ICES WKREDMP REPORT 2014

ICES ADVISORY COMMITTEE

ICES CM 2014/ACOM:52

Report of the Workshop on Redfish Management Plan Evaluation (WKREDMP)

20–25 January

Copenhagen, Denmark

ICES International Council for the Exploration of the Sea
CIEM Conseil International pour l'Exploration de la Mer

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

Recommended format for purposes of citation:

ICES. 2014. Report of the Workshop on Redfish Management Plan Evaluation (WKREDMP), 20–25 January, Copenhagen, Denmark. ICES CM 2014/ACOM:52. 269 pp.

Contents

Executive Summary

The Workshop on Redfish Management Plan Evaluation (WKREDMP) met at ICES headquarters in Copenhagen, Denmark from 20–25 January 2014. Three separate requests to evaluate management procedures for three different stocks of redfish were examined: *S. mentella* in I and II (Arctic), "Deep" *S. mentella* in Irminger Sea and adjacent waters, and *S. marinus* (golden redfish) in V–XIV. In addition, a benchmark assessment was conducted for the golden redfish stock. Members included scientists from all of the major countries involved in the exploitation of the stocks considered. Though there was no specific overlap between the stocks considered, all results and conclusions were presented and discussed in plenary to ensure agreement from the whole group.

Arctic *S. mentella*. WKREDMP evaluated 32 potential harvest control rule and operating model combinations. Operating models were conditioned on variations of the statistical catch-at-age model used by ICES to assess this stock. For the projections, different assumptions on recruitment relationship (hockey-stick vs. cyclical) and fishery selectivity (observed vs. demersal vs. pelagic) were evaluated. Key results from the simulations indicate that a high $B_{trigger}$ value in the HCR will increase variability of TAC between years. A biomass trigger of 600 kt seems to be a good starting point for future evaluations. The proposed F_{target} of F=0.039 appears to be on the lower end of the range of F candidates resulting in a high long-term yield, the upper end of the range being at 0.052. Long-term yield does not differ significantly over this range, hence F=0.039 represents a precautionary exploitation level that provides high long-term yields. However, the stock and recruitment might benefit from a delayed or gradual implementation of a management plan, or a gradual increase of F (fishing at F_{target} only after the incoming stronger year classes have fully recruited to the fishery in 2017/2018). A TAC stabilising rule in the management plan might have a similar effect if implemented on the basis of recent catch. The share of immature fish in the catch is higher in demersal fisheries than in pelagic fisheries. Management might want to consider a strategy that gives a higher share of the catch to pelagic fisheries as this would reduce F and increase SSB (if yield is fixed) or give a higher overall yield (if F is fixed).

Deep-pelagic *S. mentella* in the Irminger Sea. Both during and following WKREDMP the method for calculating the trawl index values was examined and tuned. This resulted in an almost completely changed index compared to the start of WKREDMP. Though it is considered that the quality of the index time-series has improved, it is still recommended that these changes are examined further. The index proposed as the basis for an HCR show a declining trend over time (decreasing by more than 75% in 15 years). The period of 14 years covered by the index time-series is less than a quarter of the maximum age attained by fish in this stock and is therefore a very short window of the stock development. This combined with insufficient aging data provides a very limited basis with which to gain a view of the long-term dynamics of the stock. So any simulations conducted at this stage necessitate a number of important assumptions. An exploratory biomass dynamics model was used to simulate the performance of candidate HCRs. In this framework, the performance of the HCRs depends on the catches and the intrinsic growth rate estimated for the stock (r). The value of r depends on the assumptions we make for the model parameters (B0=K, q=1). Since the assessment used has not been benchmarked, the most appropriate assumptions are not known. Hence, given the available data, it is very difficult at this stage to evaluate which HCRs are precautionary. Nevertheless,

the strong declining trend in the index suggests that future catches should be lower than those previously observed in order to allow for stock recovery to a larger biomass. None of the HCRs examined (as proposed in the request) lead to a >95% probability of stock growth over the next ten years according to the exploratory assessment. Using a TAC stabiliser would slow the reduction in catches and in turn the slow the growth of the stock, or cause further decline (this stabilising effect is doubled since TACs are set biennially). Developing age structured indices for this stock would allow for a much improved basis to evaluate short-term trends under different harvest scenarios.

Golden redfish (*S. marinus*) in V VI XII XIV. The assessment methodology for this stock was reviewed and a new benchmark assessment proposed. The same model previously used as indicative of trends (GADGET) is applied, with the following changes:

1) To account for the change in growth, mean length at recruitment (age 5) was estimated separately for year classes 1996–2000 and for 2001–recent.
2) Addition of data from the German Greenland Groundfish Survey in autumn (using a 22 500 km^2 area).
3) The weighting of the individual datasets in the GADGET model is now calculated using an iterative re-weighing algorithm.

