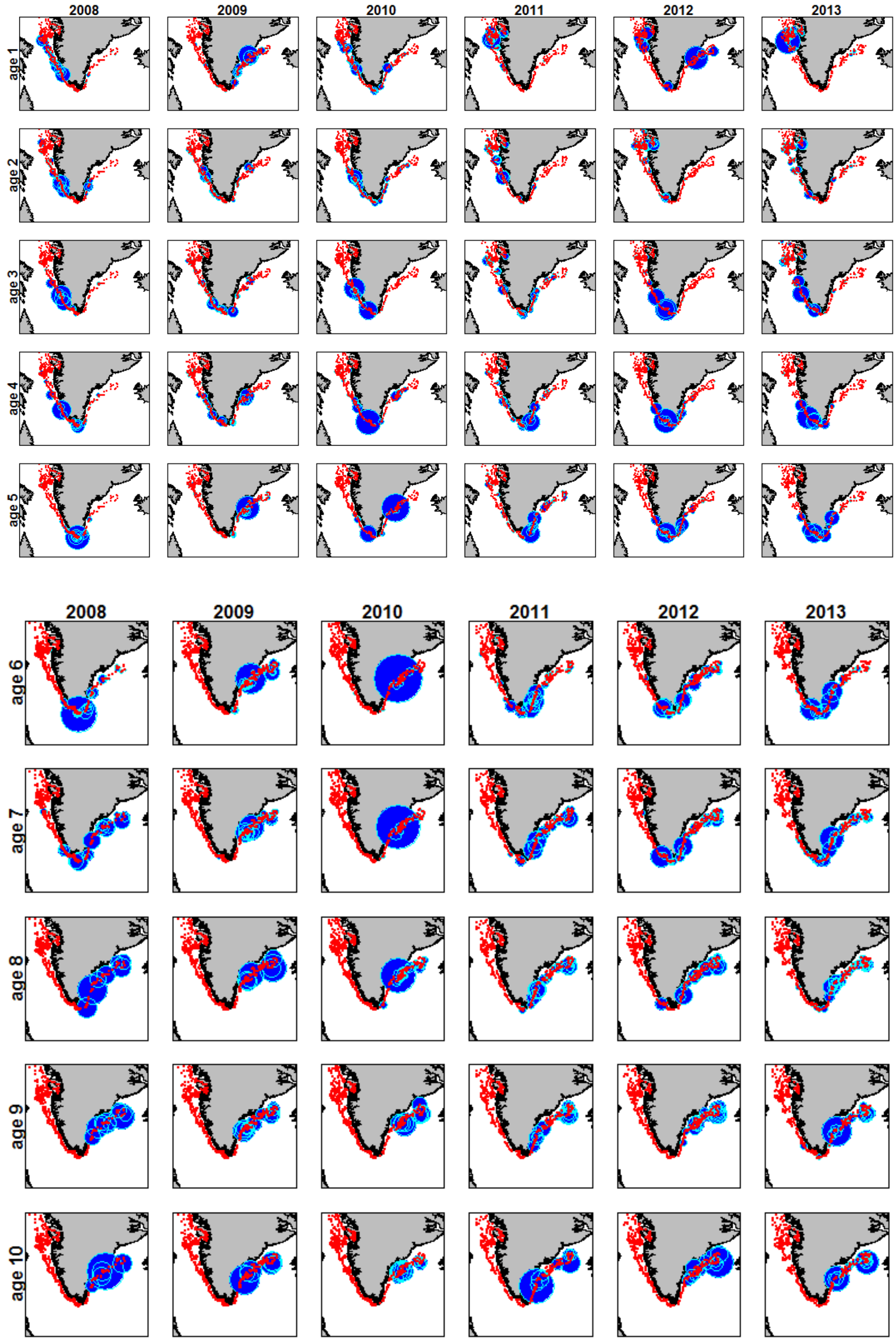

Figure A.1.1. Abundance (%) of ages 1–10 in the years 2008–2013 from the Greenland survey. The size of blue circles denotes the percentage of the cohort in the given year, where each square equals 100%. Red circles are trawl stations.

A.2. Fishery

A short historical review

The fishery in East Greenland started in 1954 as a trawl fishery (Horsted, 2000). However, until 1971 a substantial part of the landings from West Greenland were reported as 'unknown NAFO area'. Parts of the "unknown catches" were likely caught in NAFO Division 1F and were allocated to this NAFO region according to the proportion of the landings in this NAFO division (ICES 2015). The historical catches in East Greenland are shown in Figure A.2.1. Landings of about 30–60 kt dominated until the early 1970s, followed by a decrease to 10–30 kt until the early 1990s supported by the large year classes 1973 and 1984. For more than a decade catches were close to null, and cod was only caught as bycatch in the redfish fishery until the mid-2000s. Since then a fishery has developed with catches of approximately 5000 t annually.

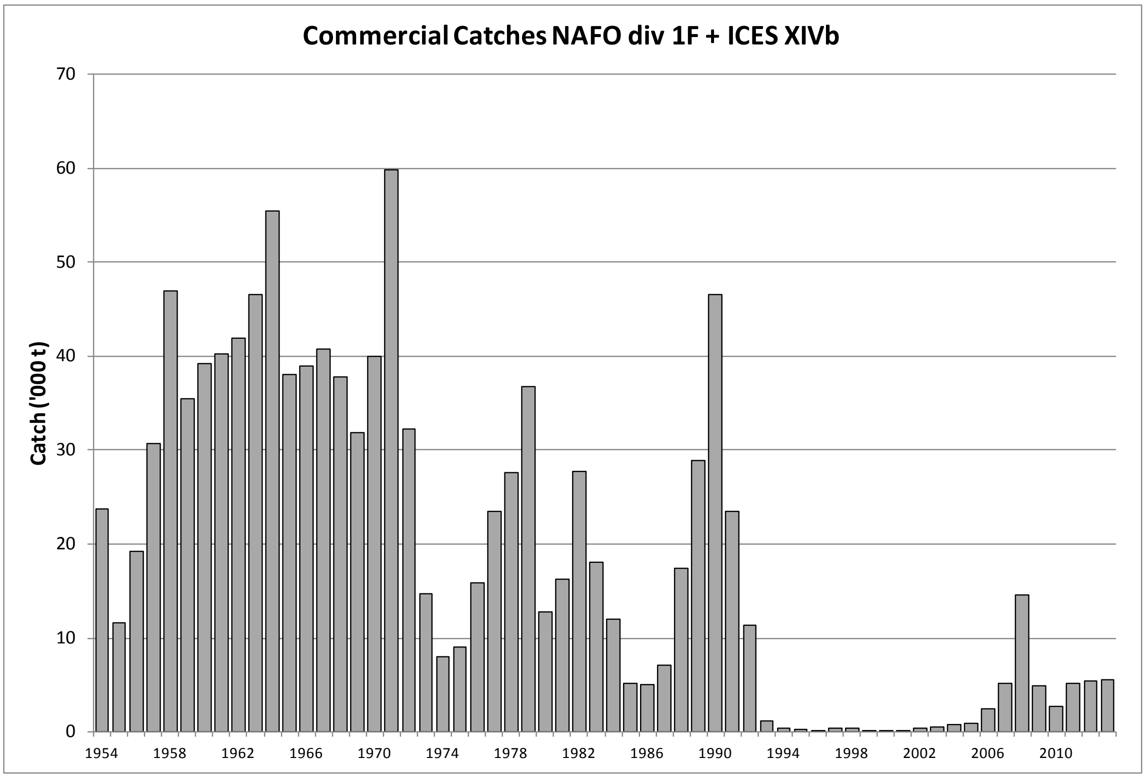

Figure A.2.1. Landings in the management area East Greenland (NAFO Division 1F and ICES XIVb).

The present fishery

Vessels in the offshore fisheries are vessels above 75BT/120BTand restricted to the area more than 3 nm off the baseline. The vessels require a licence that stipulates a unique vessel quota. Trawl and longlines are the dominating gear.

The East Greenland area has been subject to several area closures in recent years. In 2008 fishing north of N63°00′ was not allowed in order to protect the potential spawning segments, especially on Kleine Banke. In 2009–2010 the delimitation was at N62°00′ and additionally NAFO 1F was closed in 2010 primarily to protect the relatively strong incoming year classes.

In 2011 a management plan was implemented that allowed a small experimental fishery of 5000 tons per year in the period 2011–2013 in all offshore areas in Greenland (both West and East). This management plan was replaced for the period 2014–2016 where annual quota was set at 10 000 tons as experimental fishery in South and East Greenland, whereas West Greenland north of N60°45′ (corresponding to NAFO Divisions 1A–1E) was closed for fishery.

Historically several countries took part in the fishery but recently catches are taken primarily by Greenland followed by Germany/UK (EU) and Norway.

A.3. Ecosystem aspects

Some studies indicate that cod recruitment in Greenland waters is significantly influenced by environmental factors like air and sea surface temperatures in the Dohrn Bank region during spawning, in addition with the zonal wind component in the region between Iceland and Greenland during the first summer (Stein and Borokov, 2004). In addition emergence and especially decline of the cod stock in Greenland waters can be linked to sea temperature leaving the stock vulnerable to overfishing in cold periods (Hovgård and Wieland, 2008).

B. Data

B.1. Commercial catch

The information on landings in weight are compiled and processed by the Greenland Fisheries Licence Control (GFLK). The offshore information is available on the haul-by-haul scale provided by logbooks. Sampling of length frequencies and information on age, weights and maturities are collected and compiled by the Greenland Institute of Natural Resources.

Offshore sampling is laborious to acquire as most vessels produce frozen fillets that are commonly landed outside Greenland. However when it is done, it is by GFLK observers or in some cases skippers that organize the length measuring of random samples and/or to freeze individual cod for later analysis at the laboratory.

Since 2011 the offshore TAC was set as an experimental fishery which meant that the industry themselves take length measurement and biological samples of the catches and coverage of the fishery has therefore been very well.

B.2. Biological

Spawning

The recent offshore fishery has shown dense concentrations of large spawning cod off East Greenland from at least 2004. In 2007 the Greenland Institute of Natural Resources (GINR) carried out an observer programme on board two Greenland trawlers in April and May to document spawning in East Greenland. 14 000 cod were measured and 1000 examined for maturity. The average length was 70 cm. Cod maturity was determined according to Tomkiewicz *et al*. (2002). All maturity stages were recorded (non-mature 27%; maturing 23%; active spawning 36% and spent 14% spent). Length at 50% maturity was 58 cm.

In April–May 2009 an Icelandic survey in East Greenland found dense concentrations of spawning cod north of 62° at the banks between "Skjoldungen" (62°30′) and "Kleine Bank" (64°30′). The major contribution to the spawning biomass was made by the 2003 YC. Length at 50% maturity was approximately 60 cm which was consistent with the results in the 2007 observer programme.

B.3. Surveys

Trawl survey by Greenland (Greenland Shrimp and Fish survey (GRL-GFS))

Since 1992, GINR has conducted an annual stratified random bottom-trawl survey at West Greenland. The Greenland survey covers depth from 0–600 m and covers the area south of N72°00′ in West Greenland. From 2008 East Greenland was included in the survey and covers the area south of N67°00′ in East Greenland. Approximately 125 hauls are taken each year in NAFO Division 1F and East Greenland. The survey provides catch and weight-at-age.

Survey area and stratification

NAFO Division 1F: The stratification is based on designated 'Shrimp Areas' that is divided into depth zones of: 151–200, 201–300, 301–400 and 401–600 m, as based on depth contour lines. The depth zones 0–100 m and 100–150 m are delimited by the NAFO Subdivision boundaries. The "shrimp areas" are shown in Figure B.3.1 and their sizes are provided in Table B.3.1. After the split of the two offshore cod stock, the "Shrimp Area W7" that covers both NAFO Division 1E and 1F was re-measured in order to find out the area that constitutes this "shrimp area" in each NAFO division.

ICES Subdivision XIVb: The East Greenland area was for the first time properly covered in 2008. The area was intended covered in 2007, but due to a vessel breakdown only eight days were available, allowing only for a short pilot investigation.

The survey is carried out with the same gear and survey protocols as used in West Greenland. Stratification is based on the "Q-areas" used for the East Greenland survey for Greenland halibut. The areas are further depth stratified into 0–200 m, 200–400 m and 400–600 m zones, the areas are shown in Figure B.3.1 and the sizes are given in Table B.3.1.

The survey trawl and its operation: The initially used trawl was a 3000/20-mesh "Skjervøy" trouser trawl, but was from 2005 replaced by a "Cosmos" trouser trawl. Calibration experiments with the two trawls were conducted in the main shrimp areas in 2004 and 2005 and a formal analysis of conversion factors were established for shrimp (Rosing and Wieland, 2005). The catch of cod in the calibration experiments was low. However a comparison of the catch efficiency towards cod indicates that the Cosmos trawl is ca. 1.5 times as efficient as the Skjervøy (Rosing and Wieland, 2005; ICES 2008). Tow duration has over the years been gradually reduced from 60 minutes to 30 and is from 2005 fixed at 15 minutes. Survey abundance and biomass is expressed per swept-area: Wingspread*towed distance, where wingspread is inferred from SCANMAR recordings and the towed distance is measured by GPS.

Table B.3.1. The survey area (km²) in the Greenland shrimp and fish survey.

West Greenland							
	Depthstrata						
Area	0-100	100-150	150-200	200-300	300-400	400-600	Total
W1	-	-	2873	6099	7520	816	17307
W2	-	-	1674	2612	1741	915	6941
W3	-	-	2122	4725	2085	2994	11926
W4	-	-	4119	1818	821	1961	8719
W5	-	-	3001	3648	1950	3021	11620
W6	-	-	1206	2006	1585	1234	6031
W7	-	-	2442	891	265	317	3915
W7 in 1E							
W7 in 1F							
W8	-	-	424	567	405	718	2114
W9	-	-	1711	938	516	430	3595
C0	-	-	-	903	2179	1154	4236
I1	-	-	407	1963	2441	1499	6310
I2	-	-	419	815	1085	1338	3658
U1	-	-	2486	4633	4785	5129	17033
U2	-	-	-	6710	8481	7994	23185
U3	-	-	2012	3017	1675	2710	9413
1A	3039	5220	-	-	-	-	8259
1B	11346	4966	-	-	-	-	16312
1C	4183	8169	-	-	-	-	12351
1D	4136	1538	-	-	-	-	5673
1E	494	2721	-	-	-	-	3215
1F	1497	5248	-	-	-	-	6745
All strata							188559

East Greenland				
Area	0001-0200	0201-0400	0401-0600	Total
Q1	217	35445	6975	42637
Q2	93	7657	1246	8996
Q3	3363	22547	9830	35740
Q4	1337	7770	2054	11161
Q5	469	2785	1819	5073
Q6	6307	6130	2063	14500
All strata				118107

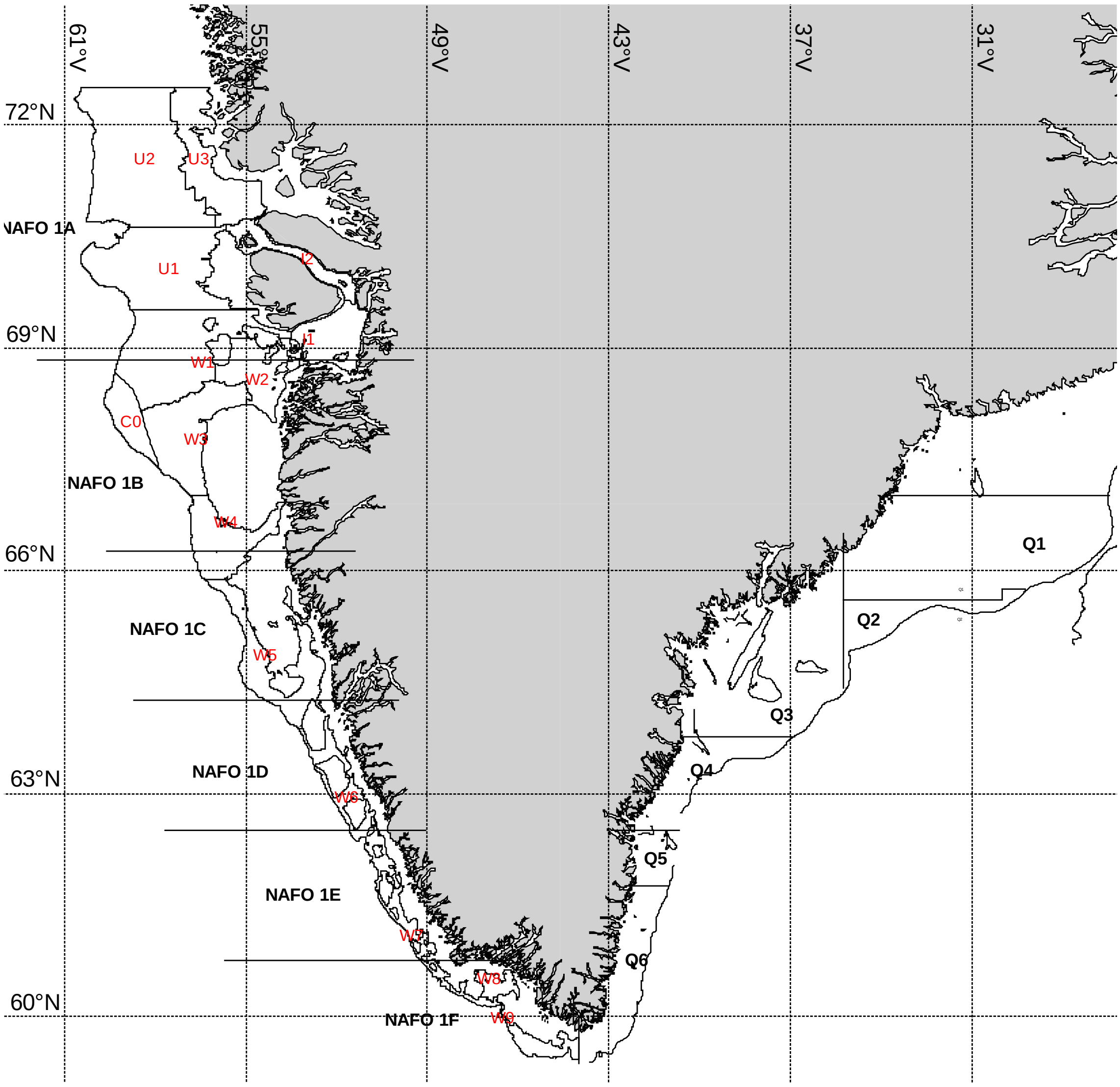

Figure B.3.1. The stratification areas used in the Greenland shrimp and fish survey. In West Greenland each strata is divided in depth strata of 150–200 m, 200–300 m, 300–400 m and 400–600 m. "Shallow" water strata of 0–100 m and 100–150 m are delimited by the 3 nm line (not shown) and the NAFO Divisions. In East Greenland each strata is divided in depth strata of 0–200 m, 200–400 m and 400–600 m. "Shallow" water strata of 0–200 m is delimited by the 3 nm line (not shown).

Trawl survey by Germany (German Greenland groundfish survey (Ger(GRL)-GFS-Q4))

The German survey has been conducted since 1982 and was designed for the assessment of cod. The survey covers both East (area south of N67°00') and West Greenland (area south of N67°00'). Up to 2012, the surveyed area ranged from 0–400 m depth divided into seven geographical strata and two depth zones, 0–200 m and 200–400 m. Numbers of hauls were initially ca. 110 per year but were reduced from the early 1990s to 50–60 per year in South and East Greenland. In 2013, the survey was re-stratified, with four strata in West Greenland resembling NAFO division structure, and five strata in East Greenland for the depth intervals 0–200 m and 200–400 m (Table B.3.2; Figure B.3.2). For further information about the re-stratification see WD 25, ICES NWWG 2013.

The surveys were carried out by the research vessel (RV) WALTHER HERWIG II 1982–1993 (except in 1984 where RV ANTON DOHRN was used) and since 1994 by

RV WALTHER HERWIG III. The fishing gear used was a standardized 140-foot wide bottom trawl, composed of a net frame rigged with heavy groundgear due to the rough nature of the fishing grounds. A small mesh liner (10 mm) was used inside the codend. The horizontal distance between wingends was 25 m and the vertical net opening being 4 m at 300 m depth. In 1994 smaller Polyvalent doors (4.5 m^2, 1500 kg) were used for the first time in order to reduce net damages due to overspread caused by bigger doors (6 m^2, 1700 kg), which have been used earlier.

Up to 2008 strata with less than five hauls were excluded in the annual stock calculations. From 2009 all valid hauls have been included and biomass indices for the entire time-series have been corrected. For strata with less than five haul samples, GLM and quasi-likelihood estimates have been recalculated based on year and stratum effects from the time-series. In some years (notable 1992 and 1994) several strata were uncovered, implying that the survey was incomplete.

Table B.3.2. Stratification in the German groundfish survey in the Greenland survey area (nm^2). In West GLD stratification equals NAFO stratification, in East GLD based on assignment to ICES rectangles, therefore geographic boundaries given as ca-values.

	BOUNDARIES				DEPTH	AREA
Stratum	south	north	east	west	(m)	(nm2)
1.1	64°15'N	67°00'N	50°00'W	57°00'W	1–200	6805
1.2	64°15'N	67°00'N	50°00'W	57°00'W	201–400	1881
2.1	62°30'N	64°15'N	50°00'W	55°00'W	1–200	2350
2.2	62°30'N	64°15'N	50°00'W	55°00'W	201–400	1018
3.1	60°45'N	62°30'N	48°00'W	53°00'W	1–200	1938
3.2	60°45'N	62°30'N	48°00'W	53°00'W	201–400	742
4.1	59°00'N	60°45'N	44°00'W	50°00'W	1–200	2568
4.2	59°00'N	60°45'N	44°00'W	50°00'W	201–400	971
5&6.1	59°00'N	ca 63°50'N	40°00'W	44°00'W	1–200	1562
5&6.2	59°00'N	ca 63°50'N	40°00'W	44°00'W	201–400	2691
7.1	ca 63°50'N	66°00'N	ca 33°00'W	41°00'W	1–200	298
7.2	ca 63°50'N	66°00'N	ca 33°00'W	41°00'W	201–400	2919
8.1	ca 63°50'N	66°00'N	ca 33°00'W	41°00'W	1–200	49
8.2	ca 63°50'N	66°00'N	ca 33°00'W	41°00'W	201–400	3895
9.1	64°45'N	67°00'N	29°00'W	33°00'W	1–200	0
9.2	64°45'N	67°00'N	29°00'W	33°00'W	201–400	1946
Sum						31 607

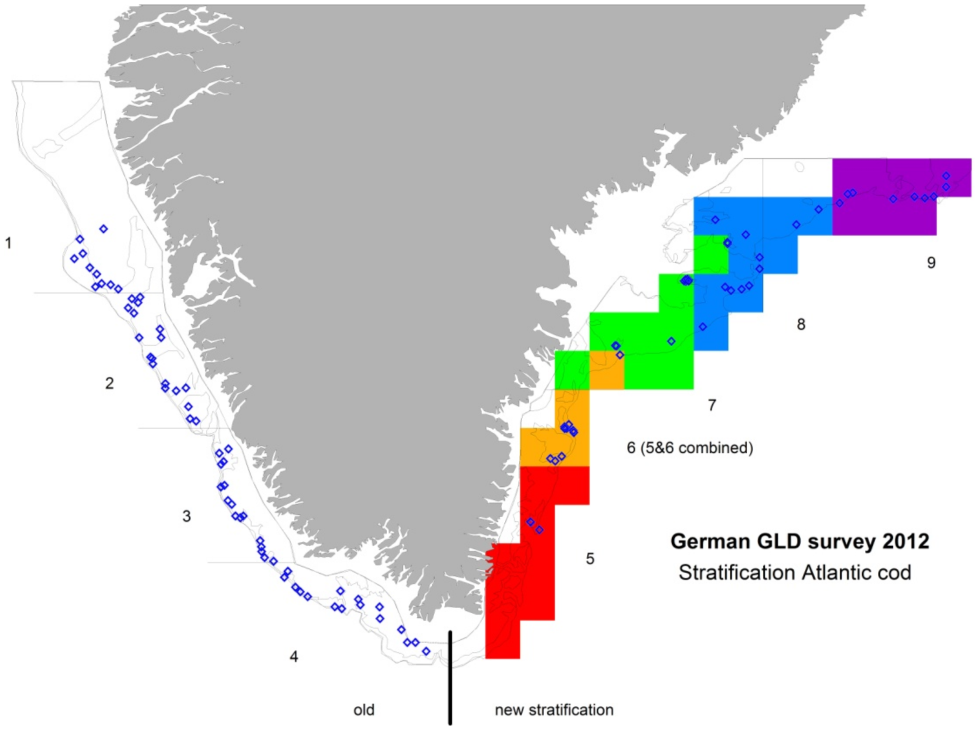

Figure B.3.2. The Stratification areas used in the German Greenland groundfish survey. Each stratum is divided into two depth zones, 0–200 m and 201–400 m.

B.4. Commercial cpue

Commercial cpue data are available from the period 1973 to present. However, due to time restrains the cpue series have not been thoroughly scrutinized as several issues need to be addressed such as; different fleets before and after the 1990s, primarily bycatch in the 1990s and recent periodic area closures.

B.5. Other relevant data

NA.

C. Assessment: data and method

DLS approach (method 3.2)

None of the analytical assessments presented at the benchmark WKICE were agreed to be capable of being used as single basis for making catch advice. It was generally considered that the big uncertainty in the two surveys was not properly accounted for in the different model runs. However, the two surveys were to a high degree thought to reflect the stock trends, especially when considering how alike the two indices are. Therefore it was decided to use survey indices in the future advice approach. One way of doing that is using the indices in a DLS framework (ICES 2012, method 3.2.) where trends are multiplied with the commercial catches. For producing catch advice, it was decided to use the method 3.2 with the following catch equation:

$$C_{y+1} = C_y \left(\frac{\sum_{i=y-x}^{y-1} I_i / x}{\sum_{i=y-z}^{y-x-1} I_i / (z-z)} \right)$$

where C_{y+1} is the catch advice for the next year (in this case 2016), C_{y-1} is the average catch of the last three years (in this case 2012–2014), *I* = Survey index value for B4+, *x* equals 2 and *z* is 5.

Uncertainty cap or "change limit" of +- 20% change in C_{y+1} if C_{y+1} from the equation is 20% greater or less than C_{y-1} is applied to C_{y-1} to address uncertainty or noise in the data and its potential influence on the catch advice.

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Annex 6: Stock Annex for Icelandic cod

Stock	Icelandic cod
Working Group	NWWG
Date	January 29, 2015
Revised by	Benchmark 2015

General

Stock definition

The Icelandic cod stock is distributed all around Iceland, and in the assessment landings of cod within Icelandic EEZ waters it is assumed to be a single homogeneous unit. Spawning takes place in late winter mainly off the southwest coast but smaller, variable regional spawning components have also been observed all around Iceland. The conventional wisdom has been that pelagic eggs and larvae from the main spawning grounds off the southwest coast drift clockwise northwards and eastward along the island to the main nursery grounds off the north coast. The mature stock takes on feeding migration from the spawning grounds to feeding grounds both to deeper waters in the northwest and southeast or within the shallow water realm of the continental shelf proper.

A larval drift to Greenland waters has been recorded in some years and substantial immigrations of mature cod from Greenland which are considered to be of Icelandic origin have been observed in some periods. This pattern was considered to be quite prevalent prior to 1970, when condition in Greenlandic waters were favourable for cod productivity. Periodic immigrations have been estimated in the assessment from anomalies in the catch-at-age matrix with timing and age of such events being based on expert judgement using external information. The most recent of such migration was from the 1984 year class in 1990, the number estimated around 30 million. Recent tagging experiments as well as abnormal decline in survey indices in West Greenlandic waters indicate that part of the 2003 and to some extent the 2002 year classes may have migrated from Greenland to Icelandic waters. In the current assessment the immigration at age 6 in 2009 is estimated around 9.7 million corresponding an additional biomass of around 31 kt in 2009. The influence of this immigration on the current biomass estimate is minimal.

A slight but significant genetic difference has been observed between the cod spawning in the northern waters vs. cod spawning in the southern waters (Pampoulie *et al.*, 2007). There are indications that different behavioural type (shallow vs. deep migration) may be found within cod spawning in the same areas (Pampoulie *et al.*, 2008). In addition genetic comparisons of cod sample in Greenlandic waters indicate that there is genetic affinity of mature cod in Icelandic and east and southwestern Greenlandic waters. These research show that management measurements operating on a finer or larger scale than is currently in place may be warranted. However, non-ambiguous methods for splitting up or combining the input measurement of stock assessment among areas (catch-at-age and survey-at-age) have yet been investigated.

Extensive tagging experiments spanning with some hiatuses over the last 100 years indicate that significant emigration of adult cod from Iceland to other areas may be rare. In recent years it has been observed that cod tagged in Iceland has been recaptured inside Faroese waters on the Faroese ridge proper. Anecdotal information from the fishing industry indicate that there may be some exchange of cod across the Denmark Strait. These migrations may be of different nature than the hypothesised net "life-history" immigration of cod described above.

Fishery

Annual landings

Annual estimates of landings of cod from Icelandic waters are available since 1905. The historical information is largely derived from Statistical Bulletin, with unknown degree of accuracy. The more recent landings (from 1980 onward) statistics are from the Directorate of Fisheries (the native enforcement body) as annually reported to ICES.

Landings in Iceland are restricted to particular licensed landing sites, with information being collected on a daily basis. All fish landed has to be weighted, either at harbour or inside the fish processing factory. The information on landing is stored in a centralized database maintained by the Directorate and is available in real time on the Internet (www.fiskistofa.is). The accuracy of the landings statistics are considered reasonable although some bias is likely. In the last years, insignificant amount of cod caught in Icelandic waters have been landed in foreign ports.

Area misreporting after the establishments of 200 miles EEZ in the 1970s has not been regarded as a major problem in the fishery of this stock. This is because the native fleet that accounts for the bulk of the total landings has had very limited access to fishing on other cod stocks. In addition they are not allowed to fish in different management areas in the same trip.

Discarding of fish of economic value is banned in Icelandic waters. Estimates of annual cod discards (Ólafur Pálsson *et al.*, 2010) since 2001 are in the range of 1.4–4.3% of numbers landed and 0.4–1.8% of weight landed. Mean annual discard of cod over the period 2001–2008 was around 2 kt, or just over 1% of landings. In 2008 estimates of cod discards amounted to 1.1 kt, 0.8% of landings, the third lowest value in the period 2001–2008. The method used for deriving these estimates assumes that discarding only occurs as highgrading.

Discarding over the whole time history from 1955 is unknown, but anecdotal information indicates that it may have been substantial even prior to the 1990s. In the absence of any quantifiable data the impact of the discarding on potential bias in dynamics of cod can however not be evaluated.

After WWII the fishery was initially dominated by foreign fleets, mainly English and German trawlers. The former were primarily targeting cod and catching saithe as a bycatch, while the latter were more directly targeting saithe as well as redfish. The domestic fleet has more or less been the sole exploiter of the cod resource since 1978, following the expansion of the Icelandic EEZ from 50 to 200 miles in 1975.

Information on landings by gear is available since 1955. Largest portion of the catch have been taken by trawlers, with gillnet fisheries being secondary in the early part of the period. The importance of the gillnet fishery was around 30% of the landings in beginning of the period but has decline continuously since the 1980s. In recent years it has been around 10% of the total landings. The longline fisheries has increased in importance, in particular at the beginning of the 2000s, and now accounts for 35–40% of the landings.

The spatial distribution of the recent catches based on logbook records show that the bottom-trawl catches are to a large extent confined to outer continental shelf area in the northwest and southeast (400–500 m) while the longline catches are more dispersed on the shelf proper. The distribution of the gillnet and Danish seine fisheries is primarily in shallow waters in the south and the western waters.

Management

Since the establishment of a 200 mile EEZ in 1976 a fishery management system has been under development for the fisheries in Iceland. In the early years various experimental effort control system where tried, but they did not result in reducing fishing mortality, for various reasons. In 1984 a mixture of a TAC and effort control system was introduced for vessels larger than 10 GRT. In the early period the entry into the TAC system for this vessel class was voluntary. Each fishing vessel in the TAC system received a fraction of the TACs, the fraction being based on average share in the catches in the three previous years. The effort options for the size classes larger than 10 GRT was fully abandoned with the Fisheries Management Act in 1990, that first came into full force for the fishing season 1991/1992. Vessels less than 10 GRT in size had until 1990 free access to the fisheries. They were under a mixed ITQ or effort control from 1991–2000. In 2001 boats larger than 6 GRT were all placed under an ITQ system. In 2003 most boast, including those under 6 GRT were under ITQ system, although some specific measures for the smaller vessels has remained in place.

Since the fishing year 1991/1992 the total allowable for cod has been set as follows: Following the annual assessment and advice and prior to the start of the fishing year, the TAC is first set (since 1995/1996 based on a formally adopted harvest control rule). From that a certain amount is set aside for various socio-economic reasons as well that likely to be caught by the effort control fleet. The remainder is then allocated to the vessels in the ITQ system, based on their individual share.

Prior to the 1990s the TAC was most often set considerably higher than that recommended by the Marine Research Institute. In the early 1990s a governmental appointed scientific committee recommended that the TAC should be set based on a formal harvest control rule. The recommended rule was of the form:

$$TAC_{y+1} = 0.22 \times B_{4+,y}$$

where the $B_{4+,y}$ is the reference biomass in the assessment year. A formal harvest control rule was adopted and became the basis for the TAC for the first time for the fishing year 1995/1996. The adopted HCR had however a higher multiplier and was also based on the predicted reference biomass:

$$TAC_{y+1} = 0.25 \times \frac{B_{4+,y} + B_{4+,y+1}}{2}$$

Some amendment to the rule (in the form of catch stabilisers) were done over time but the 0.25 multiplier in place until the mid-2000s. In the fishing year 2007/2008 when the TAC was first set based on the current form of the HCR:

$$TAC_{y+1} = min\left\{1, \frac{SSB_y}{SSB_{trigger}}\right\} \times \frac{0.20 \times B_{4+,y} + TAC_y}{2} \qquad (1)$$

The ratio of the landings relative to the catch dictated by the harvest control rule in place at any time has shown that there has been an overshoot in the landings (mean around 8%). These can be largely attributed to various socio-economic measures that were mostly foreseeable and predictable at the time of the decision-making. In the last couple of years a system has been set in place that is supposed to take account of these overshoots, but its effect is still not visible.

A system of instant area closure has been in place since the 1970s. The aim of the system is to minimize fishing on smaller fish. For cod, an area is closed temporarily (for three weeks) for fishing if on-board inspections (not 100% coverage) reveal that more than 25% of the catch is composed of fish less than 55 cm in length. No minimum landing size of any fish species exist in Icelandic waters. The minimum allowable mesh size is 135 mm in the trawl fisheries, with the exception of targeted shrimp fisheries in waters north of the island.

Management measures that aim at reducing incentives or likelihood of discarding have been in place since 1991. These include some allowance for individual vessels for changing quota from one species to another, although this measure does not apply to cod. A 5% overshoot of individual vessel quota in one fishing year is permitted, with the consequences that the vessels ITQ in the next year being reduced equivalently. In addition up to 20% of the quota in one year can be transferred to the next fishing year, without penalty. A quota leasing market is also in place, where individual vessel can lease quota from other vessel owners on a contemporary basis. The system operates in real time, meaning that if overshoot of catch of a particular species occurs during a trip, the captain can at least in theory lease quota prior to landing. The system is however somewhat limited to the supply relative demand at any particular time.

In addition to the above flexibilities additional measures to reduce incentives for discarding were set in place in 2001, by allowing vessels to report up to 5% of annual catches as outside their ITQ allowance. These measures resulted in total landings of around 2 kt, large portion being cod (around 85%).

Observations

Commercial catch

Sampling from the Icelandic fleet

The sampling protocol by the staff of the Marine Research Institute has in the last years been linked to the progression of landings within the year. The system is fully computerized (referred to as "Sýnó" by the natives) and directly linked to the daily landings statistics available from the Directorate of Fisheries. For each species, each fleet/gear and each landing strata a certain target of landings value behind each sample is prespecified. Once the cumulative daily landings value pass the target value an automatic request is made to the sampling team for a specific sample to be taken. The system as such should thus take into account seasonal variability of the landings of any species. The sampling design is not *per se* linked to the geographical distribution of the fisheries. However the fishing location of the fish measured at harbour is known with reasonably accuracy, because fishing date is registered for each fish boxes and can hence be linked to geographic location of the fishing at that date, based on the captain's logbook record.

Calculation of catch in numbers

The calculation of the annual catch in number of the Icelandic cod has since 1980 been calculated in the same way. The base is eight métiers, two areas (northeast and southwest), four gears (longlines, gillnet, Danish seine and gillnets) and two seasons (January–May, June–December). The catch in numbers are calculated for each area, season and gear combination and then combined to total catches in numbers.

Length distributions

Data used are length–frequency samples taken in area **r**, season **t** and gear **g**.

L_l is the number of fishes at length *l*.

One has the option to run the length distributions on 1 cm or 5 cm basis. If the latter one is chosen, a temporary variable *lemultfj* is assigned the value $l * L_l$ to be able to calculate the correct mean length in the length distribution. Then the grouping in 5 cm intervals is done in the way that the numbers get the middle value from the interval. As an example the values in the range 10–14 and 15–19 are assigned 12 and 17 respectively. Lengths are then in fact either

$$l \in \{1,2,3,\ldots\} \text{ or } l \in \{2,7,12,17,\ldots\}$$

Age-length and maturity keys

Data used are age-determined data from otolith samples in area **r**, season **t** and gear **g**. If no otolith samples exist from this area, season and gear combination, they have to be borrowed from other season or gear for the same area or from other areas.

K_{la} is the number at length *l* and at age *a*, *a*>0.

M_{la} is the number mature at length *l* and at age *a*, *a*>0.

IM_{la} is the number immature at length *l* and at age *a*, *a*>0.

A fish is assigned to IM_{la} if is has a maturity value 1 in the database otherwise it is assigned to M_{la}.

Multiply the age-length and maturity keys with the length distribution

Sum of the numbers at length *l* over all ages:

$$K_{l.} = \sum_a K_{la}$$

Make a new key with the number of fishes:

$$C_{la} = \frac{K_{la}}{K_{l.}} \cdot L_l$$

And new maturity keys:

$$C_{laM} = \frac{M_{la}}{M_{la} + IM_{la}} \cdot C_{la} \quad \text{and} \quad C_{laIM} = \frac{IM_{la}}{M_{la} + IM_{la}} \cdot C_{la}$$

Average length and weight

In this step average length and weight-at-age are calculated. For each area, season and gear the condition factor (*cond*) and the power (*power*) in a length–weight relationship are input data.

$$\tilde{w}_{la} = C_{la} \cdot coef(1) \cdot l^{coef(2)}$$ (the weight in each cell)

$$\tilde{l}_{la} = C_{la} \cdot l$$

Note that in the above two equations l is a midpoint if 5 cm grouping has been chosen.

The total frequency in the key is:

$$C_{..} = \sum_l \sum_a C_{la}$$

and total weight

$$\tilde{w}_{..} = \sum_l \sum_a \tilde{w}_{la}$$

So the mean weight in this area, season and gear combination is

$$\overline{w} = \frac{\tilde{w}_{..}}{C_{..}}$$

The ratio of weight and number by age from the total:

$$ratio\_wt_a = \sum_l \tilde{w}_{la} / \tilde{w}_{..}$$

$$ratio\_Ct_a = \sum_l C_{la} / C_{..}$$

The mean weight and mean length-at-age and ratio mature-at-age are:

$$\overline{w}_a = \frac{\sum_l \tilde{w}_{la}}{\sum_l C_{la}}$$

$$\bar{l}_a = \frac{\sum_l \tilde{l}_{la}}{\sum_l C_{la}}$$

$$ratio\_Mt_a = \frac{\sum_l C_{la}^{M}}{\sum_l (C_{la}^{M} + C_{la}^{I})}$$

if the denominator >0 otherwise the *ratio_M_a is set to -1.*

Catches in numbers

Input data for this module is the landings in tons (*catch*) for each area, season and gear.

The total number of fishes caught are:

$$C_{tot} = \frac{catc}{\overline{w}}$$

The catches in numbers and weight by age is then

$$C_a = C_{tot} \cdot ratio_a$$

$$W_a = C_a \cdot \overline{w}_a$$

To derive the total catches in numbers and weight summation is done over all areas, seasons and gears.

Biological data

Weight-at-age

Mean weight-at-age in the landings is available back to 1955. Prior to 1993 mean weight-at-age is compiled using fixed length–weight relationship as weighing of fish was relatively uncommon in that period. Since 1993 weighting of fish has been extensive with large proportion of cod sampled for otholiths weighted gutted and part of it ungutted. The weighting programme has shown that the error in assuming fixed length–weight relationship is relatively small (<3%) and that most of observed changes in mean weight-at-age are really changes in mean length-at-age.

Catch weight estimates in the assessment year (y): The weight-at-age in the catches is used to calculate the reference biomass (B4+). The B4+ in the assessment year (y) is the basis for the calculation of the TAC in the advisory year (y+1). Since weight-at-age in the catches for this year is not available during the annual assessment/advisory cycle, they have to be based on predictions. In the last few years, the estimates of mean weights in the landings of age groups 4–9 in the assessment year (y) have been based on a prediction from the spring survey measurements in the advisory year, using the relationship between survey and landings weights from the terminal year (y-1):

$$cW_{a,y-1} = \alpha + \beta * sW_{a,y-1} \quad (2)$$

and the catch weights in the advisory year then from:

$$cW_{a,y} = \alpha + \beta * sW_{a,y} \quad (3)$$

The weight-at-age for age groups 10–14 in the have however been taken from the terminal year. In assessment done prior to 2005, the mean weights in the landings in the assessment year were predicted from mean weights in the landings one year before and estimated abundance of adult capelin. Prediction of the capelin stock size turned out to be problematic and the survey weights on which predictions are now based are measured 3–4 months before the weights in landings assuming they are on the average in the middle of the year.

Maturity-at-age

Maturity-at-age is based on measurements obtained from spring survey. The survey time is close to the spawning time making visual detection of maturity stages optimal. Maturity-at-age data from surveys are considered to give better estimates of maturity-at-age in the stock than those from landings data, in particular because of limited ungutted samples in the landings.

Since the spring survey only commenced in 1985, maturity values prior to that were obtained from a relationship between maturity-at-age in the landings and the survey from 1985–2004.

Natural mortality

A fixed natural mortality of 0.2 is used both in the assessment and the forecast. The proportion of natural mortality before spawning (pM) and the proportion of fishing mortality before spawning (pF) are also set as constants:

	AGE	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	pM	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
2	pF	0.00	0.00	0.09	0.18	0.25	0.30	0.38	0.44	0.48	0.48	0.48	0.48	0.48	0.48

Survey indices

Two groundfish surveys, conducted be the Marine Research Institute (MRI) in Iceland, are used directly in assessment of cod, the Icelandic Groundfish Survey conducted annually in March since 1985 (here referred as the March survey or SMB) and the Autumn Groundfish Survey conducted annually in October since 1996 (here referred as the Autumn survey or SMH). Both are bottom-trawl surveys. The March survey is conducted on the continental shelf at depths shallower than 500 m and has a relatively dense station-net (approximately 600 stations towed annually). The Autumn Survey on the other hand has around 380 stations towed annually and covers larger area at depths down to 1500 m, so the density of stations is lower.

Large part of the following text is taken from citation. Where applicable the emphasis has been put on cod. The manual on how the surveys in 2009 were conducted is available in English at MRI website (citation) but the survey protocol has not changed much since 2009 and for cod things related to index have not changed much since 1989, except for weighting of all cod sampled for otoliths since 1993. The weighting has some effect on estimated mean weight-at-age. Still variability of condition only explains 10–20% of variability of mean weight-at-age while variability of length-at-age explains 80–90%.

The spring survey

Timing, area covered and tow location

The optimal time of the year to conduct the survey was considered be in March, or just before and during the spawning of cod in Icelandic waters. During this time of the year, cod is most easily available to survey gear as diurnal vertical migrations are at minimum (citation).

The total number of stations was decided to be 600. The reason of having so many stations was to decrease variance in indices but was within the constraints of what was feasible in terms of survey vessels and workforce available. With 500–600 tow-stations the average coefficient of variation (CV) of the survey indices of cod was estimated to be around 13%.

Allocation of stations and data collection is based on a division between northern and southern areas (Figure 3). The northern area is the colder part of Icelandic waters where the main nursery grounds of cod are located, whereas the main spawning grounds are found in the warmer waters in the southern area. It was assumed that 25–30% of the cod stock (in abundance) would be in the southern area at the survey time but 70–75% in the north. Because of this, 425 stations were located in the colder northern area and 175 stations in the southern area. The two areas were then divided into ten strata, four in the south and six in the north.

Stratification in the survey and the allocation of stations was based on pre-estimated cod density patterns in different "statistical squares" (citation). The statistical squares were grouped into ten strata depending on cod density. The number of stations allocated to each stratum were in proportion to the product of the area of the stratum and cod density. Finally, the number of stations within each stratum were allocated to each statistical square in proportion to the size of the square. Within statistical squares, stations were divided equally between captains chosen stations and the randomly chosen stations for decisions of location. The captains selected their stations from their fishing experience. Up to 16 stations are in each statistical square in the northern area and up to seven in the southern area.

Vessels, fishing gear and fishing method

In the early stages of the planning it was apparent that consistency in conducting the survey on both spatial and temporal scale was of paramount importance. It was decided to rent commercial stern trawlers built in Japan in 1972 and 1973 to conduct the survey. Each year, four or five of these trawlers have participated in the survey. The ten Japanese built trawlers were all built on the same plan and were considered identical for all practical purposes. The trawlers were thought to be in service at least until the year 2000. This has been the case and most of these trawlers still fish in Icelandic waters but have been modified since the start of the survey (see next section).

The survey gear is based on the trawl that was most commonly used by the commercial trawling fleet in 1984–1985. It has relatively small vertical opening of 2–3 m. The headline is 105 feet, fishing line is 63 feet, footrope 180 feet and the trawl weight 4200 kg (1900 kg submerged).

Length of each tow was set 4 nautical miles and towing speed at approximately 3.8 nautical miles per hour. Minimum towing distance of a tow to be considered valid for index calculation is 2 nautical miles.

Later changes and alterations to the survey

Vessels and fishing gear

The commercial trawlers used in the survey have been changed somewhat since the beginning of the survey. The changes include alteration of hull shape (bulbous bow), the hull extended by several meters, larger engines, and some other minor alterations. These alterations have probably changed the qualities of the ships but it is very difficult to quantify these changes.

The trawlers are now considered old and it is likely that they will soon disappear from the Icelandic fleet. Some search for replacements is ongoing. Since 2007, two MRI research vessels have taken part in the Spring Survey after elaborate comparison studies.

The trawl has not changed since the start of the survey. The weight of the otter-boards has increased from 1720–1830 kg to 1880–1970 kg. This increase may have increased the horizontal opening of the trawl and hence decreased the vertical opening. However, these changes should be relatively small as the size (area) and shape of the otter-boards is unchanged.

Trawl-stations

Initially, the numbers of trawl stations surveyed was expected to be 600. However, this number was not covered until 1995 (Table 1). The first year 593 stations were surveyed but in 1989 the stations had been decreased down to 568 mainly due to bottom topography (rough bottom that was impossible to tow), In two years, 1988 and 1998 drift ice caused problems and in 1988 only 545 stations were surveyed. In 1989–1992, between 567 and 574 stations were surveyed annually. In 1993, 30 stations were added in shallower waters to take into account fishermen's critique that the survey did not cover that area adequately.

In short, until 1995 between 545 to 600 stations were surveyed annually. In 1996, 14 of the 30 stations that were added in 1993 were omitted.

In 1996, the whole survey design was evaluated with the aim of reduce the cost. The number of stations was cut down to 532 stations. The main change was to omit all of the 24 stations on the Iceland-Faroe Ridge southeast of Iceland. This was the state of affairs until 2004 when in response to increased abundance of cod on the Faroe-Iceland Ridge nine stations were added. Since 2005 all of the 24 stations omitted in this area in 1996 have been surveyed.

Since 2008 captains have been asked to take additional tows outside the survey area when substantial amount of fish was caught in the outermost tows. This situation did nearly always apply to cod. The additional tows have not been used directly in index calculations but most of them are anyway outside the stratification scheme used that is drawn around the standard stations. The effect of additional stations near the edges of the continental shelf is usually small as the slopes are steep so the area between 400 and 600 m is relatively small. The additional stations are important for understanding cod distribution in the important fishing area in the slope of the continental shelf although they have not been used for tuning in assessment.

The autumn survey

The autumn survey has been conducted annually since 1996. The objective is to gather fishery-independent information on biology, distribution and biomass of demersal fish species in Icelandic waters, with particular emphasis on Greenland halibut (*Reinhardtius hippoglossoides*) and deep-water redfish (*Sebastes mentella*). This is because the spring survey does not cover the distribution of these deep-water species. Secondary aim of the survey is to have another fisheries-independent estimate on abundance, biomass and biology of demersal species, such as cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and golden redfish (*Sebastes marinus*), in order to improve the precision of stock assessment . Having a survey in autumn was also considered desirable if drift ice caused problems with the March survey but the extent of drift ice is much less in autumn.

Timing, area covered and tow location

The autumn survey is conducted in October as it is considered the most suitable month in relation to diurnal vertical migration, distribution and availability of Greenland halibut and deep-water redfish. The research area is the Icelandic continental shelf and slopes within the Icelandic Exclusive Economic Zone to depths down to 1500 m. The research area is divided into a shallow-water area (0–400 m) and a deep-water area (400–1500 m). The shallow-water area is the same area covered in the spring survey. The deep-water area is directed at the distribution of Greenland halibut, mainly found at depths from 800–1400 m west, north and east of Iceland, and deep-water redfish, mainly found at 500–1200 m depths southeast, south and southwest of Iceland and on the Reykjanes Ridge.

Preparation and later alterations to the survey

Initially, a total of 430 stations were divided between the two areas. Of them, 150 stations were allocated to the shallow-water area and randomly selected from the spring survey station list. In the deep-water area, half of the 280 stations were randomly positioned in the area. The other half were randomly chosen from logbooks of the commercial bottom-trawl fleet fishing for Greenland halibut and deep-water redfish in 1991–1995. The locations of those stations were, therefore, based on distribution and pre-estimated density of the species.

Because MRI was not able to finance a project in order of this magnitude, it was decided to focus the deep-water part of the survey on the Greenland halibut main distributional area. For this reason, important deep-water redfish areas south and west of Iceland were omitted. The number and location of stations in the shallow-water area was left unchanged.

The number of stations in the deep-water area was reduced to 150. A total of 100 stations were randomly positioned in the area. The remaining stations were located on important Greenland halibut fishing grounds west, north and east of Iceland and randomly selected from a logbook database of the bottom-trawl fleet fishing for Greenland halibut in 1991–1995. The number of stations in each area was partly based on total commercial catch.

In 2000, with the arrival of a new research vessel, MRI was able finance the project according to the original plan. Stations were added to cover the distribution of deep-water redfish and the location of the stations selected in a similar manner as for Greenland halibut. A total of 30 stations were randomly assigned to the distribution area of deep-water redfish and 30 stations were randomly assigned to the main deep-water redfish fishing grounds based on logbooks of the bottom-trawl fleet in 1996–1999 (Figure 2).

In addition, 14 stations were randomly added in the deep-water area in areas where great variation had been observed in 1996–1999. However, because of rough bottom which made it impossible to tow, five stations were omitted. Finally, 12 stations were added in 1999 in the shallow-water area, making total stations in the shallow-water area 162. Total number of stations taken 2000–2009 was around 381 (Table 2).

In 2010, the number of stations in deeper waters were reduced by 16 or from 219 to 203. The reduction was mainly west of Iceland where Greenland halibut is mainly found. In this area the density of stations was great and the cut down was considered not to have any effect on biomass and abundance estimates of the species. The number of stations was also cut down southwest and southeast of Iceland, where deep-water redfish are abundant and the station net very dense.

The RV ”Bjarni Sæmundsson” has been used in the shallow-water area from the beginning of the survey until 2014 when a commercial trawler replace the research vessel as a result of financial engineering exercise. For the deep-water area MRI rented one commercial trawler 1996–1999, but in 2000 the commercial trawler was replaced by the RV "Árni Friðriksson" until 2014 when financial engineering exercises cause a trawler being used instead of the research vessel (Table 2).

The survey was not conducted in 2011 due to strike by the crew of research vessels.

Fishing gear

Two types of the bottom survey trawl "Gulltoppur" are used for sampling: "Gulltoppur" is used in the shallow water and "Gulltoppur 66.6 m" is used in deep waters. The shape of the trawls are the same but the trawl used in deep waters is larger. The trawls were common among the Icelandic bottom-trawl fleet in the mid-1990s and are well suited for fisheries on cod, Greenland halibut and redfish.

The towing speed is 3.8 knots over the bottom. The trawling distance is 3.0 nautical miles calculated with GPS when the trawl touches the bottom until the hauling begins (i.e. excluding setting and hauling of the trawl).

Data sampling

The data sampling in the spring and autumn surveys are similar. The difference is that more emphasis is on stomach content analysis in the autumn survey than in the spring survey.

Length measurements and counting

All fish species are measured for length. For the majority of species, including cod, total length is measured to the nearest cm from the tip of the snout to the tip of the longer lobe of the caudal fin. At each station, the general rule is to measure at least four times the length interval of cod in both the surveys.

Example: If the continuous length distribution of cod at a given station is between 15 and 80, the length interval is 65 cm and the number of measurements needed is 260. If the number of cod caught at this station exceeds 260 individuals, the rest is counted.

Care is taken to ensure that the length measurement sampling is random so that the fish measured reflect the length distribution of the haul in question.

Otolith sampling

Otoliths for age reading are sampled from cod in both surveys. In the spring survey the sampling protocol changes between north and south (Figure 3) with 25% of cod caught in the south sampled for otoliths and 5% in the north. In both areas minimum of five cod are sampled for otoliths and a maximum of 30. Cod are selected randomly for otolith sampling, in recent years the electronic scales used for punching in the data blink when the next cod is to be taken for otolith sampling.

The sampling for otoliths is the March survey has been similar since 1989 but from 1985–1988 the sampling was stratified with area split into five strata. Within each strata certain number of fish in each length group were sampled for otolith.

In the autumn survey, the minimum is 25 otoliths extracted and the maximum is 50 otoliths. Otoliths are sampled at ten fish interval so that if in total 300 cod are caught in a single haul, 30 otoliths are sampled. The same proportion of fish is sampled for otoliths in the whole survey area.

In both surveys, each cod taken in the otolith sampling is sex and maturity determined, and weighed ungutted and gutted. Liver is also weighed and roes/gonads of mature fish in the March survey. The stomach content is also analysed in both surveys, first 15 in the March survey and 25 in the autumn survey (citation).

Data processing

Information on tow, gear and environmental factors

At each station/haul relevant information on the haul and environmental factors, are filled out by the captain and the first officer in cooperation with the cruise leader.

Abundance and biomass estimates at a given station

As described above the normal procedure is to measure at least four or five times the length interval of a given species. The number of fish caught of the length interval L_1 to L_2 is given by:

$$P = \frac{n_{measured}}{n_{counted} + n_{measured}} \quad (4)$$

$$n_{L_1-L_2} = \sum_{i=L_1}^{i=L_2} \frac{n_i}{P} \quad (5)$$

where $n_{measured}$ is the number of fished measured and $n_{counted}$ is the number of fish counted. Biomass of a given species at a given station is calculated as:

$$B_{L_1-L_2} = \sum_{i=L_1}^{i=L_2} \frac{n_i \alpha L_i^{\beta}}{P} \quad (6)$$

where L_i is length and α and β are coefficients of the length–weight relationship.

Number and biomass by age at each station

The first step is to calculate age–length key $P_{a,L}$ that describes the proportion of each age in a length group that is 5 cm. The age–length key for cod is calculated separately for the north and south area (Figure 3) due to difference in mean weight-at-age in the areas and also much higher sampling percent in the March survey.

In the March survey maturity stage is registered (and used) for each fish sampled for otoliths. In the age–length keys mature fish are treated like it was a separate age group.

Age–length keys are calculated as follows. Look at length group L with min length l_1 and max length l_2 let $N_{a,L}$ be the number of fish of age a and length group L. The age–length key is defined as.

$$P_{a,L} = \frac{N_{a,L}}{\sum_a N_{a,L}} \quad (7)$$

The number of fish at age a in each station is calculated from the length distribution at the station and the age–length key for the area where the station is:

$$n_{a,st} = \sum_L P_{a,L} n_{L,st} \tag{8}$$

Where L means length group, n_L total number of fish in length group L, a age group st station and the age–length key is calculated by equation 7.

Biomass of age group a at station st is computed from the length distribution at the station, the age–length key for the area where the station is and mean weight of length L in the area W_L (condition). Condition is calculated for the same areas as the age–length keys, since 1993 based on weighting of fish in the survey. Function of the form $W = \alpha L^\beta$ was found to have too little flexibility so a smoothing spline with 3 degrees of freedom is used.

$$B_{a,st} = \sum_L P_{a,L} n_{L,st} W_L \tag{9}$$

Mean weight of fish of age a at station st is obtained by dividing the result from equation 9 by the result from equation 8.

To be able to calculate mean length and standard deviation of length by age group the values $L \times n$ and $L^2 \times n$ must be kept track of. To calculate the same values by age the following equations are used.

$$nL_{a,st} = \sum_L P_{a,L} nL_{L,st} \tag{10}$$

$$nL^2_{a,st} = \sum_L P_{a,L} nL^2_{L,st} \tag{11}$$

In the March survey maturity-at-age and mean length by age of mature fish is calculated in addition to number, mean length and mean weight by age. Those calculations are done in similar way as shown before, except mature age in each age group is treated like a separate age group and mean length and mean weight are calculated for that group.

As mentioned earlier different age–length keys are used for the northern and southern area when compiling number and other values by age and station for cod.

Stratification

The strata used for survey index calculation for most species in the spring survey is shown in Figure 5 and for the autumn survey in Figure 4. The stratification is in general based on depth stratification and similar oceanographic conditions within each stratum.

The stratification used in the March survey was set up as part of the BORMICON multispecies project. The number of strata is quite large but so is the number of stations. When indices from the autumn survey started to be tested in assessment work it soon appeared that the number of strata should be reduced but the density of stations in the autumn survey is much lower than in the March survey. Indices for most species from both the surveys are available for both stratifications.

For cod assessment was based on indices from the March survey, using the old stratification scheme (Figure 5). Since 2009 indices from the autumn survey have also been used but they are based on the new stratification. The number of strata in the autumn survey is 33 (Figure 4) and the March survey 45. Extending the old stratification scheme to cover the autumn survey leads to 68 strata, and the subset of the new stratification scheme Figure 4 covering the March survey has 24 strata.

Some of the stations are near/at the boundary between strata and random changes in positions can lead to the stations not being in the same stratum each year. This is not desirable as the weight of each station varies between strata. Therefore a station is allocated into the strata that it has most often been calculated to be in.

Index calculation

For calculation of indices the Cochran method is used (citation) The survey area is split into strata (see the section above). Index for each stratum is calculated as the mean number in a standardized tow divided by the area covered multiplied with the size of the stratum. The total index is then a summed up estimates from the strata. A 'tow-mile' is assumed to be 0.00918 square nautical mile. That is the width of the area covered is assumed to be 17 m (17/1852=0.00918). When calculating the area of the strata closest to shore the part closest to the coast is excluded where it is not surveyed.

The same width of the trawl is used for the March survey and the smaller trawl in the autumn survey while 25% greater width is used for the large trawl in the autumn survey. As q is estimated separately for each survey the ratio of the values used does not matter. In the autumn survey the catch in the large trawl needs to be 25% higher than in the small trawl to get the same contribution to the index.

The following equations are a mathematical representation of the procedure used to calculate the survey indices:

$$\overline{Z}_i = \frac{\sum_i z_i}{N_i} \tag{12}$$

where $\overline{Z}_i$ is the mean catch (number or biomass or any other value available on station basis) in the i-th stratum, Z_i is the total quantity of the index (abundance or biomass) in the i-th stratum and N_i the total number of tows in the i-th stratum. The index (abundance or biomass) of a stratum (I_i) is:

$$I_i = \overline{Z}_i \left(\frac{A_i}{A_{tow}}\right) \tag{13}$$

and the sample variance in the i-th stratum:

$$\sigma_i^2 = \left(\frac{\sum_i (z_i - \overline{z}_i)^2}{N_i - 1}\right) \left(\frac{A_i}{A_{tow}}\right)^2 \tag{14}$$

where A_i is the size of the i-th stratum in NM ^{2} and A_{tow} is the size of the area surveyed in a single tow in NM ^{2}.

The index in a given region

$$I_{region} = \sum_{region} I_i \tag{15}$$

the variance is

$$\sigma_{region}^2 = \sum_{region} \sigma_i^2 \qquad (16)$$

and the coefficient of variation is

$$CV_{region} = \frac{\sigma_{region}}{I_{region}}. \qquad (17)$$

When compiling the age disaggregated indices for March survey the Indices are compiled based on the following values at each stations.

1) Biomass per station and age group. $I_{B,a}$

2) Number per station and age group. $I_{N,a}$

3) Biomass of mature fish per station. $I_{Bmat,a}$

4) Number of mature fish per station. $I_{Nmat,a}$

5) Number times mean length at each station. $I_{N\times\bar{L},a}$

6) Number times mean length squared at each station. $I_{N\times\bar{L}^2,a}$

These indices with associated variance estimate are available for each stratum, and specific combinations of strata (including the whole area).

When the indices are have been calculated following derived quantities can be compiled from the indices, also available for each stratum, and specific combinations of strata (including the whole area).

1) Mean weight-at-age $W_a = \frac{I_{B,a}}{I_{N,a}}$

2) Mean weight-at-age of mature fish $W_{mat,a} = \frac{I_{Bmat,a}}{I_{Nmat,a}}$

3) Proportion mature $P_a = \frac{I_{Nmat,a}}{I_{N,a}}$

4) Mean length-at-age $\overline{L_a} = \frac{I_{N\times\bar{L},a}}{I_{N,a}}$

5) Standard deviation at age $\sigma_{L,a} = \sqrt{\left(\frac{I_{N\times\bar{L}^2,a}}{I_{N,a}} - \overline{L_a}\right)^2}$

Computing the quantities in this way will give more weight to stations where density of stations is low.

The variance of the derived quantities is not calculated but it will in the end mostly depend on the number of fish in that age group sampled for otoliths and best be estimated by bootstrap.

Assessment: data and method

The Marine Research Institute's three main gadoid stocks have been assessed based on ADMB modules that were designed and written by Höskuldur Björnsson. Three modules have been in use:

- **adcam**: A forward running statistical catch-at-age model where fishing mortality-at-age is allowed to change gradually in time. The fishing mortality is allowed to deviate from separability using a random walk penalty in the objective function. This module has been used as the basis for the calculation of the annual TAC according to the HCR since 2002. Resembles the method called "correlated random walk" in SAM, but the correlation matrix has different structure and not as many variances can be estimated as the Adcam model is not a real state–space model, rather what has been Referred to as Error in Variables approach.
- **separ**: A statistical catch-at-age model were selection pattern are fixed over any given period. This module has been used in the HCR evaluations of the Icelandic cod (2009) and haddock and saithe (2013).
- **adapt**: A tuned VPA type of model, were no error is assumed in the catch-at-age.

All the models are stock assessment models with possibilities for short- and long-term predictions according to a number of HCR. Some of the predictions are adapted to the Icelandic fishing year and the HCR used for Icelandic stocks. The Separable model and the Adapt model use the same input files and 90% of the code is the same.

Evolution of the stock and fisheries

$$\hat{N}_{1,y} = f(SSB_{y-1}) \tag{18}$$

$$N_{1,y} = \hat{N}_{1,y} e^{\xi_y} \tag{19}$$

$$N_{a+1,y+1} = N_{a,y} e^{-(F_{a,y}+M_{a,y})} + \Delta a, y \tag{20}$$

Where $\Delta a, y$ are estimated migrations of specified age groups in specified years For Icelandic cod these are imports from Greenland.

For the VPA model the stock is projected backwards

$$N_{a,y} = (N_{a+1,y+1}\, \Delta_{a,y}\, e^{0.5M_{a,y}} + C_{a,y}) e^{0.5M_{a,y}} \tag{21}$$

The migration $\Delta a, y$ are here multipliers limited to the range 0–1, assuming that the migration is at the beginning of the year.

The VPA model can only estimate migrations in periods where survey indices are available but the catch-at-age models can use anomalies in catch-at-age for estimation of migrations.

If the oldest age group A is a plus group, then its numbers develop according to.

$$N_{A,y+1} = N_{A-1,y}e^{-(F_{A-1,y}+M_{A-1,y})} + N_{A,y-1}e^{-(F_{A,y-1}+M_{A,y-1})} \quad (22)$$

For Icelandic cod the oldest age group A is not a plus group, so the equation changes to:

$$N_{A,y+1} = N_{A-1,y}e^{-(F_{A-1,y}+M_{A-1,y})} \quad (23)$$

The Adapt model is not designed for plus group.

Natural mortality was assumed fixed at the value of 0.2 The values used for prerecruits that are not in the fisheries, age 1–2 for cod do of course not matter and the value 0.0 would be the best choice, helping to relate number of prerecruits to the number of those entering the catches (age 3 for cod).

Catches removed from the stocks are estimated from stock number by Baranov's equation.

$$\hat{C}_{a,y} = \frac{F_{a,y}}{Z_{a,y}}(1 - e^{-Z_{a,y}})N_{a,y} \quad (24)$$

In the separable model the fishery is simulated as a single fleet modelled as a non-parametric separable model:

$$F_{a,y} = F_y S_a \quad (25)$$

More than one separable period can be specified.

In the random walk model all the fishing mortalities $F_{a,y}$ are estimated and the random walk implemented through constraint in the likelihood function (see notes on likelihood function below). The estimation is done in two phases, first a separable model is estimated and later deviations from the separable model.

More than one stock–recruitment function is implemented in the model. Recruitment is not generated directly from the selected stock–recruitment model except in predictions. They do enter the assessment as residuals from stock–recruitment functions are used in the likelihood function to estimate the parameters. For stocks with good data the effects of the stock–recruitment function on historical assessment is small, but in predictions the stock–recruitment function is important although the parameters are often poorly estimated.

The functions allowed in the model are.

Hockey stick:

$$R_y = min\left\{R_{max}, R_{max}\frac{SSB_{y-1}}{SSB_{break}}\right\} \quad (26)$$

Ricker model:

$$R_y = R_{max}e^1\frac{SSB_{y-1}}{SSB_{max}}e^{\frac{-SSB_{y-1}}{SSB_{max}}} \quad (27)$$

and Beverton–Holt model:

$$R_y = R_{max} \frac{SSB_{y-1}}{SSB_{y-1} + SSB_{50}} \quad (28)$$

Constant recruitment

$$R_y = R_{max} \quad (29)$$

As seen from the equations R_y refers to recruitment-at-age 1 that is the first age group used in the cod assessment. The model can use other age groups as first age.

R_{max} is always estimated and also the second parameter called SSB_{break}, SSB_{max} or SSB_{50}, depending on the function specified.

R_{max} is set so that it can change in 1985 by a value that can be estimated. The reason for this setup is the 30–40% reduction in recruitment of Icelandic cod around before and after 1985. This option can be turned off by specifying the change to be zero.

In the evaluations of Harvest Control Rule for Icelandic cod in 2009 a number of other SSB–Recruitment functions were investigated, some of which are found in the code. Emphasis has also been put on statistical properties of the residuals from the SSB–recruitment function as described below.

Likelihood function

In the random walk model the error in catch in numbers is split in two parts.

- Process error i.e. the error between this years and last year's fishing mortality.
- The measurement error i.e. the difference between observed and modelled catches.

The model cannot estimate standard deviation of the total error (process + measurement error) independently for each age group. The pattern standard deviation of the total error with is specified and a multiplier estimated. The pattern is obtained from a Shephard–Nicholson model. Estimating a smooth function of age described with 2–3 parameters is also a possibility but the estimation is sometimes unstable.

The split of the total error into process error and measurement error is specified in the input file. The number given specify the proportion of the variance for each age group assigned as process error. The split is 50–50 of for ages 6–8 which are the ages with the least total error. For older fish higher proportion is allocated to measurement error and for younger age groups higher proportion is allocated to process error.

Difference in $log(F)$ between adjacent years follows multivariate normal distribution with correlation between ages.

$$\Gamma_{a_1,a_2} = \sigma_{p,a_1} \tau^{\left|\frac{(a_1-2)^{0.3}-(a_2-2)^{0.3}}{2^{0.3}-1^{0.3}}\right|} \sigma_{p,a_2} \quad (30)$$

$\Gamma_{a_1,a_2} = 1$ when $a_1 = a_2$. Where σ_{p,a_1} is standard deviation of the process error of age a_1. τ is an estimated parameter in the model called process correlation there. Equation

30 leads to more correlation between adjacent old age groups than adjacent young age groups i.e. the relative difference in age matters.

Measurement error in catch-at-age

The error in the catch-at-age is assumed to be lognormal and hence the likelihood is calculated as:

$$L_C = \sum_y \sum_a \left\{ \frac{(log[C_{a,y}+\varepsilon_C] - log[\hat{C}_{a,y}+\varepsilon_C])^2}{2\sigma_{aC}^2} + log(\sigma_{aC}) \right\} \quad (31)$$

where ε_C is to reduce the effect of very small catches that are poorly sampled. Typical value of ε_c would be catches corresponding to 2–4 sampled otoliths. The standard deviations σ_{aC} are estimated as a multiplier on prespecified pattern. The pattern was generated from a Shephard–Nicholson model run based on the data from 1980–2008.

In the random walk model, σ_{aC} is generated from the total standard deviation and the split of the total variance between process and measurement error as described above.

Total landings

As described above catch in numbers-at-age is one component in the objective function to be minimized. This does in many cases guarantee that the modelled catch in tonnes is close to the landed catch but in some years this is not the case. In all cases one has:

$$Y_y = \sum_a C_{a,y} cW_{a,y} \quad (32)$$

$$\hat{Y}_y = \sum_a \hat{C}_{a,y} cW_{a,y} \quad (33)$$

To let the model follow the "real" landed catch the following term is added to the objective function.

$$L_Y = \sum_y \left[\frac{(log\, Y_y - log\, \hat{Y}_y)^2}{2\sigma_Y^2} + log\, \sigma_Y \right] \quad (34)$$

where σ_Y is input from a file and is typically rather low (≈ 0.05). The statistical properties of this term as an addition to catch-at-age are somewhat questionable, but this formulation has often been used in statistical catch-at-age models.

Survey at-age

The predicted survey index $\hat{I}_{ay}$ is calculated from:

$$\hat{I}_{a,y} = q_a N_{a,y}^{\beta_a} \quad (35)$$

where α_a and β_a are estimated parameters. For cod the β_a is set equal to 1 for age 6 and older. The error in the survey at-age is assumed to be lognormal and hence the likelihood is calculated as:

$$L_I = \sum_y \sum_a \left\{ \frac{\left(log[I_{a,y}+\varepsilon_I] - log[\hat{I}_{a,y}+\varepsilon_I]\right)^2}{2\sigma_{aI}^2} + log(\sigma_{aI}) \right\} \quad (36)$$

where ε_I is externally set to reduce the effect of very small survey indices based on few otoliths . Typical value of ε_I would be indices that correspond to 2–4 sampled otoliths. The standard deviations σ_{aI} are estimated by the model by giving the pattern, estimating a multiplier. The pattern is estimated in the Adapt type model, the only type of model that can estimate σ_{aI} independently for each age group.

Since correlation between indices of different age groups is modelled the equation is changes to:

$$\Gamma = log[I_{a,y} + \varepsilon_I] - log[\hat{I}_{a,y} + \varepsilon_I] \quad (37)$$

$$L_I = \sum_y \left\{0.5log(det\,\Theta_I \quad) + \Gamma^T \Theta_I^{-1} \Gamma\right\} \quad (38)$$

Where $Gamma$ is the vector of residuals and Θ the correlation matrix.

In the model runs conducted here the matrix Θ_I is generated by a 1st order AR model.

$$\Theta_{Iij} = \sigma_{Ii}\sigma_{Ij}\kappa^{|i-j|} \quad (39)$$

where κ is an estimated parameter which has been estimated in the range 0.2 to 0.7 for cod, haddock and saithe in the March groundfish survey. High value of κ indicates that the residuals in the survey approach a year factor. The estimate of the parameter for cod is 0.42 for the March survey and 0.53 for the autumn survey. The effect of modelling this correlation on estimated biomass varies from year to year but the effect is to take less notice of survey abundance indices.

In the random walk model the equation for Θ_I is similar to what is used to model the correlation in process error (equation 30).

$$\Theta_{Iij} = \sigma_{Ii}\sigma_{Ij}\kappa^{\left|\frac{i^{0.7}-j^{0.7}}{2^{0.7}-1^{0.7}}\right|} \quad (40)$$

Compared to equation 39 this equation increases the correlation between age groups of old fish compared to young fish, i.e. it is more the relative difference in age that matters.

Stock-recruitment likelihood function

This component involves discrepancy between observed and modelled recruitment. The model allows for autocorrelation in residuals and CV of residuals can be a function of spawning stock size. The likelihood is calculated by the equations.

$$\hat{N}_{1,y} = f(SSB_{y-1}) \quad (41)$$

$$\Gamma_{SSB-R} = log[N_{1,y}] - log[\hat{N}_{1,y}] \tag{42}$$

$$\sigma_{3y} = \sigma_3 \left(\frac{SSB_y}{SSB_{ref}}\right)^{\beta_3} \tag{43}$$

$$\Theta_{SSB-Rij} = \sigma_{3i}\sigma_{3j}\kappa_3^{|i-j|} \tag{44}$$

$$L_{SSB-R} = \sum_y \left\{0.5log\left(det\,\Theta_{SSB-R}\right) + \Gamma_{SSB-R}^T \Theta_{SSB-R}^{-1}\Gamma_{SSB-R}\right\} \tag{45}$$

σ_3 standard deviation of the residuals, κ_3 autocorrelation and β_3 dependence on SSB, usually not included.

The parameters σ_3, κ_3 and β_3 are all among parameters that can be estimated. Estimating them all in addition to the three parameters of the SSB–rec function requires a very long time-series. The SSB–rec function has three parameters due to the change in R_{max} observed in 1985. In the work here 3–4 parameters are estimated, 2–3 parameters of the SSB–rec function and the parameter σ_3. The parameters κ_3 and β_3 were set to low values in the estimation part but a fixed value of the autocorrelation parameter, estimated external to the model is used in stochastic simulations. Anyone trying to estimate parameters of a simple AR model from 50 years of data discovers that the estimate is very poor except the autocorrelation is small.

The choice of stock–recruitment function has minor effects on the results of stock assessment but is of course of importance in future simulations.

Estimated parameters

Estimated parameters in the random walk assessment model are

- Initial numbers in stock.
- Recruitment-at-age 1 each year.
- Parameters of the stock–recruitment function.
- Fishing mortality each year and age.
- q_a and β_a for the surveys. (equation 35)
- σ_c, σ_I and σ_3, i.e. multiplier on standard deviation of catch residuals, multiplier on standard deviation of survey residuals and multiplier on SSB–recruitment residuals.
- Correlation parameters κ in the survey likelihood and τ in the process error.

Estimated parameters in the separable model are

- Initial numbers in stock.
- Recruitment-at-age 1 each year.
- Parameters of the stock–recruitment function.
- Effort for each year.

- Selection pattern for each age and selection period.
- q_a and β_a for the surveys. (equation 35)
- σ_c, σ_I and σ_3, i.e. multiplier on standard deviation of catch residuals, multiplier on standard deviation of survey residuals and multiplier on SSB–recruitment residuals.
- Correlation parameters κ in the survey likelihood.

In the Adapt type model the estimated parameters are

- Number in stock in the assessment year.
- Parameters of the stock–recruitment function.
- q_a and β_a for the surveys. (equation 35)
- σ_I and σ_3, i.e. multiplier on standard deviation of catch residuals, multiplier on standard deviation of survey residuals and multiplier on SSB–recruitment residuals.
- Correlation parameters κ in the survey likelihood.

As described at the beginning the inverse Hessian matrix of the parameter estimates is used as a proposal distribution in MCMC runs. The number of runs was usually 1.0 million with the parameter set from every 500th run saved. Probability distribution of spawning stock, reference biomass and other parameters is obtained by printing the respective values to a file in each of the stochastic simulations.

The exact settings of the historical assessment model do affect the estimate of stock in the assessment year ($\pm 20\%$) but have less effect on the results of the long-term simulation where the stock–recruitment parameters have most effect. If the simulation were run in a closed loop with assessment model in the feedback loop those settings would have more effect, but to used it to infer about “correct” model settings would require a realistic observation model.

Short–term deterministic prediction

The prediction occurs in few steps.

1) Calculate mean weight and maturity-at-age from the March survey in the assessment year.

2) Estimate true reference biomass and spawning stock.

3) Calculate recruitment from SSB–Recruitment relationship.

4) Calculate the TAC for next fishing year from equation 1.

5) Calculate catch in the assessment year $C_y = \frac{2}{3} TAC_{y-1/y} + \frac{1}{3} TAC_{y/y+1}$.

6) Calculate selection-at-age, based on the average of last five years.

7) Calculate F_y for the assessment year by iterating the equations $F_{a,y} = F_y S_{a,y}$ and $\hat{C}_y = \sum_a \frac{F_{a,y}}{Z_{a,y}} (1 - e^{Z_{a,y}}) N_{a,y} cW_{a,y}$. The two equations are solved for F_y by Newton’s method until $C_y - \hat{C}_y = 0$.

8) Project the stock forward one year.

If projection for more than one year is to be done, the steps are repeated. What is then required are catch weight, SSB weights and maturity-at-age for those years. The default is to use the values for the assessment year.

Mean weight-at-age, maturity-at-age, recruitment, selection-at-age and maturity-at-age can be multiplied with stochastic noise.

The current model used in the annual stock assessment is **adcam**. The input is as follows:

	Type	Year.range	Age.range	Variable
1	Caton	1955 onwards		Yes
2	Canum	1955 onwards	3–14	Yes
3	Weca	1955 onwards	3–14	Yes
4	West	1955 onwards	3–10	Yes
5	Mprop	1955 onwards	1–14	No
6	Fprop	1955 onwards	1–14	No
7	Matprop	1955 onwards	1–14	Yes
8	Natmor	1955 onwards	1–14	No
9	Spring survey (SMB)	1985 onwards	1–10	Yes
10	Fall survey (SMH)	1996 onwards	1–10	Yes

Short-term projections

Short-term prediction for Icelandic cod is rather simple as the TAC next fishing year does depend on TAC in the current fishing year and biomass 4+ and SSB in the assessment year. Maturity-at-age, mean weight-at-age and mean weight-at-age in the SSB in the assessment year are all available at the time of assessment, the only missing values for the TAC are mean weight-at-age in the catches that are obtained from equations 2 and 3.

Biological reference points

		Type	Value	Technical.basis
1	Management plan	MP $B_{trigger}$	220 000	Set by managers, consistent with ICES MSY framework
2		Harvest rate MP	0.2	Set by managers, consistent with ICES MSY framework
3	MSY framework	MSY $B_{trigger}$	220 000	Trigger point in HCR considered consistent with ICES MSY framework
4		F_{MSY}	Not relevant	
5	Precautionary approach	B_{lim}	125 000	Bloss
6		B_{PA}	Not defined	
7		F_{lim}	Not defined	
8		F_{PA}	Not defined	

Table 1: Number of vessels used and the number of stations taken in the Spring Groundfish Survey 1985-2014.

Year	Number of vessels	Number of stations	Year	Number of vessels	Number of stations
1985	5	593	2000	4	532
1986	5	585	2001	4	532
1987	5	566	2002	4	526
1988	5	545	2003	4	536
1989	5	568	2004	4	538
1990	5	567	2005	5	550
1991	5	570	2006	5	555
1992	5	574	2007	5	548
1993	5	597	2008	5	566
1994	5	596	2009	5	595
1995	5	600	2010	5	594
1996	4	540	2011	5	595
1997	4	533	2012	5	597
1998	4	506	2013	5	594
1999	4	530	2014	4	591

Table 2: Vessels used in the Autumn Groundfish Survey 1996-2010, their survey areas, and the number of stations taken. The survey was not conducted in 2011.

	Shallow waters		Deep waters		
Year	Vessel name	Number of stations	Vessel name	Number of stations	Total stations
1996	r/v Bjarni Sæmundsson	146	Múlaberg ÓF32	144	290
1997	r/v Bjarni Sæmundsson	150	Brettingur NS50	149	299
1998	r/v Bjarni Sæmundsson	153	Brettingur NS50	144	297
1999	r/v Bjarni Sæmundsson	166	Brettingur NS50	149	315
2000	r/v Bjarni Sæmundsson	160	r/v Árni Friðriksson	219	382
2001	r/v Bjarni Sæmundsson	160	r/v Árni Friðriksson	219	380
2002	r/v Bjarni Sæmundsson	162	r/v Árni Friðriksson	221	383
2003	r/v Bjarni Sæmundsson	162	r/v Árni Friðriksson	220	382
2004	r/v Bjarni Sæmundsson	162	r/v Árni Friðriksson	220	382
2005	r/v Bjarni Sæmundsson	162	r/v Árni Friðriksson	219	381
2006	r/v Bjarni Sæmundsson	162	r/v Árni Friðriksson	219	381
2007	r/v Bjarni Sæmundsson	162	r/v Árni Friðriksson	219	381
2008	r/v Bjarni Sæmundsson	181	r/v Árni Friðriksson	219	400
2009	r/v Bjarni Sæmundsson	178	r/v Árni Friðriksson	219	397
2010	r/v Bjarni Sæmundsson	179	r/v Árni Friðriksson	203	382
2011	No survey conducted				
2012	r/v Bjarni Sæmundsson	178	r/v Árni Friðriksson	202	381
2013	r/v Bjarni Sæmundsson	179	r/v Árni Friðriksson	201	379
2014	Jón Vídalín VE-82	179	Ljósafell SU-70	201	380

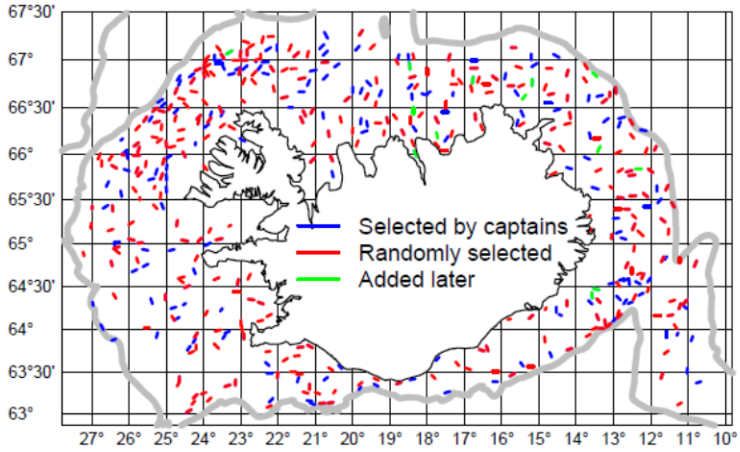

Figure 1: Stations in the spring survey. The picture shows the 1995 survey.

