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Report of the Workshop on Assessment and Catch Advice for Deep Pelagic Redfish in the Irminger Sea (WKDEEPRED)

23–25 August 2016

ICES HQ, Copenhagen, Denmark

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CIEM Conseil International pour l'Exploration de la Mer

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Executive Summary

The Workshop on Assessment and Catch Advice for Deep Pelagic Redfish in the Irminger Sea (WKDEEPRED), chaired by Carmen Fernández, ICES, and Jesper Boje, Greenland, met in ICES Headquarters (Copenhagen) from 23–25 August 2016 to conduct appropriate analyses to serve as the basis for providing a response to the NEAFC's request to ICES "to review the approach that serves as basis for the catch advice for the deep pelagic redfish stock in the Irminger Sea to ensure conformity with ICES advisory rules". The workshop successfully addressed all its terms of reference: it agreed on a stock assessment method for this stock, calculated reference points and developed a Stock Annex. The workshop additionally conducted a stock assessment and prepared catch advice for 2017 and 2018, in line with its terms of reference.

Most of the work focused on exploring two alternative stock assessment models. One of them was a biomass dynamics model (SPiCT) that used annual catches in tonnes since the start of the fishery in 1991 and a biomass indicator from a biennial survey starting in 1999. The other one was an age-length structured model (implemented in Gadget), which used not only the catch and survey indicator, but also the available composition data from the fishery (ages and lengths) and survey (lengths).

The biomass dynamics model was explored in considerable detail, and was found to display a strong retrospective revision every two years, when a new survey year was included in the assessment. The available dataseries are short relative to the lifespan of the species, the survey biomass indicator shows a continuous decline since 1999 while catches have also been declining over the same period. This results in a "one-way trip" situation in which every addition of a new survey year leads to a more pessimistic perception of stock status and the level of exploitation the stock might safely be able to sustain. A reliable assessment with a biomass dynamics model could only be possible if and when some reverse of the so-far continuously declining trend in the survey biomass indicator is observed. Therefore, WKDEEPRED concluded that a biomass dynamics model would not constitute an appropriate way to assess the stock at this point.

The age-length structured model developed with Gadget also used age and length composition data. The inclusion of these data in the assessment lent stability to the assessment results and no strong retrospective pattern emerged. Fits to the data were considered overall adequate and WKDEEPRED concluded that this model provides an appropriate way of assessing the stock at this time. Although the Gadget assessment appears to capture trends on stock biomass and fishing mortality reliably, some aspects of the assessment still require further exploration, the data currently available cover only a short period relative to the lifespan of the species, and additional age data that might bring in additional insights are expected to become available over the next few years. WKDEEPRED therefore concluded that at present this assessment should be considered as a Category 2 (instead of Category 1) assessment.

WKDEEPRED also derived precautionary and MSY reference points (B_{lim}, B_{pa}, F_{lim}, F_{pa}, F_{MSY} and MSY $B_{trigger}$) following the ICES technical guidelines for the calculation of reference points. It further agreed the settings to be used in short-term projections and developed a new Stock Annex for the stock.

Finally, WKDEEPRED conducted a stock assessment and prepared catch advice for 2017 and 2018, in line with its terms of reference.

1 Introduction

The Workshop on Assessment and Catch Advice for Deep Pelagic Redfish in the Irminger Sea (WKDEEPRED), co-chaired by Carmen Fernández, ICES, and Jesper Boje, Greenland, and with John Simmonds, UK, and Cóilín Minto, Ireland, as external reviewers, was established by ACOM and met during 23–25 August 2016 to address the following terms of reference:

a) Agree on the most appropriate approach for the assessment of this stock.

b) If an analytical assessment is agreed for the stock (categories 1 or 2), estimate Biological Reference Points and agree on the short-term forecast method. Otherwise, consider proxy reference points to the extent possible and agree on a methodology for catch advice for the stock consistent with ICES advisory rules.

c) Document the agreed methodology in a stock annex.

d) In response to NEAFC's request to ICES "to review the approach that serves as basis for the catch advice for the deep pelagic redfish stock in the Irminger Sea to ensure conformity with ICES advisory rules", conduct a stock assessment and prepare catch advice for the stock for 2017 in accordance with a) and b).

WKDEEPRED was set up to provide the answer to the following special request from NEAFC to ICES about clarifying the 2015 advice from ICES on the fishery in 2016. NEAFC request to ICES with deadline 1 October 2016:

"Advice basis for deep-sea pelagic redfish in the Irminger Sea

ICES advice on beaked redfish (*Sebastes mentella*) in Subareas 5, 12, and 14 (Iceland and Faroes grounds, north of Azores, east of Greenland) and NAFO Subareas 1+2 (deep pelagic stock > 500 m), is based on simulations conducted under an ICES benchmark workshop in early 2014, WKREDMP, with the aim to evaluate a range of harvest control rules for the deep pelagic stock. None of the scenarios evaluated met the objectives of the requested catch rules (stock biomass in 2024>stock biomass in 2014 with a high probability), but annual catches of 10.000 t gave a 50% probability that stock biomass would increase after 10 years. The latter has since been the basis for ICES advice on the deep pelagic stock.

Under the 34th Annual Meeting of NEAFC, the ICES presentation of the advice for the deep pelagic stock gave rise to several comments that overall questioned if the basis for the advice was in accordance with both management objectives and ICES advisory rules.

Therefore, ICES is requested to review the approach that serves as basis for the catch advice for the deep pelagic redfish stock in the Irminger Sea to ensure conformity with ICES advisory rules. "

The work was considered by ICES to have a very high priority and WKDEEPRED was established.

WKDEEPRED was successful in addressing its terms of reference: an age-length structured assessment model was agreed for the assessment of the stock, considered by WKDEEPRED to be appropriate as a Category 2 assessment; reference points were agreed and the Stock Annex was updated according to the workshop's conclusions. WKDEEPRED also conducted a stock assessment following the agreed methodology and prepared catch advice for 2017 and 2018. Although the WKDEEPRED's terms of reference only requested catch advice for 2017, WKDEEPRED prepared catch advice for both 2017 and 2018 because no new survey will be conducted until 2018; no information that may potentially alter the potentially alter the stock's perception is expected to become available before that time.

To deliver the work, the WKDEEPRED participants, including the two external reviewers, worked according to the following schedule: (a) two web-conference meetings in the 2 months previous to the actual physical meeting, to review available work and give further direction for work that needed completion before the meeting; (b) a physical workshop meeting in ICES Headquarters during August 23–25, 2016, and (c) work by correspondence to finish the outstanding work (mostly writing the report and the Stock Annex).

2 Stock Identity

The ToRs of WKDEEPRED refer specifically to the deep-pelagic stock in the Irminger Sea and WKDEEPRED did not revisit any stock identity analyses. The workshop proceeded with work on the request given the current stock structure for redfish in this area (ICES 2009). Description of stock structure and management units are found in the Stock Annex (see Annex 2 to this report).

3 Data

The following data are available for the deep-pelagic beaked redfish in the Irminger Sea and adjacent waters:

1) Catch data since 1991 (Section 3.1).
2) Survey indices from the international redfish survey in the Irminger Sea and adjacent waters, conducted biennially since 1999 (Section 3.2)
3) Biological data (Section 3.3):
    a) Length distributions from Icelandic commercial catches since 1992.
    b) Length distributions from the redfish surveys since 1999.
    c) Age data from the Icelandic and Norwegian catches (several years since 1996).
    d) Weight, sex and maturity samples from catches and surveys.

Commercial cpue indices are also available, but are not used for tuning the stock assessment. Although these indices have been explored and the information contained in the logbooks on effort, spatial and temporal distribution of the fishery is of value, they were not considered for inclusion during the workshop because the cpue trends are not considered to be reliable indicators of abundance and stock trends.

3.1 Fisheries-Dependent Data

The fishery for the deep pelagic beaked redfish in the Irminger Sea and adjacent waters started in the early 1990s. Annual landings quickly rose from 59 t in 1991 to nearly 140 000 t in 1996, and then stabilizing at 85 000105 000 t during the period 19972004, when some countries ceased fishing (Table 3.1.1, Figure 3.1.1). From 2005 onwards, annual landings have declined, being in the range 23 000 – 68 000 t, with the lowest landings taking place in 2014 and 2015. Landings are assumed to be fairly well reported. However, in the years 20022007 there were indications that reported effort (and consequently landings) could represent, on average over those years, only around 80% of the real effort. This was mainly because of illegal, unregulated and unreported fishing (IUU) that occurred in this period. The suspected IUU catches for the period are provided in Table 5.1.2. Since 2007, IUU has stopped and misreporting assumed to be negligible.

The main fishing area is in the northeast Irminger Sea close to the Icelandic EEZ (north of 61°N and east of 32°W) (Figure 3.1.2) from April to July (main fishing occurs in May and June) at depths between 500 and 900 m.

The fishery targets the adult part of the stock. It is a highly directed fishery, catching mainly redfish, with very low bycatch and discard rates. Therefore, for stock assessment purposes, the landings data are considered to represent the total stock catches.

Table 3.1.1 Deep pelagic beaked redfish. Catches (in tonnes) as used by the Northwestern Working Group and WKDEEPRED.

YEAR	TOTAL
1991	59
1992	3 398
1993	15 064
1994	51 820
1995	75 707
1996	138 552
1997	95 079
1998	92 818
1999	84 153
2000	93 113
2001	86 993
2002	103 128
2003	104 296
2004	91 954
2005	45 485
2006	67 288
2007	58 516
2008	30 045
2009	54 406
2010	59 288
2011	47 333
2012	32 806
2013	46052
2014	23 755
2015	27 433

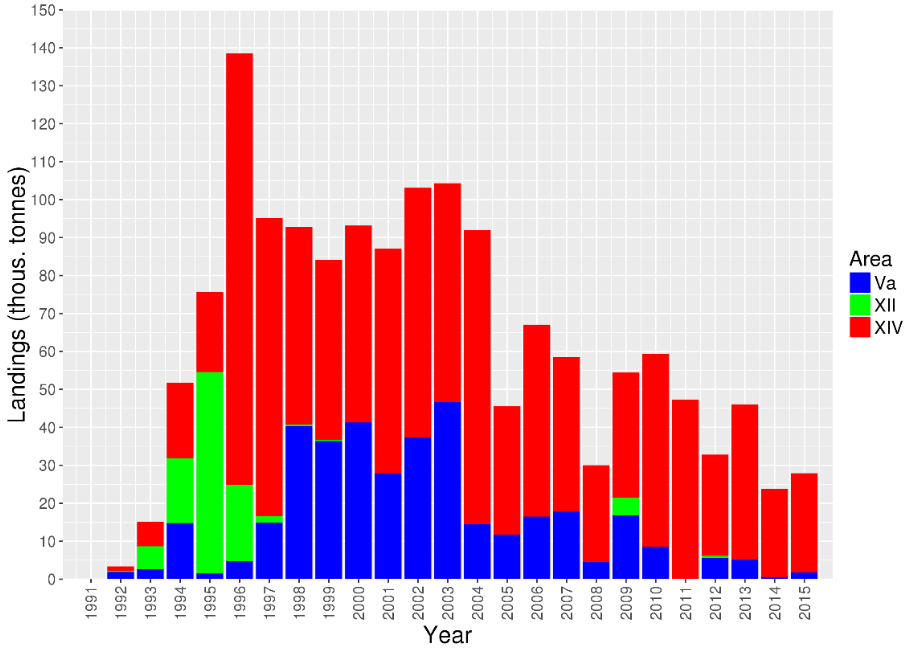


Figure 3.1.1 Deep pelagic beaked redfish: Nominal landings 19912015.

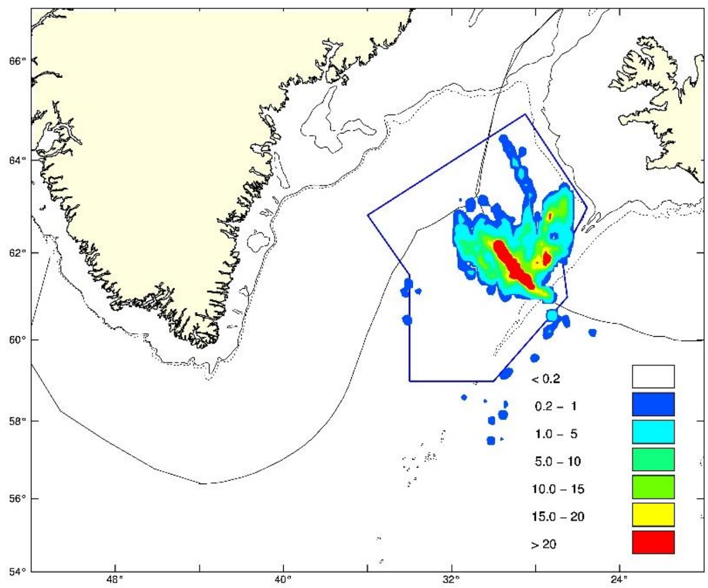


Figure 3.1.2 Fishing areas in the Irminger Sea adjacent waters 20052015 (all years combined) based on logbook data from Iceland, Faroe Islands, Germany, Greenland and Norway. No data are available from Russia.

3.2 Fisheries-Independent Data

The international trawl-acoustic redfish surveys in the Irminger Sea and adjacent waters have been conducted biennially since 1999. Their objective is to estimate the biomass and distribution of the shallow and deep pelagic stocks in the area. The results from the surveys are the basis for the ICES advice on the two pelagic redfish stocks in the area. In these surveys, the shallow pelagic redfish stock is measured by hydroacoustics and with the trawl method (within the deep scattering layer (DSL) above 500 m depth) and the deep pelagic deep-water redfish stock below 500 m with the trawl method. The results presented consist of biomass indices and the length distribution of the catch. Otoliths are also sampled but have not been systematically age read. Description of the survey procedure and calculation of the survey index is described in the Stock Annex (Annex 2 of this report).

The most recent survey took place in 2015. As can be seen in Figure 3.2.1, the area coverage was much less in 2015 compared to other years. The reason for the smaller area was that only two vessels conducted the survey instead of the three vessels from previous years. The scope of the 2015 survey was therefore altered and the emphasis was on covering the deep pelagic stock found below 500 m of depth. The area covered in 2015 was found to contain 90–95% of the biomass in the deeper layers in previous survey years (excluding the 2005 and 2007 estimates, when no separation at 500 m was included in the survey design). The biomass estimation from the survey in 2015 is, therefore, considered adequate for deep pelagic redfish.

Trawl survey estimates were relatively stable from 2005 to 2011, but are lower than the average for 1999–2003 (Figure 3.2.1 and Table 3.2.1). After 2011 the index has decreased and the 2013 and 2015 estimates are the lowest in the time-series. The 2015 estimate is about 20% of the highest value in 2001. These indices in combination with a marked decrease in landings since 2004 suggest that the stock has been reduced in the past decade.

Table 3.2.1 Results (biomass in ´000 t) for the international redfish surveys conducted biennially during 1999-2015 for deep pelagic beaked redfish. Some areas in 2015 were not surveyed (see text for detail).

YEAR	TOTAL
1999	935
2001	1001
2003	678
2005	392
2007	522
2009	458
2011	474
2013	280
2015	196

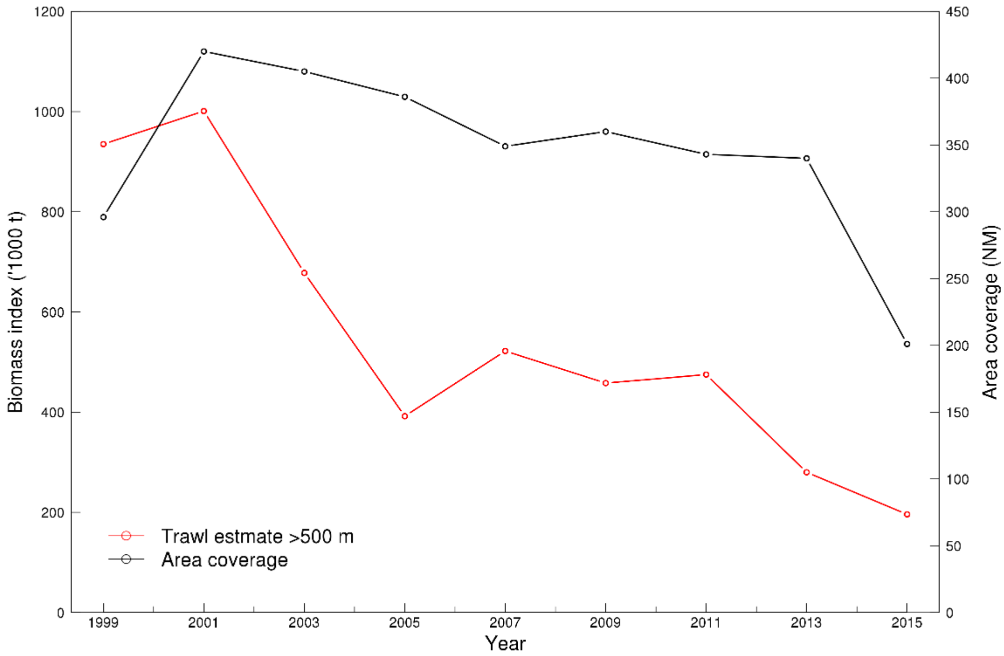


Figure 3.2.1 Survey index of deep pelagic beaked redfish 19992015 and area coverage.