A new stock annex has been produced incorporating these changes. This new assessment was used as a starting point for the forecasts made to evaluate the proposed management plan. The proposed HCR stabilises SSB above $B_{trigger}$ until at least 2020 under a wide range of assumptions on recruitment, assessment errors and stock definitions. Only if the recruitment was at the lowest observed level since 2006 and at the same time F is consistently underestimated (as could be caused by an inaccurate stock definition) would the biomass could fall below $B_{trigger}$ before 2020. This scenario is considered unlikely, and the proposed HCR is considered an appropriate basis for management. The group expects that there will be significantly better information on stock dynamics of this stock within the next five years. This will mainly be achieved by increased age reading from the survey and catch in Area XIV, and from attempts to improve the species separation of juvenile *S. marinus* and *S. mentella* in the German Greenland Groundfish survey.

1 Introduction

The **Workshop on Redfish Management Plan Evaluation** (WKREDMP) met at ICES headquarters in Copenhagen, Denmark from 20–25 January 2014. The meeting was chaired by David Miller (The Netherlands), with external reviewers Jan Jaap Poos (The Netherlands) and Daniel Duplisea (Canada). Twelve other members from Iceland, Faroe Islands, Norway, Greenland, Germany and Russia attended (see Annex 1 for the full participants list).

1.1 Terms of Reference

WKREDMP worked on responses to requests from NEAFC, Norway/Russia and from the Faroe Islands, Greenland, and Iceland, specifically:

a) Evaluate management plans as specified in the requests for:

   i) Request from NEAFC and Norway/Russia on *S. mentella* in I and II;

   ii) Request from Faroe Islands, Greenland and Iceland on "Deep" *S. mentella* in Irminger Sea and adjacent waters;

   iii) Request from Faroe Islands, Greenland and Iceland on *S. marinus* in V–XIV;

b) Review a new assessment of *S. marinus* in V–XIV, by correspondence and WebEx, prior to the WKREDMP meeting.

The full requests are found in Annexes 3–5.

Supporting Information

Priority:	Very high
Scientific justification and relation to action plan:	To answer the requests from NEAFC and some ICES member states in order improve the management of these stocks
Resource requirements:	
Participants:	Core redfish experts External reviewers Daniel Duplisea, Canada, and Jan Jaap Poos, the Netherlands
Secretariat facilities:	The meeting will be held at ICES HQ to benefit from WebEx facilities and full Secretariat support
Financial:	Included in the Secretariat budget and partly covered by NEAFC and ICES Members States. Travel and per diem will be covered for reviewers.
Linkages to advisory committees:	Reports to ACOM.
Linkages to other committees or groups:	AFWG and NWWG
Linkages to other organizations:	None

2 Long-term MP options for redfish (*Sebastes mentella*) in ICES Subareas I and II

2.1 Introduction

No management plan exists for this stock. This stock is at the moment managed by two different fisheries commissions (NEAFC and Joint Norwegian-Russian Fisheries Commission - JNRFC), and there is no agreement on how to split the TAC between areas or countries. NEAFC has set a TAC for this stock for the international area in the Norwegian Sea since 2007. In the Barents Sea, which is managed by JNRFC, there has been no directed fishery for this stock since the 1990s. However, Norway plans to open a directed *S. mentella* fishery in the Norwegian EEZ in 2014.

From 1995 to 2012, the ICES advice had been no directed catch/lowest possible level. For 2013 the advice was for a TAC of 47 000 t, based on $F_{0.1}$, which was used as an approximation to the reference point F_{MSY}. That advice was, however, based on calculations later found to be erroneous. The reference point $F_{0.1}$ was calculated to 0.039 (reference age range 12–18) by ICES (2013). The advice on catch levels for *Sebastes mentella* in ICES Subareas I and II for 2014 was based on a '*status quo*' approach of 24 000 t (approximately equal to the sum of the TAC set by NEAFC for 2013, 19 500 t, and the expected bycatch in the area managed by JNRFC). However, preliminary estimates of the catch in 2013 indicate that it is around 11 000 t. Catches have been stable around that level since 2008.

ICES was requested to test a wide range of harvest control rules for this stock. The requests are given in Annex 4. First a fairly general request on this was made by NEAFC, and then specific requests for a given range of HCRs was made by Norway and Russia.

2.2 Evaluation procedure

The PROST software (Åsnes, WD4) was used for making long-term stochastic simulations. PROST is a tool for making single-fleet, single-area long-term stochastic projections (see description in ICES, 2006) and was used for the simulations. Some new features had to be added before WKREDMP to accommodate for the features in the HCRs to be tested. It is available on the ICES web page.

PROST has previously been used in the evaluation of harvest control rules for north-east Arctic cod, haddock and saithe. In total, 10 000 simulations were run for each operating model/HCR combination.

2.3 Operating models

2.3.1 Biological model

2.3.1.1 Natural Mortality, weight-at-age and maturation

These are all assumed to be constant. M=0.05, Weight-at-age and Maturity-at-age are modelled values taken from Anon (2009). For the 19+ group, all individuals were assumed to be mature. The weight-at-age of the 19+ group was set to 700 g. This corresponds to a population at equilibrium but with longevity of 42 years, a realistic value given the age distribution presented in the AFWG report (Figure 6.16 in ICES

2013a). Weight-at-age in stock and catch are equal and the proportion of F and M before spawning is set to zero.

Figures 2.1 and 2.2 show the weight-at-age and maturity-at-age for each of the years 2003–2012 compared to the modelled values.