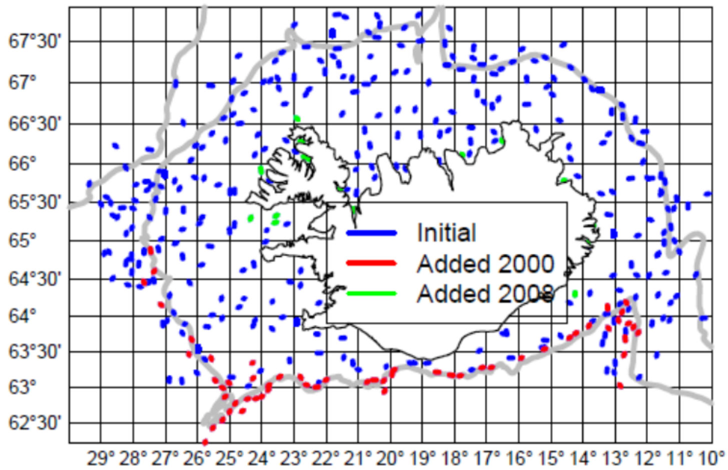

Figure 2: Stations in the autumn survey showing the 2013 survey.

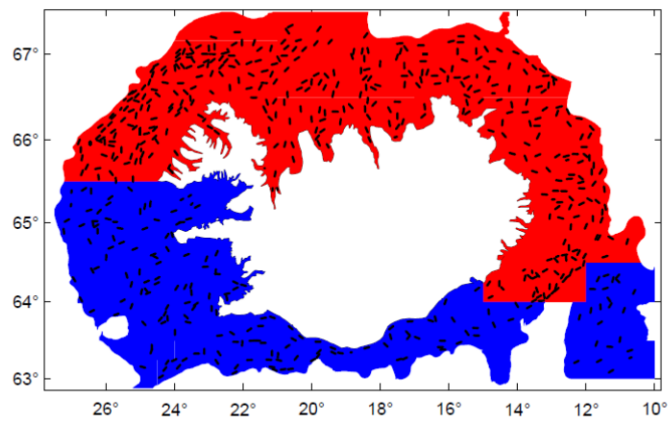

Figure 3: Division of the survey area into north and south. Stations from the March survey 2014 shown for comparison

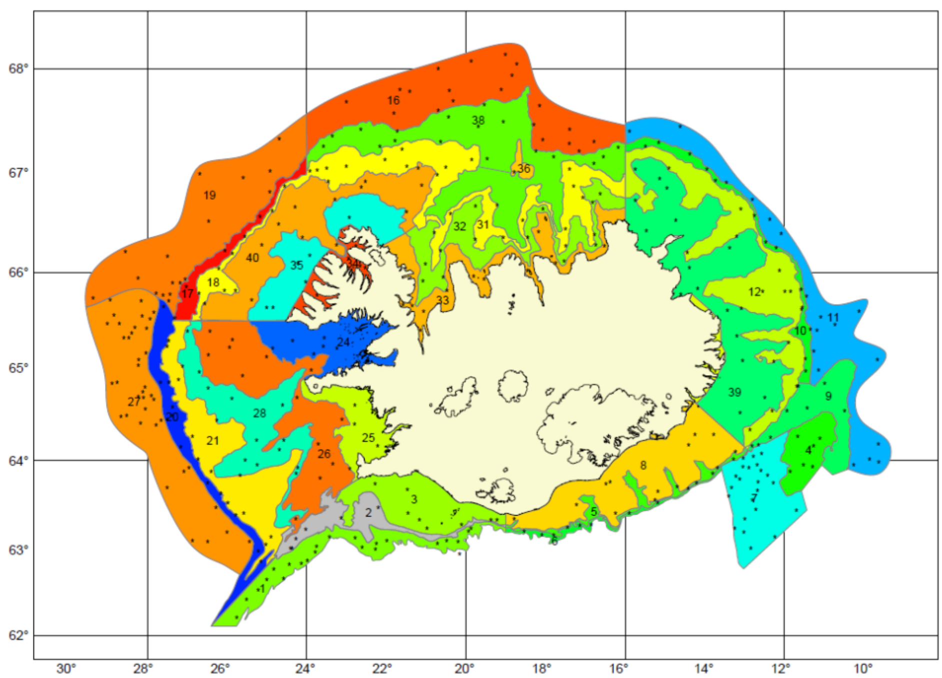

Figure 4: Sub-areas or stratas used for calculation of cod survey indices of the Autumn Survey in Icelandic waters. The dots show the stations

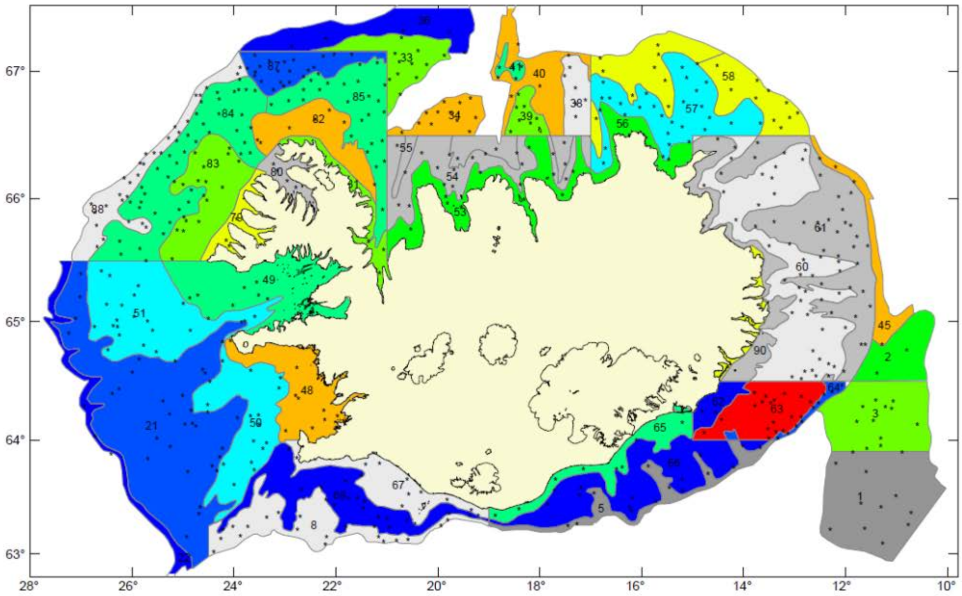

Figure 5: The old stratification that is used to calculate survey indices of cod in spring survey. The dots show the stations

Annex 7: Stock Annex for the capelin stock in the Iceland–East Greenland–Jan Mayen area

Stock	The capelin stock in the Iceland-East Greenland-Jan Mayen area
Working Group	NWWG
Date	January 2015
Revised by	WKICE 2015

A. General

A.1. Stock definition

The capelin is a small pelagic schooling fish. It is a cold-water species that inhabits arctic and subarctic waters in the North Atlantic and North Pacific. Capelin in the Iceland-East Greenland-Jan Mayen area is considered to be a separate stock.

A.2. Fishery

In the mid-1960s purse-seine fishery began on capelin. It soon became a large-scale fishery. During its first eight years, the fishery was conducted in February and March on schools of prespawning fish on or close to the spawning grounds south and west of Iceland. In January 1973 a successful capelin fishery began in deep waters near the shelf break east of Iceland. In 1976 a summer capelin fishery began in the Iceland Sea. This fishery became multinational with vessels from Iceland, Norway, Faroes, and Denmark. In mid 1990s the pelagic trawl was introduced to the capelin fishery. Fishery during winter (January–March) has taken place in all years, with the exception of 1982/1983 and 2008/2009 fishing seasons, when a moratorium was in effect. Until late 1980s the fishery in October–December was much more pronounced than the fishery in June–September, whereas it was the opposite in the 1990s. During the 1990s the fishery in autumn was at low levels and practically no autumn fishery has taken place since 2000. Since the mid-2000s, the summer fishery has only taken place twice and then at a low level.

The fishing season has extended from end of June to March the following year since the mid-1990s. However, when stock size has been estimated to be low the fishing season has started later, or after a survey in October/November, or in January/February after a winter survey.

A regulation calling for immediate, temporary area closures when a high abundance of juveniles is measured in the catch (more than 20% of the catch composed of fish less than 13 cm) is enforced, using on-board observers. In Icelandic waters, fishing with pelagic trawl is only allowed in a limited area off the NE-coast (fishing in January). The area where pelagic trawling is allowed is regulated due to the risk of juvenile bycatch in addition to concerns about mortality and behaviour disturbance associated with capelin passing through the trawl. The use of pelagic trawls in the fishery varies depending on a combination of factors, among them the timing of TAC issuance.

Areas with high abundances of juvenile age 1 and 2 capelin (on the shelf region off NW-, N- and NE-Iceland) have usually been closed to the summer and autumn fishery.

It is permissible to transfer catches from the purse-seine of one vessel to another vessel, in order to avoid slippage. However, if the catches are beyond the carrying capacity of the vessel and no other vessel is nearby, slippage is allowed. In recent years, reporting of such slippage has not been frequent in the logbooks. Industrial trawlers do not have permission to slip capelin, in order to align catch rates to the processing capacity.

In recent years, the fishery has changed from being mostly an industrial fishery to having increased emphasis on fishing for human consumption, especially when abundance and TACs have been low.

The timing and selection of the fishery that leads to the maximum yield (MSY) has not been estimated for IGJM capelin. In the Barents Sea, it has been suggested that MSY from the capelin fishery would be obtained by fishing in autumn; however, a later opening of the fisheries (January 1st) would preserve more capelin for the predators (Hamre and Tjelmeland, 1982; Gjösæter *et al.*, 2002).

Research on the ecosystem role and growth of IGJM capelin is much more limited than in the Barents Sea but the ecosystem role of capelin is likely to be similar in both areas.

A.3. Ecosystem aspects

A.3.1. Spatio-temporal distribution (spawning, nursery, feeding)

IGJM capelin are demersal spawners that deposit their eggs on fine gravel at 10–150 m depth (Vilhjálmsson, 1994). The main spawning areas are off the southeast, south and west coast of Iceland (Figure A.3.1). Other spawning areas, such as off the north coast, are of less importance. Spawning peaks in March in the main spawning areas but somewhat later (April) elsewhere. The larvae hatch after approximately three weeks and drift toward the nursery areas.

Most juveniles are found on or close to the continental shelf. Until early 2000s, the nursery areas were located northwest, north and northeast of Iceland, and on the East Greenland plateau, west of the Denmark Strait. Since the early 2000s, the nursery areas have expanded to colder waters near east Greenland, however, juveniles are still found in the western part of their old nursery area in Icelandic waters.

Maturing capelin usually undertakes extensive migrations in spring and summer to the feeding areas north of the nursery areas. The summer–autumn distribution of the maturing stock has, like that of the juveniles, shifted west since the early 2000s. Southern return migration in September–October leads the adults to the shelf edge off the northwest Iceland where they are found in November. They are also found north and northeast of Iceland in some years.

The southward spawning migration starts in December/January. The migration routes follow the shelf break off the east coast and on entering the mixed waters off the southeast coast, they move into shallow waters and follow the coast westwards on their spawning migration. The main spawning migration usually reaches the west coast and spawns there, while late arrivals spawn further east at the southeast and south coast. Only a small proportion survives spawning (Carscadden and Vilhjálmsson, 2002).

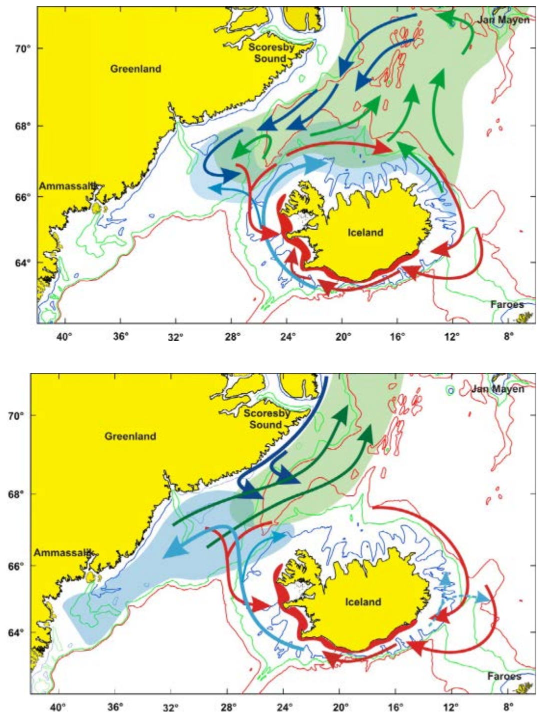

Figure A.3.1. Distribution and migration of IGJM capelin. Historical until early 2000s (top) and since early 2000s (below). Red areas: spawning grounds. Blue areas: Nursery areas. Green area: Feeding area for the maturing capelin. Green arrows indicate the adult feeding migrations, blue arrows indicate return migration from feeding areas to overwintering areas, and red arrows indicate the spawning migrations (From Carscadden *et al.*, 2013).

The observed shift in distribution and migration patterns in the early 2000s took place during a period of environmental changes observed since the mid-1990s. Temperature and salinity have increased during that period southwest of Iceland, with a temperature increase of one degree or more (Figure A.3.2). Temperature and salinity have been about or above the mean during the last two decades, except for the most recent years that were slightly colder (Hafro, 2014).

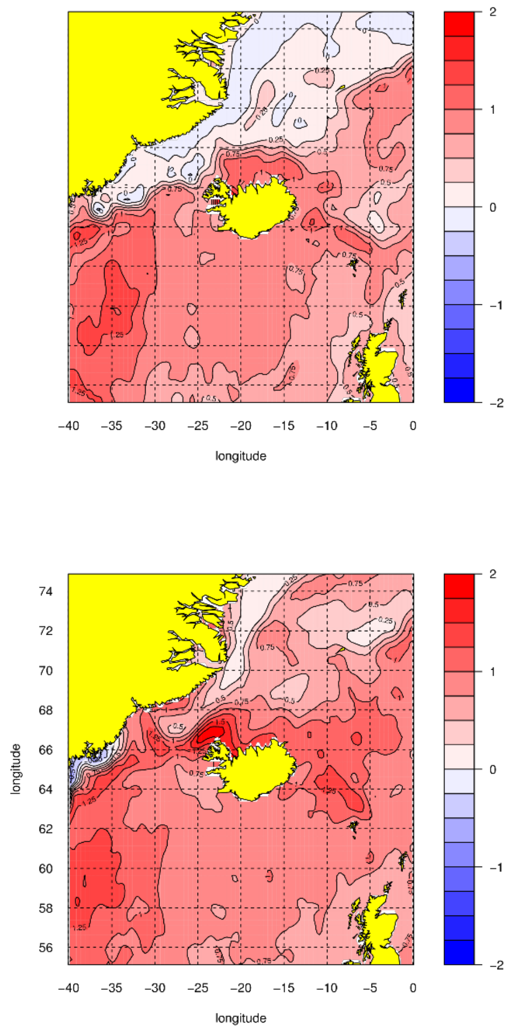

Figure A.3.2. Difference between Reynolds Optimum Interpolation Sea Surface Temperature in 1982–1999 and 2000–2014, in January (top) and October (bottom) in the IGJM habitat. (Reynolds, 2007, data from ftp://eclipse.ncdc.noaa.gov/pub/OI-daily-v2/ in December 2014 and January 2015).

A.3.2. Fecundity

Capelin reaches maturity-at-age 2–4. The main part of each year class matures and spawns at age 3 (Figure A.3.1). The remainder of the year class spawns at age 4. On occasion a small contribution to the SSB from age group 2 has been observed but only negligible from age group 5. Spawning mortality is believed to be very high.

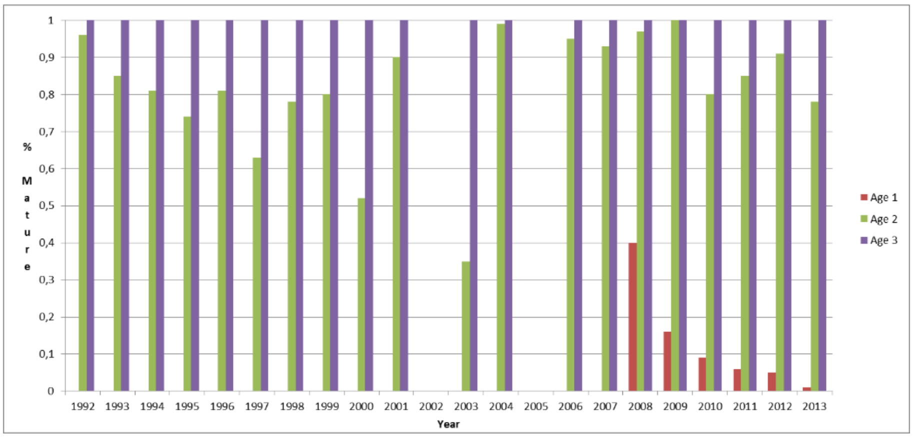

Figure A.3.1. Time-series of maturity ogives for capelin age classes 1, 2 and 3 (on autumn surveys).

A.3.3. Diet

Capelin is a planktivore that mainly eat copepods, euphausiids and amphipods (see overview in Vilhjálmsson, 1994; Gjøsæter, 1998; Carscadden *et al*., 2001). Generally, the importance of copepods decreases with capelin size and that of euphausiids and amphipods increases. On the feeding grounds north of Iceland, euphausiids were estimated to constitute between 74% and 90% of the capelin diet (in weight) (Vilhjálmsson, 1994; Trenkel *et al*., 2014). The main copepod species eaten by small larval and juvenile capelin is *Calanus finmarchicus*, *Oithona* spp, *Temora* spp, *Acartia* spp, *Oncaea borealis* and *Pseudocalanus elongatus*. The importance of each species differs according to areas and size of the capelin. Later in the season there is a shift from smaller to larger food items. *C. finmarchicus*, *C. hyperboreus* and euphausids (mainly *Thysanoessa inermis*) become increasingly important in the stomachs of larger capelin.

A.3.4. Predators

Capelin is a very important forage species in the ecosystems of Greenland and Iceland. They are the main single item in the diet of Icelandic cod. They are prey to several species of marine mammals and seabirds and are also important as food for several other commercial fish species (Vilhjálmsson, 2002).

B. Data

B.1. Commercial catch

The stock is shared between Iceland, Norway and Greenland according to a management plan agreed by the parties in 2003. The Faroe Islands participates in the fishery through an annual bilateral agreement with Iceland and the EU participates in the fishery through an annual bilateral agreement with Greenland. The vast majority of catches are landed at Icelandic harbours; however in some year capelin might also be landed in Norwegian or EU harbours.

B1.1. Landings

Information about landings in the fishery is collected by the Icelandic Directorate of Fisheries which has access to both landing figures in the Icelandic ports (the official landing) and the recorded catch in the digital logbook kept by all Icelandic vessels. The logbooks contain information about timing (day and time), location (latitude and longitude), fishing gear, duration (minutes), catch size, and species composition in the catch of each fishing operation for each vessel.

B1.2. Discards

The Icelandic legislation allows for slipping in those cases where the catches are beyond the carrying capacity of the vessel and none nearby vessels are able to take the surplus quantity on board. The practice of transferring catches from the purse-seine of one vessel to another vessel is a long-standing tradition, and since skippers of purse-seine vessels generally operate in groups due to the behaviour of the fish, discards are practically zero. In the pelagic trawl fishery, such large catches of capelin rarely occur.

B.2. Biological information

Biological samples from the catch are taken at sea by the fishermen, in the ports by the Marine Research Institute in Iceland (MRI) or inspectors from the Icelandic Directorate of Fisheries. The samples are analysed at MRI (fish length, weight, age (from otoliths), sex, maturation, and gonad weight). The information from the samples are then used along with the total landing data and the logbook data to estimate the age and length composition and numbers of fish by age of the total landings. Similar programmes are conducted by other participants in the fishery to a varying extent, sometimes providing catches in numbers; e.g. IMR Norway.

For biological data on survey, see B3.2.

B.3. Surveys

Acoustic surveys have been conducted in late autumn (October–December) in 1978–2009, in early autumn (September–October) since 2010 and in winter (January–February) since 1979.

The surveys in autumn have a dual purpose, aimed at covering both the immature and the mature part of the stock. Until 2010 the survey covered the shelf west, north and northeast of Iceland. Since 2010, it has been expanded to cover the shift in capelin distribution on the continental shelf of East Greenland (to 73°N in 2013), the Denmark Strait and the continental slope north off Iceland. The survey area varies and has often been influenced by drift ice conditions in the Denmark Strait-East Greenland-NW Iceland area. The surveys were therefore shifted forward since 2010 (starting soon after the middle of September; an exception occurred in autumn 2011 when the survey was postponed because of a strike). The shift in timing and spatial coverage from 2010 therefore, to some extent, initiated a new time-series. The indices of immature capelin are used to predict an expected catch for the fishing season starting in the year after the surveys are conducted. The estimate of the maturing stock is used to set an intermediate TAC, sometimes revising an already set initial TAC.

The winter surveys in January–March target the spawning migration. The main survey area is along the spawning migration route off NE-, E- and S-Iceland as well as off W- and NW Iceland in late February–early March. The purpose of these surveys is to assess the size of the spawning stock and on its basis to set a final TAC for the rest of the season. The stock, or parts of it, has often been covered repeatedly (up to four times e.g. in 2008 and 2009) in the area along the shelf break N and E of Iceland. Sometimes the surveys are continued onto the shelf in shallow areas, however data from those areas are not used for assessment purposes due to lack of knowledge of target strength (TS) in shallow waters, and the acoustic dead-zones near the bottom and surface as well as uncovered shallow areas where the vessel cannot navigate safely.

The acoustic surveys have often been complemented with scouting surveys by commercial vessels. In 2009 calibrated commercial vessels measured the stock in the area off NE-Iceland. Furthermore, the 2011 winter estimate of SSB was based in part on data from a commercial vessel (but in the nearshore area and therefore not covered here, see above).

B.3.1. Acoustic data

The two-dimensional distribution of backscattering energy is measured in Nautical Area Scattering Coefficient (NASC) or sA (Maclennan, Fernandes and Dalen, 2002). Along track registrations are generally averaged over the so called elementary distance sampling unit (EDSU). The EDSU size was 1 nmi in the years up to 2010 where the BI500 post-processing software was used. Since 2011 LSSS has been used with an EDSU of 0.1 nmi, except for a few cases where the EchoView has been applied on 0.2 nmi EDSUs.

The average NASC in each 'rectangle' in a grid covering the surveyed area are calculated. The rectangles used for the winter surveys measure 15′ latitude by 30′ longitude (quarter of an ICES statistical rectangle). In autumn they measure 30′ latitude by 1° longitude due to the wider distribution of the stock in autumn, and to avoid autocorrelation in NASC averages for the smaller rectangles. The Echo Abundance (EA) of a rectangle equals the product of mean NASC and the area of the rectangle. The EA of partly covered rectangles are reduced (from sailed distance or judgment of survey experts, depending on the situation).

During the survey, biological samples are collected from trawl catches on stations targeted on IGJM capelin generally numbering 100 individuals. All fish are aged and maturity staged, and in the estimation process described below, empirical values are used throughout. Maturity staging has been uncertain on a few occasions and knife edge maturity at a given length has been assumed.

B.3.2. Bootstrap treatment of survey data

The HCR bootstrap replicates use the survey estimates of SSB and the number of immature capelin. A stratified bootstrap of echo abundance by rectangle, trawl station and fish in samples has been performed, which might be simplified by omitting the resampling the fish samples. A short description of the method is given below:

Simple bootstrap: By simple we mean unstratified, which may or may not be an adequate approach. Rectangle EA values and trawl stations are bootstrapped in parallel and are assumed independent of each other. Further, for each bootstrap realization of a trawl station the individual fish on the station are bootstrapped as well, an approach similar to that taken in studies of sampling levels from landings and surveys and their effects on assessment results. For each bootstrap sample of EA values, trawl stations and fish in sample, an SSB and other stock parameters of interest are estimated.

Stratified boostrap: In order to capture structure that may be present in the capelin population/distribution, stratification is introduced. We implement a post-stratification based mainly on the proportion mature. This choice is made because the split between SSB and the immature part of the stock is of primary interest, generally in autumn and can also be important in parts of the distribution area in winter. For each area we generate bootstrap replicates in the same way as for the whole as described above. Necessary components from the defined strata are then combined in order to produce overall parameters of interest, primarily SSB and number of immature capelin in autumn.

B.4. Commercial cpue

Data on a haul by haul basis are available from logbooks. However cpue is not used in the assessment as it is not considered a reliable indicator of stock size due to among other things the schooling behaviour of the species.

B.5. Other relevant data

Projected predator (cod, haddock and saithe) stock sizes from (Hafró/NWWG) assessments, predator distributions from Icelandic Groundfish Survey (IGFS) data.

Surveying outside the main survey periods has been undertaken through the years:

B.5.1. Surveys in summer

Surveys on 0-group and 1-group in August discontinued in 2003 (ICES 2009a). The survey was aimed at 0-group fish in general and had been conducted since the early 1970s. The indices for young capelin were used in a model to predict quota for the next fishing season. The results from the model were too optimistic and in the early 1990s the model was dismissed.

B.5.2. Oceanography/ecology surveys

In July 2006 a multidisciplinary project began (oceanography/ecology) covering the area from Ammassalik in the west to about 10°W east of Iceland as well as the Iceland Sea north to 71–72°N. One of the main purposes of this project is to study the distribution, behaviour and feeding habits of all age groups of capelin in spring and summer.

C. Assessment: data and method

WKICE endorsed using 150 kt as B_{lim} (never before set for this stock). B_{lim} was set at B_{loss} as the recruitments that were generated by SSB around B_{loss} (yc 90,81 and 82) were of average strength and the S–R diagram showed that recruitment did not decline at the lowest observed stock sizes.

WKICE adopted the stochastic HCR described below. This HCR was adapted from the one for Barents Sea capelin. A new method for setting an initial/preliminary quota was also developed during the benchmark meeting.

The application of the new HCRs following acoustic assessment surveys are given below:

Following acoustic survey in winter (January–February)

Bootstrap replications of survey estimates of SSB are used in combination with predicted predator stocks from NWWG assessments in the previous year (cod, haddock, saithe). Predator distributions are sampled from observed distributions in the March survey and fed into a predation model run with varying catches until spawning in late March. The **Final TAC** is set at catch giving $p(SSB < B_{lim} = 150 \text{ kt}) < 0.05$.

Following acoustic survey in autumn (September–October)

a) For the mature/maturing part of the stock (for the current season)

Bootstrap replicates of survey estimates of SSB are updated based on revised assumptions about growth, mortality, etc. Additional uncertainty is included due to variable mortality and fed into the predation model with same supporting data as when applied to winter survey results. The **Intermediate TAC** is set at catch giving p(SSB $<B_{lim}$ = 150 kt) <0.05.

b) Based on estimates for the immature part of the stock (for the next fishing season)

Numbers of immature capelin in autumn ($U_{trigger}$) are input to a simple model estimating catch based on point estimates and assumed mortality, growth and CV in estimated numbers. The trigger is set at 50 billion and cap on a preliminary TAC at 400 kt.

New survey results can overwrite previous TACs. The final TAC will take account of both the autumn and winter surveys, down-weighting autumn results. Discrepancies (such as later surveys indicating lower stock) will be addressed on an as needed basis in the application of the new HCR suite.

The model

The assessment method is similar to the one used in the Barents Sea; i.e. stochastic projection of the stock starting from acoustic measurements, and finding the TAC that leads to SSB $<B_{lim}$ = 5%. The uncertainty in the acoustic measurements is estimated by bootstrapping (see B.3). The bootstrap returns 10 000 stochastic replicates, each of which is run through the stochastic predation model (see A.3.4).

Predation model

Processes being addressed by the model

Capelin spend most of their life in the cold water north and east of the Iceland and between Greenland and Iceland but the main spawning areas are south and west of Iceland where the capelin spawn in March. The traditional migration route to the spawning grounds is deep east of Iceland and west along the south coast. During their migration to the spawning areas capelin often stop for some time near the boundary between the warm and cold water southeast of Iceland, until the roes/gonads have matured enough to enter the warm sea and start the final trip to the spawning areas. This final trip seems to take relatively short time (three weeks) and the distance covered is 120–350 nautical miles depending on where the capelin spawn. Cod, which is the most important predator of capelin also spawns south of Iceland, migrating both the western and eastern route to the spawning areas. Immature cod is more stationary. Other predators included in the model are haddock and saithe.

As can be seen above things are changing rapidly in the period January–March with large proportion of the fishes migrating towards the spawning areas south and west of Iceland.

Data used in the model

Available data on interactions between capelin and its main predators in the period January–March are:

- Acoustic measurements of capelin in January–February.
- Landings of capelin by day 1982–2014.

- Location of catches in 1993–2014 and by statistical squares in 1982–1993.
- Spatial distribution of demersal fishes from the groundfish survey in March 1985–2014.
- Stomach samples of cod from the groundfish survey in March 1985–2014 and from haddock 1992 and 2005–2014 and from number of other demersal fishes in 1992.
- Stomach samples collected from demersal trawl contemporary with the acoustic surveys in January 1993 and 1994.
- Stomach samples from fishing vessels since 2002.

Assumptions on spatial and temporal overlap between capelin and its predators

The proportion of fish predators inhabiting the different areas along the capelin migration route is obtained from the groundfish survey in March. There may be some change in distribution from January to March as some of the mature fish may migrate to the spawning areas so the distribution in March may be underestimating the proportion of cod and other predators east of Iceland. The area crossed and time spent in it by the eastern capelin migration is divided into three parts (Figure C.1).

- Eastern Area: six weeks (January 15th–March 1st).
- Southern Area: six weeks (February 1st–March 15th)
- Western Area: four weeks (February 15th–March 15th).

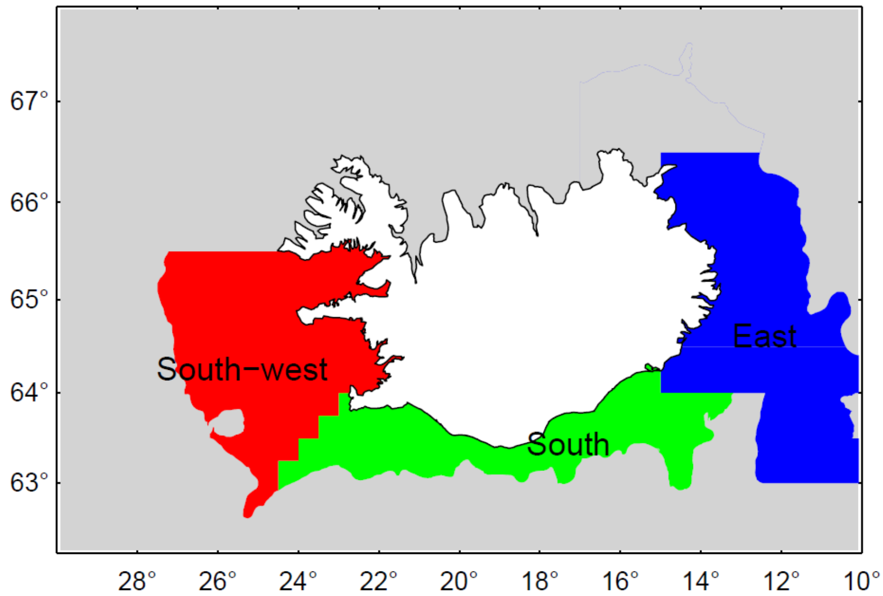

Figure C.1. The three regions used in the simulations of predation on capelin migrating through the eastern part of the Icelandic shelf.

The predators in each area are assumed to be able to prey on capelin in the time periods specified above. Proportion of the survey biomass index in each of the areas is calculated for each predator and is used as a measure of the proportion of the predator in that area. This proportion is then multiplied by total biomass of the predator from the assessment giving an estimate of the total predator biomass in the area. In the March survey the measurement error is highest for saithe which also has the largest variability of the survey distribution and therefore biomass. Cod is however by far the most important predator of capelin of the three species included in the model.

Predation mortality

Feeding is modelled using the type II feeding function below:

$$C_{pred,area} = B_{pred,area} \frac{C_{max,pred,T}\ B_{prey}}{B_{half} + B_{prey,area}}$$

The equation above is a special case for one prey, and is taken as a good approximation for predation on capelin in January–March when capelin is the dominating prey in the area.

Here *B* refers to biomass and *C* to consumption. $C_{max,pred,T}$ is called maximum consumption, theoretically the amount that the predator will eat if it is fed to satiation. Values for cod in fish farming are obtained from an equation from Jobling (1988) that indicates that capelin eat over 50% of their body weight at a temperature around three degrees, typical for the eastern area, increasing by approximately 10% for every degree. This value is unrealistic for wild populations as the prey will always be difficult to access compared to fish in captivity. B_{half} is called half feeding value and is the value where the predator eats half the maximum $C_{max,pred,T}$. B_{half} depends on the spatial overlap between predator and prey and is in each case also dependent on the spatial disaggregation used.

Setting appropriate values for the parameters $C_{max,pred,T}$ and B_{half} is not straightforward. Here the values are based on available stomach samples (see above) and consumption is based on the evacuation rate model by Magnusson and Palsson (1989). In the tables below the range of the parameters (maximum consumption and half feeding values) used in the simulations is presented:

PREDATOR	MAXIMUM CONSUMPTION (CMAX,PRED,T)
Cod	20–40% of body weight per month
Haddock	5–20% of body weight per month
Saithe	20–40% of body weight per month

AREA	HALF FEEDING VALUES (BHALF)
Eastern area	300–600 thous. Tonnes
Southern area	100–200 thous. Tonnes
Western area	100–200 thous. Tonnes

Half feeding values in the southern and western areas are lower than in the eastern area, due to smaller area inhabited by capelin in the south. The capelin are also more easily captured by demersal predators when it approaches spawning areas. The above range of values are supposed to cover interannual variability as well as uncertainty in the parameters but the overlap of capelin and cod varies from year to year, depending on the exact time of overlap and distribution of cod and capelin within the areas.

As discussed above the parameters in the feeding function are dependent on the spatial disaggregation used, the exact timing of the migrations and the spatial distribution of the predators within the areas. Variability of the parameters is obtained by randomly selecting the predation parameters in the feeding function from a uniform distribution.

Timing and location of catches

In many years relatively large proportion of the capelin stock is caught, reducing the amount of capelin available for predators. Normally the main bulk of the catches is taken from February 1st to March 15th. In the period 1993–2013 average landings per year were 68 kt in January, 240 kt in February and 162 kt in March. Additionally 75% of the landings are taken after February 10th (60% from February 10th to March 10th). Majority of the catch in the winter season after the January acoustic measurements is taken in the southern and southwestern area (Figure 4) or 65% and 25% respectively.

Bootstrap model

Acoustic measurements in January are the main indicator of capelin stock size. Results from them are given as bootstrap replicates where each bootstrap replicate is treated as if it represents the true capelin stock (see B.3).

Each bootstrap replicate is then run through a predation model as outlined above. Some of the parameters in the predation model are stochastic and are selected randomly in each run.

- The final capelin advice is given in January so the spatial distribution of predator stocks in the advisory year is not available. Therefore the spatial distribution of the predator stocks (cod, haddock and saithe) is set by randomly selecting proportions for each of the three areas in the March survey since 1985.
- The stock size of the predator stocks is based on the prediction from last year´s advice. Bootstrap replicates are generated by assuming the uncertainty in stock size is lognormal with a CV of 0.15 for cod and haddock but 0.2 for saithe. The biomass in each area is the total stock size multiplied by the proportions from the survey.
- Maximum consumption ($C_{max,pred,T}$) and half feeding (B_{half}) values are from a uniform random distribution as described above.

Predation per area is calculated independently for the three areas: east, south and southwest. In the model 10% of the catches are assumed to be taken in the eastern area between 15 January and 1 February, 65% of the catches in the southern area between 1 February and 15 March, and the remaining 25% in the southwestern area between 15 February and15 March.

Order of calculations in the predation model

The model starts with all capelin being in the eastern area on 15 January and ends with all capelin in the southern and southwestern area on 15 March where they spawn. The length of each time-step is two weeks; i.e. four time-steps. An example of the output from the model is shown in Figure C.2.

Area	Period	Catches	Consumption	Migration
East	six Weeks	10%		
	15 January–1 February	Subtract 10% of the catches from the stock	Calculate consumption for two weeks and subtract it from the capelin stock.	45% of the stock migrates to the southern area.
	1 February–15 February		Calculate consumption for two weeks and subtract that consumption from the capelin stock.	60% of the stock migrates to the southern area.
	15 February–1 March		Calculate consumption for two weeks and subtract that consumption from the capelin stock.	The remaining stocks migrates to the southern area
South	six weeks	65%		
	1 February–15 February	Subtract 23.4% of the catches from the stock	Calculate consumption for two weeks and subtract that consumption from the capelin stock.	The remaining stock migrates to the southwestern area
	15 February–1 March	Subtract 33.3% of the catches from the stock	Calculate consumption for two weeks and subtract that consumption from the capelin stock.	The remaining stock migrates to the southwestern area
	1 March–15 March	Subtract 8.3% of the catches from the stock	Calculate consumption for two weeks and subtract that consumption from the capelin stock.	The remaining stock spawns in the area
Southwest	four weeks	25%		
	15 February–1 March	Subtract 12.5% of the catches from the stock	Calculate consumption for two weeks and subtract that consumption from the capelin stock.	
	1 March–15 March	Subtract 12.5% of the catches from the stock	Calculate consumption for two weeks and subtract that consumption from the capelin stock.	The remaining stock spawns in the area

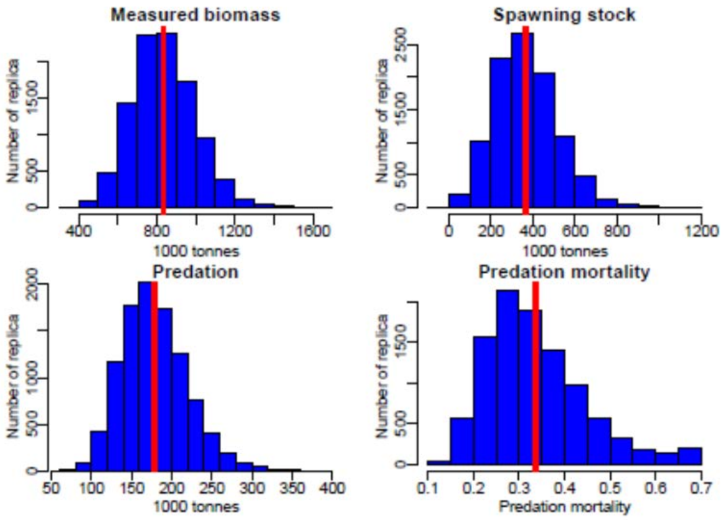

Figure C.2. Summary of results when advice is based on the autumn survey 2012 and the second January survey 2013 (taken from WD 13).

Setting an initial TAC

The proposed management scheme for IGJM-capelin is based on leaving more than 150 thous. tonnes for spawning with more than 95% probability. The basis of assessment is acoustic measurements in January with uncertainty added by bootstrapping. Stochastic predation in January–March is then added, based on the predicted abundance of predators in the assessment/advisory year. Average predation from January–March is estimated to be about 150 kt with a standard deviation of 50 kt. That standard deviation is much lower than standard deviation in the acoustic measurements (100–300 kt) and can therefore be ignored as those sources of uncertainty are assumed to be uncorrelated and the variances are therefore additive, leading to the larger standard deviation being dominant.

Acoustic estimates of the spawning stock with associated uncertainty are available since 1999 but for earlier years the average CV for the years 1999–2014 is used. In many of those years some catches are taken before the final acoustic measurement. Those catches are added to the acoustic estimate of mature stock and also to the lower fifth percentile of the acoustic estimate as the catches are assumed to be without error. All catches before January are scaled down by natural mortality in three months (0.315) i.e. like all that catch was taken in the autumn.

Adding the catches to the measured stock in January gives average and fifth percentiles of the fishable stock in January i.e. a proxy for what would have been measured if no fishery had taken place. Subtracting the average predation of capelin from 15 January to 15 March (150 kt) and B_{lim} (150) from the fifth percentile of the fishable stock will give the estimated advice each year.

The immature part of the capelin stock has been measured in the October survey since 1980. The measurements in 2002–2005 and 2007–2009 are not considered valid as the survey only located part of the immature portion of the stock.

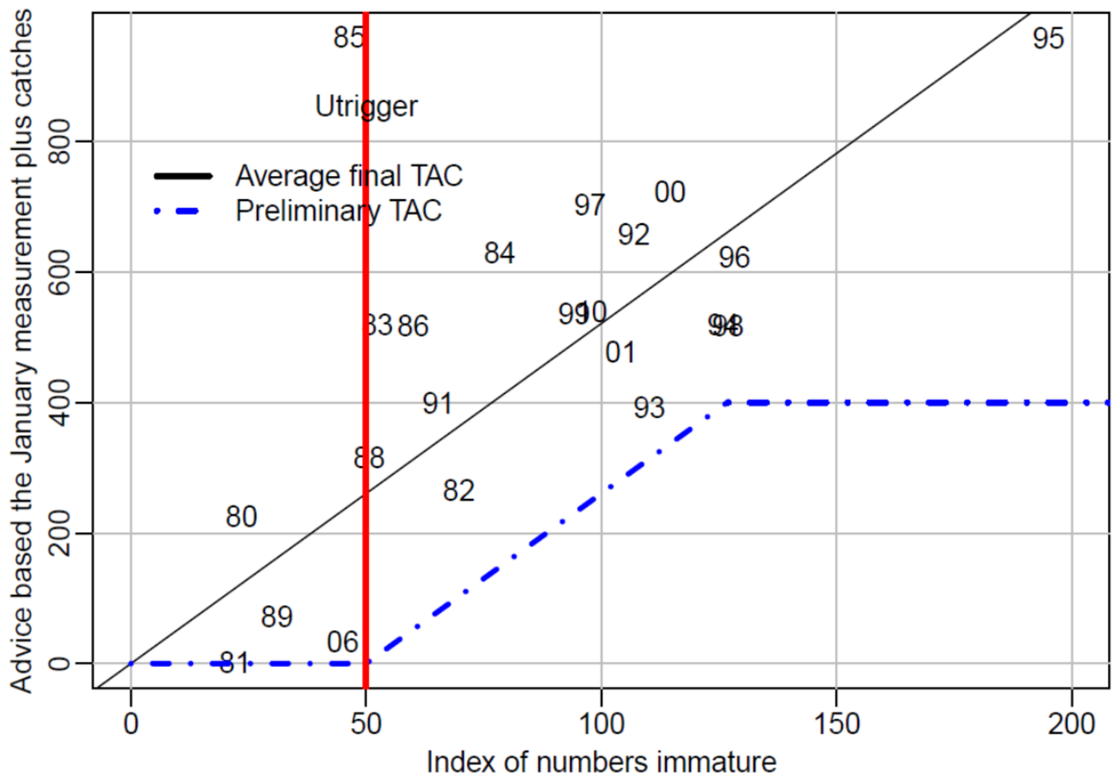

Figure C.3. Estimated final advice according to the proposed stochastic HCR against the measured number of immature capelin ~15 months earlier. The lines indicate the final TAC (unbroken) and the preliminary TAC (broken) when it is set using a $U_{trigger}$ (red vertical line) of 50 billion immature fish and a cap on the initial TAC of 400 kt.

The resulting advice is plotted in Figure C.3 against the measured number of immature capelin ~15 months earlier. The most apparent outlier is 1985. This is related to the part of the 1983 year class that spawned at age 4 but apparently did not show up in the acoustic measurement of immature capelin in 1985. Skipping this measurement leads to the regression line shown in the figure. The line is constrained to go through the origin (but if intercept was also fitted the line would intersect the y-axis at 50 kt). In one year (1981) the advice according to this equation would have been negative or -138 kt but was changed to zero here.

An index of immature numbers less than 50 billion will often mean very low final advice, so it is reasonable to set $U_{trigger}$ at 50 billion. The estimated slope of the regression line is 5.2. A preliminary TAC can be set using a line parallel with the fitted line crossing the x-axis at $U_{trigger}$ over most of the range of observations. A cap on the preliminary quota at 400 kt is prudent, since higher preliminary TACs would be the result of extrapolating beyond the main cluster of observations.

The proposal for the initial TAC is

- TAC = 5.2x(U_{imm}–$U_{trigger}$) kt for U_{imm} in the range 50–127 billion.
- TAC = 0 if U_{imm} <50 billion.
- TAC = 400 kt if Uimm >127 billion.

Capelin is a very important forage species in the ecosystems of Greenland and Iceland, playing a similar role as in the Barents Sea. For the Barents Sea ecosystem, it has been estimated that the maximum sustainable yield from its capelin fishery would be obtained by fishing in autumn, but that delaying opening of the fisheries until 1 January would be beneficial for the ecosystem (Hamre and Tjelmeland, 1982; Gjösæter *et al*., 2002).

Research on the ecosystem role and growth of IGJM-capelin is much more limited than in the Barents Sea but lack of data is generally not a sufficient reason to justify lack of action. A plausible null hypothesis is that the ecosystem role of capelin is similar in both areas. Therefore the initial TAC should not be of much importance as new measurement of the fishable stock would be available before the start of the fisheries. Initial TAC could still be beneficial for the industry to know how much to expect.

G. Biological reference points

	Type	Value	Technical basis
MSY	MSY $B_{trigger}$	xxx t	Not calculated
Approach	F_{MSY}	Xxx	Not calculated
	B_{lim}	150 000 t	B_{loss}
Precautionary	B_{PA}	xxx t	Not calculated
Approach	F_{lim}	Xxx	Not calculated
	F_{PA}	Xxx	Not calculated

H. Other issues

I. References

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Annex 8: Working documents

The following 19 working documents were presented to WKICE.

WD01: Combined VPA data for Cod in East Greenland and NAFO Division 1 in the period 1973–1995 and 2005–2013. Anja Retzel.

WD02: Management Units of the Greenland Offshore Cod. Anja Retzel.

WD03: The DLS Approach on Greenland Offshore Cod Stocks. Anja Retzel

WD04: Setting a reference point, B_{lim}, for the capelin in Iceland-East Greenland-Jan Mayen Area. Asta Gudmundsdòttir, Höskuldur Björnsson, Sigurður Þór Jónsson and Þorsteinn Sigurðsson.

WD05: Overview of Advice for Capelin in Iceland-East Greenland-Jan Mayen Area in the last 20 years and notes on future Advice giving. Asta Gudmundsdòttir, Sigurður Þór Jónsson, Höskuldur Björnsson and Þorsteinn Sigurðsson.

WD06: Stock Assessment of West Greenland Inshore Cod 2015; the Coleraine model. Søren Lorenzen Post, Rasmus Hedeholm and Jesper Boje.

WD07: Yield-per-Recruit on the West Greenland Inshore Cod. Rasmus Hedeholm and Søren Lorenzen Post.

WD08: Catch curves on the West Greenland Inshore Cod based on Commercial Landings. Rasmus Hedeholm and Søren Lorenzen Post.

WD09: Stock assessment of West Greenland Inshore Cod 2015-ADAPT VPA. Søren Lorenzen Post and Rasmus Hedeholm.

WD10: Assessment of West Greenland Inshore Cod. Søren Lorenzen Post, Rasmus Hedeholm, Anja Retzel and Jesper Boje.

WD11: Estimation of Consumption of Icelandic Capelin from January–March. Höskuldur Björnsson, Ásta Guðmundsdóttir, Sigurður Þór Jónsson and Þorsteinn Sigurðsson.

WD12: Comparison of Precautionary and Escapement Strategy for Icelandic Capelin. Þorsteinn Sigurðsson, Ásta Guðmundsdóttir, Sigurður Þór Jónsson and Höskuldur Björnsson.

WD13: Results of HCR Simulations in 2012, 2013 and 2014. Höskuldur Björnsson, Þorsteinn Sigurðsson, Sigurður Þór Jónsson and Ásta Guðmundsdóttir.

WD14: Bootstrap Estimation of Echo Abundance Uncertainty in the Iceland-East Greenland-Jan Mayen Capelin Survey Time-series. Sigurður Þór Jónsson.

WD15: A simple Climatology Exercise for the Iceland-East Greenland-Jan Mayen Capelin Distribution Area. Sigurður Þór Jónsson.

WD16: A Proposal for setting an Initial TAC for the Capelin in Iceland-East Greenland-Jan Mayen area. Ásta Guðmundsdóttir, Sigurður Þór Jónsson, Höskuldur Björnsson, Sveinn Sveinbjörnsson and Þorsteinn Sigurðsson.

WD17: Some Notes on the Icelandic Cod. Einar Hjörleifsson and Höskuldur Björnsson.

WD18: Stock Production Model on East Greenland Offshore Cod. Rasmus Hedeholm and Anja Retzel.

WD19: Assessment of (East) Greenland Cod. Höskuldur Björnsson.

Combined VPA data for cod in East Greenland and NAFO division 1F in the period 1973-1995 and 2005-2013

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Abstract
Catch at Age and Mean weight at Age was constructed for the period of 1973-1995 and 2005-2013 representing the combined areas of the offshore region in NAFO division 1F (SouthWest Greenland) and East Greenland. The CAA for this area was named New East.

Introduction
Results from genetic investigations and tagging experiments have revealed that the Atlantic cod (*Gadus morhua*) in Greenland waters is comprised of three stocks; 1) West Greenland inshore stock 2) West Greenland offshore stock and 3) East Greenland stock in the Iceland and East Greenland ecoregion (Stor-Poulsen et al. 2003, Therkildsen et al. 2013). The stock that has contributed to the very large fishery in the 1960'ies was mainly the West Greenland offshore stock (Bonanomi et al. 2014) which to this day has not recovered (ICES 2014). The offshore fishery was from the 1970'ies to the complete collapse in the 1990'ies mainly comprised of the East Greenland stock. The offshore fishery started again in 2005 mainly in East Greenland and is comprised of the East Greenland stock.

The distribution pattern of the East Greenland stock is complex as it moves around Greenland according to age. Juveniles (age 0-3 yrs) are mainly found in West Greenland and as young cod (age 4-6 yrs) they are mainly found in South Greenland. As they become mature they start to migrate to the spawning grounds in East Greenland north of 63^{o}N, and to some extent to Icelandic spawning grounds. The present offshore fishery is accordingly distributed from South Greenland (NAFO division 1F) to the Dohrn Bank area in East Greenland (ICES 2014).

The existing VPA data is combined of all three stocks (Hovgaard & Wieland 2008). For the benchmark in 2015 a new VPA was constructed that only include data for the East Greenland stock. Since genetic results show that the West Greenland offshore cod stock became severely depleted during the 1960'ies and that the fishery from the 1970'ies was mainly comprised of the East Greenland stock it was decided that the VPA data should start from the 1970'ies. The VPA includes catch statistics for the offshore area in NAFO division 1F and East Greenland in the period 1973-1995 and 2005-2013.

Materials and methods

Landings 1911-1995.

Horsted 2000 provides a comprehensive overview of the cod fisheries at Greenland in the period 1910-1995. Based on his report it was possible to divide catches in West Greenland into inshore and offshore catches and further into NAFO divisions.

The catch statistics table in ICES NWWG report is also based on Horsted 2000 publication, but several errors were detected in the table, and the table has therefore been updated.

The table used in Horsted 2000 report to define East Greenland catches was table 3. In the years 1977-1982 estimates include unreported catches. In 1988 (3000 t) and 1989 (2741 t) the reported catch in East Greenland include catches believed to be taken in NAFO division 1F. These numbers have been subtracted from the East Greenland catches (table 1).

The table used in Horsted 2000 report to define West Greenland inshore catches was table 6a which reflects the catches taken by small Greenland boats (below 50 GRT). In 1987 however the numbers are for all vessels. For this year the amount taken by larger vessels were found in Horsted 2000 table 2 and subtracted from each NAFO division accordingly to the individual NAFO division proportion of the total catch (table 2).

The table used in Horsted 2000 report to define West Greenland offshore catches was a combination of tables 1, 2, 7a and 8a. Table 8a was used to divide catches into NAFO divisions for the foreign nations fishing in Greenland in the period 1952-1991. The misreported catch in East Greenland in 1988 (3000 t) and 1989 (2741 t) are included in NAFO division 1F in Horsted 2000 table 8a. For Greenlandic vessels logbooks in combination with Horsted 2000 table 7a were used to divide catches into NAFO divisions in the period 1973-1991. In the years 1977-1980 the unknown NAFO division catch include unreported catches taken from Horsted 2000 table 2. In the period 1924-1951, where catches could not be divided into NAFO divisions, Horsted 2000 tables 1 and 2 were used. In this period total inshore catches were subtracted from the grand total catches in Horsted 2000 table 1 and 2 (table 1).

Landings 1996-2013

Offshore catches in East Greenland was compiled from ICES Marine Data Catch Statistics (ICES web) in the period 1996-2000. From 2001-2013 catches from East Greenland and West Greenland divided into NAFO divisions was compiled from logbook information registered in Greenland Fishery License Control system.

Inshore catches per NAFO division in West Greenland was compiled from ICES NWWG report 2007 which was based on Statistics Greenland (web) in the period 1994-2006. From 2007 to 2013 catches was compiled from Greenland fishery License Control system.

In 2007-2009 small vessels were fishing offshore in South Greenland (NAFO division 1F). The catches were landed to a fish factory in South Greenland (Qaqortoq), and were therefore registered as caught inshore. Therefore the catches registered in logbooks from these small vessels have been added to the offshore catch and subtracted from the inshore catch in NAFO division 1F.

VPA-data

Landings.

The timeseries of the VPA data for the East Greenland and NAFO division 1F (New East) was started at 1973. Before this year a large amount of the catches could not be appointed to NAFO division and it was therefore decided to start the timeseries from 1973.

From 1973-1976 and 1981-1984 unknown offshore NAFO division catches were ignored as they were minor compared to the total catch (table 1). From 1977-1980 and 1985-1988 and 1990 unreported and unknown NAFO division catches was added accordingly to the proportion of the known catch in offshore NAFO division 1F in relation to the total known catch in NAFO division. F.ex. in 1977 known catch in NAFO division 1F was 2175 t which is 9.246% of the known total catch in NAFO divisions (127+301+4472+7943+8506+2175=23524 t, table 1). 9.246% of the unknown catch (35477* 0.09246=3280 t) was then added to the known catch in NAFO division 1F (3280+2175=5455 t, table 3). The same exercise was done for the inshore catches in the years 1981-1984 and 2003-2006. The total catch in New East was then NAFO division 1 F offshore catch + East Greenland catch (table 3).

CAA and MEWA 1973-1995

The catch at age (CAA) and mean weight at age (MEWA) matrices for West and East Greenland was found from the background material for the article “Fishery and Environmental Aspects Relevant for the Emergence and Decline of Atlantic Cod (*Gadus morhua*) in West Greenland Waters” by Hovgård and Wieland 2008.

The available data was:

- CAA and MEWA for total West Greenland (inshore + offshore) 1924-1995 (appendix)
- CAA and MEWA for East Greenland 1965-1995 (appendix)

To calculate the CAA for offshore NAFO division 1F first the proportion of the offshore catch in NAFO division 1F in relation to the total catch in West Greenland (inshore + offshore) was found (table 4). This proportion was then multiplied to the CAA for total West Greenland. To do this exercise the assumption is that the age composition in the catches are the same in NAFO division 1F compared to the other areas in West Greenland. Raw length distributions are available for some of the years in the timeseries. Comparing the length distributions in trawl catches from NAFO division 1F with NAFO division 1B,1C,1D and 1E, show a similar size in catches between the two areas (figure 1) indicating that the age composition is similar between the areas.

Sum of Product (SOP) on the CAA and MEWA of the New East matrices revealed a slight difference between SOP and the landings (table 5). Therefore a raising factor was calculated and multiplied to the CAA matrice, resulting in the CAA matrice shown in table 6.

CAA and MEWA 2005-2013

In the period 1996-2004 no length and age information exist from the very low catches of cod in East Greenland as the catch of cod was taken as bycatch in the ? fishery. In West Greenland no cod was caught in the offshore fishery in this period. From 2005 directed cod fishery started both in East and West Greenland and CAA and MEWA was constructed for the combined areas of East Greenland + offshore NAFO area 1F in West Greenland (Table 6 and 7).

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Table: 1. Offshore catches. 1924-1995: Horsted, 2000. 1996-2000: ICES Catch Statistics. 2001-2013: Greenland Fishery and License Control.

Year	1A	1B	1C	1D	1E	1F	Unknown NAFO div.	Total West offshore	East
1924							200	200	
1925							1871	1871	
1926							4452	4452	
1927							4427	4427	
1928							5871	5871	
1929							22304	22304	
1930							94722	94722	
1931							120858	120858	
1932							87273	87273	
1933							54351	54351	
1934							88422	88422	
1935							65796	65796	
1936							125972	125972	
1937							90296	90296	
1938							90042	90042	
1939							62807	62807	
1940							43122	43122	
1941							35000	35000	
1942							40814	40814	
1943							47400	47400	
1944							51627	51627	
1945							45800	45800	
1946							44395	44395	
1947							63458	63458	
1948							109058	109058	
1949							156015	156015	
1950							179398	179398	
1951							222340	222340	
1952	0	261	2996	18188	707	37905	257488	317545	
1953	4546	46546	10611	38915	932	25242	98225	225017	
1954	2811	97306	18192	91555	727	15350	60179	286120	4321
1955	773	50106	32829	87327	3753	4655	68488	247931	5135
1956	15	56011	38428	128255	8721	4922	66265	302617	12887
1957	0	58575	32594	62106	29093	16317	47357	246042	10453
1958	168	55626	41074	73067	21624	26765	75795	294119	10915
1959	986	74304	10954	30254	12560	11009	67598	207665	19178
1960	35	58648	18493	35939	16396	9885	76431	215827	23914
1961	503	78018	43351	70881	16031	14618	90224	313626	19690
1962	1017	122388	75380	57972	25336	17289	125896	425278	17315
1963	66	70236	73142	76579	46370	16440	122653	405486	23057
1964	96	49049	49102	82936	33287	13844	99438	327752	35577
1965	385	80931	66817	71036	15594	15002	92630	342395	17497
1966	12	99495	43557	62594	19579	18769	95124	339130	12870
1967	361	58612	78270	122518	34096	12187	95911	401955	24732
1968	881	12333	89636	94820	61591	16362	97390	373013	15701
1969	490	7652	31140	65115	41648	11507	35611	193163	17771
1970	278	3719	13244	23496	23215	15519	18420	97891	20907
1971	39	1621	28839	21188	9088	20515	26384	107674	32616
1972	0	3033	42736	18699	7022	4396	20083	95969	26629
1973	0	2341	17735	18587	10581	2908	1168	53320	11752
1974	36	1430	12452	14747	8701	1374	656	39396	6553
1975	0	49	18258	12494	6880	3124	549	41354	5925
1976	0	442	5418	10704	8446	2873	229	28112	13025
1977	127	301	4472	7943	8506	2175	35477 [1]	59001	18000 [2]
1978	0	0	11856	2638	3715	549	34563 [1]	53321	26000 [2]
1979	0	16	6561	4042	1115	537	51139 [1]	63410	34000 [2]
1980	0	1800	2200	2117	1687	384	7241 [1]	15429	12000 [2]
1981	0	0	4289	4701	4508	255	0	13753	16000 [2]
1982	0	133	6143	10977	11222	692	1174	30341	27000 [2]
1983	0	0	717	6223	16518	4628	293	28379	13378
1984	0	0	0	4921	5453	3083	0	13458	8914
1985	0	0	0	145	1961	1927	2402	6435	2112
1986	0	0	0	2	72	24	1203	1301	4755
1987	0	0	5	815	67	43	3041	3971	6909
1988	0	0	919	17463	10913	6466	8101	43862	9457

Year	1A	1B	1C	1D	1E	1F	Unknown NAFO div.	Total West offshore	East
1989	0	0	0	11071	48092	14248	2	73413	14669
1990	0	0	2	563	21513	10580	7503	40162	33508
1991	0	0	0	0	104	1942	0	2046	21596
1992	0	0	0	0	0	0	0	0	11349
1993	0	0	0	0	0	0	0	0	1135
1994	0	0	0	0	0	0	0	0	437
1995	0	0	0	0	0	0	0	0	284
1996	0	0	0	0	0	0	0	0	192
1997	0	0	0	0	0	0	0	0	355
1998	0	0	0	0	0	0	0	0	345
1999	0	0	0	0	0	0	0	0	116
2000	0	0	0	0	0	0	0	0	152
2001	0	0	0	0	0	0	0	0	125
2002	0	0	0	0	0	0	0	0	401
2003	0	0	0	0	0	0	0	0	485
2004	0	0	0	5	3	1	0	9	774
2005	0	0	1	0	0	71	0	72	819
2006	0	0	0	0	0	414	0	414	2042
2007	0	0	0	31	435	2011[3]	0	2477	3194
2008	0	0	0	23	526	11370[3]	0	11919	3258
2009	0	0	0	0	6	3323[3]	0	3329	1642
2010	0	0	0	0	2	281	0	283	2388
2011	0	0	0	0	8	542	0	550	4571
2012	0	0	1	95	236	1470	0	1802	3941
2013	0	0	0	209	270	1405	0	1884	4104

1) Estimates for assessment include estimates of unreported catches. The total estimated value for West Greenland (inshore + offshore) was 73000 t in 1977 and 1978, 1979: 99000 t, 1980: 54000 t. The value given in the table are these values minus the inshore catches minus known offshore NAFO division catches.

2) Estimates for assessment include estimates of unreported catches in East Greenland.

3) Include catches taken with small vessels and landed to a factory in South Greenland (Qaqortoq), 2007:597 t, 2008: 2262 t, 2009: 136 t.

Table 2: Inshore catches. 1911-1993: Horsted, 2000. 1994-2006: Statistics Greenland. 2007-2013: Greenland Fishery and License Control.

Year	1A	1B	1C	1D	1E	1F	Unknown NAFO div	Total West inshore	Total East inshore
1911				19				19	
1912				5				5	
1913				66				66	
1914				60				60	
1915		47	6	45				98	
1916		66	24	103				193	
1917		67	28	59				154	
1918		106	26	140		169		441	
1919		39	37	140	148	137		501	
1920		117	32	187	23	95		454	
1921		116	92	97	7	196		508	
1922		82	178	144	40	158		602	
1923		120	116	147	0	307		690	
1924		131	223	221	1	267		843	
1925		122	371	318	45	168		1024	
1926		97	785	673	170	499		2224	
1927		282	974	982	305	1027		3570	
1928		426	888	1153	497	1199		4163	
1929		1479	1572	1335	642	2052		7080	
1930	137	2208	2326	1681	994	2312		9658	
1931	315	1905	2026	1520	835	2453		9054	
1932	358	1713	2130	1042	731	3258		9232	
1933	304	1799	1743	1148	948	2296		8238	
1934	451	2080	1473	652	921	3591		9168	
1935	524	1870	1277	769	670	2466		7576	
1936	329	2039	1199	705	717	2185		7174	
1937	135	1982	1433	854	496	2061		6961	
1938	258	1743	1406	703	347	1035		5492	
1939	416	2256	1732	896	431	1430		7161	
1940	482	2478	1600	1061	646	1759		8026	
1941	636	3229	1473	823	593	1868		8622	
1942	879	3831	2249	1332	1003	2733		12027	
1943	1507	5056	2016	1240	1134	2073		13026	
1944	1795	4322	2355	1547	1198	2168		13385	
1945	1585	4987	2844	1207	1474	2192		14289	
1946	1889	5210	2871	1438	1139	2715		15262	
1947	1573	5261	3323	2096	1658	4118		18029	
1948	1130	5660	3756	1657	1652	4820		18675	
1949	1403	4580	3666	2110	2151	3140		17050	
1950	1657	6358	4140	2357	2278	4383		21173	
1951	1277	5322	3324	2571	2101	3605		18200	
1952	646	4443	2906	2437	2216	4078		16726	
1953	1092	5030	3662	5513	3093	4261		22651	
1954	950	6164	3118	3275	1773	3418		18698	
1955	591	5523	3225	4061	2773	3614		19787	
1956	475	5373	3175	5127	3292	3586		21028	
1957	277	6146	3282	5257	4380	5251		24593	
1958	19	6178	3724	5456	3975	6450		25802	
1959	237	6404	5590	5009	3767	6570		27577	
1960	188	6741	6230	3614	3626	6610		27009	
1961	601	6569	6726	4178	6182	9709		33965	
1962	315	7809	6269	3824	5638	11525		35380	
1963	295	4877	3178	2804	3078	9037		23269	
1964	275	3311	2447	8766	2206	4981		21986	
1965	325	5209	4818	6046	2477	5447		24322	
1966	483	8738	5669	7022	2335	4799		29046	
1967	310	5658	6248	6747	2429	6132		27524	
1968	142	1669	2738	6123	2837	7207		20716	
1969	57	1767	4287	7540	2017	5568		21236	
1970	136	1469	2219	3661	2424	5654		15563	
1971	255	1807	2011	3802	1698	3933		13506	
1972	263	1855	3328	3973	1533	3696		14648	
1973	158	1362	1225	3682	1614	1581		9622	
1974	454	926	1449	2588	1628	1593		8638	
1975	216	1038	1930	1269	964	1140		6557	

Year	1A	1B	1C	1D	1E	1F	Unknown NAFO div	Total West inshore	Total East inshore
1976	204	644	1224	904	1367	831		5174	
1977	216	580	2505	2946	3521	4231		13999	
1978	348	1587	3244	2614	4642	7244		19679	
1979	433	1768	2201	6378	9609	15201		35590	
1980	719	2303	2269	7781	10647	14852		38571	
1981	281	2810	3599	6119	7711	11505	7678	39703	
1982	206	2448	3176	7186	4536	3621	5491	26664	
1983	148	2803	3640	7430	5016	2500	7205	28742	
1984	175	3908	1889	5414	1149	1333	6090	19958	
1985	149	2936	957	1976	1178	1245		8441	
1986	76	1038	255	1209	1456	1268		5302	
1987 [1]	77	2366	423	6407	3602	1326	403	14604	
1988	333	6294	1342	2992	3346	4484		18791	
1989	634	8491	5671	8212	10845	4676		38529	
1990	476	9857	1482	9826	1917	5241		28799	
1991	876	8641	917	2782	1089	4007		18312	
1992	695	2710	563	1070	239	450		5727	
1993	333	327	168	970	19	109		1926	
1994	209	332	589	914	11	62		2117	
1995	53	521	710	332	4	81		1701	
1996	41	211	471	164	11	46		944	
1997	18	446	198	99	13	130	282	1186	
1998	9	118	79	78	0	38		322	
1999	68	142	55	336	8	4		613	
2000	154	266	0	332	0	12		764	
2001	117	1183	245	54	0	81		1680	
2002	263	1803	505	214	24	813		3622	
2003	1109	1522	334	274	3	479	1494	5215	
2004	535	1316	242	116	47	84	2608	4948	
2005	650	2351	1137	1162	278	382	83	6043	
2006	922	1682	577	943	630	1461	1173	7388	
2007	416	2547	1195	1842	659	4391[2]		11050	42
2008	870	3066	1539	3172	225	1133[2]		10005	6
2009	325	1288	1189	2009	1142	1581[2]		7534	2
2010	559	2990	1607	1795	1458	859		9268	2
2011	567	2364	2850	2905	1274	1047		11007	0
2012	546	1376	2061	4375	1989	325		10672	0
2013	788	3271	2784	4711	1450	198		13202	35

1) Different from Horsted 2000, table 6a, because this year the catch given in the table was for all vessels. Therefore the known catch from trawlers (OTB, Horsted 2000 table 2) was subtracted from each NAFO division accordingly to the proportion of the total caught.

2) Excluding catches taken with small vessels offshore and landed to a factory in South Greenland (Qaqortoq), 2007:597 t, 2008: 2262 t, 2009: 136 t.

Table 3: New East catch table.

year	1F offshore	East	Total
1973	2908	11752	14660
1974	1374	6553	7927
1975	3124	5925	9049
1976	2873	13025	15898
1977	5455 [1]	18000	23455
1978	1561 [1]	26000	27561
1979	2775 [1]	34000	36775
1980	724 [1]	12000	12724
1981	255	16000	16255
1982	692	27000	27692
1983	4628	13378	18006
1984	3083	8914	11997
1985	3075 [1]	2112	5187
1986	319 [1]	4755	5074
1987	184 [1]	6909	7093
1988	7931 [1]	9457	17388
1989	14248	14669	28917
1990	13011 [1]	33508	46519
1991	1942	21596	23538
1992	0	11349	11349
1993	0	1135	1135
1994	0	437	437
1995	0	284	284
1996	0	192	192
1997	0	355	355
1998	0	345	345
1999	0	116	116
2000	0	152	152
2001	0	125	125
2002	0	401	401
2003	0	485	485
2004	1	774	775
2005	71	819	890
2006	414	2042	2456
2007	2011	3194	5205
2008	11370	3258	14628
2009	3323	1642	4965
2010	281	2388	2669
2011	542	4571	5113
2012	1470	3941	5411
2013	1405	4104	5509

1) Unknown NAFO division catches added accordingly to the proportion of known catch in offshore NAFO division 1F.

Table 4: Distribution of catch in NAFO division 1F in relation to total catch in West Greenland 1973-1995.

Year	Total 1F (offshore)	Total West (inshore + offshore)	% in 1F
1973	2908	62942	5%
1974	1374	48034	3%
1975	3124	47911	7%
1976	2873	33286	9%
1977	5455	73000	7%
1978	1561	73000	2%
1979	2775	99000	3%
1980	724	54000	1%
1981	255	53456	0%
1982	692	57005	1%
1983	4628	57121	8%
1984	3083	33415	9%
1985	3075	14876	21%
1986	319	6603	5%
1987	184	18575	1%
1988	7931	62653	13%
1989	14248	111942	13%
1990	13011	68961	19%
1991	1942	20358	10%
1992	0	5727	0%
1993	0	1926	0%
1994	0	2117	0%
1995	0	1701	0%

Table 5: Sum of Product (SOP) of New East CAA and MEWA compared to landings 1973-1995.

Year	SOP	Landings	Raising factor
1973	17613	14660	0.832
1974	9399	7927	0.843
1975	8989	9049	1.007
1976	14733	15898	1.079
1977	21558	23455	1.088
1978	22401	27561	1.230
1979	28781	36775	1.278
1980	12865	12724	0.989
1981	16047	16255	1.013
1982	28643	27692	0.967
1983	17267	18006	1.043
1984	11859	11997	1.012
1985	5823	5187	0.891
1986	5694	5074	0.891
1987	7549	7093	0.940
1988	16470	17388	1.056
1989	29812	28917	0.970
1990	44525	46519	1.045
1991	24279	23538	0.970
1992	10865	11349	1.045
1993	825	1135	1.376
1994	441	437	0.990
1995	270	284	1.050

Table 6: Catch at age (‘000) for New East (NAFO division 1F offshore + East Greenland)

Year	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	Age 14	Age 15
1973	8	109	793	223	308	122	637	736	191	69	19	7	2
1974	12	79	76	579	176	200	63	282	223	58	16	5	0
1975	75	293	517	205	1173	247	123	40	72	55	17	5	1
1976	1279	564	384	750	274	1817	183	139	62	17	34	3	2
1977	52	8836	1803	681	760	261	498	192	90	39	12	1	0
1978	8	670	9164	2275	245	254	138	342	160	115	69	23	0
1979	17	567	1961	6686	3546	1033	157	67	25	17	1	1	1
1980	54	137	293	247	2411	689	77	9	2	5	1	6	0
1981	0	87	104	267	388	2952	234	23	9	5	5	3	0
1982	14	14	654	1326	1970	1562	2060	142	18	6	3	0	0
1983	7	1153	788	3934	1137	419	150	268	11	4	2	0	2
1984	70	297	1342	551	1999	334	138	53	68	1	1		
1985	84	263	339	1121	123	313	25	36	6	5			3
1986	61	49	415	269	709	59	123	8	4	2			
1987	772	156	60	301	149	642	55	287	11	25		0	0
1988	550	10794	327	110	498	123	347	13	136	8	10	5	
1989	22	2840	15527	219	43	252	87	225	2	47	1	2	
1990	22	702	7199	17371	140	9	112	4	52	14			
1991	9	812	724	4989	5232	49	21	16	7	26			
1992	2	127	266	163	2594	1225	29	4		1			
1993	1	15	18	59	10	121	78	1		1			
1994	41	53	27	16	27		5						
1995	24	8	37	9	3	9	1	4					
1996													
1997													
1998													
1999													
2000													
2001													
2002													
2003													
2004													
2005	5	33	57	103	94	57	16	4	2	0	0	0	
2006	232	376	135	175	115	14	1	0					
2007	49	1529	668	158	124	120	18	12	2	1	0		
2008	77	586	6015	2417	592	44	26	8	3	1			
2009	307	1287	1231	434	119	28	16	2	0	0	0		
2010	10	87	331	193	334	58	8	3	1	0	0	0	0
2011	3	70	137	425	355	371	96	21	6	3	1	0	0
2012	13	109	471	281	258	253	148	37	12	6	2	1	0
2013	0	36	127	615	237	226	153	81	16	3	3	1	0

Table 7: Mean Weight At Age (kg) for New East (NAFO division 1F offshore + East Greenland)

Year	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	Age 14	Age 15
1973	0.508	1.251	1.652	2.392	3.311	4.504	5.487	7.049	8.106	8.693	9.352	9.680	9.600
1974	0.578	1.084	1.609	2.407	3.308	4.454	5.465	7.061	8.148	8.492	9.051	10.032	10.740
1975	0.474	1.267	1.546	2.497	3.466	4.398	5.368	6.383	8.179	8.539	9.187	9.505	10.110
1976	0.752	1.183	1.738	2.328	3.232	4.396	5.447	6.970	8.106	8.360	9.106	9.448	12.870
1977	0.740	1.176	1.478	2.234	3.237	4.406	5.468	6.984	8.043	8.312	9.053	9.714	10.500
1978	0.650	1.134	1.458	2.267	3.236	4.382	5.516	7.089	8.197	8.697	9.296	9.699	10.500
1979	0.597	1.197	1.534	2.306	3.214	4.387	5.536	7.110	8.263	8.869	9.411	9.786	10.500
1980	0.749	1.217	1.529	2.339	3.257	4.384	5.529	7.115	8.205	8.741	9.335	9.702	10.500
1981	0.830	1.090	1.528	1.846	2.894	4.246	5.949	8.702	9.787	12.480	13.426	13.728	9.320
1982	0.830	1.110	1.401	1.978	2.878	3.992	5.332	6.909	8.755	10.773	13.084	9.320	9.320
1983	0.780	0.954	1.296	2.129	3.057	3.740	4.699	6.163	5.365	6.426	7.555	6.000	6.000
1984	0.693	0.878	1.350	2.149	3.050	3.717	4.705	6.121	5.411	6.806	7.218		
1985	0.780	0.960	1.421	2.128	3.102	3.900	4.704	5.507	5.938	6.269			6.000
1986	0.253	0.800	1.595	2.582	3.636	4.894	5.803	5.450	7.579	3.170			
1987	0.341	0.944	1.790	2.737	3.671	4.567	5.359	6.029	6.588	7.048		4.700	4.700
1988	0.367	1.012	1.578	2.298	3.682	4.153	5.504	6.721	7.898	9.450			
1989	0.288	0.758	1.458	2.593	3.276	4.870	4.868	6.037	7.080	8.270			
1990	0.785	0.917	1.226	2.038	3.151	4.270	5.365	6.266	7.430	10.065			
1991	0.780	1.034	1.167	1.550	2.558	3.300	5.410	7.480	8.340	10.810			
1992	1.326	1.770	1.807	2.071	2.217	3.586	4.143	7.660		10.198			
1993	0.790	1.470	1.160	2.380	2.770	3.870	5.660	8.080					
1994	0.518	1.980	2.962	4.791	4.738	0.000	5.742	0.000					
1995	0.426	1.427	2.949	4.176	5.233	5.926	9.645	7.442					
1996													
1997													
1998													
1999													
2000													
2001													
2002													
2003													
2004													
2005	0.354	0.718	1.073	1.963	2.738	3.699	5.271	6.850	7.942	9.983	11.153	12.029	
2006	1.323	1.602	2.349	3.608	4.420	5.440	7.191	8.127					
2007	0.387	0.917	1.597	3.294	6.092	8.524	11.114	13.679	17.715	18.902	19.954		
2008	0.359	0.644	1.266	1.799	3.025	4.936	5.840	6.923	11.366	11.366			
2009	0.489	0.776	1.396	2.797	4.634	6.453	7.804	9.593	12.600	13.925	13.925		
2010	0.699	1.124	1.636	2.494	3.354	5.334	8.060	9.952	11.311	11.570	14.246	15.157	15.377
2011	0.553	1.026	1.541	2.297	3.377	4.685	6.285	8.759	11.249	13.306	14.068	14.796	15.526
2012	0.501	0.891	1.434	2.370	3.559	5.137	7.167	9.882	11.957	16.574	15.026	12.488	15.999
2013	0.480	0.998	1.698	2.272	3.408	4.745	6.827	8.352	10.443	12.190	12.808	12.630	17.782

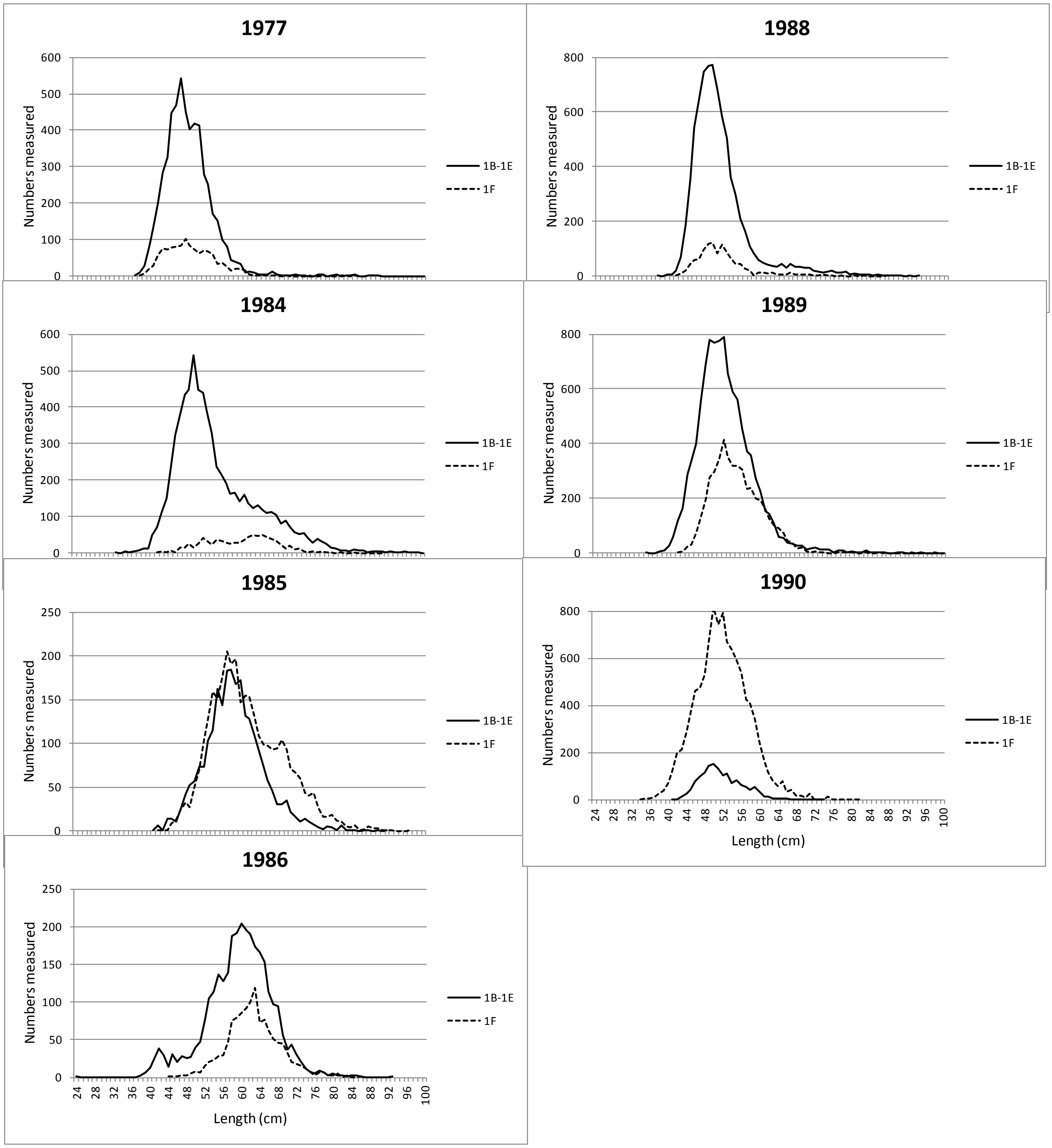

Figure 1: Length distribution of cod caught in trawl in NAFO division 1F and combined NAFO divisions 1B,1C,1D and 1E.