3.3 Biological Data

Age reading of deep pelagic beaked redfish in the Irminger Sea and adjacent waters has not been systematic. Age data are available from Iceland and Norway for some years during 19962013. Most of the age data come from the commercial catch except in 1999 where 797 age readings come from the international redfish survey (note: as the age readings from the survey correspond to a similar depth range and location as other samples, they have been included together with the commercial fishery samples). In total, 6566 otoliths have been age read. The number of age readings by year and nation is given in Table 3.3.1. Age distributions for the Icelandic data are shown in Figure 3.3.1 and for the Norwegian data in Figure 3.3.2.

Table 3.3.1 Available age data (number of otoliths read) of deep pelagic beaked redfish in the Irminger Sea and adjacent waters.

Year	Iceland	Norway	Total
1996	304		304
1999	1052	258	1310
2001	158	758	916
2003		75	75
2004	399		399
2006	200		200
2009	783		783
2011	585		585
2012	672	628	1300
2013	535	159	694
Total	4688	1878	6566

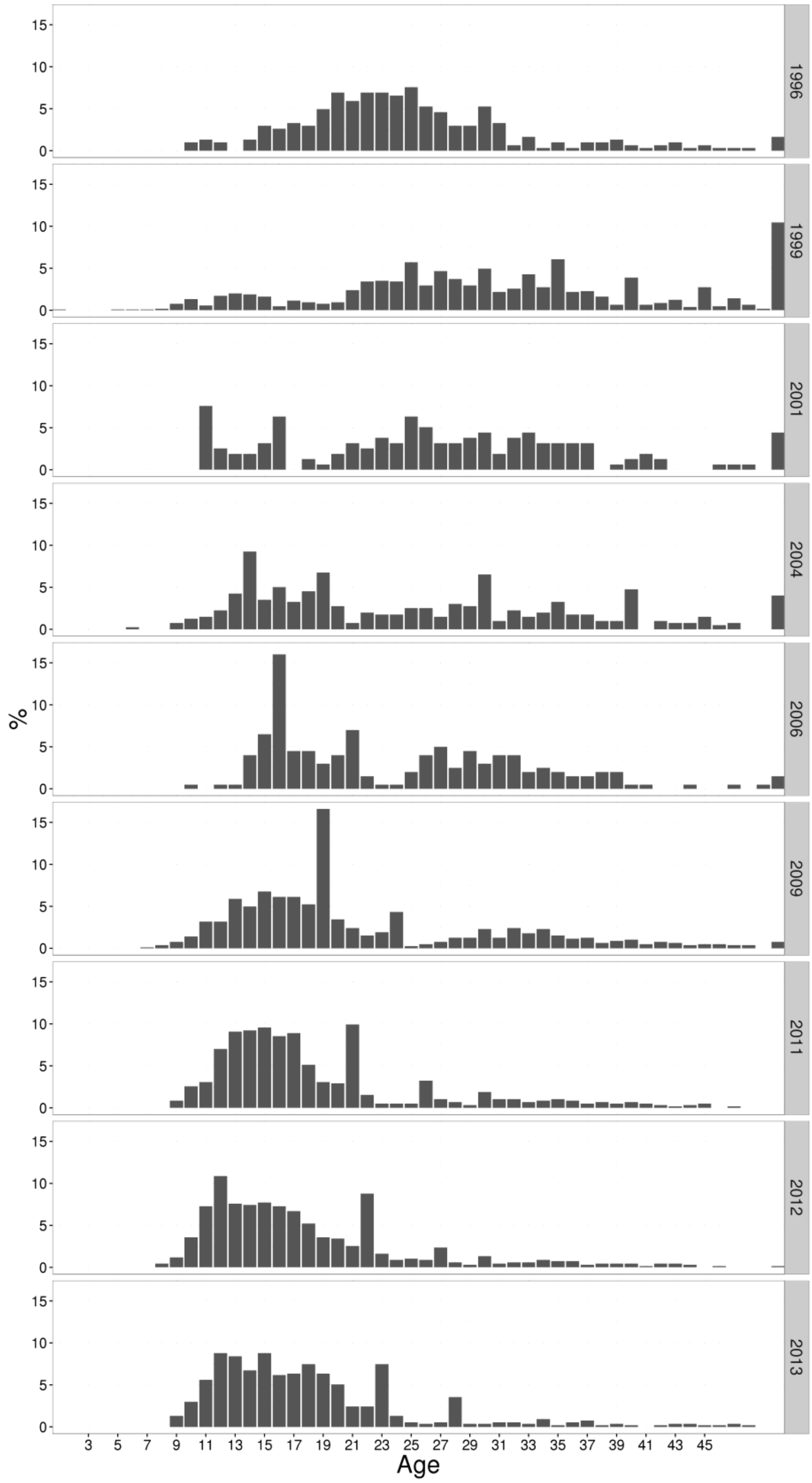


Figure 3.3.1 **Age distribution of deep pelagic beaked redfish based on age reading from the Icelandic commercial catch.**

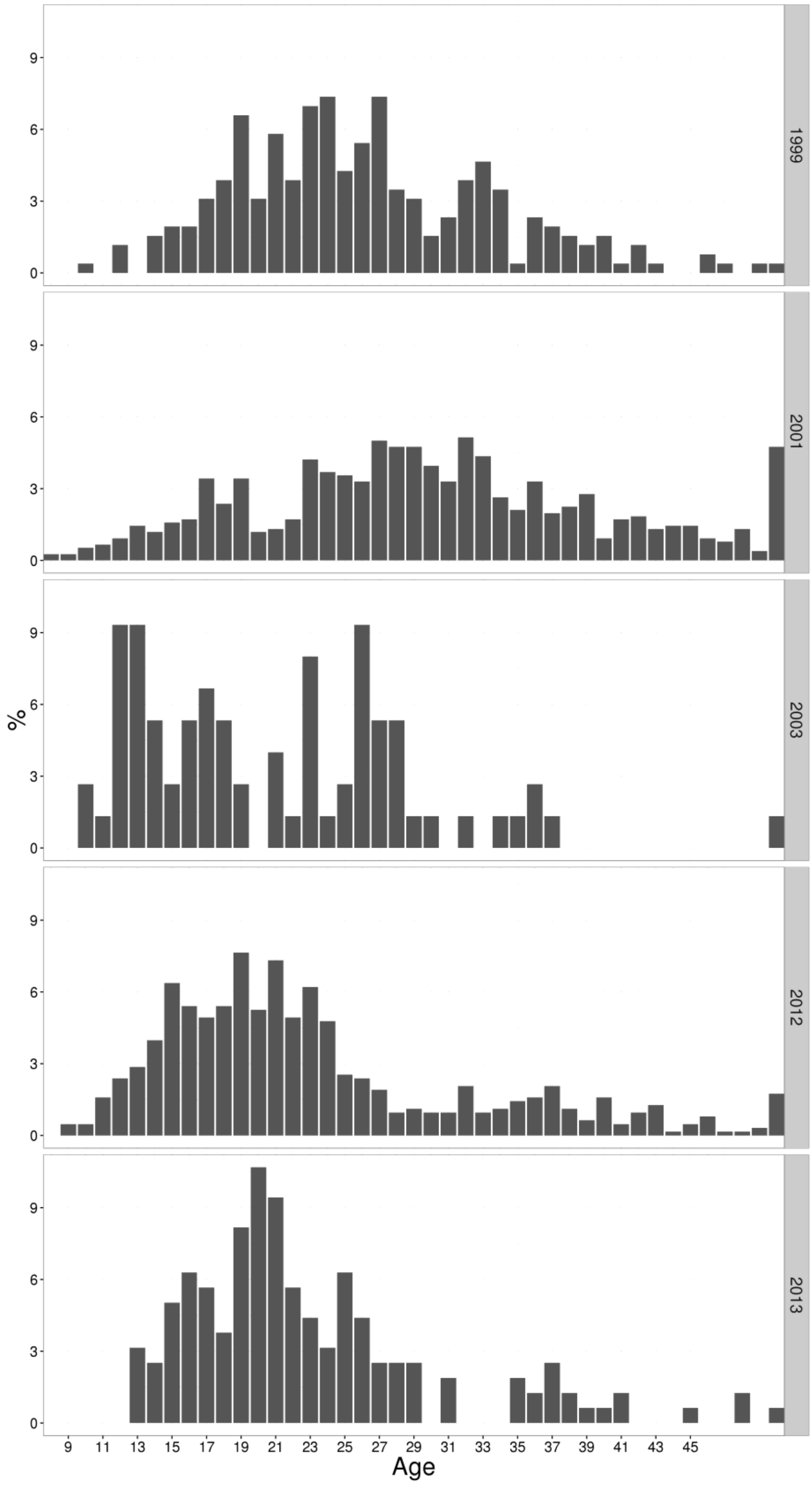


Figure 3.3.2 **Age distribution of deep pelagic beaked redfish based on age reading from the Norwegian commercial catch.**

Length data are available from the international redfish survey and from the Icelandic commercial fishery. Biological information is collected from commercial catches from other nations (Russia, Norway, Spain and other EU countries). However, the data were not available to the group.

The length data from the Icelandic commercial fishery is considered to provide a reasonable representation for all nations participating in the fishery, as the fishery is conducted in a concentrated area along the Icelandic EEZ (Figure 3.1.2) in a relatively short period (mainly May and June).

The length samples from the Icelandic commercial catch are either collected by observers on board or by the fishers who send samples for further analysis to the MRI (Marine Research Institute, Iceland). The number of fish measured for length and the number of hauls sampled are given in Table 3.3.2. In each sample 100200 fish are length measured. Length distributions are shown in Figure 3.3.3 and indicate that the bulk of the catches is at around 35-45 cm of length.

The number of deep pelagic beaked redfish length-measured from the International Trawl-Acoustic Survey in the Irminger Sea and adjacent waters is given in Table 3.3.3. No data were available for the 2005 and 2007 surveys. Length distributions are shown in Figure 3.3.4. The length distributions show a broad maximum around 35–42 cm

Table 3.3.2 Number of length measurements of deep pelagic beaked redfish and number of hauls sampled from the Icelandic commercial fishery.

Year	Number of fish	Hauls sampled
1992	447	5
1994	6915	41
1995	8128	49
1996	12185	141
1997	19258	200
1998	10104	94
1999	16264	115
2000	11079	97
2001	10589	83
2002	3840	48
2003	6705	63
2004	14774	87
2005	5693	34
2006	15296	78
2007	14449	79
2008	4993	40
2009	9231	73
2010	4113	34
2011	7339	52
2012	9458	70
2013	4093	35
2014	2927	19
2015	998	6

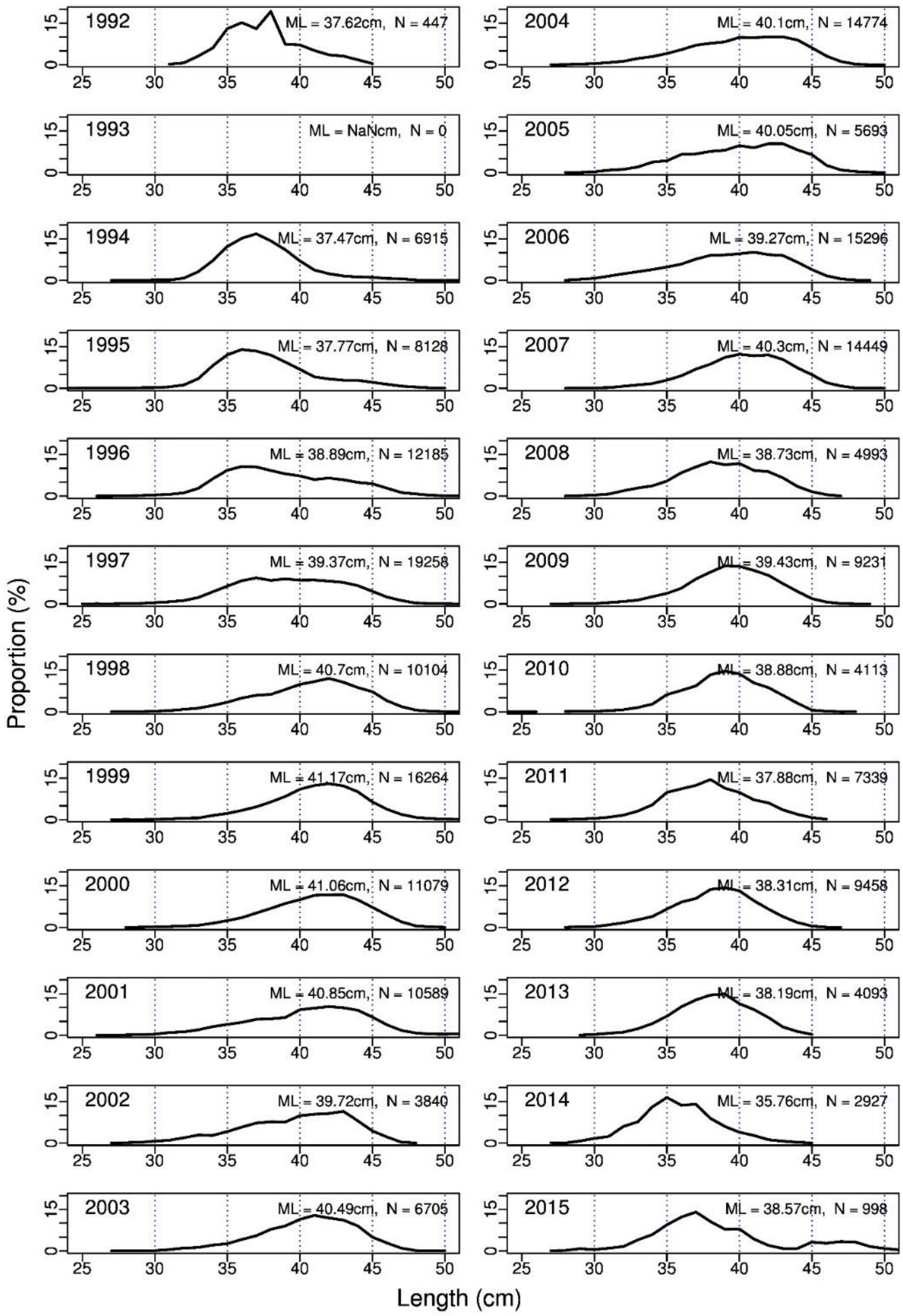


Figure 3.3.3 Length distribution of deep pelagic beaked redfish based on data from the Icelandic commercial catch.

Table 3.3.3 Number of length measurements of deep pelagic beaked redfish from the International Redfish survey in the Irminger Sea and adjacent waters 1999-2015. No data available for 2005 and 2007.