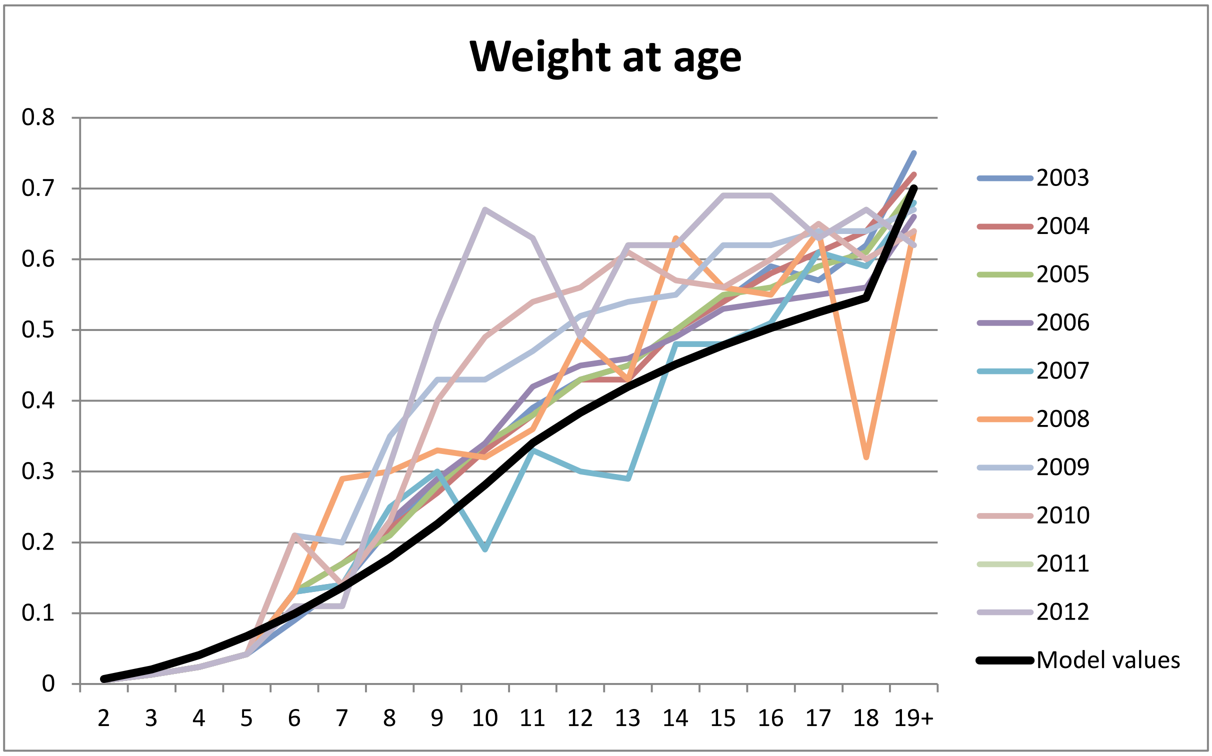

Figure 2.1. Modelled weight-at-age compared to observed values during the period 2003–2012.