Appendix:
Original VPA tables

Table 1: Catch At Age ('000) for total West Greenland (inshore + offshore)

Year	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	Age 14	Age 15
1924	0	2	11	4	129	31	12	1	1	21	1	3	13
1925	0	0	2	2	8	158	59	42	12	0	79	0	79
1926	0	4019	288	46	46	11	127	11	0	0	0	0	0
1927	0	24	1377	121	61	79	36	412	67	109	0	0	92
1928	0	350	135	2273	207	99	126	0	278	9	9	0	18
1929	0	92	1673	160	5822	298	68	68	22	275	22	22	46
1930	0	591	197	9339	526	12694	329	66	66	66	1381	66	197
1931	0	1273	6446	318	8515	398	8436	239	159	159	80	3660	239
1932	0	144	481	2403	192	7593	432	3989	192	144	385	48	2306
1933	0	164	724	592	3456	65	3752	65	2535	33	33	296	1119
1934	0	688	2063	1522	1031	5843	147	4813	147	2063	147	147	932
1935	0	1621	1288	1621	1538	790	3782	83	2535	41	1579	41	706
1936	0	2619	8350	1637	4993	1637	1065	5157	163	3028	82	1555	900
1937	0	851	3587	7296	1398	2371	973	912	2858	60	1702	60	1338
1938	0	4256	2653	5367	4750	555	1234	370	432	2467	62	1172	925
1939	0	866	3728	1205	2034	1808	339	941	414	489	1769	38	1355
1940	0	488	1232	2851	1003	924	848	205	488	308	513	823	1027
1941	0	116	905	1143	789	334	354	612	258	551	652	374	1401
1942	0	198	4001	1706	2559	264	818	752	163	752	457	426	721
1943	0	28	56	301	2509	1475	2375	626	765	1034	301	436	844
1944	0	29	534	505	505	2616	951	3568	505	714	684	180	684
1945	0	25	236	631	236	341	2609	947	3291	606	711	316	446
1946	0	302	403	251	478	554	352	2088	578	2289	151	1157	478
1947	0	87	810	347	521	578	318	376	1995	1244	3413	521	1215
1948	0	233	677	3105	1378	1354	1121	747	654	3572	841	4250	1471
1949	0	3678	803	1371	3645	1605	1405	1136	602	669	3076	1505	7991
1950	0	746	3689	2446	2487	5637	2031	1575	1244	1160	1326	3399	7377
1951	0	1054	1158	5740	4318	3897	8742	2527	1632	1949	948	1422	8583
1952	0	350	13822	4637	17322	4111	4199	9098	1837	3237	2449	1750	6998
1953	0	307	3840	25340	1689	10213	1919	2150	8063	1459	1997	230	2534
1954	0	8206	5402	4571	30850	1350	10802	1350	1350	5090	312	2285	2087
1955	0	2114	10364	5182	3409	15819	818	5318	886	1227	5318	955	4023
1956	209	1758	4996	17901	6622	6400	24418	2345	4106	1011	1363	2893	1194
1957	1177	19353	12493	9362	17367	3967	4061	8893	1271	1899	485	436	1383
1958	348	1772	15136	6751	7501	17177	3181	3652	12981	1691	2168	725	3271
1959	578	2866	5464	27411	6622	3881	5996	1124	1477	4327	999	836	960
1960	435	6186	5168	4652	20250	4492	2743	5663	805	1438	5195	741	1859
1961	2946	22958	19756	8055	6980	23126	4359	2333	4724	528	1138	5052	2383
1962	869	11423	70311	29344	7816	5050	13772	2433	1709	2599	720	1219	2897
1963	7612	6589	19301	48448	22517	3973	1708	6768	1104	1156	2325	189	3718
1964	8655	27181	11407	18624	30864	11355	2543	1027	4138	591	321	933	747
1965	14718	58619	53331	8994	9152	15125	2595	539	472	1864	73	34	265
1966	1530	7872	62130	26941	5915	4955	6912	1289	283	130	981	139	247
1967	1727	15091	30457	61848	24562	2700	1996	5237	352	93	166	453	85
1968	3764	7976	36670	29824	34591	10005	1725	833	2348	187	37	42	303
1969	662	12399	8709	27433	14664	12411	4784	513	237	704	41	62	8
1970	49	2768	10342	6465	13985	4365	2810	1280	149	85	201	27	41
1971	272	2519	10172	9283	5237	9158	2077	1841	953	78	51	134	56
1972	51	10039	9786	12020	4081	2550	2660	624	954	709	130	57	122
1973	131	2302	16378	3065	2605	1406	1203	552	165	237	93	37	44
1974	343	1079	2384	6938	1135	1806	800	194	177	152	272	147	11
1975	275	3595	2677	1803	5855	1388	619	291	84	38	9	12	10
1976	10760	4026	2243	1216	302	1594	139	148	53	27	17	14	26
1977	634	46649	6053	1515	618	425	446	168	79	88	22	1	1
1978	287	5494	30039	1004	509	83	41	13	7	7	7	1	1
1979	286	10656	12505	18970	709	400	78	52	55	80	5	5	16
1980	2999	4513	4580	1978	8014	125	60	24	1	16	3	1	2
1981	12	16864	6374	2391	1053	3382	45	65	1	1	0	0	7
1982	1204	1210	17960	2965	2078	807	610	45	88	9	4	1	13
1983	77	12356	2011	17228	1581	995	344	343	3	22	0	2	19
1984	595	2018	10384	688	3656	106	365	97	69	0	3	0	0
1985	456	1266	1303	4915	161	750	42	140	15	8	0	0	14
1986	12	113	706	318	1193	12	332	80	13	35	0	0	0
1987	5705	1636	274	662	424	686	7	30	1	2	0	1	11

1988	839	50189	1069	501	652	524	751	21	85	0	0	0	0
1989	31	8294	74268	570	84	161	253	525	0	72	0	0	0
1990	78	3390	24749	30633	69	0	8	2	41	12	0	0	0
1991	101	5399	4748	7131	690	0	0	0	0	0	0	0	0
1992	40	3802	1711	198	117	13	1	0	0	0	0	0	0
1993	22	615	683	228	17	56	19	6	0	0	0	0	0
1994	26	1664	355	57	6	6	2	0	0	0	0	0	0
1995	16	1095	554	30	11	1	1	0	0	0	0	0	0

Table 2: Mean Weight At Age (kg) for total West Greenland (inshore + offshore)

Year	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	Age 14	Age 15
1924	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1925	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1926	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1927	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1928	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1929	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1930	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1931	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1932	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1933	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1934	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1935	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1936	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1937	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1938	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1939	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1940	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1941	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1942	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1943	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1944	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1945	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1946	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1947	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1948	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1949	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1950	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1951	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1952	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1953	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1954	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1955	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1956	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1957	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1958	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1959	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1960	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1961	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1962	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1963	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1964	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1965	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1966	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1967	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1968	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1969	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1970	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1971	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1972	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1973	0.58	1.28	1.72	2.51	3.52	4.66	5.07	5.68	5.37	8.65	9.58	9.6	9.6
1974	0.65	0.99	1.68	2.77	3.84	4.72	5.34	5.34	5.48	5.39	8.7	10.19	10.74
1975	0.71	1.3	1.85	2.67	3.99	4.43	5.06	5.6	7.92	5.16	6.11	8.51	10.11
1976	0.85	1.21	2.03	2.71	3.42	4.58	4.49	5.88	7.02	6.46	5.14	9.03	12.87
1977	0.74	1.238	1.714	2.118	3.614	4.58	4.812	5.6	6	6.6	7.7	9.9	10.5
1978	0.65	1.15	2.18	2.89	3.69	4.58	5.06	5.6	6	6.6	7.7	9	10.5
1979	0.72	1.23	2.02	2.71	3.78	4.9	6.4	7.8	9	9.7	10.2	10.4	10.5
1980	0.87	1.33	2.06	3	4.28	5.84	6.4	7.8	9	9.7	10.2	10.4	10.5
1981	0.83	1.11	1.7	2.35	3.2	4.3	6.5	9.02	9.32	9.32	9.32	9.32	9.32
1982	0.83	1.11	1.7	2.35	3.2	4.3	6.5	9.02	9.32	9.32	9.32	9.32	9.32

1983	0.78	0.98	1.38	2.08	2.95	3.85	4.78	5.58	6	6	6	6	6
1984	0.78	0.98	1.38	2.08	2.95	3.85	4.78	5.58	6	6	6	6	6
1985	0.78	0.98	1.38	2.08	2.95	3.85	4.78	5.58	6	6	6	6	6
1986	0.66	0.98	1.79	2.24	2.43	3.08	3.62	3.17	3.17	3.17	3.17	3.17	3.17
1987	0.9	1.07	1.8	2.12	2.61	3.24	4.3	4.7	4.7	4.7	4.7	4.7	4.7
1988	0.55	1.08	1.37	2	2.75	3.5	3.94	4.92	4.92	4.92			
1989	0.52	0.72	1.27	1.67	2.31	3.71	4.21	4.67	4.07	3.12			
1990	0.86	0.91	1.02	1.36	2.04	2.12	2.2	2.89	3.79	7.95			
1991	0.78	1.03	1.12	1.16	1.61								
1992	0.63	0.82	1.16	1.71	1.79	2.26	3.5						
1993	0.53	0.81	1.16	1.65	1.99	2.92	3.64	6.39					
1994	0.62	0.88	1.46	2.27	2.87	3.04	5.04	5.86					
1995	0.75	0.76	1.16	1.52	2.59	3.05	3.69						

Table 3: Catch At Age ('000) for East Greenland

Year	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	Age 14
1965	0	131	35	91	879	661	1484	59	27	139	29	178
1966	28	21	470	89	137	1071	359	418	23	3	27	36
1967	0	145	302	2346	564	210	1292	492	371	37	17	81
1968	0	104	630	502	2505	238	62	144	69	27	5	25
1969	0	31	252	849	770	2103	170	38	82	68	24	86
1970	0	66	76	500	1539	1060	1715	237	32	63	48	27
1971	0	25	171	159	1051	3785	1580	1326	171	19	4	14
1972	0	27	85	254	295	1299	3184	818	470	136	26	53
1973	4	25	197	126	250	82	710	859	222	72	19	7
1974	4	63	22	488	176	185	52	329	259	65	11	2
1975	57	57	339	86	783	155	82	21	66	52	16	4
1976	257	175	162	590	228	1546	158	116	53	13	30	2
1977	0	4635	1205	513	652	208	424	164	77	29	9	1
1978	0	427	6808	1828	188	205	111	278	130	93	56	19
1979	5	145	1184	4700	2755	797	121	51	18	11	1	1
1980	14	78	235	223	2330	695	77	9	2	5	1	6
1981	0	5	72	252	378	2898	231	22	9	5	5	3
1982	0	0	458	1335	2012	1605	2123	146	18	6	3	0
1983	0	104	593	2376	962	321	116	229	10	2	2	0
1984	14	107	368	481	1638	320	103	43	61	1	1	0
1985	0	34	111	242	105	196	19	12	4	4	0	0
1986	68	50	432	287	738	66	122	5	4	0	0	0
1987	765	150	61	314	154	676	58	305	12	27	0	0
1988	415	3868	174	41	389	50	234	10	118	8	9	5
1989	19	1872	6554	153	34	239	57	165	2	39	1	2
1990	6	32	2220	10843	121	9	106	3	42	11	0	0
1991	0	322	293	4463	5328	50	22	17	7	27	0	0
1992	2	122	255	156	2482	1172	28	4	0	1	0	0
1993	1	11	13	43	7	88	57	1	0	1	0	0
1994	41	54	27	16	27	0	5	0	0	0	0	0
1995	23	8	35	9	3	9	1	4	0	0	0	0

Table 4: Mean Weight At Age (kg) for East Greenland

Year	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	Age 14
1965	0.4	1.13	1.39	2.26	3.21	4.38	5.52	7.09	8.2	8.7	9.3	9.7
1966	0.4	1.13	1.39	2.26	3.21	4.38	5.52	7.09	8.2	8.7	9.3	9.7
1967	0.4	1.13	1.39	2.26	3.21	4.38	5.52	7.09	8.2	8.7	9.3	9.7
1968	0.4	1.13	1.39	2.26	3.21	4.38	5.52	7.09	8.2	8.7	9.3	9.7
1969	0.4	1.13	1.39	2.26	3.21	4.38	5.52	7.09	8.2	8.7	9.3	9.7
1970	0.4	1.13	1.39	2.26	3.21	4.38	5.52	7.09	8.2	8.7	9.3	9.7
1971	0.4	1.13	1.39	2.26	3.21	4.38	5.52	7.09	8.2	8.7	9.3	9.7
1972	0.4	1.13	1.39	2.26	3.21	4.38	5.52	7.09	8.2	8.7	9.3	9.7
1973	0.4	1.13	1.39	2.26	3.21	4.38	5.52	7.09	8.2	8.7	9.3	9.7
1974	0.4	1.13	1.39	2.26	3.21	4.38	5.52	7.09	8.2	8.7	9.3	9.7
1975	0.4	1.13	1.39	2.26	3.21	4.38	5.52	7.09	8.2	8.7	9.3	9.7
1976	0.4	1.13	1.39	2.26	3.21	4.38	5.52	7.09	8.2	8.7	9.3	9.7
1977	0.4	1.13	1.39	2.26	3.21	4.38	5.52	7.09	8.2	8.7	9.3	9.7
1978	0.4	1.13	1.39	2.26	3.21	4.38	5.52	7.09	8.2	8.7	9.3	9.7
1979	0.4	1.13	1.39	2.26	3.21	4.38	5.52	7.09	8.2	8.7	9.3	9.7
1980	0.4	1.13	1.39	2.26	3.21	4.38	5.52	7.09	8.2	8.7	9.3	9.7
1981	0.316	0.776	1.455	1.823	2.89	4.246	5.948	8.698	9.787	12.483	13.426	13.728
1982	0.359	0.727	1.258	1.968	2.874	3.990	5.328	6.901	8.721	10.799	13.145	15.769
1983	0.352	0.700	1.273	2.158	3.071	3.713	4.680	6.234	5.350	6.806	7.555	8.304

1984	0.352	0.700	1.273	2.158	3.071	3.713	4.680	6.234	5.350	6.806	7.555	8.304
1985	0.290	0.810	1.520	2.330	3.150	3.940	4.670	5.330	5.890	6.380	6.790	
1986	0.250	0.780	1.580	2.600	3.730	4.910	6.090	7.210	8.270	9.230	10.110	11.000
1987	0.300	0.930	1.790	2.750	3.700	4.580	5.360	6.030	6.590	7.050	7.420	
1988	0.320	0.900	1.740	2.760	3.880	5.020	6.140	7.200	8.170	9.450		
1989	0.240	0.780	1.730	3.030	3.580	4.970	5.240	6.590	7.080	9.480		
1990	0.600	1.060	1.660	2.400	3.270	4.270	5.410	6.690	8.100	10.500		
1991	0.000	1.040	1.240	1.610	2.570	3.300	5.410	7.480	8.340	10.810		
1992	1.326	1.770	1.807	2.071	2.217	3.586	4.143	7.660		10.198	7.758	
1993	0.790	1.470	1.160	2.380	2.770	3.870	5.660	8.080				
1994	0.518	1.98	2.962	4.791	4.738		5.742					
1995	0.426	1.427	2.949	4.176	5.233	5.926	9.645	7.442				

Management units of the Greenland offshore cod

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Abstract

SIMWG evaluated the scientific investigations (tagging and genetics) of the offshore cod in Greenland and concluded that "*there is a valid scientific basis supporting the presence of distinct eastern and western spawning population*". Based on studies of the demography of the two stock components we propose that the stocks are advised on and managed according to the distribution of the fishable cod biomass (age 4+). West Greenland north of 60°45N is proposed as the management area for the West Greenland offshore cod stock and SouthWest Greenland south of 60°45N and East Greenland is proposed as the management area for the East Greenland offshore cod stock.

Introduction

Results from genetic investigations and tagging experiments suggest that the Atlantic cod (*Gadus morhua*) in Greenland waters is comprised of three spawning stocks; 1) West Greenland inshore 2) West Greenland offshore and 3) East Greenland/Iceland (Stor-Poulsen et al. 2003, Therkildsen et al. 2013). The stock that contributed to the very large fishery in the 1960'ies was mainly the West Greenland offshore stock (Bonanomi et al. 2014) which to this day has not recovered (ICES 2014a). The offshore fishery from the 1970'ies to the complete collapse in the 1990'ies was mainly comprised of the East Greenland/Iceland stock. The offshore fishery started again in 2005 mainly in East Greenland and is comprised of the East Greenland/Iceland stock.

Until 2011 a single advice was given for all three stock components combined. Since 2012 separate advice has been given for the inshore stock component and SIMWG supported this separation (ICES, 2012). To assess whether or not the offshore cod should be advised on and managed according to the two offshore stock components a request was sent by NWWG to SIMWG to evaluate the scientific investigations (tagging and genetic studies and general demography) of the offshore cod stock components.

The conclusions of SIMWG were:

"*SIMWG finds that there is a valid scientific basis supporting the presence of distinct eastern and western spawning populations of offshore cod stocks in Greenland waters. SIMWG recommends that ICES recognize the mixed-stock nature of the Atlantic cod fishery in offshore Greenlandic waters and the associated risks of managing the mixture as a single unit in their advice. Stock composition analysis would improve the scientific basis of advice and permit assessment and management eastern and western spawning populations as distinct stocks*." (ICES 2014b)

Discussion

The distribution pattern of the East Greenland stock is complex as it moves around Greenland according to age. Juveniles (age 0-3 yrs) are mainly found in West Greenland and as young cod (age 4-6 yrs) they are mainly found in South Greenland. As they become mature at age 6 they start to migrate to the spawning grounds in East Greenland north of 63^{o}N, and to some extent to Icelandic spawning grounds. The present offshore fishery is accordingly distributed from SouthWest Greenland (NAFO division 1F) to the Dohrn Bank area in East Greenland (ICES 2014a).

Tagging data shows, that when fish are maturing (>40cm) they will primarily stay in West Greenland waters when tagged north of NAFO 1F, while fish tagged in NAFO 1F or East Greenland only move east or stay (figure 1, Stor-Paulsen et al. 2003). Hence, the distinct spawning stocks are maintained and seem to be spatially separated at roughly the NAFO 1F northern limit which corresponds to 60^{o}45N. This may not be historically stable, but in the current situation with a very low West Greenland offshore stock size, it seems the most appropriate division of the stocks. A similar conclusion can be made based on the distribution of year classes. Currently, the West Greenland stock biomass is so low, that the majority of the fish found in West Greenland are of East Greenland/Iceland origin, and consequently, when these fish approach maturity they migrate out of West Greenland waters. Consequently, almost all fish age 4 and older are in either NAFO 1F or ICES XIVb, whereas juveniles are found in NAFO areas 1A-1E, which is presently considered a nursing area for the East Greenland/Iceland stock (figure 2).

We propose that the two stocks are advised on and managed separately and that the management area of the West Greenland stock is comprised of NAFO divisions 1A-1E (West Greenland north of 60^{o}45N), whereas the management area for the East Greenland stock is comprised of ICES subarea XIVb in East Greenland and NAFO division 1F (SouthWest Greenland south of 60^{o}45N, figure 3). There are however implications to this area management as the juveniles of the East Greenland stock is missing in the survey series when the nursing area north of 60^{o}45N is left out of the calculations. Likewise when the West Greenland stock is recovering stock composition analysis are necessary in order to minimize the effect of spatial overlap of especially juveniles of the East Greenland stock. However when the cod become fishable (age 4+) the two stocks seems to be spatially separated and it is therefore valid to manage them according to the areas proposed.

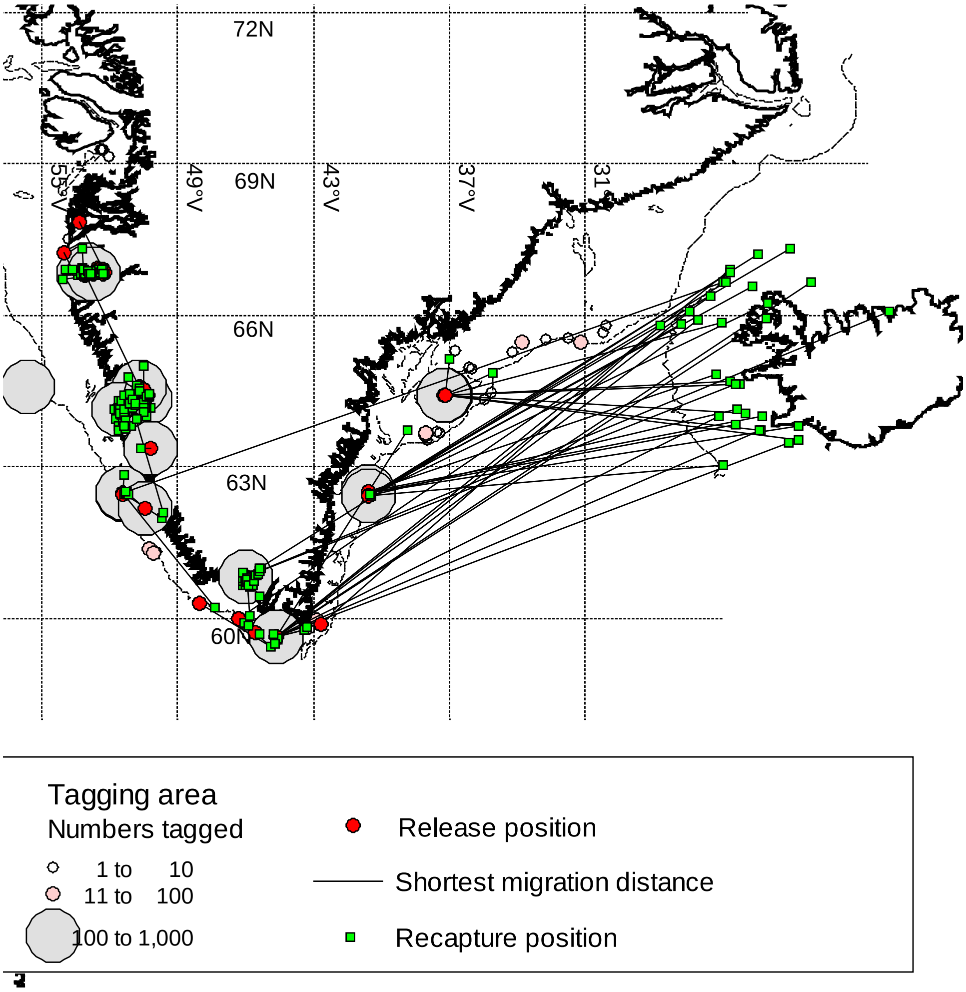

Figure 1: Tagging data 2003-2010.

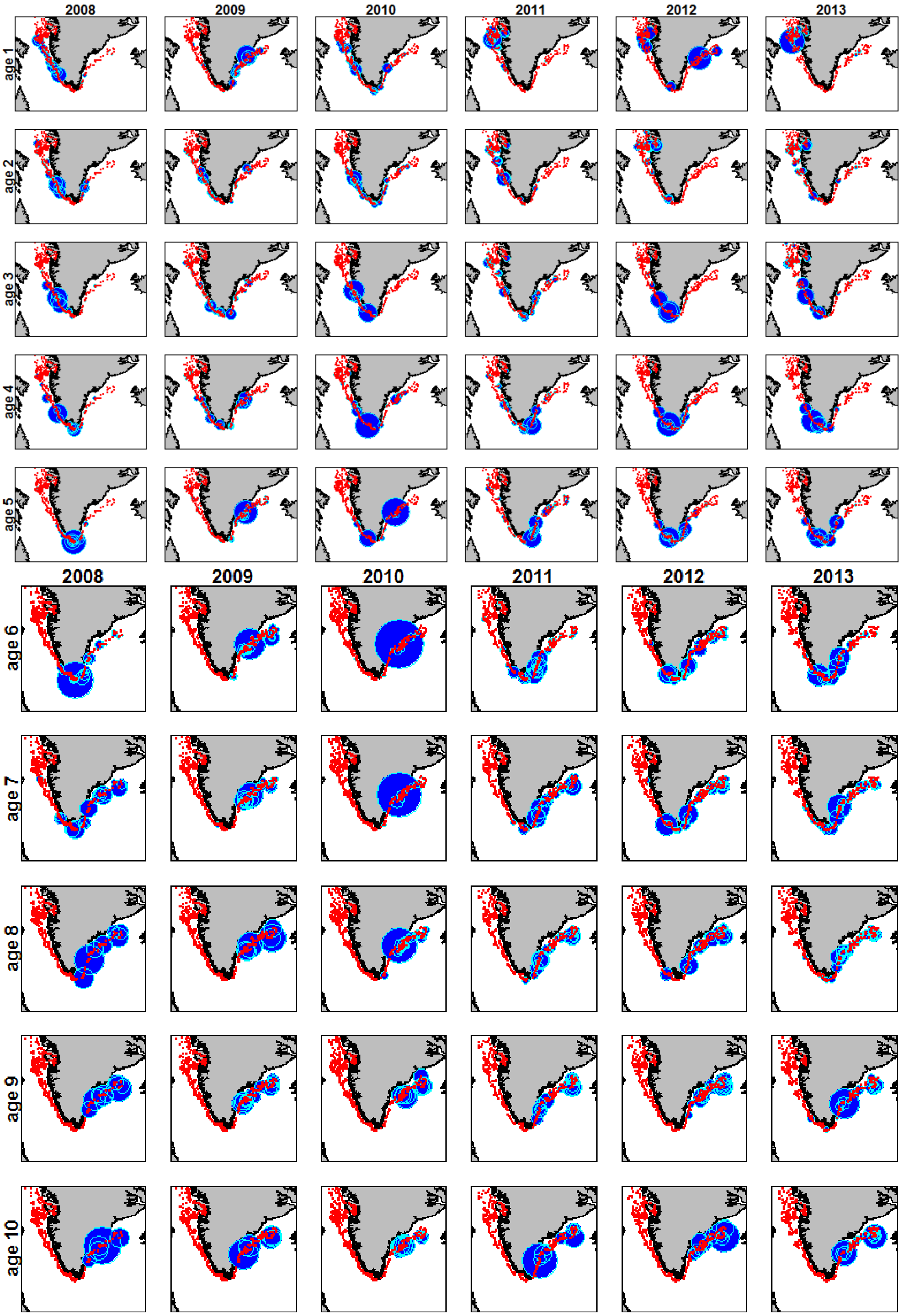

Figure 2: Abundance (%) of ages 1-10 in the years 2008-2013 from the Greenland shrimp and fish bottom trawl survey (SFW). Size of blue circles denotes the percentage of the cohort in the given year, where each square equals 100 %. Red circles marks position of sampling stations from the survey.

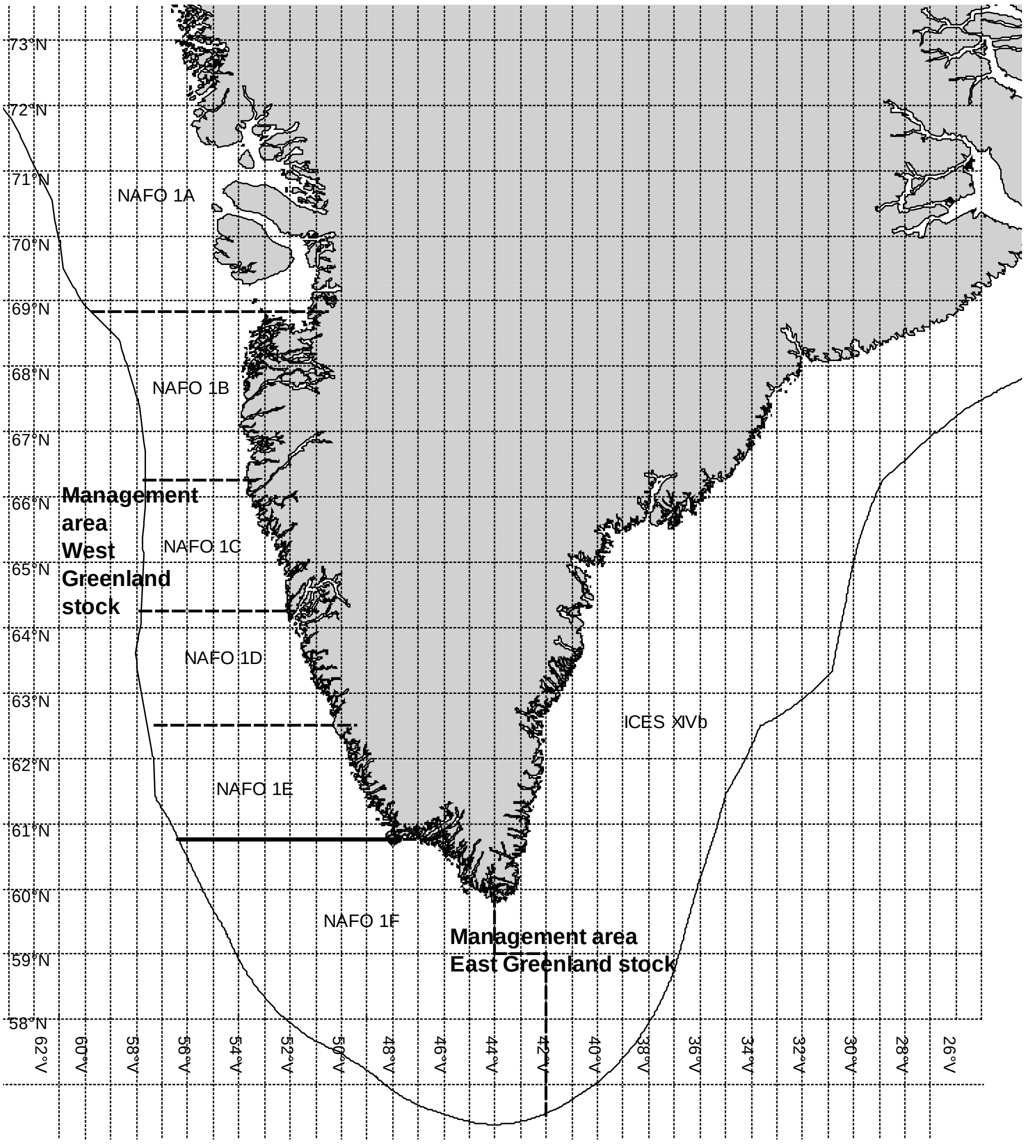

Figure 3: Proposed management areas for the offshore West Greenland cod stock (NAFO divisions 1A-1E) and offshore East Greenland cod stock (NAFO division 1F and ICES XIVb).

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The DLS approach on Greenland offshore Cod Stocks

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Introduction and methods

Results from genetic investigations and tagging experiments suggest that the Atlantic cod (*Gadus morhua*) in Greenland waters is comprised of three spawning stocks; 1) West Greenland inshore stock 2) West Greenland offshore stock and 3) East Greenland stock in the Iceland and East Greenland ecoregion (Stor-Poulsen et al. 2003, Therkildsen et al. 2013).

Currently separate advice is given for the inshore stock and combined advice is given for the offshore stocks. The advice for the offshore cod is based on the precautionary approach and has been zero for many years (ICES 2014a).

In WD02 we argue that advice should be given separately for the two offshore stock components based on the distribution of the fishable biomass (B4+, see WD02). Accordingly, all indices presented here are B4+ indices.

Currently no assessment procedure is agreed upon on either stock. The Data Limited Stock (DLS) approach could be an alternative for both offshore stocks, and here we present this procedure as it applies to both stocks.

In the DLS framework both stocks are considered to belong to category 3: "*Stocks for which survey-based assessment indicate trends*". Accordingly, the suggested Year_{t+1} advice is based on a comparison of the two most recent index values with the three preceding values, combined with recent catch data (method 3.2):

$$C_{y+1} = C_{y-1}\left(\frac{\sum_{i=y-x}^{y-1} I_i / x}{\sum_{i=y-z}^{y-x-1} I_i / (z-x)}\right)$$

where

C_{y+1} = Catch advice for the next yea (in this case 2016)

C_{y-1} = the average catch of the last three years (in this case 2012 - 2014).

I = Survey index value for B4+

x = 2

z = 5

Results and discussion

West Greenland Offshore Cod Stock

The advise management area for this stock is proposed to cover the West Greenland area north of 60°45N (equals NAFO divisions 1A-1E, figure 1, see WD02). Data available for this area are German survey data from 1982-present (covering NAFO divisions 1C, 1D and 1E), and Greenland survey data (covering NAFO divisions 1A to 1E) from 1992-present. No fishery has been going on in the period 1992-2006, since 2007 catch have fluctuated between 0-500 tons (table 1).

Table 1 shows the proposed advice in the years 2011-2016. Advice based on both surveys in recent years exceeds the y-1 catches by more than 20%, and consequently the “Uncertainty cap” is invoked as is the “Precautionary buffer”. Hence, the advice would be similar using either survey in 2014 and 2015 (and possible 2016 pending the German survey).

The difference between survey indices is best explained by difference in coverage, with the Greenland survey covering a larger area (stops at 72°00N) than the German survey (stops at 67°00N). Also, single large hauls tend to dominate the index meaning that year to year variation has been large in recent years. Such an effect is most likely to be most pronounced at low stock sizes, which is currently the case. For example, the large increase in the Greenland survey in 2014 is caused by one large haul.

The recent advice is low as a result of recent catches being below ~500 t and the stock appears to be increasing noticeably in numbers for the first time since 1990. Nevertheless, based on survey results and catch the stock is considered to be at very low biomass compared to historic levels (ICES 2014b) which is supported by the German survey series (figure 2).

According to the DLS approach (DLS method 3.1.4) such a situation warrants a different approach: “*For extremely low biomass, a recovery plan and possibly zero catch is advised*”. Hence, given the historical fishery and recent small increase in the stock, we suggest that a catches should be zero and that national recovery plan is developed, aimed at rebuilding the stock.

Table 1. Recent data and advice based on survey numbers (B4+) from two surveys calculated after the DLS category 3.2 for the management area of the West Greenland offshore cod.

Year	German index	Greenland index	Catch (t)	Advice based on German index (t)	Advice based on Greenland index (t)	Advice with Uncertainty Cap and Precautionary Buffer
2005	153	1423	1			
2006	4359	3063	0			
2007	8860	1085	466			
2008	5250	3849	549			
2009	543	1504	6			
2010	1504	1872	2			
2011	1004	2656	8	221	491	
2012	19589	6007	332	31	118	
2013	30753	28484	479	1	6	
2014		84348	66	483	205	109
2015				6756	2341	262
2016					4696	281

East Greenland offshore cod stock

The advice management area for this stock is proposed to cover the SouthWest Greenland area south of 60°45N and East Greenland (equals NAFO divisions 1F and ICES subdivision XIVb, figure 1). Data available for this area are German survey data from 1982-present, and Greenland survey data from 2008-present (table 2). Further, Commercial Catches with Catch at age is available for the period 1973-1995 and 2005-present (See WD01).

Table 2 shows the proposed advice for 2011-2016 if the DLS approach is applied. The earliest advice based on the Greenland survey is for from 2014 as the survey first covers the East Greenland part from 2008. The advice is similar between the two surveys in 2014 and 2015, but the advice in 2015 would result in C_{y+1} being >20% higher than C_{y-1}, and therefore the "Uncertainty Cap" and "Precautionary Buffer" were both applied to calculate the advice based on the catches.

Table 2. Recent data and advice based on survey numbers (B4+) from two surveys calculated after the DLS category 3.2 for the management area of the East Greenland offshore cod. * No Uncertainty Cap applied as calculated advice based on both surveys are not 20% different from the average catches in 2010-2012 (C_{y-1}), Precautionary Buffer therefore applied to the average of the advice from the two surveys.

Year	German index	Greenland index	Catch (t)	Advice based on German index (t)	Advice based on Greenland index (t)	Advice with Uncertainty Cap and Precautionary Buffer
2005	30682		890			
2006	41958		2456			
2007	145002		5205			
2008	84674	64771	14628			
2009	71639	54860	4965			
2010	65402	113423	2669			
2011	54800	79848	5113	8905		
2012	100796	75161	5411	5616		
2013	140819	205092	5509	2543		
2014		209703	7000	4629	4387	3607*
2015				10096	9054	5131
2016					13845	5734

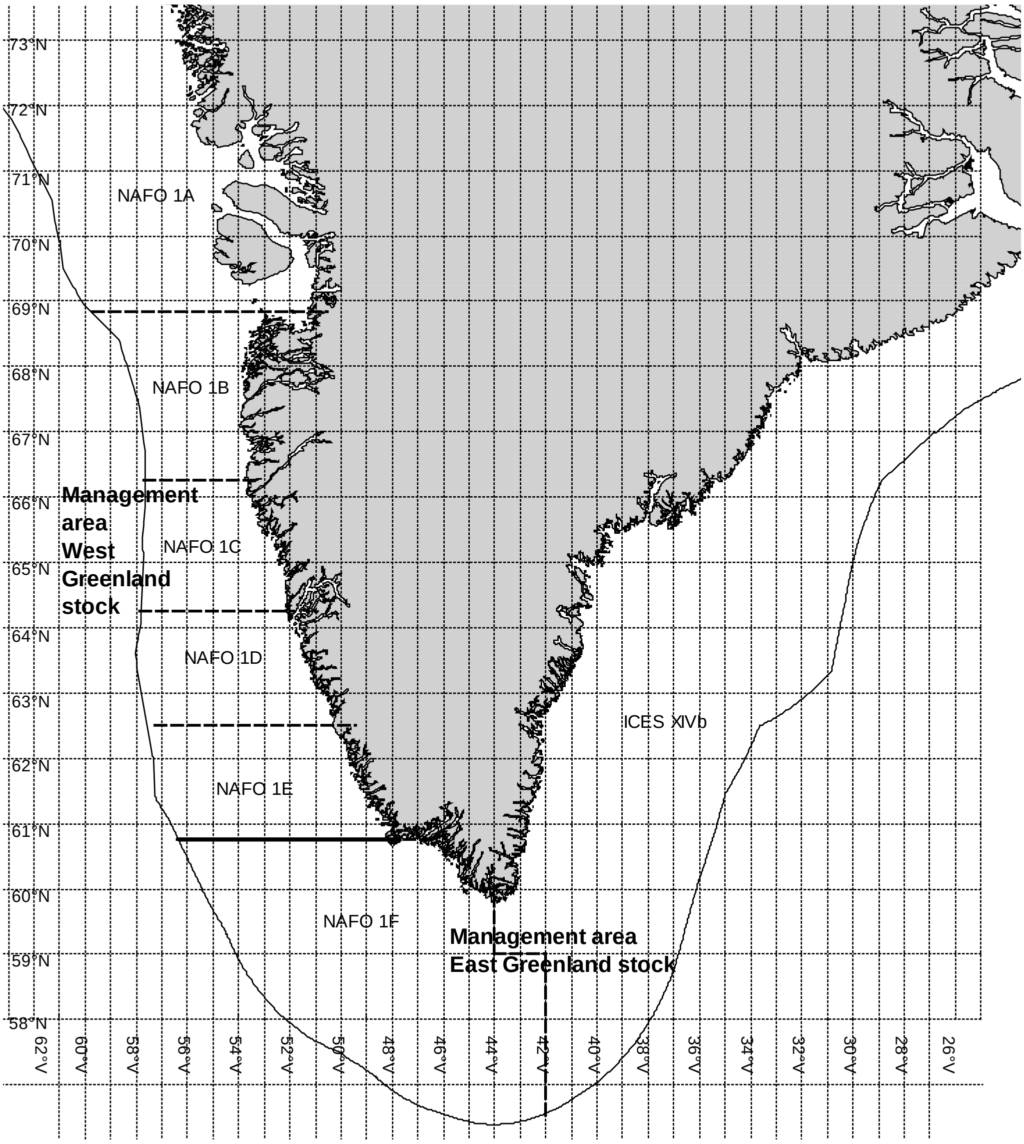

Figure 1: Proposed management areas for the offshore West Greenland cod stock (NAFO divisions 1A-1E) and offshore East Greenland cod stock (NAFO division 1F and ICES XIVb) (see WD02).

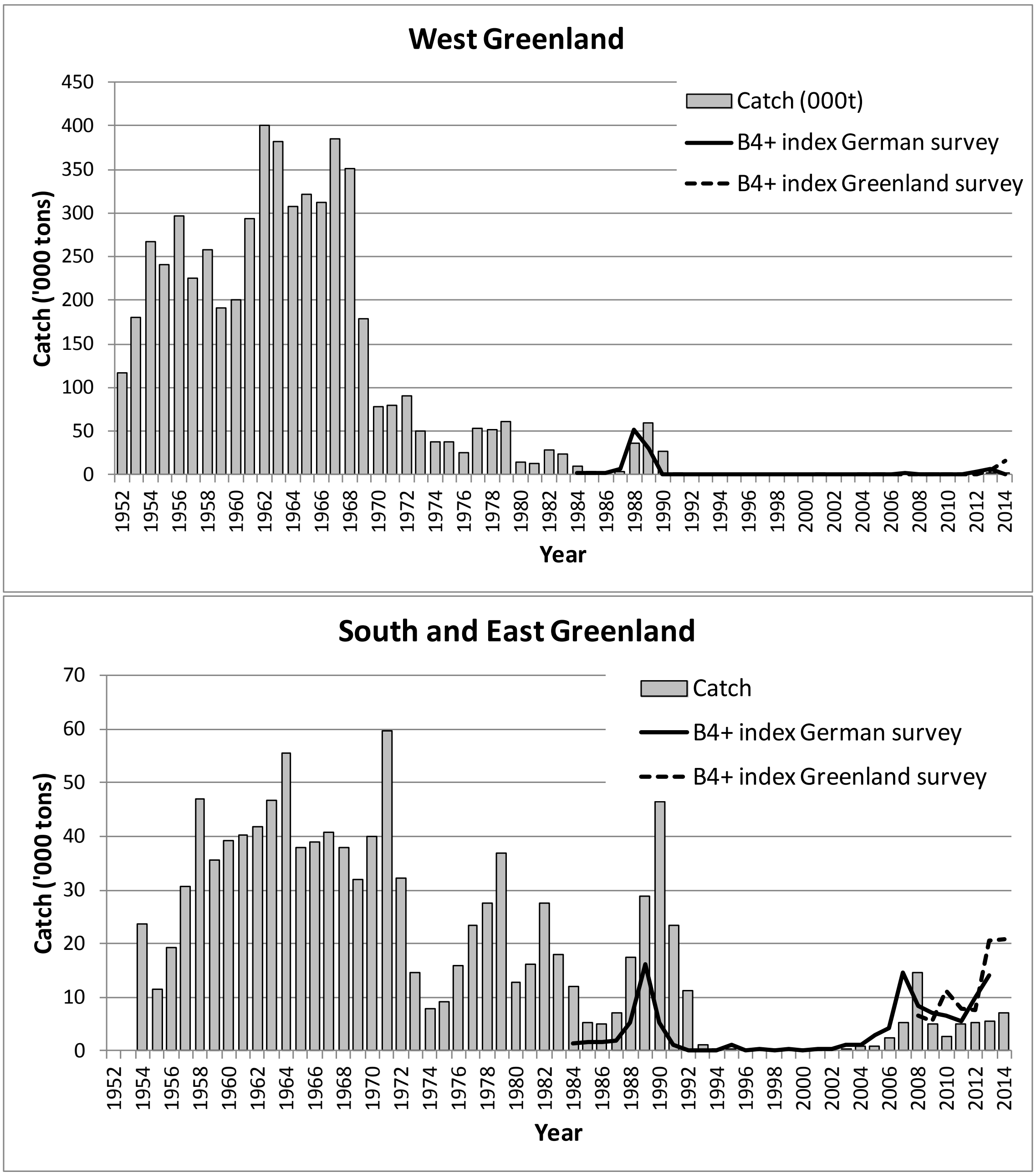

Figure 2: Commercial catch, German survey B4+ biomass and Greenland survey B4+ biomass in the management areas in West Greenland (NAFO divisions 1CDE) and South and East Greenland (NAFO division 1F and ICES subdivision XIVb).

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A working document to WKICE 2015

Setting a reference point, B_{lim}, for the capelin in Iceland-East Greenland-Jan Mayen area.

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Introduction

The prime management objective for short-lived species like capelin is to preserve a large enough spawning stock to ensure propagation. Since 1979/1980, the target for the capelin in Iceland-East Greenland-Jan Mayen area (IGJM) has been to leave 400 000 tonnes to spawn (Vilhjálmsson and Carscadden 2002; Gudmundsdottir and Vilhjálmsson 2002). It was considered that those 400 000 tonnes should be enough to sustain the stock and for the predators as well (Gudmundsdottir and Vilhjálmsson 2002). In short, then this HCR of leaving 400 000 tonnes to spawn has been in place ever since 1979.

At the time of the establishment of the 'target remaining spawning stock' an analytical assessment of target SSB was not possible. As the capelin stock had only been acoustically measured since 1978 (Vilhjálmsson and Carscadden 2002), there were too few points to base a stock-recruitment relationship on. Therefore, other approaches had to be used. Firstly, it was not considered advisable to reduce the stock to less than 2/3 of the 1979 spawning stock of 600 000 tonnes, while gaining more experience with the acoustic measurements (Vilhjálmsson 1994). Secondly, a minimum of 500 000 tonnes had been set as required for spawning of the Barents Sea capelin and as the Barents Sea capelin stock was thought to be bigger than the IGJM capelin and the stock of species predating on the Barent Sea capelin thought to be much larger too, then 400 000 tonnes were set for the IGJM capelin stock (Vilhjálmsson and Carscadden 2002). The '500 000 tonnes' for the Barents Sea capelin stock were however based on a stock-recruitment relationship but with a limited number of years and rather poor data (Carscadden et al. 2013, Gjøsæter et al. 2015).

Reference points have not been defined for the IGJM capelin. In the current management agreement, 400 000 tonnes are still used as the target remaining spawning stock, but it has not been evaluated as a reference point by ICES. In the ICES working group reports in the years 1998-2010 it is suggested to use 400 000 tonnes as B_{lim}, but since 2011 it is called an escapement target, $B_{escapement}$.

The assessment model used for the IGJM capelin was examined during the benchmark meeting WKSHORT in 2009 and not endorsed. Now a model in line with the one for the Barents Sea capelin is being developed. Uncertainty in measurements and predation by cod, haddock and saithe on capelin has been integrated into the model. The current HCR of 'leaving 400 000 tonnes to spawn' is replaced by a new one based on probabilistic terms saying that 'the realised SSB is larger than B_{lim} with a given probability'. This is a pure escapement strategy and for this kind of HCR the only reference point needed is B_{lim} (ICES 2014a).

The aim with this working document is to argue for setting the reference point B_{lim} for the IGJM capelin.

Material and methods

Data for spawning stock (SSB) and recruitment at age 1 (R) are taken from the NWWG report in 2014 (ICES 2014b). The SSB/R relationship was explored graphically (Figure 1) for SSB in 1979-2010 and corresponding R.

Results

Carscadden et al. 2013 attempted to fit a Beverton-Holt stock-recruitment model by using data from 1980-2006. No significant relationship were found and the additional few points since then have not changed the picture, so that conclusion still holds.

There are some shortcomings inherent in these data. The stock has been managed in the way to leave 400 000 tonnes for spawning and that requirement has been met in most year. Hence it is not strange to see the SSB estimates close to 400 000 tonnes in most years and a wide range of recruitment associated to them, as the year class strength is variable like in any other stock. So these data are of no use for SSB/R relationship.

As said, the management failed in some years. Early 1980s preliminary catch quotas were set on arbitrary grounds, resulting in too high quotas, temporary closures of the fishery and moreover a moratorium in the winter 1982 and the whole fishing season 1982/1983 (Vilhjálmsson and Carscadden 2002). After this collapse a more cautious management was adopted and a model was made to predict the quota (Gudmundsdottir and Vilhjálmsson 2002). The model was used without trouble in the fishing seasons 1983/1984-1988/1989 but predicted too high quota for the fishing seasons 1989/1990 and 1990/1991, resulting in temporary closure of the fishery and SSB below the target in 1990 and 1991. As a consequence that model was abandoned and a new made.

The newest point in the time series being under the target of 400 000 tonnes is the spawning stock in 2009. A preliminary quota for the fishing season 2008/2009 could not be set as the indices on immature capelin were too low, so for the 2008/2009 fishing season the ICES advice was that "There should be no fishery until new information on stock size becomes available and it shows a predicted spawning-stock biomass sufficiently larger than 400 000 t in March 2009 to ensure that there is a high probability that the actual SSB will be at least 400 000 t if any fishery is allowed" (ICES 2008). Acoustic surveys during the fishing season estimated the SSB to be under the 400 000 tonnes target and no quota was recommended that year. However, 15 000 tonnes were allocated to the scouting vessels.

Fortunately the stock recovered all years, where the SSB was under the target of 400 000 tonnes, and produced recruitment from the third lowest to the highest. The highest recruitment is from 1983, but in that year several fish stocks in Icelandic and Norwegian waters produced strong year classes. It was suggested to be linked to increased inflow of warm Atlantic water to the Icelandic and the Barents Sea area (Jakobsson 1992). As the stock recovered it is the question whether any of the points from 1980-1983, 1990-1991 and 2009 could be a basis for B_{lim}, but a reference point B_{lim} may be identified as the stock size below which there may be reduced reproduction resulting in a reduced recruitment (ICES 2013).

The range of the spawning stock in the years 1980-1983, 1990-1991 and 2009 is from 115 000 to 330 000 tonnes and the range in the recruitment is from 49 to 251 billions (10^9). A candidate for B_{lim} is the average of the three lowest SSBs, that is in 1981, 1982 and 1990. They all produced recruitment at or slightly above the long term average recruitment, $R_{1979\text{-}2010}$=124 billions. As there are no uncertainty estimates available for the SSBs in these years it is suggested to use the average, $SSB_{1981,1982,1990}$=142 000 tonnes, and raise the number to the nearest ten thousand tonnes. On basis on these observations the proposal is is: B_{lim}=150 000 tonnes.

Discussion

Carscadden et al. 2013 came to the conclusion that the 400 000 tonnes as a target spawning-stock biomass has not compromised recruitment and would continue to be a prudent management objective. The B_{lim} rule is expected to be safeguarding against recruitment failure and we have suggest B_{lim}=150 000 tonnes for the IGJM capelin. A corresponding value for the Barents Sea capelin is 200 000 tonnes whereas their formerly rule of minimum target spawning stock was 500 000 tonnes. By changing the model procedure for the Barents Sea capelin from being based on the 'target spawning stock' to 'B_{lim} rule' then the underlying harvest strategy likely didn't change much (Gjøsæter et al. 2015). Based on that, it is expected that it also holds for the IGJM capelin stock.

F reference points may not be relevant for short-lived species (ICES 2014a). ACFM agreed on the view that fishing mortalities reference points were not relevant for the Barents Sea capelin stock (ICES 1999), hence also valid for the IGJM capelin stock.

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Figures

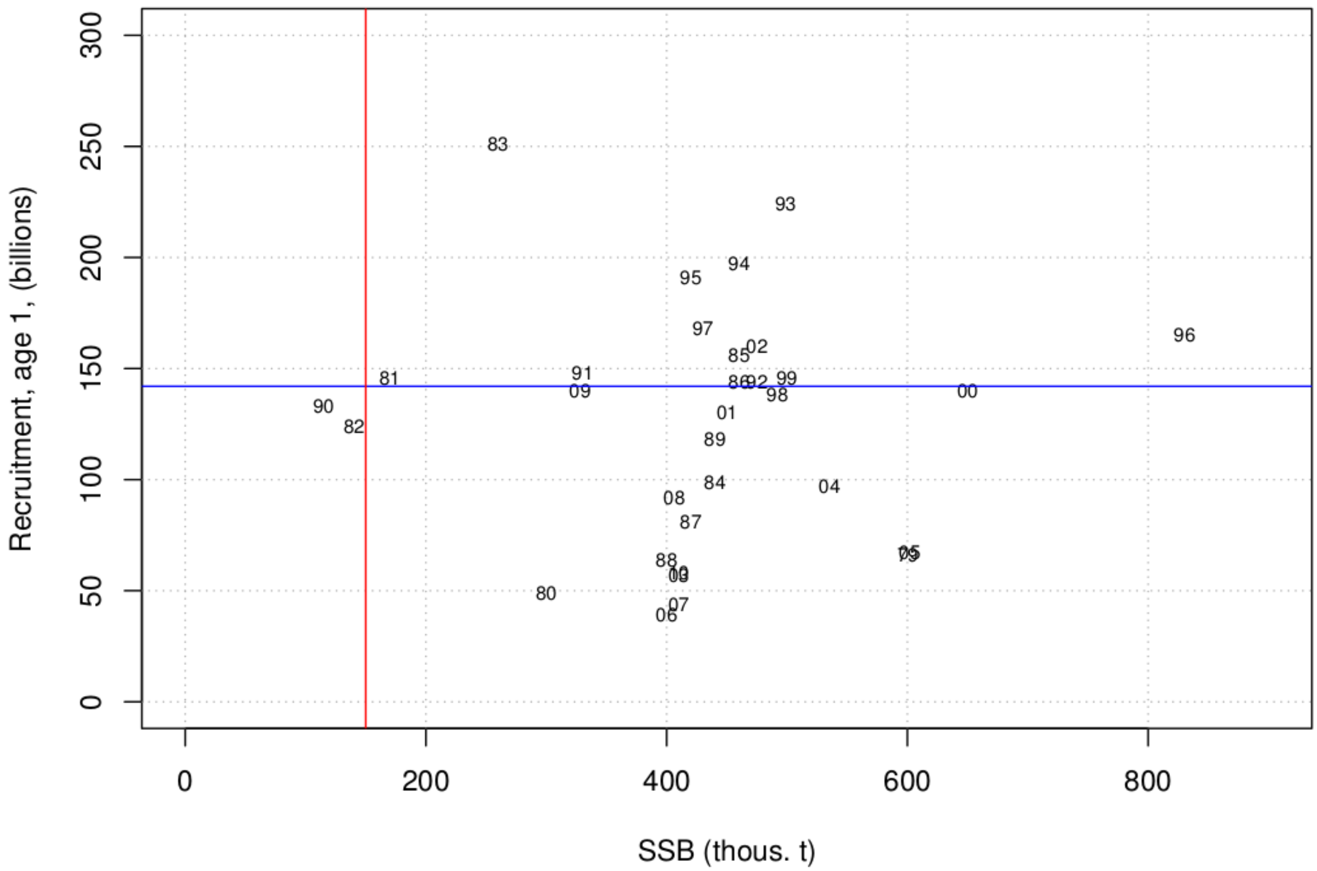

Figure 1. Icelandic capelin. SSB/R relationship. Numbers denote years of spawning. The red line is the proposed B_{lim} and the blue line is the long term average recruitment.

A working document to WKICE 2015

Overview of advice for capelin in Iceland-East Greenland-Jan Mayen area in the last 20 years and notes on future advice giving.

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Introduction

The capelin stock in the Iceland-East Greenland-Jan Mayen area (IGJM) has been managed according to the same management plan since 1989. It is a two-step management plan, where the first step is to set an initial TAC for a fishing season and the second step is a revision of the initial TAC in the fishing season itself. Both these steps take account to the HCR that has been in place since 1979, namely that a minimum of 400 000 tonnes should be left for spawning.

The pillars in the assessment of the IGJM capelin have been surveys conducted in autumn (October) and in winter (January-February). initial TAC for a fishing season is based on estimates of the number of immature capelin from a survey in autumn the year before the fishing season starts. Theoretically both immature and maturing capelin can be assessed by the same survey in autumn, so if an initial TAC is not at hand, a quota could be set based on the estimates of the maturing capelin, given the restriction that sufficient quantities are measured. Final TAC is based on the results from the acoustic measurements during winter, but the surveys in winter are aimed at the spawning migration. As always there are exceptions from the rule and in some years the autumn surveys are basis for the final TAC.

Since early 1990s the same prediction model has been used and the same method for setting the final TAC. These methods were not endorsed by WKSHORT 2009 but suggestions made to new ones. The methods were 'old fashioned' using point estimates and the recommendation was to adopt an stochastic approach incorporating key uncertainty factors.

Vilhjálmsson and Carscadden (2002) gave an overview of the assessments surveys in the years 1978 to 2001 and in Gudmundsdottir and Vilhjálmsson (2002) and Vilhjálmsson and Carscadden (2002) is an overview of the advice given in these years. The intention with this working document is to round up how the advice has been done in the last 20 years or so and also discuss briefly how to give advice in nearest future with new models.

Material and Methods

Annual reports about the State of the Marine Stocks in Icelandic waters, ICES reports, ICES advice sheets and survey reports of acoustic surveys on capelin in Iceland-East Greenland-Jan Mayen area are used in addition to the reference list.

Advice history

In the nineties, initial TAC could be set based on acoustic estimates of immature capelin from the autumn surveys. Estimates of the maturing part of the stock were also available from the same surveys until 1997. Based on these the initial TAC was only once revised, in autumn 1992. A final TAC for the fishing seasons 1995/96 and 1996/97 was set after the autumn surveys in 1995 and 1996 and no surveys took place in the following winter. In the last two years of this decade, that is 1998 and 1999, the autumn surveys failed to locate the maturing part of the stock (Vilhjálmsson and Carscadden, 2002) and it was also so throughout the next decade. Winter surveys were conducted in the nineties, except the before mentioned two years. Final TAC was set on their basis, except in 1994 and 1998, as it was decided after the surveys in winter to let the autumn surveys be the basis for the final TAC, so de facto the final TAC was set four times in the nineties on the basis of the autumn surveys.

In the first decade of the 21st century, initial TACs could only be set three times on the basis of acoustic estimates of immature capelin from autumn surveys (in the autumn of 2000, 2001 and 2006). initial TACs were set two more times in this decade, for the fishing seasons 2003/04 and 2004/05, but these were based on acoustic measurements in April 2003 and in June/July 2004. The advice for the fishing seasons 2005/06, 2006/07, 2008/09 and 2009/10 was that there should be no fishery until new information on stock size became available and it showed a predicted spawning stock biomass of at least 400 000 t the following spring in addition to a sizeable amount for fishing. In these fishing seasons an advice was not given the until after the measurement of the spawning migration in the winter, as the surveys in autumn during this decade failed to assess the maturing part of the stock. Winter surveys were conducted all years during this decade and final TAC set on their basis. In the winter 2004 and 2008 there was temporary closure of the fishery and the fishing season, 2008/09 was never opened for fishing.

In the second decade of the 21st century, acoustic surveys have been conducted in autumn in all years, except in 2011 due to a strike. initial TAC, based on acoustic estimates of immature capelin from these surveys, could only be set twice, that is based on results from autumns 2010 and 2013. In the other years the estimates of the immature capelin were too low for advising an initial TAC, so the advice was not to open the fishery until new information on stock size became available and it showed a predicted spawning stock biomass of at least 400 000 t the following spring in addition to a sizeable amount for fishing. However, during this decade then the maturing stock could be assessed in the autumn surveys and on their basis a quota could be set and after the survey in autumn 2014 the initial TAC was revised, 35 000 tonnes were added to the already set initial TAC. Final TAC during this decade was set on the basis of acoustic surveys in winter, except in the fishing season 2013/14. As the surveys in 2014 were not valid for assessment purposes the autumn survey in 2013 is the basis for the final TAC that season.

Discussion

In contrast to the 1990s the whole distribution area of capelin could not be covered in autumn in the 2000s. The stock was westerly distributed in the “usual” survey area and often bad weather and drift ice hampered the measurements. The estimated abundance of immature capelin in the autumn surveys was very low and an initial TAC could only be set twice on their basis. The estimates of the maturing part of the stock were considered invalid and therefore could not be used to set a quota for the fishing season. In the second half of the 2000s the return migrations from the feeding area occurred later, so the spawning migration started later too and where it entered the continental shelf was variable too. During this time the stock decreased as well. This is mirrored in lower final TAC in the late 2000s than in the 1990s and early 2000s (figure 1). A lot of effort was made in surveying the capelin stock in these years. In addition to the research vessels, scouting vessels took part in the search too.

It is know that environmental changes can affect distribution of fish stocks (reference??). Warming has been observed in the North Atlantic Ocean since the mid 1990s and as capelin is a cold water species it could be a natural reaction to warming environment to seek for colder water. So it was suggested that the capelin stock had expanded/moved the nursery and the feeding area to the west Vilhjálmsson (2007).

So a larger area than before had to be covered, that is from the continental shelf of East Greenland in the west, north along the continental shelf edge (to about 73ºN in 2013), as well as Denmark Strait and the continental slope north off Iceland. The surveys were brought about a month forward in time, as then there is more chance of surveying the area without ice. So to a certain extent a new time series in acoustic surveys starts in autumn 2010. It is believed that since autumn 2010 the distribution area of the capelin stock has been covered in autumn.

The final TAC has only once been set lower than the initial TAC, that is in the fishing season 1994/1995 (figure 1). Then is was decreased of 100 000 tonnes. During this century the stock has always been surveyed again in winter, which generally has led to increases in the quota, but also to a moratorium on fishing, temporary in one case (2008), for the whole season in another (2009). It is obvious that there has been a change in the level of the TAC since mid 2000s, being much lower in recent years.

When no initial TAC can be advised it means that there will be no summer fishery in the fishing season. The next possible time to set a TAC is after a survey in autumn in the corresponding fishing season. It then depends on the outcome of the maturing part of the stock, if it is possible or not. If not then the results from the survey in winter in the fishing season have to be awaited. If it is the case, that is a TAC can only be given after an acoustic measurement in winter, then the fishing season spans over just two months or so. Three such cases have occurred in the 2000s, in the fishing seasons 2005/06, 2006/07 and 2009/10. The TAC in these seasons were low. These cases show the necessity of repeated-surveys approach.

The same surveys as hitherto will be the pillars for the assessment of the IGJM capelin in the next future, but new methods will be applied. The deterministic harvest control rule (HCR) which is based on point estimates of SSB will be abandoned and a stochastic approach incorporating key uncertainty factors will be adopted as suggested (WKSHORT 2009). A multi-species component will be included as well, addressing predation on capelin by cod, haddoc and saithe. The Barents Sea capelin HCR has been used as a template for the proposed HCR for IGJM capelin, although implementation details are different. The proposed rule is to find the TAC so that $P(SSB < B_{lim}) < 5\%$.

The same steps as hitherto will be taken when giving the advise:

- **Initial TAC** will be set on the basis of estimates of immature capelin from the autumn surveys. As the initial TAC can be overridden by estimates made next autumn and/or winter of the same cohorts as mature fish and closer to its spawning event, we do not propose a stochastic model for this part of the fishery management plan but propose a revision of the current method of setting a preliminary qouta, through simplification and contrast with historic estimates of uncertainty in numbers immature and SSB (Wdxx).
- **Intermediate TAC**. Based on the acoustic estimates of the maturing part of stock in autumn either an already set initial TAC can be revised or a TAC can be set in the absence of an initial TAC. The proposed rule of finding a TAC so that $P(SSB < B_{lim}) < 5\%$ will be used. See further WDxx (Höski).
- **Final TAC**. Based on the acoustic estimates of the spawning stock in winter a final TAC will be set. The proposed rule of finding a TAC so that $P(SSB < B_{lim}) < 5\%$ will be used. See further WDxxs (Höski, Siggi).

A few points to consider:
From the above it is clear that **decisions** will have to be made if there is a discrepancy between the autumn survey estimates of the maturing stock and the 'prediction' based on immature numbers in the previous year's autumn survey, or if there is a chance that the autumn survey was unsuccessful or missed the mature stock or part of it .

Opening of the fishery can be done on the basis of an initial TAC and will in that case be clear well in advance. It can also occur in-season shortly pre-season on the basis of autumn (intermediate TAC) or winter (final TAC) estimates of SSB.

Closing of the fishery should in this framework be a rare event. However after the formulation of an intermediate TAC in autumn it is possible that an initial TAC would have to be revoked. Also in-season closing of the fishery based on winter estimates will continue to be a necessary management option (last employed in winter 2008). If the most simple but admittedly slightly risky alternative for decision making in autumn mentioned below (*i.e.* letting an initial TAC stand despite 'failed' autumn survey) is opted for, the final assessment would be the only grounds for closing the fishery.

Starting the fishery on October 1 has been recommended in previous NWWG reports and in (Wdxx – Setting an initial TAC) with supporting argumentation.

General survey strategy for the IGJM capelin:

- Acoustic survey in autumn should start mid September and cover the whole of the distribution of the stock, off North Iceland west of the Kolbeinsey Ridge, from the Vestfjords onto the East Greenland shelf extending north to Scoresby Sound, and further north as necessary. Taking into account how large this area is it would be natural to aim for surveying with more than one vessel. Transect spacing should be 10--20 / <15--<30 nmi and the rectangle area used in bootstrapping is 30' latitude x 60' longitude (statistical rectangle).
  This survey should yield estimates of the immature part of the stock and of the SSB.
- Acoustic survey in winter should be undertaken in January, possibly extending into February, and cover the stock twice, against (SE to NW) and with (NW to SE) the direction of migration, in order to cancel out the inevitable bias associated with acoustic surveying of a non--stationary distribution. To achieve near--synopticity, two calibrated vessels could start from the NW and SE ends of the spawning migration. The survey should as a rule cover the area east of the Kolbeinsey Ridge along the shelf break south to the frontal area SE of Iceland. Scouting by industry vessels prior to the survey has lead to increased survey efficiency in the past and should be continued. Transect spacing 5-10 / <10-<15 nmi, rectangle area 15' latitude x 30' longitude (sub-rectangle).
  This survey is the main measurement of the SSB. We suggest not using effort at this time to survey the immature part of the stock.

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Figures

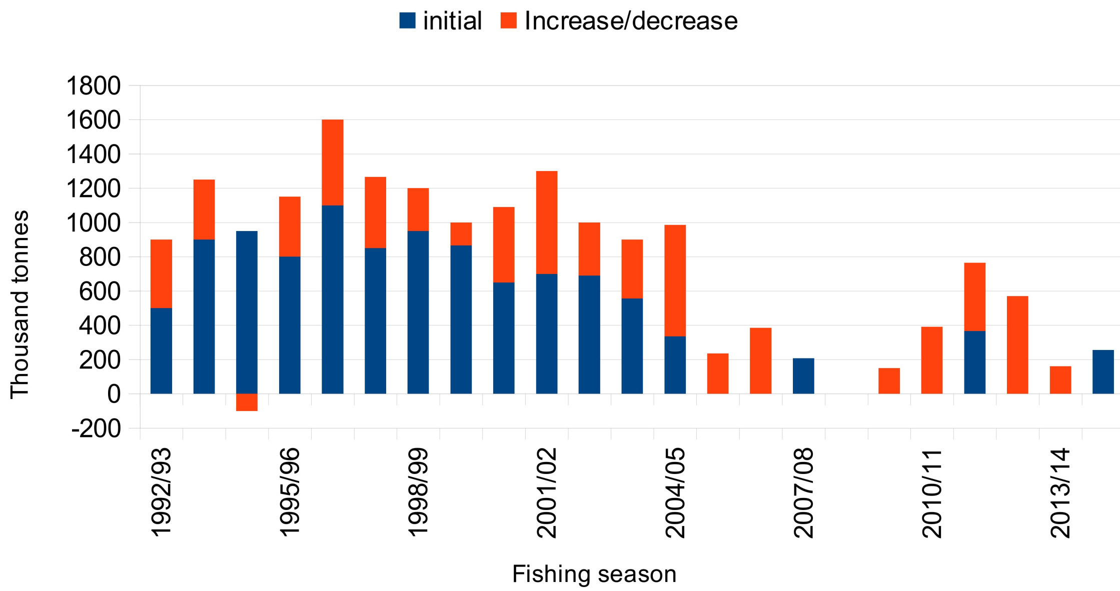

Figure 1. An initial TAC set for the capelin in Iceland-East Greenland-Jan Mayen area and additonal/subtractive TAC set on the basis of a final acoustic survey.

Stock assessment of West Greenland Inshore cod 2015 – the Coleraine model

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1 Introduction

In 2012 the first ICES advice was given separately for the West Greenland Inshore cod. Prior to that, the stock had been considered part of a larger Greenland cod stock complex but genetics, demography and tagging studies clearly indicated otherwise.

Initially, advice was given as the average of preceding catches and for the two latest years it was based on the Data limited stock (DLS) approach. For a number of reasons the DLS approach is not suitable for this stock; most noticeably because the only data (in addition to landings) available for such an approach is a recruitment survey. This survey does not reflect stock development, but only incoming recruits. Hence, the stock may be increasing due to one/several large year classes, but if these are followed by average/below average year classes, the recruitment survey will decline and consequently, the advice will follow.

The work presented here are model runs using the Coleraine statistical catch-at-age model with commercial and survey catch-at-age data being used as input. A similar approach was presented at the 2013 NWWG meeting (ICES 2013a, ICES 2013b), but it was not adopted for advice as it was not within the currently accepted framework for this stock. In this document we present a new Coleraine model run using improved and updated data and the estimates of uncertainty and summary information from the run.

1.1 Input Data

The data used in the assessment (Table 1) are annual landings (Fig. 1), biomass index from the gill net recruitment survey (Fig. 2) and catch-at-age from both commercial and survey catches (Fig. 3). The survey is a gill net survey conducted in June/July. Using various mesh sizes (16-33mm) it targets primarily ages 2-3 year olds. The selectivity curve is considered dome shaped, and mature cod are only caught in low numbers. The commercial fishery is conducted with different gears, but throughout the period it has been dominated by pound net catches (>80%). The pound nets are set near shore in shallow water, and there is a tendency for larger fish to be unavailable to the fishery due to depth preferences.

Table 1: Input data for the Coleraine Statistical catch-at-age model

Data	Years	N
Landings	1976-2014	39
Commercial catch-at-age	1976-2014 (except 1998 and 2001)	37
Recruitment survey biomass index	1985-98, 2002-06, 2010-14	24
Survey catch-at-age	1985-98, 2002-06, 2010-14	24

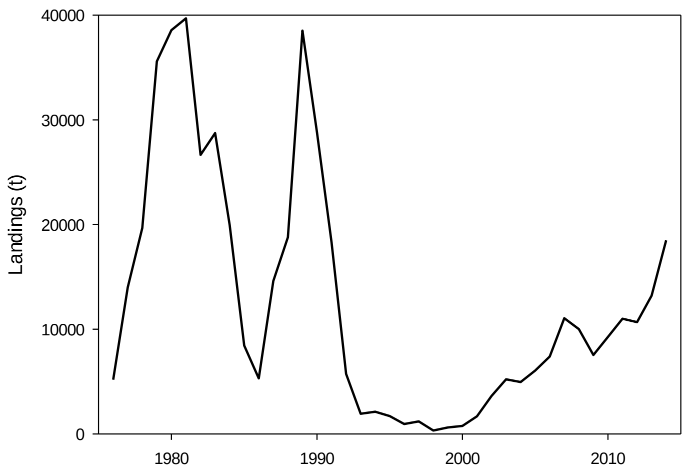

Figure 1: Annual landings in the West Greenland inshore cod fishery.

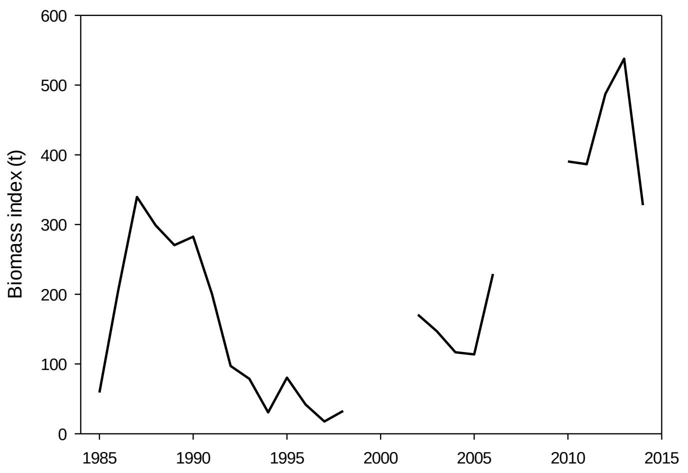

Figure 2: Biomass index from the gill net recruitment survey.

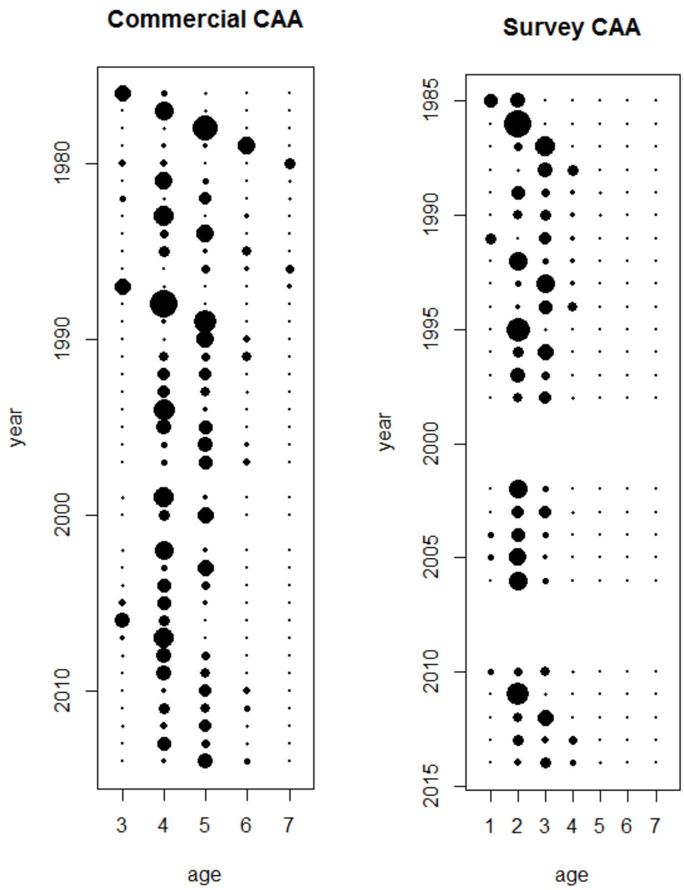

Figure 3: Commercial (left) and survey (right) catch-at-age. The circles represent relative frequency in each year.

1.2 Input data scrutiny

Catch in numbers

In order to examine the catch matrix for changes in selectivity and consistency a separable VPA was conducted. Reference age was assumed at age 5 (age group with fully recruited to gear). Among a range of terminal Fs and Ss exploited, lowest SSQ was obtained with a terminal F of 0.2 and an S of 0.5. Residuals from this setting are provided in Fig. 4 (upper) along with the selection pattern (lower). No obvious trend is observed in the residuals over the time series indicating that no shifts in fishing pattern have occurred. However, residuals are high in many cases, up to 4.5, suggesting that the catch matrix is noisy. Internal consistency in the catch matrix (e.g. ability to follow cohorts) is illustrated in Fig. 5 where year-class is plotted against the year-class observed next year. Overall, no regressions are significant (R2<0.95) but in the range 0.4-0.8. Catch curves indicate consistent decay of cohorts and illustrates the low numbers caught in the 1990s (Fig. 6). These low numbers likely impede exact estimation of fishing mortality in this decade.

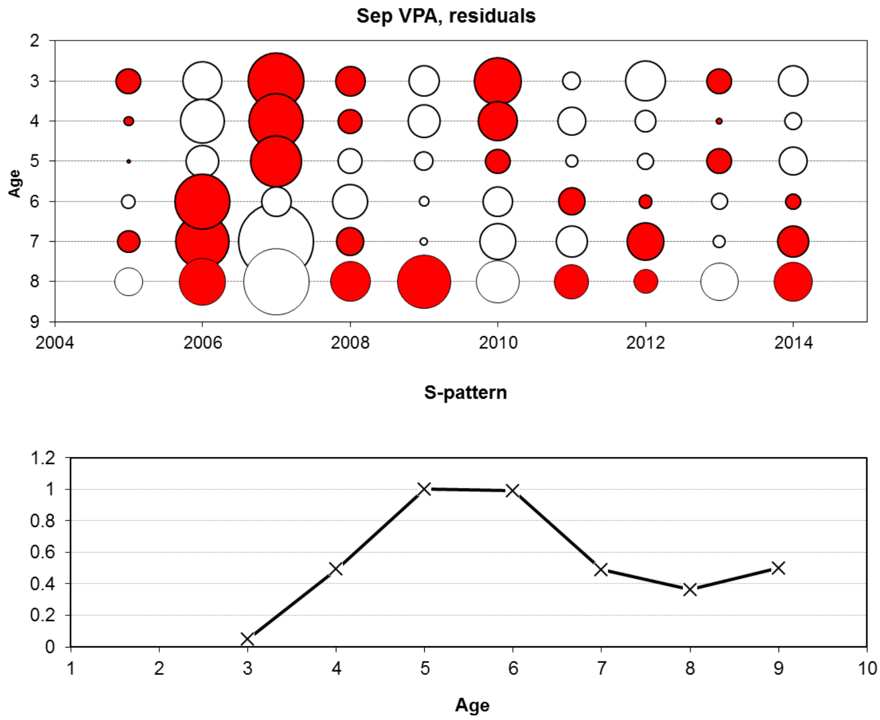

Figure 4: Upper: residuals from a Separable VPA assuming the selection pattern as provided in lower figure. Reference age is set to age 5 and terminal F to 0.2. Red bubbles are positive and white bubbles negative. Largest bubbles in plot represents residuals of approx. -4.5 (age 7 in 2007).

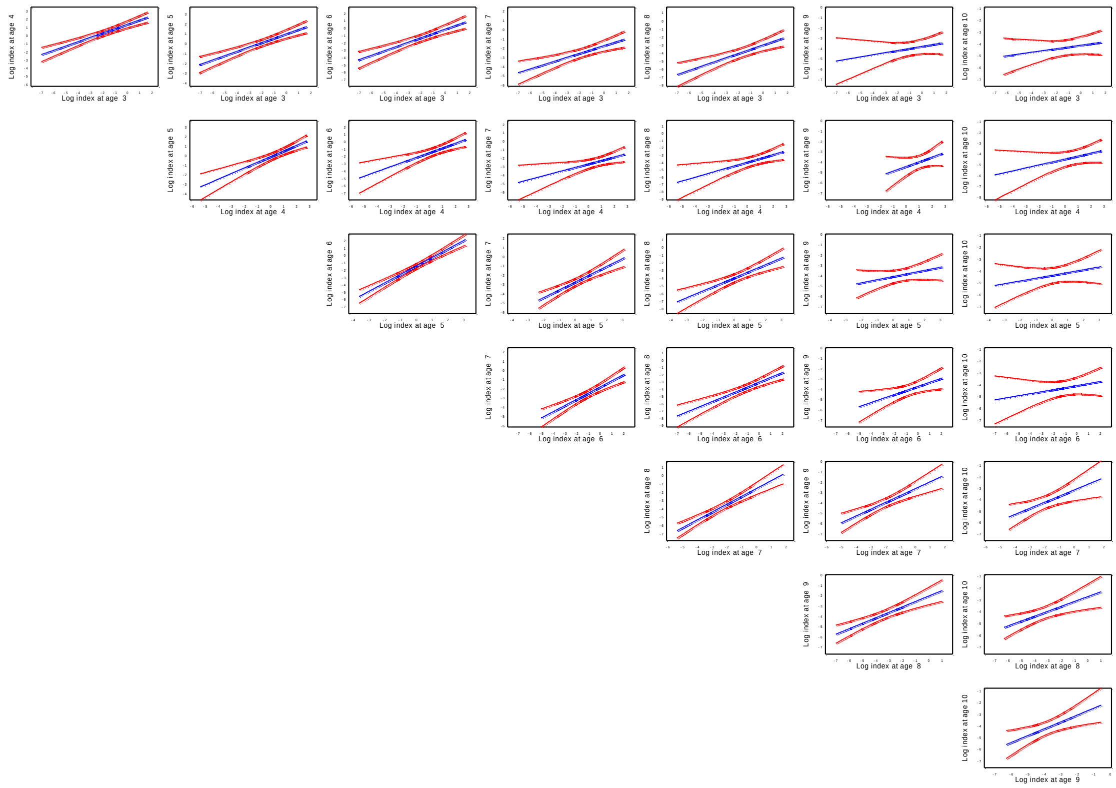

Figure 5: Scatterplot of age regressions (log log) in catch matrix with linear regressions indicated.

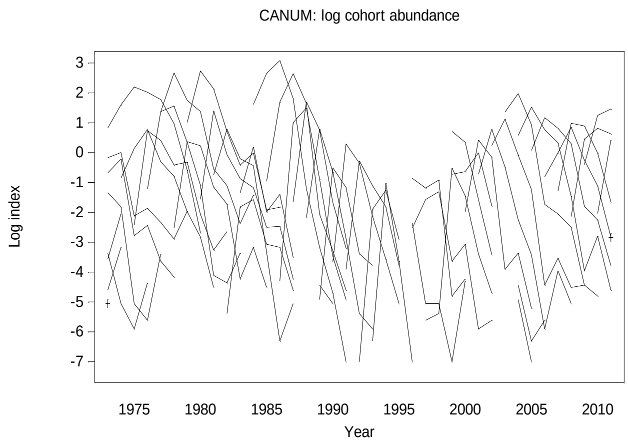

Figure 6: Catch curves based on catch matrix.

Survey

The gillnet survey is designed to select small fish and ages 2-4 are considered fully selective to the small meshed gillnets. The ability of the survey to track year-classes are shown in Fig. 7. The 1984 and 2009 YC's are tracked markedly by most age-groups while the remaining YC are tracked with various extents. The internal consistency in the survey is given in Fig. 8. No regressions are significant, but in the range 0.27-0.65. Thus the internal consistency only seems reasonable well for the survey, and could be improved. Even for the predominant age-groups in the survey (ages 3-4) cohorts are followed poorly (R2=0.27).

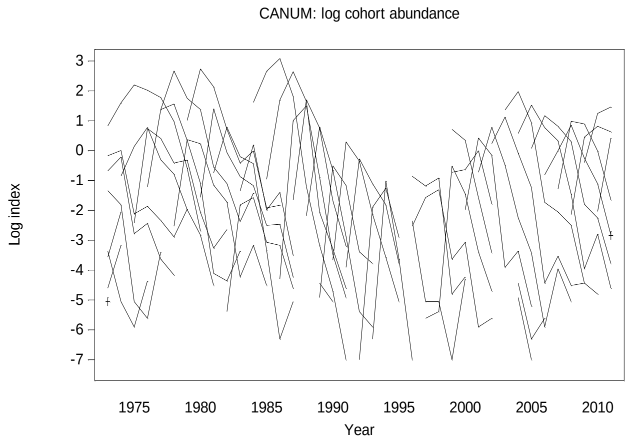

Figure 6: Catch curves based on catch matrix.

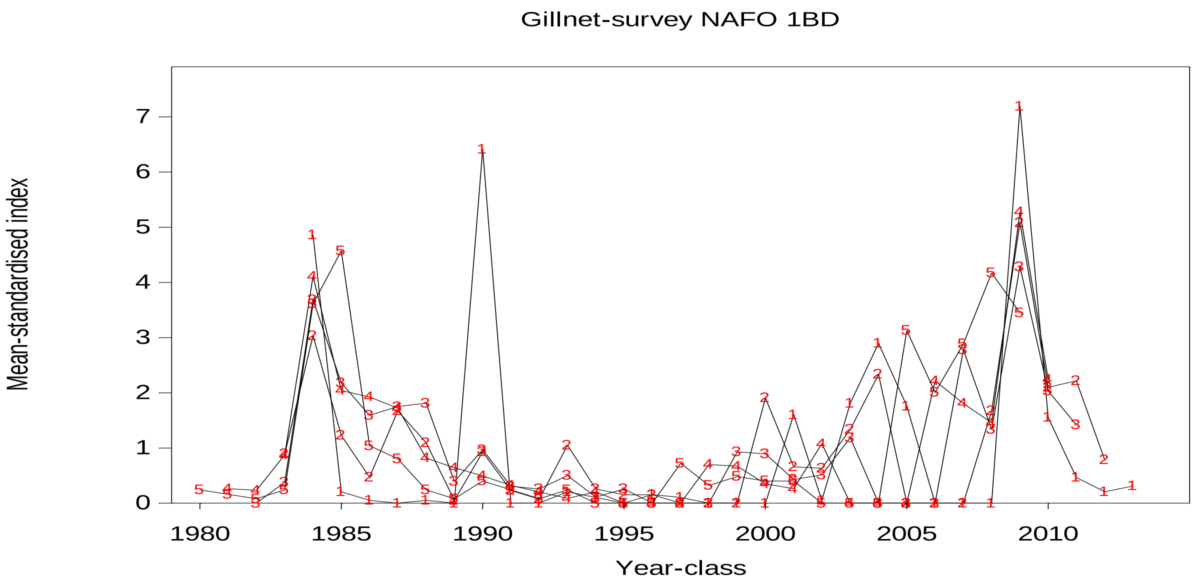

Figure 7: Time-series of year-class strength by age group in the gillnet survey.

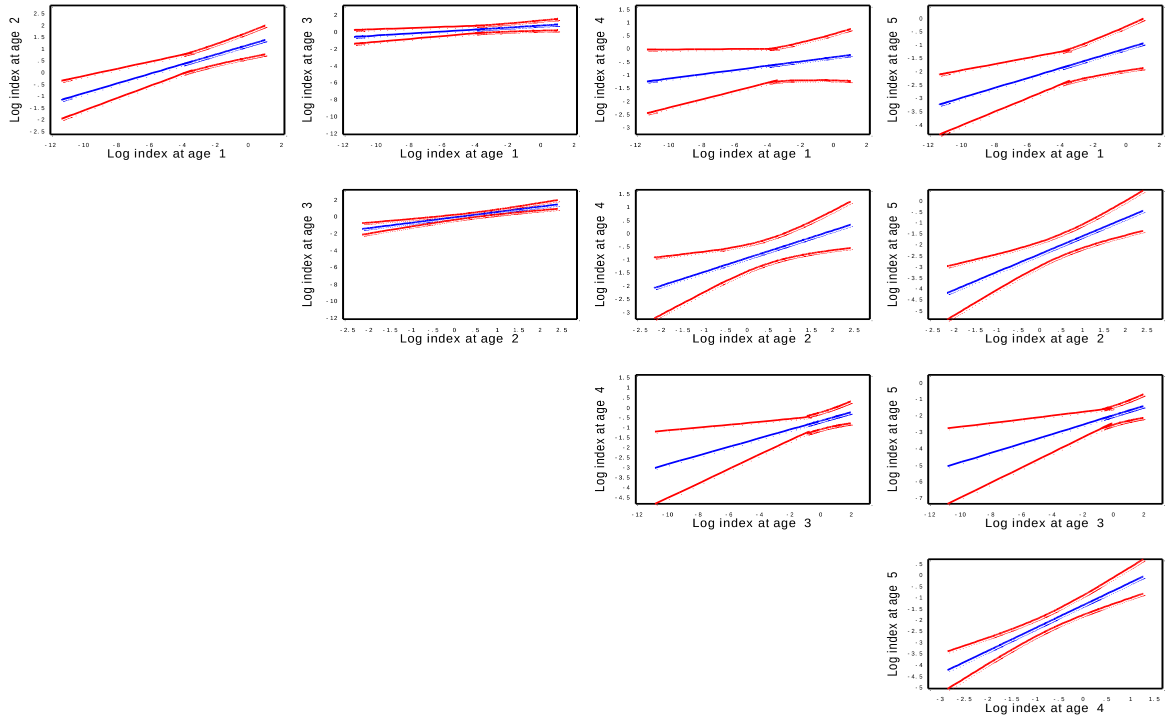

Figure 8: Scatterplot of age regressions (log log) in survey with linear regressions indicated.