Year	Number of fish
1999	3015
2001	3083
2003	1380
2009	994
2011	1829
2013	1184
2015	925

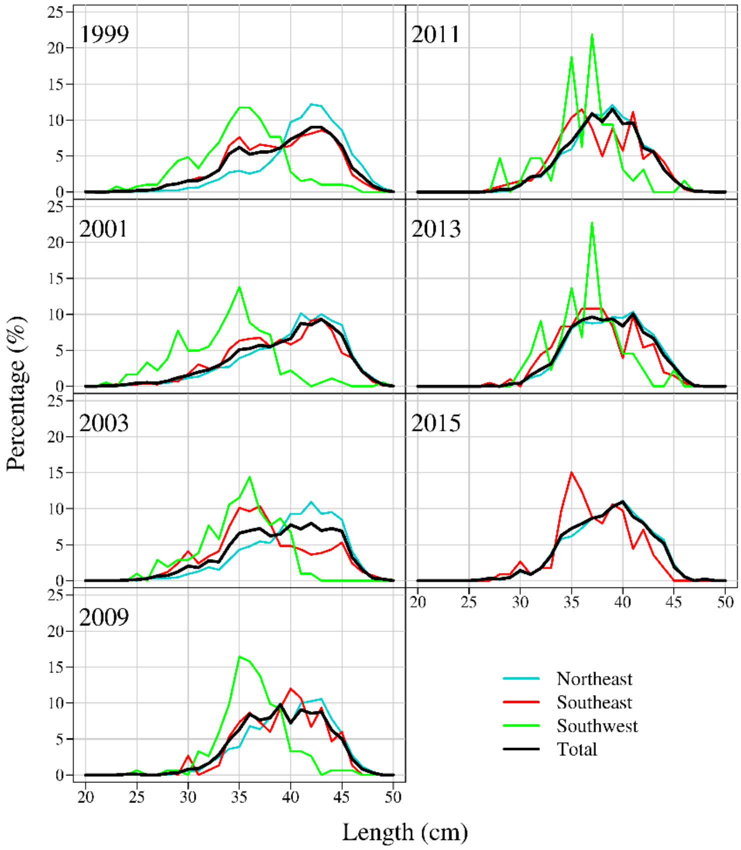


Figure 3.3.4 Length distribution of redfish in the survey trawls (International Redfish survey in the Irminger Sea and adjacent waters), by geographical area (see Figure B.3.1 in Stock Annex, Annex 2 to this report) and total, from fish caught deeper than 500 m 19992003 and 20092015.

3.4 Overview of Data Quality

This was not discussed in detail at the meeting.

4 Ecosystem Drivers

This was not discussed in detail at the meeting. No new information was presented at WKDEEPRED.

5 Stock Assessment

Two options were presented at WKDEEPRED as potential ways of assessing the state of deep pelagic redfish in the Irminger Sea: a biomass dynamics model, discussed in Section 5.1, and an age-length structured model, discussed in Section 5.2.

5.1 Biomass Dynamics Model (SPiCT)

A stochastic Surplus Production model in Continuous-Time (SPiCT) developed by Pedersen and Berg (2016) was explored as a potential assessment model for the deep pelagic *S. mentella* stock in the Irminger Sea. The model uses a Pella-Tomlinson surplus production function and incorporates stochasticity in the dynamics of both biomass and fisheries, and observation error in both catches and biomass indices. The model has a general state-space form that as special cases contains process and observation-error models. The model is accessible online at www.assessment.org, which contains the code, input data and sufficient output as tables and figures. A technical description of the model is given in Pedersen and Berg (2016).

5.1.1 Assessment Model Settings

Reported catches and biomass estimates from the international trawl-acoustic survey were used as input to the model. Survey data extend back to 1999 and are available for every two years. Catch data were utilized back to the origin of the fishery (1991) in order to make a prior assumption that biomass in 1991 was at virgin state K. Four priors were set in the baserun; n, the shape of the production curve; alpha and beta, the ratios between observation and process error for biomass and fishing mortality, respectively; and BKfrac, the initial fraction of biomass (i.e. biomass in 1991) in relation to K. The prior settings are shown in Table 5.1.1 for the baserun. The prior mean of log(Bkfrac) was set to log(1) with a very low standard deviation, meaning that initial population in 1991 was assumed at virgin state equal to K. The prior means and variances for the remaining parameters, n, alpha and beta, were set to arbitrary values within an expected range (Pedersen and Berg, 2016) (Table 5.1.1).

It is noted that biomass dynamics models represent the harvestable biomass in the population and intrinsically assume the same selection for the fishery and any biomass indicator used to tune the assessment. The population is modelled as an undifferentiated biomass (i.e. without any age structure considered) and no annual recruitment process is explicitly modelled; instead, the processes of recruitment, growth and natural mortality are implicitly incorporated in the surplus production function.

Alternative settings of the model were also explored. The catchability (q) of the survey biomass indicator was estimated by the model in the base run. A setting with an assumed catchability equal to 1 was also explored.

Sensitivity analyses were performed on various assumptions of prior values (Table 5.1.1) and their SD in order to evaluate the robustness of the model approach.

Additional runs were performed including suspected catch misreporting in 2002-2007. In these years non-contracting NEAFC members might have taken additionally approximately 15-33% annually (see Table 5.1.2) (ICES 2016a). For the remaining period, catches are assumed to be fairly precise. Therefore, runs with the additional catches in 20022007 were conducted with and without assuming high precision in the catch data, i.e. with the standard deviation (sd) of the log(observed catches) either set to 0.05 or estimated by the model.

Finally, exploration allowing for differences in sd(log(F)) over time, recognizing different periods of interannual changes of fishing mortality to accommodate for the initial learning and developing period of the fishery in 19911996 with steep increases in F, followed by the remaining relatively stable period for F, failed due to inability to obtain convergence.

5.1.2 Results and Diagnostics

5.1.2.1 Base Run

The base run is stored on the webpage stockassessment.org under the name smn_dp_new and all input settings and results can be accessed there.

The base run estimates n (shape of the production function), r (intrinsic growth-rate parameter) and K (virgin biomass) to be 2.5, 0.09 and 1.3 million t, respectively, and MSY is estimated at 26 thousand t. The survey catchability q is estimated to be 1.1.

Figure 5.1.1 provides the estimated relative biomass (B/B_{MSY}) and fishing mortality (F/F_{MSY}) since 1991 from the base run. The prior distribution sets the biomass in 1991 at K with very low dispersion. The biomass then decreases from approximately 2*B_{MSY} in 1991 to 0.28*B_{MSY} in the final year. Relative fishing mortality is estimated to increase sharply after the start of the fishery in early 1990s and remains on a level of about 3.5*F_{MSY} since 1997 and is in the final year estimated at 3.6.

The uncertainty on the estimates of relative fishing mortality is very high with the 95% CI on the 2015 estimate expanding the range 0.265. The uncertainty in the estimates of relative biomass is lower; the 95% CI for the estimate of relative biomass at the start of 2016 ranges from 0.10.77. The relative biomass estimates fit the survey indices reasonable well (see Figure 5.1.1). The standard deviation on the log(observed catches) is estimated relatively high at 0.27. This is partly due to the low catch in 1991 and omission of that catch observation lowers the standard deviation to 0.20.

The diagnostic plots (Figure 5.1.2) show results of statistical tests for bias, autocorrelation and normality of model residuals. All tests were passed except the test for normality of catch residuals, which failed as a result of an extreme catch residual (1991). This violation is of minor concern, however, as removal of these data point resolved the failed test without markedly influencing the model fit. These data point is therefore maintained in all subsequent runs.

The retrospective plots from the base run are given in Figure 5.1.3 for relative B and F. The retrospective pattern is clearly evident with significant underestimation of relative F and corresponding overestimation of relative biomass. The addition of a survey biomass index every two years gives rise to a new perception of stock biomass and fishing mortality. Initial biomass is revised every two years due to a revised estimate of MSY. With such revision of the productivity of the stock when new data arrive, the relative F and B values become unstable and are not appropriate to describe recent stock status.

5.1.2.2 Sensitivity Analyses and Alternative Runs

Putting less emphasis on the assumption that the stock at the starting year is assumed to be at virgin state (B/K fraction) affects all parameters markedly. The assumption is a key assumption in the entire approach, and was therefore maintained.

Sensitivity analyses on the precision of the prior distribution for the parameters alpha and beta (the ratios between observation and process error) shows an effect on the estimates of the remaining parameters. Decreasing the prior precision on alpha and beta from sd = 1 to 3 causes MSY to more than double (from 26 kt to 57 kt). However, stock status $B2016/B_{MSY}$ and $F2015/F_{MSY}$ is only insignificantly affected by the alpha and beta precision (sd).

Adding the assumed misreporting to the time-series for 2002-2007 gave significantly different parameters estimates, with higher K and lower MSY, and the relative F history changed with recent relative F being at 9^*F_{MSY}. However, the estimated high sd of log(observed catches) (sd=0.29) might contribute to the F level change and catches are believed to be better known than estimated from the model. Therefore a run with a prior on the sd of the log(observed catches) (model parameter sdc) equal to 0.05 was performed. This run with assumed known catch gave, however, a different q estimate (1.3) from the base run (1.1) and resulted in a slightly different historic perception of F and B. Fixing q to 1.0 gave minor changes relative to the base run in the estimated relative F and B. Since the addition of misreported catches is not currently accepted in the assessment of the stock (ICES 2016a) it was concluded that misreporting could be ignored at this stage of exploratory runs.

The assumption of well-known catches is critical for estimation of the parameters and stock status. The assumption is well grounded and was therefore applied by WKDEEPRED in further exploratory runs (i.e. sd(log(observed catch))=0.05 was assumed). This assumption reduces the uncertainty on the estimated fishing mortality but increases the productivity estimate of the population markedly (MSY). The estimated catchability of the survey (q) is also strongly changed by this assumption which affects the absolute estimates and the scaling of the assessment.

A retrospective run with the absolute estimates of F and B from the model assuming well-known catches is illustrated in Figure 5.1.4. The retrospective behaviour is clearly improved relative to that observed in Figure 5.1.3; note, however, that Figure 5.1.4 displays absolute F and B, whereas Figure 5.1.3 shows F/F_{MSY} and B/B_{MSY}, so the two figures are not directly comparable. The estimate of survey catchability changes markedly with the addition of years in the retrospective analysis from the run assuming well-known catches (Figure 5.1.5). This could indicate that the assumption of a constant catchability without trend over time is violated or could just be indicative of an inability to get stable model parameter estimates from the available data. Reference points were also found to change with the addition new data. Fixing both catch precision to 0.05 and q to 1 improves the retrospective pattern for the absolute values of F and B, but not for the relative values (Figure 5.1.6). The retrospective pattern in the relative F and B values occurs because the estimated productivity (n, r and MSY) gradually changes as years of data are added or removed, impeding a determination of stock status relative to reference points and the use of this model for providing catch advice according to the MSY approach.

5.1.3 Conclusions

The approach by the Surplus Production model (SPiCT) is overall not suited for data with a one-way trend as is currently the case for deep pelagic redfish in the Irminger Sea. The model has difficulties in estimating the productivity of the stock and revises its estimates when new data arrive. This is expressed as changed initial values of biomass, changes in the shape of the production function and population growth (n and r), changes in MSY, and also in revisions of point estimates of stock status relative to reference points in retrospective analyses. The model is therefore not sufficiently robust in an assessment and advice context with the present data. Contrasting data, where some reverse of the one-way trend becomes visible, are likely required for the model to properly estimate population parameters.

5.1.4 Tables and Figures of Section 5.1

Table 5.1.1. Base run settings of priors (note that priors are for the log of the parameter).

Parameter	Mean	SD
n	Log(2)	1
alpha	Log(2)	3
beta	Log(2)	1
B/K fraction	Log(1)	0.05

Table 5.1.2 ICES catches (tonnes) and estimates of suspected catches of deep pelagic *S.mentella* in the years 20022007 (interpreted from information in ICES, 2008).

Year	ICES catches	Suspected IUU catches	catches including suspected IUU catches	% increase
2002	103128	27845	130973	27%
2003	104296	34418	138714	33%
2004	91954	13793	105747	15%
2005	45485	13191	58676	29%
2006	67288	12785	80073	19%
2007	58516	11118	69634	19%

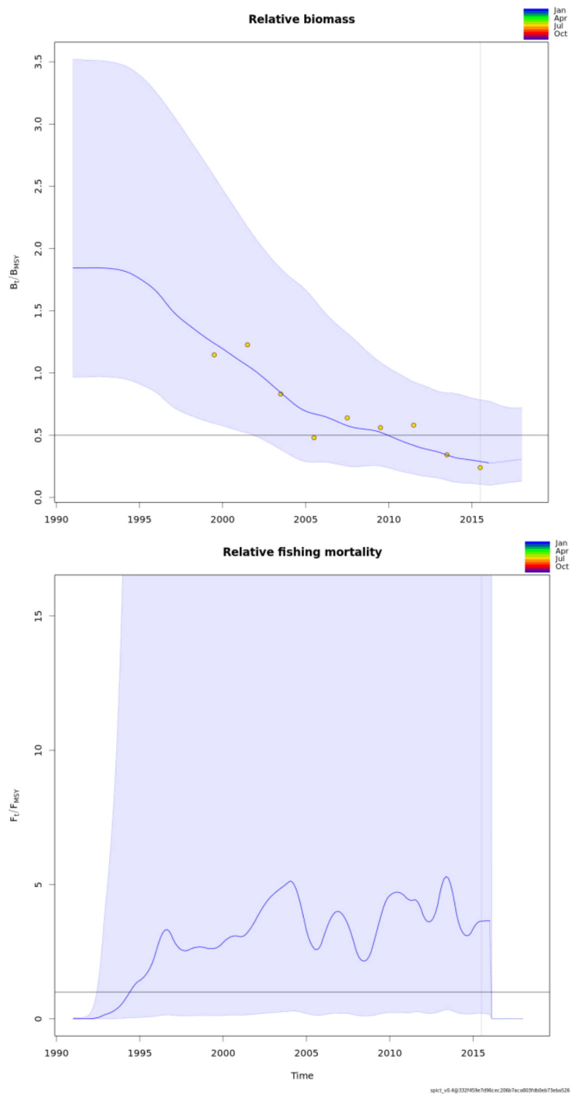


Figure 5.1.1. Stock summary of base run. Median and 95% Cis. Zero catch is assumed for 2016/17. Left panel: B/BMSY, Right panel: F/FMSY.

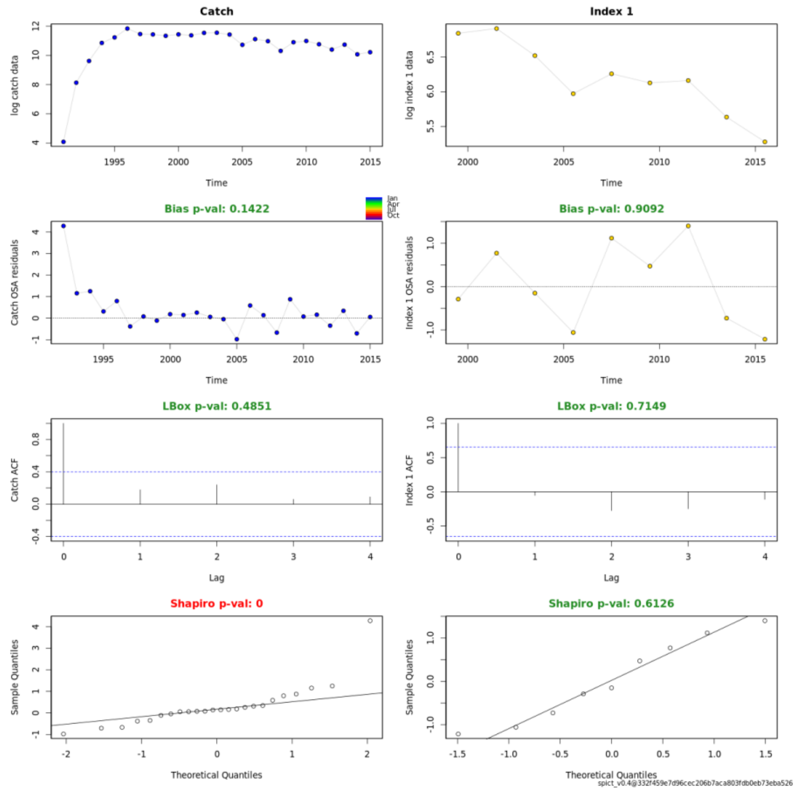


Figure 5.1.2. Baserun diagnostics for the two input series; catch and survey biomass index (index 1). 1st row: log catch and index observations, 2nd row: residuals with test for bias of residuals, 3rd row: autocorrelation function for residuals with test for significant lags, 4th row: QQ-plot of residuals with Shapiro test for normality. Green headings indicate a non-significant test and red indicates a significant test. The first catch observation, which results in an extreme residual, causes the Shapiro test to fail.