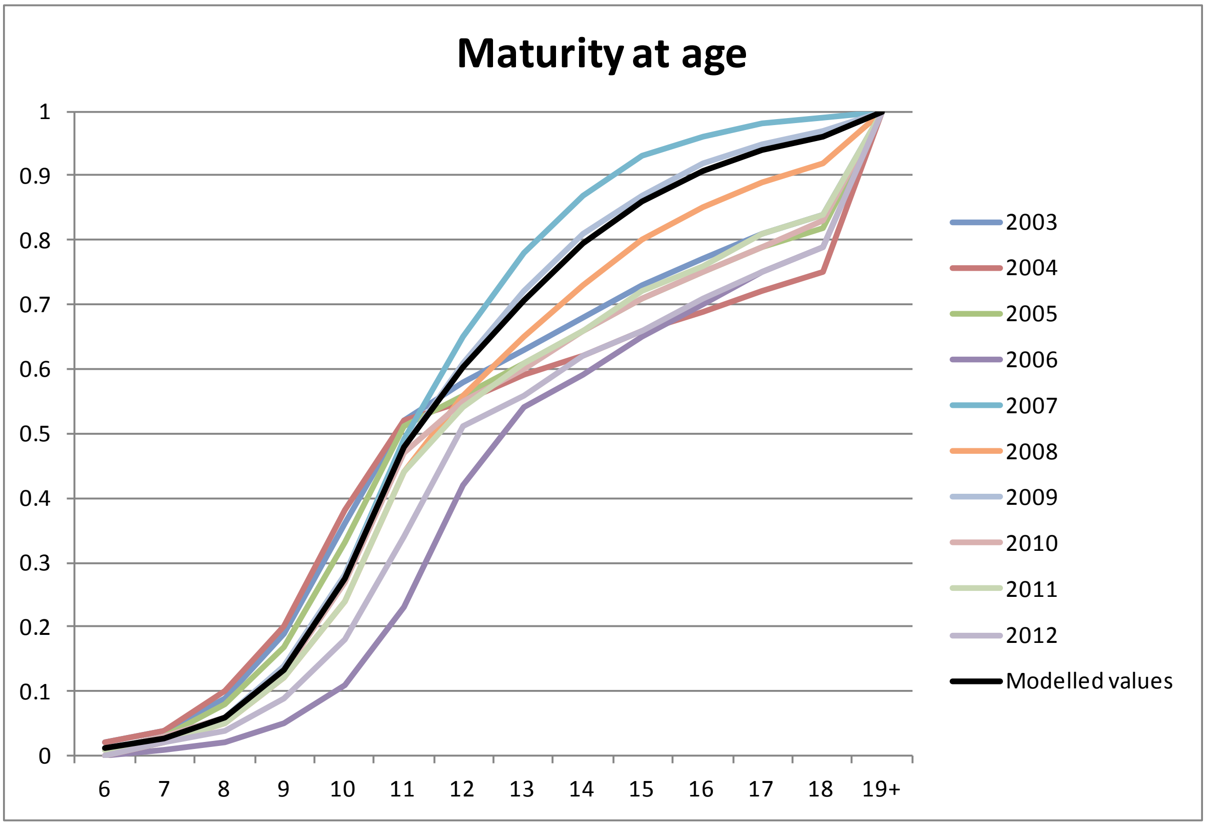

Figure 2.2. Modelled proportion mature at age compared to observed values during the period 2003–2012.

2.3.1.2 Recruitment

Two recruitment scenarios were considered which we denote here as hockey-stick and cyclic (the latter is a hockey-stick function multiplied by a cyclic term). The hockey-stick-function is given by:

$$R2(y+2) = \min\left(\frac{\alpha SSB(y)}{\beta}.\alpha\right)e^{\varepsilon}$$

where ε is normally distributed, ε =N(0,σ). The breakpoint β was fixed at the lowest observed value - 132 kT, the plateau α was estimated to 134 million and the error term ε was estimated to 1.19 using the method outlined by Skagen and Aglen (2002). The fit to the data is not very good, as shown in Figures 3.3–3.5. As a period of low recruitment recently has occurred, and the request considers the issue of low incoming recruitment, we also fit a cyclic recruitment function (hockey-stick function multiplied by exp(1.242*sin(2π(year-2005)/26)), to the data, see Figure 2.6. The cycle was estimated based on the recruitment variation observed in the period 1992–2012. The plateau α in the cyclical function was fixed at 107 million to make the average recruitment approximately equal for the two functions. This should not be taken to mean that there is any evidence of recruitment being cyclical, but only as a scenario for exploring consequences of periods of bad and good recruitment.

Howell (WD5) suggested using the biomass of 19+ fish (SSB19+) in the stock–recruitment function, as this gives a better fit to the data. This approach was not used in the simulations made by WKREDMP. However, the issues concerning the age composition are discussed in Section 2.7.

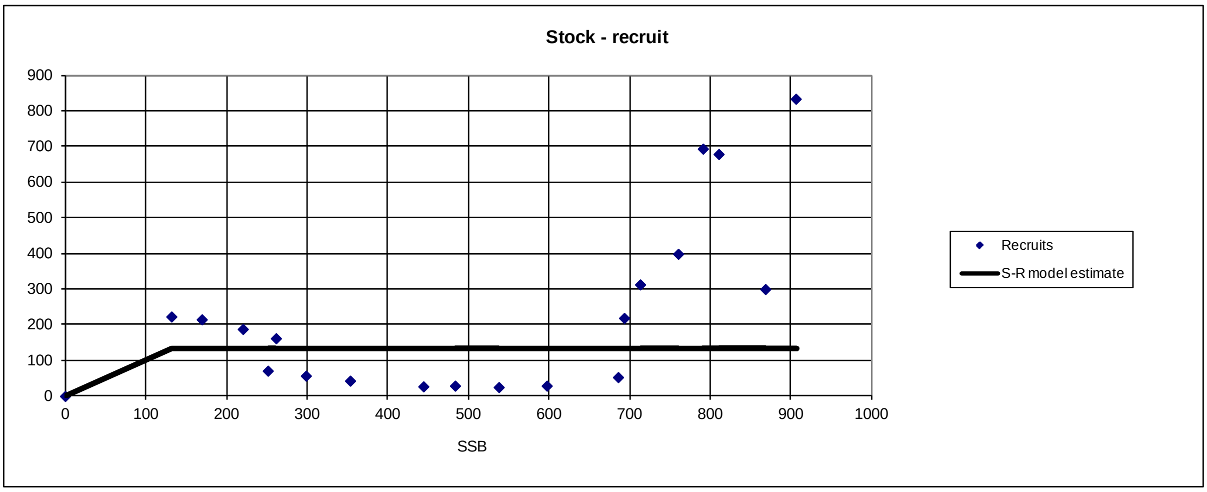

Figure 2.3. Hockey-stick recruitment function with fixed breakpoint at 132 million fit to data for spawning stock and recruitment at age 2 for the cohorts 1992–2010.