2 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, abundance indices from different fisheries and surveys and allowing for missing years. In addition data and parameters can be sex- and gear specific. The model is implemented in AD Model Builder (Fournier et al. 2012), supporting maximum likelihood or Bayesian estimation, using the delta method and/or Bayesian MCMC to analyze the uncertainty. Several variations of simple age-based Coleraine models have been described and analyzed in detail by Magnusson and Hilborn (2007). The model used in this assessment is an age-based Coleraine model. Natural mortality (M) rate is assumed to be M =0.25 and age 7 is a plus group, selectivity is constant between years and landings are assumed to be known without error. M was set slightly higher than usual for cod to compensate for the fact that some migration out of the area by offshore cod stocks is expected. Age 7 was used chosen as a plus group as on average only 6% of the landings were in these older age groups. Various M scenarios where explored as early runs indicated that this had an effect on the output. Also, two time series scenarios were examined. The 1984 year class was in previous model runs identified as the cause of large anomalies. Hence, a series of runs using only data from 1992 and onwards were preformed. Due to model instability, it was not possible to run uncertainty analysis using the delta method or MCMC procedure. Instead, model uncertainty was evaluated by comparing several runs with variations in key input parameters.

2.1 Model dynamics

Population dynamics are governed by the equation:

$$N_{t+1,a+1} = N_{t,a}\, e^{-M}(1 - {}_{C}S_a u_t)$$

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 the harvest rate. The oldest age group, A, is treated as a plus group and is described by the equation:

$$N_{t+1,A} = N_{t,A-1}\, e^{-M}(1 - {}_{C}S_{A-1} u_t) + N_{t,A}\, e^{-M}(1 - {}_{C}S_A u_t)$$

Selectivity is an asymmetric normal determined by three shape parameters:

$$S_a = \begin{cases} \exp\left(\frac{-(a-S_{\text{full}})^2}{\exp(S_{\text{left}})}\right), & a \leq S_{\text{full}} \\ \exp\left(\frac{-(a-S_{\text{full}})^2}{\exp(S_{\text{right}})}\right), & a > S_{\text{full}} \end{cases}$$

where S_{full} is the age at full selectivity, S_{left} describes the left hand slope of the curve, and S_{right} the right hand slope of the curve. Both fleet and survey selectivity is thus allowed to be dome-shaped, as a priori, it seems likely that the pound net fleet and juvenile survey may not fully select the oldest fish.

Harvest rate is defined as the fraction removed from the vulnerable biomass in the middle of the fishing year:

$$u_t = Y_t / V_t$$

where Y is catch and V vulnerable biomass:

$$V_t = \sum_a ({}_{C}S_a N_{t,a} w_{t,a}) e^{-M/2}$$

and *w* is body weight.

The abundance in the first year $N_{1,a}$ and annual recruitment $N_{t,1}$ are unconstrained parameter vectors. The default approach in Coleraine is to model the initial population and recruitment as deviates from the negative exponential and Beverton-Holt, respectively (Hilborn et al. 2003, Magnusson and Hilborn 2007). Due to high recruitment variability and general instability of the model, these constraints were not used in this assessment, except in one sensitivity model run.

2.2 Parameters

A total of 52 parameters were estimated (Table 2) including 45 recruitment deviates.

Table 2: Estimated parameters

Parameter	Meaning
$N_{1,a}$	Initial population (7 parameters)
$N_{t,1}$	Annual recruitment (38 parameters)
${}_{C}S_{full}$, ${}_{C}S_{left}$, ${}_{C}S_{right}$	Fleet selectivity
${}_{S}S_{full}$, ${}_{S}S_{left}$, ${}_{S}S_{right}$	Survey selectivity
Q	Survey catchability coefficient

2.3 Estimation

The objective function for the parameter estimation is the sum of three components:

$$f = - \log L_I - \log L_C - \log L_S$$

The survey biomass index likelihood component L_I is lognormal:

$$-\log L_I = \sum_t \frac{(\log I_t - \log \hat{I}_t)^2}{2\sigma_I^2}$$

where I and Î are observed and fitted abundance indices,

$$\hat{I}_t = qV_t$$

V_t is the biomass vulnerable to the survey, 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,

$$-\log L_C = -\sum_t \sum_a \log\left[\exp\left(\frac{({}_{C}P_{t,a} - {}_{C}\hat{P}_{t,a})^2}{2\left[{}_{C}P_{t,a}(1 - {}_{C}P_{t,a}) + 0.1/A\right]{}_{C}n_t^{-1}}\right) + 0.01\right]$$

as well as the survey catch-at-age data:

$$-\log L_S = -\sum_t \sum_a \log\left[\exp\left(\frac{({}_{S}P_{t,a} - {}_{S}\hat{P}_{t,a})^2}{2\left[{}_{S}P_{t,a}(1 - {}_{S}P_{t,a}) + 0.1/A\right]{}_{S}n_t^{-1}}\right) + 0.01\right]$$

where P and ^P are observed and fitted catch-at-age,

$$\hat{P}_{t,a} = \frac{S_a N_{t,a}}{\sum_a S_a N_{t,a}}$$

and n_t is the year-specific effective sample size.

2.4 Likelihood weights

The effective sample size for the commercial catch-at-age (n_t) was scaled according to the commercial catches (range 20-100), which was taken as a proxy of year-specific sample intensity. During the modeling process 1997 commercial catch-at-age residuals were consistently large. To examine this, a sub sample of the aged individuals was age read and showed up to 50% errors in the estimated age. Consequently, the sample intensity in 1997 was set at 1 (i.e. ignoring this year). The survey effective sample size was set at 30 in all years.

The model was fitted with different values of survey biomass indices likelihoods (σ, range 0.2-0.8). 0.4 was chosen for all years as a starting point, taking into consideration that the model fit was not optimal.

3 Results

Initially, a choice was made regarding the time series to be used for further analysis (1976-2014 vs. 1992-2014). The output generated using the 1992-2014 time series was on several points not perceived as a good representation of the fishery or stock dynamics. For instance, the model was highly sensitive to changes in key input parameters (i.e. M, initial recruitment (R_0)), the plus group had a tendency to fill up in later years, harvest rate estimates were 4-6% (B3+) which are unrealistically low when the catch history is considered and the plus group in the initial year was often extremely large. The shortened time series approach was not explored any further.

3.1 Key quantities

The parameter estimates can be seen from table 3. Only point estimates are shown. No confidence intervals were available as the model fit did not allow for uncertainty runs. The estimated selectivity curve for catches and the survey are displayed in figure 4.

Table 3: Parameter estimates.

Parameter	Estimate
$_{C}S_{full}$	4.7
$_{C}S_{left}$	0.2
$_{C}S_{right}$	3.0
$_{S}S_{full}$	2.1
$_{S}S_{left}$	-0.9
$_{S}S_{right}$	1.3
Q	0.0167

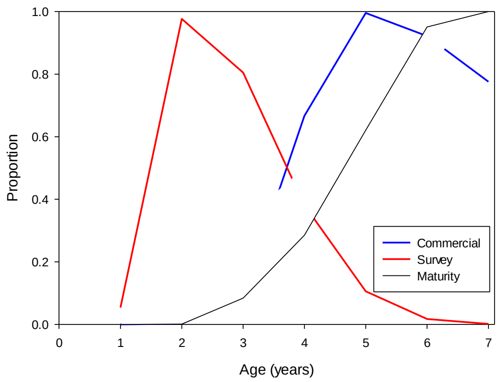

Figure 9: Selectivity for the survey and the commercial fishery and maturity.

3.2 Fit to data

The model fit was reasonable (Fig. 10). The largest discrepancies were in the early part of the survey time series which is a direct result of the 1984 YC being present in the large landings from 1988-1990 but no extraordinary recruitment came from this large YC. Additionally, the fit to the 1991 data was poor (Fig. 12).

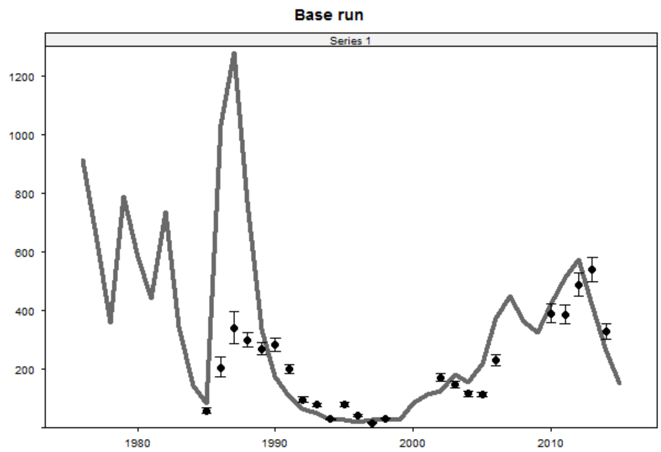

Figure 10: Model fit to the survey biomass index.

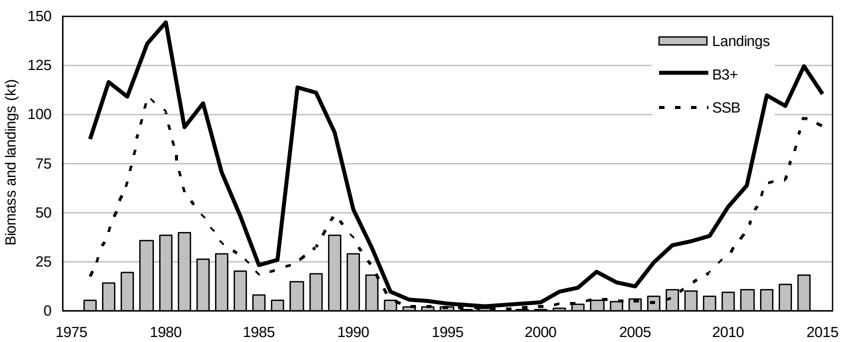

Figure 11: Landings, SSB and biomass of B3+ fish.

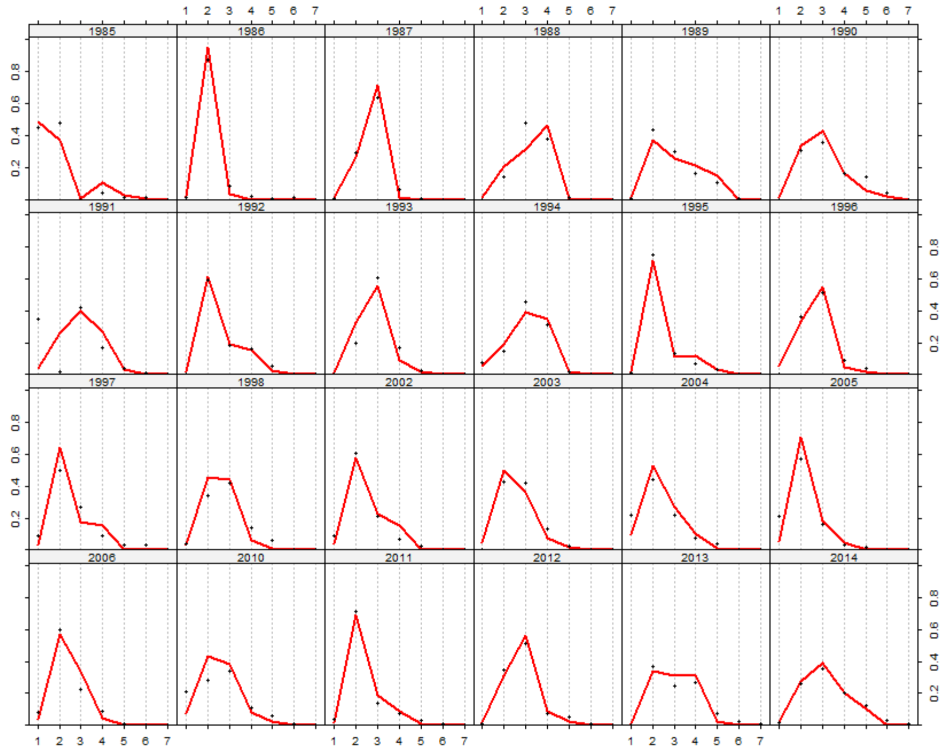

Figure 12: Model fit (line) to observed survey catch-at-age (dots), from 1985-2014.

The fit to the commercial catch-at-age data seemed reasonable in all years except 1985, 1990 and 1997 (Fig. 13) with the latter probably caused by errors in age determinations.

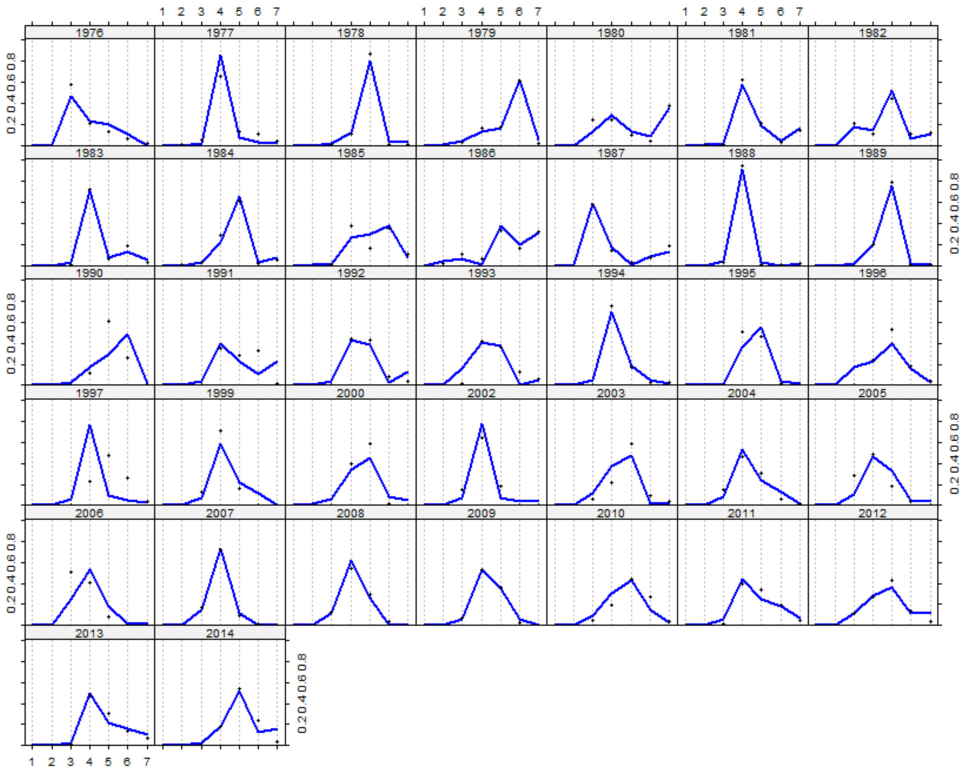

Figure 13: Model fit (line) to observed commercial catch-at-age (dots), from 1976-2014.

Using the base run, the harvest rate has been declining and is in recent years below 20% (Fig. 14). It has periodically been much higher with peaks 1980-1985 and 1990-1997. The fishing mortality has been high throughout most of the time period, rarely being below 0.5 (Fig. 14). However recently it has been below 0.2.

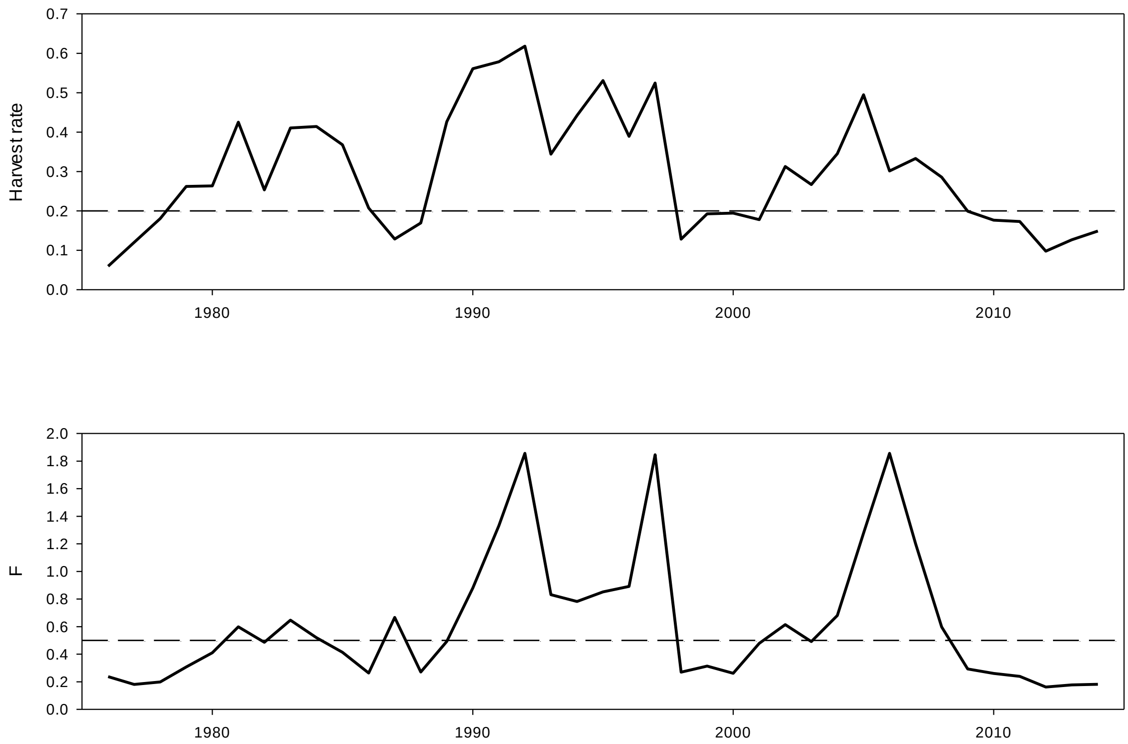

Figure 14: Top: Harvest rate calculated as the proportion of B3+ being caught by the fishery. Bottom: Average fishing mortality, averaged over ages 3-5. Dotted lines are harvest rate=0.2 and F=0.5.

3.3 Uncertainty

To assess model uncertainty, we compared the base model run to six diagnostic runs, representing different assumptions (table 4, Fig. 15) and evaluated the effect on current biomass (SSB_{2015}) and F_{2014}.

Table 4: Sensitivity runs where key input parameters were varied relative to the base run. Only the mentioned parameters differ between runs.

Run name	Description	SSB_{2015}	F_{2014} (ages 3-5)
Run64 (base run)	• No Baysian priors. • Year specific commercial effective sample sizes re-scaled (n_C: 20-100) • 1997 comm. CAA=0.1 • M=0.25 • Survey weights=0.8 (1985-1988) and =0.4 all others	93.8	0.18
Run65	• Survey biomass index weights (σ_I = 0.61). • Fixed effective sample sizes (commercial: 31 and survey: 30).	80.1	0.2
Run 60	• Recruitment estimated as deviations from Beverton-Holt (σ_R = 0.8)	89.1	0.18

Run59	•	Fixed recruitment in 1976 close to MLE (R_0=100,000)	91.3	0.18
Run55	•	M=0.3	95.1	0.22
Run 56	•	Survey weights fixed at 0.4	112.9	0.16
Run 58	•	All commercial CAA sample sizes fixed at 0.3	66.9	0.22
	•			

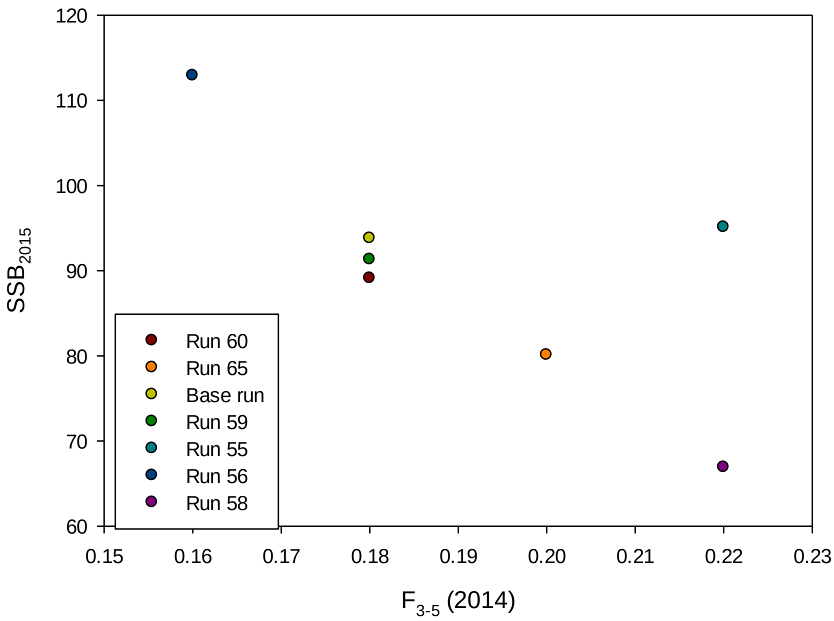

Figure 15: Spawning stock biomass in 2015 (SSB_{2015}) and current F (F_{2014}) from selected runs.

The model was sensitive to changes, and a wide range of especially SSB values were estimated. Several input data are associated with uncertainty all of which contribute to the model sensitivity. These include:

- The survey only covers a limited range of the stock distribution.
- The fishery is a mixed stock fishery, with the proportions from offshore stocks being unknown.
- Age readings of especially older fish have proven difficult, but this has not been formally addressed.
- The spawning migration of offshore stocks out of the area renders the spawner-recruit relationship questionable. Seemingly large YC do not contribute to inshore spawning.

Retrospective analysis on the base run was also preformed. These showed fairly reliable results (Fig. 16), with only the 2011 abundance being highly overestimated. This was due to an expected high input of 1-year olds in that year, but these did not appear in the survey as 2 and 3-year olds, and the estimate was adjusted down in subsequent years. Such an over estimation is probably linked to the variability mentioned above, with offshore YC's being in the landings, but not contributing to recruitment.

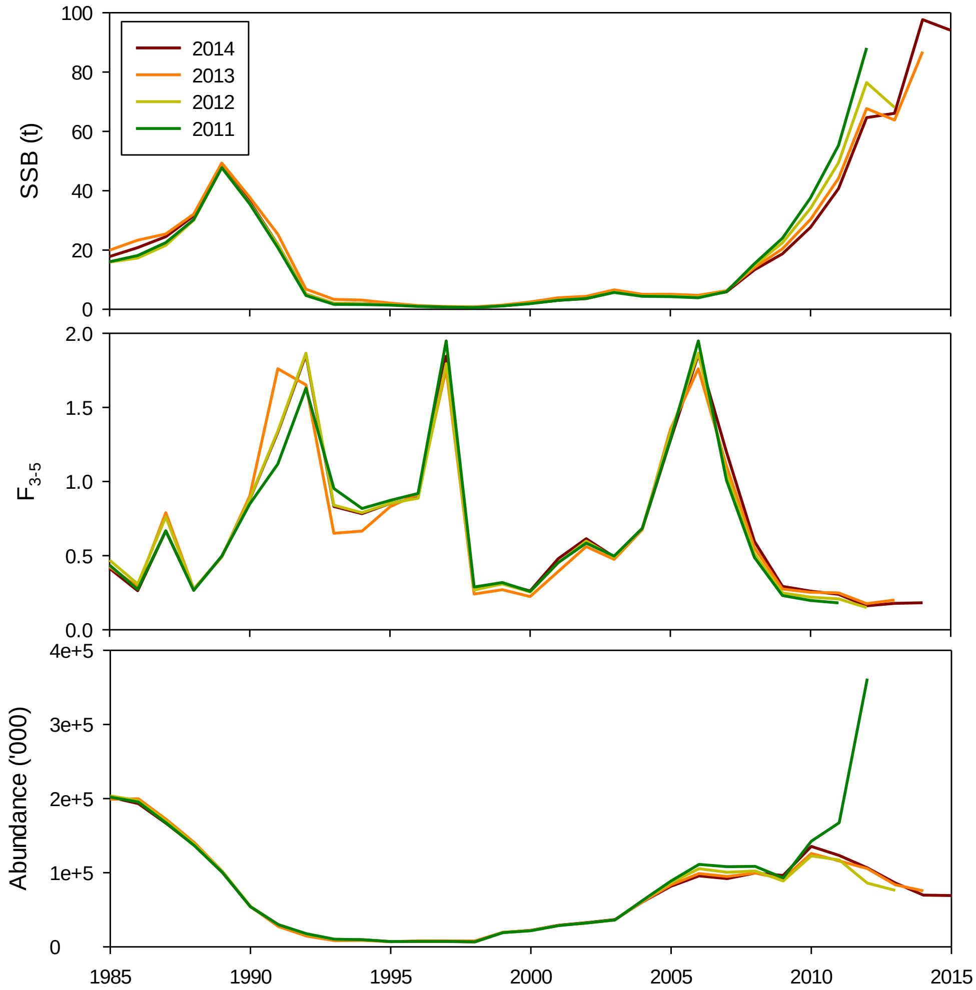

Figure 16: Retrospective analyses on the base run.

4.0 Discussion

The base run produced reasonable estimates but model instability did not allow for uncertainty analyses. This indicates noise in the data, which may have several causes. The Greenland inshore area is to some extent a mixing zone for Icelandic, Greenland offshore and Greenland inshore cod, which may cause problems for two reasons. 1) The survey is a recruitment survey and therefore does not necessarily represent the cod caught in the commercial fishery as fish present in the recruitment survey may migrate out of the area when they mature, thus being unexpectedly missing from the fishery. 2) The fish may leave the area (and the fishery) when reaching maturity (age 5-6) inflating Z values although the fish have not been caught. To accommodate this, M was set higher than normal for cod (0.25) and model runs with as high as 0.35 was done to explore the effect of high M values. Additionally, this effect may vary considerably between years, as the influx of larvae from the East Greenland/Iceland stock complex is a sporadic and unpredictable event. For instance, the large discrepancy between the model fit and data in the late 1980's may well be the result of such an event. However, Coleraine does not allow for age and year specific mortalities which would have been ideal to better model the expected migration out of the area of age 5 and older.

One joint characteristic of all reasonable runs was an increase in biomass in the later part of the time series irrespective of minor changes in model input parameters. Compared to model runs presented during the 2013 NWWG Model, the output presented here produce higher SSB_{2015} and consequently also lower estimates of F (ICES 2013a). Especially the 2009 YC continues to contribute greatly to the stock, but a decline in coming years is expected due to low number of recruits.

The survey and fleet selectivity were a priori allowed to be dome shaped. For the survey, this shape is fairly well known, as mesh size clearly excludes larger fish (> 3 year olds) from the catches. The commercial selectivity is however unknown and its shape is vital for model output. Current knowledge on cod life history suggests that older cod prefer depths not covered by the dominant gear, pound nets. However, we are not able to ascertain if the fish indeed do survive but are unavailable to the fishery (forming a large plus group) or if they are simply caught, and that is the reason why we do not see many old fish in the catches (high F). Estimates of average historical F is high (1976-2000 F=0.64) suggesting an overfished stock, especially when comparing to the much lower F considered sustainable for the offshore stock component (0.14, Hovgård and Wieland 2008). However, current harvest rates (average of 14% over the last five years) and low current F (F_{2014}=0.18) indicate an improvement, and perhaps even an under exploitation. This does however rest largely on the 2009 YC that produced time series high recruitment values in 2011 and 2012 and now forms the primary basis of the fishery. If this YC is solely of offshore origin, the estimated SSB can quickly decline when the 2009 YC matures in 2015-2016.

We conclude that the present model is not stable enough to serve as the single basis for advice on the inshore Atlantic cod in Greenland. However, the model did produce realistic numbers-at-age estimates and retrospective runs where fairly consistent, and hence may be used as a starting point in other analyses such as yield per recruit which could in turn produce reference points.

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ICES 2013a. Stock assessment of West Greenland Inshore cod 2012 – the Coleraine model. NWWG working document no. 19.

ICES 2013b. Stock assessment of West Greenland Inshore cod 2012 – Yield per Recruit. NWWG document no. 20.

Yield per Recruit on the West Greenland Inshore cod

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1 Introduction

In WD#06 a statistical catch-at-age model (Coleraine) is presented for the inshore Atlantic cod in West Greenland. The model did not converge to a point where it was possible to define reference points to use in generating advice for this stock. However, the model did produce useable point estimates and an age specific selectivity curve of the commercial fishery. Since the age specific F can be expected to follow the trend in gear selectivity (assuming an age independent natural mortality, M), the selectivity estimates can be used as an F proxy, serving as input for a yield per recruit analysis. Applying a multiplier allows for an evaluation of the yield associated with different fishing mortalities, which in turn can produce estimated reference points for management purposes.

In this WD we present a yield per recruit analyses, generated on output from the statistical catch-at-age model and suggest $F_{0.1}$ and F_{MAX} reference points and catches associated with different harvest rates.

1.1 Data

Table 1 shows the input data. Natural mortality (M) was set at 0.25. Age-specific fish weights were calculated as the average weight in the period 2005-2014. The age-specific gear selectivity is the output from the statistical catch-at-age model.

Table 1: Input data.

	Age						
	1	2	3	4	5	6	7+
Weight (kg)	0.030	0.360	0.700	1.040	1.630	2.450	6.36
Selectivity	0.000	0.002	0.091	0.667	0.995	0.922	0.776
M	0.25	0.25	0.25	0.25	0.25	0.25	0.25

2.1 Calculations

The number of fish at age was calculated from the exponential decay function:

$$N_{a+1} = N_a \times e^{-Z_a}$$

where N_a is number of fish at age a and Z_a is the age specific total mortality.

Catch-at-age (C_a) was based on the catch equation:

$$C_a = \frac{F_a}{Z_a} \times N_a(1 - e^{-Z_a})$$

where a denotes age, F_a fishing mortality, Z_a total mortality and N_a number of fish.

To calculate Yield-per-Recruit, the total yield was divided by the number of fish ages 3-7 (7 being a plus group). The Yield was optimized using the Solver function in Excel. The harvest rate was calculated as the proportion of the biomass of 3-6 year old caught.

3.1 Results

Using F values derived directly from the selectivity curve (no scaling, Table 1), the arbitrary population developed as in figure 1 (left).

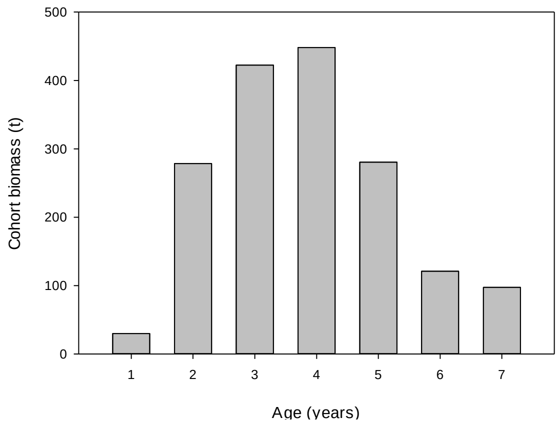

Figure 1: Cohort development using an arbitrary starting point and F values from the selectivity curve.

Applying F values ranging from 0 to 1.5 produced a yield-per-recruit curve with F_{MAX} = 0.53 (averaged over ages 3-6), but F_{MAX} was not well defined (Fig. 2). F_{MAX} produced a yield pr. recruit of 507 g. The appurtenant cohort development can be seen in Fig. 1 (right). The harvest rate associated with F_{MAX} was 36% (Fig. 3). $F_{0.1}$ was estimated at 0.32.

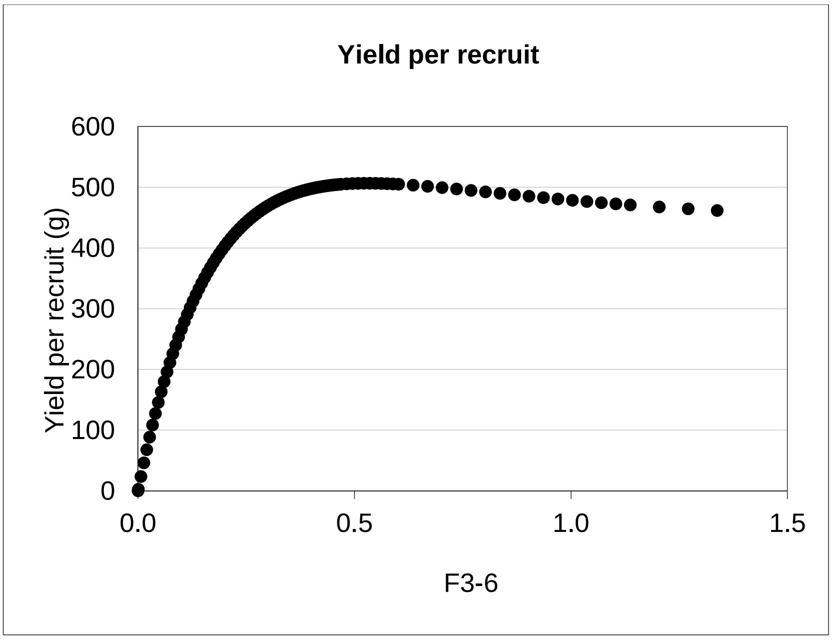

Figure 2: Yield per recruit at various F values.

Figure 3: Yield per recruit at various harvest rates.

4.1 Discussion

The F_{MAX} estimate was 0.53 and the point estimate of current F from the statistical catch-at-age model was 0.18 suggesting a fishing mortality below what is currently the optimal value. However, the current stock is unknown, but trends in survey, catches and model output suggest an increase in population size.

Applying a 20% harvest control rule similar to that implemented in the management plan for Icelandic cod, would produce an advice of approx. 22 000 t when using the estimate of the current stock size produced by the statistical catch-at-age model. $F_{0.1}$ is equivalent to a harvest rate of approx. 30%, which would result in a catch advice of 33 000 t.

Untraditionally, age 3 was included in all calculations of fishable biomass and consequently influenced expected yield and the $F_{0.1}$ estimate. This was done, as fish of this age constitutes a significant part of the catches (6% averaged over the last three years). Had ages 4-6 been used, $F_{0.1}$ would decrease to 0.24 and the harvest rate would change from 30% to 25% (projected catches of 33 000 t and 27 500 t, respectively). From a precautionary approach (as used for the advice in 2012), target F should be below F_{MAX} to allow for any rebuilding to progress, and $F_{0.1}$ is a likely candidate.

Catch curves on the West Greenland Inshore cod based on commercial landings

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Introduction

There is currently no analytical assessment on the West Greenland Inshore cod, but in WD#06 and WD#07 some point estimates of stock status and possible reference points are suggested. For comparison, we here present catch curves from the commercial fishery and estimate F values. The inshore fishery is dominated by pound nets that have a tendency to be size selective, excluding older fish due to lack of overlap between fish habitat and fishable depths. This may produce greater catch curve slopes (i.e. Z values) that are beyond what is actually the case in the stock.

Data and method

Landings in the inshore fishery have fluctuated substantially, especially before 1995 (Figure 1). From 1993-2001 landings where below 5 000 t and data from this period is associated with low sample size and consequently high variability and in 1998 and 2001 commercial catch at age data are not available. Age 10 was used as a plus group.

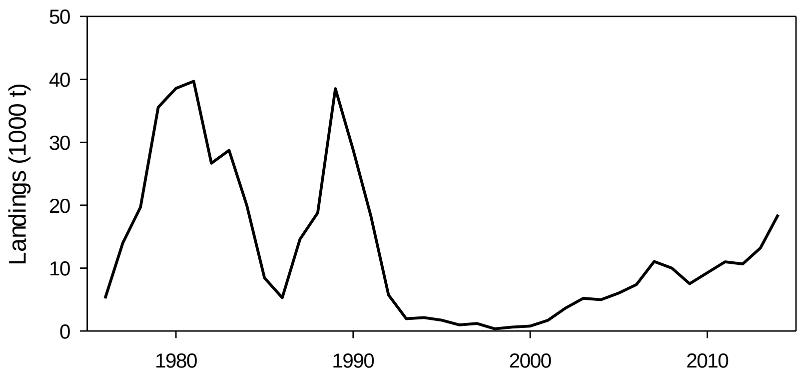

Figure 1: West Greenland Inshore landings from 1976-2014.

All analyses were done on catch proportions to deal with the fact that catches are not similar between years. Due to the size selective nature of the fishery, two different scenarios were set up:

1) No data modification was done.
2) The age specific gear selectivity from the statistical catch-at-age model (Coleraine, Figure 2, see WD#06) was used as a scaling factor on age specific proportions. This should improve the estimates as the drop in selectivity at ages 6 and older would inflate F estimates if untreated. This model run however used 7 as a plus group, so we assumed that gear selectivity for ages 8-10 was equal to that at age 7.

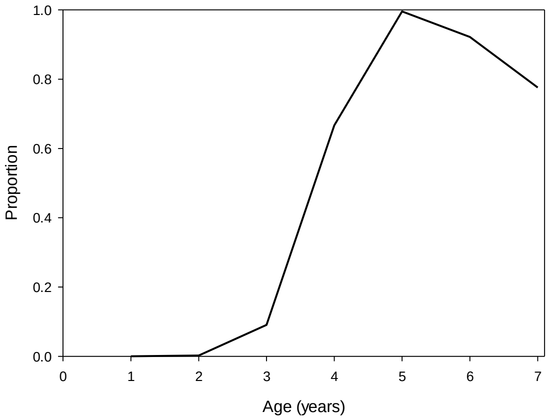

Figure 2: Estimated selectivity curve from the Coleraine output.

Results and Discussion

In scenario 1 and 2 $F_{4\text{-}8}$ and $F_{5\text{-}8}$ where examined because a positive slope from age 4 to 5 in the catch curves was observed in some cases. The reason could be a wrong selectivity curve, age reading bias, high grading etc.. Few fish of age 8 and older are typically in the catch (i.e. large variability). Therefore, F for ages 5-7 was also explored.

The results can be seen in Figure 3 where the development in average F for all YC is displayed for all scenarios. For illustrative purposes, the landings are also shown below. Generally, F estimated from un-scaled catch proportions (Fig. 2 middle panel) and F scaled according to gear selectivity (Fig. 2 top panel) are similar, although point estimates vary. From now on only age range 5-8 using scaled values are discussed.

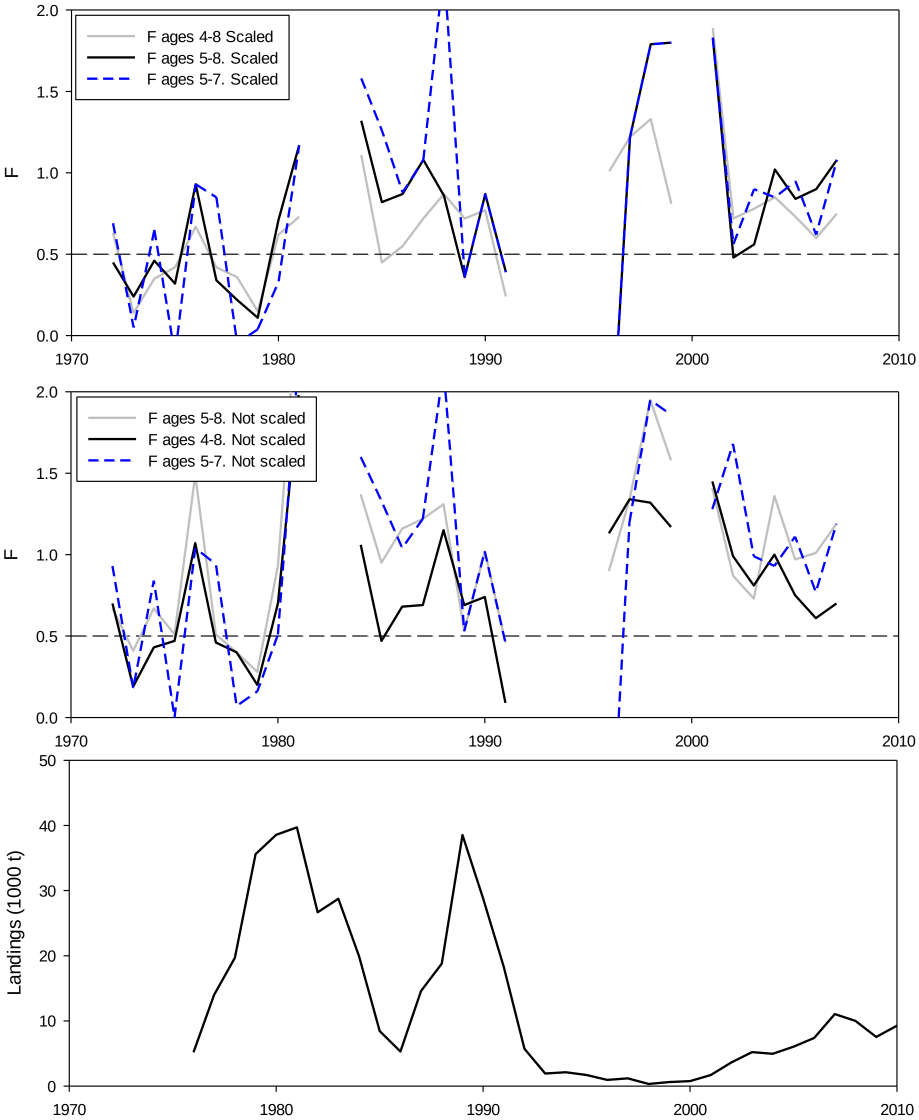

Figure 3: Top: Development in estimated F using scaled proportions. Middle: Same as top, but with un-scaled catch proportions. Bottom: total landings.

The fishing intensity, and hence sampling effort, has been variable in the available time period. Cohorts between 1991 and 2002 were barely fished, and thus little weight should be put on results from this period. Besides this “low catch” period, the development in estimated F can be seen as three periods.

1) The cohorts from before 1980
2) The 1984-1991 cohorts
3) The 2002-present cohorts.

In period 1, several cohorts from the 1970’s were present in the fishery and average F for the cohorts 1972 to 1979 was 0.38 (based on scaled values, age range 5-8). In period 2, F was generally higher, being on average 0.82 but variable. Finally, in period 3, F has to a large extend been similar, averaging 0.81. The period 2 fishery was characterized by being based on a single cohort (1984) and F for the YC alone was estimated at 1.32. Due to the intense fishery on this YC (40-60 000 t) sampling was extensive and the estimate of F is probably among the most robust in the time series. If a similar analysis is done on German survey data (not shown) the estimate is 1.47. The fishery on the 1984 YC was short lived and landings declined to almost nothing in 1992/1993. The fishery in period 3 is to a larger extent based on more than one YC (ICES XX), and the same sharp increase in landings as in the two previous periods has not been seen. Nevertheless, F appears to be similar in period 2 and 3, suggesting that the current fishing intensity is not sustainable. However, the 1984 YC was to a large extent of offshore origin and almost no recruits came from it. If the present fishery is based on local inshore cod, no such recruitment failure is expected.

The recent fishery has not caused a decline in the stock size or indeed the positive trend all analyses point to (i.e. surveys, Coleraine model, VPA, fishers observations). This indicates that current F is not above any non-defined reference point which is in contrast to those calculated from the catch curve. The F_{MAX} estimate from the Yield per Recruit analyses (WD#04) was 0.53 and $F_{0.1}$ was 0.32 which is well below the catch curve estimates. However, when interpreting the catch curves, the fact that the main fishing gear has a dome shaped selection curve should be considered. Here we attempted to scale according to the selection pattern estimated in the statistical-catch-at-age model, but this is an estimate, and the exact selection curve is unknown. But since the scaled and un-scaled curves are similar, results seem robust to such changes. More likely, the migration out of the inshore area is not taken into consideration in these simple analyses and this will have a far greater effect on F and will tend to inflate estimates. Hence, the catch curves are most useful when comparing current fishing intensity to historical trends.

WKICE, 26 January – 30 January 2015, Working document no. 09

Stock assessment of West Greenland Inshore cod 2015 – ADAPT VPA.

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1 Introduction

No analytical assessment is currently available for the West Greenland Inshore cod. In preparation for the 2015 benchmark on the stock (WKICE) model runs in Coleraine (Statistical catch-at-age), yield per recruit and catch curves have provided insights into stock dynamics (WD#06, WD#07 and WD#08). These are not stable model runs and estimates of F and SSB are variable, highlighting the need for multiple approaches in generating sensible advice for this stock.

Here we present results from model runs in the ADAPT VPA environment offered through the NOAA fisheries toolbox.

2 Data and Methods

Data used in the assessment are annual landings (Table 1, Fig. 1), biomass index from a recruitment survey (Fig. 2), catch-at-age from commercial catches (Fig. 3) and a maturity index from 1985-2014. The survey is a gill net survey conducted in June/July. Using various mesh sizes (16-33mm) it targets primarily 2-3 year olds. The selectivity curve is considered dome shaped, as mature cod are only caught in low numbers. The commercial fishery is conducted with different gears, but throughout the period it has been dominated by pound net catches (>80%). The pound nets are set near shore in shallow water, and there is a tendency for larger fish to be unavailable to the fishery due to depth preferences. This aspect is not implemented in the model.

Some years (1998 and 2001) have no catch-at-age data due to very low landings. These data gaps where filled in by calculating the share of a given cohort in the catches in the preceding year, and assuming a similar share in the following year. The share of the youngest YC was estimated based on survey values. Survey numbers are missing in 1999-2001 and 2007-2010. The model can handle missing survey values, so two settings were tried: 1) No fill in and 2) Missing years filled in by assuming a linear trend from the last year with survey until the next with a survey value.

Table 1: Input data for the ADAPT model

Data	Years	N
Landings	1985-2014	30
Commercial catch-at-age	1985-2014 (except 1998 and 2001)	28
Recruitment survey abundance index	1985-98, 2002-06, 2010-14	24

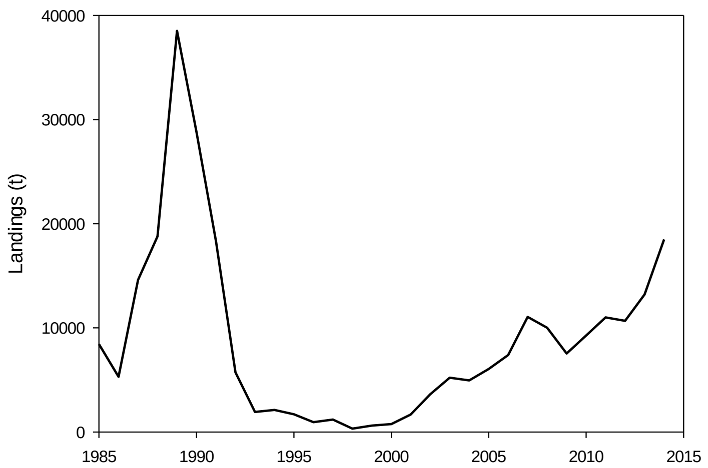

Figure 1: Annual landings in the West Greenland inshore cod fishery.

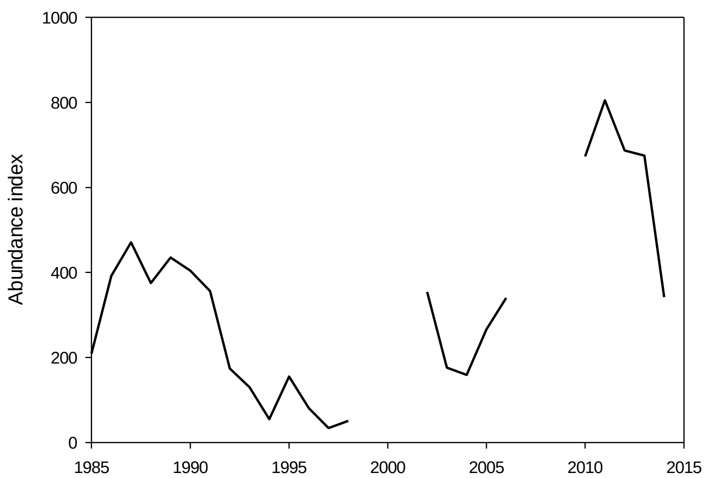

Figure 2: Biomass index from the gill net recruitment survey.

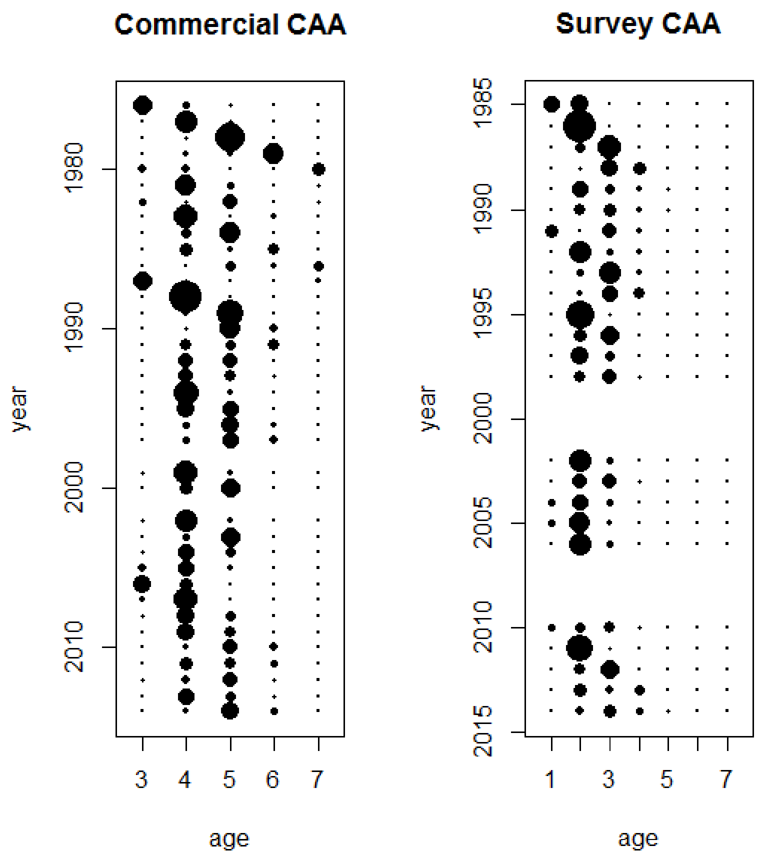

Figure 3: Commercial (left) and survey (right) catch-at-age. The circles represent relative frequency in each year.

2.1 Initial settings

Stock weights-at-age and SSB weights where calculated using the Rivard weighting procedure. Survey selection was set at ages 1-5 due to the selective nature of the gill nets. Natural mortality (M) was initially set at 0.2 for all ages and years. However, stock dynamics in the inshore region is influenced by offshore stocks (East and West) with the inshore area functioning as nursing area until age 4-6 when a spawning migration is initiated for the offshore fish. For this reason, M was set at 0.2 for ages 1-3, 0.25 for age 4 and 0.3 for all older ages. Also, the 1984 and 2003 YC are known to be large offshore YC's that had a large influence on inshore landings, and for this reason M was set at 0.5 at age 5, 0.7 for ages 6-7 and 1 for ages 8-10 for these two YC's. Other more extreme options wer also tried, but these often produced unrealistic output and are not shown.

The fraction of M and F prior spawning was set to 0.25 and 0.05 respectively.

The maturity ogive was identical between years (Fig. 4). Initial stock estimates for the terminal year plus one (2015) were based on the most recent survey values and were set at: 20 000, 170 000, 120 000, 150 000, 150 000, 170 000 and 4 000 for ages 1-7. Preliminary model runs indicated that these were appropriate. The partial recruitment to the fishery in the terminal year must be estimated before model runs, and based on size at age data this was set at 5% for age 3, 80% for age 4 and 100% for all older age groups. F for the last true age (age 9) is estimated from F at ages 4-8.

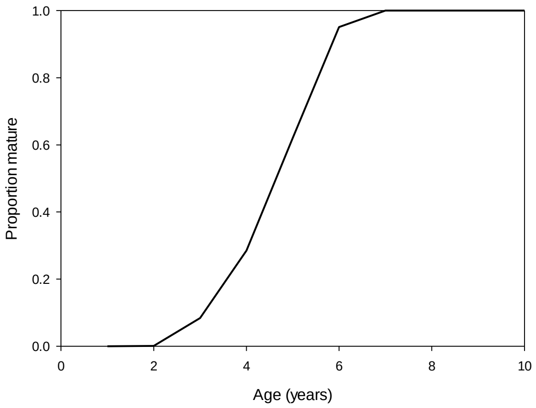

Figure 4: Maturity ogive.

Several exploratory runs where preformed before settling on a base run (table 2). The run chosen as the base run was conservative and did not include any estimated input data other than the estimated catch at age mentioned above.

Table 2: Key parameter estimates from several exploratory runs.

Run	Key variables
Run 19	• YC specific M • Survey fill in
Base run (1985-2014 base run, run 20)	• No survey fill in • YC specific M
Run 21	• M=0.25 for all • Survey fill in
Run 21_2	• M=0.25 for all • No survey fill
Run 22	• F by average
Run 23	• F by Heinke
Run 24	• Adjusted survey weights (1985-1987=0.2)
Run 25	• Exclude 2002 survey • No survey fill in
Run 26	• No survey fill in • 1985-1987 survey weights=0.8
Run 27	• No survey fill in • 1985-1987 survey weights=0.8 • M set high for 1984 and 2003 YC's.
Run 28	• Same as run 27, except survey weights all set to 1. • M for 84 and 03 YC set very high.
Run 29	• Landings time series extended back to 1976. • Same as base run otherwise

2.2 Sensitivity analysis.

The model allows for sensitivity analyses, using M as the variable input. This was tried using a minimum M value of 0.2 and a maximum value of 0.6 with steps of 0.05. Several exploratory runs were also preformed changing year and age specific M (a feature not available in the statistical catch-at-age with which model output is compared) and year specific survey weights. The latter was a key parameter in the statistical catch-at-age model.
Additionally, retrospective analyses were done on the selected base run.

3.1 Model output and exploratory runs

The various exploratory runs produced variable estimates of both SSB and F over time (Fig. 5). There are however some characteristics that are seen in most runs including those not presented. The biomass increases in recent years and coincidental with this is a decline in abundance. This is caused primarily by the dominant 2009 YC that is growing, but also a removal through fishing and perhaps offshore spawning migration. A similar situation was observed in the late 1980'ies, when a very strong 1984 YC appeared.

Due to this sporadic recruitment pattern observed for this stock (i.e. 94, 03 and 09 YC's), average F may overestimate true F when catch-at-age is dominated by a single YC. Therefore we have chosen to report biomass weighted F. Average F is used in the comparison to other model approaches.
$F_{4\text{-}8}$ was on average high throughout the period, particularly in the mid-late 1990'ies, suggesting an overexploitation in this period. F has generally been declining since 2005 in all runs and is currently at a much lower level, but some runs show a slight increase in recent years.

All runs also show similar residual patterns (Fig. 6). The pattern seen in the early part of the period is most likely related to the 1984 offshore YC. This YC appeared in the catches without being picked up in the recruitment survey (negative residuals). A similar thing is seen in 2004-2006 when the also large 2003 offshore YC was seen in the catches but not as recruits.

Run 29 used the landings back to 1976, although no tuning series was available prior to 1985. The SSB_{2014} estimate was similar being only 0.4% below the base run but biomass weighted $F_{4\text{-}8}$ increased from 0.2040 to 0.5057. As no tuning series was available for the period prior to 1985, and since the fishery in these years was most likely heavily influenced by offshore YC (but not quantifiable) we chose not to include this period in further analyses.

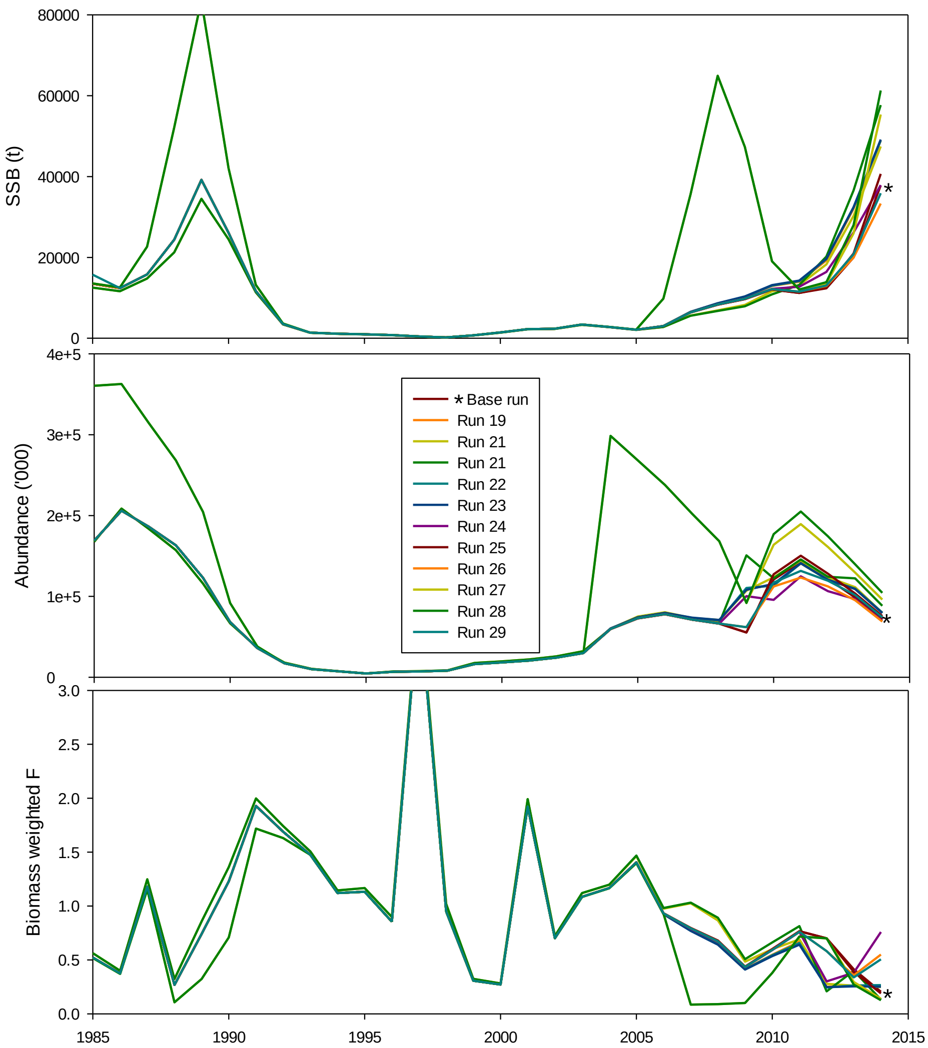

Figure 5: Estimated spawning stock biomass, stock numbers and biomass weighted F from all runs listed in table 2.

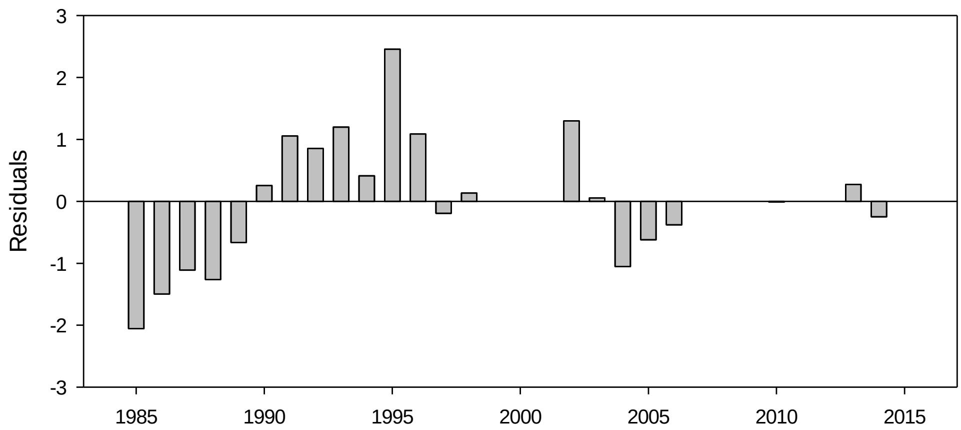

Figure 6: Residual pattern from the survey fit from the base run (run 20).

3.2 Sensitivity and retrospective analysis

In the sensitivity analysis with varied M there was little effect on especially abundance, which increased gradually with increasing M (Fig. 7, top). SSB showed a similar trend except in the final three years, where estimates were generally at two different levels, depending on M. Between M=0.2 and M=0.3, SSB was ~55 Kt, but was reduced by approximately 50% when M changed from 3 to 3.5 (Fig. 7, bottom). M values higher than 0.3 as an overall trend seems high. The reason for the pattern was explored, and was explained by the lack of survey available for tuning in 2007-2009, similar to what was observed for the retrospective pattern (see below).

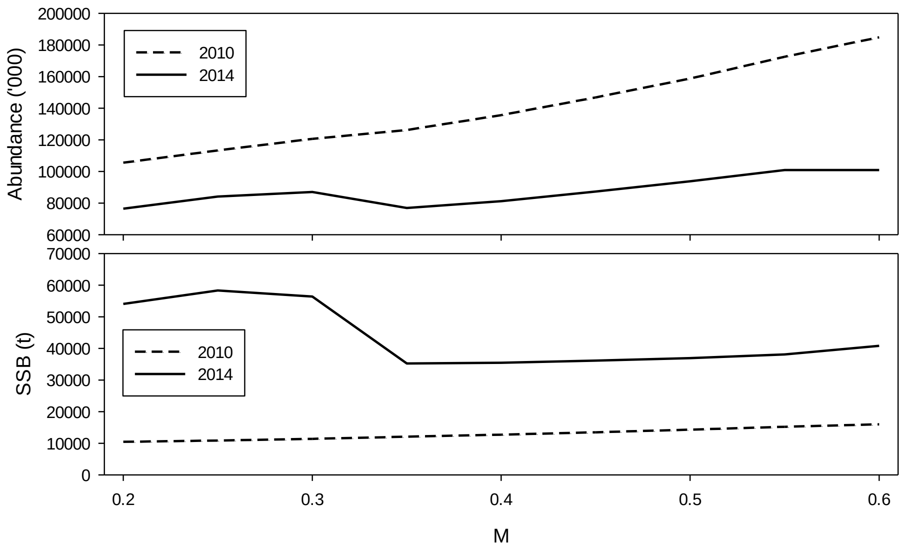

Figure 7: SSB as a function of different fixed M values. 2010 shown as example of the 1985-2010 period. 2014 was similar to 2012-2014 results.

Retrospective analyses are only allowed as far back as survey data are available (2010). The retrospective plots show large discrepancies on SSB, especially in the last year. The 2013 SSB estimate was reduced by 46% in 2014. The reason for this pattern is apparently the lack of survey data available for tuning in 2007-2009. If these years are filled in with best guess estimates of survey values, the retrospective pattern disappears (as does the SSB trend described in the sensitivity analysis above). There is less noise in the abundance retrospective pattern. This is most likely because the SSB noise is caused by older fish, and they will have less weight in the abundance estimates. See WD#10 for F retrospective patterns. Generally, the retrospective patterns means that the ADAPT point estimates are greatly revised from year to year making it difficult to base any forecast on it.

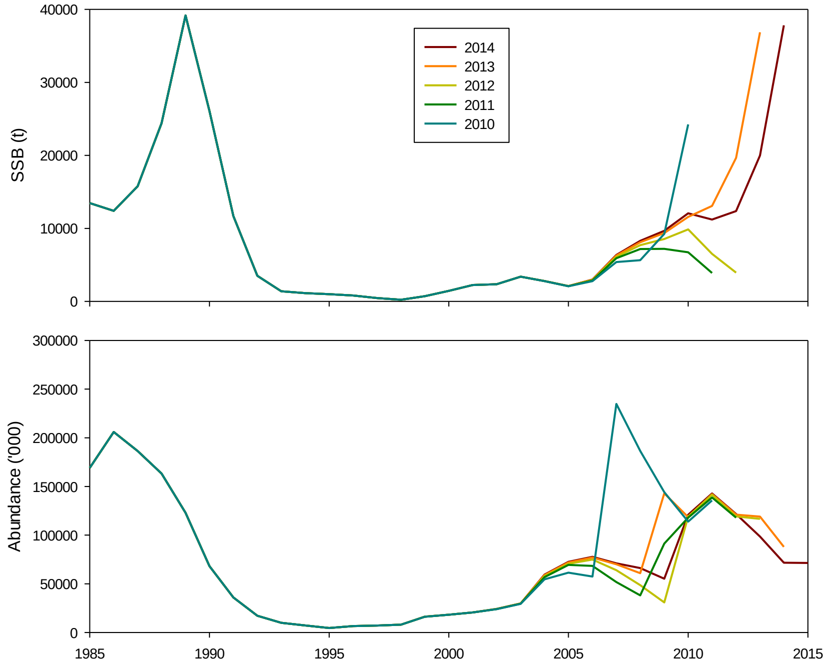

Figure 8: Retrospective plots of SSB (top) and total stock numbers (bottom).

WKICE, 26 January – 30 January 2015, working doc 10

Assessment of West Greenland Inshore cod

S. Post, R. Hedeholm, A. Retzel and J. Boje

1 Introduction

In preparation for the 2015 benchmark on the West Greenland inshore cod stock (WKICE) model runs in Coleraine (Statistical catch-at-age), VPA-ADAPT (Virtual Population Analysis Model - NOAA), XSA (Extended Survivor Analysis), Yield per Recruit and catch curves (WD 06, 07, 08 and 09) have provided insights into stock dynamics and information on the possibilities and limitations with the available data. In general, estimated stock trends were similar in all approaches but there are large variations in the absolute level of stock size and fishing mortality estimates and residuals are generally rather large due to noise in the input data. The large residuals are the integrated effect of missing survey years, the lack of a survey of the adult biomass, a mixed stock fishery and general uncertainty. Also, there were some data input discrepancies that are yet to be resolved. The effect of this is unknown but initial updated runs indicate small changes.

In this document we briefly summarize and compare trends from various modeling approaches and suggest an approach to generate advice for this stock. Model runs from Statistical catch-at-age and ADAPT model runs are compared and discussed in the light of suggested reference points generated by YR analyses and catch curves. The XSA is not included as the model failed to fit the data, with especially F values being highly unrealistic

2 Results and a comparison of ADAPT and Coleraine.

In figure 1 the results from the Coleraine and ADAPT base runs are compared. Recent SSB estimates increases in both models but also in additional runs preformed in each model environment. The SSB estimates from the ADAPT model were in general much lower than the Coleraine estimate. ADAPT SSB_{2014} from the conservative base run was 37.8 Kt while the most optimistic runs produced estimates around 50-60 Kt, whereas the Colerain base run estimate was 94.1. Kt. One explanation could be the lack of an option to vary gear selectivity in the ADAPT model. Since older fish are not fully selected by the main fishing gear, the model must interpret the lack of older fish in the landings as “fish that are not there” and not as the Coleraine model approach of “they are there, but cannot be caught”. This will lead to lower ADAPT biomass estimates.

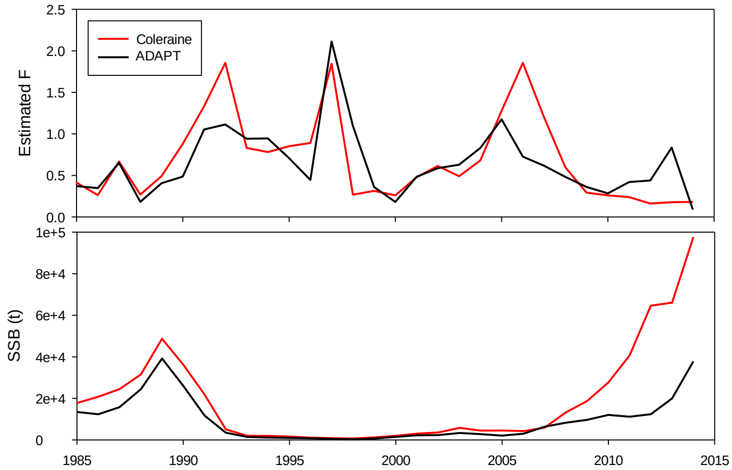

Figure 1: Top: F estimates from Coleraine ($F_{3\text{-}5}$) and ADAPT ($F_{4\text{-}8}$) base runs.

Bottom: Development in SSB from ADAPT and Coleraine base runs.

Both models indicate a low recent F of approximately 0.2. The trend in F is similar until 2011, when the ADAPT F estimate increases unlike the Coleraine estimate that continue a downward trend. This pattern is to some extent explained from the ADAPT retrospective analysis where F is – at least in the last 4 years – consistently over estimated (Fig. 2). The F_{2014} estimate is however very similar between models.

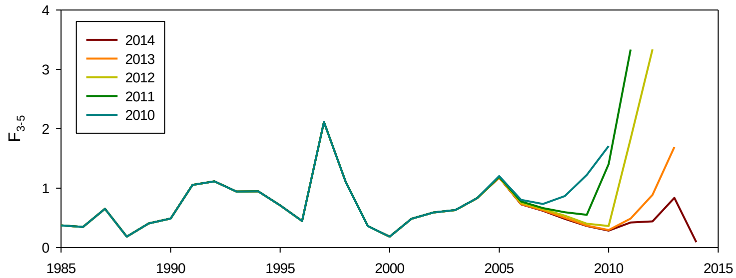

Figure 2: Retrospective $F_{4\text{-}8}$ patterns from the ADAPT model

Catch curves indicated that current F is similar to that observed historically. This could lead to the conclusion, that since the historical fishery did not appear to be sustainable a similar situation would be expected with the present F. However, a changed environment may be conducive for increased stock productivity and greater resilience to fishing. For instance, the temperature in the area has risen. Before 1995 mid water temperatures fluctuated between 1°C and 2°C (in offshore regions) whereas it from around 1995 has been fluctuating between 2°C and 3°C and this is expected to be beneficial to cod productivity in this region (Hovgård and Wieland 2008) perhaps altering the sustainable level of fishing mortality. This is also supported by weight-at-age data, where the weights have increased consistently with for example a 4 year-old cod now being 67% heavier than in 1985. A similar pattern is seen for all older ages but not in ages 2 and 3.

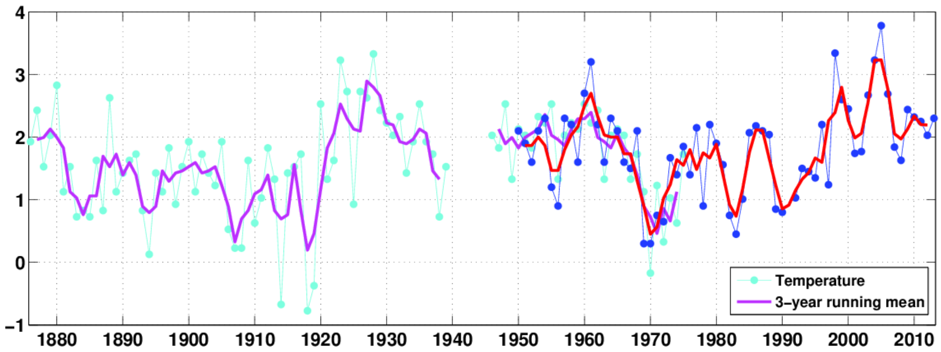

Figure 2: Time series of mean temperature on top of Fylla Bank (adjacent to Nuuk fjord) in the middle of June for the period 1950–2013. The red curve is the 3 year running mean value. Taken from Ribergaard 2014.

3 Suggested advice procedure.

Based on the irregularity of the ADAPT SSB retrospective pattern in general, the point estimates it generates are not reliable as use for forecasting and generating advice. Rather, the Coleraine statistical catch-at-age appears the best candidate for generating advice especially based in stabile retrospective patterns. However, the model did not converge to produce point estimates and the absolute stock levels are questionable. Instead of relying on the absolute estimates, the stabile trends could be used as the basis for advice and the Data Limited Stock approach (DLS) could be a useable framework.

3.1 DLS categorization

In order to apply the ICES procedure on DLS for West Greenland Inshore cod stock the most recent ICES DLS Guidance Report was used as guidance (ICES 2012). Here we propose that the stock should be put in Category 2 "*Stocks with analytical assessments and forecasts that are only treated qualitatively*" (ICES 2012), as the analytical assessments exercises have been capable of producing quantitative estimates of stock development, reference point's proxies and short term forecasts. Significant differences in F and SSB estimates between model runs makes it a less than perfect Category 1 candidate.

3.2 Data and Methods for DLS approach

Although the Coleraine model was considered the more robust model, ADAPT estimates were also considered for comparative purposes.

Input data were taken from the ADAPT and Coleraine analytical assessments. Estimates of SSB, F and reference points were collated for use in the analyses for the DLS method.

3.3 Catch advice

To evaluate HCR Method 2.1.1. or 2.1.2. is used depending on whether estimated biomass is greater than MSY $B_{trigger}$. Currently no MSY $B_{trigger}$ or proxies are available. It is however our evaluation that current SSB is above any MSY $B_{trigger}$ candidate based on continued high recruitment and stable landings. However, both methods were tested, thus if $B_{trigger}$ are defined at a later stage, one of the following examples can be applied.

Method 2.1.1: By following first method for calculating catch advice the Baranov Catch equation was used:

$$C_{y+1} = \sum_a \frac{s_a F_{y+1}}{s_a F_{y+1} + M_a} N_{a,y+1} w_a [1 - \exp(-s_a F_{y+1} - M_a)]$$

Where s_a is selectivity-at-age, M_a is natural mortality-at-age, N_a is abundance-at-age, and w_a is weight-at-age (ICES 2012). For this stock no F transition period is considered. Instead the catch advice could be based directly on an F_{MSY} estimate. As a conservative proxy we chose to base the advice calculations on the $F_{0.1}$ estimate from the YR analysis. Consequently, the catch advice for 2016 uses an $F_{y+1} = F_{0.1}$. , If the calculated catch advice deviates more than 20% from last year's catches a 20% Uncertainty Cap is subsequently applied to the catches

4 Results - DLS output for advice

HCR advice is presented in Table 1. The advice based on both Coleraine and adapt estimates are very similar. In both cases, the suggested 2016 catch advice is more than a 20% increase compared to 2014 landings, and consequently the uncertainty cap applies in both cases. Therefore, the catch advice simply becomes a 20% increase compared to 2014.

Table 1: F and HCR from Method 2.1.1. and 2.1.2..

Method 2.1.1	Colerain advice	VPA-ADAPT advice
$F_{0.1}$	0.32	0.32
Advice (without U.cap.)	24,239t	22,240t
Advice (with U.cap.)	22,200t	22,200t

5 Discussion

When generating advice for this stock, the overall picture of the Greenland cod stock complex should be considered. In recent years, the inshore stock biomass appears to be increasing (in spite of catches exceeding current advice) and estimates from the yield per recruit analyses suggests that landings >30.000 t could be sustainable. This is mainly driven by the 2009 YC, which we believe to be partly of offshore origin. Hence two things must be considered:

1) The fish may quickly disappear from the inshore area as a result of a spawning migration in 2015-2016.

2) Cod in West and East Greenland offshore waters are considered in a rebuilding phase. If an offshore YC is fished intensively in inshore waters, it might impair offshore recruitment.

References

ICES, 2012. ICES Implementation of Advice for Data limited Stocks in 2012 in its 2012 Advice. ICES DLS GUIDANCE REPORT 2012. ICES CM 2012/ACOM 68.

Estimation of consumption of Icelandic capelin from January - March

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January 19, 2015

1 Introduction

Capelin spend most of their life in the cold water north and east of the Iceland and between Greenland and Iceland but the main spawning areas are south and west of Iceland in areas 1 and 10 (figure 1) where the capelin spawn in March. Sometime the spawning occurs further east in area 9 and spawning north of Iceland has also been seen in many years.

The traditional migration route to the spawning areas is east of Iceland and west along the south cost ([4]). Final acoustic measurments of the spawning stock of Icelandic capelin are usually conducted in January east of Iceland in areas 5, 6 and 8 (figure 1). This final acoustic measurement is usually conducted between 15th and 30th of January and the time from the middle of the survey to spawning time of capelin is 6-8 weeks.

During their migration to the spawning areas the capelin often stop for some time near the boundary between the warm and cold water south east of Iceland (area 8 in figure 1) , until the roes/gonads have matured enough to enter the warm sea and start the final trip to the spawning areas. This final trip seems to take relatively short time (3 weeks) and the distance covered is 120-350 nautical miles depending on where the capelin spawn.

Cod, that are the most important predators of capelin do also spawn south of Iceland in areas 1, 9 and 10, migrating both the western and eastern route to the spawning areas, the cod feeding east of Iceland take the eastern route. Immature cod is more stationary.

As may be seen from the short description above things are changing rapidly in the period January - March with large proportion of the fishes migrating towards the spawning areas south and west of Iceland.

Available data on interaction between capelin and its predators in the period January - March are.

1. Acoustic measurements in January - February.
2. Landings by day 1982-2014.
3. Location of catches 1993-2014 and catches by statistical square 1982-1993.
4. Spatial distribution of demersal fishes from the groundfish survey in March 1985-2014.
5. Stomach samples of cod from the groundfish survey in March 1985-2014 and from haddock 1992 and 2005-2014 and from number of other demersal fishes in 1992.
6. Stomach samples from demeral trawl contemporaty with the acoustic surveys in January 1993 and 1994.
7. Stomach samples from fishing vessels since 2002.

2 Spatial distribution of predators

The proportion fish predators inhabiting the area east of Iceland is obtained from the groundfish survey in March. There will be some change in distribution from January to March with some of the mature fish leaving for the spawning areas so the distribution in March is probably underestimating the proportion east of Iceland. The area crossed by the the eastern capelin migration is divided in 3 parts (figure 2).

These areas (figure 2) will be referred to as east, south and southwest later in this report.

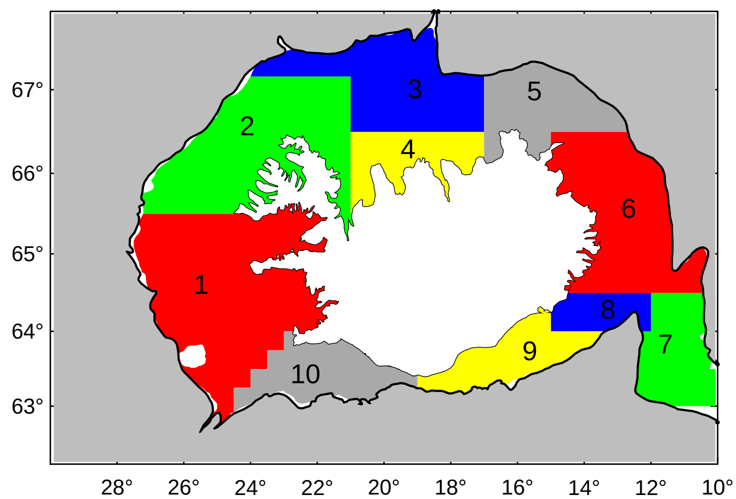

Figure 1: Areas referred to in the text. Areas 1, 9 and 10 are characterised by warm saline Atlantic water while areas 5 and 6 are characterized by cold artic water. The boundary between the water masses is sharp with tempearature changing by 2-5 degrees in relatively short distance. The location of the front is variable but usually in area 8.

- Areas 6-8 sea east of Iceland 6 weeks (January 15th -March 1st).
- Areas 9-10 south of Iceland 6 weeks (February 1st - March 15th)
- Area 1 west of Iceland 2 weeks (March 1st - March 15th).

Table 1: Split of the area travelled by the eastern spawning migration of capelin after January 15th and the assumed time of the spawning migration inhabiting the areas.

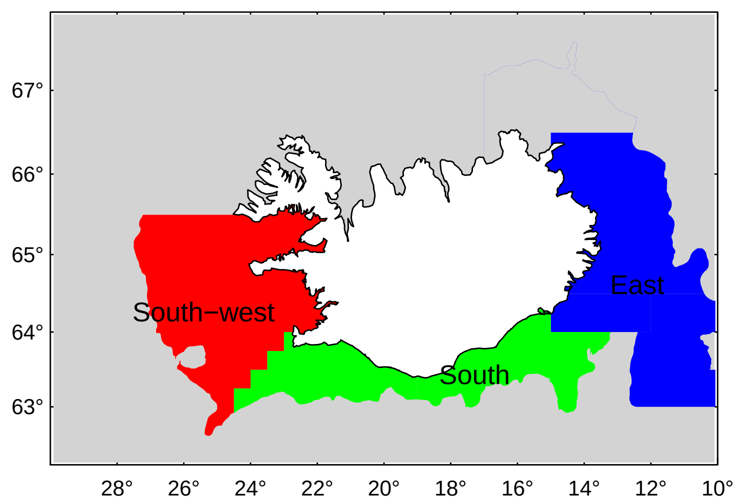

Figure 2: The 3 regions used in the simulations of predation on the eastern capelin migration

Here it is assumed that all spawning capelin will have left the east area on March 1st and the first capelin enter the south - west area February 15th.

The predator abundance in all areas is taken from the same survey so no predator is counted twice. Fish in each location is assumed to be able to prey on capelin in the timeperiods specified in table 1. In time of reduced capelin stock this time might be shorter.

Proportion of the survey biomass index in each of the areas is calculated for each predator and is used as a measure of the proportion of the predator in that area. This proportion is then multiplied by total biomass of the predator from the assessment giving an estimate of the total biomass in the area.

Abundance of cod, haddock and saithe in the migration route of capelin (areas 6-10) is shown in figures 3 and 4. The variability in the proportion shown is probably higher than in reality as measurement error in the survey is added to the "real variability". The measurement error is highest for saithe that also shows the largest variability in the survey biomass. Cod is by far the most important predator of capelin of those 3 species.

3 Modelling predation mortality

All analysis here will be based on the type II feeding function.

$$C_{pred,area} = B_{pred,area} \frac{C_{max,pred,T} B_{prey}}{B_{half} + B_{prey,area}} \tag{1}$$

The equation above is a special case for one prey, good approximation for predation on capelin in January - March where capelin is the dominating prey in the area.

Here B refers to biomass and C to consumption. $C_{max,pred,T}$ is called maximum consumption, theoretically the value that the predator will eat if it is fed to satiation . Values for cod in fish farming are obtained from an equation by [1]. The equation gives over 50% of body weight at temperature around 3 degrees, typical for the eastern area, increasing by approximately 10% for every degree . This value will never be reached here as the prey will always be difficult to access compared to fed fish in cages and part of the potential predators will not be close to the capelin schools.

B_{half} is called half feeding value and is the value where the predator eats half the maximum $C_{max,pred,T}$. B_{half} depends on the spatial overlap between predator and prey and is in each case also dependent on the spatial disaggregation used.

The characteristics of equation 1 is that for prey stock size well above B_{half}, amount eaten is independent of prey abundance but well below B_{half} predation mortality is constant. Low value of B_{half} indicates risk to the prey stock as natural mortality increases with reduced stock size of prey. This can occurr if the prey is confined to a small part of the area and the predators "know it" and get abundant capelin even though the stock is small.