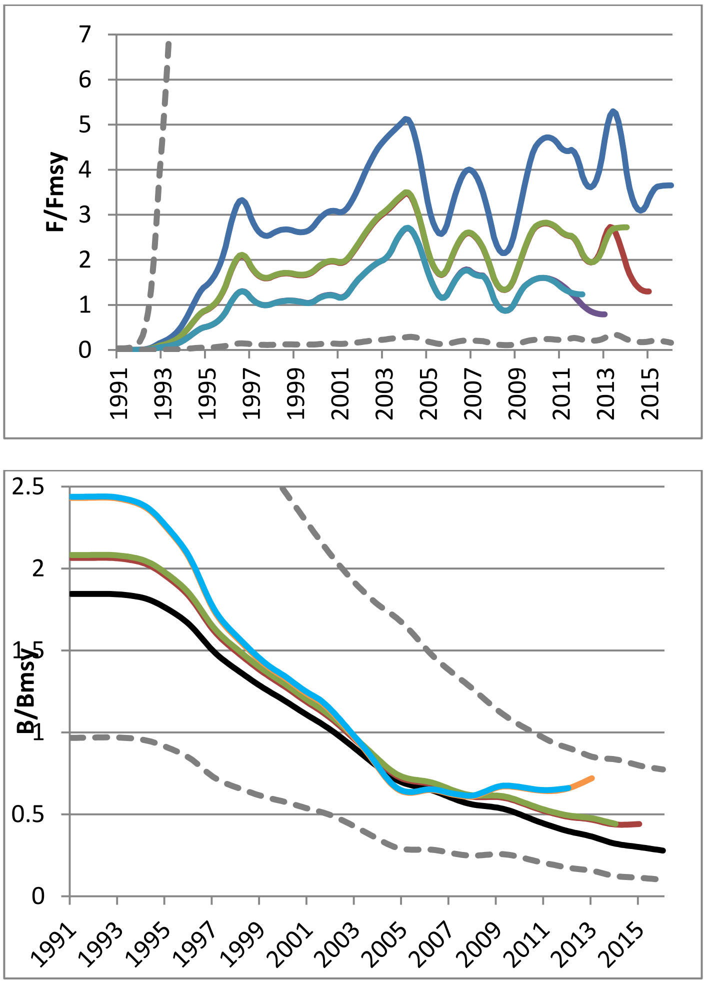
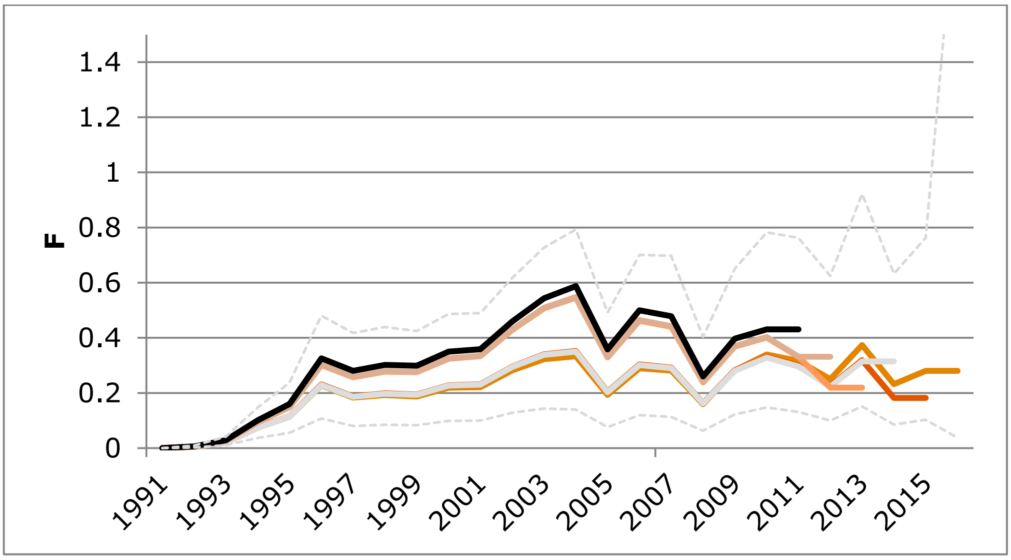
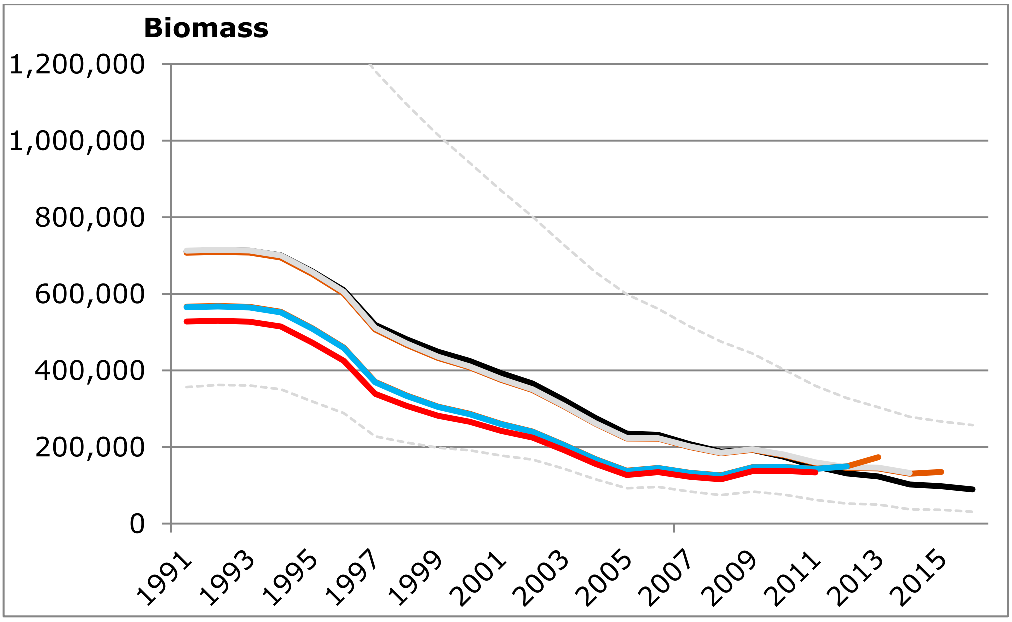


Figure 5.1.3. Retrospective plots for F/F$_{MSY}$ and B/B$_{MSY}$ with base run settings. 95% CI indicated as dotted line.


F
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015


Biomass
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015

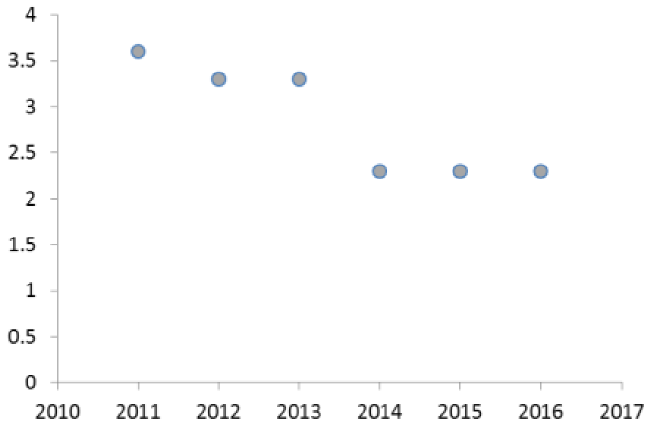


Figure 5.1.4. Retrospective plots for absolute estimates of F and B. Catch is assumed to be well-known (sd of log(observed catch)=0.05). 95% CI indicated as dotted line.

Figure 5.1.5. Estimates of survey catchability (q) from the retrospective run provided in Figure 5.1.4.

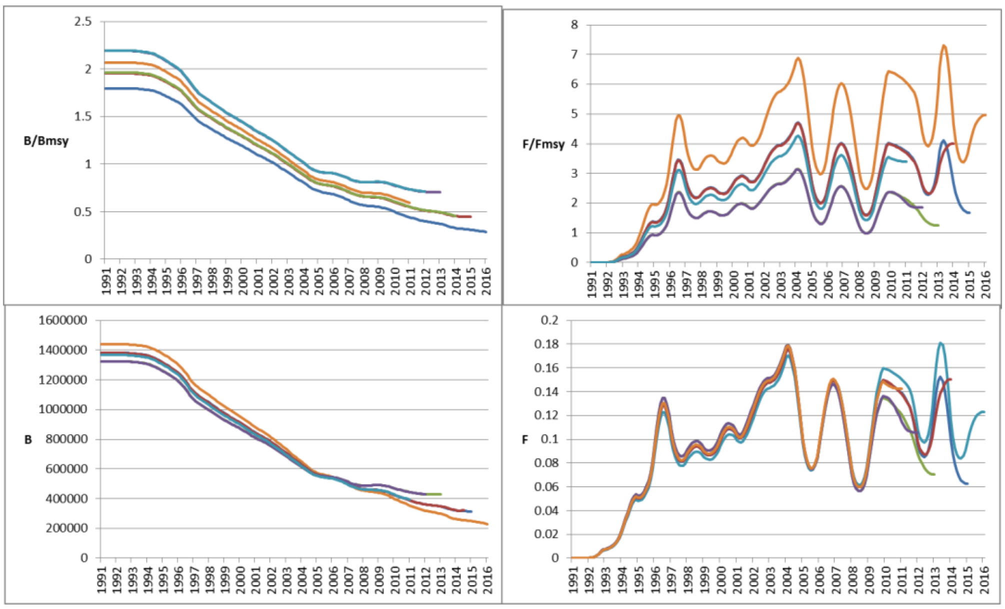


Figure 5.1.6. Retrospective plots for B/B$_{MSY}$ and F/F$_{MSY}$, and absolute B and F, assuming catches are well-known (sd of log(observed catch)=0.05) and q=1.

5.2 Age-Length Structured Model (Gadget)

At the WKDEEPRED meeting a Gadget model for deep pelagic beaked redfish in the Irminger Sea was proposed as an assessment model. Gadget (described by Begley and Howell 2004), shorthand for the "Globally applicable Area Disaggregated General Ecosystem Toolbox", is a statistical modelling framework that allows the creation of models of marine ecosystems. Typical Gadget models are age–length structured forward-simulation models, coupled with an extensive set of data comparison and optimization routines for model fitting. Processes are generally modelled as dependent on length, but age is tracked within the models, and observed data can be compared with model-predicted values either on a length and/or age scale. The Gadget framework is designed to allow for the development of multi-area, multistock, multifleet models, and is capable of including predation and mixed fisheries issues; however it can also be used on a single species basis. A detailed description of Gadget and references to published papers can be found in the Stock Annex for deep pelagic redfish (see Annex 2 to this report).

The input data come from samples taken from the catches, biological samples from Icelandic fishing vessels and the international redfish survey. Specifically the datasets used in the model were:

- Total annual landings since the start of the fishery (1991), divided into quarters based on historical effort by quarter.
- Length frequencies, in 1cm bins, by year and quarter, where applicable, from Icelandic fishing vessels and the international redfish survey. For the commercial length distribution, data are available from 1994 until 2015 by quarter, while the survey data were sampled biennially from 1999.
- Age – length frequencies by year and quarter from Icelandic and Norwegian fishing vessels. Norwegian data on age – length frequencies was used from the 5 available years (1999, 2001, 2003, 2012 and 2013) and the Icelandic data from 9 years (1996, 1999, 2001, 2004, 2006, 2009, 2011, 2012 and 2013).
- Index of biomass from the international redfish survey

The model was fitted to the observations detailed above using a weighted residual sums of squares function. In the case of (age—)length distributions, fitted values are compared as proportions, whereas biomass indices are compared on a log—scale. The weights were assigned using an iterative reweighting heuristic originally implemented by Taylor *et al.* (2007) and inspired on weighted regression analysis. The heuristic is essentially an inverse variance weighing of datasets, where the model is used to estimate the variance associated with the fit to each dataset. Essentially, the estimates of these variances are the residual sum of squares by dataset when the objective function is set up to emphasize the fit to a particular dataset, divided by the number of comparisons between the model and data.

The iterative reweighting heuristic does not explicitly take into account the number of fish sampled in the (age) length distributions but implicitly considers the amount available at each quarter by the number of comparisons between fitted and observed values. The uncertainty in the biomass index values was used to set an upper bound on the weight to the survey index dataset. Further information on the input data can be read in the Stock Annex.

5.2.1 Assessment Model Settings

The population dynamics model runs internally with a quarterly time-step. In each quarter, the population is defined as the number of individuals assigned to 1 cm length groups, ranging from 1050 cm, and to ages ranging from 5 to 40+ years. Although the fishery started in 1991, the model simulation starts in 1970, in part to capture the pre—exploitation recruitment signal. Recruitment to the stock takes place in the first quarter of each year and is set to age 5; annual recruitment values are treated as "free" parameters, without any stock–recruitment function incorporated in the redfish stock assessment model. The mean length-at-recruitment is estimated as part of the stock assessment. Growth between length bins is based on a beta-binomial distribution with mean value assumed to follow a growth-in-length adapted version of the von Bertalanffy growth function; for the redfish implementation, the parameter K is estimated as part of the stock assessment and L_∞ fixed to 50 cm in most of the runs. A fixed weight–length relationship is estimated from data collected in the commercial catches and surveys aggregated across all available years and treated as a fixed input in the stock assessment. Natural mortality (M) is assumed to be 0.05 as the deep pelagic redfish is a long—lived species. The commercial landings are modelled as single fleet starting in 1991, with a logistic length-based selection function, and the total catch in tonnes specified for each quarter; discarding is considered to be negligible and landings are assumed to represent the total catches for stock assessment purposes. The survey (1999 onwards, biennially), is similarly modelled as one fleet with constant nominal (very small) catch and a logistic length-based selection function.

Four different model configurations were tested during the workshop:

1) Catchability for the survey was estimated (L_∞ fixed to 50 cm).

2) Catchability for the survey was fixed to 1 (L_∞ fixed to 50 cm).

3) L_∞ estimated with survey catchability fixed to 1.

4) Unreported catch in the years 20022007, substantial catches are believed to be unreported in those years. Catches during these years were increased by 24 %. Survey catchability was fixed to 1 (L_∞ fixed to 50 cm).

Only the results from the model variant where the catchability is estimated (model configuration number 1) are presented below, both for the sake of brevity and as the results did not differ substantially between the four configurations (with the biggest difference found between model configuration 4 and the other configurations).

5.2.2 Diagnostics

Figure 5.2.1 shows the model fit to the biomass index. The model appears to capture sufficiently the downward trend in the survey biomass index. The fitted values fall outside the estimated range of two data points, the 2011 and 2015 survey estimates, although the model-fitted trajectory falls between these points. These discrepancies were considered to be within reasonable limits, as the model also takes into account the information provided by the length and age-length data.

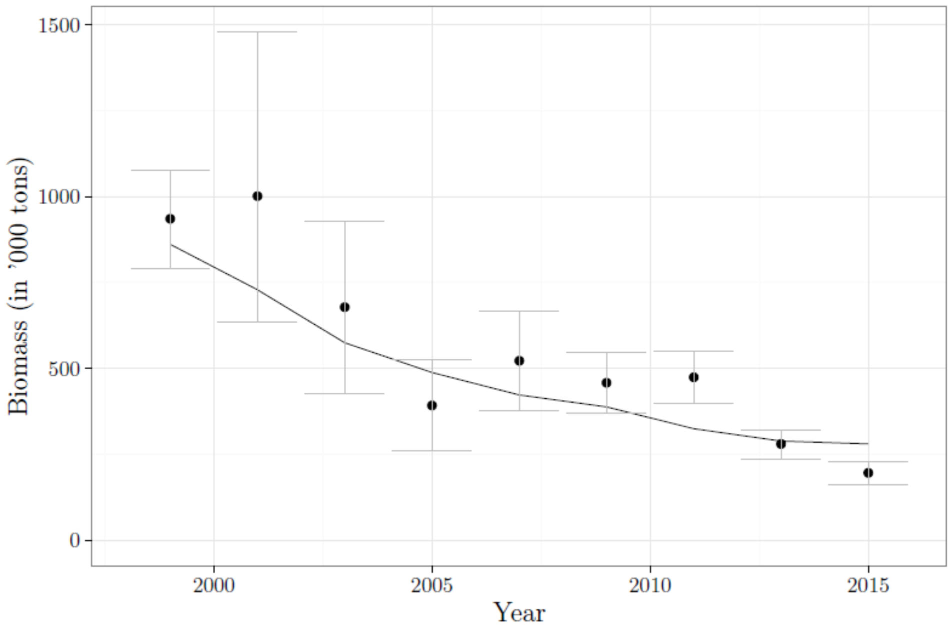


Figure 5.2.1 Deep-pelagic redfish in the Irminger Sea. Biomass index from the international redfish survey in the Irminger sea. Black line is the estimated trajectory from the stock assessment model (model configuration number 1), dots the observed values and error bars the 95% confidence interval for the observed values.