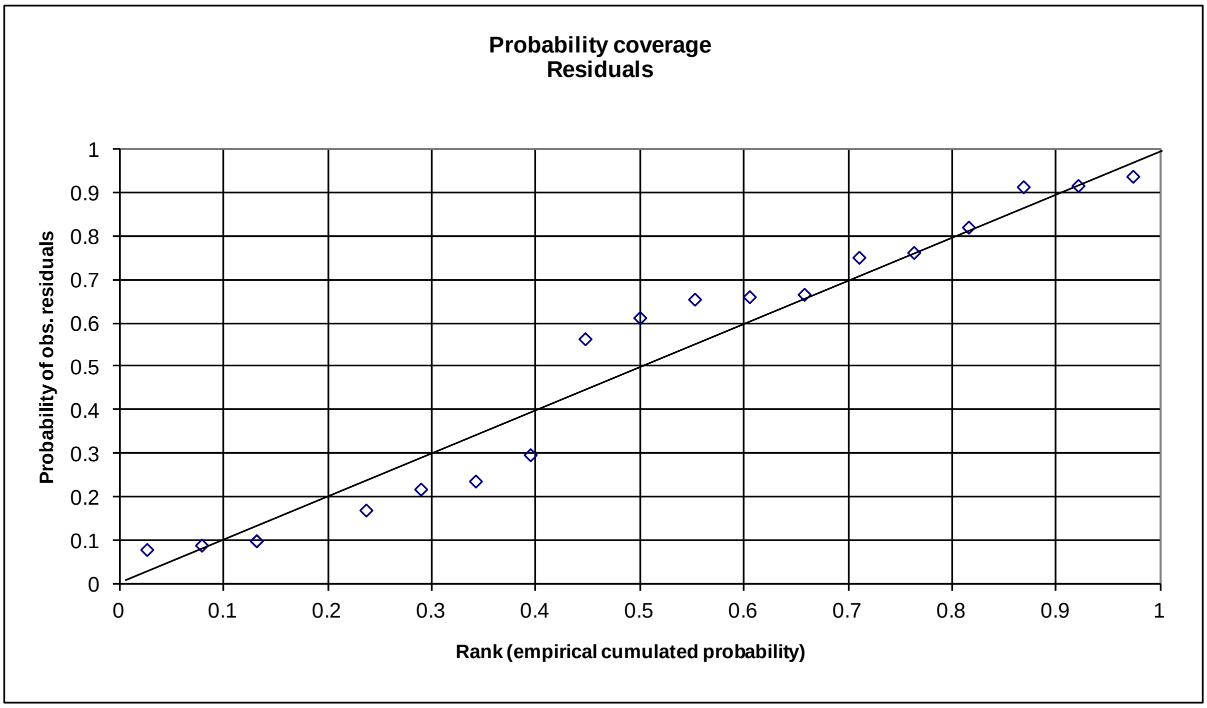

Figure 2.4. Probability coverage for stochastic stock–recruitment function.

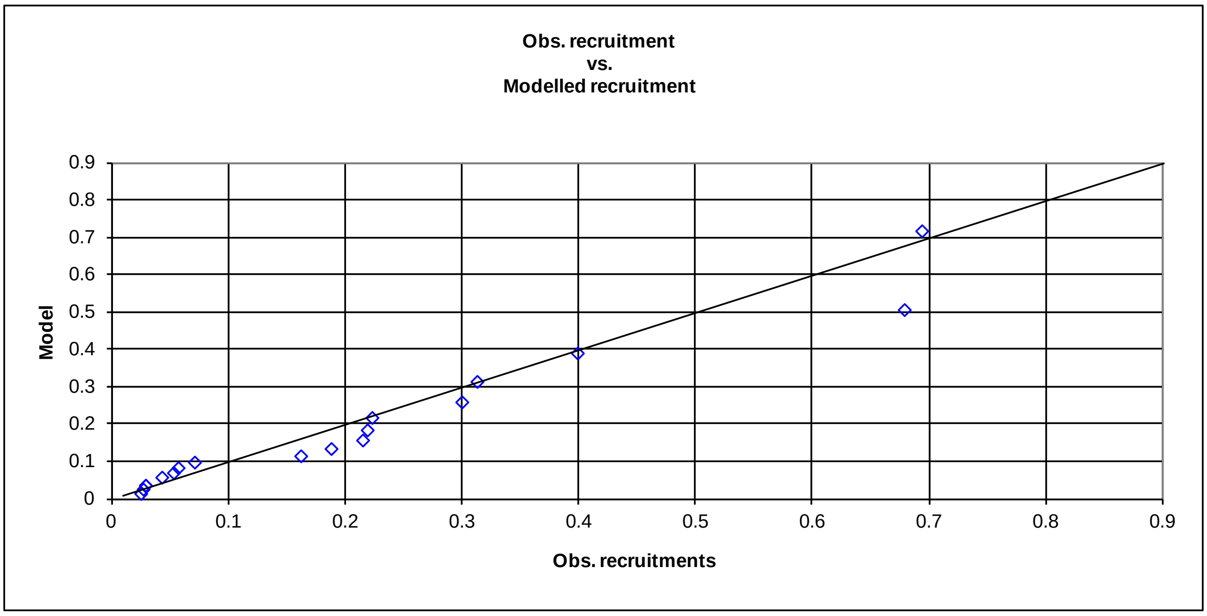

Figure 2.5. Observed vs. modelled recruitment for stochastic stock–recruitment function.