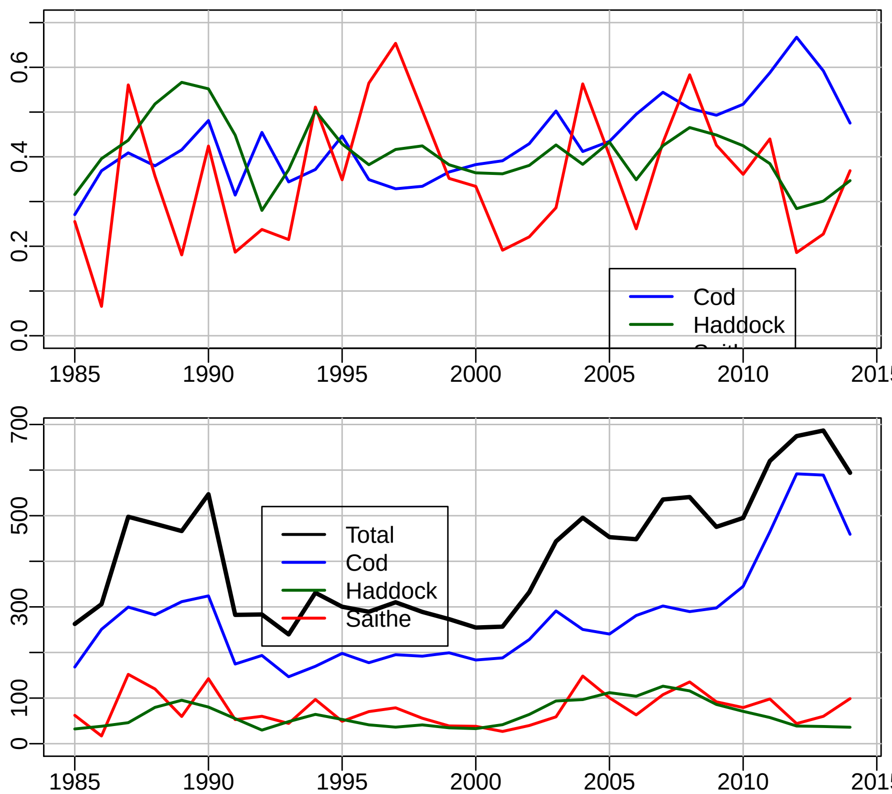

Figure 3: Proportion and amount of the stock of cod, haddock and saithe in regions 6-10 1985:2014. The amount is obtained by multiplying the proportion by the biomass according to the 2014 assessment.

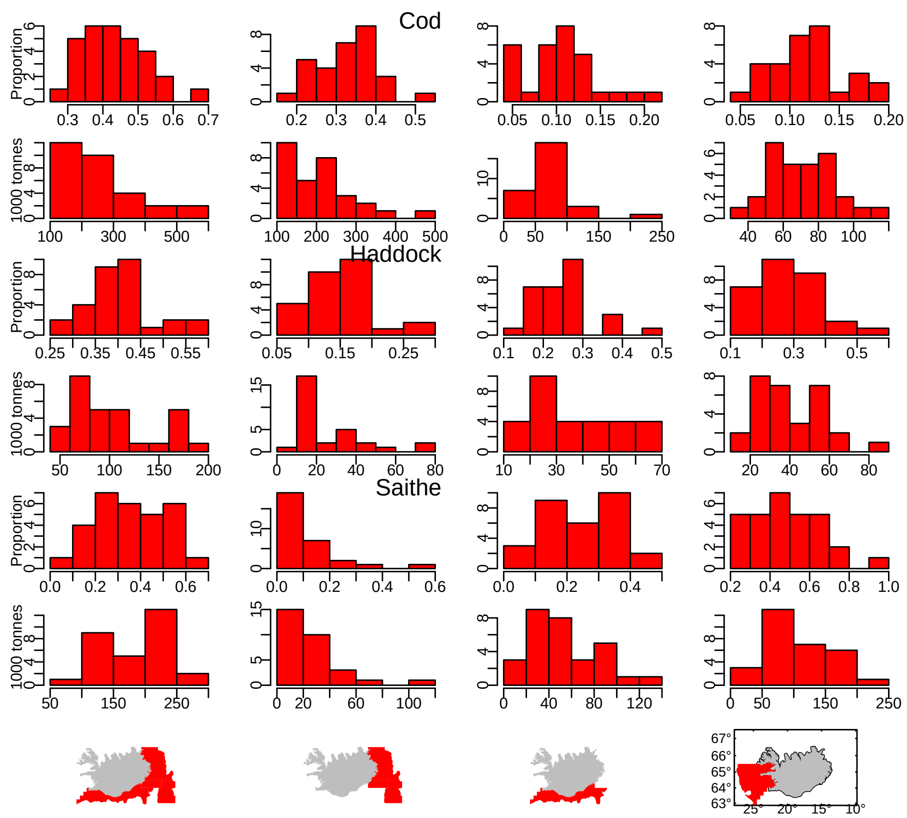

Figure 4: Distribution of the predators in different areas

Setting appropriate values for the parameters $C_{max,pred,T}$ and B_{half} is difficult. The parameters are positively correlated so range of parameter value can lead to the same calculated consumption in given year.

The estimated consumption of capelin has to be based on available stomach samples. In March, stomachs have been sampled in the groundfish survey since 1985. In January-February the sampling is more limited. All estimates of consumption from stomach content will be based on the evacuation rate model by [2]

Stomach samples from the groundfish survey in March indicate average capelin consumption of 13% of body weight in the capelin spawning area. (areas 1, 9 and 10 in figure 1 In the groundfish survey period (1-20th of March) most of the capelin that is going to spawn has probably entered the spawning areas. In March some capelin is found in cod stomachs east and south east of Iceland and the average consumption there is estimated to be around 10% of body weight per month. Part of the capelin found east of Iceland in March is mature but the question is if that capelin is ever going to spawn in the traditional spawning area south and west of Iceland.

Cod stomachs were sampled east of Iceland in January 1993 and 1994. ([3]. The cod were caught by bottom trawl contemporary to the acoustic survey, both close to the capelin schools but also further away from them, within the area. On the average cod, in the area was eating 20% of their bodyweight of capelin per month, more close to the capelin schools. Cod stomachs sampled by the crew of fishing vessels since 2002 give similar indications about consumption in January. This consumption is close to average total consumption in March but much lower than the 50% obtained from the equation by [1] as "maximum consumption" at 3 degrees. Looking at comparable numbers from the Barentssea, stomach samples from the February survey indicate that cod eat around 30% of their weight per month in years with enough capelin (Bjarte Bogstadt personal communication). Recent estimates from the Barents Sea are that cod stock of 3.7 million tonnes eats 9 million tonnes per year or 20% of body weight/month on the average. Mean weight at age of Icelandic cod is considerably higher than of Barentssea cod, in 2012 7 year old cod in the Barentssea is 10% lighter than 6 years old cod in Iceland (NWWG and AFWG reports).

To be able to estimate predation on capelin in January - February dependence of the predation on capelin stock size and estimates of cod abundance or proportion of the cod stock in the area are needed.

In January 1993 - 1994 when the stomach samples were sampled east of Iceland the capelin survey were considered "invalid" which means that capelin measured is less than expected based on earlier autumn surveys. This was most likely caused by bad weather, but could mean that the capelin stock was smaller than expected. Looking at stomach content data from the March survey the amount of capelin in cod stomachs is around average (1985-2014) in 1994 and high in 1993 and in both years the allocated TAC was easily caught. The conclusion is that the size of the capelin stock in January 1993 and 1994 when the stomachs were sampled was most likely above average.

After entering the warm waters south of Iceland the capelin migrate relatively rapidly south west to the spawning areas south and west of Iceland, and is in most years subjected to heavy fisheries in the period. Predators in the area are cod, haddock and saithe. Stomach samples from the March survey indicate that haddock in the area is on the average eating 10% of their body weight, saithe 15% and cod 15%. The proportion of each stock and the biomass inhabiting the areas is shown in figure 3. The capelin migrate relatively rapidly through the area or in 3 weeks. The capelin schools do on the other hand not migrate all at the same time so the time where predation occurs in the area is approximately 6 weeks.

As discussed above the parameters in equation 1 as it is used here are dependent on the spatial disaggregation used, the exact timing of the migrations and the spatial distribution of the predators within the areas. Variability in the parameters is included randomly selecting the predation parameters in equation 1 from a uniform distribution.

- Cod 20-40 percent of body weight
- Haddock 5-20 perecent of body weight
- Saithe 20-40 percent of body weight

Table 2: Distribution of maximum consumption used

- Eastern area 300-600 thous. tonnes
- Southern area 100-200 thous. tonnes
- Western area 100-200 thous. tonnes

Table 3: Distribution of half feeding values used.

Half feeding values in the southern and western areas are lower than in the eastern area, due to smaller area inhabited by capelin in the south. The capelin are also more easily captured by demersal predators when it approaches spawning. Getting the functional relationship between capelin stock and predation in March is impossible as the target is to always leave the same spawning stock.

The above range of values are supposed to cover interannual variability as well as uncertainty in the parameters but the overlap of capelin and cod varies from year to year, depending on the exact time of overlap and distribution of cod and capelin within the areas.

4 Timing and location of catches

In many years relatively large proportion of the capelin stock is caught, reducing the amount of capelin available for predators.

In most years bulk of the catches is taken from February 1st to March 15th. (figure 5). In the period 1993 - 2013 average landings per year were 68 thous tonnes in January, 240 thous tonnes in February and 162 thous. tonnes in March. Also 75% of the landings are taken after February 10th (60% from February 10th to March 10th). Majority of the catch in the winter season is taken in areas 9, 10 and 1 (figure 1 or 25, 19 and 23%.

Some increase in mean weight due to addition of seawater to the gonads has been predicted between the time of acoustic measurements in late January and February 20th . This predicted weight increase would be used to reduce the catches taken, but the spawning stock would be based on the January weights. Quick analysis of samples from the winter season indicate that the addition in weight from the above mentioned factor was small or $< 1\%$.

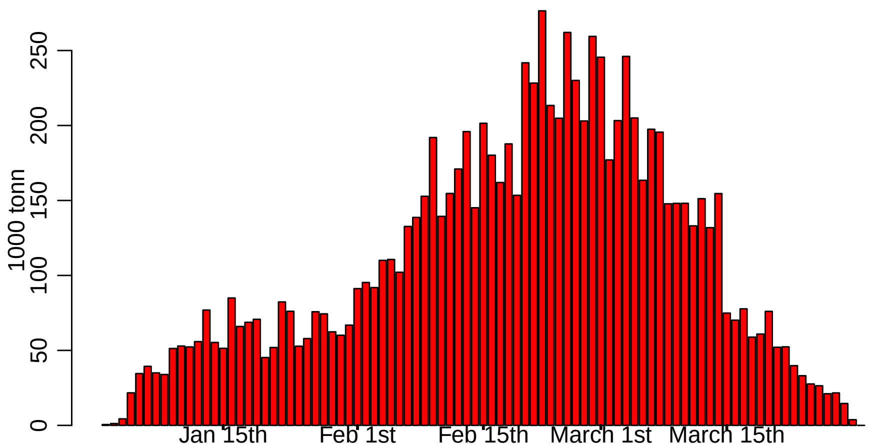

Figure 5: Catch by day in the winter fishery 1991-2014

5 Bootstrap model

Acoustic measurments in January are the main indicator of capelin stock size. Results from them are given as bootstrap replicas where each bootstrap replica is treated as it is the true capelin stock. Each bootstrap replica is then run through a predation model based on the discussions above.

Some of the parameters in the predation model are stochastic and will be selected randomly for each run.

- Spatial distribution of the predator stocks will be randomly selected from the proportions in each area in the March survey since 2008. The final capelin advice is given in January so the spatial distribution of predator stocks in the advisory year is not available.

- Stock size of the predator stocks is based on the prediction from the last years advice. Bootstrap replicas are generated by assuming the uncertainty in stocksize being lognormal with CV of 0.15 for cod and haddock but 0.2 for saithe. The biomass in each area is the total stock size multiplied by the proportions from the survey.

- Maximum consumption and half feeding values are from a uniform random distribution as described in tables **??** and 3.

Predation per area is calculated independently for the 3 areas, east , south and south west. 1/10 of the catches are assumed to be taken in the east 15th of January-February-1st, 13/20 of the catches take place in the south February-1st - March 15th and 1/4 in the west February 15th to March 15th.

Flow of the predation model.

Start with all capelin in the east January 15th, end with all capelin in the south and south west March 15th where they spawn. Length of timestep is 2 weeks i.e 4 time steps.

East Time where capelin is in this area is 6 weeks January 15th to March 1st and consumption is calculated in 3 steps, each 2 weeks.

10% of the catch is assumed to take place in this area January 15th to February 1st.

January 15th - February 1st. Calculate consumption for 2 weeks. Subtract that consumption from the stock. Subtract the catch from the stock. 45% of the remaining stock migrates over to the southern area.

February 1st - February 15th. Calculate consumption for 2 weeks. Subtract that consumption from the stock. 60% of the remaining stock migrates over to the southern area.

February 15th - March 1st. Calculate consumption for 2 weeks. Subtract that consumption from the stock. The remaining stock migrates over to the southern area.

South Time where capelin is in the area is 6 weeks, February 1st to March 15th and consumption is calculated in 3 steps, each 2 weeks.

13/20 of the total catch is assumed to be taken in the south.

February 1st - February 15th. Start with the stock coming from the eastern area February 1st. Calculate consumption for 2 weeks. Subtract that consumption from the stock. Subtract 7/30 of the catch from the stock. The remaining stock migrates over to the south west area February 15th.

February 15th - March 1st. Start with the stock coming from the eastern area February 15th. Calculate consumption for 2 weeks. Subtract that consumption from the stock. Subtract 1/3 of the catch from the stock. The remaining stock migrates over to the south west area March 1st.

March 1st - March 15th Start with the stock coming from the eastern area March 1st. Calculate consumption for 2 weeks. Subtract that consumption from the stock. Subtract 1/12 of the catch from the stock. The remaining stock spawns in the southern area.

South West: Time where capelin is in the area is 4 weeks, February 15th to March 15th.

February 15th - March 1st. Start with the stock coming from the southern part February 15th. Calculate consumption for 2 weeks. Subtract that consumption from the stock. Subtract 1/12 of the catch from the stock.

March 1st - March 15th. Add the stock coming from the south March 1st. Calculate consumption for 2 weeks. Subtract that consumption from the stock, Subtract 1/6 of the catch from the stock. The remaining stock spawns in the south west.

If the catch in any area in any period can not be reached the remaining spawning stock in reduced by the missing catch. This happens rarely when the catch is adjusted to the probability of $SSB < Blim < 0.05$. The proportion migrating into each area in each timestep has been adjusted to avoid this problem.

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Comparison of precautionary and escapement stragety for Icelandic capelin

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1 Introduction

The assessment model used for Icelandic capelin is assuming $q = 1$ in the January acoustic measurements. Results from this assessment model are used in stochastic projections.

Icelandic capelin has since around 1980 been managed by escapement stragety i.e leaving 400 thous. tonn for spawning. The spawning stock is based on acoustic measurements of the maturing stock, usually in January, approximately 6-8 weeks before spawning. The measured stock in January is predicted 6-8 weeks ahead using $M = 0.035$ per month and the adviced catch is predicted spawning stock - 400 thous. tonn. $M = 0.035/month$ has been used since 1985, before that the values used were

- M = 0.04/month from August - December
- M = 0.08/month from January - March.

The stock was benchmarked by WKSHORT in 2009 and the prediction method used was not endorsed nor was the HCR due to following reasons.

1. The current HCR is based on deterministic prediction of spawning stock from acoustic measurements without regards to the uncertainty in the

acoustic measurements. The suggestion is to use precautionary approach, i.e define B_{lim} and give advice that leads to less than 5% propability of $SSB < B_{lim}$.

2. $M = 0.035$ is probably too low and needs to be looked at again, based on potential predation.

The proposed method is similar to that used in the Barents sea, i.e stochastic projection of the stock starting from acoustic measurements, finding the TAC that lead to $SSB < B_{lim} = 5\%$. The uncertainty in the acoustic measurments is estimated by bootstrapping (see working document **) The bootstrap returns 10000 stochastic replicas, each of which is run through the stochastic predation model described in Working document 11.

The main difference between the situation in Iceland compared to the Barents sea is that the last acoustic measurement is much closer to spawning of capelin (6-8 weeks compared to 7-8 months), making effect of predation much less. As shown later the uncertainty in acoustic measurements has more weight than uncertainty in predation when the advice is based on January measurement while in the Barents sea uncertainty in predation has more weight.

2 Comparison of the precautionary approach and target spawning biomass

In this section the precautionary approach and using target SSB are compared, using simple predation model, i.e $M = 0.0$.

The starting point is a simple case where the real stock is million tonnes and the measurement error lognormal with $CV = 0.2$, giving average measured biomass of 1.021 million tonnes and standard deviation of 206 thous. tonnes (figure 1d). The plan is to leave 400 thous. tonnes so the adviced catch is the measured biomass minus 400 thous. tonnes, giving catch that is lognormally distributed with mean of 621 thous. tonnes and standard deviation of 206 thous. tonnes. The spawning stock is 378 thous. tonnes with standard deviation of 206 thous. tonnes. Probability of $SSB < 150$ thous. tonnes is 13.3%. If the goal is to have 5% probability of $SSB < 150$ the target spawning stock has to be 560 thous. tonnes. If the CV is 14.1% leaving 410 thous. tonnes will precautionary.

What matters here is the standard deviation, not the CV of the meassurements. If the standard deviation of the measurement is approximately $\frac{400-150}{1.645}$ escapement biomass of 400 thous. tonnes is approximately equivalent to B_{lim} of 150 thous. tonnes. Usually the standard deviation tends to increase with stock size so B_{escape} must increase when the stock size increases if probability of being below B_{lim} is to remain the same (figure 2). The concept of $B_{escapement}/B_{pa}$ is therefore rather questionable if the goal is to be precautionary, the relationship between appropriate $B_{escapement}$ and B_{pa} is not a simple multiplier.

Summary of the results (figure 2 shows that escapement rule is only precautionary for very low stock sizes except CV is low or 0.14. For reference the CV of a reasonably well conducted acoustic measurement is close to 0.2.

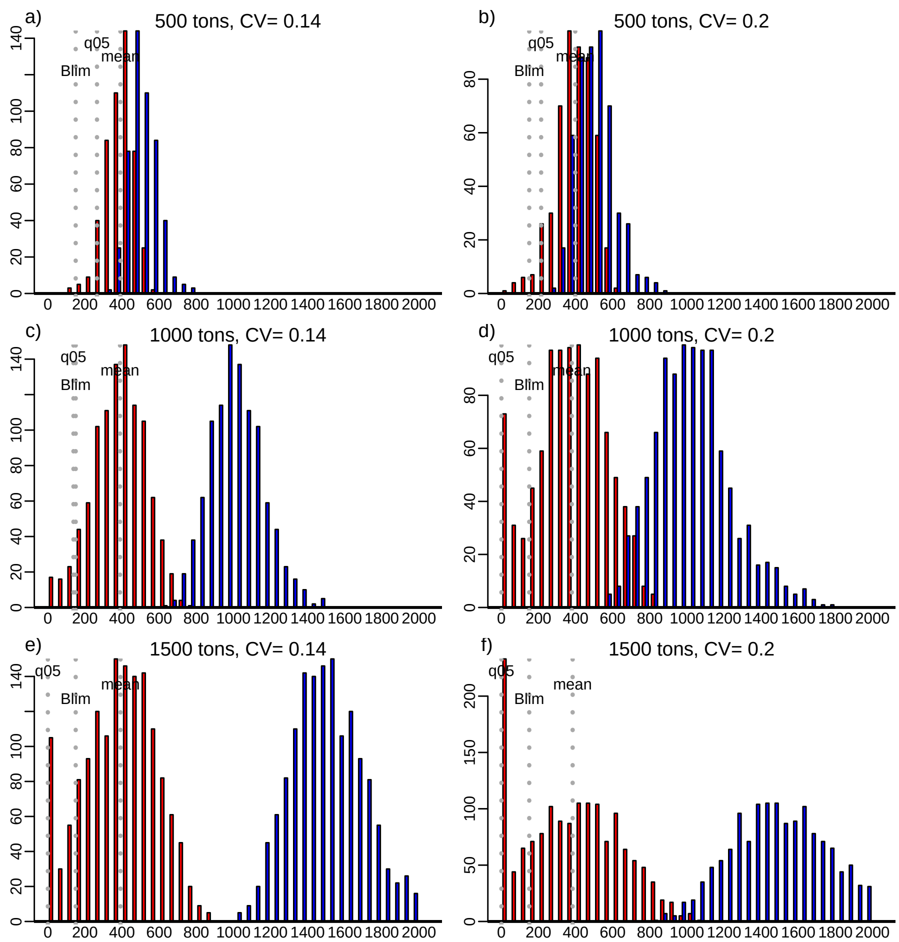

Figure 1: Distribution of the spawning stock and measured biomass for 3 values of "real biomass" and 2 values of CV. Catch is measured biomass - 400 thous. tonnes.

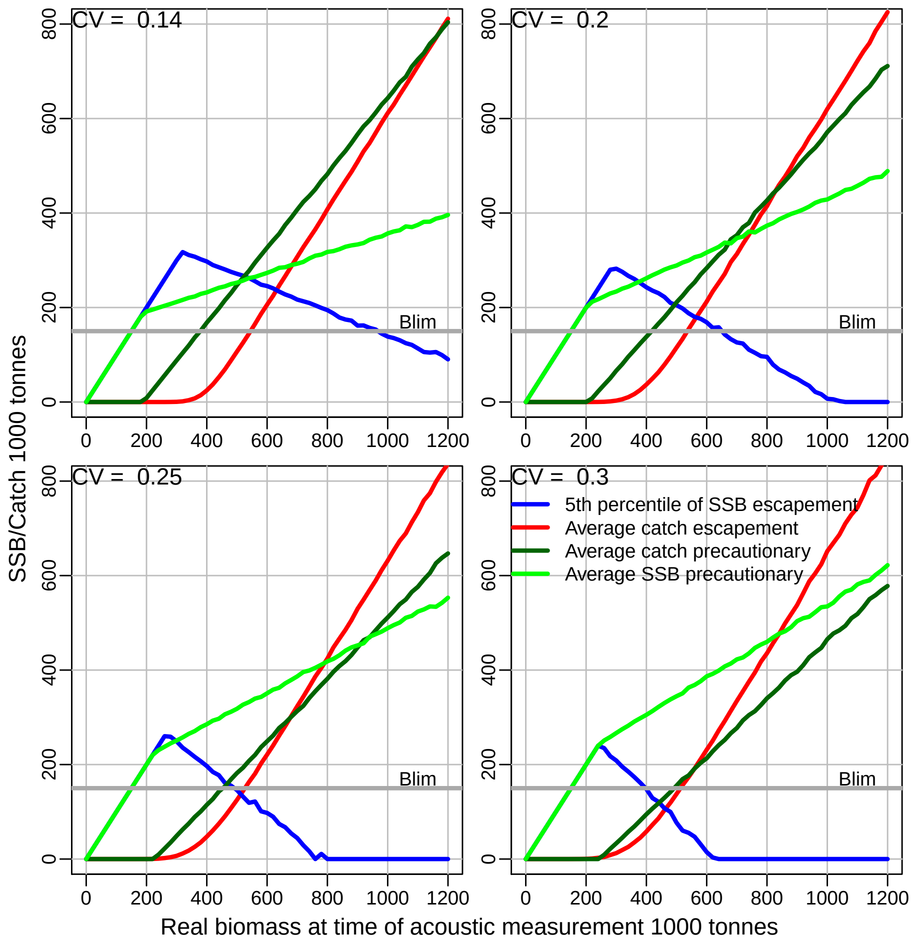

Figure 2: Comparison of PA approach based on $B_{lim} = 150$ and escapement stragety based on $B_{escapement}$=400 thous. tonnes

The basis for figure 2 is that for each set of biomass and CV 2000 replicas of measured biomass are generated using lognormal distribution with the specified CV.

$$B_{measured} = B_{real} e^{\sigma \epsilon} \tag{1}$$

Where ϵ is drawn from a standard normal distribution

The catch and spawning stock for the escapement stragety are calculated by.

$$C_{esc} = B_{measured} - 400 \tag{2}$$

$$SSB = B_{real} - C_{esc} \tag{3}$$

Based on the precautinary approach the catch is calculated by subtracting B_{lim} from the fifth percentile of $B_{measured}$. But how do we get the the fifth percentile of $B_{measured}$ as each time we do acoustic measurements we get only one value and can not take fifth percentile of that. Included with the estimate are bootstrap values and the figure is really based on assuming that the bootstrap values give us the right distribution.

To summarize, the results in figure 2 are somewhat questionable for the precautionarly rules but demonstrate well the problem with the escapement rule.

3 Combining surveys

In January more than one survey have been conducted in some years. If the surveys have been conducted with short time interval and other factors been favourable, the consistency has usually been good ($<$ 10% difference). Short time is a necessity as acoustic measurements of capelin are difficult when they have entered the warm sea south east of Iceland. The phrase "other factors been favourable" does most often refer to the weather, that is a major problem in January . The "resistance to bad weather" did though increase when the MRI got a larger vessel with adjustable keel in 2001. Stopping an acoustic measurement for several days due to storm is not desirable in January when the capelin are migrating.

When the spawning migration of capelin has been located, it is measured in relatively short time to reduce the risk of getting storm in the middle of the measurement and minimize the effect of migration during the measurement. Therefore, the distance between transsects is larger than would be used if these factors did not have to be taken into account. When bootstrapping, spatial correlation between transsects does not have to be taken into account as they are relatively far apart.

After finishing one measurement of the spawning stock another measurement can often be conducted soon after. This second measurement is often taken in the opposite direction to the first one, cancelling the effect of migration.

As the effects of spatial correlation are relatively small the surveys can be combined by averaging the bootstrap replicas from the surveys. If the stock was stationary and both surveys covered the same area this method would give similar results to bootstraping both surveys at once. The approximate effect of adding two surveys with mean μ_1 and μ_2 and standard deviation σ_1 and σ_2 is.

$$\mu = \frac{\mu_1 + \mu_2}{2} \tag{4}$$

$$\sigma = \frac{\sqrt{\sigma_1^2 + \sigma_2^2}}{2} \tag{5}$$

The effect of adding a second survey is most often to reduce the total variance and therefore increase the TAC, based on the precautionary HCR. The situation where two surveys give very different indication of the stock has to be treated in each case, but making prescription that can completely remove the need for the "judgement" of the assessors is difficult .

4 Use of acoustic measurements in the autumn

Acoustic measurements in the autumn have been carried out in most years since 1977 . The goal is both to get information about the amount of immature and mature capelin. What will be discussed here below are predictions of the measured amount of maturing capelin from September-October to middle of January.

The distribution of capelin in the autumn is much wider than in the summer and in many years the stock has not been covered due to insufficent vessel time or problems with drift ice.

The value of $0.035/month$ used for M was obtained by comparing acoustic measurements of the maturing stock in October and January in the period 1978/79 to 1984/85 (table 14.8 in [2]) but the ratio of the number measured in January and October was interpreted as an indicator of M. Natural mortality varied between 0.07 and 0.15 in approximately 3 months with the average M being 0.105/3 months or 0.035/month. Looking at the data behind this estimate the variability in calculated M is relatively low, taking into account that some measurement error is also included in the ratio.

Estimated predation on capelin by cod from stomach samples collected from 1978-1987 was estimated by [1] . Their findings were that predation by cod on capelin was on the average 90 thous. tonnes/month in the autumn 1979-1985. Average measured biomass of the maturing stock in the same years was around 700 thous. tonnes and immature stock 200 thous. tonnes. The average natural mortality caused by predation was therefore $log(1 - \frac{90}{900}) = 0.105$. This is three times the estimated predation mortality obtained from direct comparison of indices. Likely explanation of the difference is that q in the autumn surveys is lower than in the winter survey. Possible explanations are.

- Lower TS value in autumn compared to winter. Higher fat content?

- Lower proportion of the stock covered in autum.

In the period 1979-1985 large part of the capelin stock was often found relatively close to the Icelandic continental shelf in the autumn. Cod was the main predator there, although there are some other predators. If total M between autumn and winter measurements was 0.105x3 or 0.315 catchbility in autumn must be 20% lower than in the winter and biomass 20% higher than estimated, assuming $q = 1$ in winter. As biomass is higher consumption of 90 thous. tonnes/month leads to M=0.087/month leaving 0.018/month for other predators than cod .

Compared to the period 1979-1985 the autumn distribution of the capelin stock in recent years is further away from the Icelandic continental shelf, so predation by cod is less but other predators might be there.

Running the predation model for the January measurements gives average M of 0.3 or 0.15/month with CV of 0.3 (See working document 11).

The predation mortality assumed for the autumn measurements will be based on the value obtained for the period 1979-1985. Considerable variability in M is assumed or CV of 0.3. The simulations works as follows.

1. Generate M from October - January. $M = 0.315e^{0.3\delta}$ where δ is drawn standard normal distribution.
2. Start with bootstrap replicas of biomass from the autumn survey.
3. Multiply the stock by $e^{0.21}$ i.e $\frac{1}{q}$.
4. Reduce the number by the natural mortality generated.
5. Subtract catch in October - January from the stock.
6. Increase stock size by 13% due to increase in mean weight at age.
7. The outcome will be used in the predation model based on the January survey.

The assumed CV in natural mortality is higher than indicated by relationship between autumn and winter measurements in [2]. This is partly because less is known about predation in the current areas of distribution of the stock, compared to the areas closer to the Icelandic continental shelf where the capelin was found in autumn in the early 1980's. Increased variability is also to reduce the weight of the survey in advice compared to winter survey. It will also cover the case if M is higher and q in the autumn survey lower than used here, then variability in predation will have more effect. What matters is the standard deviation of predation in tonnes compared to the standard deviation biomass estimate in tonnes. If the difference is large the higher value dominates as the variances are added.

Just to put things in perpective a small example can demonstrate the method used.

$$B_{real} = 1200kt \tag{6}$$
$$B_{measured} = e^{-0.21}e^{0.2\gamma}B_{real} \tag{7}$$
$$M = 0.315e^{0.3\delta} \tag{8}$$
$$B_{pred,jan} = 1.13e^{0.21}e^{-M}B_{measured} \tag{9}$$

If $M = 0.315$ the last equation changes to

$$B_{pred,jan} = 1.017B_{measured} \tag{10}$$

Where δ and γ are standard normal variables. 1.13 is the weight increase between October and January and $e^{-0.21}$ is the catchability in the autumn measurements. CV of $B_{measured}$ is 0.206 but CV of $B_{pred,jan} = 0.225$. The fifth percentile of $B_{pred,jan}$ is 670 tous. tonnes but would be 711 thous. tonnes if no variability predation is included.

One factor that might be discussed in if the M should be bias corrected but average value of a lognormal distribution with $CV = 0.3$ is $e^{\frac{0.3^2}{2}}$=1.045 leading to average M being 0.33 instead of 0.315 or or approximately 1.5% lower predicted biomass. Here the approach is taken not to bias correct.

$B_{pred,jan}$ calculated this way will then be treated as bootstrapped January acoustic measurement. If used in that way the factor 1.13 to account for the growth will each year be replaced by the ratios of measured weights in the winter and in the autum.

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Results of HCR simulations in 2012, 2013 and 2014

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The basis for new HCR for Icelandic capelin has been described in working papers on bootstrap, predation mortality and other working papers. In this section bootstrap replicas from acoustic measurements in January will be combined with the stochastic predation model and the results compared with the current HCR of leaving 400 thous. tonnes for spawning . M=0.035 for 6 weeks will be assumed for the current HCR

When simulating bootstrap replicas forward, each replica has to be treated like it was the real stock and simulated forward using one specified set of parameters in the predation model. If more than one survey is available they will be averaged like shown in section ??. The surveys investigated are.

- Two surveys from January 2012
- Survey from October 2012 and two surveys from January 2013
- Survey from October 2014

The surveys for the same fishing season are averaged.

The investigations here do not take into account details like catch between January surveys, something that would be taken into account in assessment every year.

1 January 2012

Two surveys were conducted, the first giving biomass of 1014 thous. tonnes, with CV of 0.18 and the second 966 thous. tonnes with CV of 0.20. The adviced catch from the first survey would be 435 thous. tonnes, from the second survey 375 thous. tonnes. The surveys combined give average biomass of 990 thous. tonnes, with CV of 0.13 and adviced catch of 480 thous. tonnes using the criteria of $<$ 5 percent probability of SSB $<$ 150 thous. tonnes.

The old escapement stragety would have given $990e^{-1.5x0.035} - 400 = 540$ thous. tonnes catch. The proposed HCR is in case more precautionary than the old escapement stragety, both due to higher predicted predation but also uncertainty in the measurments when the advice is only based on one survey.

Results shows substantial variability in the spawning stock (figures 1 and 2.

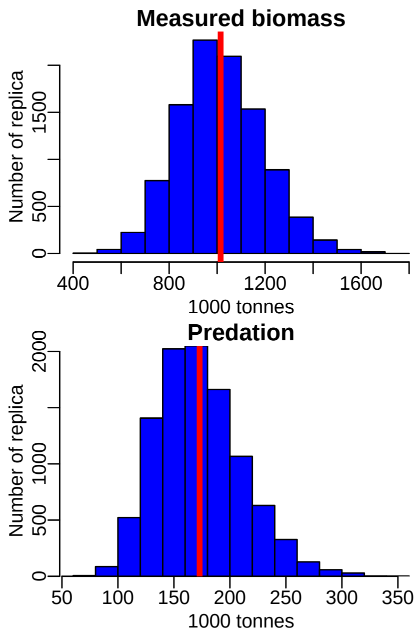

Figure 1: Summary of results when advice is based on the first survey in January 2012

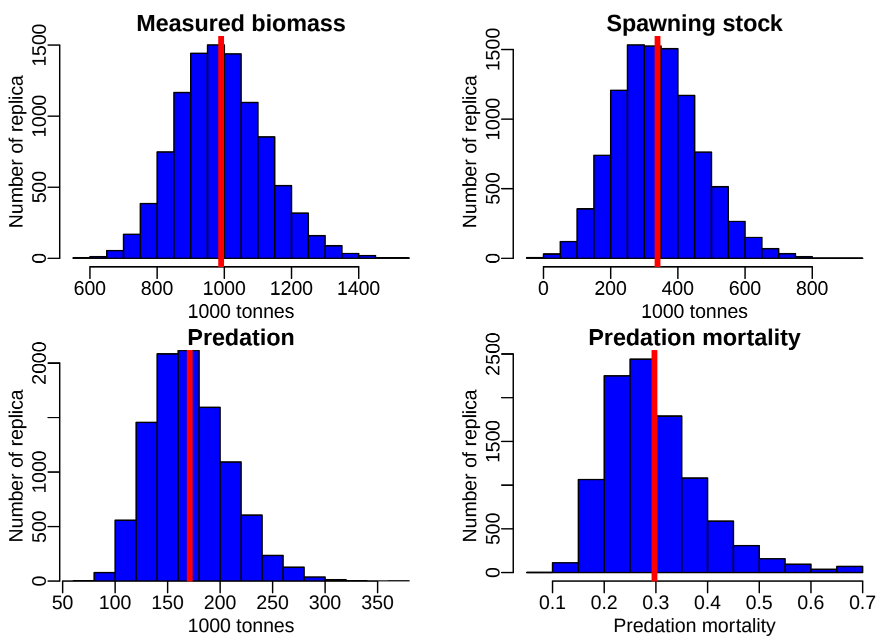

Figure 2: Summary of results when advice is based on both the surveys in January 2012. The red lines show averages.

2 Surveys in the fishing season 2012-2013

In this fishing season 3 surveys of the maturing stock are available, one in the autumn and 2 in January.

The first survey in January gives average biomass of 322 thous. tonnes with CV of 0.22. With no catch $P(SSB < 150) = 0.16$ so no catch is adviced. The second survey in January 2013 gives average biomass of 869 thous. tonnes with CV of 0.2. The advice would be 298 thous. tonnes compared to $869e^{-0.035x1.5} - 400 = 424$ thous. tonnes according to the old HCR. Combining the surveys gives average value of 595 thous. tonnes with CV of 0.155 and advice of 160 thous. tonnes.

In this case combining the surveys gives considerably lower advice than basing the advice on survey 2. Acoustic measurements can be overestimates but the level of overestimation seen here is more than expected, as the second survey does not have high CV. The likely explanation is that the first survey did not cover the whold spawning stock.

The autumn survey 2012 gives average spawning stock biomass of 795 thous. tonnes with CV of 0.34, that calculated forward into January as describe in working paper 12 gives January biomass of 801 thous. tonnes with CV of 0.35. The advice based only on the October measurement is 130 thous. tonnes but the CV of the measurement is very high and a January survey with the same values (CV=0.34) would only give 145 thous. tonn TAC but as described in working document 12 the biomass in the January and October should be similar as differences in q, M and weight at age increase do approximately cancel out. Using the old method would give an advice of $801e^{-0.035x1.5} - 400 = 360$ thous. tonnes. The large difference between the precautionary and the escapement biomass method is high measurement CV.

The autumn survey 2012 indicates that the first survey in January 2013 did not cover the whole stock and the second survey in 2013 supports this conclusion
.

Combining the second survey from 2013 and the autumn survey from 2012 leads to a catch of 287 thous. tonnes. This is lower than obtained from the second survey only but the average of the combined surveys is lower or 834 thous. tonnes compared with 870 thous. tonnes. The CV of the combined survey is also the same as of the second winter survey alone. The result of adding the autumn survey is in this case lower TAC compared to using only survey 2. The autumn survey results do on the other hand support the decision of not using survey 1 in calculating the final TAC. Using the second January survey of both the autumn and the second January survey leads to similar TAC or 298 vs. 287 thous. tonnes.

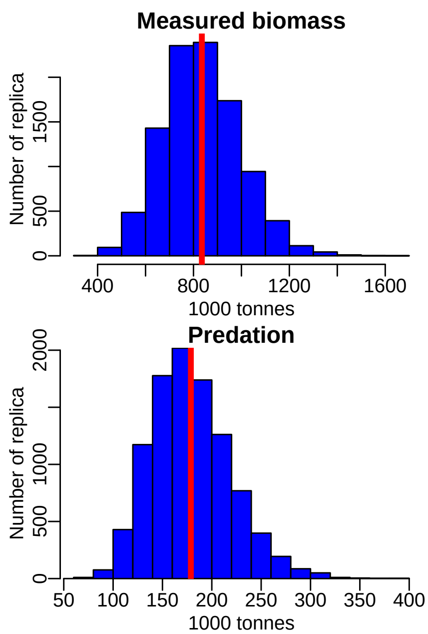

Figure 3: Summary of results when advice is based on the autumnsurvey 2012 and the second January survey 2013

3 Surveys in the fishing season 2014-2015

Currently the only available survey available on the mature part of the stock is from September to October 2014, giving average of 665 thous. tonnes and CV of 0.22. Projected to January the average is 657 thous. tonnes with CV of 0.24 and the advice based on the proposed HCR is 150 thous. tonnes, compared to approximately 235 thous. tonnes using the old HCR assuming the same biomass in autumn and January. Here again the proposed HCR is more precautionary than the old one, mostly as the CV on the projected October measurement is rather high.

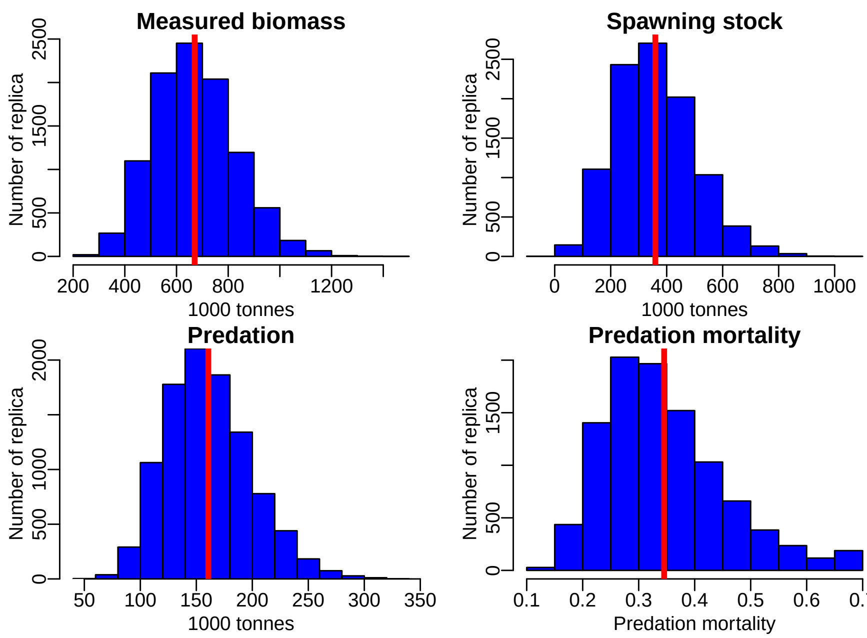

Figure 4: Summary of results when advice is based on the autumnsurvey 2014

4 Summary

The case studies shown in this documents show that the proposed HCR is considerably more precautionary in all cases then the HCR that has been used for the last years. The difference is both due to how predation is taken into account and how uncertainty is accounted for. In January 2012 when two consistent surveys, each with relatively low CV were conducted the difference between TAC from the old and new HCR is though small or 480 vs. 530 thous. tonnes.

Bootstrap estimation of echo abundance uncertainty in the Iceland–East Greenland–Jan Mayen capelin survey time series

DRAFT

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January 19, 2015

Abstract

Estimation methods for the Iceland–East Greenland–Jan Mayen capelin survey time-series are presented. A boostrap approach to uncertainty estimation is developed with elements from traditional point estimation. Bootstrap statistics (SD, CV and percentile intervals) are used to assess estimation uncertainty, and bootstrap replicates of SSB prepared for use in a candidate Harvest Control Rule including a predation model (see WDs x, ...).

1 Introduction

For soon two and a half decades a time series of results from Icelandic capelin surveys conducted with similar methods and technology has accumulated. The surveys are acoustic, and the survey estimates based on simple, time-honored methods (Vilhjálmsson, 1994; Vilhjálmsson and Carscadden, 2002).

In preparation for the following study and subsequent working documents the time series of two-dimensional caplelin nautical area scattering coefficent (NASC) or s_A is being made available in a comprehensive manner.

The following gives an overview of the surveys, their timing and coverage, as there are a number of cases of repeated coverage within survey or on subsequent surveys. Steps in data compilation and numbers and biomass estimation are described briefly.

We attempt to get a handle on the fundamental component of survey uncertainty with a bootstrap of echo abundance and survey estimates of SSB.

We study the effect of different rectangle sizes used as the basis for calculations and stratification on bootstrap distributions of total echo abundance, its mean, coefficient of variation and 5th percentile. Rectangle dimensions have been chosen after delibrations at the MRI and were guided by the assessment of the Barents Sea capelin which has for many years used fixed rectangle dimensions in their estimation procedure.

Boostrap replicates of SSBs will then be used further in a framework accounting for uncertainty in spawning stock biomass (SSB) both from the autumn and winter measurements in subsequent WDs.

2 Material and Methods

2.1 Surveys

Available data from capelin surveys in autumn 1996–2014 and winter 2000-2013 are the material for this study (winter 2014 surveys were unsuccessful). Historic data from earlier years may become available for future studies, but it was decided to limit the present analysis to the most recent and almost unbroken part of the series.

In-house survey reports, available on request from the authors, are our source for contemporary survey estimates, give information on which surveys and parts of surveys were considered to have covered the stock, and enable us to subset the right parts of the acoustic data for our analysis. Further, the survey reports along with advice reports show which survey estimates resulted in TAC-advice or advice revisions.

2.1.1 Autumn

In autumn, survey timing has evolved through the years (see discussion in WDxxx Icelandic Capelin Starting Quota). In the period under study, surveys mostly took place in October–November until 2010 when the surveys were moved forward and have since started soon after the middle of September. An exeption occured in autumn 2011 when the survey was postponed because of a strike.

2.1.2 Winter

In winter, in a number of years, the stock, or parts of it, has been covered repeatedly, so we have to deal with up to 4 comprehensive coverages a year (e.g. 2008 and 2009). Generally, surveying activity starts early in a new year, in the area NE of Iceland, and then follows the migration of the stock south along the eastern shelfbreak. Surveys sometimes continue onto the shelf into nearshore areas following later stages of the spawning migration but surveys attempted there will not be treated here due to lack of knowledge on TS in shallow waters and other factors that make acoustic estimation difficult in the near shore area (potentially triple dead-zone, *i.e.* bottom, surface and shallower than the vessel can safely navigate).

The assessment surveys have in many years been complemented with scouting surveys on commercial vessels and in 2009 calibrated commmercial vessels measured the stock in the area off NE-Iceland. Furthermore, the 2011 winter estimate of SSB was based in part on data from a commercial vessel (but in the nearshore area and therefore not covered here, see above).

2.2 Data Compilation

A crucial result from an acoustic survey targeting a given fish species is the two-dimensional distribution of nautical area scattering coefficient (NASC) or s_A (Maclennan, Fernandes, and Dalen, 2002).

This measure gives acoustic density or reflective area attributed to the target species, in this case capelin, in square meters per unit area in nautical miles (nmi) squared. Along track registrations are generally averaged over the so called elementary distance sampling unit (EDSU). On the capelin surveys 1 and 0.1 nmi (2011 and onwards) and in a few cases 0.2 nmi have been used as EDSU.

2.2.1 Report tables

The 2D results from acoustic surveys are saved in tabular form, often referred to as 'report tables' with the crucial columns latitude, longitude, time and NASC value.

Data compilation work in order to make the time series of acoustic tables availabe is in underway. Various metadata and some environmental data should be added. These include variables such as: sea surface temperature (SST) either from from continous recording or blended analysis SST, chief scientist/scrutineer, was coverage used in stock estimate?, was resulting assessment used in advice?, and possibly others.

2.2.2 Stratification

The NASC values are averaged (again) over a 'rectangle' grid covering the surveyed area. The assessment group at Hafró has decided to use a fixed rectangle size of 15' latitude by 30' longitude (quarter of an ICES statistcal rectangle) in which to average nautical area scattering coefficient (NASC or sA) along the survey track with a resolution of 1 nmi, which has traditionally been the elementary distance sampling unit (EDSU) in acoustic work on Icelandic Capelin. In recent years the EDSUs have been 0.1 nmi. The decision to increase resolution by reducing the EDSUS was made because it was felt that having to sacrifice upto 1 nmi of data on each side of an exclusion zone (*e.g* due to manuvering in connection with trawling)q was wasteful. Adoption of new software and acquisition of more powerful hardware enable the change.

Furthermore, the survey area is stratified into a varying number of strata depending mainly on the distribution of the stock and its composition as regards maturity (see subsection 2.3).

2.3 Numbers and Biomass Estimation

During survey, biological samples collected from trawl catches on stations targeted on IGJM capelin generally number 100 individuals. All fish are aged and maturity staged, and in the estimation process, the empirical values are used throughout. Maturity staging has been uncertain on a few occasions and knife edge maturity at a given length has been opted for.

The results of trawling and scrutiny of echo registrations, where a fair amount of expert judgment is applied, are used to allocate registrations to species.

A two stage stratification approach has generally been used in the past for analysis of the results of surveys of IGJM capelin.

As described in 2.2 acoustic registrations have been averaged for rectangles (average of EDSU interval averages). Fish biology samples are allocated to these in order to establish length distributions which enable estimation of numbers of fish in a square. Generally, samples are lacking in a number of squares. Traditionally, in such cases, a length distribution based on a sample or samples from adjoining or neighbouring squares are used (sometimes given *ad hoc* weights) was used. In the present work however, samples are used for all rectangles within strata with equal weight.

As capelin are generally measured on a $1/2$ cm measuring board and rounded to the next unit below, an addition of $1/4$ of a centimeter is applied to make conversion of fish lengths to target strength and on to number per square consistent with previous treatment of acoustic data on IJMG capelin.

2.3.1 Formulae, acoustic and otherwise

In the following subscripts i and j denote rectangle and stratum and a and l age and length, respectively. Letters n, w and m denote numbers sampled, average weight in samples and numbers determined mature, N and B 'total' numbers and biomass, SSB and SSN spawning stock B and N, A and P area of a rectangle and proportion of rectangle area covered by fish, all respectively.

From pelagic trawling and sample allocation and the resulting length distribution for rectangle i, we get proportions of fish per length group l

$$p_{il} = n_{il} / \sum_l n_{il} \tag{1}$$

where n_{il} is the number of fish in samples in rectangle i of length l. From standard acoustic texts and TS-relationships we have $\sigma_l = 4\pi 10^{TS_l/10}$ which gives the average back-scattering cross section of fish in rectangle i as

$$\overline{\sigma_i} = \sum_l p_{il}\sigma_l \tag{2}$$

in m^2.

Length distributions from trawl samples are converted to distributions of back-scattering cross-section, based on physics and established working relationships for target strength (TS = 19.1 log L − 74.5 dB where L is fish length and dB is decibels) (Vilhjálmsson, 1994). Average back-scattering cross-section in a rectangle enables conversion of acoustic density to fish density.

Area density of fish in numbers of fish per square nautical mile is determined from the area back scattering coefficient (in m^2/nm^2) attributed to the species being measured and the average back-scatterer in rectangle i

$$N_{A_i} = S_{A_i}/\overline{\sigma_i} \tag{3}$$

and this is split on length groups and raised to total area of the rectangle with

$$N_{il} = p_{il} N_{A_i} P_{A_i} A_i \tag{4}$$

where P_{A_i} is proportion of square i 'guesstimated' to 'contain' fish and A_i its area.

All samples used in stratum j are used with equal weight to set up an age length key and average weights and maturity by length yielding numbers

$$N_{ial} = N_{il} n_{jal} / \sum_l n_{jl} \tag{5}$$

biomass

$$B_{ial} = w_{jl} N_{ial} \tag{6}$$

and SSB

$$SSB_{ial} = m_{jl} B_{ial} \tag{7}$$

by age and length in square i in area j.

Simple model fits of weight and proportions mature by length can replace the averages used for capelin when the strategy to sample more fish for length distributions than are aged, weighed and checed for maturity is adopted.

Now there only remains some adding up, $N_{jal} = \sum_i N_{ijal}$, $N_{ja} = \sum_l N_{jal}$, $N_j = \sum_a N_{ja}$ and $N = \sum_j N_j$ for numbers, the same naturally goes for biomass and spawning stock biomass and numbers.

[NOTE An even simpler approach has been adopted for in the bootstrap studies, as regards treatment of the biological samples.]

2.4 Bootstrap

In their monograph, 'An Introduction to the Bootstrap', Efron and Tibshirani (1993) describe how percentiles of bootstrap distributions can be used as Confidence Intervals (CIs). This simple method, called 'the percentile method', will be used in bootstrap estimation of uncertainty around IGJM capelin stock parameters. A property of bootstrap CIs is that they are transformation and range preserving, which is helpful when dealing with stock parameters for a highly variable stock such as IGJM capelin.

We assume the principles of bootstrap are known, *i.e.* it is a method that consists of drawing a bootstrap sample with replacement from the observations under study, calculation of estimates of parameters of interest based on the bootstrap sample and generation of bootstrap distributions based on a large number of replicates.

The bootstrap algorithm for estimating the standard error of a parameter θ is given on p. 47 in Efron and Tibshirani (1993). It consists of 3 steps, *i.e.* selecting bootstrap samples from the observed data set, evaluating the bootstrap estimates $\hat{\theta}^*$ and estimating their standard error. For determining bootstrap $100 \cdot (1-2\alpha)\%$ CIs the third step is changed to reading off the $100 \cdot (\alpha, 1-\alpha)$ percentiles of the bootstrap distribution of $\hat{\theta}^*$.

2.4.1 Simple bootstrap

By simple we mean unstratified, which may or may not be an adequate approach.

Rectangle EA values and trawl stations are bootstrapped in parallel and are assumed independent of each other. Further, for each bootstrap realization of a trawl station the individial fish on the station are bootstrapped as well, an approach taken by several authors studying precision in landings at age (O'Brien et al., 2001; Kell et al., 2003) and inhouse work at Hafró by Guðmundur Þórðarsson.

For each boostrap sample of EA values, trawl stations and fish in sample a $\widehat{\text{SSB}}^*$ and other stock parameters of interest is estimated as given in 2.3.

2.4.2 Stratified boostrap

In order to capture structure that may be present in the capelin population/distribution stratification is introduced.

We implement a post-stratification based mainly on proportion mature. This choice is made because the split between SSB and the immature part of the stock is of primary interest, generally in autumn and can also be important in parts of the distribution area in winter.

For each area we generate bootstrap replicates in the same way as for the whole as described above.

Necessary components from the i defined strata are then combined in order to produce overall parameters of interest, e.g. $\widehat{\text{SSB}}^* = \sum_{s=1}^{S} \widehat{\text{SSB}}_s^*$.

2.4.3 Bootstrap experiments

A number of bootstrap experiments have been performed to investigate components of the estimation variability:

1. Comparison of uncertainty estimated based on a bootstrap of EDSU average NASC values and rectangle EA values and retangle EA values only. => preliminary conclusion: omit the EDSU NASC bootstrap.

2. Comparison of recangles sizes, statistical rectangles vs subrectangles. => preliminary conlusion: use 1 deg by 30 min in autumn, 30 by 15 min in winter.
3. Comparison of estimation variability in total SSB with stratified and unstratified bootstraps. => preliminary lesson: apparent variablity reduction with increased number of strata.
4. Comparison of SSB variability based on a boostrap of EA only, of EA and trawl stations and the one regarded the full bootstrap *i.e.* bootstrap of EA, trawl stations and fish in samples. => preliminary conclusion: use the one that feels most natural, *i.e.* EA, stations and fish, possibly omitting the fish.

2.5 R-packaging

Data manipulation and analysis was done in R (R Core Team, 2014), utility functions for reading in the report table format and the data base dumps, along with functions dealing with the acoustics and processing of bootstrap results were collected in package 'bionechi'. Rectangle gridding and graphical presentation was all done in package 'geo' (Bjornsson et al., 2014).

3 Results

Results from earlier studies leading into this work have been presented to NWWG as WD23 2011 (made available in 'Background Docs') and later to a Nordic work shop, and developed further and presented in-house post-survey recent years.

3.1 Data Compilation Results

to be added

3.2 Numbers and Biomass Estimation Results

to be added

3.3 Bootstrap Results

to be added

4 Discussion

4.1 Main issues

4.2 Some Minor (or not) Caveats

The data available are not always complete and some choices were made in their treatment. To name a few:

- Due to missingness in the BI500 observation table acoustic registrations (in Scatter and ScatterData tables) lack registrations of time and position. These could in theory be added by interpolation, but these cases were rare. [[probably??, sá þetta í leiðangri sem þurfti að sækja í dump en ekki í report-töflu]]
- Integration interval middle position was found from interval start and end positions, this has not been adjusted for, yet.
- When rectangle averages were converted to EA the values were discounted when coverage in a rectangle was below a threshold. This threshold was set *ad hoc* (like a lot of things in the whole IGJM work package) at sailed distance within a rectangle corresponding to one pass through the rectangle in the shorter dimension. A more strict threshold would have led to considerable discounting of rectangle area within the main distribution area of the capelin in some cases.
- Data from the beginning of the BI500 period of (digital collection of acoustic data) starting in 1991/92 at the MRI partly suffer from inexperience when a new system was introduced, but also from limitation of the hardware at the time. Space limitations were sometimes severe, and the survey personell sometimes resorted to saving at coarser intervals than the 1 nmi used for the bulk of the capelin analysis period.

There is scope for further refinement in the treatment and presentation of the acoustic survey results [but lack of resources/competance/cooperation, . . .]. Further studies could include anlysis of results by depth layers, re-interpretation of older surveys, multifrequency analysis and expert system interpretation, avoidance or un-avoidance studies (see the herring stuff), . . .]

For Barents Sea capelin the rectangle size is considerably larger, while a smaller rectangle size would be prone to autocorrelation and possibly underestimation of the estimation uncertainty. It is stressed that the 'correct' rectangle size has not been established but we feel that it is a step forward to deal with the whole timeseries in the same framework, the estimation uncertainty should at least be comparable between years if factors affecting the general distribution and behaviour of capelin remain similar.

5 Conclusions

The uncertainty in the echo abundance is by far the greatest contribution to the observation uncertainty in the acoustic estimates of IGJM capelin. This is based on privous work and preliminary estimates where the stations and fish in the samples from each station are bootstrapped as well as the rectangle averages (unpublished Hafró material). The next step in dealing with the uncertainty will be to take these three factors into account for the whole time series, yielding a frame of bootstrap replicates Icelandic capelin SSB and number of immatures for each survey coverage as applicable. This will then be coupled into a stochastic framwork where predation mortality is also modelled.

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A simple climatology exercise for the Iceland–East Greenland–Jan Mayen capelin distribution area
DRAFT

Sigurður Þór Jónsson

January 19, 2015

Abstract

SST based on AVHRR satellite data is used to compare conditions in the Iceland–East Greenland–Jan Mayen capelin distribution area in 1982–1999 and 2000–2014. SST has risen by 1° C or more in large parts of the area, and areas with SST range 1–3° C preferred by capelin have, on average, shifted considerably towards north and northwest.

1 Introduction

Climate is changing, and this has indubitably influenced the Iceland–East Greenland–Jan Mayen (IGJM) capelin distribution.

In connection with the ICES 'benchmark' workshop on IGJM capelin (WKICE2015), it was felt that changes in sea surface temperature (SST) in the IGJM capelin distribution area should be presented, at least in a rudimentary fashion, although analysis of survey results with respect to SST was not accomplished in time. At times, SST can be considerd a proxy for the ambient temperature of capelin, *i. e.* when in near surface layers and in absence of a thermocline due to frequent storms (Olafsdottir and Rose, 2012).

Pre-2000 and post-1999 climatologies for the months of October and January, in which IGJM capelin surveys often take place, were established. They were based on daily Reynolds Optimum Interpolation SST from Advanced Very High Resolution Radar (AVHRR) data with 1/2 degree resolution. An example of a different presentation of AVHRR data is shown in figure 1.

2 Material and Methods

Data are daily Optimum Interpolation AVHRR SST, version 2, for 1982–2014 Reynolds et al. (2007), accessed on `ftp://eclipse.ncdc.noaa.gov/pub/OI-daily-v2/` in December 2014 and January 2015. These data have been referred to as 'NOAA NCDC 1/4 degree AVHRR only Daily Optimum Interpolation SST'.

The data grids were subsetted for longitudes between 40° W and the prime meridian and latitudes 50–75° N.

In analysis, we used the 'nco'-toolkit by Charlie Zender, Department of Earth System Science University of California, Irvine, available at `http://nco.sourceforge.net` and the 'ncdf' package to get the data into R for presentation (and future analysis).

3 Results and Discussion

Figure 2 shows the average SST field in October and January 1982–1999 and 2000–2014.

Figure 3 highlights the area with average temperature between 1° and 3° C close to IGJM capelin temperature preference (Olafsdottir and Rose, 2012), before and after 2000. In October 2000–2014

SST in this range was on average observed further to the west on the East Greenland shelf. Average SST in January 1982–1999 for the north Icelandic shelf was 1°–3° C while after 2000 it has been greater than 3° C.

Figure 4 shows the difference between the latter and former periods chosen for this study, i.e. subtracting Figure 2a from 2c and Figure 2b from 2d. An almost overall temperature increase is evident, stronger and more widespread in October than in January. In October the temperature increase is more than 1° C over much of the Denmark strait and over the large parts of the northern Icelandic shelf. In January the SST difference between the pre-2000 and post-1999 average SST fields is generally less than for October. The temperature increass on the shelf north of Iceland extending almost north to 68° N was more than 1° C.

Different aggregations and analyses of SST based on the AVHRR and other sources of data are available on a number of websites. This anlysis is based on the daily OI SST SVHRR version 2 product which could be used in the orginal resolution or in weekly or 'longer' aggregations in future. Data products with larger timesteps might be more suitable as basis of a climatology by month as these might take better account of the variability in the data within the time period over which aggregation is done. However, such products might only be available at a coarser resolution or for a limited year range . Higher resolution products for SST and sea Ice are also available e.g. `http://ghrsst-pp.metoffice.com/pages/latest_analysis/ostia.html`, based on a suite of instruments and satellites (Donlon et al., 2012).

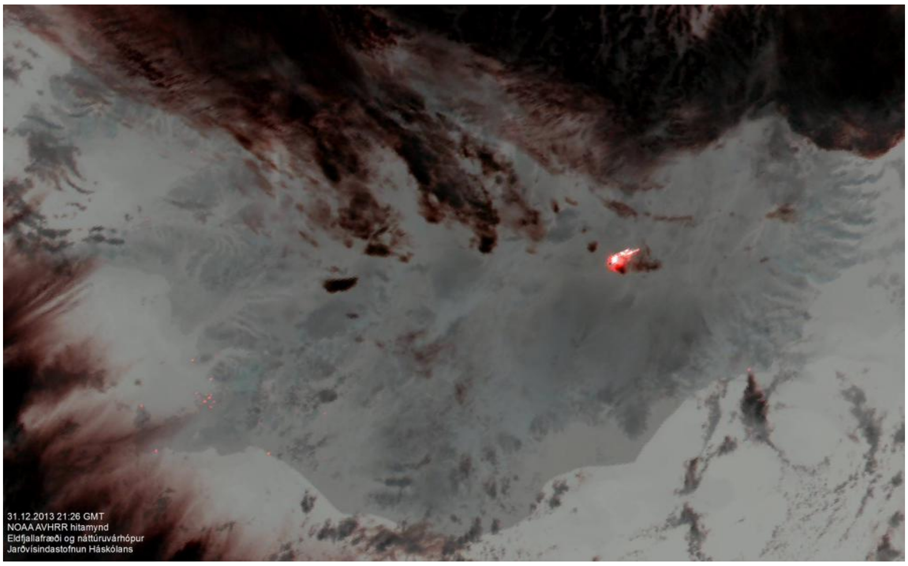

Figure 1: The Holuhraun eruption and a few rather indistinct New Year's Eve bonfires mainly discernble in the vicinity of Reykjavík sensed with AVHRR. NOAA image lifted from the Twitter account of Jarðvísindastofnun HÍ.

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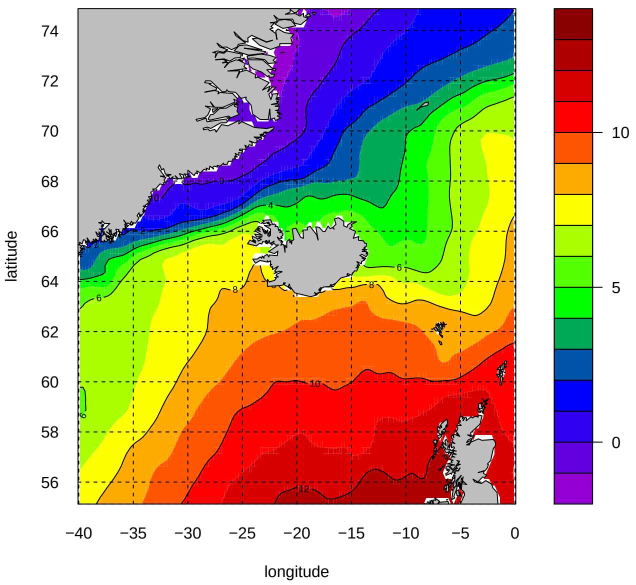
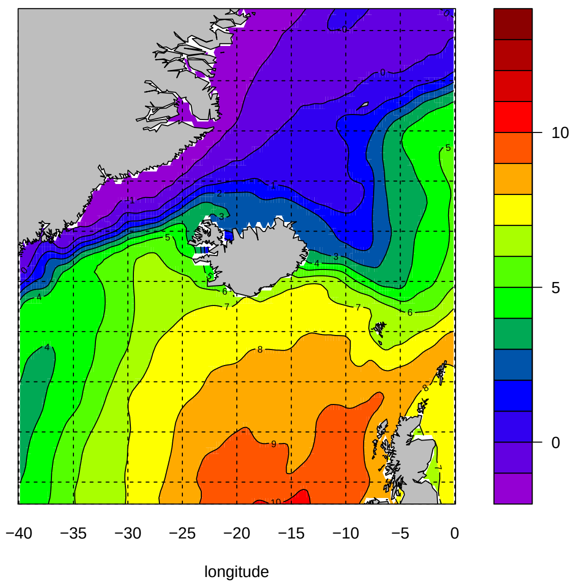
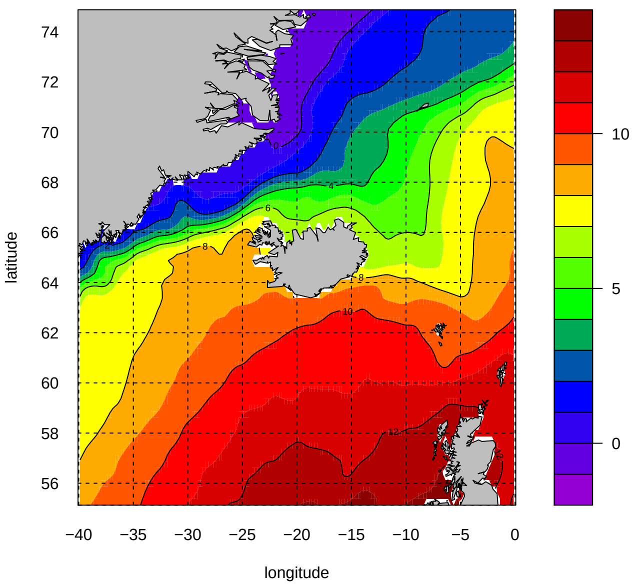


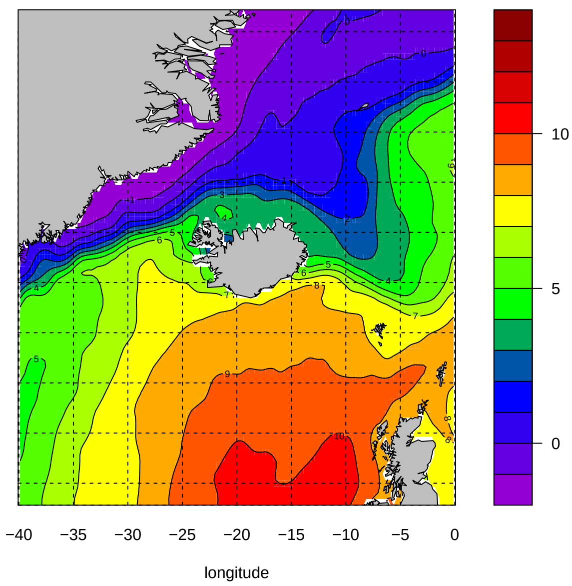
(a) October 1982–1999



(b) January 1982–1999

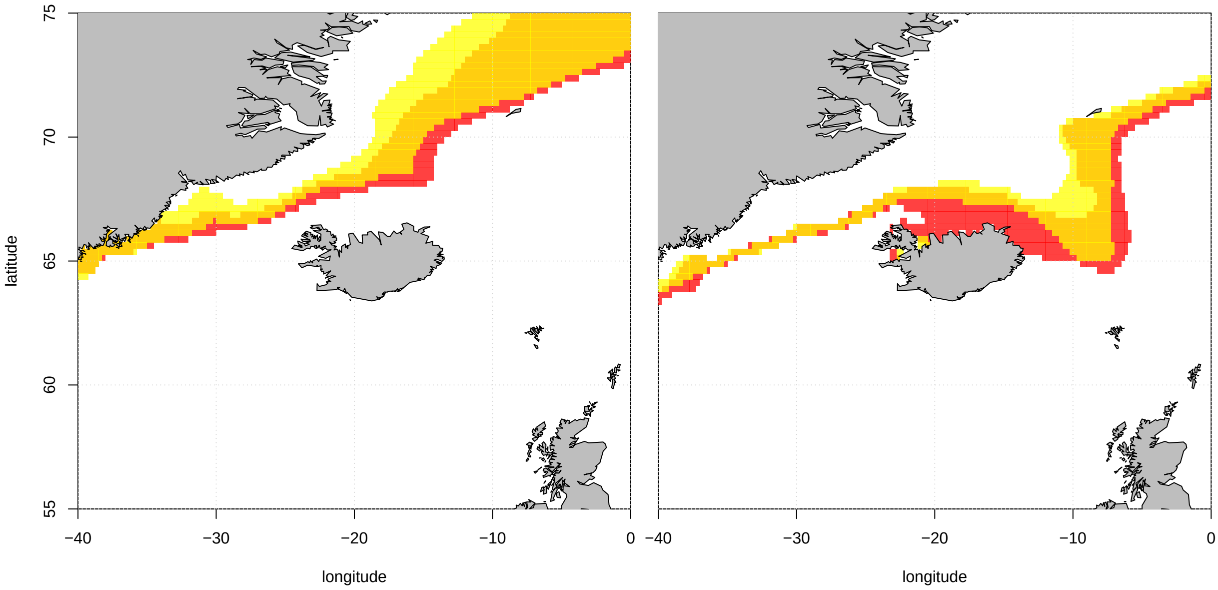


(c) October 2000–2014



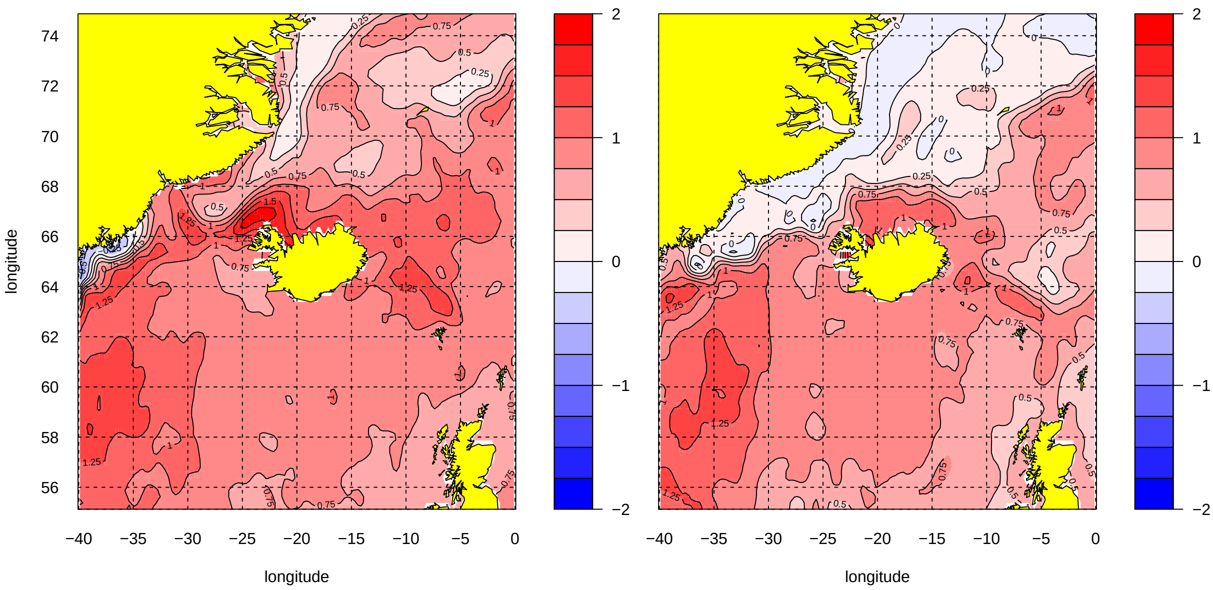
(d) January 2000–2014

Figure 2: Average SST in October (a); January (b) 1982–1999; October (c); and January (d) 2000–2014 in an area including the overall (approximate, until now) IGJM capelin distribution.



(a) (b)

Figure 3: Areas with average SST in the range 1–3° C shown for October (a) and January (b) in 1982–1999 (orange-red) and 2000–2014 (yellow) and overlap between the two periods in an intermediate color.



(a) (b)

Figure 4: Difference in average SST between the year ranges 2000–2014 and 1982–1999 in October (a) and January (b). Positive values warmer in the more recent period.

A working document to WKICE 2015

A proposal for setting an initial TAC for the capelin in Iceland - East Greenland - Jan Mayen area.

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1 Introduction

A fishery of Icelandic capelin started in the early 1960s. In the first years it was conducted in the winter months on or close to the spawning grounds south and west of Iceland. In the early 1970s the capelin was also caught during winter in deeper waters east of Iceland and in 1976 a summer fishery started in the Iceland Sea. The capelin fishery soon became both multinational and multiseasonal. The catches increased from about 50 000 t in 1965 to 1 200 000 t in the 1979/80 fishing season. The landings since early 1960s are shown in figure 1.

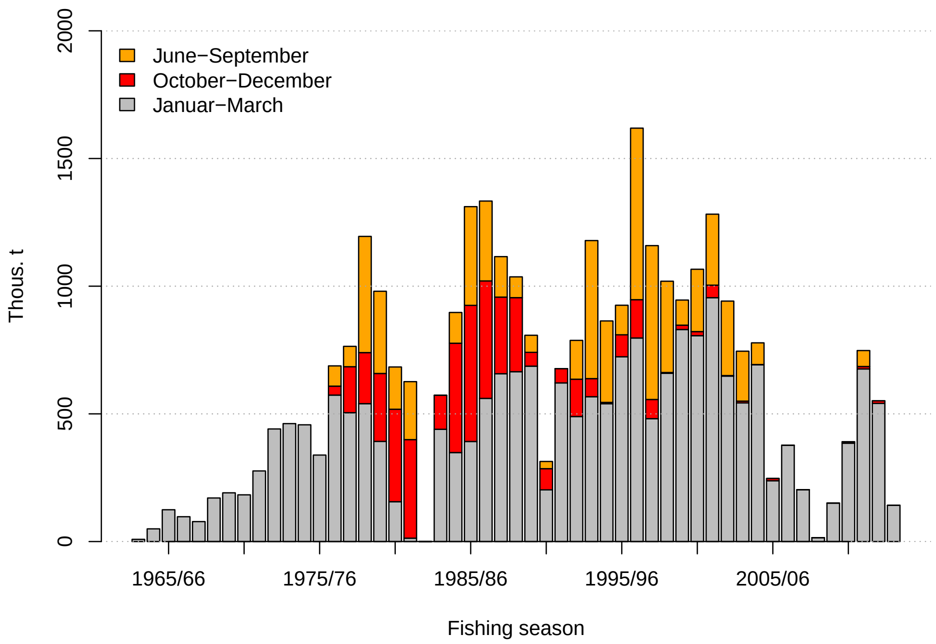
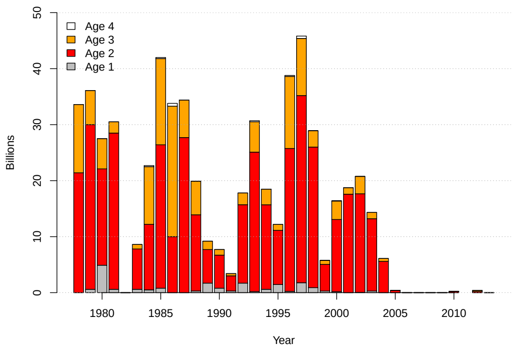
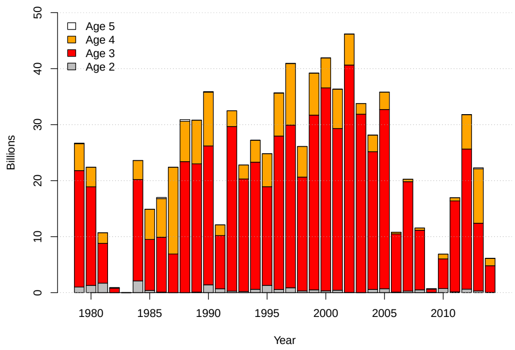


Figure 1: Icelandic capelin. Landings taken in summer, autumn and winter since 1963/1964.

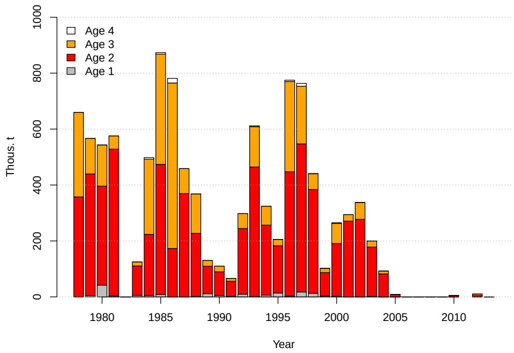
The fishery takes place on the mature part of the stock. Two yearclasses are usually dominnant in the in the fishery i.e age 2 and 3 in the summer-autumn fishery (June-December) age 3 and 4 in the winter fishery (January-March). The younger year class is generally much more pronounced than the older one, the main exception being the 1983 year class in the 1986/87 season when the older fish (age group 4) outnumbered age group 3 in the landings. To a lesser extent this also applies for the 1981 year class which was almost on par with the 1982 year class in autumn 1984 and a high proportion of the older age group was found in landings the subsequent winter. More recently the 2009 year class was 44% of abundance in winter 2013 (Figure 2) landings but the 2009 yearclass is the largest since the 2002 yearclass.



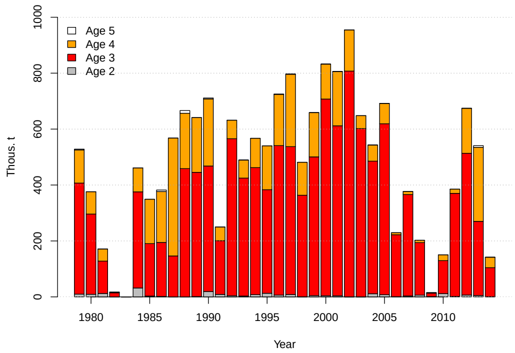
(a) Summer-autumn (numbers).



(b) Winter (numbers).



(c) Summer-autumn (weight).



(d) Winter (weight).

Figure 2: Icelandic capelin. Catches by numbers and weight at age from the fishery in summer-autumn and winter.

In the late 1970s it became clear that the fishery had to be regulated, in order to prevent over-fishing. Detailed management history of the capelin fishery is given in Vilhjálmsson [4],[5] and Vilhjálmsson and Carscadden [6]. A short version is given in Guðmundsdóttir and Vilhjálmsson [1]. In brief then the management objectives have been to leave sufficient spawners to sustain the stock and also enough for its predators. Since 1979 the targeted spawning stock (B_{target}) has been 400 000 t.

The stock has been acoustically measured since 1978 both in autumn and winter. Autumn surveys are conducted in September–November and winter surveys as a rule in January–February. Both immature and mature part of the stock are measured in the autumn. In some years the distribution of the mature stock has been very wide, sometime covered by ice. In those years more emphasis has been put on estimating the immature part of the stock, leaving measurement of the mature part for the winter months. The main rule has though been that the final measurment of the adult stock is in the winter months. Since 2010 the autumn measurements have been started earlier than before and more time has been allocated for the surveys, leading to measurements that seem to cover the whole stock. The advantages with earlier start is better weather and less ice while the disadvantage is wider distribution.

Since early 1980s an initial TAC for the summer/autumn part of the capelin fishing season has been set on the basis of acoustic estimates of immature capelin. The final TAC was then, and still is [almost without exception], set on the basis of an in-season survey on the mature part of the stock upto one and a half year later.

In the early 1990's a model was developed, that relates indices of immature capelin from the acoustic surveys October/November to backcalculated stock size August 1st the following year Guðmundsdóttir and Vilhjálmsson [1]. TAC for the following fishing year (1-1.5 years later) was then predicted based on the criterion of leaving 400 thous. tonnes for spawning. To minimize the risk of overfishing the initial TAC was set to 2/3 of the predicted TAC for the fishing season. This model replaced similar model based on measurements of immature capelin in August as part of a 0 group survey.

The model was evaluated by the benchmark group WKSHORT in 2009 [2] but was not endorsed as there were reasons to believe that the natural mortality used in back calculating the stock size to August 1st was too low.

Therefore it was recommended that another model should be established to predict, during the winter prior to the fishing season, a possible outtake from the capelin stock.

In March and December 2012 scientists from Iceland and Norway met in Reykjavik and discussed among other things how an initial TAC could be set. The main conclusion from the meeting was to keep it simple and precautionary, as it is only used to set initial TAC, with the final TAC set after an acoustic survey during the fishing season.

The group proposed to base the model on relationship between the number of immature capelin measured in autumn and the final measurement of the spawning stock 12-16 months later, correcting for the catches prior to the final surveys that have often been significant. (Figure 3). Adding the catches is possible as the acoustic surveys on the adult stock in January are considered to be absolute measurements.

In this WD we will show one potential model to use to set an initial TAC, based on the suggestions from the March and December 2012 meetings in Reykjavik.

2 Material and Methods

Data used are indices from acoustic surveys and catch data from 1980 to 2012. The survey indices are disaggregated by age and sexual maturity. Catch at age data are available by periods, i.e. from the fishery during summer-autumn (June–December) and from winter (January–March).

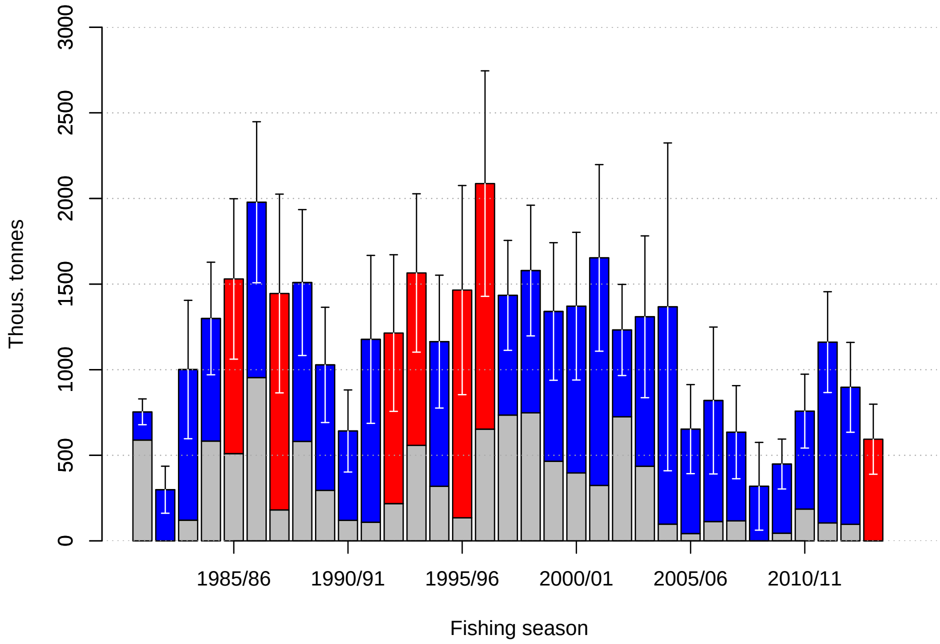


Figure 3: Icelandic capelin. Approximate catches in thous. tonnes (grey bars) taken before the surveys, which were used to set the final TAC for the seasons. Surveybiomass in thous. t and temporary estimated CV. Colors denote survey time: winter surveys (blue) and autumn surveys (red).

The objective of all the models that have been applied is to predict the possible catches in the next fishing season. Hitherto the models have predicted the size of each year class in numbers separately in the fishable stock. Another way is to predict catches, either in numbers or in weight, by a common immature index (regardless of age).

Indices of immature 1 and 2 years old capelin are combined as indices of immature capelin and indices of mature 3 and 4 years old capelin from the winter surveys as indices of mature capelin. Fishable stock is then defined as the index of mature capelin in winter plus the catches since the beginning of the fishing season.