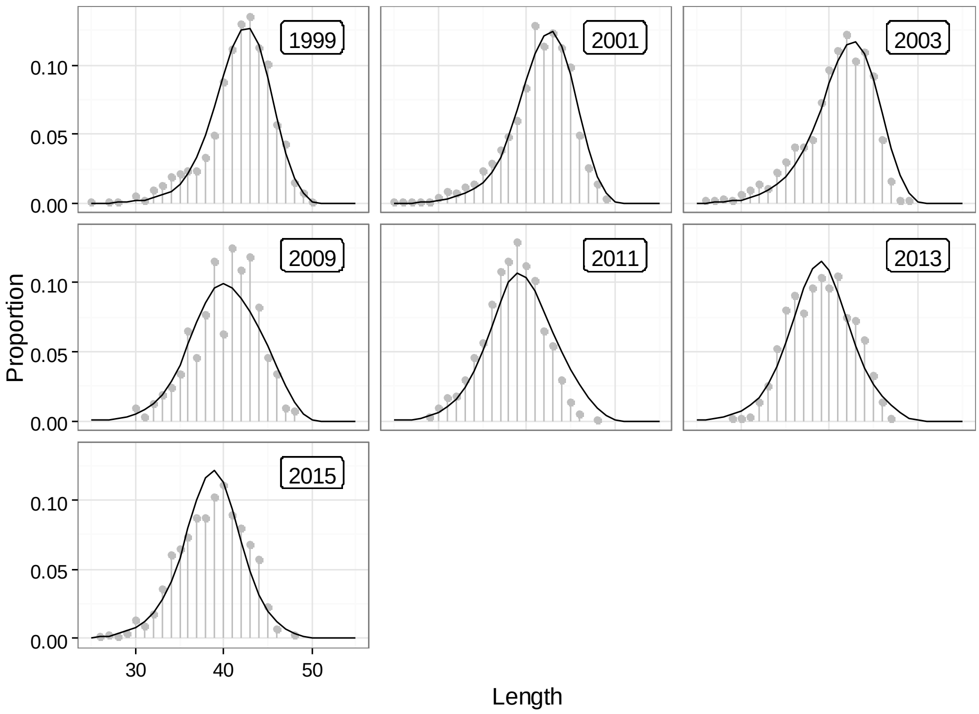


Figure 5.2.2 Deep-pelagic redfish in the Irminger sea. Length distributions (proportions at length) from the biennial redfish survey. Grey bars denote the observed values and solid black lines the predictions by the base model (model configuration number 1).

The length distributions from the biennial redfish survey, shown in Figure 5.2.2, are fairly well captured by the model. Similarly, the model fit to the commercial length distributions are satisfactory, although discrepancies can be seen in the early years of the fishery; this is illustrated in Figure 5.2.3, which shows that fitted mean length in the fishery is substantially higher than observed in the fishery in the first years of commercial activities. This effect is more pronounced in the first two years, and hardly present in the samples from 1998 and onwards. During those first years the commercial effort was more dispersed spatially, possibly reflecting a learning period for the fishery, before it became more concentrated.

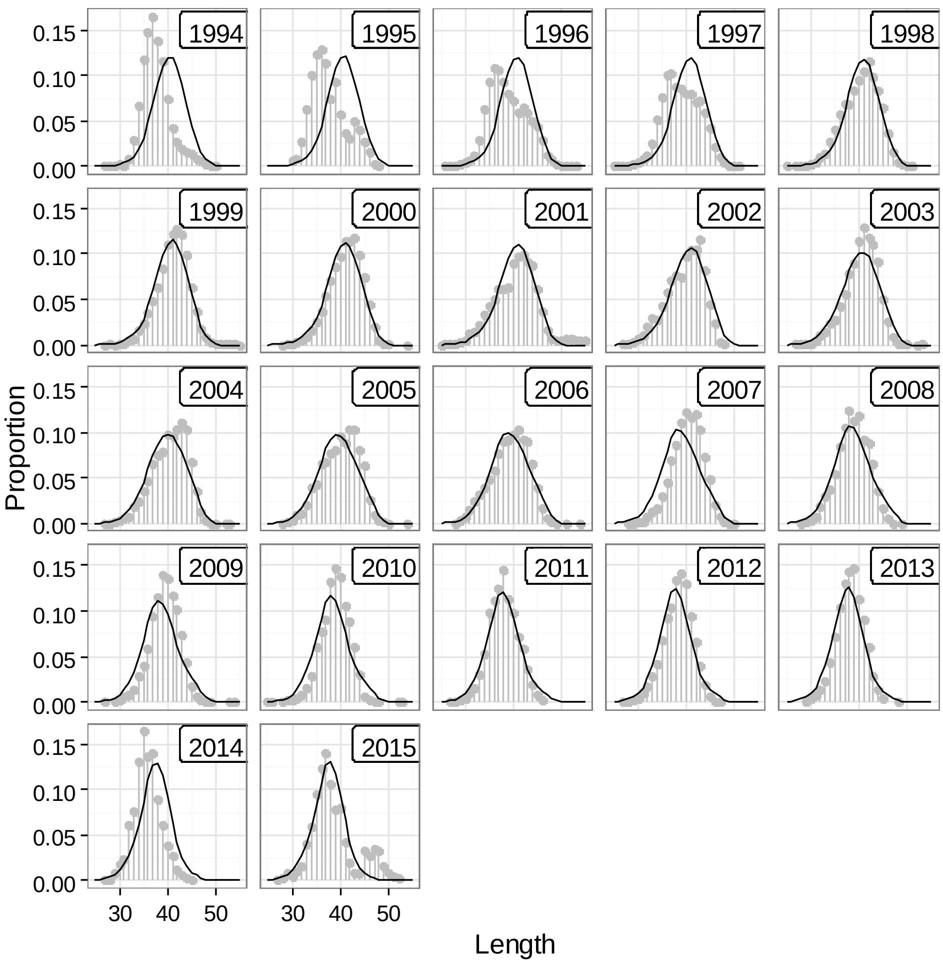


Figure 5.2.3 Deep-pelagic redfish in the Irminger Sea. Length distribution (proportions at length) from commercial redfish samples in the 2nd quarter, the fit to other quarters is omitted for brevity. Grey bars denote the observed values and solid black lines the predictions by the base model (model configuration number 1.

Figure 5.2.4 compares the fitted age structure in the catch to the observed proportions at age (from the age-length composition dataset) in the commercial catches. The fit to the age data are considered acceptable, particularly in the later years of the model time. Note that the number of samples varies considerably between years and quarters, e.g. in 2003 only 74 otoliths have been analysed whereas in 2012, 1300 otoliths have been read (see Table 3.3.1). The model appears to follow the strong 1985 and 1990 year classes, present in the observed catches since the early/mid 2000s, adequately.

In this model age composition data are important indicators of past recruitment. For ages 1 to 10 data are sparse. The youngest fish recorded in the catches (in 2004) was 5 years old; however the information on recruitment is only considered reliably available approximately 10 years after spawning.

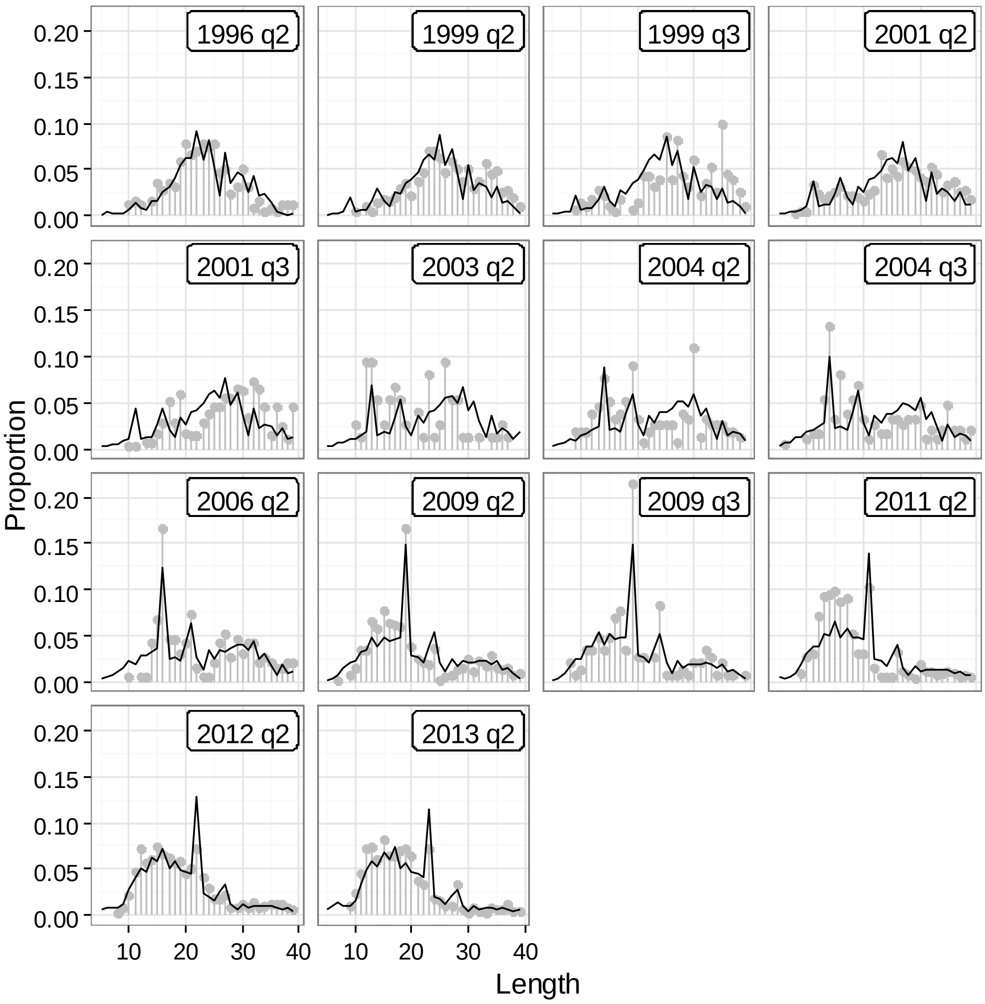


Figure 5.2.4 Deep-pelagic redfish in Irminger sea. Age distribution (proportions at age) from commercial redfish samples split by year and quarter. Grey bars denote the observed values and solid black lines the predictions by the base model (model configuration number 1).

The age–length frequencies also provide information on fish growth. Figure 5.2.5 shows a comparison between the model-fitted mean–length-at-age and the length-at-age observations from the commercial catches. The model appears to follow the general tendency of the data and to capture the spread in lengths-at-age. In most cases, however, the mean length of fish older than 30 years as well as the mean length of the youngest age classes are overestimated. This overestimation of mean length is considered to be a model artefact, as the model effectively forces all fish towards L_∞ as the fish grow older.

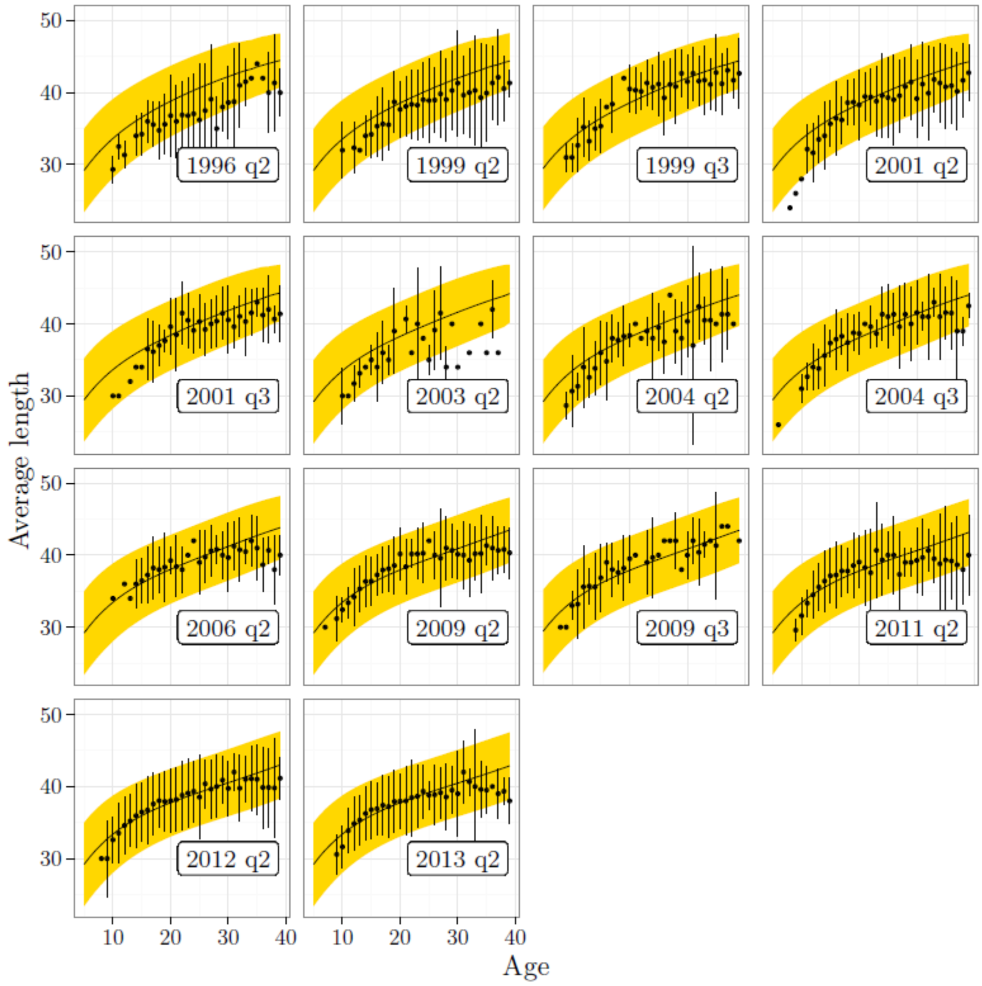


Figure 5.2.5 Deep-pelagic redfish in the Irminger Sea. Mean length-at-age by year and quarter from commercial catches. Black dots represent observed mean values, vertical bars 95% confidence range for the observations (where possible), solid line fitted mean and yellow ribbon the predicted 95% confidence limit (model configuration number 1).

Table 5.2.1 and Figure 5.2.6 illustrate the estimated trajectories from the Gadget model. The biomass estimates refer to biomass at the start of the year, catches are the total annual landings, recruitment is the number of 5 year old fish that enter the model during the 1st quarter of the year, and the annual fishing mortality is the average of the quarterly apical fishing mortalities. The model estimates that the total biomass peaked in the early 1990's but has been on a steady decline since then. Although catches have decreased, the fishing mortality has increased substantially since the late 1990s, with the fishing mortality ranging between five to ten times the natural mortality. Recruitment of 5 year old fish into the stock has been relatively stable between 1985 and 2006. Estimates of recruitment after 2006 (i.e. after year class 2001) are considered unreliable as the fish do not consistently enter the fishery and the survey until they are 15 years old. Therefore, recruitment from 2007 onwards was fixed in the projections to the geometric mean recruitment (at age 5) of the years 19852006 (see Section 6 below for further details). All biomass and fishing mortality estimates from 2007 onwards were recalculated based on these fixed recruitment values, so as to match the observed catches in each of those years. Figure 5.2.7 and Table 5.2.2 show the stock assessment results including the recalculated values and this constitutes the final stock assessment. Estimated model parameters are shown in Table 5.2.3. Figure 5.2.8 shows the estimated selection curve and maturity ogive.