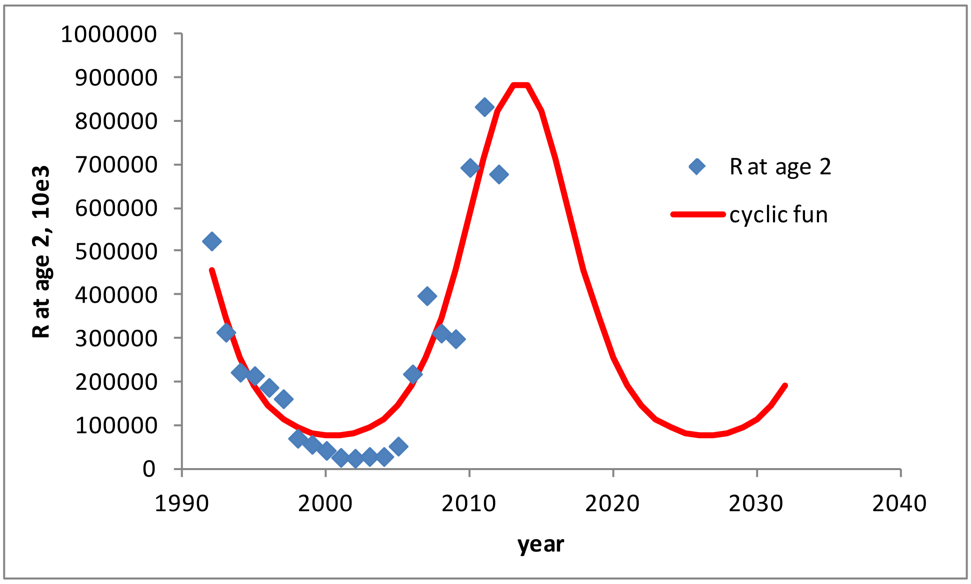

Figure 2.6. Fit of cyclic function to stock–recruitment data.

2.3.1.3 Selection at age

Three alternative selection curves are considered – demersal fleet and pelagic fleet selection calculated at the 2013 assessment, as well as five year average for total fleet, respectively (Figure 2.7). The five year average 2008–2012 for the total fleet is used as the default selection pattern.

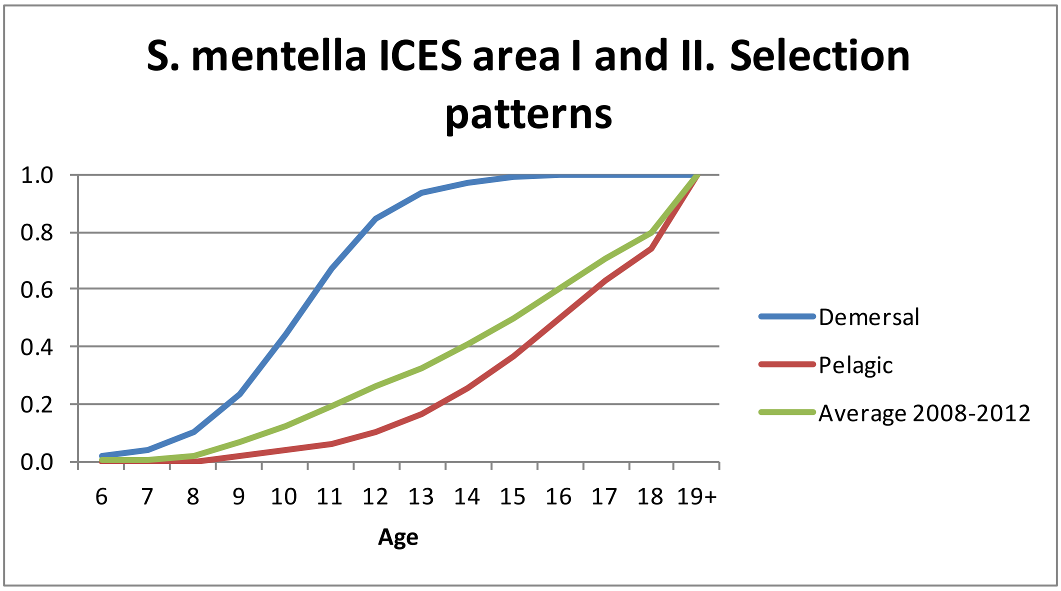

Figure 2.7. Selection pattern calculated by AFWG 2013 for the demersal and pelagic fleets, as well as the average total selection pattern (2008–2012 average) used in the simulations.

2.3.1.4 Initial stock numbers

The stock size at the beginning of 2013 was taken from the last assessment (ICES 2013a). This assessment is made with a statistical catch-at-age model. The absolute level of this model requires that one of the surveys is used as an absolute index of numbers-at-age. For this purpose, the ecosystem survey level was fixed. It was assumed that the ratio between the stock accessible to bottom trawling and the total stock was 1/3.5 (hereafter referred to as q=1/3.5).