Figure 4 shows the fishable stock biomass plotted against the index of immature capelin in numbers. The numbers on the figure denote the years when survey on the immature part of the stock took place. The colors denote the time of the year when the surveys to set the final TAC for the fishing season took place. Red numbers stand for an acoustic measurement from autumn (October/November) while the blue numbers mean that the survey took place in winter (January/February), about 15-16 months after surveys on immature capelin. Grey number indicate exceptions where the measurement of the immature part of the stock did not suceed in the autumn and and 'initial' TAC was set on the basis of other surveys (in March 2003 and June/July 2004 for the fishing seasons 2003/04 and 2004/05).

The 90% confidence intervals of the estimates of the maturing stock are shown in figure 4 but the uncertainty has been estimated for the autumn 1996-2012 (Presentation during Nordic meeting 2012, WDxx WKICE) and for winter surveys in the years 2000-2012 (NWWG WD, 2011, [3]).

For estimates in earlier years the mean of the CV from all surveys in winter is used, a value of 0.28. The mean of the CV from the autumn surveys is also 0.28. Catches are considered correct so all uncertainty comes from the surveys. The adopted B_{target} of 400 000 t is also shown.

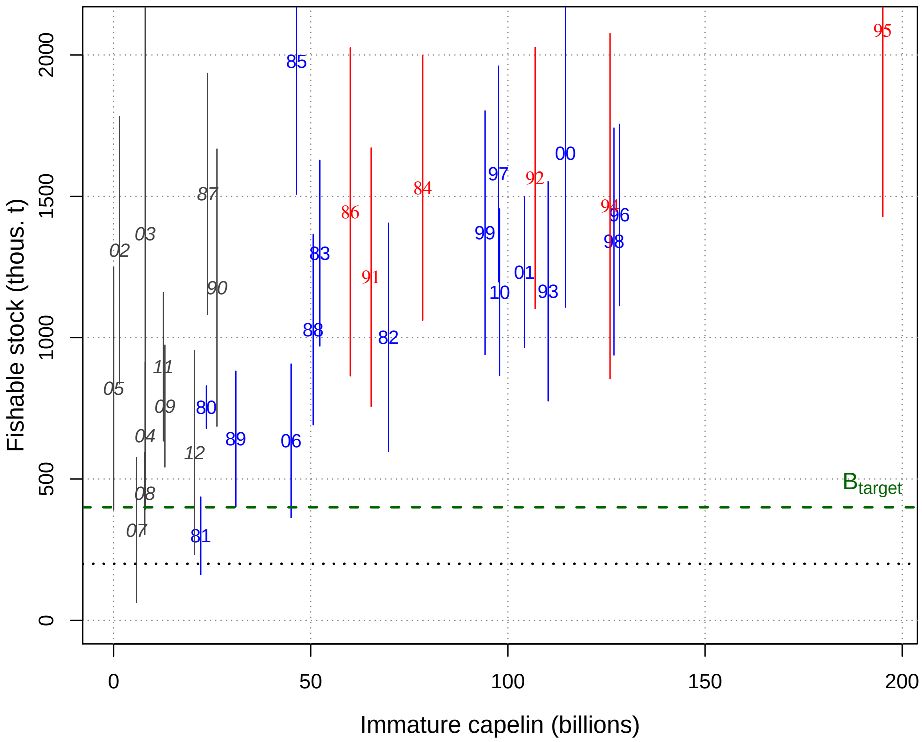


Figure 4: Icelandic capelin. Index of immature capelin against biomass of the fishable stock 12-15 months later. The numbers on the plot denote the years when the measurment of the immature capelin was conducted. The vertical bars denote 90% confidence intervals so the lower end of the vertical bars is the fifth percentile used in the precautionary approach. The horizontal lines show the old B_{target} and proposed B_{lim} of 150 thous. tonnes multiplied by averge estimated M in between January measurments and spawning $150 * e^{0.3} = 200$ (black dotted line)

3 Results and Recommendations

Potential catch can be considered as the difference between the B_{lim} multiplied by M and the lower end of the confidence intervals each year (figure 4) and the initial TAC should be lower or approximately 1/2 the final catch. From looking at figure 4 it is obvious that an initial TAC independent of the size of the immature index can't be set, as the requirement regarding B_{lim} would not be met in some years, when the immature index is low.

A straightforward way of predicting potential catch could be done by drawing an increasing line below all confidence intervals and say that the difference between it and the $B_{lim}e^{0.3}$ was the maximum potential catch and the preliminary catch would be approximately half that catch.

A proposal for setting an initial TAC is the following rule:

1. when the index of immature capelin is less than or equal to 45 the initial TAC is 0.
2. when the index of immature capelin is between 45 and 85 the initial TAC increases linearly from 0 to 300 000 t.
3. When the index of young capelin is larger than or equal to 85 the initial TAC is 300 000 t.

This proposal is shown on figure 5.

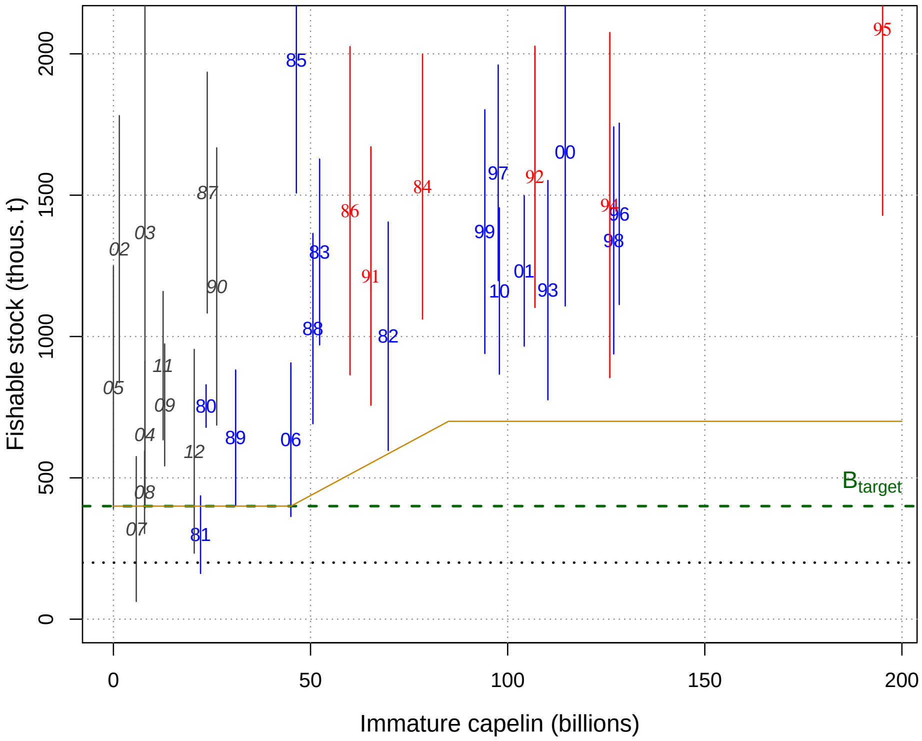


Figure 5: Icelandic capelin. The proposed initial TAC (orange line) by index of immature capelin. When index < 45, initial TAC=0; initial TAC increases linearly from 0 to 300 when immature index is between 45 and 85; initial TAC=300 when immature index > 85.

The outcome of this proposal is compared to what was assigned as a starting quota for the fishing seasons 1993/94–2013/14 (figure 6). It is clear that the proposed rule is more cautious than the one made in the beginning of the 1990s. Outstanding difference is for 3 fishing seasons in the 2000s, where starting quota was set, but would not have been done if the proposed rule would have been applied. This difference is explainable. In the fishing season 2003/04 and 2004/05 the the starting quota was based on acoustic measurements from other time of the year, namely March in 2003 and June/July in 2004. The acoustic estimate of the immature capelin in the autumns 2002 and 2003 were so low, that on their basis an initial TAC was zero. Therefore much effort was used to locate and measure the year classes that were expected to be in the fishable stock in the coming fishing season. In autumn 2006 a little something of immature capelin was measured, enough to set an initial TAC for the fishing season 2007/08, but the final TAC that fishing season amounted only the initial TAC!

In autumn 2013 the acoustic index of immature capelin was 60.1 billions. As an initial TAC ICES adviced on the basis of precautionary approach an initial TAC of 225 000 t, which is 50% of the predicted quota by the current method. Due to the proposed method, the initial TAC would have been 165 000 t.

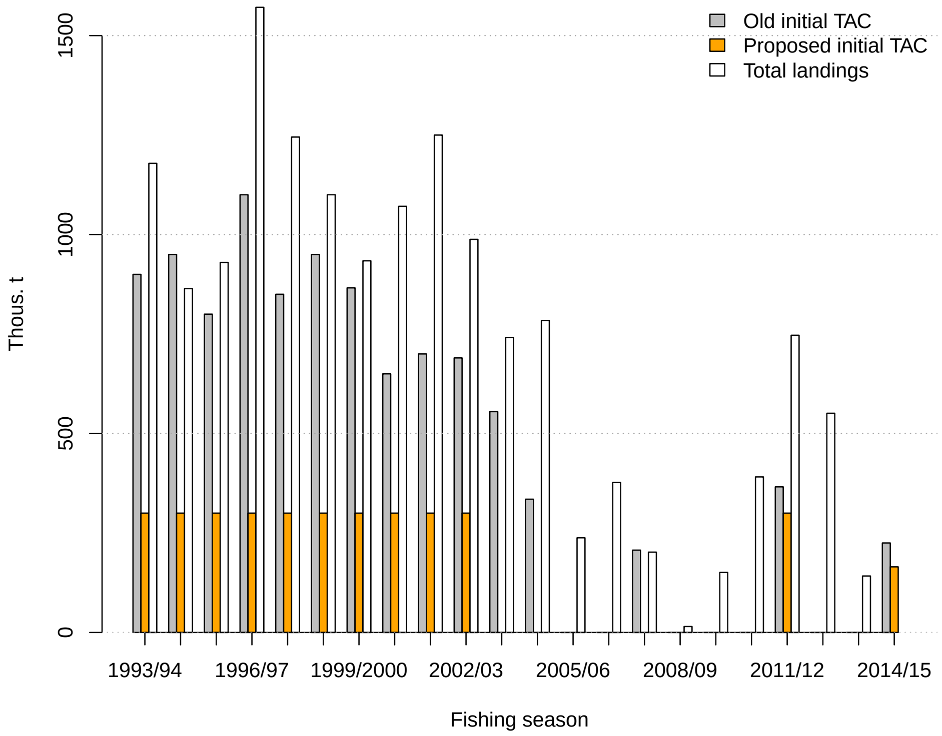


Figure 6: Icelandic capelin. Initial TAC as set on the basis of an older model, proposed initial TAC and landings for the fishing seasons since 1993/94.

In addition to the proposed rule of setting an initial TAC it is also proposed that:

- an initial TAC is based on indices of immature capelin from autumn surveys
- the fishing season will begin 1 October
- if the index of immature capelin in a year Y is so low that an initial TAC for the fishing season starting in year $Y+1$ can't be set on its basis, then the next chance of setting an 'initial' TAC is based on estimates of maturing capelin after the autumn survey in year $Y+1$.
- the final TAC for a fishing season is always set after an acoustic survey in winter (January/February), like it is now.

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Some notes on the Icelandic cod

Einar Hjörleifsson and Höskuldur Björnsson

January 24, 2015

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[1] "Document knitted 2015-01-24 12:33:58"
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- R version 3.1.2 (2014-10-31), `x86_64-redhat-linux-gnu`
- Base packages: base, datasets, graphics, grDevices, grid, methods, stats, utils
- Other packages: fishvise 0.01, ggplot2 1.0.0, knitr 1.6, lubridate 1.3.3, plyr 1.8.1, RColorBrewer 1.0-5, reshape2 1.4, scales 0.2.3, stringr 0.6.2, xtable 1.7-3
- Loaded via a namespace (and not attached): colorspace 1.2-4, dichromat 2.0-0, digest 0.6.4, evaluate 0.5.3, formatR 1.0, gtable 0.1.2, labeling 0.2, MASS 7.3-35, memoise 0.1, munsell 0.4.2, proto 0.3-10, Rcpp 0.11.3, tools 3.1.2

Contents

1 Preamble

"WKICE – Benchmark Workshop on Icelandic Stocks 2014/2/ACOM32 A Benchmark Workshop on Icelandic0 Stocks (WKICE), chaired by External Chair tbc. and ICES Chair Gudmundur Thordarsen, Iceland, and attended by two invited external experts Paul Spencer, US, Hans Lassen, Denmark and Pamela Mace, New Zealand will be established and work 25–26 November 2014 in Reykjavik, Iceland for data compilation and at ICES Headquarters for a 5 day Benchmark meeting 26–30 January 2015 back to back with WKARCT to:

1. 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:
   (a) Stock identity and migration issues
   (b) Life-history data
   (c) Fishery-dependent and fishery-independent data
   (d) Further inclusion of environmental drivers, multi-species information, and ecosystem impacts for stock dynamics in the assessments and outlook
2. Agree and document the preferred method for evaluating stock status and (where applicable) short term forecast and update the stock annex as appropriate. Knowledge about environmental drivers, including multispecies interactions, and ecosystem impacts should be integrated in the methodology If no analytical assessment method can be agreed, then an alternative method (the former method, or following the ICES data-limited stock approach) should be put forward
3. Evaluate the possible implications for biological reference points, when new standard analyses methods are proposed. Propose new MSY reference points taking into account the WKFRAME2, results and the introduction to the ICES advice (section 1.2), and WKMSYREF3. Develop recommendations for future improving of the assessment methodology and data collection
4. As part of the evaluation:
   (a) Conduct a 3 day data compilation workshop (DCWK). Stakeholders are invited to contribute data (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality. As part of the data compilation workshop consider the quality of data including discard and estimates of misreporting of landings
   (b) Following the DCWK, produce working documents to be reviewed during the Benchmark meeting at least 7 days prior to the meeting
5. For Iceland cod evaluate the management plan in relation to the PA and MSY approaches

Stocks Stock leader Cod-iceg Einar Hjörleifsson Cod-in/offgrl Anja Retzel and Rasmus Hedeholm Cap-icel Asta Gudmundsdottir

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

2 General

2.1 Stock definition

The Icelandic cod stock is distributed all around Iceland and in the assessment landings of cod within Icelandic EEZ waters it is assumed to be a single homogeneous unit. Spawning takes place in late winter mainly off the south west coast but smaller, variable regional spawning components have also been observed all around Iceland. The conventional wisdom has been that pelagic eggs and larvae from the main spawning grounds off the south west coast drift clockwise northwards and eastward along the island to the main nursery grounds off the north coast. The mature stock takes on feeding migration from the spawning grounds to feeding grounds both to deeper waters in the northwest and southeast or within the shallow water realm of the contintental shelf proper.

A larval drift to Greenland waters has been recorded in some years and substantial immigrations of mature cod from Greenland which are considered to be of Icelandic origin have been observed in some periods. This pattern was considered to be quite prevalent prior to 1970, when condition in Greenlandic waters were favourable for cod productivity. Periodic immigrations have been estimated in the assessment from anomalies in the catch at age matrix with timing and age of such events being based on expert judgement using external informations. The most recent of such migration was from the 1984 year class in 1990, the number estimated around 30 millions. Recent tagging experiments as well as abnormal decline in survey indices in West Greenlandic waters indicate that part of the 2003 and to some extent the 2002 year classes may have migrated from Greenland to Icelandic waters. In the current assessment the immigration at age 6 in 2009 is estimated around 9.7 millions corresponding an additional biomass of around 31 kt in 2009. The influence of this immigration on the current biomass estimate is minimal.

A slight but significant genetic difference has been observed between the cod spawning in the northern waters vs cod spawning in the southern waters (Pampoulie et al 2007). There are indications that different behavioural type (shallow vs. deep migration) may be found within cod spawning in the same areas (Pampoulie et al 2008). In addition genetic comparisons of cod sample in Greenlandic waters indicate that there is genetic afinnity of mature cod in Icelandic and east and southwestern Greenlandic waters. These research show that management measurements operating on a finer or larger scale than is currently in place may be warranted. However, non-ambiguous methods for splitting up or combining the input measurement of stock assessment among areas (catch at age and survey at age) have yet been investigated.

Extensive tagging experiments spanning with some hiatuses over the last 100 year indicate that significant emigration of adult cod from Iceland to other areas may be rare. In recent years it has been observed that cod tagged in Iceland has been recaptured inside Faroese waters on the Faroese ridge proper. Anecdotal informations from the fishing industry indicate that there may be some exchange of cod across the Denmark Strait. These migrations may be of different nature than the hypothesised net “life history” immigration of cod described above.

2.2 Fishery

Annual landings

Annual estimates of landings of cod from Icelandic waters are available since 1905 (Figure 1). The historical information is largely derived from Statistical Bulletin, with unknown degree of accuracy. The more recent landings (from 1980 onwared) statistics are from the Directorate of Fisheries (the native enforcement body) as annually reported to ICES.

Landings in Iceland are restricted to particular licensed landing sites, with information being collected on a daily basis. All fish landed has to be weighted, either at harbour or inside the fish processing factory. The information on landing is stored in a centralized database maintained by the Directorate and is available in real time on the internet (www.fiskistofa.is). The accuracy of the landings statistics are considered reasonable although some bias is likely. In the last years insignificant amount of cod caught in Icelandic waters have been landed in foreign ports.

Area misreporting after the establishments of 200 miles EEZ in the 1970’s has not been regarded as a major problem in the fishery of this stock. This is because the native fleet that accounts for the bulk of the total landings has had very limited access to fishing on other cod stocks. In addtion they are not allow to fish in different management areas in the same trip.

Discarding of fish of economic value is banned in Icelandic waters. Estimates of annual cod discards (Ólafur Pálsson et al 2010) since 2001 are in the range of 1.4-4.3% of numbers landed and 0.4-1.8% of weight landed. Mean annual discard of cod over the period 2001-2008 was around 2 kt, or just over 1% of landings. In 2008 estimates of cod discards amounted to 1.1 kt, 0.8% of landings, the third lowest value int the period 2001-2008. The method used for deriving these estimates assumes that discarding only occurs as high grading.

Discarding over the whole time history from 1955 is unknown, but anecdotal information indicate that they may have substantial even prior to the 1990’s. In the absence of any quantifiable data the impact of these discarding on potential bias in dynamics of cod can however not be evaluated.

Current fisheries

After WWII the fishery was initially dominated by foreign fleets, mainly English and German trawlers. The former were primarily targeting cod and catching saithe as a bycatch, while the latter were more directly targeting saithe as well as redfish. The domestic fleet has more or less been the sole exploiter of the cod resource since 1978, following the expansion of the Icelandic EEZ from 50 to 200 miles in 1975.

Information on landings by gear is available since 1955 (Figure 1). Largest portion of the catch have been taken by trawlers, with gillnet fisheries being secondary in the early part of the period. The importance of the gillnet fishery was around 30% of the landings in beginning of the period but has decline continuously since the 1980's. In recent years it has been around 10% of the total landings. The long line fisheries has increased in importance, in particular in the beginning of the 2000's, and now accounts for 35-40% of the landings.

The spatial distribution of the recent catches based on logbook records (Figures 2 and 3) show that the bottom trawl catches are to a large extent confined to outer continental shelf area in the northwest and southeast (400-500 m) while the long line catches are more dispersed on the shelf proper. The distribution of the gill net and danish seine fisheres is primarily in shallow waters in the south and the western waters (figure not shown).

Management

Since the establishment of a 200 mile EEZ in 1976 a fishery management system has been under developement for the fisheries in Iceland. In the early years various experimental effort control system where tried, but they did not result in reducing fishing mortality, for various reasons. In 1984 a mixture of a TAC and effort control system was introduced for vessels larger than 10 GRT. In the early period the entry into the TAC system for this vessel class was voluntary. Each fishing vessel in the TAC system received a fraction of the TACs, the fraction being based on average share in the catches in the three previous years. The effort options for the size classes larger than 10 GRT was fully abandoned with the Fisheries Management Act in 1990, that first came into full force for the fishing season 1991/1992. Vessels less than 10 GRT in size had until 1990 free access to the fisheries. They were under a mixed ITQ or effort control from 1991-2000. In 2001 boats larger than 6 GRT were all placed under an ITQ system. In 2003 most boast, including those under 6 GRT were under ITQ system, although some specific measures for the smaller vessels has remained in place.

Since the fishing year 1991/1992 the total allowable for cod has been set as follows: Following the annual assessment and advice and prior to the start of the fishing year, the TAC is first set (since 1995/1996 based on a formally adopted harvest control rule). From that a certain amount is set aside for various socioeconomic reasons as well that likely to be caught by the effort control fleet. The remainder is then allocated to the vessels in the ITQ system, based on their individual share.

Prior to the 1990's the TAC was most often set considerably higher than that recommended by the Marine Research Institute. In the early 1990's a govermental appointed scientific committe recommended that the TAC should be set based on a formal harvest control rule. The recommended rule was of the form:

$$TAC_{y+1} = 0.22 \times B_{4+,y}$$

where the $B_{4+,y}$ is the reference biomass in the assessment year. A formal harvest control rule was adopted and became the basis for the TAC for the first time for the fishing year 1995/96. The adopted HCR had however a higher multiplier and was also based on the predicted reference biomass:

$$TAC_{y+1} = 0.25 \times \frac{B_{4+,y} + B_{4+,y+1}}{2}$$

Some ammendment to the rule (in the form of catch stablisers) were done over time but the 0.25 multiplier in place until the mid 2000's. In the fishing year 2007/08 when the TAC was first set based on the current form of the HCR:

$$TAC_{y+1} = 0.20 \times min\left\{1, \frac{SSB_y}{SSB_{trigger}}\right\} \times \frac{B_{4+,y} + TAC_y}{2} \quad (1)$$

The ratio of the landings relative to the catch dictated by the harvest control rule in place at any time (Figure 4) show that there has been an overshoot in the landings (mean around 8%). These can be largely attributed to various socioeconomic measures that were mostly foreseeable and predictable at the time of the decision making. In the last couple of years a system has been set in place that is supposed to take account of these overshoots but it's effect is still not visible.

A system of instant area closure has been in place since the 1970's. The aim of the system is to minimize fishing on smaller fish. For cod, an area is closed temporarily (for 3 weeks) for fishing if onboard inspections (not 100% coverage) reveal that more than 25% of the catch is composed of fish less than 55 cm in length. No minimum landing size of any fish species exist in Icelandic waters. The minimum allowable mesh size is 135 mm in the trawl fisheries, with the exception of targeted shrimp fisheries in waters north of the island.

Management measures that aim at reducing incentives or likelihood of discarding have been in place since 1991. These include some allowance for individual vessels for changing quota from one species to another, although this measure does not apply to cod. A 5% overshoot of individual vessel quota in one fishing year is permitted, with the consequences that the vessels ITQ in the next year being reduced equivalently. In addition up to 20% [CHECK] of the quota in one year can be transferred to the next fishing year, without penalty. A quota leasing market is also in place, where individual vessel can lease quota from other vessel owners on a contemporary basis. The system operates in real time, meaning that if overshoot of catch of a particular species occurs during a trip, the captain can at least in theory lease quota prior to landing. The system is however somewhat limited to the supply relative demand at any particular time.

In addition to the above flexibilities additional measures to reduce incentives for discarding were set in place in 2001, by allowing vessels to report up to 5% of annual catches as outside their ITQ allowance. These measures resulted in total landings of around 2 kt, large portion being cod (around 85%).

3 Observations

3.1 Commercial catch

Sampling from the Icelandic fleet

The sampling protocol by the staff of the Marine Research Institute has in the last years been linked to the progression of landings within the year. The system is fully computerized (referred to as "Sýnó" by the natives) and directly linked to the daily landings statistics available from the Directorate of Fisheries. For each species, each fleet/gear and each landing strata a certain target of landings value behind each sample is pre-specified. Once the cumulative daily landings value pass the target value an automatic request is made to the sampling team for a specific sample to be taken. The system as such should thus take into account seasonal variability in the landings of any species. The sampling design is not per se linked to the geographical distribution of the fisheries. However the fishing location of the fish measured at harbour is known with reasonably accuracy, because fishing date is registered for each fish boxes and can hence be linked to geographic location of the fishing at that date, based on the captain's log-book record.

Calculation of catch in numbers

The calculation of the annual catch in number of the Icelandic cod has since 1980 been based on 8 metiers, two areas (northeast and southwest), 4 gears (longlines, gillnet, danish seine and gillnets) and 2 seasons (Jan-May, June-Dec). The calculation are described in the stock annex.

3.2 Biological data

Weight at age

Mean weight at age in the landings is available back to 1955. Prior to 1993 mean weight at age is compiled using fixed length - weight relationship as weighing of fish was relatively uncommon in that period. Since 1993 weighting of fish has been extensive with large proportion of cod sampled for otholiths weighted gutted and part of it ungutted. The weighting program has shown that the error in assuming fixed length-weight relationship is relatively small ($<3\%$) and that most of observed changes in mean weight at age are really changes in mean length at age.

Catch weight estimates in the assessment year (y): The weight at age in the catches is used to calculate the reference biomass (B4+). The B4+ in the assessment year (y) is the basis for the calculation of the TAC in the advisory year (y+1). Since weight at age in the catches for this year is not available during the annual assessment/advisory cycle, they have to be based on predictions. In the last few years, the estimates of mean weights in the landings of age groups 4-9 in the assessment year (y) have been based on a prediction from the spring survey measurements in the advisory year, using the relationship between survey and landings weights from the terminal year (y-1):

$$cW_{a,y-1} = \alpha + \beta * sW_{a,y-1} \tag{2}$$

and the catch weights in the advisory year then from:

$$cW_{a,y} = \alpha + \beta * sW_{a,y} \tag{3}$$

The weight at age for age groups 10-14 in the have however been taken from the terminal year. In assessment done prior to 2005, the mean weights in the landings in the assessment year were predicted from mean weights in the landings one year before and estimated abundance of adult capelin. Prediction of the capelin stock size turned out to be problematic and the survey weights on which predictions are now based are measured 3-4 months before the weights in landings assuming they are on the average in the middle of the year.

Maturity at age

Maturity at age is based on measurements obtained from spring survey. The survey time is close to the spawning time making visual detection of maturity stages optimal. Maturity at age data from ssurveys are considered to give better estimates of maturity at age in the stock than those from landings data, in particular because of limited ungutted samples in the landings.

Since the spring survey only commenced in 1985, maturity values prior to that were obtained from a relationship between maturity at age in the landings and the survey from 1985-2004.

Natural mortality

A fixed natural mortality of 0.2 is used both in the assessment and the forecast. The proportion of natural mortality before spawning (pM) and the proportion of fishing mortality before spawning (pF) are also set as constants:

	age	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	pM	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
2	pF	0.00	0.00	0.09	0.18	0.25	0.30	0.38	0.44	0.48	0.48	0.48	0.48	0.48	0.48

3.3 Survey indices

Two annual bottom trawl survey indices are available, the spring survey (SMB) that started in 1985 and the fall survey (SMH) that started in 1996. The surveys design is a classical random stratified design with fixed stations with time. With the caveat that experienced captains given the freedom to choose particular stations within a certain predefined geographical contraint determined by the scientist. The number of stations in the spring survey is 530, the number of stations in the fall are 380 (Figure 5). The spring survey covers depth to 500 meters, but the fall survey covers depths down to 1200 m. Details of the surveys are provided in Annex X.

The total biomass indices from the spring (SMB) and the fall (SMH) surveys (Figure 6) indicate that the stock biomass has been increasing substantially in recent years as is in the last 3 years among highest since the commencment of the surveys.

Abundance indices by age (Tables 6) and 8) show that older fish are all relatively high in recent years despite the indices of these year classes when younger are low or moderate in size (Figure 7). This is in part attributed to the recent estimated reduction in fishing mortalities. The CV's are generally in the range of ≈0.10-0.15, being lowest in the middle age groups (Tables 7 and 9). High variance is observed in some years which can be attributed to few hauls with extremely high cod catches.

4 Modeling framworks

The modeling frameworks are described in the stock annex and appendix.

5 Stock assessment

5.1 Historical performance

The earliest report of a catch-at-age assessment of Icelandic cod is from the year 1970 and annual assessments have been conducted since. In the beginning the assessments was `vpa`-based, either using a reiterative approach or tuned with effort and later age-disaggregated commercial cpue indices. Around

1990 the spring survey (SMB) indices were included with the commerical cpue indices as a tuning indices. The software platform used in the 1990's was `xsa`. Use of commerical indices were abandoned in 2001. Since 2002 the `adcam` module (see Appendix) has been the base for the final assessment (i.e. the assessment upon which quantitative advise was based on). The fall survey indices (SMB) were first used in the 2010 assessment.

Contemporary estimates of the reference biomass (B_{4+}) compared with the NWWG 2014 assessment (Figures 8 and 9) indicate a mean positive bias of around 4.5%, the standard error 0.14 and the autocorrelation (1st order AR) of 0.58. The retrospective pattern show a classical case of periods of under and overestimation. The largest underestimation occured in 1978 and the greatest overestimation in 1999.

5.2 Current assessment

The current assessment is based on a forward running statistical catch at age model `adcam` where fishing mortality at age is allowed to change gradually in time (random walk). The inputs are:

- Catch at age from 1955-2013, age groups 3-14 (Table 1).
- Spring survey indices at age from 1985-2014, age groups 1-10 (Table 6).
- Fall survey indices at age from 1996-2013 (no survey in 2011), age groups 1-10 (Table 8).

In the link equation between stock in numbers and survey indices:

$$U_{ay} = q_a N_{ay}^{\beta_a}$$

the β is estimated for age groups 1 to 5.

The dynamics of cod based on this asseement (Figure 10) can be summarised as follows: The spawning stock of Icelandic cod is increasing and is higher than has been observed over the last four decades. Fishing mortality has declined significantly in the last decade and is presently close to historical low. Year classes since 1985 are estimated to have been relatively stable but with the mean around 35% lower than that observed for year classes 1953 to 1984. The increase in stock size in the last decades can most likely be attributed to the reduction in fishing mortality as intended with the establishment of the HCR.

A residual block for spring survey indices age groups 2 to 5 in recent years may indicate that there may have been some change in catchability although the values are not strikingly large.

A retrospective analysis based on the current framework (Figures 12 and 13 indicate a slight overestimation of reference biomass and underestimation of fishing mortalities over the last decade. The inference made from these patterns should however be weighted against that the fishing mortality is currently low implying that older data have still influence on the terminal estimates. In otherwords, convergence is slow when fishing mortality is low.

5.3 Alternative explorations

Different surveys

As has been observed in recent years the assessment based on `adcam` module tuning with the fall survey only gives around 10% higher reference biomass than when both surveys are used, while tuning with the spring survey results in around 10% lower reference biomass. The differerence is more or less seen in all age groups (Figures 18 and 15). There are hence some conflict with respect to the extent of the increase in the biomass and reduction in fishing mortality in recent years between the two survey input sources.

Different models

Models where the catch/fishing mortality is not modelled (`adapt`) and where the fishing pattern is not considered to change each year (`separable`) (see Appendix) have been routinely run for comparative purpose (principal results shown in figures 16,17 and 18). Within these two alternative framework the observation with respect to different survey fleets on the biomass estimates is the same as observed in `adcam`, i.e. the fall survey showing generally a higher biomass estimates than the spring survey (Figure 19). The `adapt` framwork results generally in higher biomass estimates than `separable`, while current model framwork (`adcam` fall somewere in the middle.

In addition to the above models, "The Old Faithful" (`xsa` as well as the newest fad (`sam`) were run using both survey indices as tuning fleet. They resulted in somewhat higher estimates of reference biomass than the current framework (Figure 19).

In summary, with the exception of the `adapt` tuned with the fall survey and `xsa` tuned with both surveys, all model configuration tried give a reference biomass estimates in 2014 that are within around x/- 10% of the estimates in the current modeling framwork. In a sense one could argue that different model assumptions have only minor impact on the assessment results.

In addition to the above model, the data have also been annually explored in the TSA framework, a Time Series Analysis program developed and run by Guðmundur Guðmundsson (1994, 2004, details of model description are given in WD 29, NWWG 2013).

In addition to some conflict in the survey signals, the year classes seem to be declining at a faster rate in the fisheries than in the surveys. This can be demonstrated when the tuning is done only using age groups 1-4 (Figure 20). As in the base run the fishing mortality is declining in the oldest age groups (Figure 21) but the overall scaling of the fishing mortality is somewhat higher.

In a TSA analysis (done for the NWWG 2014) Guðmundur Guðmundsson made exploration on potential changes in catchability in the surveys. His conclusions were: "Significant estimates of linear trend or random walk in survey catchability are an important warning that results, based on the assumption that no permanent or long-term variations are present in the survey catchability are unreliable. But they are not a strong evidence for the assumption that linear trend or random walk are a good model of the actual process."

Given the decline in fishing mortality in recent years means that older data still have influence on the estimates in the most recent years and convergence is slow. It is hence unclear at this moment which modeling configurations most likely represent the true state of nature. It must be kept in mind that in the HCR evaluations difference in assessment results as shown above were expected, the assessment error coefficient of variation being set to 0.15 and the first order autocorrelation to 0.45 (see Figure 22).

6 HCR evaluation revisited

6.1 Preamble

In 2009 the Icelandic management body sent the following request to ICES:

"Since the mid 1990's the Government of Iceland has attempted through its management scheme for the Icelandic cod fishery to increase the size of the cod stock towards the size that generates maximum sustainable yield. To that end, progress has been made, reflected in lower fishing mortality and increase in spawning stock biomass from historical low of 120 thousand tons in 1993 to 220 thousand tons at present.

In accordance with this general aim, the Government has adopted a management plan for the Icelandic cod stock for the next five fishing years, starting by the 2009/2010 fishing season. The main objective of the management plan is to ensure that the spawning stock biomass (SSB) will with high probability (>95%) be above the present size of 220 thousand tons by the year 2015. According to a medium-term simulation conducted by the ICES North West Working Group this spring, this will be achieved by applying the following harvest control rule (HCR) to calculate the total allowable catch (TAC):

$$TAC_{y/y+1} = 0.2\frac{B_{4+,y} + TAC_{y-1/y}}{2} \quad (4)$$

This HCR formulation is based on recommendation from national committee of experts that re-evaluated the performance of the initial catch rule adopted in 1995. The Marine Research Institute, Reykjavik has used this HCR as a basis for advice the last two years. The Government of Iceland will determine the TAC for the next five fishing years according to this harvest control (HCR) and informs hereby the General Secretary of this harvest strategy. The Government of Iceland requests the Council to evaluate this management plan at its earliest convenience."

The simulation work is described in `ICES CM 2009/ACOM:56 - Report of the Ad hoc Group on Icelandic Cod HCR Evaluation (AGICOD)` (see copy in 02. Background documents)

ICES 2010 response was: " the plan is consistent with the precautionary approach (low probability of the stock declining to a level where future productivity of the stock may be impaired) and the medium-term projected fishing mortality is consistent with international commitments to achieve maximum sustainable yield (high long-term average yield, $F_{max} \approx 0.3$)

Biological reference points have not been defined for this stock. The latest ICES' assessment and advice, indicates that the SSB in 1993 was the lowest in the time series. This gives an estimated Bloss at ≈ 123 kt. The estimated SSB for 2009 is 220 kt (≈ 1.8 x B_{loss}) which is the reference biomass for the management plan. ICES' evaluation of the management plan indicates a projected SSB in 2015 that has a high probability (> 95%) of being above the estimated SSB for 2009. This statement implies a low probability (< 5%) that the projected SSB for 2015 will be below B_{loss} (a candidate value of B_{lim}) and hence, ICES' evaluates the management plan to be precautionary.

The exact conditions leading to MSY are not well known, and may depend on external conditions. The expected decrease in fishing mortality should increase stock biomass closer to that producing maximum sustainable yield. The projected management plan catch fraction of ≈ 0.2 on average is similar to common proxies for F_{msy}."

Following this response, the final form of the rule, adopted in May 2010 was of the form specified in equation 1. Given that the current calendar year is now upon which the initital objectives were set the management authorities have requested that the rule be reevaluated.

6.2 Realizations

In the 2009 simulations it was expected that the stock would increase substantially until 2015 (Figure 23). According to the 2014 assessment the biomass increased somehwhat faster than expected, given the available measurements of the incoming recruits. In part this is due to increase in the mean weights at age but changes in tuning input (only SMB in 2009 vs. both SMB and SMH in the 2014 assessment) resul in higher mean starting values in 2009. Measurements of new year classes that have become available since 2009 are also somewhat higher than expected on average. All in all the developement is within the expectd range anticipated in the 2009 simulations.

6.3 Current simulations setup

- The base model (`separable`) was the same as used in the 2009 simulations.
- The historical assessment that was the basis for the forward simulation in 2009 was based on the spring survey tuning only. This year it is based on spring and the fall tuning survey. This only has some minor effect in the initial years of the simulation but no effect on the long term dynamics.
- In 2009 the simulations were based on historical low mean weights at age in 2006-2008. The mean weights have increased since then and are in 2014 close to the long term mean. These higher weights were used as the basis of the mean weights in the current simulations. The basis for stochasticity in mean weights is the same as in 2009.
- As in 2009 no variability was assumed in maturity at age.
- The basis of the selection patterns is the most recent estimates and as in 2009 no variability was included. Given the form of the catch rule the selection pattern does not have large effect on the results.
- In 2009 the sensitivity of the HCR to different spawning stock-recruitment were investigated. One of the pessimistic recruitment-scenario (a hockey stock with mean future recruitment being based the year class 1985 onwards) was used as a basis for precautionary considerations. This year, only the hockey stick, the basis of the mean recruitment being the same.
- The basis of the stock assessment errors are the same as in 2009.

The simulation was run onwards for 50 years and the longterm metrics being based on the results from the last 10 terminal years where starting values in 2014 have little influence on results.

6.4 Results

Harvest rate in the HCR that result in maximum sustainable yield is 0.22 while harvest rate that results in less than 5% probability of going below $B_{trigger}$ is 0.21 (Figure 24).

6.5 Conclusion

The current analysis show that the developments of the stock dynamics from 2009 are similar as expected at that time. And confirms the conclusion from 2009 that the HCR is in accordance with the precautionary approach and the ICES MSY approach.

year	3	4	5	6	7	8	9	10	11	12	13	14
1955	4.790	25.164	46.566	28.287	10.541	5.224	2.467	25.182	2.101	1.202	1.668	0.665
1956	6.709	17.265	31.030	27.793	14.389	4.261	3.429	2.128	16.820	1.552	1.522	1.545
1957	13.240	21.278	17.515	24.569	17.634	12.296	3.568	2.169	1.171	6.822	0.512	1.089
1958	25.237	30.742	14.298	10.859	15.997	15.822	12.021	2.003	2.125	0.771	3.508	0.723
1959	18.394	37.650	23.901	7.682	5.883	8.791	13.003	7.683	0.914	0.990	0.218	1.287
1960	14.830	28.642	27.968	14.120	8.387	6.089	6.393	11.600	3.526	0.692	0.183	0.510
1961	16.507	21.808	19.488	15.034	7.900	6.925	3.969	3.211	6.756	1.202	0.089	0.425
1962	13.514	28.526	18.924	14.650	12.045	4.276	8.809	2.664	1.883	2.988	0.405	0.324
1963	18.507	28.466	19.664	11.314	15.682	7.704	2.724	6.508	1.657	1.030	1.372	0.246
1964	19.287	28.845	18.712	11.620	7.936	18.032	5.040	1.437	2.670	0.655	0.370	1.025
1965	21.658	29.586	24.783	11.706	9.334	6.394	11.122	1.477	0.823	0.489	0.118	0.489
1966	17.910	30.649	20.006	13.872	5.942	7.586	2.320	5.583	0.407	0.363	0.299	0.311
1967	25.945	27.941	24.322	11.320	8.751	2.595	5.490	1.392	1.998	0.109	0.030	0.106
1968	11.933	47.311	22.344	16.277	15.590	7.059	1.571	2.506	0.512	0.659	0.047	0.098
1969	11.149	23.925	45.445	17.397	12.559	14.811	1.590	0.475	0.340	0.064	0.024	0.021
1970	9.876	47.210	23.607	25.451	15.196	12.261	14.469	0.567	0.207	0.147	0.035	0.050
1971	13.060	35.856	45.577	21.135	17.340	10.924	6.001	4.210	0.237	0.069	0.038	0.020
1972	8.973	29.574	30.918	22.855	11.097	9.784	10.538	3.938	1.242	0.119	0.031	0.001
1973	36.538	25.542	27.391	17.045	12.721	3.685	4.718	5.809	1.134	0.282	0.007	0.001
1974	14.846	61.826	21.824	14.413	8.974	6.216	1.647	2.530	1.765	0.334	0.062	0.028
1975	29.301	29.489	44.138	12.088	9.628	3.691	2.051	0.752	0.891	0.416	0.060	0.046
1976	23.578	39.790	21.092	24.395	5.803	5.343	1.297	0.633	0.205	0.155	0.065	0.029
1977	2.614	42.659	32.465	12.162	13.017	2.809	1.773	0.421	0.086	0.024	0.006	0.002
1978	5.999	16.287	43.931	17.626	8.729	4.119	0.978	0.348	0.119	0.048	0.015	0.027
1979	7.186	28.427	13.772	34.443	14.130	4.426	1.432	0.350	0.168	0.043	0.024	0.004
1980	4.348	28.530	32.500	15.119	27.090	7.847	2.228	0.646	0.246	0.099	0.025	0.004
1981	2.118	13.297	39.195	23.247	12.710	26.455	4.804	1.677	0.582	0.228	0.053	0.068
1982	3.285	20.812	24.462	28.351	14.012	7.666	11.517	1.912	0.327	0.094	0.043	0.011
1983	3.554	10.910	24.305	18.944	17.382	8.381	2.054	2.733	0.514	0.215	0.064	0.037
1984	6.750	31.553	19.420	15.326	8.082	7.336	2.680	0.512	0.538	0.195	0.090	0.036
1985	6.457	24.552	35.392	18.267	8.711	4.201	2.264	1.063	0.217	0.233	0.102	0.038
1986	20.642	20.330	26.644	30.839	11.413	4.441	1.771	0.805	0.392	0.103	0.076	0.044
1987	11.002	62.130	27.192	15.127	15.695	4.159	1.463	0.592	0.253	0.142	0.046	0.058
1988	6.713	39.323	55.895	18.663	6.399	5.877	1.345	0.455	0.305	0.157	0.114	0.025
1989	2.605	27.983	50.059	31.455	6.010	1.915	0.881	0.225	0.107	0.086	0.038	0.005
1990	5.785	12.313	27.179	44.534	17.037	2.573	0.609	0.322	0.118	0.050	0.015	0.020
1991	8.554	25.131	15.491	21.514	25.038	6.364	0.903	0.243	0.125	0.063	0.011	0.012
1992	12.217	21.708	26.524	11.413	10.073	8.304	2.006	0.257	0.046	0.032	0.009	0.008
1993	20.500	33.078	15.195	13.281	3.583	2.785	2.707	1.181	0.180	0.034	0.011	0.013
1994	6.160	24.142	19.666	6.968	4.393	1.257	0.599	0.508	0.283	0.049	0.018	0.006
1995	10.770	9.103	16.829	13.066	4.115	1.596	0.313	0.184	0.156	0.141	0.029	0.008
1996	5.356	14.886	7.372	12.307	9.429	2.157	0.837	0.208	0.076	0.065	0.055	0.005
1997	1.722	16.442	17.298	6.711	7.379	5.958	1.147	0.493	0.126	0.028	0.037	0.021
1998	3.458	7.707	25.394	20.167	5.893	3.856	2.951	0.500	0.196	0.055	0.033	0.013
1999	2.525	19.554	15.226	24.622	12.966	2.795	1.489	0.748	0.140	0.046	0.010	0.005
2000	10.493	6.581	29.080	11.227	11.390	5.714	1.104	0.567	0.314	0.074	0.022	0.006
2001	11.338	25.040	9.311	19.471	5.620	3.929	2.017	0.452	0.202	0.118	0.013	0.009
2002	5.934	18.482	24.297	6.874	8.943	2.227	1.353	0.689	0.123	0.040	0.041	0.002
2003	3.950	16.160	21.874	18.145	5.063	4.419	1.124	0.401	0.172	0.034	0.020	0.015
2004	1.778	19.184	25.003	17.384	9.926	2.734	2.023	0.481	0.126	0.062	0.014	0.005
2005	5.102	5.125	26.749	16.980	8.339	4.682	1.292	0.913	0.203	0.089	0.025	0.002
2006	3.258	12.884	8.438	22.041	10.418	4.523	2.194	0.497	0.336	0.067	0.027	0.002
2007	2.074	11.961	15.948	8.280	9.593	5.428	2.205	1.229	0.366	0.198	0.053	0.010
2008	2.616	4.850	12.585	11.973	5.238	4.582	2.040	0.831	0.308	0.053	0.037	0.004
2009	3.660	8.150	9.480	17.330	10.060	3.910	2.290	0.770	0.310	0.090	0.020	0.010
2010	3.174	7.219	9.385	8.692	10.695	5.588	1.599	1.095	0.337	0.197	0.071	0.016
2011	4.780	7.257	9.284	10.735	6.032	6.152	2.361	0.666	0.459	0.151	0.041	0.010
2012	3.839	10.010	10.400	9.435	8.866	4.834	3.206	1.269	0.369	0.218	0.101	0.030
2013	5.206	12.328	14.846	11.194	7.357	5.636	2.694	1.937	0.676	0.290	0.157	0.052

Table 1: Icelandic cod in Division Va. Estimateded catch in numbers by year and age in millions of fish in 1955-2013.

year	3	4	5	6	7	8	9	10	11	12	13	14
1955	0.827	1.307	2.157	3.617	4.638	5.657	6.635	6.168	8.746	8.829	10.086	14.584
1956	1.080	1.600	2.190	3.280	4.650	5.630	6.180	6.970	6.830	9.290	10.965	12.954
1957	1.140	1.710	2.520	3.200	4.560	5.960	7.170	7.260	8.300	8.290	10.350	13.174
1958	1.210	1.810	3.120	4.510	5.000	5.940	6.640	8.290	8.510	8.840	9.360	13.097
1959	1.110	1.950	2.930	4.520	5.520	6.170	6.610	7.130	8.510	8.670	9.980	11.276
1960	1.060	1.720	2.920	4.640	5.660	6.550	6.910	7.140	7.970	10.240	10.100	12.871
1961	1.020	1.670	2.700	4.330	5.530	6.310	6.930	7.310	7.500	8.510	9.840	14.550
1962	0.990	1.610	2.610	3.900	5.720	6.660	6.750	7.060	7.540	8.280	10.900	12.826
1963	1.250	1.650	2.640	3.800	5.110	6.920	7.840	7.610	8.230	9.100	9.920	11.553
1964	1.210	1.750	2.640	4.020	5.450	6.460	8.000	9.940	9.210	10.940	12.670	15.900
1965	1.020	1.530	2.570	4.090	5.410	6.400	7.120	8.600	12.310	10.460	10.190	17.220
1966	1.170	1.680	2.590	4.180	5.730	6.900	7.830	8.580	9.090	14.230	14.090	17.924
1967	1.120	1.820	2.660	4.067	5.560	7.790	7.840	8.430	9.090	10.090	14.240	16.412
1968	1.170	1.590	2.680	3.930	5.040	5.910	7.510	8.480	10.750	11.580	14.640	16.011
1969	1.100	1.810	2.480	3.770	5.040	5.860	7.000	8.350	8.720	10.080	11.430	13.144
1970	0.990	1.450	2.440	3.770	4.860	5.590	6.260	8.370	10.490	12.310	14.590	21.777
1971	1.090	1.570	2.310	2.980	4.930	5.150	5.580	6.300	8.530	11.240	14.740	17.130
1972	0.980	1.460	2.210	3.250	4.330	5.610	6.040	6.100	6.870	8.950	11.720	16.000
1973	1.030	1.420	2.470	3.600	4.900	6.110	6.670	6.750	7.430	7.950	10.170	17.000
1974	1.050	1.710	2.430	3.820	5.240	6.660	7.150	7.760	8.190	9.780	12.380	14.700
1975	1.100	1.770	2.780	3.760	5.450	6.690	7.570	8.580	8.810	9.780	10.090	11.000
1976	1.350	1.780	2.650	4.100	5.070	6.730	8.250	9.610	11.540	11.430	14.060	16.180
1977	1.259	1.911	2.856	4.069	5.777	6.636	7.685	9.730	11.703	14.394	17.456	24.116
1978	1.289	1.833	2.929	3.955	5.726	6.806	9.041	10.865	13.068	11.982	19.062	21.284
1979	1.408	1.956	2.642	3.999	5.548	6.754	8.299	9.312	13.130	13.418	13.540	20.072
1980	1.392	1.862	2.733	3.768	5.259	6.981	8.037	10.731	12.301	17.281	14.893	19.069
1981	1.180	1.651	2.260	3.293	4.483	5.821	7.739	9.422	11.374	12.784	12.514	19.069
1982	1.006	1.550	2.246	3.104	4.258	5.386	6.682	9.141	11.963	14.226	17.287	16.590
1983	1.095	1.599	2.275	3.021	4.096	5.481	7.049	8.128	11.009	13.972	15.882	18.498
1984	1.288	1.725	2.596	3.581	4.371	5.798	7.456	9.851	11.052	14.338	15.273	16.660
1985	1.407	1.971	2.576	3.650	4.976	6.372	8.207	10.320	12.197	14.683	16.175	19.050
1986	1.459	1.961	2.844	3.593	4.635	6.155	7.503	9.084	10.356	15.283	14.540	15.017
1987	1.316	1.956	2.686	3.894	4.716	6.257	7.368	9.243	10.697	10.622	15.894	12.592
1988	1.438	1.805	2.576	3.519	4.930	6.001	7.144	8.822	9.977	11.732	14.156	13.042
1989	1.186	1.813	2.590	3.915	5.210	6.892	8.035	9.831	11.986	10.003	12.611	16.045
1990	1.290	1.704	2.383	3.034	4.624	6.521	8.888	10.592	10.993	14.570	15.732	17.290
1991	1.309	1.899	2.475	3.159	3.792	5.680	7.242	9.804	9.754	14.344	14.172	20.200
1992	1.289	1.768	2.469	3.292	4.394	5.582	6.830	8.127	12.679	13.410	15.715	11.267
1993	1.392	1.887	2.772	3.762	4.930	6.054	7.450	8.641	10.901	12.517	14.742	16.874
1994	1.443	2.063	2.562	3.659	5.117	6.262	7.719	8.896	10.847	12.874	14.742	17.470
1995	1.348	1.959	2.920	3.625	5.176	6.416	7.916	10.273	11.022	11.407	13.098	15.182
1996	1.457	1.930	3.132	4.141	4.922	6.009	7.406	9.772	10.539	13.503	13.689	16.194
1997	1.484	1.877	2.878	4.028	5.402	6.386	7.344	8.537	10.797	11.533	10.428	12.788
1998	1.230	1.750	2.458	3.559	5.213	7.737	7.837	9.304	10.759	14.903	16.651	18.666
1999	1.241	1.716	2.426	3.443	4.720	6.352	8.730	9.946	11.088	12.535	14.995	15.151
2000	1.308	1.782	2.330	3.252	4.690	5.894	7.809	9.203	10.240	11.172	13.172	17.442
2001	1.499	2.050	2.649	3.413	4.766	6.508	7.520	9.055	8.769	9.526	11.210	13.874
2002	1.294	1.926	2.656	3.680	4.720	6.369	7.808	9.002	10.422	13.402	9.008	16.893
2003	1.265	1.790	2.424	3.505	4.455	5.037	5.980	7.819	8.802	10.712	12.152	13.797
2004	1.257	1.771	2.323	3.312	4.269	5.394	5.872	7.397	10.808	11.569	13.767	12.955
2005	1.194	1.712	2.374	3.435	4.392	5.201	6.200	5.495	7.211	9.909	12.944	18.151
2006	1.070	1.614	2.185	3.052	4.347	5.177	5.382	5.769	6.258	5.688	7.301	15.412
2007	1.083	1.556	2.144	2.754	3.920	5.255	6.272	6.481	7.142	6.530	9.724	10.143
2008	1.162	1.627	2.318	3.120	3.846	5.367	6.771	7.648	8.282	11.181	14.266	17.320
2009	1.109	1.680	2.204	3.206	4.098	4.884	6.744	8.505	10.126	12.108	12.471	15.264
2010	1.131	1.769	2.334	3.161	4.422	5.498	6.552	7.945	8.913	10.090	10.417	13.489
2011	1.163	1.795	2.615	3.471	4.469	5.850	6.742	7.850	8.810	9.797	13.534	13.033
2012	1.256	1.667	2.448	3.728	4.713	5.894	7.616	8.358	9.543	10.916	10.884	11.758
2013	1.248	1.722	2.478	3.559	4.931	6.165	7.522	8.415	9.336	9.926	11.195	12.691
2014	1.226	1.820	2.344	3.108	4.222	5.998	7.558	8.414	9.335	9.924	11.193	12.689

Table 2: Icelandic cod in Division Va. Estimated mean weight at age in the landings (kg) in period the 1955-2013. The weights for age groups 3 to 9 in 2014 are based on predictions from the 2014 spring survey measurements. The weights in the catches are used to calculate the reference biomass (B_{4+}).

year	3	4	5	6	7	8	9	10	11	12	13	14
1955	0.645	1.019	1.833	3.183	4.128	5.657	6.635	6.168	8.746	8.829	10.086	14.584
1956	0.645	1.248	1.862	2.886	4.138	5.630	6.180	6.970	6.830	9.290	10.965	12.954
1957	0.645	1.334	2.142	2.816	4.058	5.960	7.170	7.260	8.300	8.290	10.350	13.174
1958	0.645	1.412	2.652	3.969	4.450	5.940	6.640	8.290	8.510	8.840	9.360	13.097
1959	0.645	1.521	2.490	3.978	4.913	6.170	6.610	7.130	8.510	8.670	9.980	11.276
1960	0.645	1.342	2.482	4.083	5.037	6.550	6.910	7.140	7.970	10.240	10.100	12.871
1961	0.645	1.303	2.295	3.810	4.922	6.310	6.930	7.310	7.500	8.510	9.840	14.550
1962	0.645	1.256	2.218	3.432	5.091	6.660	6.750	7.060	7.540	8.280	10.900	12.826
1963	0.645	1.287	2.244	3.344	4.548	6.920	7.840	7.610	8.230	9.100	9.920	11.553
1964	0.645	1.365	2.244	3.538	4.850	6.460	8.000	9.940	9.210	10.940	12.670	15.900
1965	0.645	1.193	2.184	3.599	4.815	6.400	7.120	8.600	12.310	10.460	10.190	17.220
1966	0.645	1.310	2.202	3.678	5.100	6.900	7.830	8.580	9.090	14.230	14.090	17.924
1967	0.645	1.420	2.261	3.579	4.948	7.790	7.840	8.430	9.090	10.090	14.240	16.412
1968	0.645	1.240	2.278	3.458	4.486	5.910	7.510	8.480	10.750	11.580	14.640	16.011
1969	0.645	1.412	2.108	3.318	4.486	5.860	7.000	8.350	8.720	10.080	11.430	13.144
1970	0.645	1.131	2.074	3.318	4.325	5.590	6.260	8.370	10.490	12.310	14.590	21.777
1971	0.645	1.225	1.964	2.622	4.388	5.150	5.580	6.300	8.530	11.240	14.740	17.130
1972	0.645	1.139	1.878	2.860	3.854	5.610	6.040	6.100	6.870	8.950	11.720	16.000
1973	0.645	1.108	2.100	3.168	4.361	6.110	6.670	6.750	7.430	7.950	10.170	17.000
1974	0.645	1.334	2.066	3.362	4.664	6.660	7.150	7.760	8.190	9.780	12.380	14.700
1975	0.645	1.381	2.363	3.309	4.850	6.690	7.570	8.580	8.810	9.780	10.090	11.000
1976	0.645	1.388	2.252	3.608	4.512	6.730	8.250	9.610	11.540	11.430	14.060	16.180
1977	0.645	1.491	2.428	3.581	5.142	6.636	7.685	9.730	11.703	14.394	17.456	24.116
1978	0.645	1.430	2.490	3.480	5.096	6.806	9.041	10.865	13.068	11.982	19.062	21.284
1979	0.645	1.526	2.246	3.519	4.938	6.754	8.299	9.312	13.130	13.418	13.540	20.072
1980	0.645	1.452	2.323	3.316	4.681	6.981	8.037	10.731	12.301	17.281	14.893	19.069
1981	0.645	1.288	1.921	2.898	3.990	5.821	7.739	9.422	11.374	12.784	12.514	19.069
1982	0.645	1.209	1.909	2.732	3.790	5.386	6.682	9.141	11.963	14.226	17.287	16.590
1983	0.645	1.247	1.934	2.658	3.645	5.481	7.049	8.128	11.009	13.972	15.882	18.498
1984	0.645	1.346	2.207	3.151	3.890	5.798	7.456	9.851	11.052	14.338	15.273	16.660
1985	1.306	1.382	1.752	2.710	3.443	4.675	7.220	10.320	12.197	14.683	16.175	19.050
1986	1.306	1.604	2.892	3.234	4.572	5.805	7.247	9.084	10.356	15.283	14.540	15.017
1987	1.706	1.589	2.426	3.516	4.879	6.459	7.656	9.243	10.697	10.622	15.894	12.592
1988	0.929	1.480	2.263	3.273	4.387	4.566	8.275	8.822	9.977	11.732	14.156	13.042
1989	0.822	1.501	2.346	3.428	4.676	7.388	8.506	9.831	11.986	10.003	12.611	16.045
1990	0.725	1.043	2.179	2.809	4.421	6.359	9.230	10.592	10.993	14.570	15.732	17.290
1991	0.114	1.286	2.042	2.752	3.404	6.091	9.152	9.804	9.754	14.344	14.172	20.200
1992	0.448	1.344	2.096	3.029	3.755	5.143	7.562	8.127	12.679	13.410	15.715	11.267
1993	0.773	1.363	2.309	3.236	4.111	5.710	6.352	8.641	10.901	12.517	14.742	16.874
1994	1.611	1.728	2.253	3.341	4.515	6.535	10.039	8.896	10.847	12.874	14.742	17.470
1995	0.514	1.636	2.346	3.186	4.488	5.528	8.620	10.273	11.022	11.407	13.098	15.182
1996	0.543	1.754	2.491	3.534	4.254	5.634	8.300	9.772	10.539	13.503	13.689	16.193
1997	1.112	1.347	2.267	3.746	5.426	5.972	6.958	8.537	10.797	11.533	10.428	12.788
1998	1.112	1.821	2.261	3.263	4.468	5.784	6.812	9.304	10.759	14.903	16.651	18.666
1999	1.307	1.467	1.933	2.997	3.961	5.120	6.494	9.946	11.088	12.535	14.995	15.151
2000	0.496	1.355	1.916	2.881	4.318	5.580	8.497	9.203	10.240	11.172	13.172	17.442
2001	0.816	1.583	2.108	2.700	4.086	6.202	6.907	9.055	8.769	9.526	11.210	13.874
2002	0.780	1.590	2.259	3.120	3.985	5.958	9.234	9.002	10.422	13.402	9.008	16.893
2003	1.149	1.324	2.239	3.052	4.231	5.057	6.838	7.819	8.802	10.712	12.152	13.797
2004	1.149	1.430	2.099	3.049	3.743	5.319	5.682	7.397	10.808	11.569	13.767	12.955
2005	0.649	1.120	1.898	2.962	3.875	4.806	7.281	5.495	7.211	9.909	12.944	18.151
2006	0.907	1.384	1.999	2.907	4.384	5.122	6.536	5.769	6.258	5.688	7.301	15.412
2007	1.403	1.264	2.022	2.582	4.081	5.725	6.736	6.481	7.142	6.530	9.724	10.143
2008	0.912	1.842	2.232	2.925	3.915	5.462	7.075	7.648	8.282	11.181	14.266	17.320
2009	0.644	1.441	2.028	2.873	3.913	4.919	7.046	8.505	10.126	12.108	12.471	15.264
2010	0.644	1.588	2.153	3.131	4.173	5.197	6.356	7.945	8.913	10.090	10.417	13.489
2011	0.794	2.377	2.651	3.203	4.517	6.000	6.866	7.850	8.810	9.797	13.534	13.033
2012	1.403	1.698	2.594	3.683	4.483	5.921	7.988	8.358	9.543	10.916	10.884	11.758
2013	0.944	2.282	2.983	3.827	5.206	6.543	8.298	8.415	9.336	9.926	11.195	12.691
2014	0.944	1.333	2.539	3.306	4.459	6.423	8.224	8.412	9.333	9.922	11.191	12.687

Table 3: Icelandic cod in Division Va. Estimated weight at age in the spawning stock (kg) in period the 1955-2015. These weights are used to calculate the spawning stock biomass (SSB).

year	3	4	5	6	7	8	9	10	11	12	13	14
1955	0.019	0.022	0.033	0.181	0.577	0.782	0.834	0.960	1.000	1.000	1.000	1.000
1956	0.019	0.025	0.033	0.111	0.577	0.782	0.818	0.980	0.980	1.000	1.000	1.000
1957	0.019	0.026	0.043	0.100	0.549	0.801	0.842	0.990	1.000	1.000	1.000	1.000
1958	0.019	0.028	0.086	0.520	0.682	0.801	0.834	1.000	1.000	1.000	1.000	1.000
1959	0.019	0.029	0.070	0.535	0.772	0.818	0.834	0.990	1.000	1.000	1.000	1.000
1960	0.019	0.026	0.066	0.577	0.782	0.826	0.834	0.990	1.000	1.000	1.000	1.000
1961	0.019	0.025	0.053	0.450	0.772	0.818	0.834	0.990	0.990	1.000	1.000	1.000
1962	0.019	0.025	0.048	0.281	0.791	0.834	0.834	0.990	0.990	1.000	1.000	1.000
1963	0.019	0.025	0.048	0.237	0.706	0.834	0.849	1.000	1.000	1.000	1.000	1.000
1964	0.019	0.026	0.048	0.329	0.762	0.826	0.849	1.000	1.000	1.000	1.000	1.000
1965	0.019	0.025	0.045	0.354	0.751	0.826	0.842	1.000	1.000	1.000	1.000	1.000
1966	0.019	0.026	0.045	0.394	0.791	0.849	0.849	1.000	1.000	1.000	1.000	1.000
1967	0.019	0.028	0.051	0.341	0.772	0.842	0.849	1.000	1.000	1.000	1.000	1.000
1968	0.019	0.025	0.051	0.292	0.682	0.801	0.842	1.000	1.000	1.000	1.000	1.000
1969	0.019	0.028	0.043	0.227	0.682	0.801	0.842	1.000	1.000	1.000	1.000	1.000
1970	0.019	0.023	0.041	0.227	0.644	0.772	0.818	1.000	1.000	1.000	1.000	1.000
1971	0.019	0.025	0.037	0.074	0.657	0.706	0.772	0.979	0.994	0.982	0.993	1.000
1972	0.019	0.023	0.035	0.106	0.450	0.772	0.809	0.979	0.994	0.982	0.993	1.000
1973	0.022	0.028	0.163	0.382	0.697	0.801	0.834	0.996	0.996	1.000	1.000	1.000
1974	0.020	0.031	0.085	0.346	0.636	0.790	0.818	0.989	1.000	1.000	1.000	1.000
1975	0.020	0.035	0.118	0.287	0.715	0.809	0.839	1.000	1.000	1.000	1.000	1.000
1976	0.025	0.026	0.086	0.253	0.406	0.797	0.841	1.000	1.000	1.000	1.000	1.000
1977	0.019	0.024	0.060	0.382	0.742	0.817	0.842	1.000	1.000	1.000	1.000	1.000
1978	0.025	0.025	0.052	0.192	0.737	0.820	0.836	1.000	1.000	1.000	1.000	1.000
1979	0.019	0.021	0.053	0.282	0.635	0.790	0.836	0.919	1.000	1.000	1.000	1.000
1980	0.026	0.021	0.047	0.225	0.653	0.777	0.834	0.977	1.000	0.964	1.000	1.000
1981	0.019	0.022	0.030	0.090	0.448	0.751	0.811	0.962	0.988	1.000	1.000	1.000
1982	0.021	0.025	0.038	0.065	0.297	0.705	0.815	0.967	1.000	1.000	1.000	1.000
1983	0.019	0.030	0.047	0.116	0.264	0.530	0.715	0.979	0.985	1.000	1.000	1.000
1984	0.019	0.024	0.053	0.169	0.444	0.620	0.716	0.949	0.969	0.948	1.000	1.000
1985		0.021	0.185	0.412	0.495	0.735	0.572	1.000	1.000	1.000	1.000	1.000
1986	0.001	0.023	0.149	0.395	0.682	0.734	0.941	0.962	0.988	1.000	1.000	1.000
1987	0.002	0.033	0.093	0.360	0.490	0.885	0.782	1.000	0.979	1.000	1.000	1.000
1988	0.006	0.029	0.225	0.511	0.448	0.683	0.937	0.946	0.974	0.821	1.000	1.000
1989	0.008	0.025	0.142	0.372	0.645	0.652	0.634	0.991	1.000	0.903	0.859	1.000
1990	0.006	0.012	0.155	0.437	0.581	0.796	0.814	0.986	1.000	1.000	1.000	1.000
1991		0.055	0.149	0.369	0.637	0.790	0.682	0.842	1.000	1.000	1.000	1.000
1992	0.002	0.062	0.265	0.402	0.813	0.917	0.894	1.000	1.000	1.000	1.000	1.000
1993	0.006	0.085	0.267	0.464	0.693	0.801	0.843	0.968	1.000	1.000	1.000	1.000
1994	0.008	0.110	0.339	0.591	0.702	0.917	0.698	0.852	0.985	1.000	1.000	1.000
1995	0.005	0.109	0.384	0.528	0.752	0.787	0.859	1.000	1.000	1.000	1.000	1.000
1996	0.002	0.031	0.186	0.499	0.650	0.733	0.812	1.000	1.000	0.986	0.971	1.000
1997	0.006	0.037	0.246	0.424	0.685	0.787	0.804	0.932	1.000	0.913	1.000	1.000
1998		0.061	0.209	0.491	0.782	0.814	0.810	0.925	0.998	1.000	1.000	1.000
1999	0.012	0.044	0.239	0.516	0.649	0.835	0.687	0.988	1.000	1.000	1.000	1.000
2000	0.001	0.065	0.248	0.512	0.611	0.867	0.998	0.980	1.000	1.000	1.000	1.000
2001	0.004	0.043	0.261	0.589	0.750	0.742	0.862	0.987	1.000	1.000	1.000	1.000
2002	0.008	0.086	0.322	0.656	0.759	0.920	0.550	0.979	1.000	1.000	1.000	1.000
2003	0.005	0.046	0.218	0.524	0.870	0.798	0.860	0.998	1.000	1.000	1.000	1.000
2004		0.038	0.246	0.549	0.626	0.843	0.816	0.990	1.000	1.000	1.000	1.000
2005	0.003	0.109	0.281	0.493	0.792	0.805	0.951	0.908	1.000	1.000	1.000	1.000
2006	0.002	0.023	0.294	0.448	0.752	0.871	0.743	0.747	1.000	1.000	1.000	1.000
2007	0.012	0.032	0.159	0.501	0.693	0.785	0.836	0.924	1.000	1.000	1.000	1.000
2008	0.001	0.041	0.276	0.549	0.727	0.827	0.846	0.954	1.000	1.000	1.000	1.000
2009	0.002	0.015	0.132	0.456	0.688	0.883	0.741	0.631	1.000	1.000	1.000	1.000
2010		0.016	0.058	0.377	0.822	0.869	0.923	0.802	1.000	1.000	1.000	1.000
2011	0.002	0.012	0.135	0.431	0.734	0.926	0.940	0.958	1.000	1.000	1.000	1.000
2012	0.004	0.029	0.126	0.411	0.728	0.882	0.961	0.830	1.000	1.000	1.000	1.000
2013	0.003	0.008	0.061	0.343	0.738	0.923	0.957	1.000	1.000	1.000	1.000	1.000
2014		0.026	0.068	0.236	0.614	0.893	0.967	0.957	1.000	1.000	1.000	1.000

Table 4: Icelandic cod in Division Va. Estimated maturity at age in period the 1955-2014.

year	1	2	3	4	5	6	7	8	9	10
1985	14	137	388	1118	1735	2581	3226	4675	5873	7045
1986	15	159	616	1220	2249	2965	4331	5594	7234	8327
1987	14	117	467	1199	1752	2982	4201	6347	6996	10113
1988	11	122	495	1076	1963	3098	3553	4368	8166	9482
1989	22	150	548	1141	1934	3052	4390	6271	7024	12565
1990	19	135	460	1040	1816	2597	3876	6051	8172	9600
1991	18	147	553	1167	1844	2589	3270	5741	7622	14483
1992	24	134	501	1013	1846	2570	3655	5053	7452	13568
1993	12	171	576	1166	1944	2991	3961	5378	5985	9338
1994	13	174	686	1412	2044	3182	4134	6274	8312	9893
1995	10	134	605	1377	2284	2989	4450	5324	8070	9256
1996	11	155	551	1350	2083	3323	4045	5266	7484	9965
1997	18	140	546	1194	2168	3220	4864	5508	6459	6901
1998	15	158	485	1208	2041	3017	4253	5437	6348	8385
1999	14	140	578	1070	1847	2867	3820	4981	5627	8196
2000	16	124	486	1195	1817	2771	4066	5349	8505	8403
2001	17	152	531	1186	1852	2641	3760	5453	6443	8177
2002	11	132	510	1206	1998	2920	3780	5760	6267	6287
2003	16	131	466	1179	1918	2788	4139	4678	6261	9600
2004	20	147	481	1062	1873	2803	3458	4989	5315	7797
2005	11	118	451	1029	1760	2644	3646	4362	7249	6674
2006	13	105	417	982	1689	2600	4050	4750	5624	8384
2007	14	101	410	969	1663	2342	3635	5018	6122	7749
2008	11	121	376	937	1805	2612	3592	4933	6395	8408
2009	12	113	413	845	1602	2633	3659	4684	5770	6289
2010	13	98	391	1008	1697	2570	4021	4912	6101	7754
2011	12	102	395	1126	2114	2986	4225	5876	6645	7905
2012	12	142	477	1143	1929	3180	4249	5718	7826	7610
2013	13	113	495	1054	1785	3022	4772	6381	8054	9538
2014	11	114	359	1079	1710	2632	3987	6168	8069	10118

Table 5: Icelandic cod in Division Va. Estimated survey weight at age in the spring survey (SMB).

year	1	2	3	4	5	6	7	8	9	10
1985	16.54	110.43	35.40	48.20	64.15	22.57	14.85	4.85	3.21	1.76
1986	15.05	60.24	95.89	22.42	21.21	26.34	6.63	2.48	0.83	0.73
1987	3.65	28.21	103.74	81.99	21.08	12.20	12.01	2.56	0.89	0.38
1988	3.44	6.96	72.09	101.40	66.59	7.81	5.88	6.41	0.58	0.24
1989	4.04	16.38	21.97	77.79	67.59	34.20	4.20	1.45	1.14	0.24
1990	5.56	11.78	26.08	14.07	27.05	32.38	14.21	1.50	0.52	0.41
1991	3.95	16.00	18.20	30.17	15.24	18.09	20.93	4.24	0.79	0.29
1992	0.71	16.80	33.54	18.89	16.34	6.54	5.70	5.12	1.29	0.22
1993	3.57	4.75	30.78	36.48	13.22	9.90	2.13	1.75	1.17	0.36
1994	14.38	14.94	9.01	26.66	21.90	5.77	3.63	0.70	0.48	0.47
1995	1.08	29.13	24.75	8.98	23.88	17.69	3.78	1.80	0.35	0.17
1996	3.72	5.43	42.58	29.44	12.89	14.63	14.02	3.81	1.04	0.18
1997	1.18	22.18	13.55	56.31	29.10	9.50	8.78	6.61	0.56	0.21
1998	8.06	5.36	29.92	16.04	61.73	28.58	6.50	5.24	3.03	0.66
1999	7.39	32.98	7.01	42.25	13.00	23.66	11.12	2.35	1.32	0.70
2000	18.85	27.60	54.99	6.94	30.00	8.28	8.18	4.14	0.51	0.30
2001	12.13	21.74	36.38	38.04	4.95	15.11	3.30	1.96	0.81	0.29
2002	0.91	37.85	41.22	40.13	36.25	7.09	8.32	1.49	0.72	0.30
2003	11.17	4.17	46.36	36.58	28.42	16.89	3.82	4.34	1.03	0.20
2004	6.57	24.43	7.87	61.79	35.00	24.83	14.44	2.82	2.88	0.47
2005	2.56	14.54	38.70	9.68	43.57	22.97	10.84	5.77	0.93	0.92
2006	8.79	6.39	22.67	38.44	10.83	27.74	10.05	3.55	1.38	0.25
2007	5.61	18.21	8.58	21.09	27.60	9.06	9.75	5.08	2.11	0.75
2008	6.40	11.77	22.08	9.31	20.43	20.40	8.10	6.63	2.47	0.60
2009	21.27	11.62	15.80	21.82	14.59	23.45	14.59	4.18	2.73	1.02
2010	18.29	20.00	18.00	17.73	23.75	13.27	16.60	8.93	2.71	1.70
2011	3.57	21.49	26.63	19.90	22.48	25.32	13.51	12.31	4.55	0.91
2012	19.94	9.75	37.59	56.57	41.59	30.22	26.99	9.96	6.30	2.76
2013	10.80	31.40	17.68	43.76	46.47	25.24	16.50	13.81	6.94	3.33
2014	3.31	23.97	38.00	23.48	47.17	37.60	17.31	8.18	4.26	2.22

Table 6: Icelandic cod in Division Va. Survey indices of the spring bottom trawl survey (SMB).

year	1	2	3	4	5	6	7	8	9	10
1985	0.08	0.44	0.19	0.11	0.11	0.10	0.10	0.10	0.14	0.16
1986	0.09	0.10	0.10	0.10	0.09	0.08	0.09	0.07	0.08	0.07
1987	0.13	0.11	0.09	0.10	0.10	0.10	0.09	0.11	0.10	0.13
1988	0.19	0.18	0.10	0.10	0.11	0.10	0.09	0.09	0.12	0.12
1989	0.12	0.10	0.15	0.21	0.16	0.12	0.10	0.10	0.12	0.13
1990	0.14	0.09	0.13	0.13	0.10	0.09	0.09	0.11	0.13	0.17
1991	0.12	0.10	0.07	0.12	0.12	0.10	0.10	0.11	0.16	0.31
1992	0.11	0.08	0.07	0.09	0.10	0.09	0.08	0.09	0.12	0.23
1993	0.20	0.10	0.09	0.11	0.11	0.10	0.10	0.10	0.09	0.10
1994	0.26	0.12	0.09	0.12	0.14	0.14	0.13	0.11	0.14	0.16
1995	0.17	0.08	0.09	0.10	0.10	0.10	0.10	0.12	0.15	0.16
1996	0.12	0.10	0.11	0.15	0.14	0.11	0.10	0.10	0.15	0.22
1997	0.14	0.08	0.08	0.10	0.10	0.09	0.10	0.11	0.15	0.25
1998	0.12	0.15	0.09	0.12	0.17	0.15	0.11	0.11	0.13	0.17
1999	0.11	0.08	0.07	0.10	0.10	0.09	0.09	0.10	0.08	0.10
2000	0.07	0.07	0.08	0.08	0.09	0.09	0.08	0.10	0.10	0.08
2001	0.09	0.10	0.10	0.15	0.17	0.20	0.15	0.12	0.10	0.16
2002	0.18	0.09	0.13	0.16	0.18	0.15	0.15	0.10	0.14	0.11
2003	0.10	0.11	0.07	0.12	0.11	0.10	0.10	0.15	0.19	0.19
2004	0.10	0.08	0.10	0.16	0.15	0.16	0.15	0.13	0.17	0.21
2005	0.12	0.12	0.07	0.09	0.12	0.12	0.12	0.12	0.15	0.19
2006	0.09	0.11	0.08	0.10	0.10	0.11	0.12	0.15	0.13	0.20
2007	0.09	0.12	0.10	0.10	0.11	0.09	0.08	0.09	0.11	0.18
2008	0.11	0.09	0.07	0.09	0.10	0.10	0.10	0.09	0.10	0.09
2009	0.10	0.10	0.09	0.10	0.13	0.13	0.12	0.11	0.09	0.10
2010	0.08	0.10	0.12	0.10	0.11	0.10	0.10	0.09	0.08	0.09
2011	0.11	0.12	0.10	0.12	0.14	0.14	0.12	0.14	0.11	0.09
2012	0.09	0.14	0.08	0.32	0.41	0.34	0.24	0.17	0.11	0.14
2013	0.06	0.13	0.08	0.11	0.13	0.12	0.10	0.11	0.14	0.16
2014	0.13	0.35	0.11	0.13	0.13	0.12	0.11	0.13	0.19	0.30

Table 7: Icelandic cod in Division Va. Survey CV of the spring bottom trawl survey (SMB).

year	1	2	3	4	5	6	7	8	9	10
1996	6.69	3.57	20.00	13.98	5.40	7.44	6.26	1.60	0.31	0.09
1997	0.67	16.89	6.83	29.57	15.76	4.09	3.62	2.36	0.25	0.17
1998	5.92	2.63	15.62	7.36	16.01	16.03	5.20	2.24	1.27	0.20
1999	8.61	14.54	5.68	23.38	7.42	9.94	4.05	0.59	0.34	0.36
2000	4.60	13.17	15.25	3.71	11.15	3.49	2.61	1.11	0.34	0.28
2001	7.11	11.51	19.53	21.13	3.30	6.73	1.60	0.76	0.17	0.03
2002	0.92	13.72	16.11	23.39	15.94	5.41	4.77	1.11	0.61	0.08
2003	5.16	2.68	25.66	16.98	13.22	8.99	1.89	2.55	0.38	0.10
2004	3.67	16.28	6.92	29.86	18.85	11.73	7.38	1.88	1.65	0.23
2005	2.15	9.03	20.37	6.82	25.62	10.88	3.86	1.91	0.29	0.31
2006	4.51	4.52	16.28	23.04	7.67	13.93	6.12	2.05	1.02	0.16
2007	3.73	9.82	4.93	11.73	15.68	6.34	5.91	3.14	0.76	0.50
2008	5.30	11.88	15.19	7.66	17.57	18.51	5.67	5.61	1.50	0.79
2009	7.04	8.30	13.14	18.11	12.39	16.46	10.22	3.15	2.75	0.84
2010	10.78	18.82	16.18	15.52	17.96	9.81	11.21	6.81	2.29	1.20
2012	7.43	9.43	23.38	20.66	12.72	10.82	9.53	5.31	3.33	1.55
2013	6.25	19.28	13.41	27.13	21.99	12.60	7.72	5.94	2.93	1.87

Table 8: Icelandic cod in Division Va. Survey indices of the fall bottom trawl survey (SMH).

year	1	2	3	4	5	6	7	8	9	10
1996	0.35	0.18	0.11	0.14	0.13	0.13	0.17	0.23	0.27	0.33
1997	0.34	0.54	0.22	0.26	0.21	0.14	0.12	0.12	0.12	0.13
1998	0.16	0.12	0.12	0.11	0.13	0.19	0.32	0.35	0.38	0.34
1999	0.32	0.14	0.24	0.30	0.32	0.23	0.20	0.19	0.19	0.21
2000	0.18	0.26	0.14	0.14	0.15	0.18	0.16	0.18	0.33	0.31
2001	0.17	0.14	0.14	0.11	0.11	0.11	0.17	0.33	0.41	0.79
2002	0.16	0.12	0.12	0.13	0.12	0.11	0.11	0.12	0.15	0.50
2003	0.13	0.14	0.12	0.11	0.11	0.09	0.10	0.14	0.19	0.32
2004	0.14	0.17	0.13	0.14	0.11	0.10	0.09	0.08	0.08	0.09
2005	0.27	0.10	0.11	0.10	0.12	0.11	0.10	0.08	0.09	0.10
2006	0.15	0.14	0.13	0.13	0.11	0.11	0.11	0.10	0.09	0.16
2007	0.21	0.14	0.11	0.14	0.14	0.14	0.13	0.11	0.11	0.12
2008	0.17	0.11	0.10	0.10	0.11	0.11	0.15	0.20	0.24	0.22
2009	0.17	0.11	0.13	0.14	0.13	0.12	0.11	0.11	0.11	0.14
2010	0.17	0.16	0.11	0.13	0.13	0.11	0.15	0.17	0.19	0.20
2012	0.15	0.11	0.12	0.13	0.14	0.14	0.12	0.12	0.14	0.15
2013	0.16	0.14	0.14	0.14	0.12	0.11	0.11	0.12	0.13	0.14

Table 9: Icelandic cod in Division Va. Survey CV of the fall bottom trawl survey (SMH).