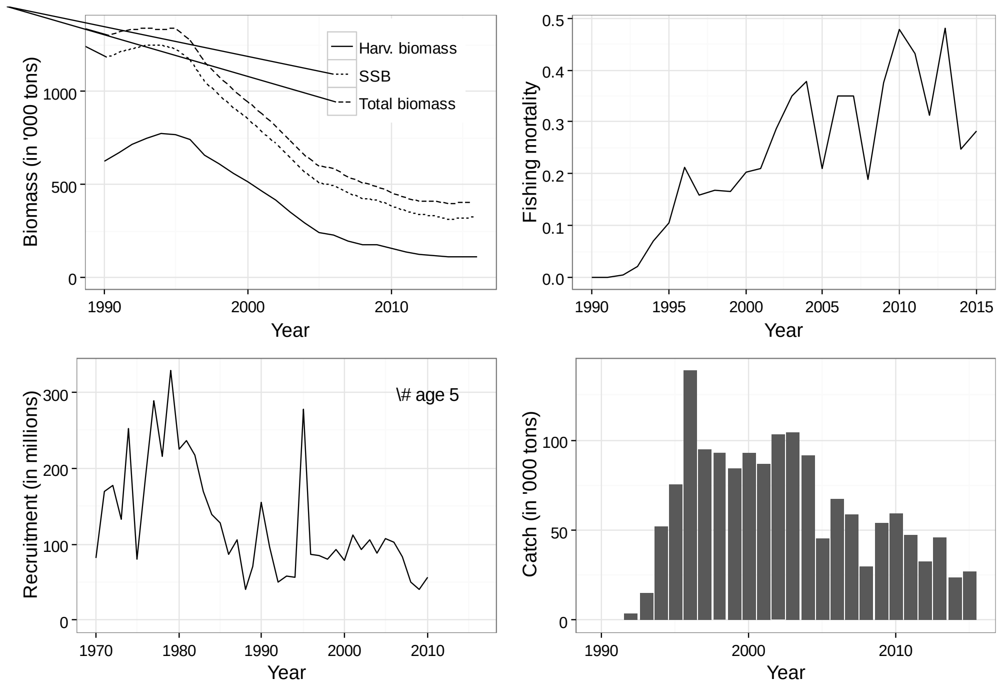


Figure 5.2.6 Deep-pelagic redfish in the Irminger Sea. Summary of results from the stock assessment (model configuration number 1); outputs as directly obtained from the Gadget model. Top left: Total biomass, spawning-stock biomass and harvestable biomass (kt). Bottom left: Recruitment-at-age 5 (millions). Top right: Fishing mortality (apical F, i.e. the F of fully selected lengths). Bottom right: Total annual catches (kt) (not estimated).

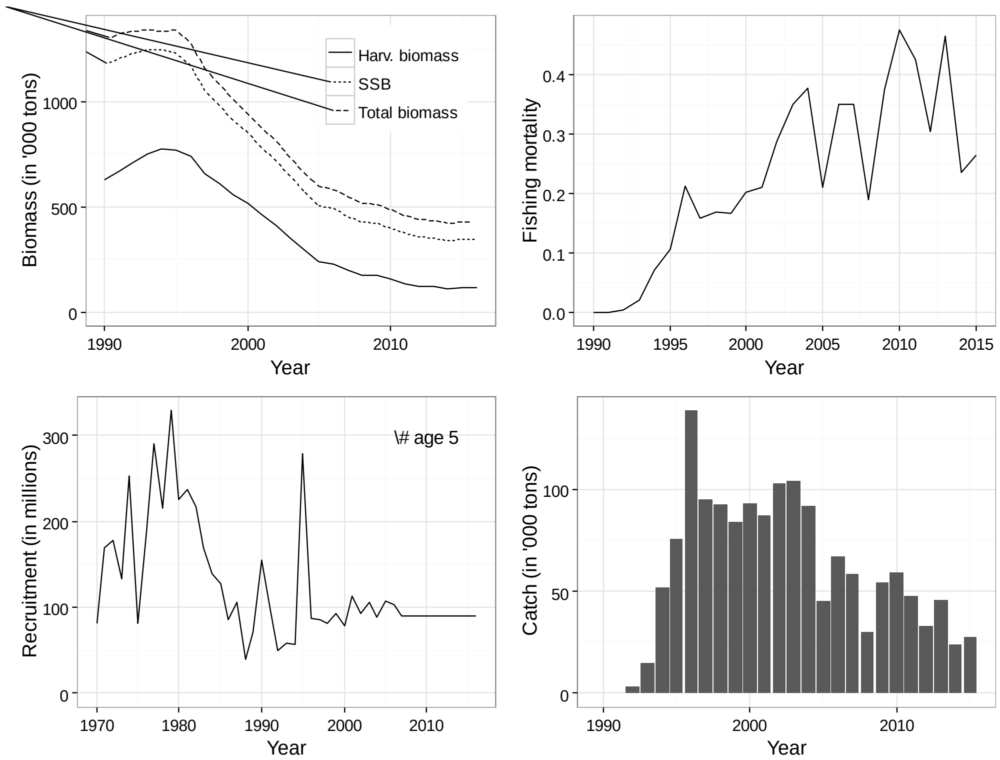


Figure 5.2.7 Deep-pelagic redfish in the Irminger Sea. Summary of results from the stock assessment (model configuration number 1); recruitment from 2007 onwards is fixed to the geometric mean age 5 recruitment between 1985 and 2006, and F and SSB recalculated accordingly. Top left: Total biomass, spawning-stock biomass and harvestable biomass (kt). Bottom left: Recruitment-at-age 5 (millions). Top right: Fishing mortality (apical F, i.e. the F of fully selected lengths). Bottom right: Total annual catches (kt) (not estimated).

Table 5.2.1 Deep pelagic redfish in the Irminger sea. Summary of results from the stock assessment (model configuration number 1); outputs as directly obtained from the Gadget model. Biomass values are in kt and the recruitment in millions of fish. Estimates of recruitment after 2006 (year class 2001) were considered unreliable and omitted from this table.

Year	Biomass	Harvestable	SSB	Catch	F	Recruitment
1985	1140.659	402.424	962.497	0.000	0.000	127.624
1986	1176.275	445.854	1014.113	0.000	0.000	86.128
1987	1213.363	490.669	1062.766	0.000	0.000	105.498
1988	1233.380	536.036	1102.061	0.000	0.000	39.875
1989	1256.773	581.553	1137.993	0.000	0.000	70.828
1990	1295.983	626.822	1175.735	0.000	0.000	154.506
1991	1321.057	670.896	1206.600	0.059	0.000	96.700
1992	1333.318	713.049	1230.206	3.398	0.005	49.882
1993	1341.083	750.250	1246.657	15.064	0.021	58.747
1994	1333.482	775.027	1246.880	51.820	0.071	56.317
1995	1337.545	768.926	1226.119	75.707	0.106	278.065
1996	1276.802	739.019	1169.264	138.552	0.212	86.454
1997	1157.601	658.703	1054.511	95.079	0.159	84.810
1998	1080.066	609.143	981.412	92.818	0.169	81.079
1999	1008.255	559.476	911.953	84.153	0.166	93.306
2000	941.988	514.641	849.783	93.113	0.203	78.802
2001	875.549	462.127	782.282	86.993	0.210	112.447
2002	811.498	413.353	719.794	103.128	0.287	93.107
2003	736.082	352.326	644.048	104.296	0.350	106.036
2004	657.734	291.527	567.852	91.954	0.377	88.640
2005	598.182	242.477	507.503	45.485	0.210	107.439
2006	582.387	227.563	491.048	67.288	0.351	103.174
2007	542.267	198.186	453.474	58.516	0.351	-
2008	504.547	176.493	422.762	30.045	0.190	-
2009	490.600	173.955	416.277	54.406	0.375	-
2010	455.973	155.581	386.529	59.288	0.479	-
2011	427.177	134.945	355.425	47.333	0.432	-
2012	410.987	122.661	336.539	32.806	0.312	-
2013	408.773	119.159	331.400	46.052	0.481	-
2014	395.030	108.229	315.209	23.755	0.247	-
2015	402.993	110.412	320.522	27.433	0.282	-
2016	407.702	110.563	323.035	-	-	-

Table 5.2.2 Deep pelagic redfish in the Irminger sea. Summary of results from the stock assessment (model configuration number 1). Biomass values are in kt and the recruitment in millions of fish. Estimates of recruitment after 2006 (year class 2001) were considered unreliable and replaced using a geometric mean recruitment (at age 5) between 1985 and 2006. All biomass and fishing mortality estimates from 2007 onwards were recalculated accordingly, so as to match the observed catches in each of those years. The recalculated values are indicated in italics.

YEAR	BIOMASS	HARVESTABLE	SSB	CATCH	F	RECRUITMENT
1985	1140.659	402.424	962.497	0.000	0.000	127.624
1986	1176.275	445.854	1014.113	0.000	0.000	86.128
1987	1213.363	490.669	1062.766	0.000	0.000	105.498
1988	1233.380	536.036	1102.061	0.000	0.000	39.875
1989	1256.773	581.553	1137.993	0.000	0.000	70.828
1990	1295.983	626.822	1175.735	0.000	0.000	154.506
1991	1321.057	670.896	1206.600	0.059	0.000	96.700
1992	1333.318	713.049	1230.206	3.398	0.005	49.882
1993	1341.083	750.250	1246.657	15.064	0.021	58.747
1994	1333.482	775.027	1246.880	51.820	0.071	56.317
1995	1337.545	768.926	1226.119	75.707	0.106	278.065
1996	1276.802	739.019	1169.264	138.552	0.212	86.454
1997	1157.601	658.703	1054.511	95.079	0.159	84.810
1998	1080.066	609.143	981.412	92.818	0.169	81.079
1999	1008.255	559.476	911.953	84.153	0.166	93.306
2000	941.988	514.641	849.783	93.113	0.203	78.802
2001	875.549	462.127	782.282	86.993	0.210	112.447
2002	811.498	413.353	719.794	103.128	0.287	93.107
2003	736.082	352.326	644.048	104.296	0.350	106.036
2004	657.734	291.527	567.852	91.954	0.377	88.640
2005	598.182	242.477	507.503	45.485	0.210	107.439
2006	582.387	227.563	491.048	67.288	0.351	103.174
2007	543.804	198.212	454.026	58.516	0.351	90.343
2008	515.092	176.694	426.700	30.045	0.189	90.343
2009	513.035	174.502	425.519	54.406	0.374	90.343
2010	487.571	156.687	401.280	59.288	0.475	90.343
2011	458.112	136.762	373.027	47.333	0.426	90.343
2012	440.850	125.398	356.624	32.806	0.305	90.343
2013	437.167	123.000	353.410	46.052	0.464	90.343
2014	421.569	113.453	338.484	23.755	0.234	90.343
2015	427.318	117.050	344.310	27.433	0.265	90.343
2016	429.478	118.724	346.606	-	-	90.343

Table 5.2.3 Deep pelagic redfish in the Irminger sea. Parameter estimates from the stock assessment (model configuration 1). In this configuration, L_∞ is fixed at 50 cm. For a detailed description of the model parameters see Stock Annex.

PARAMETER	ESTIMATE
k	0.05
β	50.00
L_0	26.29
σ_0	2.42
b_s	0.42
$L_{50,s}$	42.41
b_c	0.46
$L_{50,c}$	38.42
q	1.09

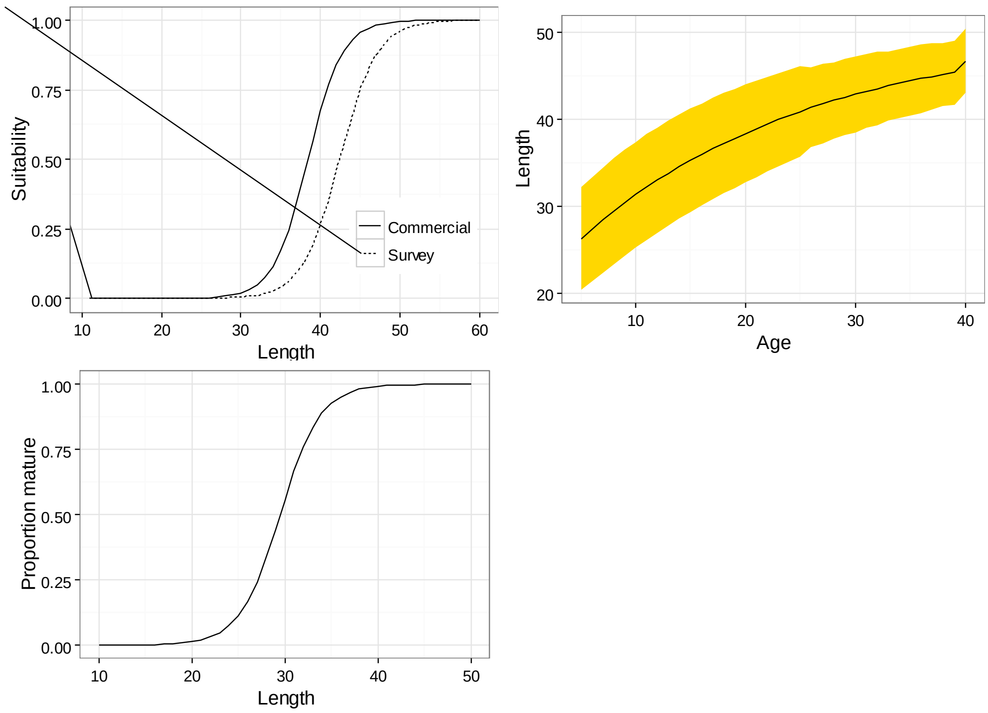


Figure 5.2.8 Deep pelagic redfish in the Irminger Sea. Illustration of selected modelled processed (model configuration 1). Top left panel: fitted length based selection. Top right panel: estimated mean length-at-age along with the standard deviation in length. Bottom left panel: maturity at length (estimated outside the model).

A retrospective analysis is illustrated in Figure 5.2.9. The estimates of biomass and fishing mortality are consistently estimated and there is no obvious retrospective pattern. The recruitment estimates, however, decrease substantially as years of data are removed from the model. Model runs omitting the 2013 age data (the most recent year for which age composition data are available) estimate substantially fewer recruits than the runs that include those data.

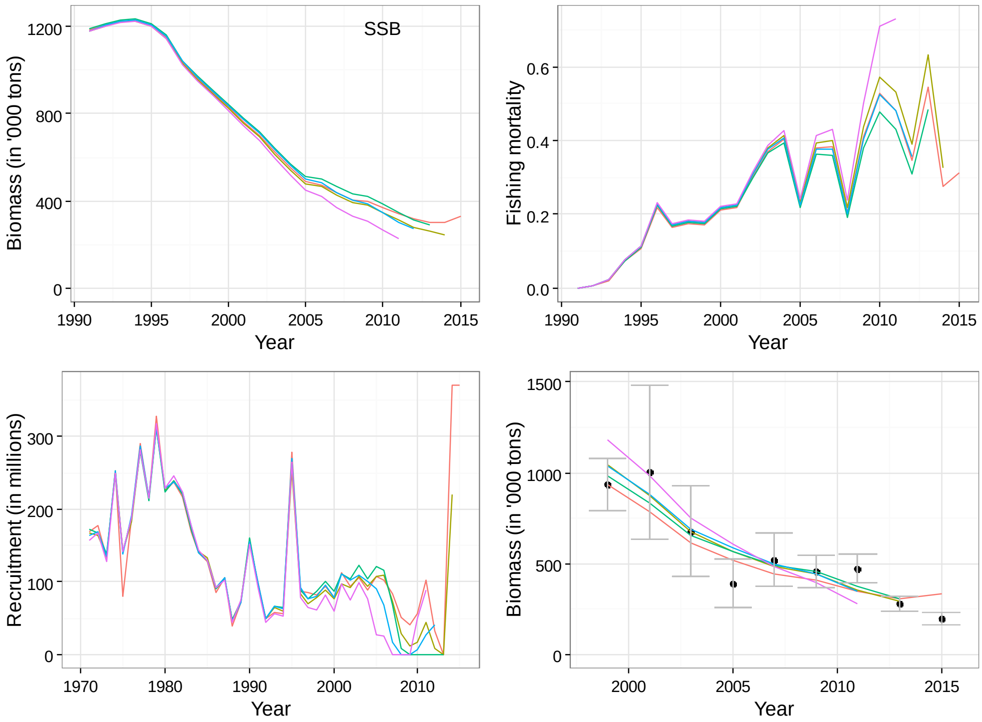


Figure 5.2.9 Deep-pelagic redfish in the Irminger Sea. Retrospective estimates, for the last 5 years, of spawning-stock biomass, recruitment (age 5), fishing mortality (apical), and the fit the biomass index. Model configuration number is 1.