The stock was projected through 2013 (intermediate year) assuming fishing mortality to be the same in 2013 as in 2012 (it is known that catch level is approximately the same in 2013 as in 2012). The recruitment at age 2 for the 2011, 2012 and 2013 year classes was calculated based on two regressions between survey indices (i.e. the 0-group survey and the 5–9 cm fish in the winter (February) survey) and number at age 2 for the period 1992–2012 taken from the most recent stock assessment (ICES 2013a). The coefficients of determination were r^2=0.63 and r^2=0.62 for the two regressions, respectively. For the 2011 and 2012 year classes the average of these regressions was used, while for the 2013 year class the regression with the 0-group survey was used. The values obtained for the 2011, 2012 and 2013 year classes were 210, 322 and 101 million, respectively.

Stochasticity was added to the projections by including uncertainty in the values for number-at-age for 2013. Uncertainty was higher for the most recent year classes (CV=0.2 on log scale for the year classes prior to 2004 and 0.3 for the year classes 2004–2011. A CV of 0.4 on log scale was assumed for the 2012 and 2013 year classes.

2.3.1.5 Stock size

Three alternative stock size scenarios were considered, calculated by assuming different values for the fixed q for the Barents Sea ecosystem survey (1/3.5 – benchmarked value for current assessment, 1/3 – similar to GADGET, 1/6 – similar to Schaeffer – see ICES 2013a for an explanation).

2.3.2 Observation model

The simulations were not full feedback (i.e. an assessment was not run each year in the projection). Uncertainty in deriving the perceived view of the true stock (i.e. accounting for observation error in future catches and indices and model error) is included in a single 'assessment error' term. The assessment error was set to CV=0.2 on log scale for all age groups in all years. The assessment error in a given year is uncorrelated between age groups. A run with no assessment error was also made in order to check the effect of the assessment error. Calculations of equilibrium yield vs. F were made assuming no assessment error.

2.4 Harvest Control Rule options examined

2.4.1 The requests

ICES received two requests on the same topic, the evaluation of a harvest control rule for *Sebastes mentella* in Subareas I and II. The requests are given in Annex 3.

2.4.2 Clarifications and amendments to request

Reference and trigger points: $F_{0.1}$=0.039 for age range 12–18 (AFWG 2013). In addition to F=4/3* $F_{0.1}$=0.052 and F=3/4 =0.029 we found it useful to explore the stock development also with F=0.

B_{MSY} (and B_{lim} and B_{PA}) are not defined for this stock at the moment. Thus $B_{trigger}$ and B_{stop} in harvest control rules should be given as numerical values, and no references should be made to B_{MSY} in the harvest control rules. It is not known what the suggested trigger points in the request are based on; possibly 800 kT is based on the recent SSB level and 400 kT just chosen as half of that value.

Reduction of F when recruitment is reduced: "cutting fishing mortality with 25 or 50% if the average strength at age 2 for year classes which are 3–12 years old in the year for which the TAC advice is given is at or below 33% of average recruitment at age 2 for the period 1992–1996". The 1992–1996 average is 293 million, so we have used 100 million as the threshold here since that is very close to 33% of the average. If SSB<$B_{trigger}$, the reduction in F due to weak incoming year classes is applied to the F after it has been adjusted for SSB<$B_{trigger}$ (this issue was not dealt with in the request). For simplification, we only considered the effect of a 50% reduction.

Concerning TAC stability, we suggest that limits on annual variability of TAC should be suspended when the SSB is below $B_{trigger}$, in the same way as in the HCR for NEA cod. It was decided to have no stability clause as default, and then check the consequences of having a five year rule, a 20% limit in annual TAC variation, as well as a combination of those measures.

Further, it was decided to explore the effect of the various operating models and HCRs by varying one or two factors at the time compared to the base case, rather than run all combinations. The 32 runs performed are described in Section 2.4.3.

The second request was submitted by NEAFC and was less specific

Based on the advice for 2013, ICES is requested to explore possible long-term management plan options for redfish in ICES Subareas I and II. The objective of such a management plan shall be to establish levels of catches and fishing effort, which will result in the sustainable exploitation of pelagic redfish in ICES Subareas I and II, consistent with the precautionary approach and the principle of Maximum Sustainable Yield.

2.5 Runs performed

The assumptions made for the 32 runs made are given in Table 2.1.

Base case – Run 1: Initial stock size based on q=1/3.5, hockey-stick recruitment, assessment error – CV=0.2, $B_{trigger}$=B_{stop}=0, no stabilizer, no reduction of F if low incoming year classes, fishing pattern equal to recent five year average.

Changes in operating model

Initial stock size (2013) calculated using runs with (q=1/3, 1/6) – Run 2–3

(SSB 2014: 646, 786 and 1447 kT respectively for q=1/3, 1/3.5, 1/6)

Cyclic recruitment – 2 runs (q=1/3.5 and 1/3) – Run 4 and 5

No assessment error – 1 run – Run 6

Changes in Harvest control rule

Alternative F levels: (F=4/3*F0.1, 3/4* F0.1, 0, dvs 0.052, 0.02925,0) – Run 7–9

Variable $B_{trigger}$ and B_{stop} combinations (800/400, 800/200, 800/0, 400/200, 400/100, 400/0) for both 1/q =3 and 1/q=3.5 (2x6=12 runs). In addition $B_{trigger}$/B_{stop} combinations of 800/0 and 400/0 for cyclic recruitment and q=1/3.5 (2runs) Run 10–23

Stabilizer (five year averaging and/or maximum 20% annual TAC variation) both for hockey-stick and cyclic recruitment (2x3=6 runs) Run 24–29

Reducing F if low incoming recruitment (only for cyclic recruitment – 1 run) Run 30

Fishing pattern (demersal, pelagic) – Run 31–32 (Scaling F to give approximately same yield as for base case run)

Table 2.1 Overview of runs made to explore sensitivity to changes in Operating model and HCR.