year	3	4	5	6	7	8	9	10	11	12	13	14
1955	-0.122	-0.208	0.077	0.114	0.208	-0.115	-0.164	0.135	-0.099	-0.450	-0.201	0.002
1956	-0.027	-0.048	0.026	-0.007	-0.134	-0.200	-0.006	0.006	0.182	0.095	0.230	0.223
1957	0.092	0.017	-0.016	0.167	-0.133	0.092	0.063	-0.148	-0.097	-0.106	-0.380	0.525
1958	0.154	0.176	-0.265	-0.073	0.059	0.080	0.132	-0.231	0.235	0.003	-0.220	0.399
1959	-0.214	0.211	0.260	-0.243	-0.218	-0.061	-0.069	0.278	-0.262	0.383	-0.228	-0.389
1960	0.101	-0.356	0.141	0.188	0.063	0.075	-0.024	-0.116	-0.039	0.037	-0.637	0.916
1961	0.052	0.041	-0.403	0.119	-0.017	0.272	0.203	-0.141	0.085	-0.190	-0.972	0.841
1962	0.092	-0.007	0.126	-0.243	0.116	-0.296	0.091	0.260	-0.063	0.031	-0.401	0.708
1963	-0.056	0.297	-0.173	0.013	-0.031	-0.070	-0.376	0.208	0.350	0.063	0.069	-0.608
1964	-0.126	-0.015	0.128	-0.251	-0.117	0.377	-0.102	-0.457	-0.013	0.266	-0.158	0.010
1965	-0.032	-0.114	0.085	0.164	-0.128	0.050	0.473	-0.481	-0.056	-0.509	-0.361	0.642
1966	-0.043	-0.043	-0.178	0.096	-0.069	0.124	-0.346	0.591	-0.828	0.278	0.007	1.063
1967	0.189	-0.130	0.023	-0.198	0.025	-0.371	0.492	0.047	0.671	-0.726	-0.837	-0.178
1968	0.033	-0.022	-0.273	-0.120	0.233	0.158	-0.415	0.368	-0.123	0.599	-0.657	0.661
1969	-0.090	-0.028	0.152	-0.011	0.052	-0.150	-0.324	-0.244	-0.040	-0.257	-0.809	-0.137
1970	-0.097	0.135	-0.054	-0.137	0.053	-0.161	0.478	-0.580	-0.117	0.246	0.294	0.456
1971	-0.104	0.070	0.090	0.175	-0.185	0.283	-0.169	0.055	-0.451	-0.019	0.123	0.365
1972	-0.168	-0.127	0.068	-0.034	0.117	-0.052	-0.103	0.293	-0.070	0.171	0.526	-2.759
1973	0.274	-0.022	-0.099	0.027	-0.004	-0.241	0.087	0.172	0.158	-0.196	-1.251	-2.091
1974	-0.160	0.209	-0.022	-0.178	-0.006	-0.003	-0.222	0.289	0.011	0.186	-0.435	0.809
1975	0.188	-0.074	0.040	-0.054	0.030	-0.152	-0.208	-0.005	0.407	-0.016	-0.120	0.093
1976	0.097	0.002	-0.169	0.077	-0.092	0.252	-0.157	-0.154	0.056	0.272	-0.232	0.238
1977	-0.400	-0.063	0.046	-0.093	0.126	0.052	0.308	0.029	-0.702	-0.480	-1.222	-2.495
1978	0.079	-0.014	0.037	-0.096	0.043	-0.206	0.120	-0.188	0.016	-0.052	0.530	1.201
1979	0.157	0.094	-0.217	0.102	-0.047	0.030	-0.312	-0.078	0.045	-0.146	0.411	-0.199
1980	0.210	0.010	0.078	0.060	-0.009	-0.091	0.124	-0.486	0.295	0.096	0.158	-1.083
1981	-0.301	-0.207	0.083	-0.137	0.070	0.089	0.021	0.325	-0.076	0.598	-0.015	1.170
1982	0.010	0.152	0.071	-0.055	-0.222	0.191	0.177	0.136	-0.231	-0.870	0.051	-0.862
1983	-0.321	-0.357	0.111	0.141	0.043	0.008	-0.039	-0.028	0.003	0.370	-0.193	0.583
1984	0.347	0.026	-0.058	-0.046	-0.098	-0.005	0.054	-0.138	-0.353	0.163	0.715	0.099
1985	0.040	0.182	-0.102	0.122	-0.098	-0.023	-0.139	0.133	0.026	-0.347	0.476	0.465
1986	0.149	-0.118	0.015	-0.016	0.179	-0.048	0.116	-0.212	0.075	0.049	-0.591	0.177
1987	-0.147	0.124	0.015	-0.165	0.063	0.035	-0.028	0.111	-0.381	-0.118	0.122	-0.310
1988	-0.086	-0.058	-0.051	0.137	-0.087	0.066	0.156	0.028	0.476	0.013	0.539	0.097
1989	-0.213	0.043	0.149	-0.069	-0.003	-0.155	-0.327	-0.093	-0.026	0.512	-0.023	-1.441
1990	-0.002	-0.139	-0.107	0.003	0.040	0.091	-0.086	-0.231	0.287	0.110	-0.213	0.059
1991	0.071	0.041	-0.131	-0.066	0.093	-0.074	0.115	-0.075	-0.317	0.399	-0.563	0.103
1992	-0.224	0.081	0.045	0.028	0.103	-0.006	-0.043	-0.067	-0.749	-0.774	-0.564	-0.173
1993	0.257	0.047	-0.201	-0.055	-0.074	-0.125	0.066	0.488	0.497	-0.216	-0.983	0.402
1994	0.031	0.247	-0.132	-0.194	-0.040	0.064	-0.193	-0.136	0.426	0.516	0.524	-0.423
1995	0.277	-0.034	0.085	-0.034	-0.041	-0.119	-0.129	-0.290	-0.215	0.730	1.126	0.597
1996	0.004	-0.051	-0.176	0.078	0.042	0.013	0.124	0.174	-0.383	-0.406	0.621	-0.070
1997	-0.157	0.026	-0.027	-0.124	-0.095	0.206	0.172	0.258	0.408	-0.734	-0.216	0.161
1998	-0.180	-0.169	0.066	0.075	0.018	-0.168	0.241	0.047	0.085	0.273	0.166	-0.748
1999	-0.102	0.034	0.036	0.028	0.089	-0.047	-0.245	-0.184	-0.268	-0.411	-0.472	-0.936
2000	0.173	-0.240	0.108	-0.039	0.014	0.107	0.034	-0.112	-0.010	0.134	-0.132	-0.118
2001	0.189	0.195	-0.160	-0.004	0.026	-0.182	0.098	0.282	-0.046	0.131	-0.523	-0.066
2002	-0.020	0.085	0.035	-0.077	-0.024	-0.010	-0.152	0.293	0.266	-0.335	0.383	-1.180
2003	-0.229	0.030	-0.009	-0.031	0.175	0.006	0.224	-0.307	0.059	0.137	0.154	0.435
2004	-0.221	0.109	0.101	-0.084	-0.058	0.232	0.027	0.236	-0.494	-0.018	0.245	-0.388
2005	0.195	-0.293	0.146	-0.055	-0.119	-0.089	0.320	0.102	0.327	0.075	0.053	-0.871
2006	-0.064	0.028	-0.136	0.067	0.053	-0.087	-0.081	0.182	-0.009	0.086	-0.184	-1.689
2007	-0.103	0.182	-0.039	-0.010	-0.148	0.052	-0.029	0.186	0.760	0.335	0.779	-0.394
2008	0.018	-0.187	0.078	-0.113	0.082	-0.182	0.016	0.074	0.000	0.043	0.012	-0.582
2009	0.130	-0.063	0.082	0.139	-0.052	0.255	-0.199	-0.233	-0.055	-0.455	0.023	-0.567
2010	0.007	0.007	-0.137	0.080	0.029	-0.070	0.177	-0.108	-0.120	0.278	0.307	0.542
2011	0.121	-0.034	0.009	0.021	-0.020	-0.000	-0.130	0.063	-0.044	-0.178	-0.248	-0.906
2012	-0.131	-0.019	0.019	-0.034	-0.007	0.170	-0.005	-0.186	0.206	-0.307	0.199	-0.140
2013	0.107	0.041	0.012	0.016	-0.097	-0.072	0.179	0.014	-0.173	0.316	0.001	-0.191

Table 10: Icelandic cod in Division Va. Catch at age residuals from the ADCAM model tuned with the spring (SMB) and the fall (SMH) surveys.

year	1	2	3	4	5	6	7	8	9	10
1985	-0.460	0.032	0.217	0.442	0.126	0.268	0.410	0.197	0.314	0.663
1986	0.439	-0.063	-0.401	-0.231	-0.082	0.007	-0.154	-0.261	-0.251	-0.046
1987	0.636	0.003	0.122	-0.459	-0.028	-0.066	0.050	-0.075	-0.096	-0.008
1988	-0.193	0.029	0.490	0.154	-0.117	-0.333	0.095	0.498	-0.118	-0.102
1989	0.372	0.066	0.524	0.554	0.243	0.198	-0.113	-0.094	0.212	0.106
1990	-0.468	0.125	0.066	0.056	-0.152	-0.142	0.087	-0.139	-0.043	0.155
1991	-0.165	-0.449	0.097	0.157	0.253	0.047	0.140	-0.136	0.223	0.194
1992	-0.247	0.029	-0.196	0.117	-0.087	-0.123	-0.132	-0.128	-0.107	-0.007
1993	-0.502	-0.026	0.181	-0.048	0.052	-0.031	-0.206	-0.144	-0.224	-0.213
1994	0.539	-0.247	0.025	0.113	-0.192	-0.312	-0.155	-0.209	-0.183	-0.051
1995	-0.232	0.139	-0.226	-0.046	0.168	-0.005	-0.212	-0.076	-0.065	-0.203
1996	-0.627	-0.103	0.094	-0.120	0.208	-0.032	0.265	0.408	0.205	0.054
1997	0.179	-0.048	0.134	0.278	-0.029	-0.035	-0.025	0.266	-0.349	-0.293
1998	-0.092	0.132	-0.186	0.129	0.510	0.306	0.100	0.219	0.433	0.496
1999	-0.024	0.180	-0.036	0.050	-0.045	0.093	0.038	-0.007	-0.017	0.136
2000	0.895	0.134	0.275	-0.163	-0.084	-0.198	-0.184	0.010	-0.244	-0.230
2001	0.205	0.025	0.005	-0.095	-0.452	-0.211	-0.364	-0.540	-0.326	0.204
2002	-0.168	0.246	0.140	0.063	0.048	-0.138	-0.166	-0.264	-0.403	-0.138
2003	0.003	-0.121	0.039	-0.043	-0.117	-0.198	-0.187	-0.050	0.171	-0.523
2004	-0.090	0.169	-0.113	0.265	0.107	0.236	0.204	0.153	0.421	0.278
2005	-0.131	0.077	0.188	-0.116	0.087	0.113	0.011	0.056	0.027	0.235
2006	0.174	-0.034	-0.032	0.057	-0.093	0.167	-0.093	-0.305	-0.343	-0.229
2007	0.004	0.146	-0.299	-0.236	-0.173	-0.171	-0.296	-0.041	0.041	-0.086
2008	-0.001	-0.005	-0.091	-0.396	-0.279	-0.101	0.127	-0.034	0.101	-0.186
2009	0.417	-0.099	-0.182	-0.238	-0.157	-0.069	-0.068	0.039	-0.201	-0.120
2010	0.187	-0.167	-0.187	-0.248	-0.212	-0.174	-0.063	-0.038	0.339	0.010
2011	-0.459	-0.166	-0.353	-0.272	-0.120	0.060	0.132	0.115	-0.042	-0.122
2012	0.179	-0.133	-0.085	0.203	0.334	0.300	0.409	0.295	0.121	0.076
2013	-0.101	0.094	-0.148	-0.074	0.053	0.075	0.041	0.232	0.536	-0.004
2014	-0.252	0.036	-0.160	-0.042	0.031	0.189	0.023	-0.164	-0.282	-0.008

Table 11: Icelandic cod in Division Va. Spring survey (SMB) at age residuals from the ADCAM model, assessment tuned with both the spring and the fall survey.

year	1	2	3	4	5	6	7	8	9	10
1996	0.037	-0.079	-0.011	-0.184	-0.008	-0.059	0.175	0.191	-0.160	-0.021
1997	-0.152	0.118	-0.018	0.248	0.053	-0.149	-0.130	-0.034	-0.317	-0.021
1998	-0.206	-0.013	-0.190	0.035	-0.036	0.372	0.515	0.115	0.285	0.078
1999	0.266	-0.092	0.113	0.109	0.082	0.012	-0.096	-0.289	-0.321	0.146
2000	-0.262	-0.071	-0.264	-0.078	-0.225	-0.207	-0.367	-0.308	0.035	0.240
2001	-0.126	-0.144	0.038	-0.014	-0.212	-0.233	-0.227	-0.488	-0.523	-0.306
2002	-0.164	-0.196	-0.126	0.151	-0.001	0.130	0.005	0.019	0.017	-0.349
2003	-0.106	-0.106	0.088	-0.150	-0.114	-0.136	-0.127	0.063	-0.043	-0.403
2004	-0.110	0.152	0.100	0.125	0.166	0.118	0.225	0.319	0.458	0.200
2005	0.107	-0.071	0.094	0.078	0.245	0.012	-0.263	-0.296	-0.230	-0.116
2006	0.086	-0.055	0.098	0.092	0.074	0.061	0.037	-0.216	-0.073	-0.069
2007	0.143	-0.002	-0.317	-0.262	-0.111	-0.015	-0.185	0.021	-0.259	0.083
2008	0.310	0.275	0.048	-0.111	0.088	0.234	0.272	0.233	0.049	0.355
2009	-0.028	-0.056	0.088	0.073	0.156	0.066	0.127	0.214	0.255	0.144
2010	0.301	0.124	0.162	0.115	0.079	0.010	0.107	0.188	0.519	0.079
2011										
2012	-0.139	0.141	0.028	-0.206	-0.203	-0.152	0.034	0.207	-0.089	-0.053
2013	-0.007	0.039	0.081	0.007	-0.022	-0.042	-0.081	-0.036	0.208	-0.076

Table 12: Icelandic cod in Division Va. Fall survey (SMH) at age residuals from the ADCAM model, assessment tuned with both the spring and the fall survey.

year	3	4	5	6	7	8	9	10	11	12	13	14
1955	0.040	0.170	0.253	0.275	0.303	0.306	0.285	0.329	0.329	0.314	0.329	0.329
1956	0.051	0.182	0.250	0.259	0.291	0.305	0.297	0.347	0.361	0.342	0.340	0.340
1957	0.081	0.215	0.274	0.272	0.301	0.329	0.329	0.368	0.370	0.339	0.306	0.306
1958	0.114	0.248	0.302	0.291	0.324	0.373	0.400	0.443	0.450	0.394	0.334	0.334
1959	0.091	0.233	0.282	0.257	0.299	0.342	0.353	0.402	0.387	0.327	0.236	0.236
1960	0.101	0.233	0.295	0.292	0.338	0.398	0.429	0.479	0.479	0.392	0.278	0.278
1961	0.094	0.225	0.259	0.262	0.334	0.399	0.419	0.461	0.443	0.354	0.232	0.232
1962	0.111	0.248	0.282	0.264	0.347	0.424	0.467	0.514	0.490	0.383	0.244	0.244
1963	0.130	0.283	0.328	0.309	0.383	0.492	0.587	0.647	0.627	0.466	0.291	0.291
1964	0.126	0.290	0.372	0.360	0.435	0.570	0.740	0.811	0.837	0.613	0.394	0.394
1965	0.121	0.284	0.385	0.403	0.471	0.602	0.744	0.849	0.881	0.658	0.431	0.431
1966	0.094	0.254	0.341	0.382	0.491	0.622	0.781	0.916	1.008	0.789	0.538	0.538
1967	0.077	0.229	0.303	0.338	0.484	0.610	0.749	0.879	0.930	0.727	0.465	0.465
1968	0.077	0.247	0.342	0.406	0.576	0.765	1.035	1.200	1.361	1.086	0.744	0.744
1969	0.056	0.232	0.323	0.354	0.505	0.609	0.719	0.837	0.871	0.717	0.447	0.447
1970	0.069	0.270	0.390	0.426	0.551	0.650	0.760	0.892	0.950	0.803	0.518	0.518
1971	0.088	0.309	0.479	0.533	0.620	0.717	0.799	0.957	1.034	0.883	0.582	0.582
1972	0.088	0.302	0.480	0.554	0.650	0.730	0.791	0.959	1.059	0.913	0.603	0.603
1973	0.119	0.321	0.489	0.565	0.668	0.754	0.799	0.953	1.042	0.902	0.591	0.591
1974	0.113	0.325	0.499	0.575	0.699	0.832	0.920	1.055	1.179	1.027	0.695	0.695
1975	0.108	0.310	0.502	0.601	0.722	0.884	1.021	1.126	1.251	1.099	0.768	0.768
1976	0.066	0.258	0.428	0.552	0.695	0.852	0.947	1.007	1.060	0.940	0.649	0.649
1977	0.030	0.195	0.330	0.428	0.609	0.721	0.727	0.737	0.695	0.624	0.403	0.403
1978	0.027	0.174	0.281	0.354	0.525	0.602	0.545	0.547	0.482	0.444	0.277	0.277
1979	0.028	0.171	0.274	0.344	0.502	0.567	0.495	0.489	0.417	0.389	0.243	0.243
1980	0.028	0.175	0.306	0.386	0.538	0.620	0.556	0.544	0.467	0.436	0.287	0.287
1981	0.023	0.176	0.353	0.488	0.648	0.819	0.849	0.816	0.748	0.686	0.510	0.510
1982	0.028	0.192	0.395	0.558	0.699	0.898	0.957	0.866	0.743	0.665	0.500	0.500
1983	0.023	0.179	0.377	0.555	0.705	0.881	0.913	0.849	0.729	0.665	0.511	0.511
1984	0.039	0.200	0.377	0.530	0.674	0.805	0.750	0.699	0.592	0.553	0.420	0.420
1985	0.050	0.230	0.422	0.577	0.714	0.832	0.762	0.695	0.589	0.553	0.425	0.425
1986	0.061	0.262	0.516	0.712	0.823	0.953	0.870	0.763	0.653	0.605	0.471	0.471
1987	0.056	0.272	0.554	0.816	0.904	1.059	0.989	0.843	0.736	0.682	0.549	0.549
1988	0.047	0.258	0.522	0.793	0.920	1.102	1.075	0.933	0.863	0.811	0.687	0.687
1989	0.041	0.242	0.463	0.653	0.793	0.893	0.794	0.712	0.635	0.610	0.485	0.485
1990	0.050	0.250	0.471	0.661	0.787	0.856	0.743	0.679	0.607	0.585	0.463	0.463
1991	0.086	0.302	0.566	0.811	0.882	0.944	0.836	0.759	0.696	0.665	0.542	0.542
1992	0.102	0.320	0.599	0.870	0.923	1.001	0.883	0.789	0.724	0.687	0.567	0.567
1993	0.138	0.313	0.554	0.803	0.887	1.029	1.014	0.916	0.876	0.827	0.715	0.715
1994	0.088	0.241	0.383	0.531	0.676	0.764	0.710	0.684	0.633	0.616	0.509	0.509
1995	0.061	0.196	0.319	0.421	0.568	0.624	0.553	0.559	0.510	0.507	0.408	0.408
1996	0.036	0.161	0.282	0.411	0.557	0.622	0.572	0.584	0.536	0.527	0.432	0.432
1997	0.025	0.145	0.275	0.421	0.582	0.667	0.651	0.664	0.623	0.603	0.509	0.509
1998	0.029	0.154	0.331	0.521	0.664	0.779	0.804	0.802	0.782	0.748	0.661	0.661
1999	0.044	0.177	0.394	0.654	0.750	0.870	0.914	0.879	0.859	0.816	0.735	0.735
2000	0.058	0.181	0.393	0.629	0.752	0.890	0.957	0.936	0.931	0.887	0.817	0.817
2001	0.066	0.188	0.380	0.578	0.696	0.854	0.976	0.984	0.997	0.948	0.892	0.892
2002	0.043	0.164	0.337	0.483	0.593	0.702	0.800	0.842	0.836	0.807	0.740	0.740
2003	0.031	0.149	0.331	0.494	0.568	0.642	0.687	0.732	0.713	0.700	0.628	0.628
2004	0.031	0.144	0.331	0.526	0.576	0.648	0.679	0.713	0.692	0.684	0.613	0.613
2005	0.030	0.126	0.291	0.478	0.544	0.621	0.656	0.687	0.674	0.669	0.599	0.599
2006	0.029	0.119	0.263	0.458	0.530	0.622	0.671	0.693	0.686	0.679	0.611	0.611
2007	0.027	0.108	0.228	0.381	0.483	0.589	0.662	0.694	0.703	0.698	0.635	0.635
2008	0.021	0.088	0.177	0.291	0.395	0.469	0.482	0.497	0.463	0.463	0.386	0.386
2009	0.030	0.094	0.183	0.301	0.394	0.464	0.464	0.457	0.406	0.403	0.325	0.325
2010	0.028	0.087	0.161	0.255	0.350	0.406	0.385	0.380	0.325	0.327	0.253	0.253
2011	0.028	0.085	0.153	0.233	0.318	0.361	0.322	0.312	0.251	0.252	0.183	0.183
2012	0.028	0.087	0.158	0.241	0.318	0.360	0.326	0.306	0.242	0.243	0.175	0.175
2013	0.043	0.098	0.173	0.256	0.323	0.370	0.346	0.327	0.261	0.269	0.196	0.196

Table 13: Icelandic cod in Division Va. Estimates of fishing mortality 1955-2013 based on ACAM using catch at age and spring and fall bottom survey indices.

year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1955	170.68	152.84	151.98	217.59	211.68	115.18	35.93	24.44	12.85	86.16	9.08	7.69	7.98	2.60
1956	220.63	170.68	152.84	119.55	150.24	134.54	71.61	21.72	14.74	7.91	50.77	5.35	4.60	4.70
1957	289.18	220.63	170.68	118.92	81.57	95.82	84.99	43.83	13.10	8.97	4.58	28.97	3.11	2.68
1958	154.23	289.17	220.63	128.85	78.54	50.78	59.75	51.47	35.05	7.72	5.08	2.59	16.91	1.88
1959	192.68	154.23	289.18	161.13	82.29	47.54	31.08	35.38	51.42	19.25	4.06	2.65	1.43	9.91
1960	128.69	192.69	154.23	216.21	104.48	50.80	30.11	18.87	20.57	37.47	10.54	2.25	1.57	0.92
1961	177.36	128.69	192.69	114.19	140.22	63.71	31.07	17.58	10.38	10.97	19.00	5.34	1.25	0.97
1962	203.84	177.36	128.69	143.63	74.65	88.58	40.16	18.22	23.60	5.59	5.66	9.99	3.07	0.81
1963	216.39	203.85	177.36	94.25	91.76	46.12	55.72	23.25	9.76	12.11	2.74	2.84	5.58	1.97
1964	229.21	216.39	203.84	127.56	58.15	54.12	27.72	31.10	11.63	4.45	5.19	1.20	1.46	3.42
1965	320.37	229.21	216.39	147.18	78.12	32.82	30.90	14.70	14.39	4.54	1.62	1.84	0.53	0.81
1966	172.07	320.37	229.21	157.01	90.70	43.54	17.96	15.79	6.59	5.60	1.59	0.55	0.78	0.28
1967	247.67	172.07	320.37	170.79	99.76	52.79	24.34	9.00	6.94	2.47	1.83	0.48	0.20	0.37
1968	180.62	247.67	172.07	242.93	111.20	60.30	30.82	12.28	4.00	2.69	0.84	0.59	0.19	0.11
1969	188.75	180.62	247.67	130.46	155.41	64.68	32.91	41.22	4.68	1.16	0.66	0.18	0.16	0.07
1970	139.35	188.75	180.62	191.76	84.67	92.15	37.16	32.89	18.36	1.87	0.41	0.23	0.07	0.09
1971	273.18	139.35	188.75	138.07	119.89	46.96	49.27	17.53	14.05	7.03	0.63	0.13	0.08	0.03
1972	179.07	273.18	139.35	141.46	82.99	60.81	22.57	21.69	23.28	5.17	2.21	0.18	0.04	0.04
1973	260.88	179.07	273.18	104.52	85.65	42.05	28.62	9.65	8.56	8.64	1.62	0.63	0.06	0.02
1974	367.74	260.88	179.07	198.62	62.10	43.02	19.58	12.02	3.72	3.15	2.73	0.47	0.21	0.03
1975	143.36	367.74	260.88	130.90	117.54	30.87	19.81	7.96	4.28	1.21	0.90	0.69	0.14	0.09
1976	227.71	143.36	367.74	191.69	78.64	58.25	13.86	7.88	2.69	1.26	0.32	0.21	0.19	0.05
1977	243.31	227.71	143.36	281.76	121.23	41.98	27.47	5.66	2.75	0.86	0.38	0.09	0.07	0.08
1978	140.04	243.31	227.72	113.86	189.77	71.39	22.40	12.23	2.26	1.09	0.34	0.15	0.04	0.04
1979	140.44	140.04	243.31	181.43	78.34	117.30	41.02	10.85	5.48	1.07	0.52	0.17	0.08	0.02
1980	131.67	140.44	140.04	193.66	125.24	48.76	71.81	20.32	5.04	2.74	0.54	0.28	0.09	0.05
1981	232.97	131.67	140.44	111.47	133.11	75.51	27.14	47.12	8.95	2.37	1.30	0.28	0.15	0.06
1982	139.00	232.97	131.67	112.40	76.54	76.58	37.94	11.62	17.01	3.13	0.86	0.50	0.11	0.07
1983	140.19	139.00	232.97	104.86	75.92	42.22	35.89	15.44	3.88	5.35	1.08	0.33	0.21	0.06
1984	329.05	140.19	139.00	186.32	71.82	42.64	19.85	14.52	5.24	1.27	1.87	0.43	0.14	0.10
1985	259.92	329.05	140.19	109.50	124.85	40.32	20.54	8.28	5.31	2.03	0.52	0.85	0.20	0.08
1986	175.46	259.92	329.05	109.17	71.24	67.05	18.54	8.24	2.95	2.03	0.83	0.24	0.40	0.11
1987	89.21	175.46	259.92	253.34	68.82	34.82	26.93	6.67	2.60	1.01	0.77	0.35	0.11	0.20
1988	130.52	89.21	175.46	201.31	158.06	32.37	12.61	8.93	1.89	0.79	0.36	0.30	0.15	0.05
1989	106.85	130.52	89.21	137.05	127.33	76.76	11.99	4.11	2.43	0.53	0.25	0.12	0.11	0.06
1990	174.35	106.85	130.52	70.13	88.09	100.18	32.72	4.44	1.38	0.90	0.21	0.11	0.05	0.06
1991	135.50	174.35	106.85	101.63	44.69	45.03	42.33	12.19	1.55	0.54	0.37	0.09	0.05	0.03
1992	77.76	135.50	174.35	80.29	61.52	20.79	16.38	14.34	3.88	0.55	0.21	0.15	0.04	0.02
1993	150.97	77.76	135.50	128.96	47.74	27.68	7.13	5.33	4.31	1.31	0.20	0.08	0.06	0.02
1994	165.44	150.97	77.76	96.64	77.23	22.45	10.15	2.40	1.56	1.28	0.43	0.07	0.03	0.03
1995	88.26	165.44	150.97	58.28	62.15	43.10	10.81	4.23	0.92	0.63	0.53	0.19	0.03	0.01
1996	161.36	88.26	165.44	116.24	39.24	37.00	23.16	5.02	1.85	0.43	0.29	0.26	0.09	0.02
1997	70.84	161.36	88.26	130.63	81.05	24.22	20.08	10.87	2.20	0.86	0.20	0.14	0.13	0.05
1998	171.56	70.84	161.36	70.44	92.52	50.38	13.01	9.18	4.57	0.94	0.36	0.09	0.06	0.06
1999	161.46	171.56	70.84	128.38	49.45	54.40	24.50	5.48	3.45	1.67	0.35	0.14	0.03	0.03
2000	158.93	161.46	171.56	55.48	88.07	27.30	23.15	9.48	1.88	1.13	0.57	0.12	0.05	0.01
2001	178.34	158.93	161.46	132.50	37.89	48.69	11.92	8.93	3.19	0.59	0.36	0.18	0.04	0.02
2002	80.29	178.34	158.93	123.73	89.93	21.21	22.37	4.86	3.11	0.98	0.18	0.11	0.06	0.01
2003	154.78	80.29	178.34	124.66	86.01	52.55	10.71	10.12	1.97	1.15	0.35	0.06	0.04	0.02
2004	134.79	154.78	80.29	141.53	87.93	50.58	26.25	4.97	4.36	0.81	0.45	0.14	0.03	0.02
2005	96.00	134.79	154.78	63.73	100.37	51.69	24.48	12.08	2.13	1.81	0.33	0.18	0.06	0.01
2006	133.41	96.00	134.79	122.93	45.99	61.40	26.25	11.63	5.31	0.90	0.75	0.14	0.08	0.03
2007	119.56	133.41	96.00	107.22	89.35	28.96	31.80	12.64	5.11	2.22	0.37	0.31	0.06	0.03
2008	128.01	119.56	133.41	76.52	78.79	58.23	16.20	16.07	5.74	2.16	0.91	0.15	0.13	0.02
2009	169.88	128.01	119.56	106.91	57.38	63.70	35.63	8.93	8.23	2.90	1.08	0.47	0.08	0.07
2010	174.94	169.88	128.01	94.99	79.70	39.11	38.60	19.66	4.60	4.24	1.50	0.59	0.26	0.05
2011	123.00	174.94	169.88	101.96	71.30	55.55	24.81	22.28	10.72	2.56	2.37	0.89	0.35	0.16
2012	181.37	123.00	174.94	135.26	76.71	50.09	36.02	14.78	12.71	6.36	1.53	1.51	0.57	0.24
2013	160.04	181.37	123.00	139.28	101.55	53.61	32.23	21.47	8.44	7.51	3.84	0.99	0.97	0.39
2014	109.39	160.04	181.37	96.48	103.36	69.93	33.99	19.10	12.14	4.89	4.43	2.42	0.62	0.65

Table 14: Icelandic cod in Division Va. Estimates of numbers at age in the stock 1955-2014 based on ACAM using catch at age and spring and fall bottom survey indices.

Year	Yield	F5-10	SSB	Reference biomass	Recruits	Harvest rate	NA
1955.000	545.250	0.292	928.654	2344.840	220.633	0.224	0.292
1956.000	486.909	0.292	783.979	2070.870	289.175	0.229	0.292
1957.000	455.182	0.312	764.918	1869.050	154.233	0.242	0.312
1958.000	517.359	0.355	866.222	1857.480	192.685	0.272	0.355
1959.000	459.081	0.323	845.690	1820.680	128.692	0.250	0.323
1960.000	470.121	0.372	706.252	1751.150	177.363	0.269	0.372
1961.000	377.291	0.355	563.391	1494.420	203.845	0.253	0.355
1962.000	388.985	0.383	567.267	1490.620	216.394	0.262	0.383
1963.000	408.800	0.458	506.463	1313.790	229.206	0.313	0.458
1964.000	437.012	0.548	449.862	1217.300	320.374	0.352	0.548
1965.000	387.106	0.576	317.097	1021.450	172.067	0.357	0.576
1966.000	353.357	0.589	276.790	1030.500	247.671	0.333	0.589
1967.000	335.721	0.561	256.045	1102.000	180.624	0.300	0.561
1968.000	381.770	0.721	221.289	1222.310	188.755	0.314	0.721
1969.000	403.205	0.558	313.513	1325.590	139.348	0.307	0.558
1970.000	475.077	0.612	330.931	1337.110	273.178	0.345	0.612
1971.000	444.248	0.684	242.404	1098.130	179.074	0.393	0.684
1972.000	395.166	0.694	221.716	997.098	260.882	0.401	0.694
1973.000	369.205	0.705	245.397	844.002	367.739	0.431	0.705
1974.000	368.133	0.764	187.014	918.425	143.364	0.393	0.764
1975.000	364.754	0.809	168.326	895.542	227.714	0.407	0.809
1976.000	346.253	0.747	138.572	955.649	243.306	0.359	0.747
1977.000	340.086	0.592	198.755	1290.030	140.041	0.261	0.592
1978.000	329.602	0.476	212.465	1298.340	140.438	0.258	0.476
1979.000	366.462	0.445	304.359	1397.880	131.668	0.260	0.445
1980.000	432.237	0.492	356.847	1489.790	232.974	0.288	0.492
1981.000	465.032	0.662	264.268	1242.270	139.003	0.363	0.662
1982.000	380.068	0.729	167.478	970.856	140.186	0.384	0.729
1983.000	298.049	0.713	130.374	791.396	329.046	0.367	0.713
1984.000	282.022	0.639	141.392	913.802	259.917	0.316	0.639
1985.000	323.428	0.667	163.936	927.614	175.457	0.349	0.667
1986.000	364.797	0.773	196.395	854.411	89.210	0.421	0.773
1987.000	389.915	0.861	151.166	1029.470	130.517	0.372	0.861
1988.000	377.554	0.891	168.028	1030.530	106.850	0.368	0.891
1989.000	363.125	0.718	172.722	1000.960	174.351	0.357	0.718
1990.000	335.316	0.700	214.165	841.151	135.500	0.406	0.700
1991.000	307.759	0.800	164.647	698.333	77.763	0.443	0.800
1992.000	264.834	0.844	150.863	550.844	150.974	0.472	0.844
1993.000	250.704	0.867	121.350	595.253	165.438	0.423	0.867
1994.000	178.138	0.625	156.792	576.276	88.262	0.313	0.625
1995.000	168.592	0.507	177.367	557.273	161.364	0.297	0.507
1996.000	180.701	0.505	159.456	670.714	70.839	0.269	0.505
1997.000	203.112	0.543	189.536	783.110	171.560	0.258	0.543
1998.000	243.987	0.650	200.704	720.827	161.462	0.330	0.650
1999.000	260.147	0.743	178.433	731.200	158.931	0.352	0.743
2000.000	235.092	0.760	166.424	590.430	178.341	0.384	0.760
2001.000	234.229	0.745	160.315	688.043	80.290	0.333	0.745
2002.000	208.487	0.626	197.994	729.026	154.777	0.284	0.626
2003.000	207.543	0.576	190.420	739.772	134.794	0.279	0.576
2004.000	226.762	0.579	201.541	799.967	96.002	0.278	0.579
2005.000	213.403	0.546	229.166	723.558	133.410	0.295	0.546
2006.000	196.077	0.540	224.118	700.822	119.564	0.278	0.540
2007.000	170.300	0.506	209.028	681.282	128.014	0.250	0.506
2008.000	146.104	0.385	271.851	704.205	169.879	0.217	0.385
2009.000	181.151	0.377	256.809	798.725	174.939	0.221	0.377
2010.000	168.880	0.323	294.284	842.868	123.001	0.201	0.323
2011.000	170.425	0.283	367.454	932.304	181.375	0.185	0.283
2012.000	194.795	0.285	408.997	1046.970	160.036	0.186	0.285
2013.000	223.548	0.299	448.072	1161.650	109.393	0.193	0.299
2014.000		0.300	411.194	1106.650	140.561		
2015.000		0.289			139.411		
2016.000		0.289			137.229		

Table 15: Icelandic cod in Division Va. Landings (thousand tonnes, average fishing mortality of age groups 5 to 10, recruitment to the fisheries at age 3 (millions), reference fishing biomass (B4+, thousand tonnes), spawning stock biomass (thousand tonnes) at spawning time and harvest ratio.

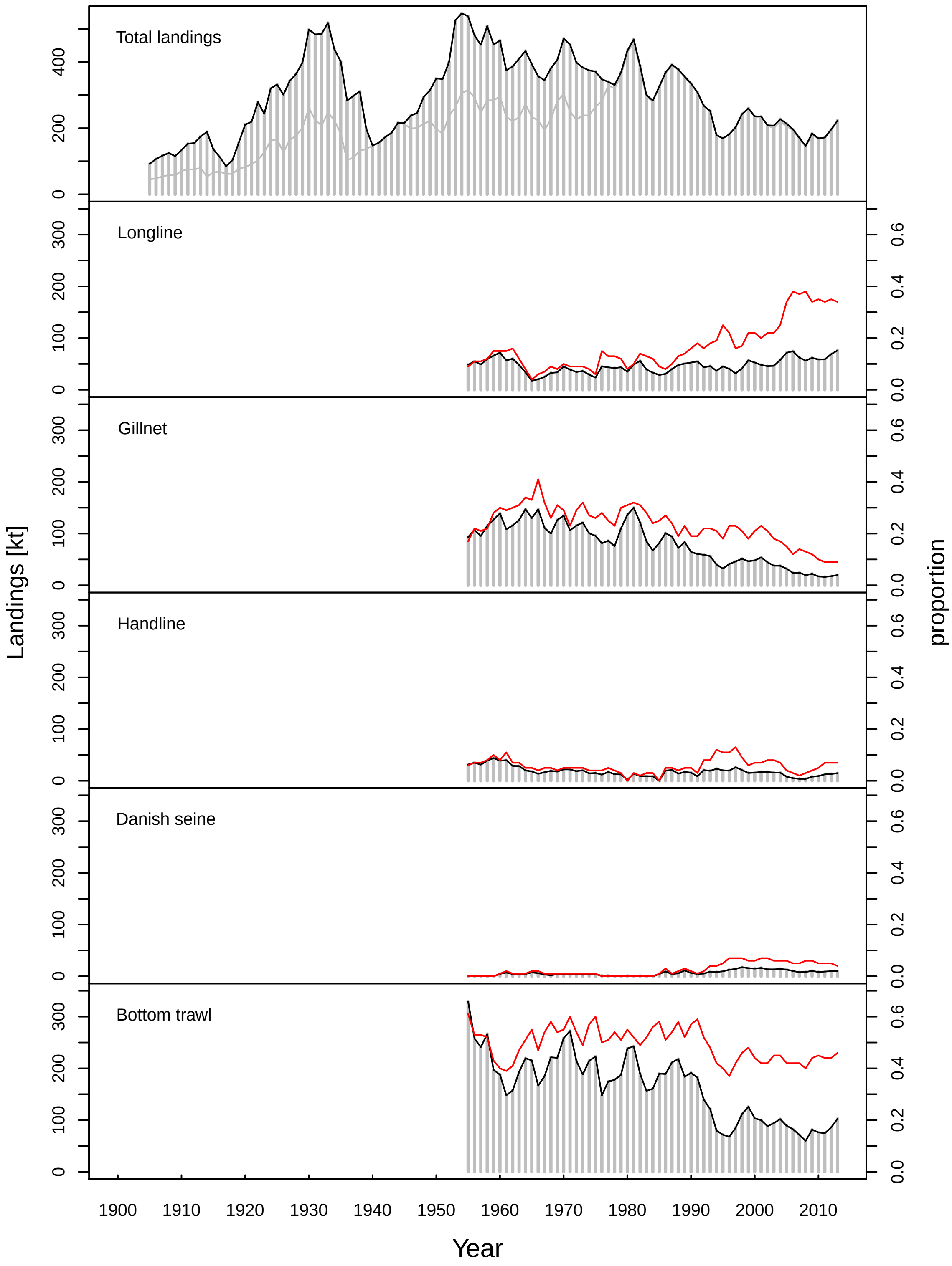

Figure 1: Icelandic cod division Va. Total landings from 1905 to 2013 and landings by principal gear from 1955 to 2013. The proportion of landings by each gear is shown by the red line.

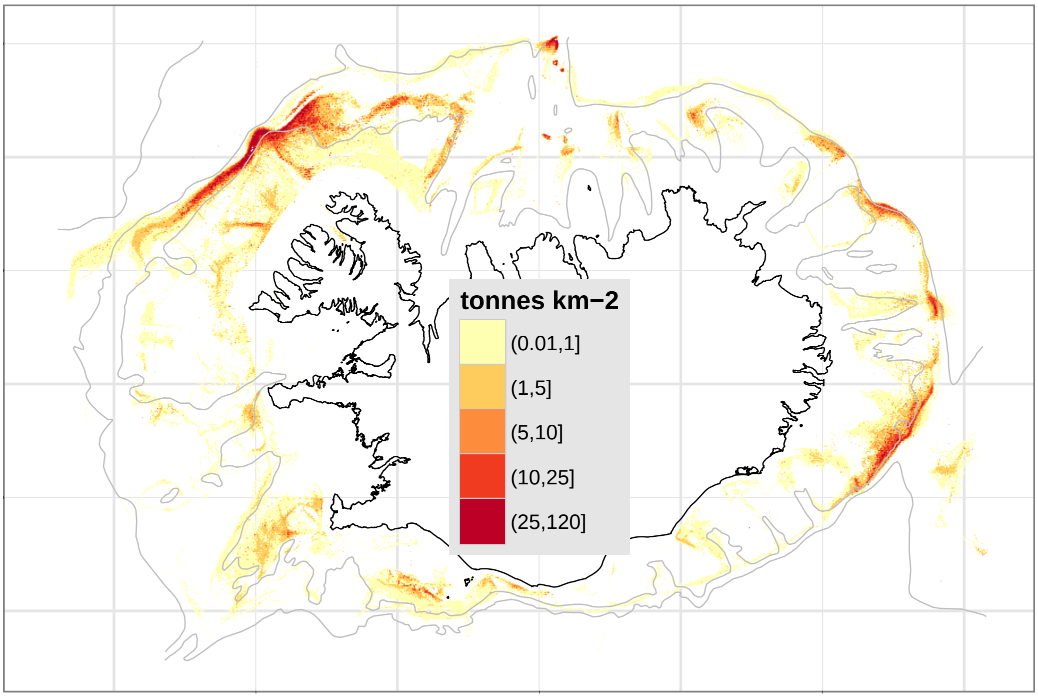

Figure 2: Icelandic cod division Va. Location and magnitude of cod catches by the bottom trawl fleet in 2013. The grey lines represent 200 and 500 m depth contours.

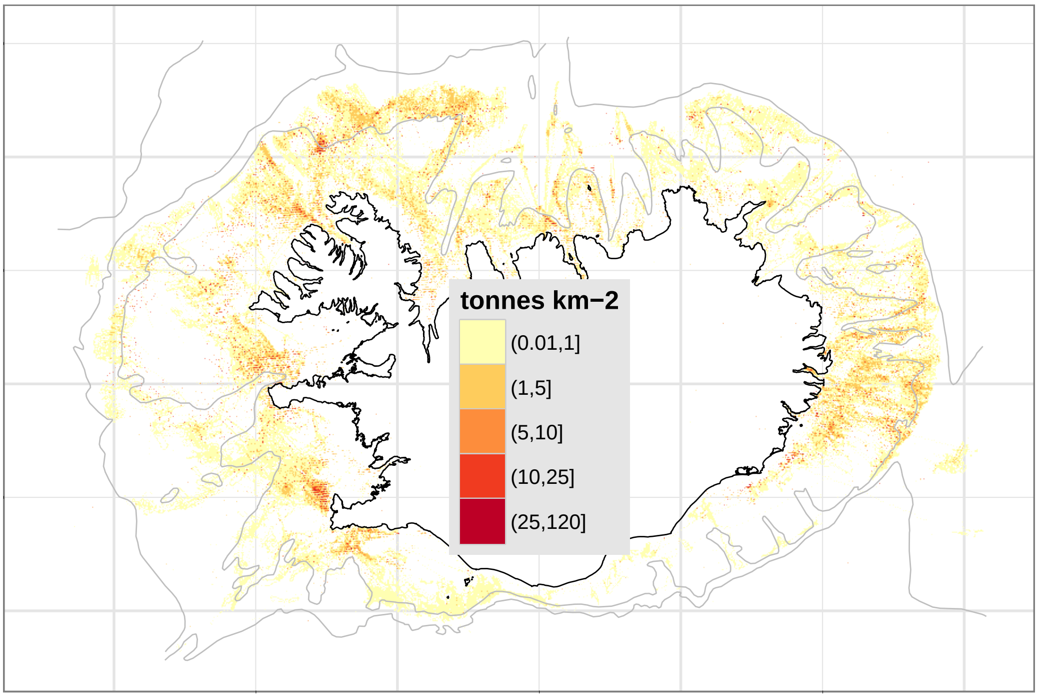

Figure 3: Icelandic cod division Va. Location and magnitude of cod catches by the long line fleet in 2013. The grey lines represent 200 and 500 m depth contours.

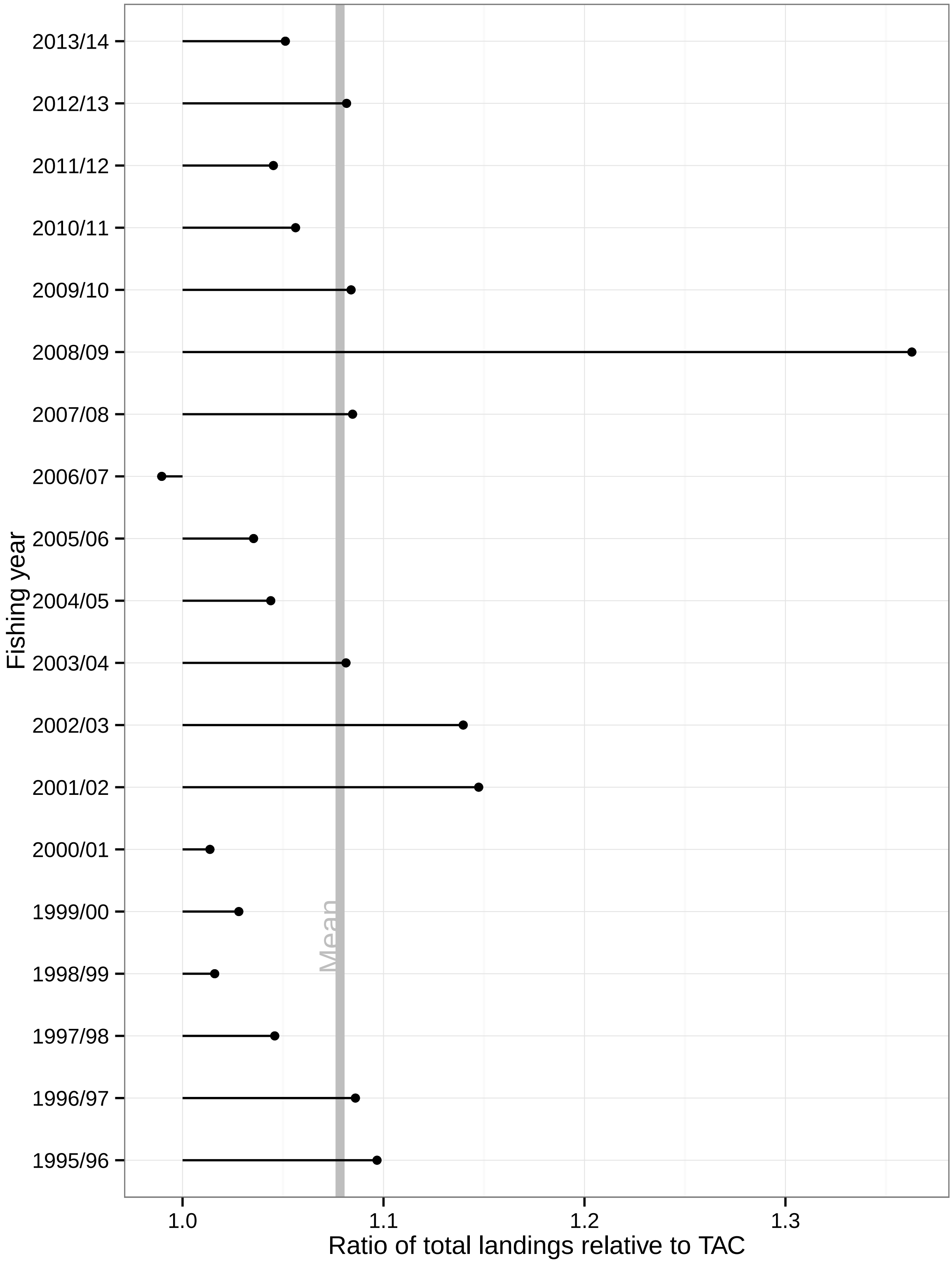

Figure 4: Icelandic cod in division Va. Ratio of total landings relative to the TAC as dictated by the harvest control rule.

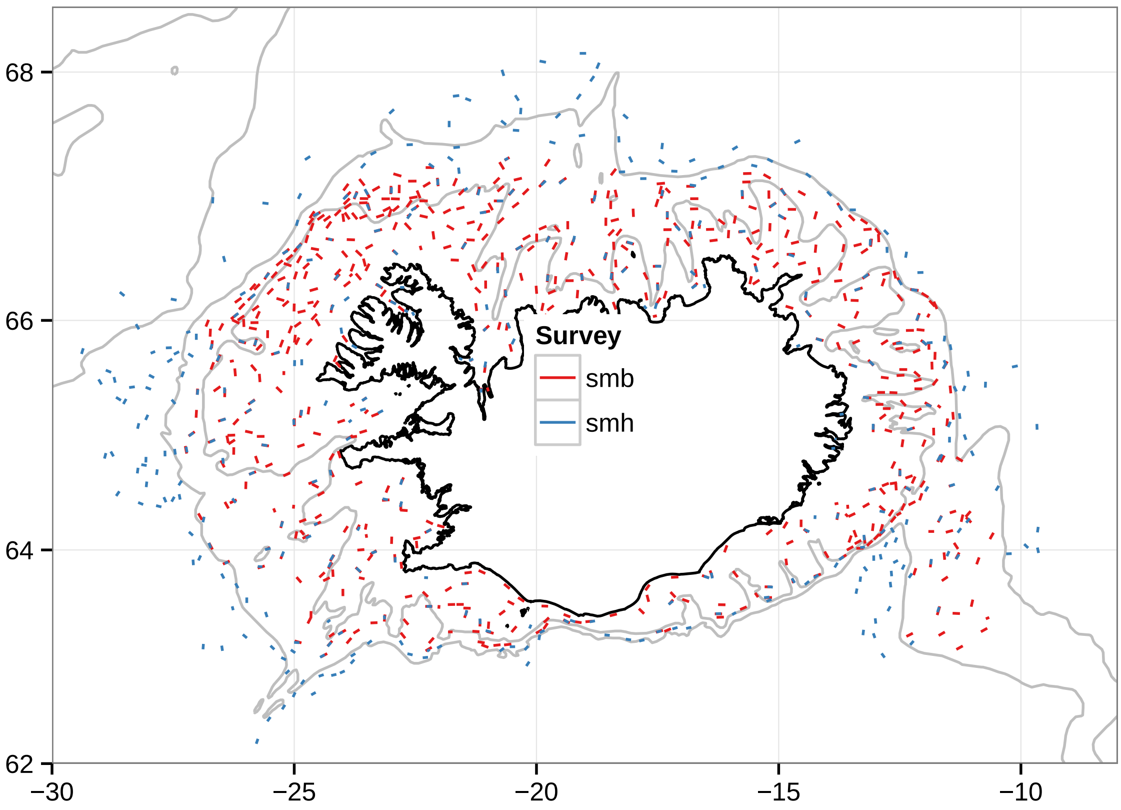

Figure 5: Icelandic cod division Va. Survey station location of the spring (SMB) and fall (SMH) in 2013.

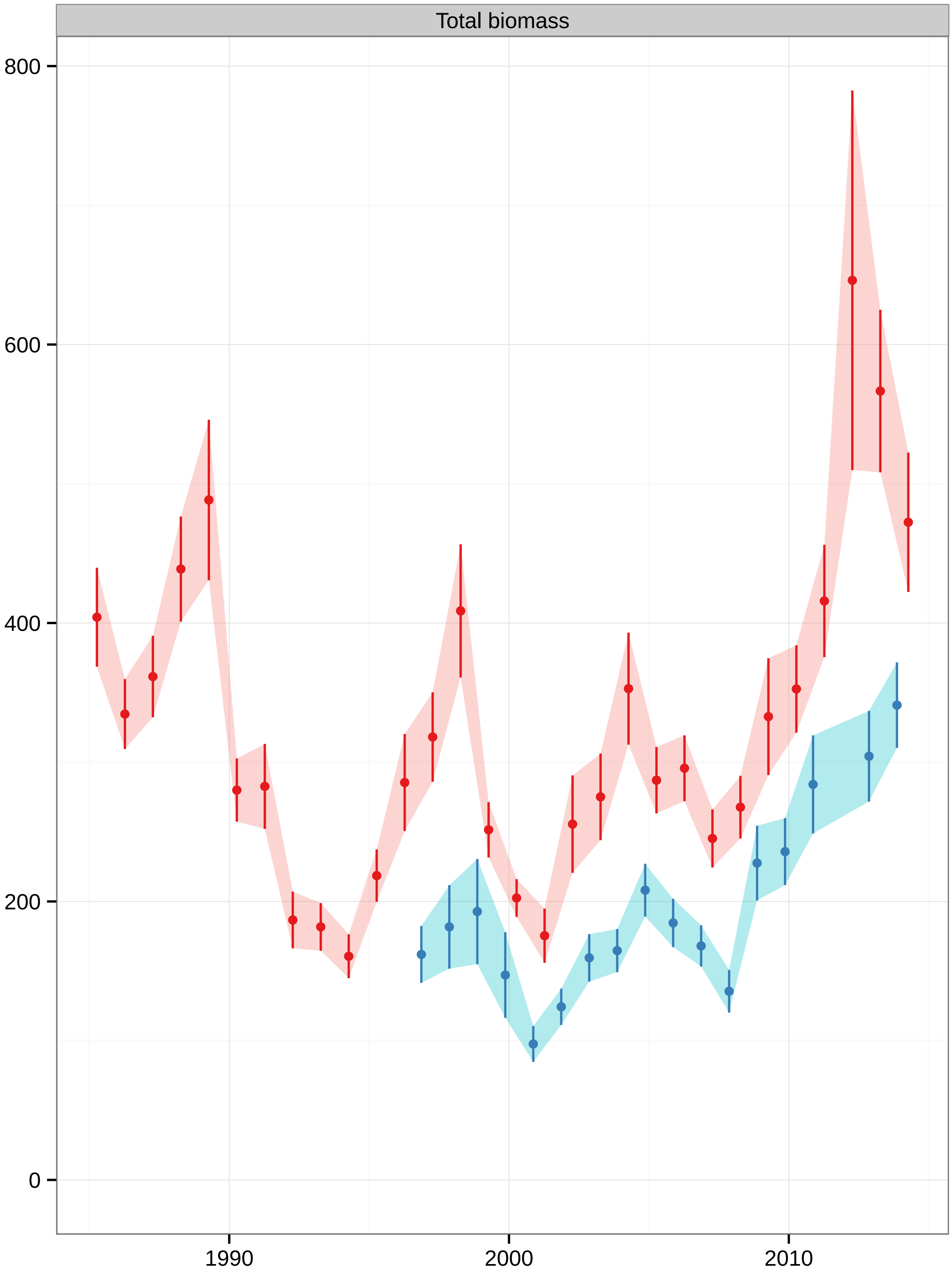

Figure 6: Icelandic cod division Va. Total biomass indices of cod in the groundfish survey in spring 1985-2014 (SMB red, longer time series) and fall 1996-2013 (SMH blue, shorter time series). The shaded area and the vertical bar show 1 standard error of the estimate.

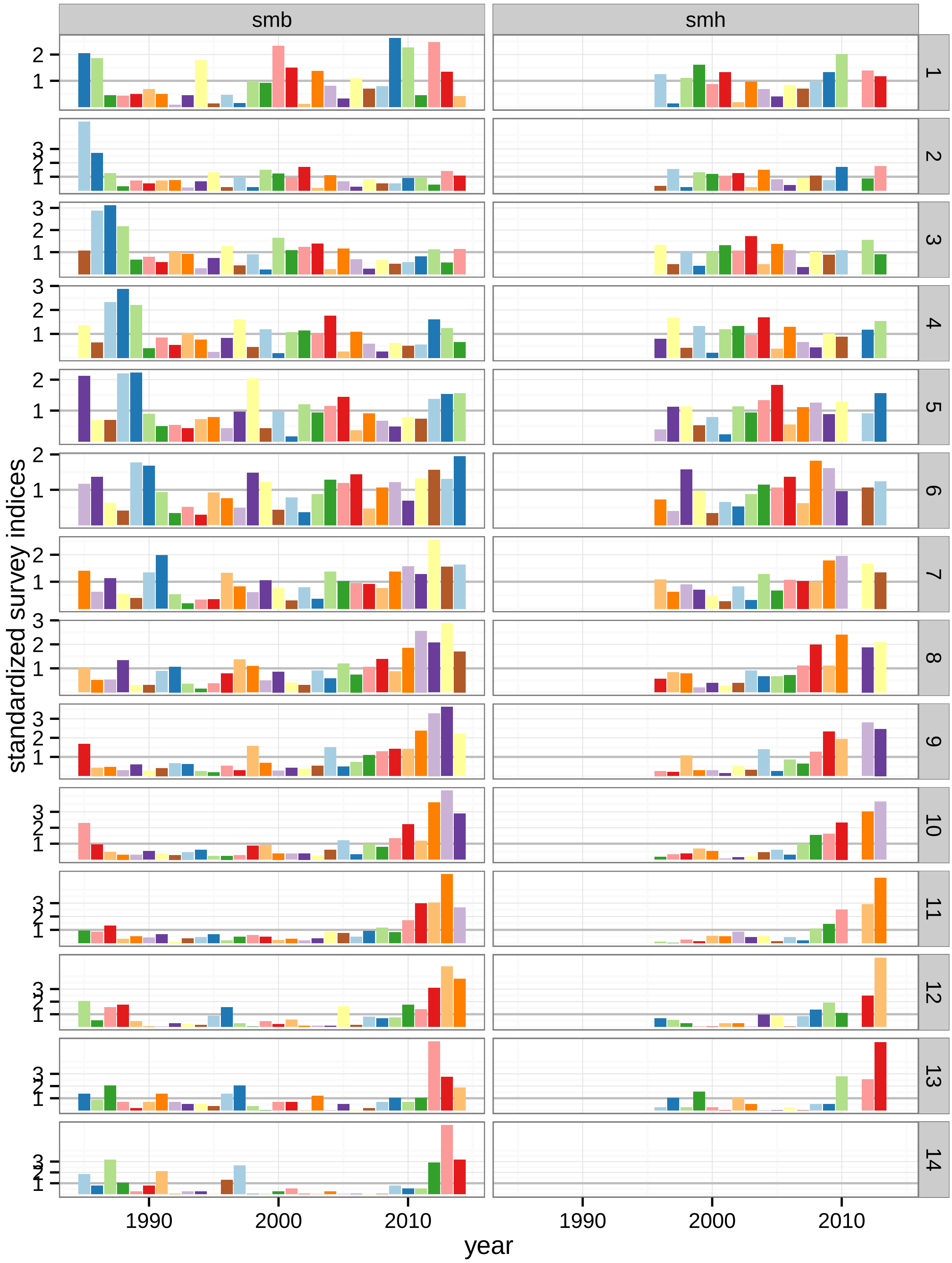

Figure 7: Icelandic cod division Va. Age based abundance indices of cod in the groundfish survey in spring 1985-2014 (SMB) and fall 1996-2013 (SMH). The indices are standardized within each age group and within each survey.

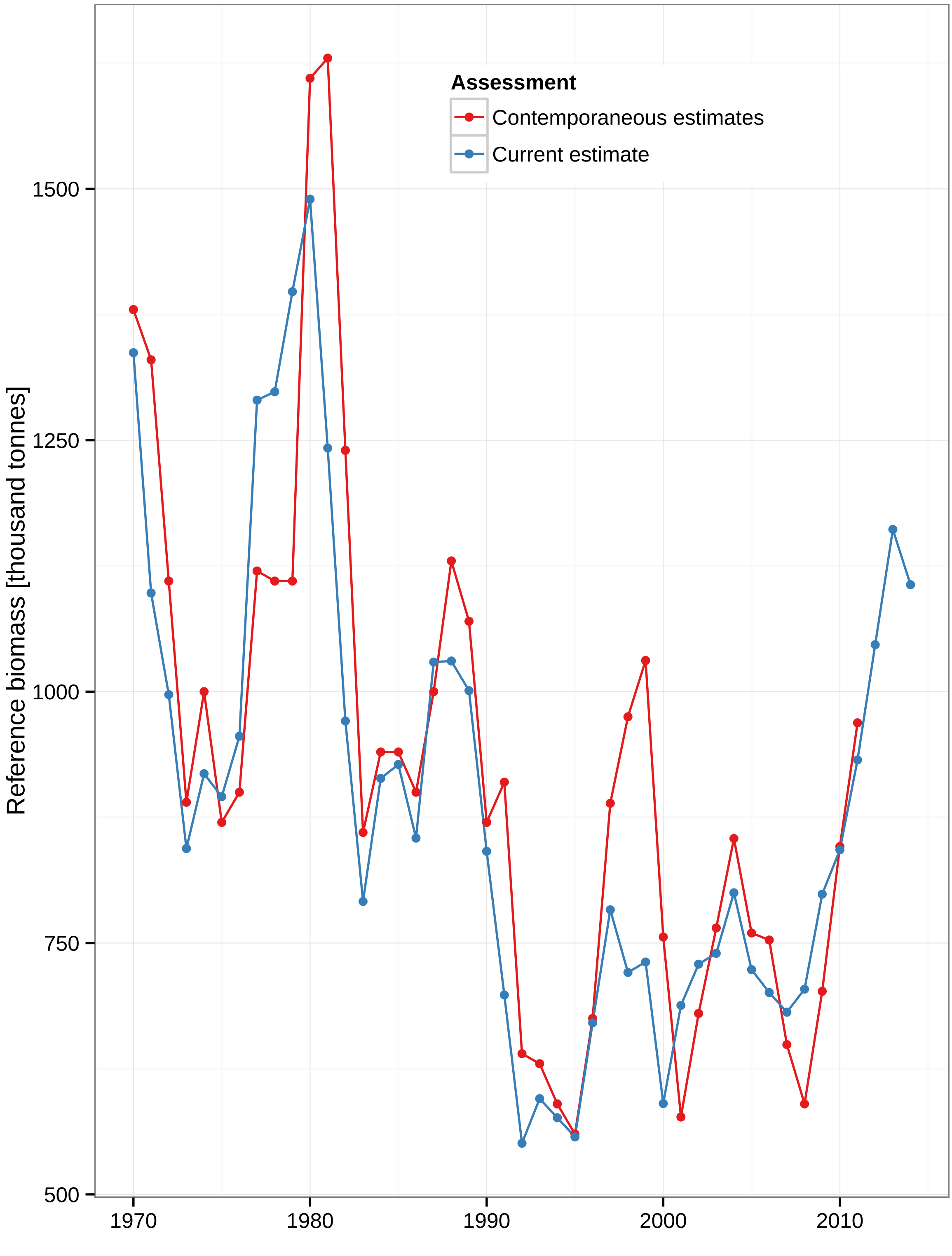

Figure 8: Icelandic cod in division Va. Contemporaneous and current estimates of reference biomass.

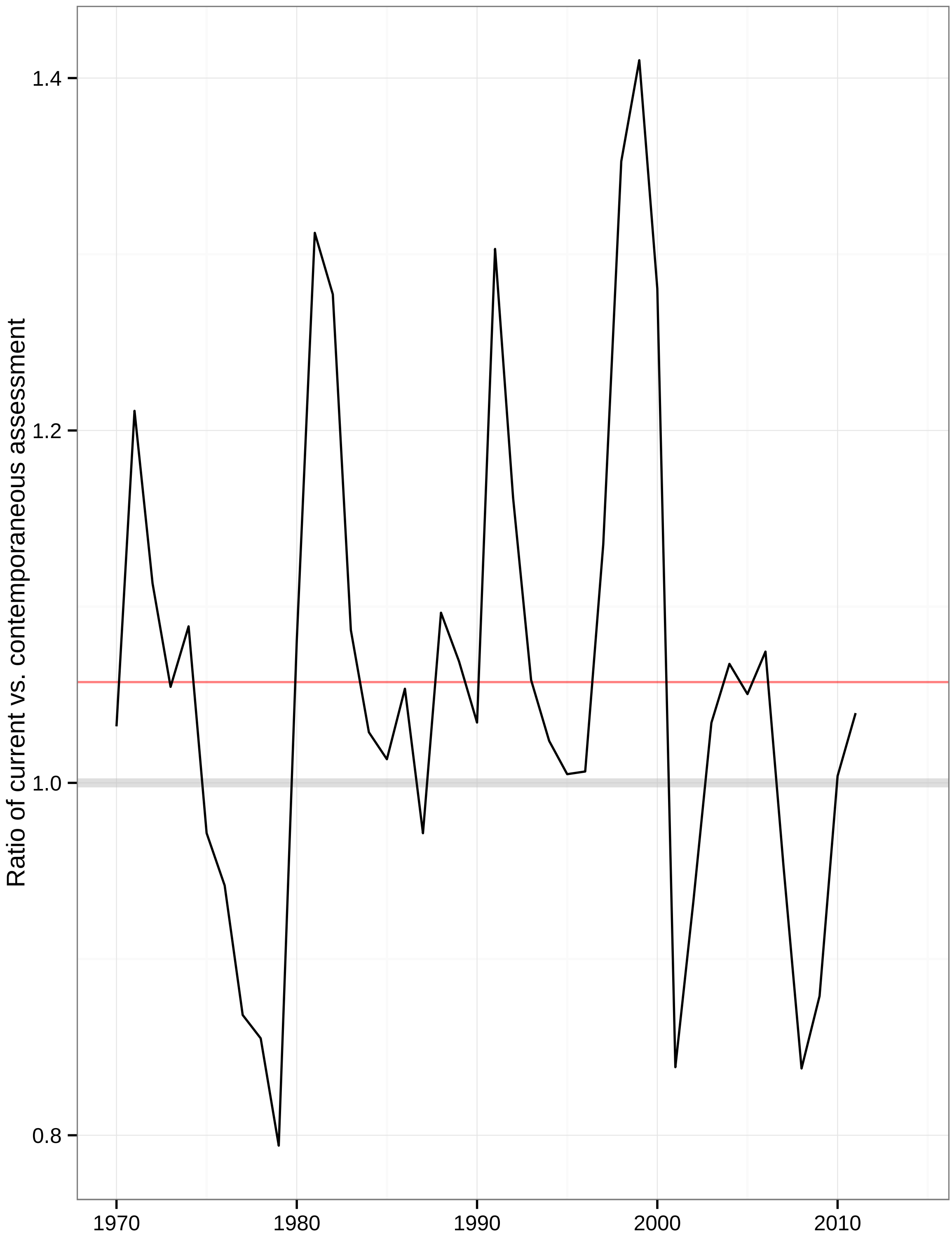

Figure 9: Icelandic cod in division Va. Contemporaneous and current estimates of reference biomass.

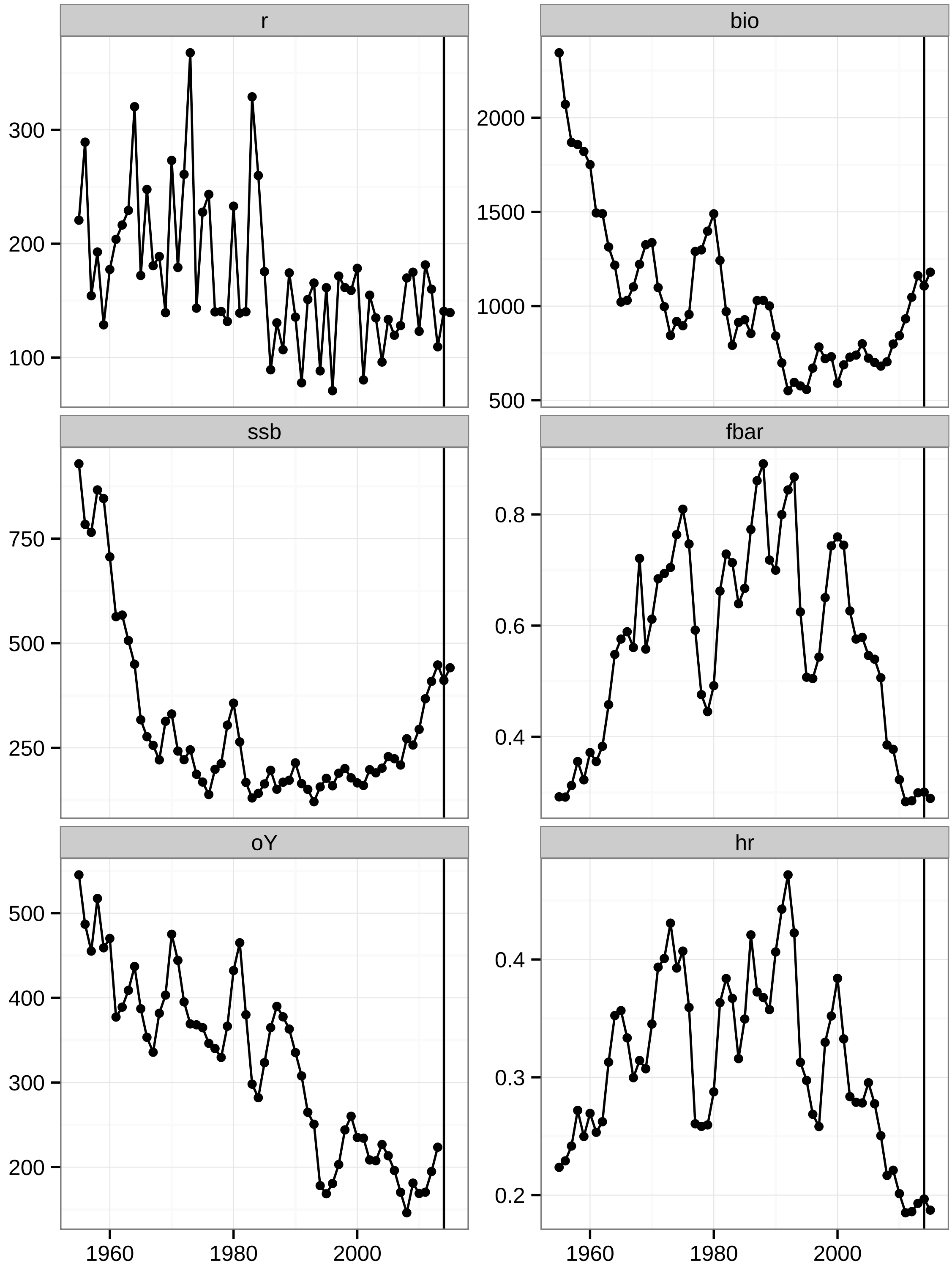

Figure 10: Icelandic cod in division Va - NWWG 2014 assessement. Assessment summary based ADCAM tuned with the spring and the fall survey.

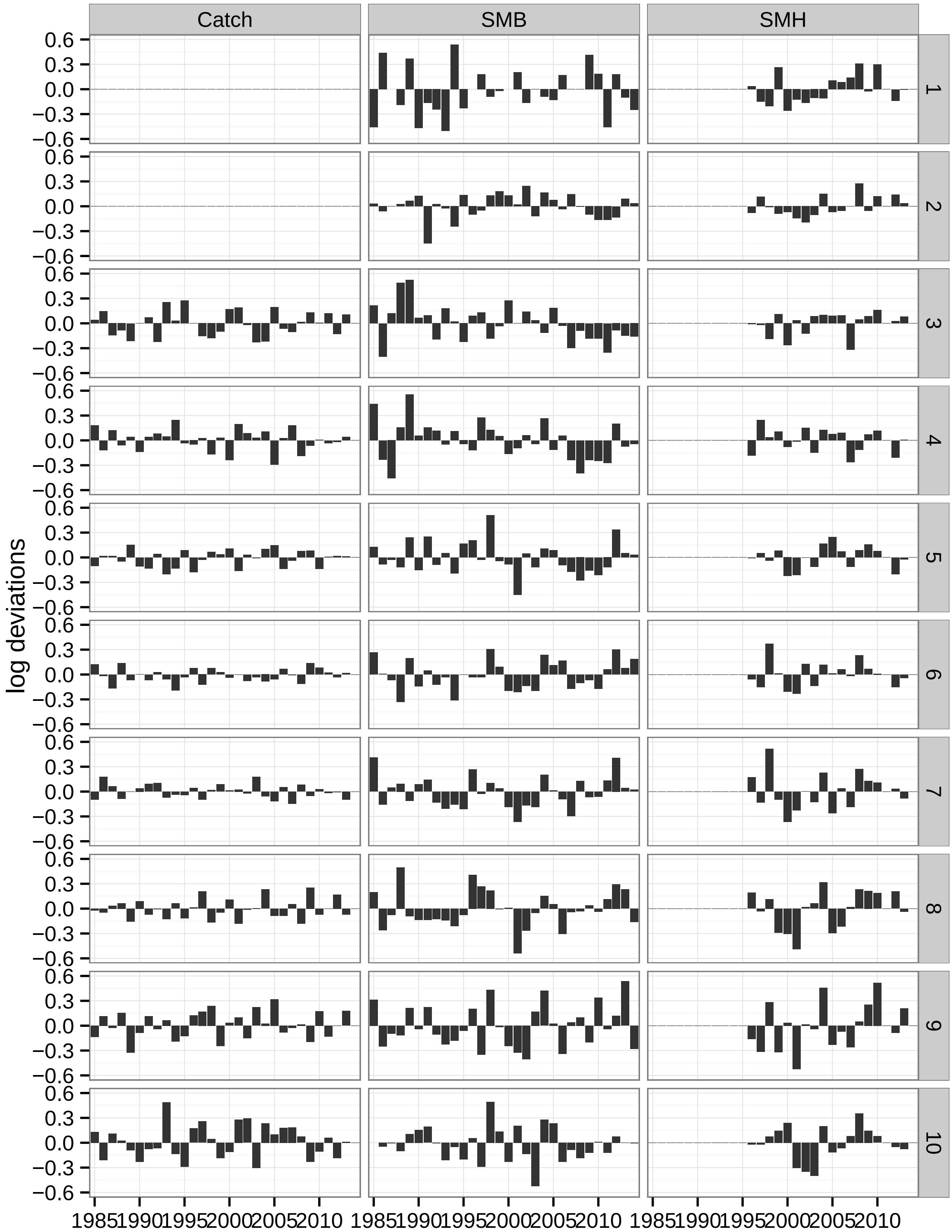

Figure 11: Icelandic cod in Va - NWWG 2014 assessement. Catch residuals (left), spring survey residuals (SMB, middle) and fall survey residuals (SMH, right) by year and age from the spaly ADCAM run. Note that values that are equal to the mean are not visible in this type of a plot and that no survey was carried out in the fall 2011.

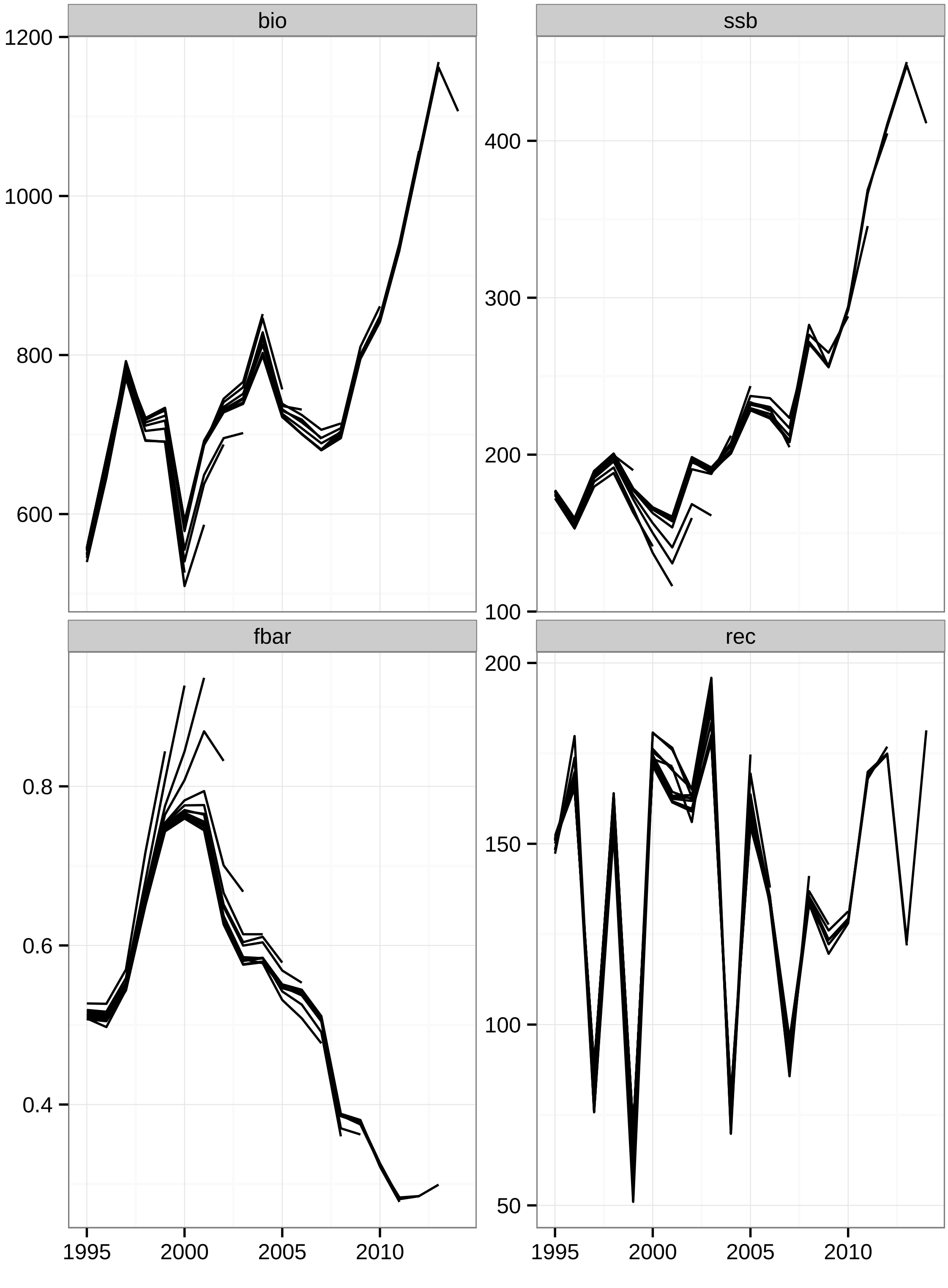

Figure 12: Icelandic cod in division Va. Retrospective analysis of the current model setup (tuning with both the spring and the fall survey).

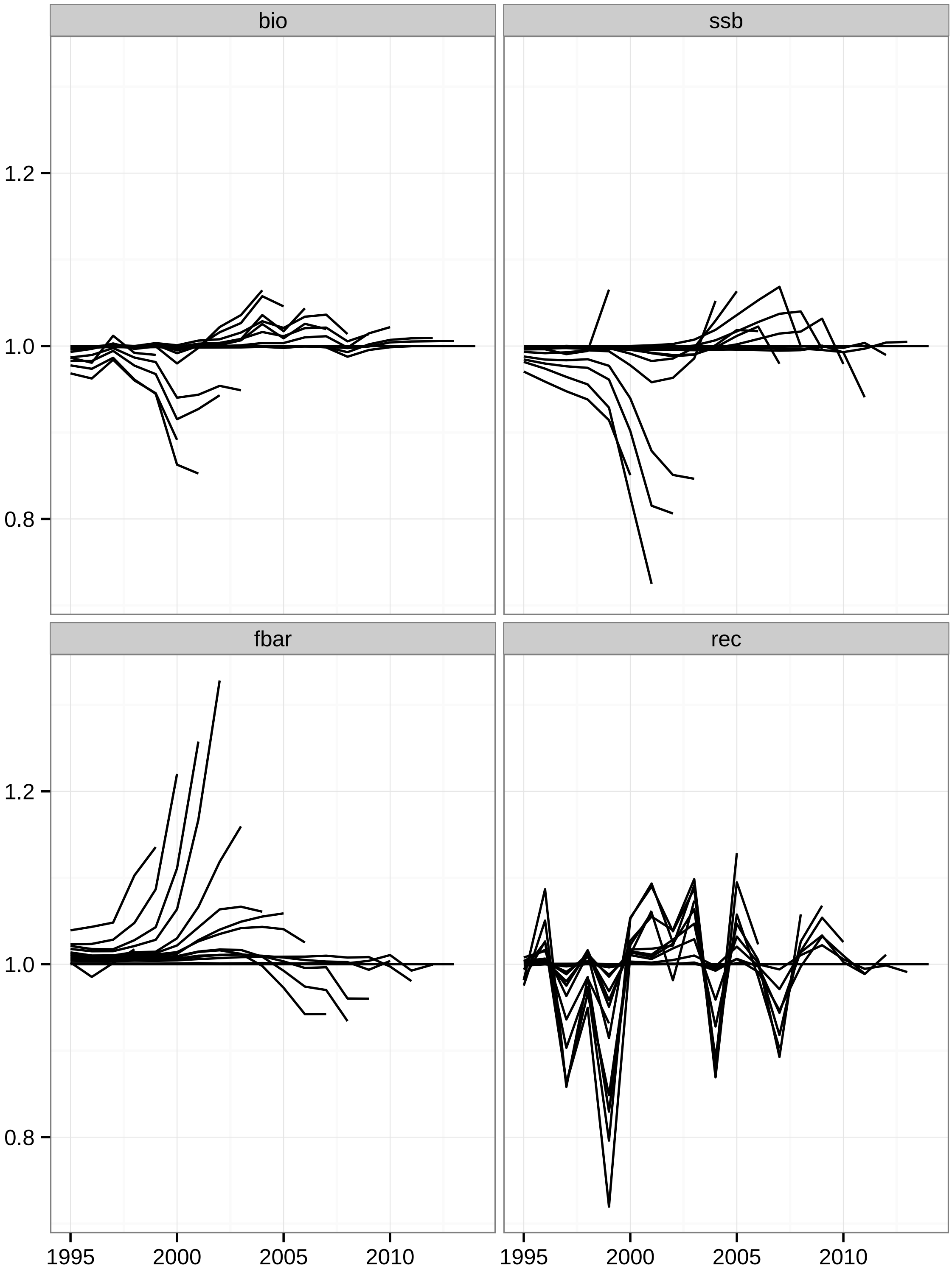

Figure 13: Icelandic cod in division Va. Retrospective analysis of the current model setup expressed as the ratio of the 2014 estimates.

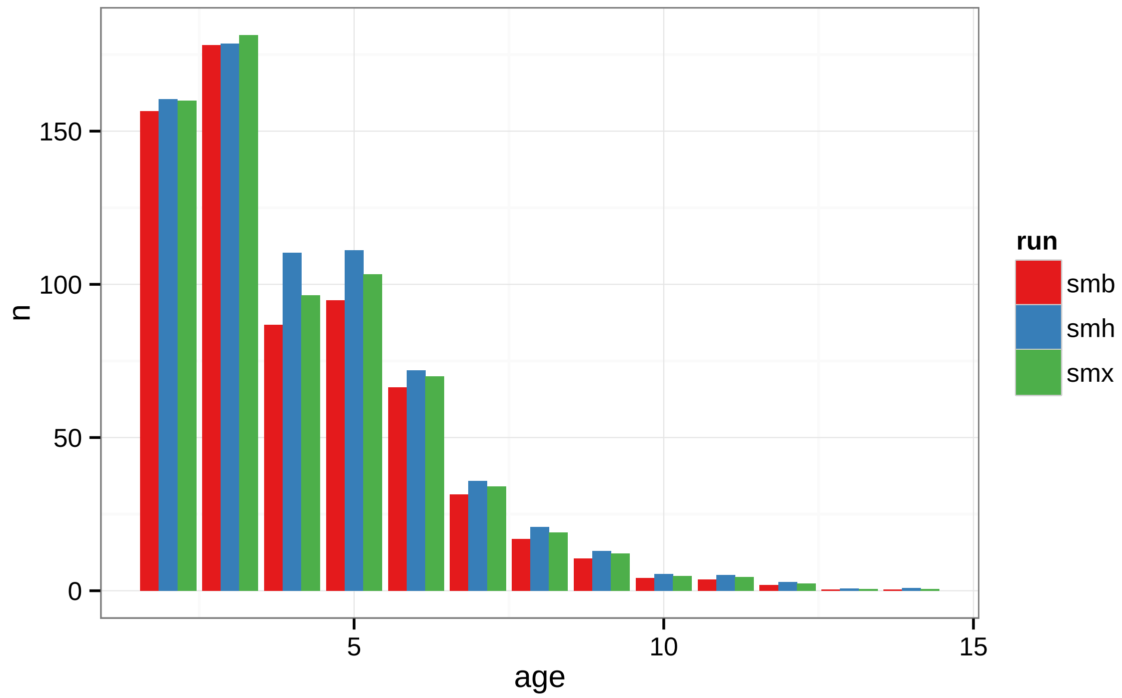

Figure 14: Icelandic cod in division Va. Stock in numbers in 2014 from the adcam run tuning with spring survey only (smb), fall survey only (smh) and both survyes (smx).

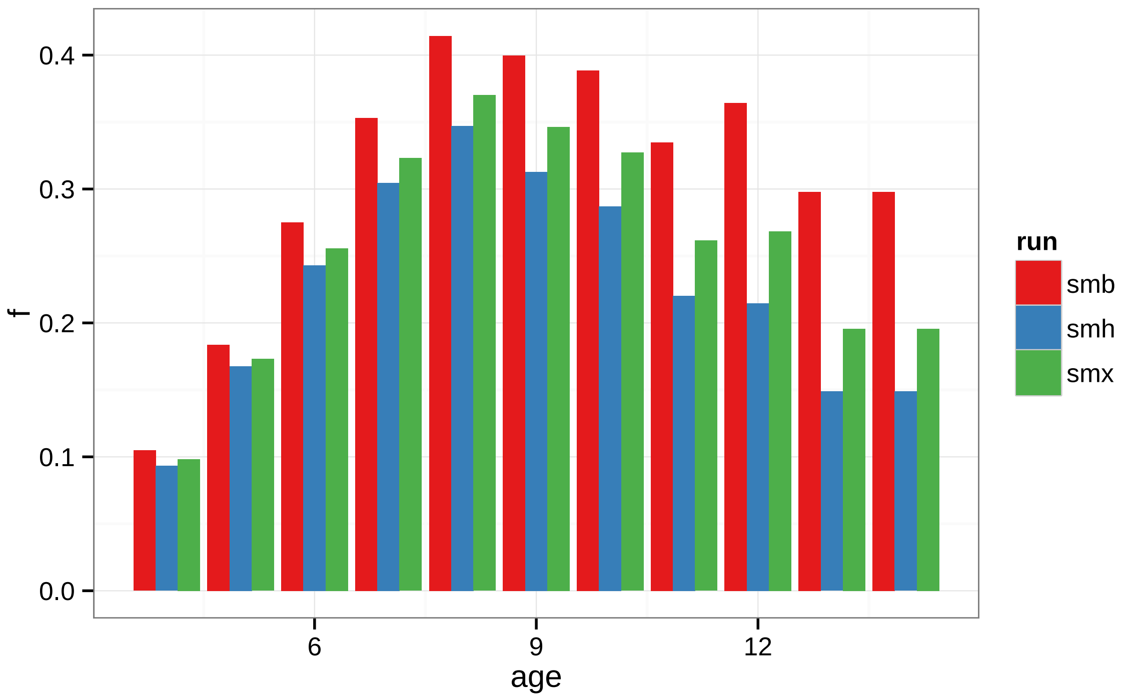

Figure 15: Icelandic cod in division Va. Fishing mortality in 2013 from the adcam run tuning with spring survey only (smb), fall survey only (smh) and both survyes (smx).