5.2.3 Conclusions

The Gadget model for the deep pelagic beaked redfish in the Irminger Sea is overall considered to give a satisfactory description of stock trends. It synthesizes information on the stock development based on available biological samples from the fishery as well as the stock biomass index from the international redfish survey. Several issues remain that could not be resolved during the WKDEEPRED workshop.

Notably the retrospective analysis revealed that the estimates of recruitment are unstable and require almost 10 years of age data to converge. Although it is believed that further information on age will improve the stability in the retrospective analysis, information on fish younger than 10 years is not considered likely to improve in the foreseeable future as such young fish are only very rarely caught by the fishery or survey.

The modelled growth appears to be biased towards producing larger fish than currently observed. Although this can influence the effect of fishing, particularly when projecting the stock biomass forward for the calculation of reference points, this is not considered to have substantial effect in the short-term projections.

WKDEEPRED concluded that model configuration number 1 (see Section 5.2.1), where the survey catchability is estimated instead of fixed to 1, is an appropriate basis for the assessment of deep-pelagic redfish in the Irminger Sea. Mainly because of the aspects that still require further exploration, including additional age data from collected otoliths that will likely become available over the next few years and could bring additional insights, and the fact that the data currently only cover a short period relative to the lifespan of the species, it was concluded that it is more appropriate to consider this assessment as a Category 2 (instead of Category 1) at this point in time.

A full set of assessment results from the stock assessment agreed by WKDEEPRED has been provided in Section 5.2.2.

6 Short-Term Projections

Projection settings:

WKDEEPRED agreed the following settings to conduct short-term projections:

Model used: Same age-length structured population dynamics model used in the stock assessment (implemented in Gadget)

Software used: Gadget and RGadget (see github.com/hafro/gadget and github.com/hafro/rgadget)

Initial stock size:

As estimated from the stock assessment with the following modifications (see Section 5.2):

Recruitment (at age 5) in the last 10 years in the assessment is replaced by the geometric mean of the recruitment estimated for the years ranging from 1985 to (last year included in the assessment9); for example, for an assessment based on data until 2015, recruitment for years 2007 and onwards is replaced by the geometric mean of the recruitment estimates for the years 19852006. Fishing mortality and stock abundance in the last 10 years in the assessment are recalculated according to the replaced recruitment values so as to match the observed catches (in overall tonnage) in each of those years.

Recruitment (at age 5) in the intermediate year (the year following the last year included in the assessment) and any subsequent forecast years uses the same geometric mean value applied for the replaced recruitments in the assessment (described in previous paragraph).

Maturity: The projections use the same maturity ogive at length applied in the stock assessment (assumed constant over time).

F and M before spawning: SSB is calculated on January 1st; therefore, the proportion of F and M before spawning is 0.

Weight at age in the stock: The model uses weight-at-length. The weight-at-length relationship used for the projections is the same one used in the stock assessment (assumed constant over time)

Weight at age in the catch: The model uses weight-at-length. The weight-at-length relationship used for the projections is the same one used in the stock assessment (assumed constant over time)

Exploitation pattern: The projections the selection-at-length pattern estimated in the stock assessment (assumed constant over time)

Intermediate year assumptions: Recruitment in intermediate year has been explained above. An assumption about either catch or F in the intermediate year is also necessary in order to project the stock to the start of the year(s) for which catch options are provided; the intermediate year assumption should be based on the most reliable information available to NWWG experts.

Stock recruitment model used: Recruitment in the forecast years has been explained above.

Procedures used for splitting projected catches: Total catches are not split into any components. Discards are considered to be negligible.

Projections for 2017 and 2018:

WKDEEPRED applied the agreed settings to conduct short-term projections for 2017 and 2018, with results as follows:

Assumptions needed for projections:

Recruitment (age 5) in 2016, 2017 and 2018 was assumed to be equal to the geometric mean of the estimated recruitment during 1985-2006, i.e. 90 million fish.

Catch in 2016 was assumed to be 29 kt, based on the fact that the fishery until mid-July had taken approximately 28 kt and that experts with knowledge of the fishery indicated that the 2016 fishery would be almost concluded by that time. This assumption about catch results in F(2016) = 0.279 and SSB(2017) = 336 kt (which is below B_{lim}).

Projections at different values of F in 2017 and 2018:

Table 6.1: Short-term forecast. Values of catch and SSB are in kt

MAN.TYPE	F 2017	SSB 2017	CATCH 2017	F 2018	SSB 2018	CATCH 2018	F 2019	SSB 2019	CATCH 2019
0.1 * Status quo	0.028	335.79	3.011	0.028	361.68	3.439	0.025	387.00	3.884
0.2 * Status quo	0.056	335.79	5.908	0.056	358.82	6.658	0.05	381.07	7.422
0.3 * Status quo	0.084	335.79	8.695	0.084	356.15	9.672	0.076	375.43	10.650
0.4 * Status quo	0.112	335.79	11.378	0.112	353.55	12.498	0.102	370.43	13.598
0.5 * Status quo	0.14	335.79	13.961	0.14	351.04	15.148	0.13	365.01	16.293
0.6 * Status quo	0.167	335.79	16.449	0.167	348.62	17.637	0.158	360.19	18.761
0.7 * Status quo	0.195	335.79	18.846	0.195	346.30	19.974	0.187	355.60	21.023
0.8 * Status quo	0.223	335.79	21.155	0.223	344.05	22.172	0.217	351.23	23.099
0.9 * Status quo	0.251	335.79	23.381	0.251	341.89	24.240	0.247	347.07	25.006
1 * Status quo	0.279	335.79	25.531	0.279	339.81	26.187	0.279	343.09	26.763
Fmsy	0.041	335.79	4.386	0.041	360.34	4.978	0.041	384.18	5.587
Scale * Fmsy	0.018	335.52	1.953	0.019	362.79	2.378	0	387.63	0
Zero catch	0	335.79	0	0	364.6	0	0	393.27	0

7 Reference Points (PA and MSY)

The age-length-structured assessment implemented in Gadget was considered by WKDEEPRED to form an appropriate basis to assess the stock and to provide catch advice at this time, as a Category 2 assessment. The assessment results are presented in Section 5.2 and shown again here (Figure 7.1) for ease of reference in this section. Although results are presented with absolute scales in this section, the final presentation of assessment results and reference points for the ICES advice sheet will be on a relative scale (i.e. the time-series of estimated recruitment, F and SSB will be scaled such that each will have an average = 1 over the time-series; fishing mortality and biomass reference points will be scaled by the same number), as corresponding to Category 2 assessments.

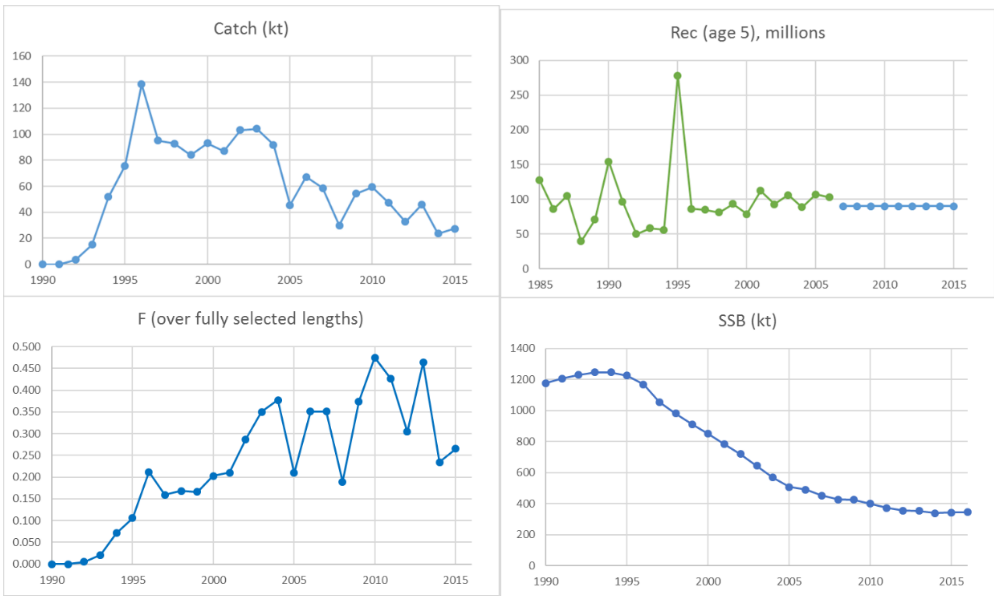


Figure 7.1: Summary of stock assessment agreed by WKDEEPRED, see Table 5.2.2 for a tabulation of results (to be presented as a Category 2 assessment, i.e. with Recruitment, F and SSB on relative, rather than absolute, scale). Recruitment after 2006 is not considered to be reliably estimated and has been replaced by the geometric mean of the estimated recruitment during 19852006. SSB and F values after 2006 were recalculated accordingly, so as to match the observed catches in those years.

As stated in the Introduction to the ICES advice (ICES 2016b), for Category 1 and 2 stocks ICES provides advice in accordance with agreed management plans/strategies evaluated to be consistent with the precautionary approach. If such plans/strategies are not agreed or have been evaluated by ICES not to be precautionary, ICES will give advice on the basis of the ICES MSY approach or, in the absence of defined F_{MSY} reference point, on the precautionary approach. WKDEEPRED undertook the derivation of biological reference points following the principles indicated in the ICES technical guidelines on reference points (ICES 2016c).

Setting B_{lim} and B_{pa}:

B_{lim} was considered from examination of the SSBRecruitment (at age 5) scatterplot based on the estimates from the agreed stock assessment. As recruitment after 2006 is not considered reliably estimated from the current assessment (stock assessment retrospective plots indicate that recruitment estimates take about 10 years to stabilize), the points shown on the stock–recruitment plot (Figure 7.2) correspond to the year classes 19902001.

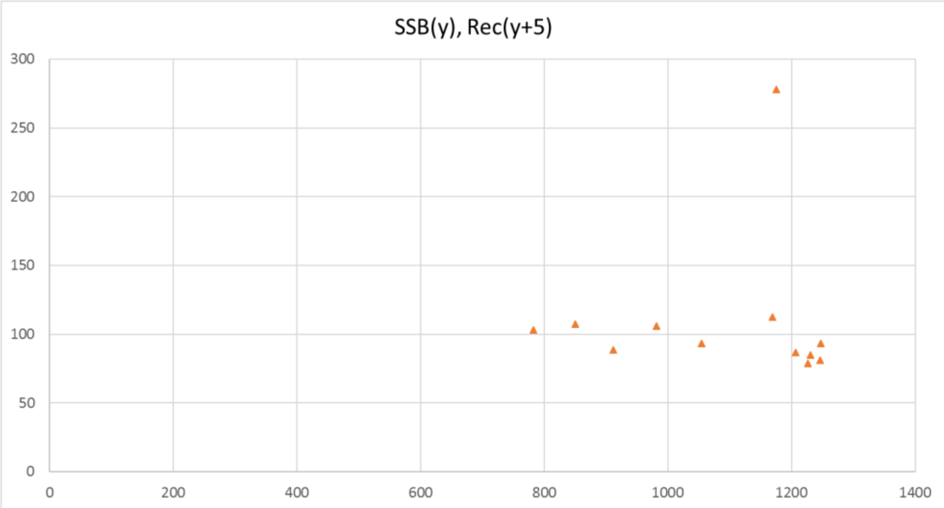


Figure 7.2: Scatterplot of (SSB (year y), Recruitment (year y+5)), as estimated from the stock assessment for the year classes 19902001.

Figure 7.2 shows a relatively narrow dynamic range of SSB and no evidence of impaired recruitment. In this situation, WKDEEPRED considered that B_{lim} could not be estimated from these data and that the lowest observed SSB during that period (i.e. B_{loss} = SSB(2001) = 782 kt) was an appropriate value at which to set B_{pa} at this point in time.

In line with ICES technical guidelines, since B_{pa} but no B_{lim} can be estimated, a proxy for B_{lim} can be calculated based on the inverse of the standard factor used for calculating B_{pa} from B_{lim}. Therefore, WKDEEPRED considered that a proxy for B_{lim} could be set at B_{pa}/1.4 = 782/1.4 = 559 kt. It should be noted that the factor 1.4 is not a value based on the true assessment uncertainty, which has not been quantified.

Setting F_{lim} and F_{pa}:

According to the ICES guidelines, F_{lim} is derived from B_{lim} by simulating a stock with segmented regression stock–recruitment function with the point of inflection at B_{lim} and setting F_{lim} as the F that, in equilibrium, gives a 50% probability of SSB > B_{lim}.

For this stock, because B_{lim} was derived as a proxy from B_{pa} and there are currently no reliable recruitment estimates to inform about recruitment when SSB is below the B_{loss} of Figure 7.2, WKDEEPRED considered it more appropriate to fix the inflection point of the stock–recruitment function to be used in all long-term simulations at the B_{loss} from Figure 7.2 (=SSB(2001)). A similar idea was applied by ICES in the calculation of reference points for several Western Waters stocks (ICES, 2016d).

During the simulation period, recruitment (at age 5) was stochastically drawn from the recruitment values estimated for the period 1985-2006 (see Figure 7.1). For simulation years y in which SSB(y) < SSB(2001), the simulated recruitment value in year y+5 was multiplied by SSB(y)/SSB(2001). The simulations considered a burn-in period of 200 future years, followed by a period of 100 years from which results were extracted.

The results of the long-term simulations are shown in Figure 7.3; the value of F resulting in 50% long-term probability of SSB > B_{lim} is F_{lim} = 0.057.

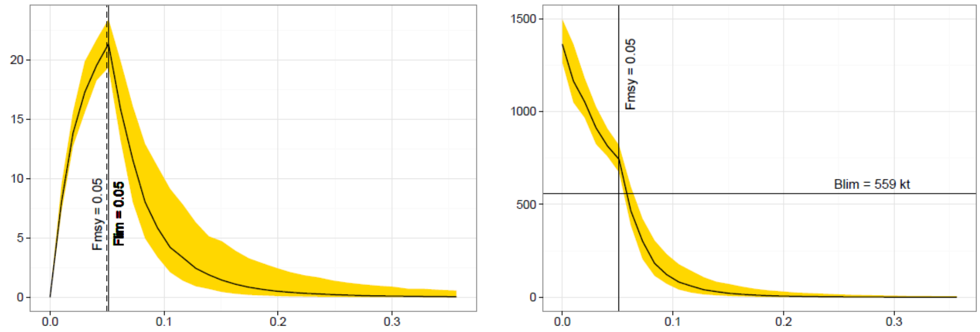


Figure 7.3: Long-term equilibrium catch (left panel) and SSB (right panel) vs. F. Black lines represent median catch and SSB, and yellow bands 90% probability intervals.

In the absence of a quantification of assessment uncertainty, F_{pa} is set using the default factor 1.4. This results in $F_{pa} = F_{lim}/1.4 = 0.041$.

Setting F_{MSY} and MSY $B_{trigger}$:

F_{MSY} was based on the same stochastic simulation used to determine F_{lim}. According to the ICES technical guidelines, the simulation for F_{MSY} should also incorporate assessment/advice error; this, however, was not possible with the available software, so the simulation was conducted without including this source of error.

The plot of long-term equilibrium catch vs. F (left-hand side of Figure 7.3) indicates that median long-term yield is maximized when F=0.05, which would, therefore, be a first candidate value for F_{MSY}. However, this first candidate value for F_{MSY} is > F_{pa}, which is not considered acceptable in the ICES framework; therefore, F_{pa} = 0.041 becomes the candidate F_{MSY} value. From Figure 7.3 (right-hand panel), a value of F=0.041 results in < 5% probability of the long-term SSB falling below B_{lim} and, therefore, it is proposed by WKDEEPRED as F_{MSY} for this stock.

Since the stock has been fished above F_{MSY} for almost its entire exploitation history, it is not possible at this point to get a reliable estimate of the lower range of SSB values expected when the stock is continuously fished at F_{MSY}. Therefore, for the time being, MSY $B_{trigger}$ is set at B_{pa}.

Summary of reference points agreed by WKDEEPRED:

Note: the reference point values in the ICES advice sheet will be presented as relative values with respect to the average of the F and SSB estimates over the stock assessment series, as corresponds to Category 2 assessments.