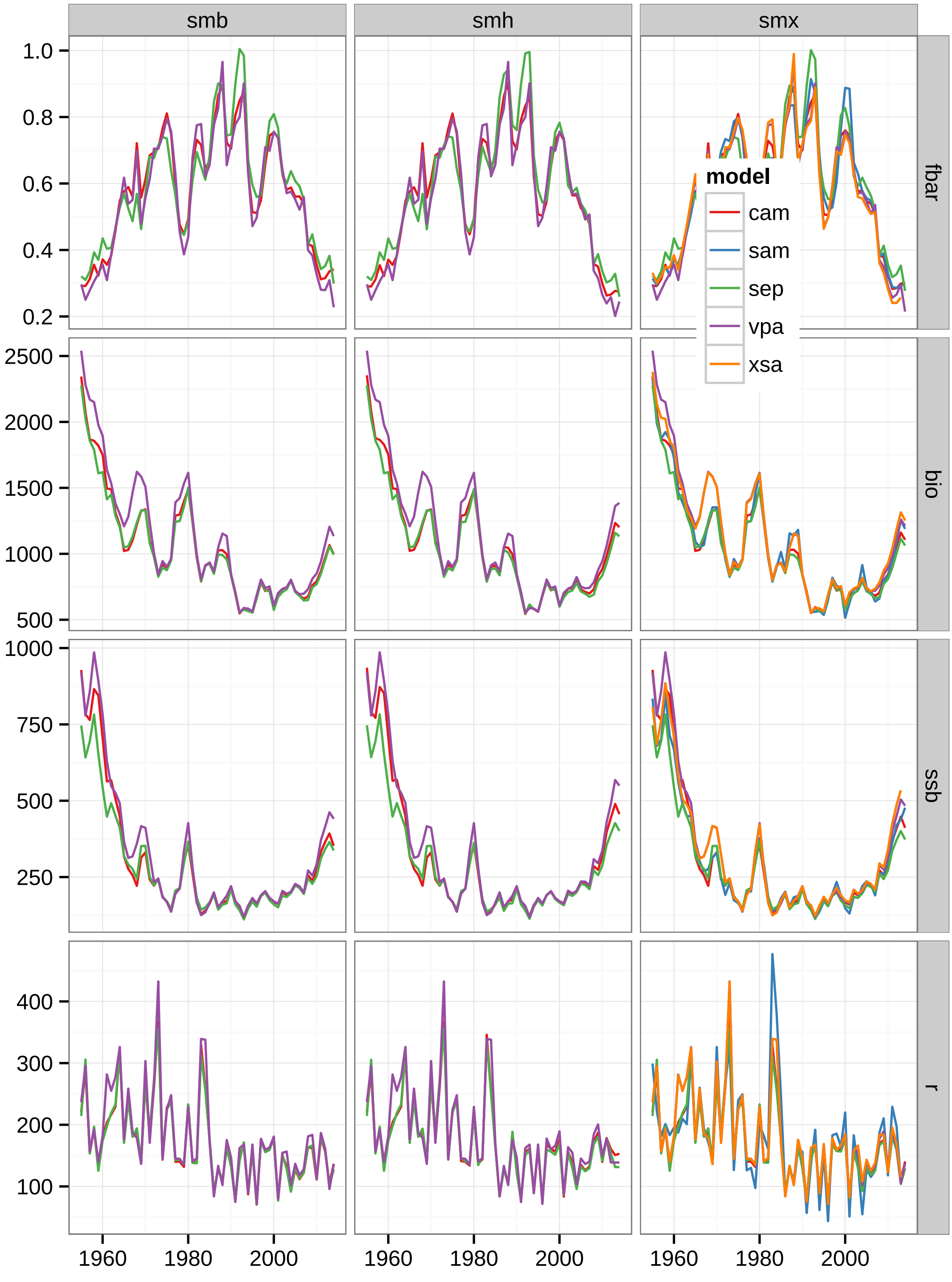

Figure 16: Icelandic cod in division Va. General overview of the principle assessment results using five different assesment models. The left panels are the fit using the spring survey (SMB), the middle panels to the fall survey (SMH) and the right panels using both surveys. The models are: adcam (cam), separable (sep), adapt (vpa), xsa and sam.

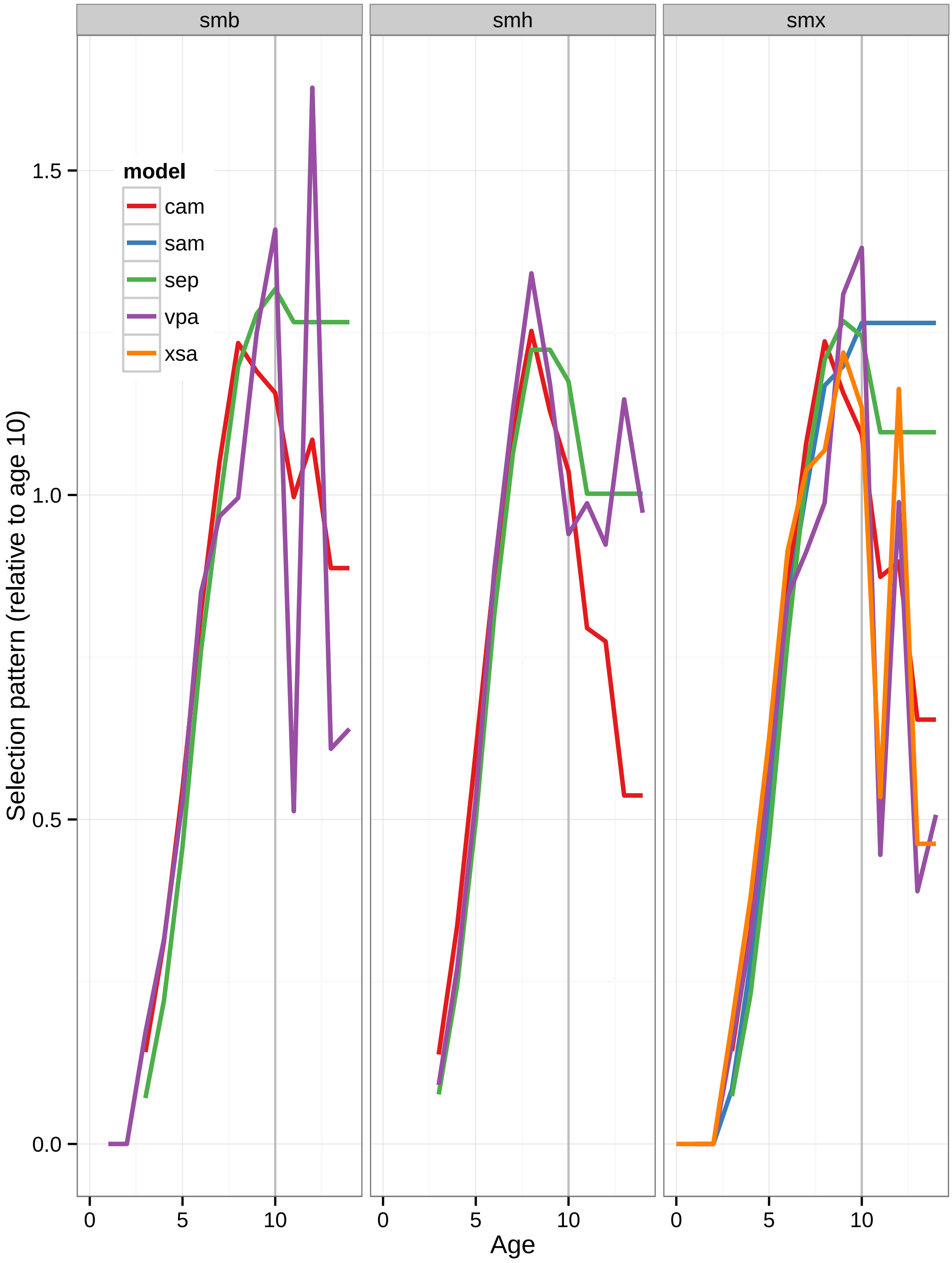

Figure 17: Icelandic cod in division Va. Overview of the selection pattern by age in the terminal year (2013). The left panels are the fit using the spring survey (SMB), the middle panels to the fall survey (SMH) and the right panels using both surveys. The models are: adcam (cam), separable (sep), adapt (vpa), xsa and sam.

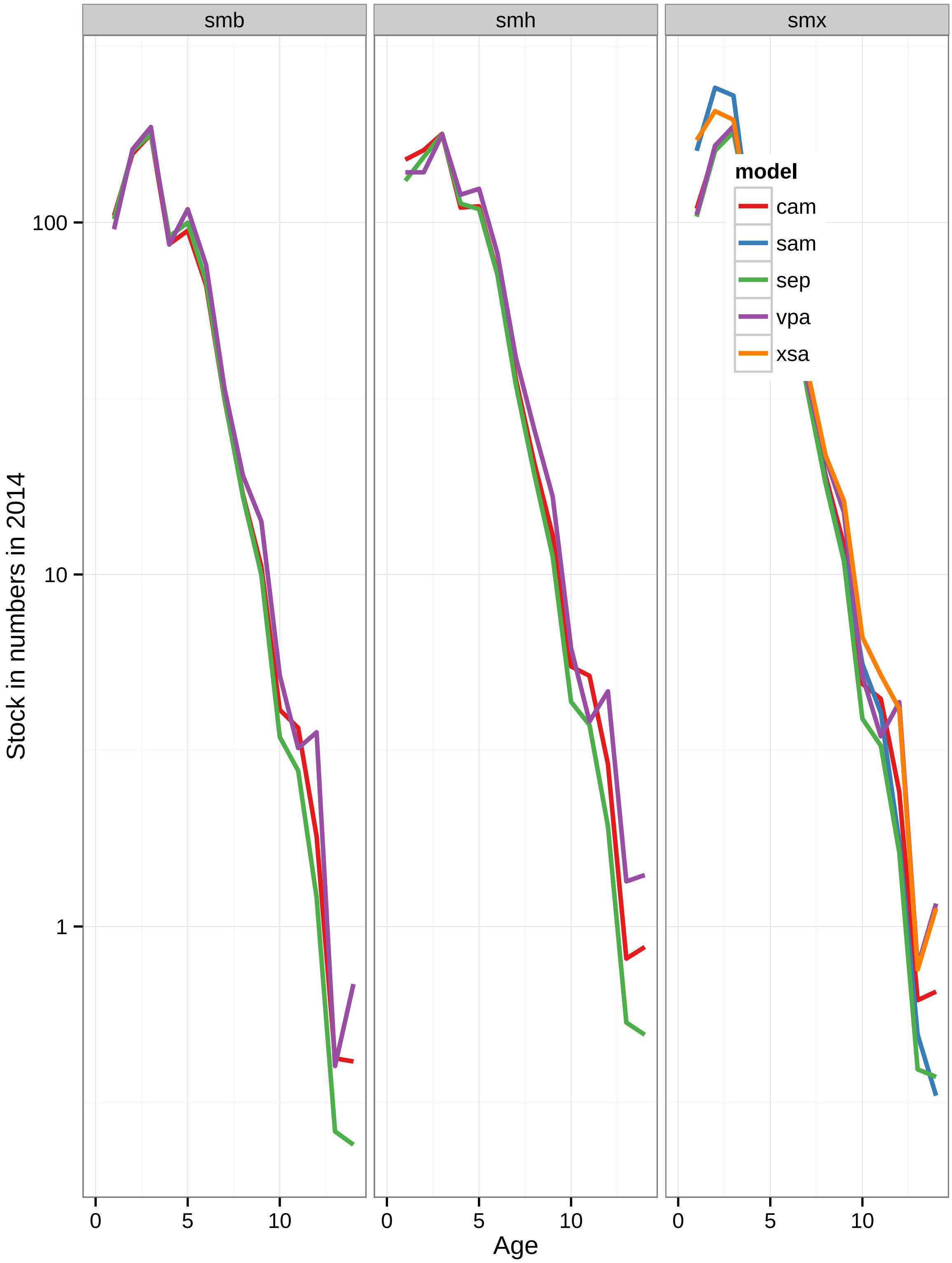

Figure 18: Icelandic cod in division Va. Stock in numbers in the start of the assessment year (2014). The left panels are the fit using the spring survey (smb), the middle panels to the fall survey (smh) and the right panels using both surveys. The models are: adcam (cam), separable (sep), adapt (vpa), xsa and sam.

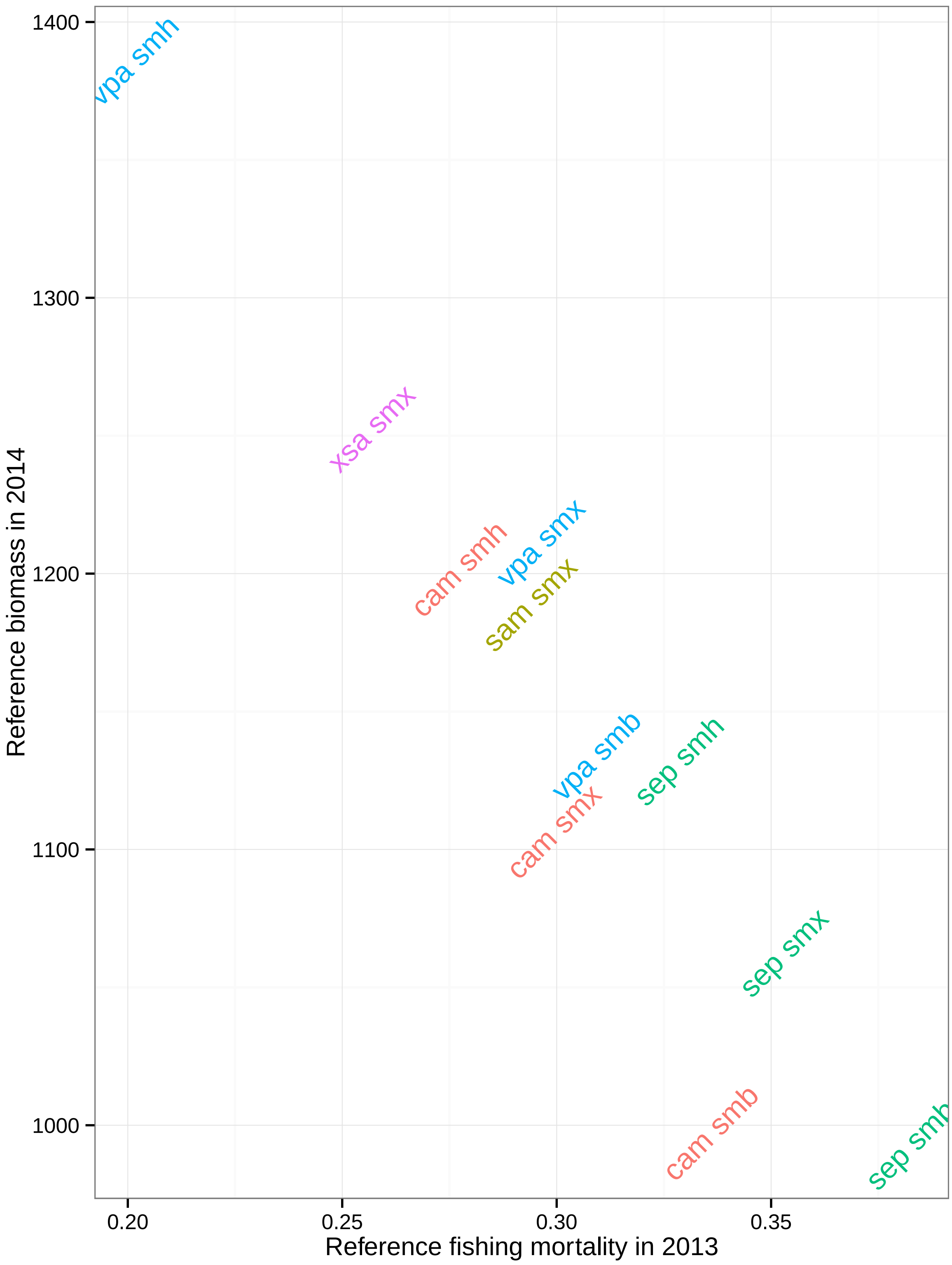

Figure 19: Icelandic cod in division Va. Fishing mortality in 2013 vs. the reference biomass estimates in 2014. The tunings are spring survey only (smb), fall survey only (smh) and both surveys (smx). The models are: adcam (cam), separable (sep), adapt (vpa), xsa and sam.

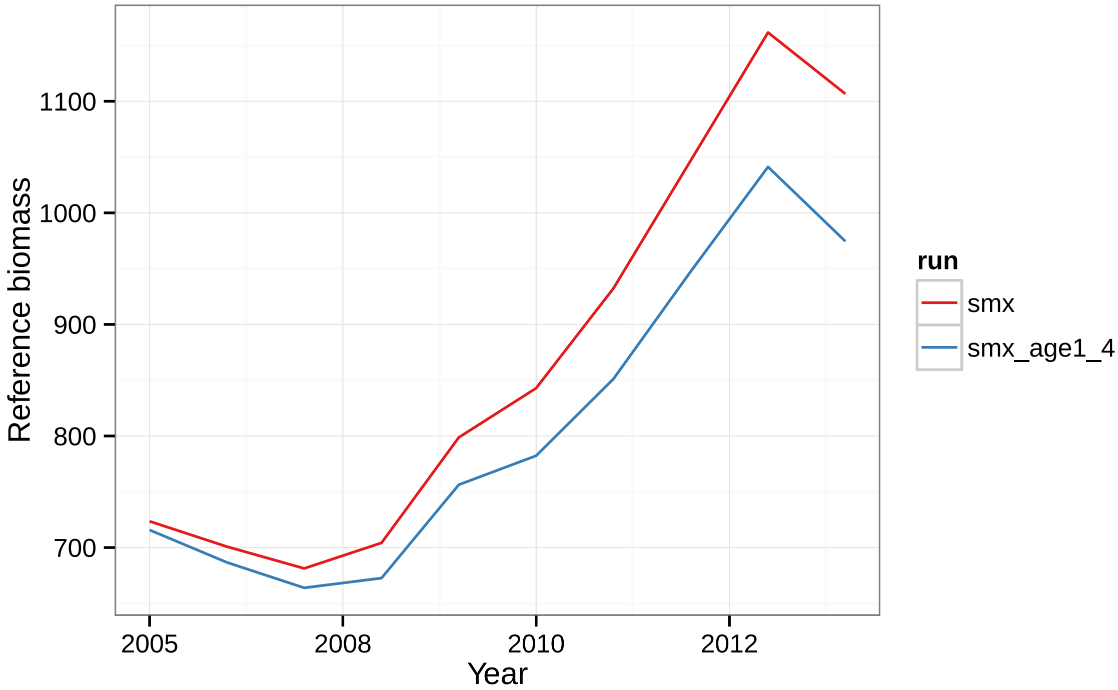

Figure 20: Icelandic cod in division Va. Comparison of biomass trajectory of the base run (adcam using both survyes - smx, age groups 1-10) and one were only age groups 1-4 are included in the tuning (smx_age1_4).

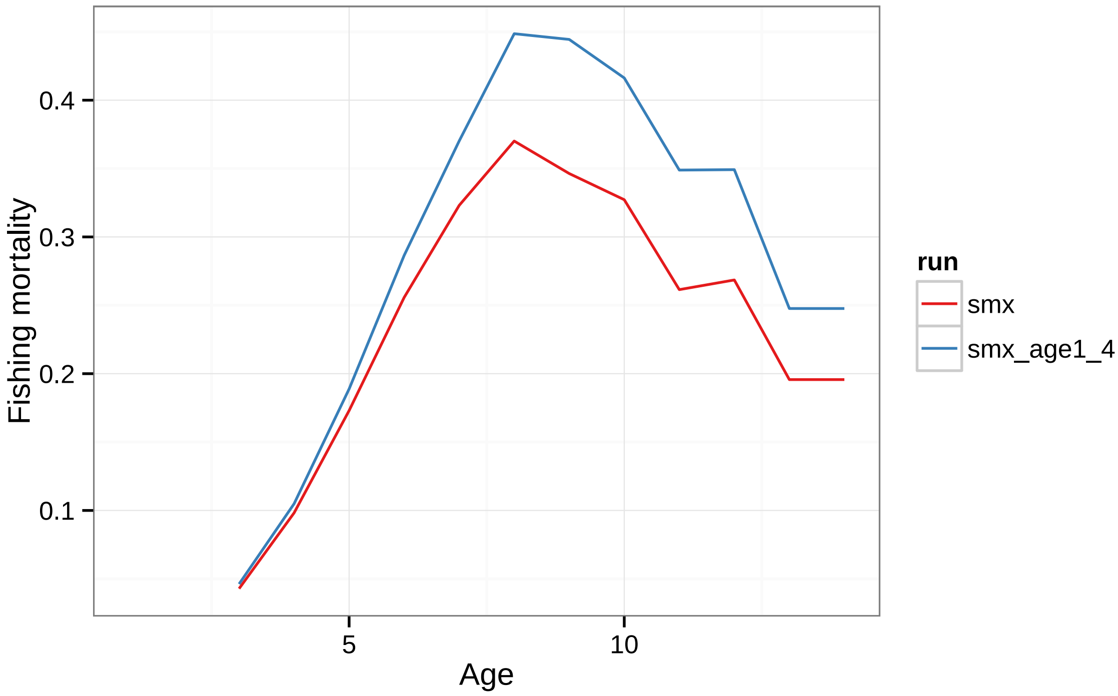

Figure 21: Icelandic cod in division Va. Fishing mortality in 2013 vs. the reference biomass estimates in 2014. The tunings are spring survey only (smb), fall survey only (smh) and both surveys (smx). The models are: adcam (cam), separable (sep), adapt (vpa), xsa and sam.

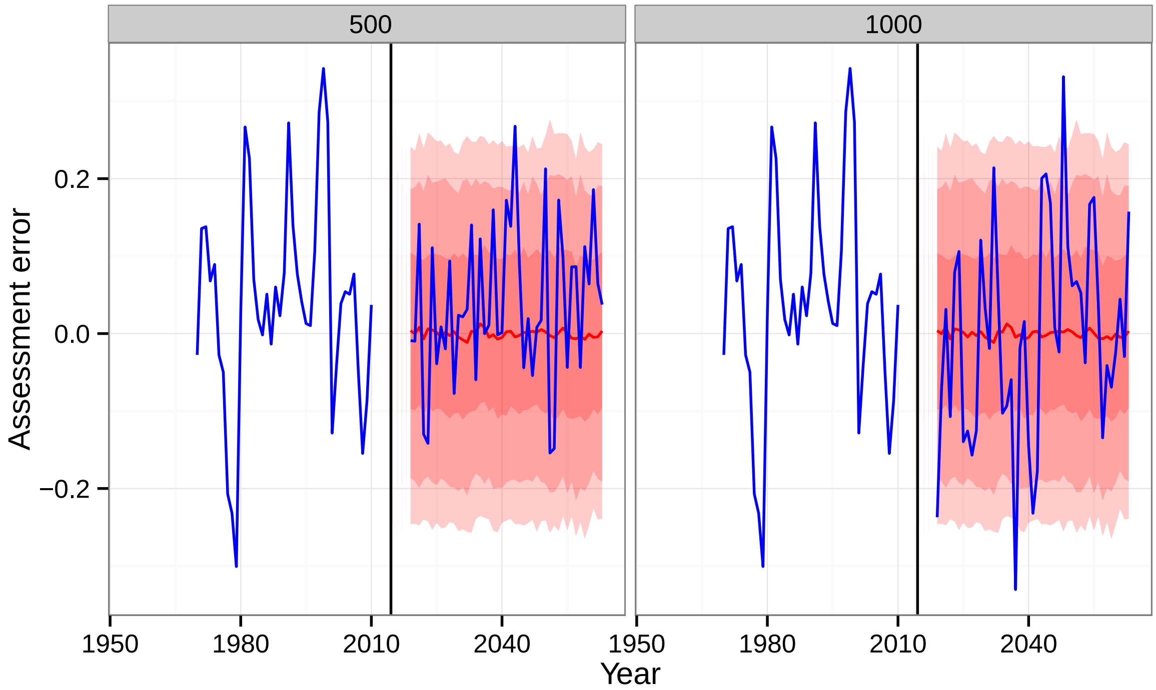

Figure 22: Icelandic cod in division Va. Historical and future assessment errors. The shaded are refer to the 90% probability distribution and the two panels show two iterations.

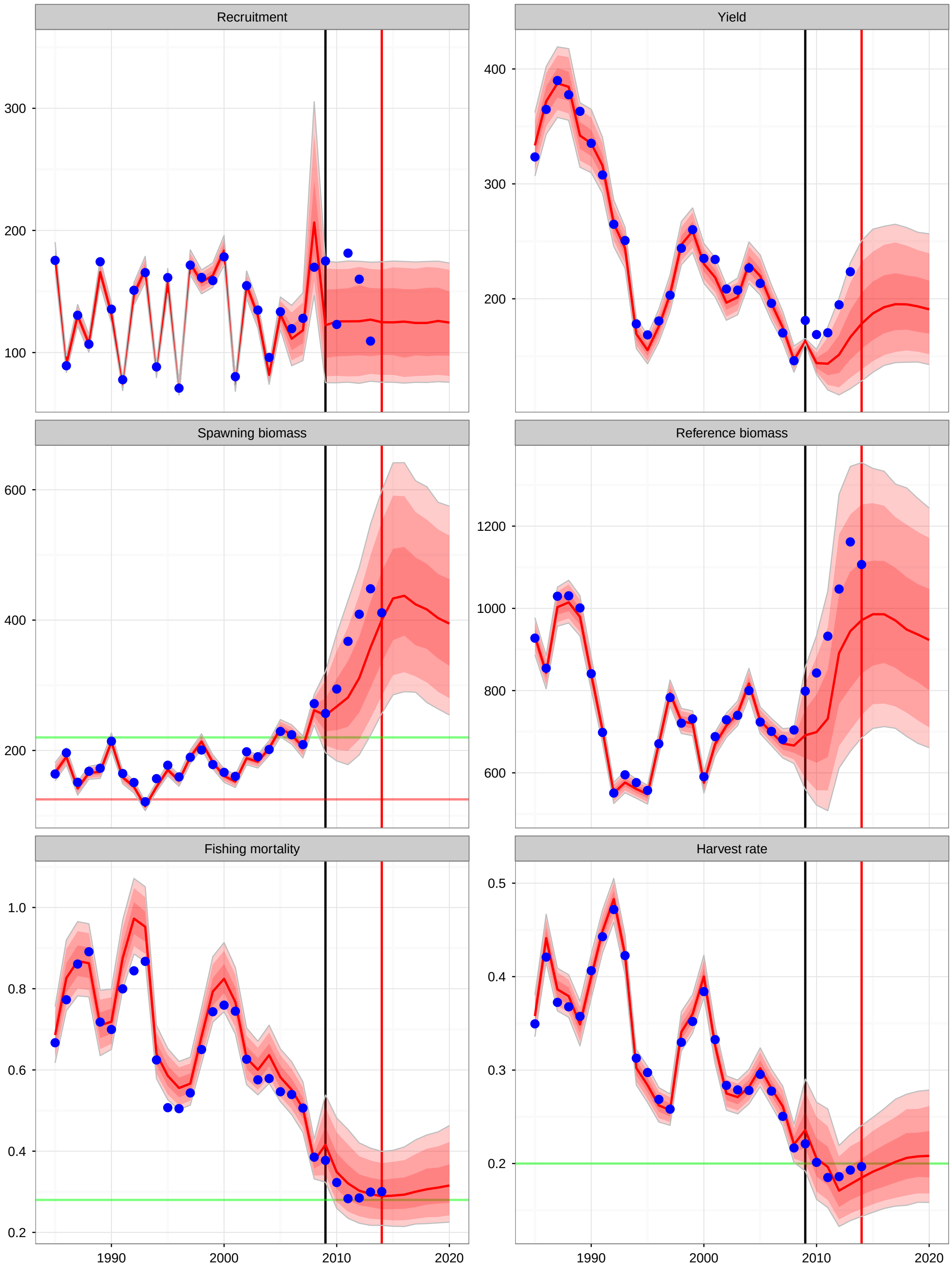

Figure 23: Comparison of the expected stock dynamics done in 2009 if the 20% harvest control rule would be followed (red colours, outer ribbons show the upper and lower 5%) and the dynamics as estimated in the 2014 assessment (blue colours).

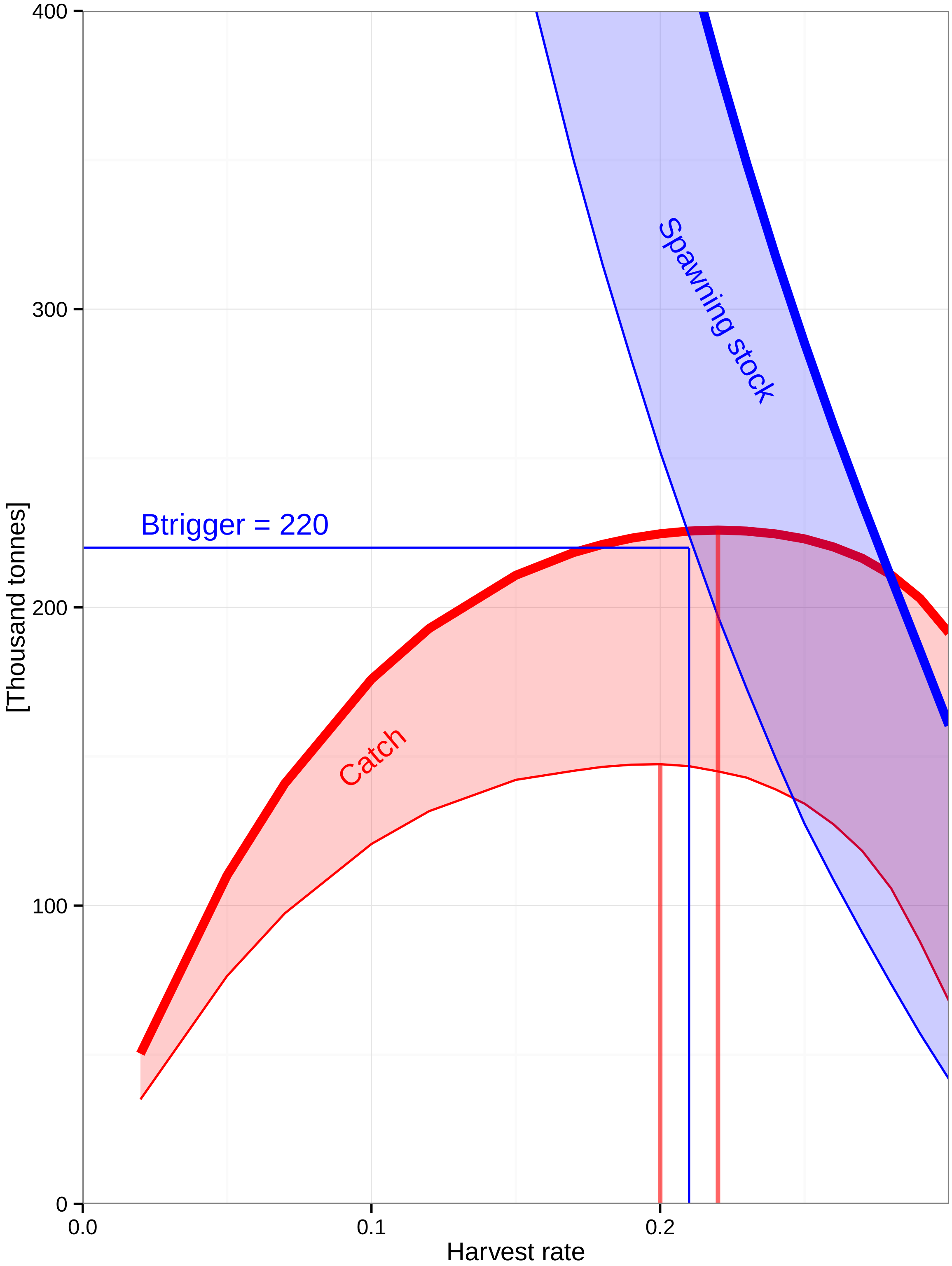

Figure 24: Icelandic cod in Va - HCR evaluations. Catch (red colours) and spawning stock biomass (blue colours) at equilibrium as a function of harvest rate. The thick lines refer to the mean and the thin lines to the lower 5th quantile.

7 Appendix A: Calculation of catch at age

- See old stock annex

8 Appendix B: Survey indices

- See old stock annex

9 Appendix C: Modelling frameworks

The Marine Research Institute's three main gadoid stocks have been assessesed based on ADMB modules that were designed and written by Höskuldur Björnsson. Three modules have been in use:

- **Adcam**: A forward running statistical catch at age model where fishing mortality at age is allowed to change gradually in time. The fishing mortality is allowed to deviate from separability using a random walk penalty in the objective function. This module has been used as the basis for the calculation of the annual TAC according to the HCR since 2002. Resembles the method called "correlated random walk" in SAM, but the correlation matrix has different structure and not as many variances can be estimated as the Adcam model is not ar real statespace model, rather what has been Referred to as Error in Variables approach.

- **Separ**: A statistical catch at age model were selection pattern are fixed over any given period. This module has been used in the HCR evaluations of the Icelandic cod (2009) and haddock and saithe (2013).

- **adapt**: A tuned VPA type of model, were no error is assumed in the catch-at-age.

All the models are stock assessment models with possibilities for short and long term predictions according to a number of HCR. Some of the predictions are adapted to the Icelandic fishing year and the HCR used for Icelandic stocks. The Separable model and the Adapt model use the same input files and 90% of the code is the same.

9.1 Historical assessment

This part includes both equations describing the evolution of the stock and fisheries and function to do the estimation.

9.1.1 Evolution of the stock and fisheries

$$\hat{N}_{1,y} = f\left(SSB_{y-1}\right) \tag{5}$$

$$N_{1,y} = \hat{N}_{1,y} e^{\xi_y} \tag{6}$$

$$N_{a+1,y+1} = N_{a,y} e^{-(F_{a,y}+M_{a,y})} + \Delta a, y \tag{7}$$

Where $\Delta a, y$ are estimated migrations of specified agegroups in specified years For Icelandic cod these are imports from Greenland.

For the VPA model the stock is projected backwards

$$N_{a,y} = (N_{a+1,y+1} \Delta_{a,y} e^{0.5M_{a,y}} + C_{a,y}) e^{0.5M_{a,y}} \tag{8}$$

The migration $\Delta a, y$ are here multipliers limited to the range 0-1, assuming that the migration is in the beginning of the year.

The VPA model can only estimate migrations in periods where survey indices are available but the catch at age models can use anomalies in catch at age for estimation of migrations.

If the oldest agegroup A is a plus group its then numbers develop according to.

$$N_{A,y+1} = N_{A-1,y} e^{-(F_{A-1,y}+M_{A-1,y})} + N_{A,y-1} e^{-(F_{A,y-1}+M_{A,y-1})} \tag{9}$$

For Icelandic cod the oldest ageproup A is not a plus group so the equation changes to

$$N_{A,y+1} = N_{A-1,y} e^{-(F_{A-1,y}+M_{A-1,y})} \tag{10}$$

The Adapt model is not designed for plus group.

Natural mortality was assumed fixed at the value of 0.2 The values used for precruits that are not in the fisheries, age 1-2 for cod do of course not matter and the value 0.0 would be the best choice, helping to relate number of prerecruits to the number of those entering the catches (age 3 for cod).

Catches removed from the stocks are estimated from stock number by Baranov's equation.

$$\hat{C}_{a,y} = \frac{F_{a,y}}{Z_{a,y}}(1 - e^{-Z_{a,y}})N_{a,y} \tag{11}$$

In the separable model the fishery is simulated as a single fleet modeled as a non-parametric separable model:

$$F_{a,y} = F_y S_a \tag{12}$$

More than one separable period can be specified.

In the random walk model all the fishing mortalities $F_{a,y}$ are estimated and the random walk implemented through constraint in the likelihood function (see notes on likelihood function below). The estimation is done in two phases, first a separable model is estimated and later deviations from the separable model.

More than one stock-recruitment function is implemented in the model. Recruitment is not generated directly from the selected stock-recruitment model except in predictions. They do enter the assessment as residuals from stock - recruitment functions are used in the likelihood function to estimate the parameters. For stocks with good data the effects of the stock-recruitment function on historical assessment is small, but in predictions the stock - recruitment function is important although the parameters are often poorly estimated.

The functions allowed in the model are.

Hockey stick:

$$R_y = min\left\{R_{max}, R_{max}\frac{SSB_{y-1}}{SSB_{break}}\right\} \tag{13}$$

Ricker model:

$$R_y = R_{max}e^1\frac{SSB_{y-1}}{SSB_{max}}e^{\frac{-SSB_{y-1}}{SSB_{max}}} \tag{14}$$

and Beverton-Holt model:

$$R_y = R_{max}\frac{SSB_{y-1}}{SSB_{y-1} + SSB_{50}} \tag{15}$$

Constant recruitment

$$R_y = R_{max} \tag{16}$$

As seen from the equations R_y refers to recruitment at age 1 that is the first agegroup used in the cod assessment. The model can use other age groups as first age.

R_{max} is always estimated and also the second parameter called SSB_{break}, SSB_{max} or SSB_{50}, depending on the function specified.

R_{max} is set so that it can change in 1985 by a value that can be estimated. The reason for this setup is the 30-40% reduction in recruitment of Icelandic cod around before and after 1985. This option can be turned off by specifying the change to be zero.

In the evaluations of Harvest Control Rule for Icelandic cod in 2009 a number of other SSB-Recruitment functions were investigated, some of which are found in the code. Emphasis has also been put on statistical properties of the residuals from the SSB-recruitment function as described below.

9.1.2 Likelihood function

In the random walk model the error in catch in numbers is split in two parts.

- Process error i.e the error between this years and last years fishing mortality.
- The measurement error i.e the difference between observed and modelled catches.

The model can not estimate standard deviation of the total error (process + measurement error) indepently for each agegroup. The pattern standard deviation of the total error with is specified and a multiplier estimated. The pattern is obtained from a Shephard Nicholson model. Estimating a smooth function of age described with 2 - 3 parameters is also a possibility but the estimation is sometimes unstable.

The split of the total error into process error and measurement error is specified in the input file. The number given specify the proportion of the variannce for each age group assigned as process error. The split is 50-50 of for ages 6-8 which are the ages with the least total error. For older fish higher proportion is allocated to measurment error and for younger age groups higher proportion is allocated to process error.

Difference in $log(F)$ between adjacent years follows multivariate normal distribution with correlation between ages.

$$\mathbf{\Gamma}_{a_1,a_2} = \sigma_{p,a_1}\tau^{|\frac{(a_1-2)^{0.3}-(a_2-2)^{0.3}}{2^{0.3}-1^{0.3}}|}\sigma_{p,a_2} \tag{17}$$

$\mathbf{\Gamma}_{a_1,a_2} = 1$ when $a_1 = a_2$

Where σ_{p,a_1} is standard deviation of the process error of age a_1. tau is an estimated parameter in the model called process correlation there. Equation 17 leads to more correlation between adjacent old agegroups than adacent young agegroups i.e the relative differenc in age matters.

Measurement error in catch at age

The error in the catch at age is assumed to be lognormal and hence the likelihood is calculated as:

$$L_C = \sum_y \sum_a \left\{ \frac{\left(log\left[C_{a,y} + \epsilon_C\right] - log\left[\hat{C}_{a,y} + \epsilon_C\right]\right)^2}{2\sigma^2_{aC}} + log\left(\sigma_{aC}\right) \right\} \tag{18}$$

where ϵ_C is to reduce the effect of very small catches that are poorly sampled. Typical value of ϵ_c would be catches corresponding to 2-4 sampled otholiths. The standard deviations σ_{aC} are estimated as a multiplier on prespecified pattern. The pattern was generated from a Shephard - Nicholson model run based on the data from 1980-2008.

In the random walk model, σ_{aC} is generated from the total standard deviation and the split of the total variance between process and measurement error as described above.

Total landings

As described above catch in numbers at age is one component in the objective function to be minimized. This does in many cases guarantee that the modelled catch in tonnes is close to the landed catch but in some years this is not the case. In all cases one has:

$$Y_y = \sum_a C_{a,y} cW_{a,y} \tag{19}$$

$$\hat{Y}_y = \sum_a \hat{C}_{a,y} cW_{a,y} \tag{20}$$

To let the model follow the “real” landed catch the following term is added to the objective function.

$$L_Y = \sum_y \left[\frac{\left(logY_y - log\hat{Y}_y\right)^2}{2\sigma^2_Y} + log\sigma_Y \right] \tag{21}$$

where σ_Y is input from a file and is typically rather low (≈ 0.05). The statistical properties of this term as an addition to catch at age are somewhat questionable, but this formulation has often been used in statistical catch at age models.

Survey at age

The predicted survey index $\hat{I}_{ay}$ is calculated from:

$$\hat{I}_{a,y} = q_a N^{\beta_a}_{a,y} \tag{22}$$

where α_a and β_a are estimated parameters. For cod the β_a is set equal to 1 for age 6 and older. The error in the survey at age is assumed to be lognormal and hence the likelihood is calculated as:

$$L_I = \sum_y \sum_a \left\{ \frac{\left(log\left[I_{a,y}+\epsilon_I\right] - log\left[\hat{I}_{a,y}+\epsilon_I\right]\right)^2}{2\sigma_{aI}^2} + log\left(\sigma_{aI}\right) \right\} \tag{23}$$

where ϵ_I is externally set to reduce the effect of very small survey indices based on few otoliths . Typical value of ϵ_I would be indices that correspond to 2-4 sampled otholiths. The standard deviations σ_{aI} are estimated by the model by giving the pattern, estimating an multiplier. The pattern is estimated in the Adapt type model, the only type of model that can estimate σ_{aI} independently for each agegroup.

Since correlation between indices of different age groups is modelled the equation is changes to:

$$\mathbf{\Gamma} = log\left[I_{a,y}+\epsilon_I\right] - log\left[\hat{I}_{a,y}+\epsilon_I\right] \tag{24}$$

$$L_I = \sum_y \left\{0.5 log\left(det\Theta_I\right) + \mathbf{\Gamma}^T \Theta_I^{-1} \Gamma\right\} \tag{25}$$

Where Γ is the vector of residuals and Θ the correlation matrix.

In the model runs conducted here the matrix $\mathbf{\Theta_I}$ is generated by a 1st order AR model.

$$\Theta_{Iij} = \sigma_{Ii}\sigma_{Ij}\kappa^{|i-j|} \tag{26}$$

where κ is an estimated parameter which has been estimated in the range 0.2 to 0.7 for cod, haddock and saithe in the March groundfish survey. High value of κ indicates that the residuals in the survey approach a year factor. The estimate of the parameter for cod is 0.42 for the March survey and 0.53 for the autumn survey. The effect of modelling this correlation on estimated biomass varies from year to year but the effect is to take less notice of survey abundance indices.

In the random walk model the equation for Θ_I is similar to what is used to model the correlation in process error (equation 17).

$$\Theta_{Iij} = \sigma_{Ii}\sigma_{Ij}\kappa^{\left|\frac{i^{0.7}-j^{0.7}}{2^{0.7}-1^{0.7}}\right|} \tag{27}$$

Compared to equation 26 this equation increases the correlation between agegroups of old fish compared to young fish, i.e it is more the relative difference in age that matters.

Stock - recruitment likelihood function.

This component involves discrepancy between observed and modelled recruitment. The model allows for autocorrelation in residuals and CV of residuals can be a function of spawning stock size. The likelihood is calculated by the equations.

$$\hat{N}_{1,y} = f\left(SSB_{y-1}\right) \tag{28}$$

$$\mathbf{\Gamma_{SSB-R}} = log\left[N_{1,y}\right] - log\left[\hat{N}_{1,y}\right] \tag{29}$$

$$\sigma_{3y} = \sigma_3 \left(\frac{SSB_y}{SSB_{ref}}\right)^{\beta_3} \tag{30}$$

$$\Theta_{SSB-Rij} = \sigma_{3i}\sigma_{3j}\kappa_3^{|i-j|} \tag{31}$$

$$L_{SSB-R} = \sum_y \left\{0.5 log\left(det\Theta_{SSB-R}\right) + \mathbf{\Gamma^T_{SSB-R}} \Theta^{-1}_{SSB-R} \Gamma_{SSB-R}\right\} \tag{32}$$

σ_3 standard deviation of the residuals, κ_3 autocorrelation and β_3 dependence on SSB, usually not inclded.

The parameters σ_3, κ_3 and β_3 are all among pameters that can be estimated. Estimating them all in addition to the 3 parameters of the SSB-rec function requires a very long time series. The SSB-rec function has 3 parameters due to the change in R_{max} observed in 1985. In the work here 3 - 4 parameters are estimated, 2-3 parameters of the SSB-rec function and the parameter σ_3. The parameters κ_3 and β_3 were set to low values in the estimation part but a fixed value of the autocorrelation parameter , estimated external to the model is used in stochastic simulations. Anyone trying to estimate parameters of a simple AR model from 50 years of data discovers that the estimate is very poor except the autocorrelation is small.

The choice of stock recruitment function has minor effets on the results of stock assessment but is of course of importance in future simulations.

Estimated parameters

Estimated parameters in the random walk assessment model are

- Initial numbers in stock.
- Recruitment at age 1 each year
- Parameters of the stock - recruitment function.
- Fishing mortality each year and age.
- q_a and β_a for the surveys. (equation 22)
- σ_c, σ_I and σ_3, i.e multiplier on standard deviation of catch residuals, multiplier on standard deviation of survey residuals and multiplier on SSB-recruitment residuals.
- Correlation parameters κ in the survey likelihood and τ in the process error.

Estimated parameters in the separable model are

- Initial numbers in stock.
- Recruitment at age 1 each year
- Parameters of the stock - recruitment function.
- Effort for each year.
- Selection pattern for each age and selection period.
- q_a and β_a for the surveys. (equation 22)
- σ_c, σ_I and σ_3, i.e multiplier on standard deviation of catch residuals, multiplier on standard deviation of survey residuals and multiplier on SSB-recruitment residuals.
- Correlation parameters κ in the survey likelihood.

In the Adapt type model the estmated parameters are

- Number in stock in the assessment year
- Parameters of the stock - recruitment function.
- q_a and β_a for the surveys. (equation 22)
- σ_I and σ_3, i.e multiplier on standard deviation of catch residuals, multiplier on standard deviation of survey residuals and multiplier on SSB-recruitment residuals.
- Correlation parameters κ in the survey likelihood.

As described in the beginning the inverse Hessian matrix of the parameter estimates is used as a proposal distribution in MCMC runs. The number of runs was usually 1.0 million with the parameter set from every 500th run saved. Probability distribution of spawning stock, reference biomass and other parameters is obtained by printing the respective values to a file in each of the stochastic simulations.

The exact settings of the historical assessment model do affect the estimate of stock in the assessment year ($\pm 20\%$) but have less effect on the results of the longterm simulation where the stock-recruitment parameters have most effect. If the simulation were run in a closed loop with assessment model in the feedback loop those settings would have more effect, but to used it to infer about "correct" model settings would require a realistic observation model.

9.2 Short term deteministic prediction

Short term prediction for Icelandic cod is rather simple as the TAC next fishing year does depend on TAC in the current fishing year and biomass 4+ and SSB in the the assessment year. Maturity at age, mean weight at age and mean weight at age in the SSB in the assessment year are all available at the time of assessment, the only missing values for the TAC are mean weight at age in the catches that are obained from equations 2 and 3

The prediction occurrs in few steps.

1. Calculate mean weight and maturity at age from the March survey in the assessment year.
2. Estimate true reference biomass and spawning stock.
3. Calculate recruitment from SSB-Recruitment relationship
4. Calculate the TAC for next fishing year from equation **??**
5. Calculate catch in the assessment year $C_y = \frac{2}{3}TAC_{y-1/y} + \frac{1}{3}TAC_{y/y+1}$
6. Calculate selection at age, base on the average of last 5 year.
7. Calculate F_y for the assessment year by iterating the equations $F_{a,y} = F_y S_{a,y}$ and $\hat{C}_y = \sum_a \frac{F_{a,y}}{Z_{a,y}}(1 - e^{Z_{a,y}})N_{a,y}cW_{a,y}$ The two equations are solved for F_y by Newtons method until $C_y - \hat{C}_y = 0$.
8. Project the stock forward one year.

If projection for more than one year is to be done the steps are repeated. What is then required are catch weight, ssb weights and maturity at age for those years. The default is to use the values for the assessment year.

Mean weight at age, maturity at age, recruitment, selection at age and maturity at age can be multiplied with stochastic noise as in.

Stock production model on East Greenland offshore cod

R. Hedeholm and A. Retzel

1 Introduction

This document briefly describes and reports results from a stock production model implemented in ASPIC. The data used are from the South and East Greenland offshore cod as defined in WD01. This produces a simple yet useful input on this stock, and provides novel estimates of F_{msy} and B_{msy} and an estimate of recent stock trend.

2 Data

The input data are the German survey from 1982-2014 using the B4+ biomass index (see justification in WD02), landings from 1982-2014 and CPUE from 1982-2014 (Fig. 1). The CPUE time series is standardized by year, management area and vessel. CPUE data are missing from 1986 and 1987. All data covers ICES XIVb+NAFO 1F.

The CPUE time series is dependent on very few data points between 1994 and 2002 due to very low landings.

3 Model

The model is a Stock Production model implemented in the ASPIC framework provided by the NOAA fisheries toolbox. Here the logistic production model (Schaefer) is fitted but the generalized Pella-Tomlinson is also an option (including the Fox model as a special case) but this was not explored. For more details on the model setup see the reference manual (Prager, 2014).

Initial guesses of B1/K, msy and K (including constraints on msy and K) were used a first run. Following this fit, initial guesses were adjusted to allow for a bootstrap procedure (200 iterations) that in turn provides approximate confidence intervals on model parameters as well as point estimates of reference points.

Initial guesses and boundaries were:

B1/K=0.2

msy=40,0000 [10,000-150,000]

K=500,000 [80,000-2,000,000]

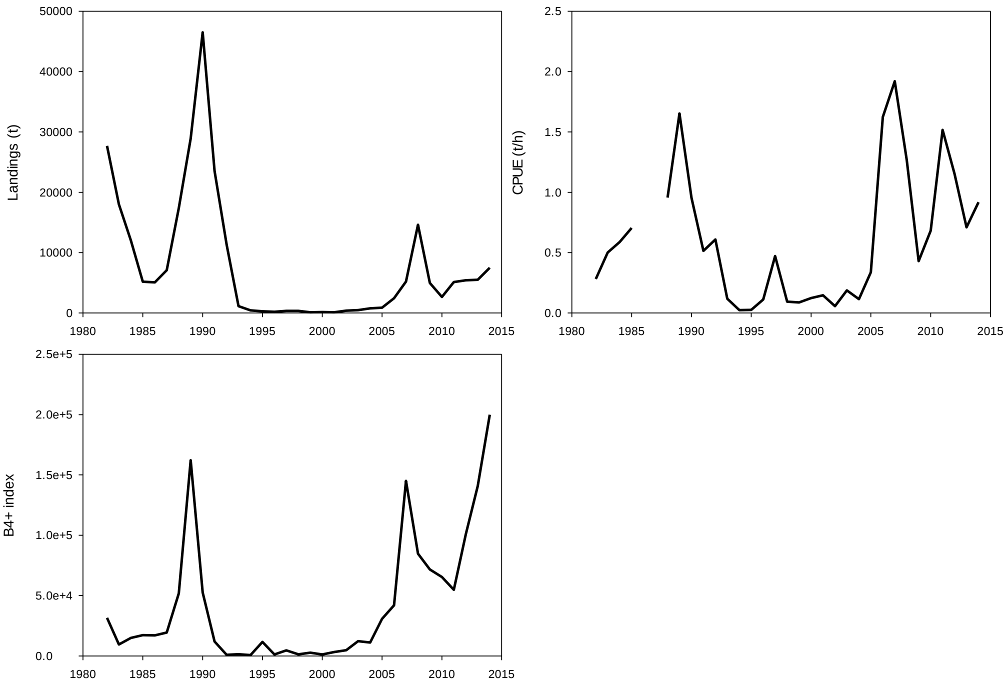

Figure 1: Input data to the Stock Production model.

3.1 Model fit

Generally, the CPUE data were quite noisy, but the model fitted the overall trend well (Fig. 2, left). As a result, the residuals were relatively large, but with no distinct pattern (Fig. 2, right). The period from 1994-2002 had catches below 1,000t. Consequently, the CPUE varies considerably in this period and catches are primarily by-catch in the redfish fishery where by-catch of cod is a common problem in especially East Greenland. In other periods, the CPUE reflects the presence of single year classes; namely the 1984 YC and the 2003 YC both of which produced short lived increases in CPUE.

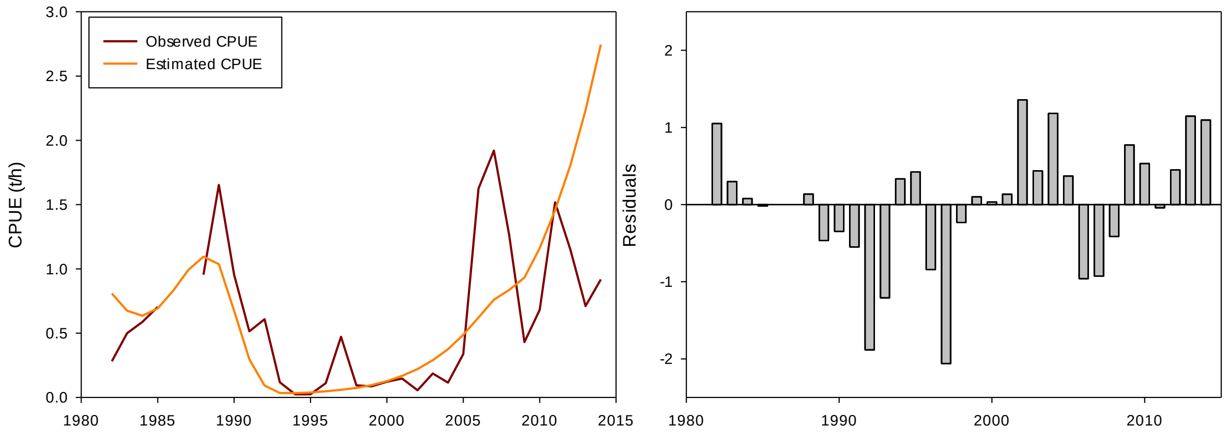

Figure 2: Left: observed and estimated CPUE values. Right: residuals

Similarly, the survey is highly influence by single large YC that produce relatively large residuals, but the model fits the overall trend (Fig. 3). Both the 1984 and 2003 YC's were fished relatively intensely, and associated estimated F values are the highest seen in the time series (Fig. 4)

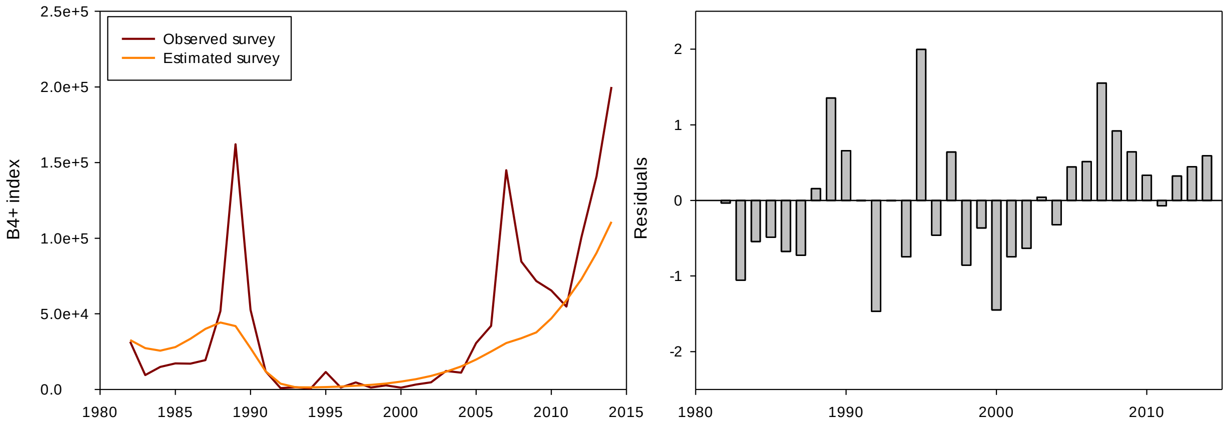

Figure 3: Left: observed and estimated survey values. Right: residuals

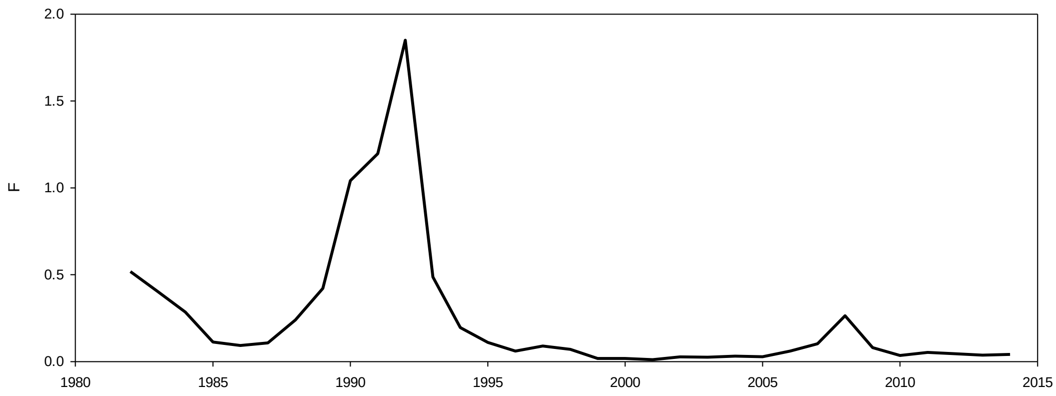

Figure 4: Total F estimate. The 1984 YC was fished intensely around 1990-1992 and the 2003 YC was fished in 2007-2008.

3.2 Key output and discussion

Key output following the bootstrapping procedure can be seen in table 1.

Table 1: Estimates from the stock production model following bootstrap procedure.

Parameter	Estimate
F_{msy}	0.15
B_{msy}	459,500 t
MSY	68,550 t
F_{2014}/F_{msy}	0.28
B_{2014}/B_{msy}	0.44
K	919,000
B1/K	0.06

Given the large fishery from 1930-1970 the low estimates of B1/K is considered realistic. Fmsy is estimated low, but it is consistent with Hovgård and Wieland (2008) who estimated an equilibrium F of 0.14 for the offshore region (East+West). The development In B and F compared to msy-values indicates that the fishing mortality has been below F_{msy} since 1995 except in 2008, which is consistent with a rather large fishery on the 2003 YC. In the same period, the stock has been slowly increasing and is currently at the highest level observed in the time series (B/B_{msy}=0.44, Fig. 6).

The highest catches ever observed in the east Greenland area are approximately 60,000 t. This level was not maintained over a longer period, and the MSY estimated of 68,550 t seems high. A run using the entire catch time series should be preformed to evaluate the validity of the msy estimate.

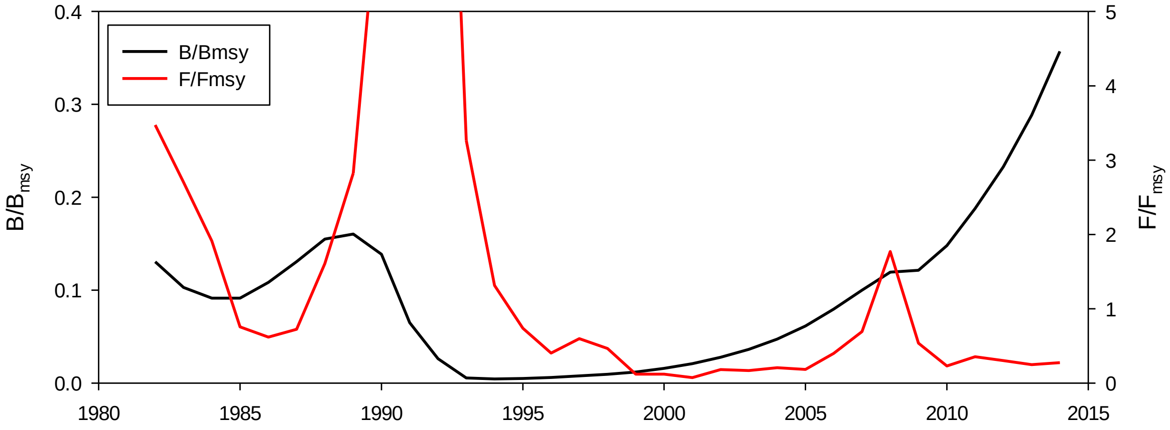

Figure 5: Development in F/F_{msy} and B/B_{msy}.

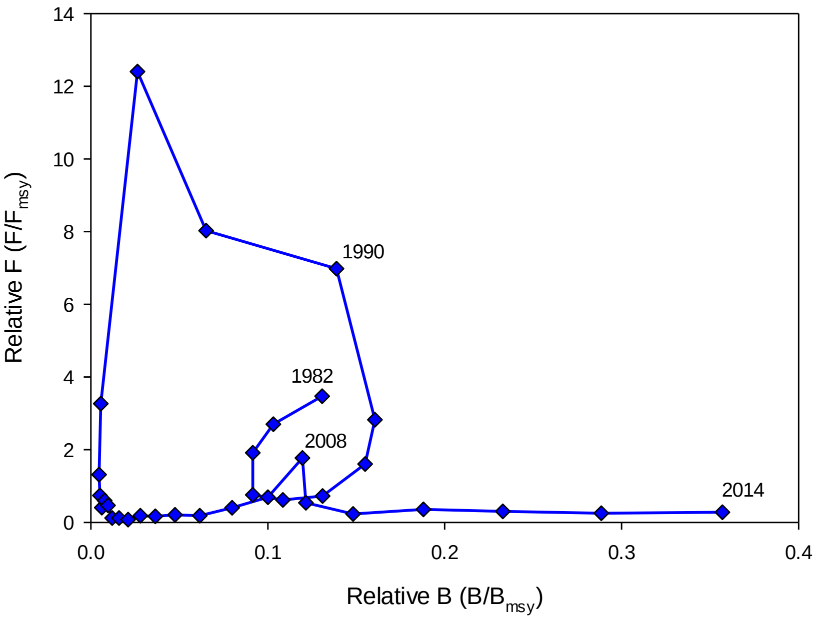

Figure 6: Stock development from 1982-2014.

Based on the bootstrap procedure, probability distributions are available for Fmsy and Bmsy. The Fmsy distribution has a single mode whereas the Bmsy distribution is bimodal, with the peaks being at 94,000 t and 460,000 t, respectively (Fig. 7).

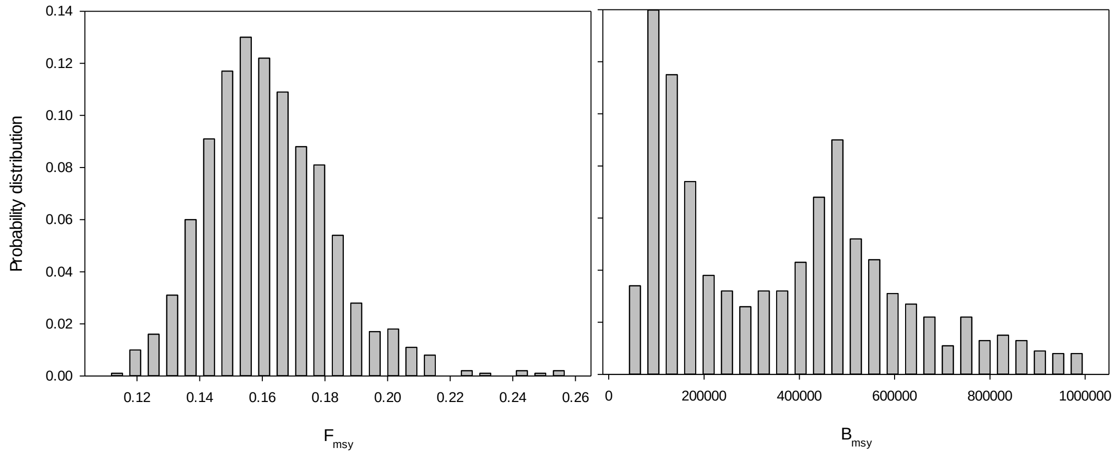

Figure 7: Probability distributions for the F_{msy} and B_{msy} estimates

The analysis presented here are only preliminary. Further explorations should be done, as should retrospectives and sensitivity analyses. In addition to the run presented here, using data from 1973-2014 was also explored. No survey data is available before 1982. We were not successful in finding a fit that produced useable results. The model continuously hit parameter boundaries and for instance MSY was estimated at 150,000 t which is highly improbable.

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Prager M.H. 2014. User's Guide for ASPIC Suite, version 7: A Stock–Production Model Incorporating Covariates and auxiliary programs. http://www.mhprager.com/aspic7-guide.pdf

Hovgård H. and Wieland K. 2008. Fishery and Environmental Aspects Relevant for the Emergence and Decline of Atlantic cod (*Gadus morhua*) in West Greenland waters. Resilience of Gadid Stocks to Fishing and Climate Change. Alaska Sea Grant College Program. 89-110

Assessment of (East) Greenland cod
Working Document 19 for WKICE 2015

Höskuldur Björnsson

February 10, 2015

East Greenland cod was assessed by a separable model. The model is tuned with survey indices for age groups 1-10. The catch and survey data used are from NAFO-Division 1F and Ices area XIV. Pattern of the CV in survey and catches are given but a multiplier estimated. The pattern is obtained from a Shephard Nicholson model.

Immigration/Emmigration is estimated in 4 cases, 1 for the 1973 yearclass, 2 for the 1984 yearclass and 1 for the 2003 yearclass, i.e the immigration estimated in Icelandic assessment.

Summary of the results show that some discrepancy between observed and modelled survey biomass in recent years , with the measured survey biomass being more variable.

Observed and predicted catches are the same, as they are constrained to be so by CV of 0.1 on total catches. If not done strange deviations are seen in some years, that need to be investigated.

Harvest rate has been low in recent years according to the model while it was often very high before 2000. Migrations through the area that might be randomly be picked up by either the survey or catches make the data problematic and extremely high harvest ratios can be seen around 1990. Low harvest ratio in recent years is certain, the question is just how low.

Of the migrations estimated the export of the 2003 is 9 millions in the beginning of 2009. For the 1984 yearclass there is a little export one year and a little import one year, net result zero. For the 1973 yearclass the estimated export is 3.5 million fishes. For the 1973 and 1984 yearclasses the export is much less than the estimated immigration to Iceland from Icelandic assessment.

The estimated imports from those 3 yearclasses are according to Icelandic assessment.

- 1973 yearclass 12.7 million
- 1984 yearclass 33 million
- 2003 yearclass 9.6 million

Retrospective pattern (figure 2 indicates reasonable consistency but the time-series is though very short. (figure 2)

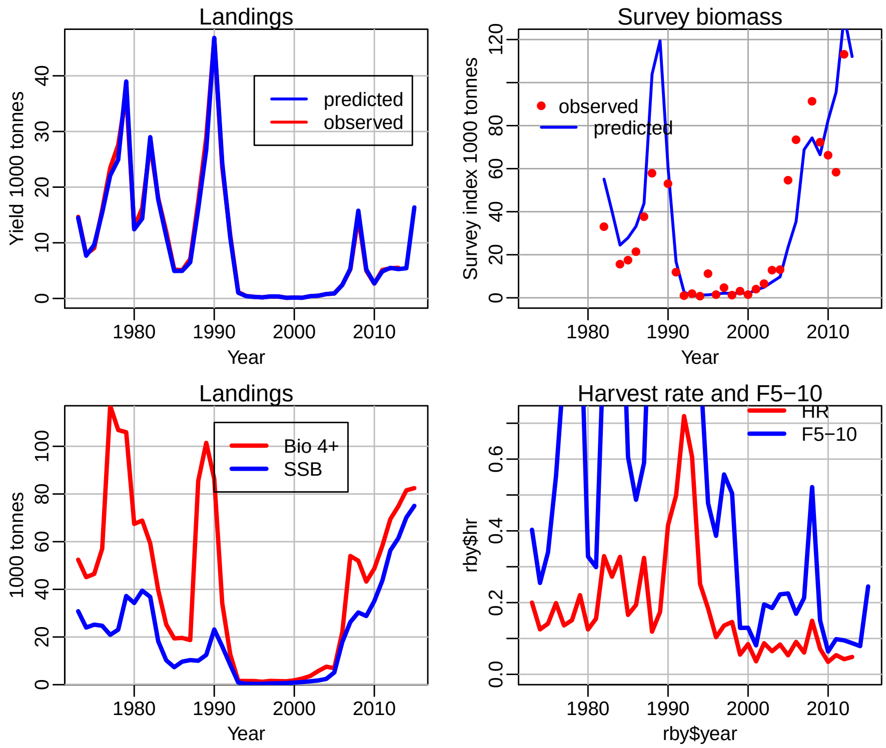

Figure 1: Summary of results from the assessment

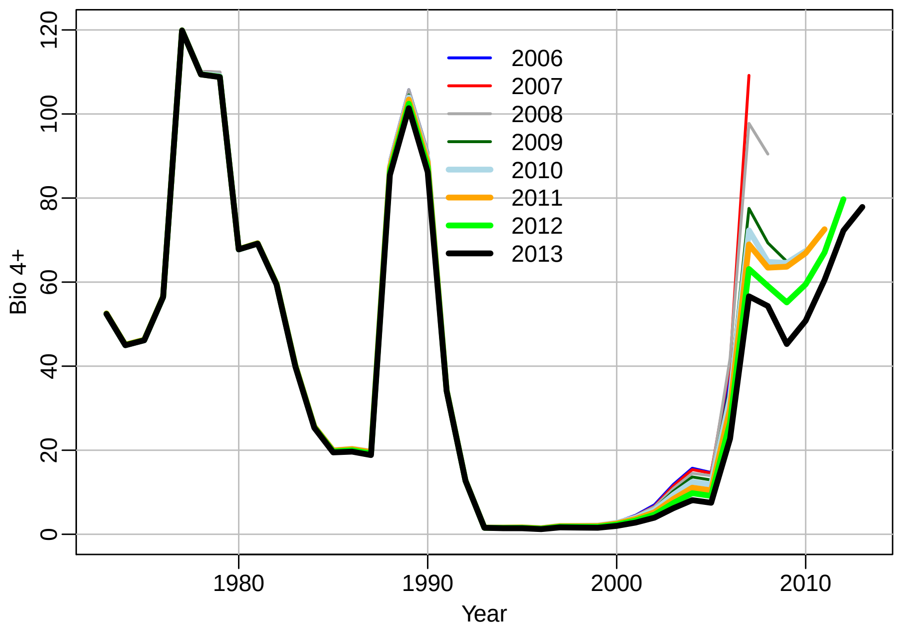

Figure 2: Retrospective from the assessment

Including the prediction with given catch demonstrates problems with the retro (figure 3) but it must be born in mind that one migration event is estimated and those kind of events are always uncertain.

Uncertainty in the estimation of the biomass is very high. The biomass in 2014 is estimate as 81.5 thous. tonnes with standard deviation of 21 thous. tonnes or 26% CV that is very high as these kind of models do usually underestimate CV.

The signal that we loose 40-50% of the 2003 yearclass between 2008 and 2009 is very clear in both surveys. That the size of the migration matches what is estimated as import from the Icelandic side could be an indication that the scaling is approximately correct.

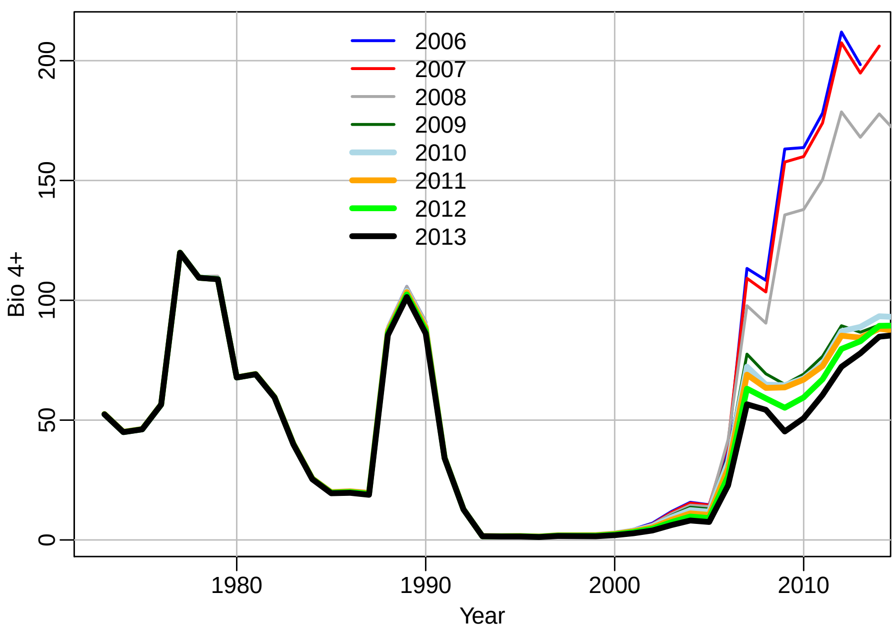

Figure 3: Retro from the assessment

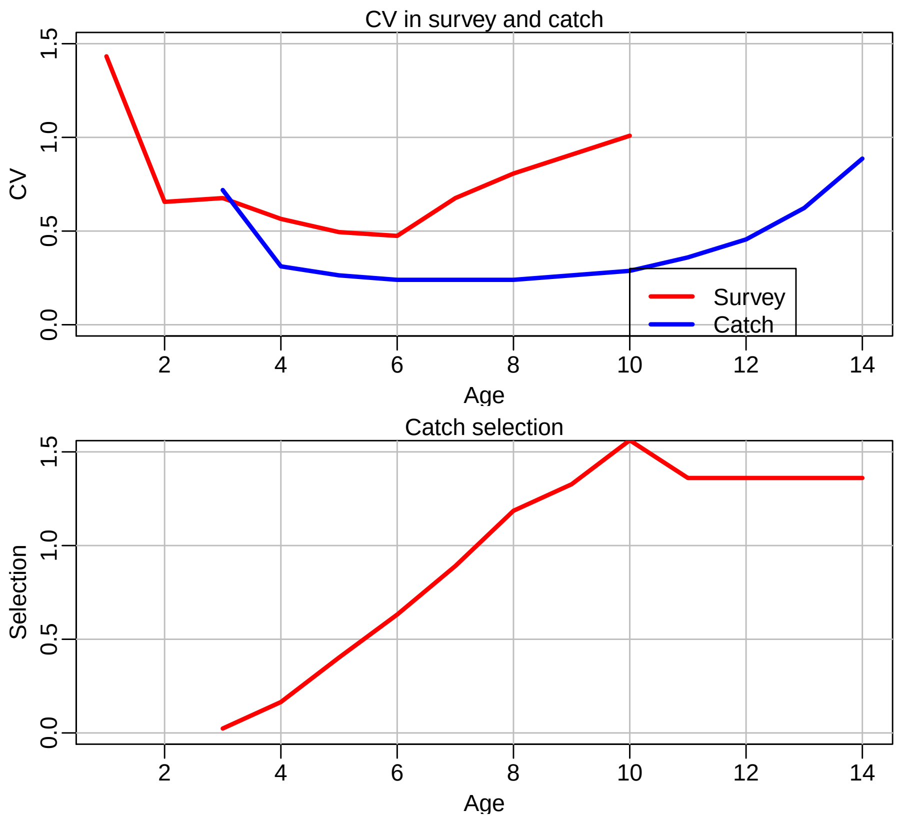

Figure 4: Estimated CV of survey and catches and selection of the fisheries. The pattern of the CV's with age is given but a multiplier estimated

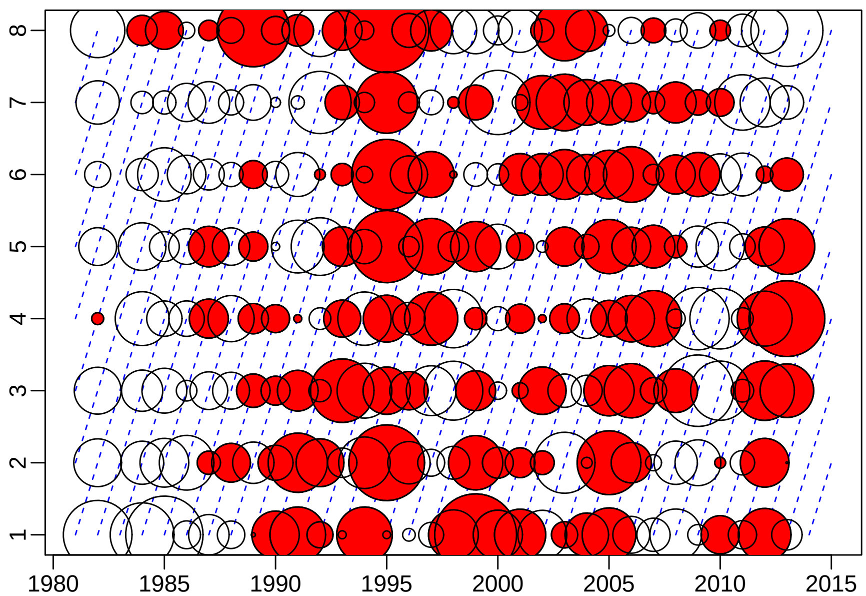

Figure 5: Residuals from the survey

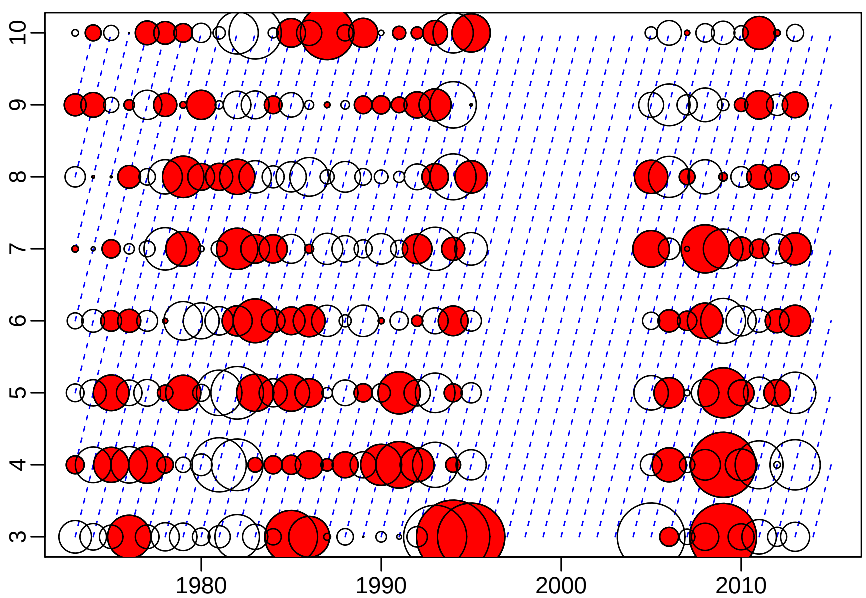

Figure 6: Residuals from the catch

Few alternatives that were tested are

1. Include the Greenland survey in tuning
2. Not including weight on tons landed in the likelihood function.
3. Not including weight on tons landed in the likelihood function and increasing weight on catch in numbers by a factor of 10.
4. Shortening the German survey series to 1995 onwards
5. Shortening the German survey series to 1995 onwards and including the Greenland survey

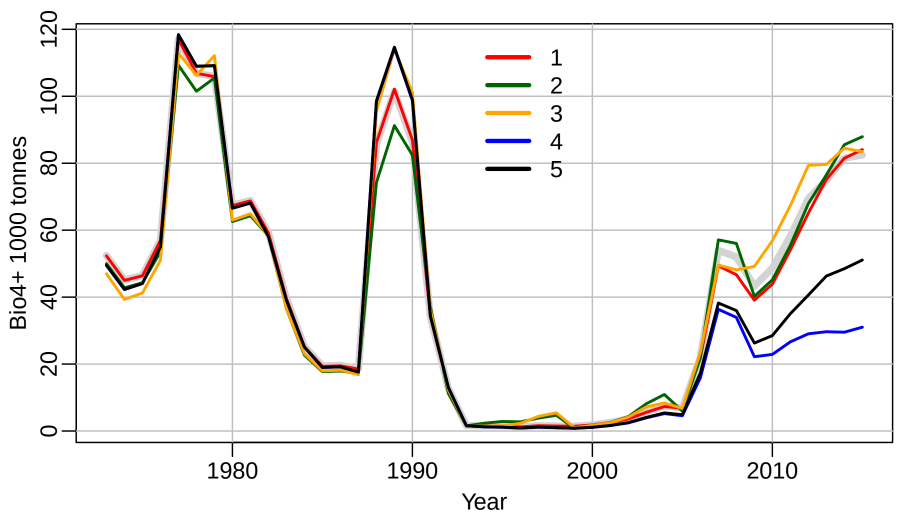

Figure 7: Bioass 4+ from differnet runs. The base run based on the German survey since 1982 is the wide grey line

All the alternatives except those shortening the German survey give similar results (figure 7). For those shortened survey series the catchability is poorly determined as the time series with any fish is short and fishing mortality low.

One factor that could help to pointing to the right stock size is comparing the estimated emigration to the Icelandic estimate of corresponding immigration. The ratio of the 2003 yearclass that disappaears between 2008 and 2009 is similar in both the surveys. The runs based on survey data since 1982 give estimates on par with the Icelandic estimates while those base on shorter time series give lower estimates.

1 Summary

- The scaling of the presented assessment could be OK, but the scaling is dependent on including data around around 1990 in the model.
- Consistency between survey and catch poor, and mean weight at age in German survey 1.5 years higher. Needs to be looked at.
- Reasonable correlation between Greenland and German survey in spite of different mean weight at age.
- Data north of NAFO division 1F should be included in the assessment. Does change the data before 1994 that the model requires to fix q in th survey.
- Structure within the east Greenland area needs to be investigated. Part of the catches are taken very close to the Icelandic borders but part in south Greenland.
- Emigration events can be identified from the surveys but the proportion emigrating has to be rather high to be able to see it in the data as the surveys are noisy.
- Combining the data from Greenland to the Icelandic data in the assessment would make the fit to the data worse. The surveys in Greenland are in autumn and if the fish migrates back and forth between Iceland and Greenland the Icelandic autumn survey should indicate smaller stock than the March survey, contrary to what is seen.
- Smaller migration events will only be detectable by tagging that should be started.