Framework	Reference point	Value	Technical basis
MSY approach	MSY $B_{trigger}$	782 kt	Bpa
	F_{MSY}	0.041	F that maximizes median long-term catch in stochastic simulations with recruitment drawn from 1985-2006 estimates while incorporating a factor to gradually reduce recruitment when SSB < SSB(2001) (where SSB(2001) is the Bloss from the converged stock–recruitment period). FMSY is constrained not to exceed Fpa.
Precautionary approach	B_{lim}	559 kt	Bpa / 1.4
	B_{pa}	782 kt	SSB(2001), corresponding to Bloss from the years with converged SSB and recruitment estimates (year classes 1990-2001)
	F_{lim}	0.057	F corresponding to 50% long-term probability of SSB > Blim.
	F_{pa}	0.041	Flim / 1.4

8 Future Research and Data Requirements

The following items were identified by WKDEEPRED:

Data needs:

- Age and length composition data from the catch of Russia, the country taking most of the catches, should be made available for the stock assessment.
- Additional age composition data could be available from currently un-aged otoliths sampled from Icelandic commercial catches and should be explored for possible incorporation in future assessments
- Explore why would there be a consistent difference in the length-at-age (in range 2030 years) between quarters 2 and 3 in years 1999 and 2004?
- Although this was not discussed in detail at the workshop, the reviewers recommend that in the future the survey procedures and gear standardization should be considered and data should be examined to determine if the mean catch rate is better estimated across countries or by country. See reviewers' report (Annex 3 to this report) for additional detail.

Model needs:

Overall, further exploration and development of the Gadget model is encouraged.

- Fits to the length-at-age data do not seem good for ages > 30. Length appears to be overestimated for those ages. Investigate likely reasons, potential impacts on assessment and reference points, and ways to solve this.
- Explore the sensitivity of results to the choice of weights assigned to the different datasets.
- Explore potential changes in the selectivity-at-length of the fishery over time. There is a consistent tendency from 2003 onward for the number of observed small fish to be lower than that predicted by the model. Is this the cause of the retrospective recruitment pattern in that the smallest fish aren't present in the samples but that these cohorts show up later?
- Explore the lack of fit of the early (19941997) commercial length distributions. How does this affect estimates of early recruitment?
- Explore sensitivity to the length of the model time-step, e.g. by changing it from 3 months to 6 months.

9 Conclusions

Because redfish is a long-lived species, the stock biomass indicator from the survey, which starts in 1999, is not sufficiently long to be able to estimate the stock's productivity (or a level of exploitation that the stock could safely sustain) from the time-series of catches and biomass survey series. The biomass indicator shows a continuously declining trend over the available time-series and the perception of the stock's productivity from the biomass dynamics model becomes progressively more pessimistic as new survey values are added to the time-series (see retrospective pattern of F/F_{MSY} and B/B_{MSY} shown in Section 5.1, Figures 5.1.3 and 5.1.6). A biomass dynamics model is only likely to become an effective tool once the declining trend observed so far in the biomass indicator starts to reverse.

An age-length structured stock assessment model was developed with Gadget; this model also used age and length composition data. The inclusion of the composition data in the assessment lent stability to the assessment results, and no strong retrospective pattern emerged. Fits to the data were considered overall adequate and WKDEEPRED concluded that this model provides an appropriate way of assessing the stock at this time. Although the Gadget assessment appears to capture trends on stock biomass and fishing mortality reliably, some aspects of the assessment still require further exploration, the data currently available cover only a short period relative to the lifespan of the species, and additional age data that might bring in additional insights are expected to become available over the next few years. WKDEEPRED therefore concluded that currently this assessment should be considered as a Category 2 (instead of Category 1) assessment and await future incoming data to evaluate its robustness.

The details of the agreed stock assessment model, settings for short-term forecast, and reference points are described in the Stock Annex.

10 References

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ICES. 2008. Report of the North-Western Working Group (NNWG), 2129 April 2008, ICES CM 2008/ACOM:03.

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ICES. 2016a. Report of the North-Western Working Group (NWWG), 27 April–4 May, 2016, ICES Headquarters, Copenhagen. ICES CM 2016/ACOM:08.

ICES. 2016b. ICES advice basis. ICES Advice books, 2016, Section 1.2.

ICES. 2016c. ICES fisheries management reference points for category 1 stocks. Document available in draft form, final reference not currently available.

ICES. 2016d. Report of the Workshop to consider FMSY ranges for stocks in ICES categories 1 and 2 in Western Waters (WKMSYREF4), 13–16 October 2015, Brest, France. ICES CM 2015/ACOM:58. 187 pp.

Pedersen, M.W. and Berg, C.W. 2016. A stochastic surplus production model in continuous-time. Fish and Fisheries, DOI: 10.1111/faf.12174.

Taylor, L., Begley, J., Kupca, 5. and Stefansson, G. 2007. A simple implementation of the statistical modelling framework Gadget for cod in Icelandic waters. African Journal of Marine Science, 29(2):223245.

Annex 1: Participant List

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Annex 2: New Stock Annex

The table below provides an overview of the Stock Annexes. Stock Annexes for other stocks are available on the ICES website Library under the Publication Type "Stock Annexes". Use the search facility to find a particular Stock Annex, refining your search in the left-hand column to include the *year*, *ecoregion*, *species,* and *acronym* of the relevant ICES expert group.

Stock ID	Stock name	Last updated	Link
smn-dp_SA	Deep Pelagic beaked redfish (Sebastes mentella) in ICES Subareas 5, 12, and 14 (Iceland and Faroes grounds, north of Azores, east of Greenland) and NAFO Subareas 1+2 (deep pelagic stock >500 m)	August 2016	smn-dp_SA

Annex 3: External Reviewers Report

Review of Deep Pelagic Redfish workshop 2325 August Copenhagen

John Simmonds and Cóilín Minto

Summary:

The reviewers support the decision of the workshop to propose the proposed Gadget assessment model for Deep Pelagic Redfish as a category 2 assessment. The choice of values for reference points is also supported by the reviewers and considered to be in accordance with ICES guidance (ICES Technical Guidelines document on reference points) and practice (Report of WKMSYREF4).

Review

General

The main issues addressed during the meeting and remaining are discussed briefly below, more detail is provided in the report as contributions to the section on future work. The review is a combined report and reflects the consensus of both reviewer considerations. It addresses input data, and related modelling preferences; the two main model approaches individually; the decision between models; reference points and short-term forecast.

Input data

Survey analysis The treatment of survey data are intended to give an absolute estimate based on extending the echo integration acoustic survey for shallow pelagic redfish to the deep stock. The methodology depends on the assumption that the catchability (cpue) of the survey gear is independent of depth over the depth range for the two stocks. This assumption and general approach is accepted as preferable to the use of the acoustic survey to depths greater than 500m. The methodology uses a mean catch rate for the gear by country. For future the procedures and gear standardization should be considered and data should be examined to determine if the mean catch rate is better estimated across countries or by country. Given that the survey relies not just on acoustic assumptions but also stability of gear catchability it was considered that it was preferable to estimate survey q in both models tested.

Uncertainty in catch It's accepted that generally catch is well documented from reported landings, however, underreporting was noted for a 5 year period the sensitivity of the assessment models appears to be acceptable (very small) for both models. However, parameterization of error in catch did influence the surplus production model and was of some concern.

Age and length samples from the fishery Currently, age data appears to come almost entirely from Icelandic fishery. While the issue does not appear to be a problem given overlapping length distributions in previous work. Reliance on these samples is not good practice, data from other fisheries should also be included would be helpful for development of age/length based models. Efforts should be made to obtain age data particularly from the Russian catch. This may be even more important if different countries respond differently to the ICES advice for reduced catch.

Models

SPiCT Assessment Model

Two major issues were identified with the SpiCT assessment:

In the initial model the intervals on F are much larger than intervals on B but catch is not particularly uncertain. The model was modified to decrease the implied uncertainty, which appears to give more precise estimates of F that fit better with perceptions of uncertainty in catch. However, the survey q appears to be particularly sensitive to this assumption, leading to concerns regarding the absolute scaling of the assessment.

The retro analysis shows considerable instability in B_{MSY} and F_{MSY} so that interannual variability of advice based on MSY approach would be driven not just by revised SSB and F but also in the changes in MSY reference points. In particular, the parameters governing productivity at low biomass (r and n) change with each new survey data point in the direction of increasingly lower estimates of productivity. This reflects the one-way trip nature of the survey index. Due to this issue the SPICT assessment was considered to be more applicable as a relative assessment, but even as a relative assessment the retro analysis suggests it performs poorly for MSY advice and would limit the utility of the assessment for MSY advice overall.

Gadget Assessment Model

Age-length fit While the model fits well to length-at-age through the middle ranges the model looks slightly problematic at both small and large lengths (See main report for a detailed discussion). The use of a single L_∞ for both the L_∞ in the von Bertalanffy model and the maximum allowed length appears to potentially give curves that head for a higher asymptotic value than that supported by the data. While small fish are estimated to grow rather quickly. These effects are considered likely to have a small influence on SSB of catch options. The miss fit at large size does not appear to affect the MSY values as the yield-per-recruit curve continually rises (a low peak would result from overestimation of biomass at large size). However, the increased growth at young age could be contributing to a tendency to give the highest precautionary F as MSY. This effect is not currently influencing the advice which is dominated by perceptions of current biomass.

Retrospective performance: Retros show better performance than for SPICT. Suggesting a more consistent model, however, further sensitivity to modelling constraints should be investigated to discover if the relatively stable estimated survey q is being constrained by other assumptions. This is one reason for using the trends from the assessment rather than the absolute value in a category 1 assessment. The retrospective performance is good for F and SSB but suggests poor estimation of recent recruitment. This has some issues for the short-term forecast but does not suggest an invalid assessment for management purposes. The use of a single fixed selection pattern may be causing the poor recruitment retro. This could be investigated further, however, the issue is not affecting the advice (see short-term forecast).

Weighting of samples: The approach used in gadget appears to be complex, involving some sample weighting related to number of length and age cells followed by a type of inverse weighting (model fit related) that applies to the data in groups or sets (i.e, length or age). As weighting can change the results substantially more exploration of the basis and sensitivity to weights would be helpful. The concepts are discussed in Francis (2011), in developing the gadget model more attention should be allocated to weighting (see discussion in main report).

R.I.C. Chris Francis 2011. Data weighting in statistical fisheries stock assessment models Can. J. Fish. Aquat. Sci . *Fish. Aquat. Sci.* 39(8): 11951207

High recruitment in the early years of the model (in years before catch and survey data are available). These values of R are found to be higher than recent R in order to provide the Ns at older ages in the early fishery. It's unclear how reliable these higher R may be and it's thought they may be sensitive to assumptions on natural mortality. They do not influence the advice considerations as only recent recruitment (after 1985) is used for reference point calculation and catch advice.

Modelling Conclusions

The SPICT biomass model has been extensively explored and the best model configuration identified. However, this model is intrinsically less suitable for advice due to the nature of the available input data; i.e. the indicator of stock biomass shows only decline without any indication of stable or increasing biomass. The Gadget based assessment has been explored less completely, the exploration carried out supports the view that this model provides a more stable assessment which is less sensitive about retrospective performance of F, SSB and survey q. Throughout, the exploration the models explored gave a consistent picture of stock dynamics that did not significantly depend on model.

In conclusion it is considered that both two proposed assessments are sufficiently stable to be used as a basis for trend advice. The SPiCT model while able to capture trends (category 3) is not considered suitable for either category 1 or 2 assessments. The Gadget model performs well in that it captures the trend as well as more stable biomass and F estimates compared with the SPiCT. While some further exploration is advised (see report) it is considered sufficient to provide advice based on the Gadget Model as a relative (category 2) assessment. This basis is considered to be a considerable improvement over the methods used as the basis of advice for the last few years.

Reference Points

The reference points have been evaluated fully in accordance with ICES recommendations and practice. The only issue is the specific biomass reference point starting point of $B_{pa} = B_{loss}$ for the most recent year where recruitment is considered stably estimated. Initial estimates of R at recent lower biomass are below the geomean (1985 on), but these are considered unreliable from the diagnostics (retros). If these R were judged realistic B_{pa} might have been set higher than the value chosen. However B_{pa} might be considered a little high relative to biomass at the start of the time-series/fishery, but for an age based perspective it is unclear how the biomass at the beginning might correspond to B0 associated with a production model. It was also noted that the SSB is currently below B_{lim} whatever the choice was. It is anticipated that the biomass reference points may need to be revised once the stock shows signs of increasing SSB and more recruit values are estimated. So, in conclusion, the final choice of B_{pa} appears to be an acceptable compromise and the value is not considered critical for the advice.

Short-term Forecast

The deterministic short-term forecast follows ICES procedures. The proposed assessment provides poor estimates of recent recruitment. Replacement of recruitment from 2007 onwards by geometric mean recruitment from 19852006 appears to be the best option. The effect of this on F and SSB in the terminal year of the assessment is seen to be small (67%) because the species is so long lived

Annex 4: Working Documents

Four working documents were presented at WKDEEPRED. Titles and brief summaries are included here, with the full documents available on the WKDEEPRED's Share-Point.

Working Document 1: Exploratory assessment of deep pelagic beaked resfish (*Sebastes mentella*) in the Irminger Sea and adjacent waters using Schaefer biomass dynamic model (Kristjan Kristinsson, Marine Resources Sections, Marine Research Institute, Reykjavik, Iceland)

Summary:

No analytical assessment is carried out on deep-pelagic beaked redfish (*Sebastes mentella*) in the Irminger Sea and adjacent waters because of data uncertainties and the lack of reliable age data. The results from the international redfish surveys since 1999 are the bases for the ICES advice of the stock and the status is assessed from biomass trends derived from the survey indices. Supplementary data includes relevant information from the fishery and length distribution from the commercial catch and the survey.

At the WKREDMP in 2014 (ICES 2014) a simple Gordon Schaefer assessment model was applied on nine candidate harvest control rules (HCR). The purpose was to do some initial evaluations of the candidate HCR performance. This working document is an update of this work with inclusion of catch data for 2014 and 2015 and new survey data point in 2015. None of the HCRs examined have a >95% probability of the stock in 2027 being larger than in 2016. The current update with new data gives an even more pessimistic view of the current status of the stock than the exercise done in 2014. Another aim of this working document was to document and describe the model used in the work in 2014. However, little documentation is available so the R-code is given at the end of this document.

Working Document 2: A surplus production model approach to assess Deep Pelagic *S. mentella* in the Irminger Sea (J. Boje and M. W. Pedersen. Greenland Institute of Natural Resources, 3900 Nuuk, Greenland; DTU Aqua, National Institute of Aquatic Resources, Denmark)

Summary:

Based on annual landing data available back to the start of the fishery for this stock in 1991 and biomass indices from the international trawl-acoustic survey every two years in 1999-2015, a stochastic Surplus Production model in Continuous-Time (SPiCT) was applied to assess the stock. The robustness of the model was explored by various sensitivity analyses of variability of model parameter priors, their precision and in precision of input to the assessment. The model was relatively robust to variability of parameters assumptions. However, retrospective analyses did show that the model has difficulties in estimating the productivity of the stock and revises its estimates when new data arrive. The model is therefore not sufficiently robust in an assessment and advice context with the present data. Contrasting data, where some reverse of the one-way trend becomes visible, are likely required for the model to properly estimate population parameters.

Working Document 3: An exploratory assessment of deep pelagic beaked redfish (*Sebastes mentella*) in the Irminger Sea, and adjacent waters, using the Gadget modelling framework (Bjarki Þór Elvarsson and Kristján Kristinsson, Demersal Fisheries Section, Marine Research Institute, Reykjavík, Iceland)

Summary:

This document describes a Gadget stock assessment of deep pelagic beaked redfish. The model is able to follow trends in the tuning data and the fit to other datasets is good. It briefly outlines the processes modelled, the types of data the gmodel fits to, the parameters and optimization process.

Working Document 4: Deep pelagic beaked redfish (*Sebastes mentella*) in the Irminger Sea and adjacent waters (Kristján Kristinsson, Marine Research Institute, Reykjavík, Iceland)

Summary:

This working document describes available data of deep pelagic beaked redfish (*Sebastes mentella*) in the Irminger Sea and adjacent waters.