Run no	1/q	Recr	Assess. Error	F	Selectivity	Btrigger	Bstop	Stabiliser	F dep incom recr
1	3.5	H-st	0.2	0.039	Recent average	0	0	No	No
2	3	H-st	0.2	0.039	Recent average	0	0	No	No
3	6	H-st	0.2	0.039	Recent average	0	0	No	No
4	3.5	Cyclic	0.2	0.039	Recent average	0	0	No	No
5	3	Cyclic	0.2	0.039	Recent average	0	0	No	No
6	3.5	H-st	0	0.039	Recent average	0	0	No	No
7	3.5	H-st	0.2	0.052	Recent average	0	0	No	No
8	3.5	H-st	0.2	0.02925	Recent average	0	0	No	No
9	3.5	H-st	0.2	0	Recent average	0	0	No	No
10	3.5	H-st	0.2	0.039	Recent average	800	400	No	No
11	3.5	H-st	0.2	0.039	Recent average	800	200	No	No
12	3.5	H-st	0.2	0.039	Recent average	800	0	No	No
13	3.5	Cyclic	0.2	0.039	Recent average	800	0	No	No
14	3.5	H-st	0.2	0.039	Recent average	400	200	No	No
15	3.5	H-st	0.2	0.039	Recent average	400	100	No	No
16	3.5	H-st	0.2	0.039	Recent average	400	0	No	No
17	3.5	Cyclic	0.2	0.039	Recent average	400	0	No	No
18	3	H-st	0.2	0.039	Recent average	800	400	No	No
19	3	H-st	0.2	0.039	Recent average	800	200	No	No
20	3	H-st	0.2	0.039	Recent average	800	0	No	No
21	3	H-st	0.2	0.039	Recent average	400	200	No	No
22	3	H-st	0.2	0.039	Recent average	400	100	No	No
23	3	H-st	0.2	0.039	Recent average	400	0	No	No
24	3.5	H-st	0.2	0.039	Recent average	0	0	20%	No
25	3.5	Cyclic	0.2	0.039	Recent average	0	0	20%	No
26	3.5	H-st	0.2	0.039	Recent average	0	0	5-year av.	No
27	3.5	Cyclic	0.2	0.039	Recent average	0	0	5-year av.	No
28	3.5	H-st	0.2	0.039	Recent average	0	0	20% +5-year	No
29	3.5	Cyclic	0.2	0.039	Recent average	0	0	20% +5-year	No
30	3.5	Cyclic	0.2	0.039	Recent average	0	0	No	Yes
31	3.5	H-st	0.2	0.060	Demersal	0	0	No	No
32	3.5	H-st	0.2	0.032	Pelagic	0	0	No	No

2.6 Choice of performance indicators

The probability of SSB falling below a target value during a period was calculated as SSB is below the target at least once during the period (prob2 in the terminology used in ICES 2013b). This probability was calculated for the periods 2014–2018, 2014–2023 and 2024–2063. The period 2024–2063 was chosen instead of 2014–2063 because the mean SSB at the start of the period (786 kT) is close to the highest trigger point used (800 kT). Thus the value for the period 2014–2063 will be strongly affected by the stock development in the first years of the period.

In addition to the performance indicators given in the request, we calculated the average interannual variation in catches for the period 2014–2063. Also the mean F over the period 2014–2063 was calculated, to give an indicator of how much the F values on average were reduced due to SSB falling below the trigger point. Additionally, the mean SSB over the period 2014–2063 was calculated. Note that the average values calculated for the period 2014–2063 or 2024–2063 are not equilibrium values. Equilibrium projections are given in Section 2.9.

The following indicators were thus used:

- Mean Yield for the years 2014,2015,2016,2017 and 2018;
- Mean Yield for the periods 2014–2018, 2014–2023 and 2014–2063;
- Mean Interannual variation in yield for the period 2014–2063;
- Mean F and SSB for the period 2014–2063;
- Probability of SSB falling below 800 kT for the periods 2014–2018, 2014–2023 and 2024–2063;
- Probability of SSB falling below 400 kT for the periods 2014–2018, 2014–2023 and 2024–2063.

2.7 Results

When the initial stock size (2013) is calculated using runs with (q=1/3, 1/3.5, 1/6), the SSB 2014 is 646, 786 and 1447 kT respectively for q=1/3, 1/3.5, 1/6. From Table 3.2 we see that when fishing at a fixed F, the yield will decrease somewhat in the years to come in all cases. The risk of falling below 800 kT in the long term (2024–2063) is between 70 and 100% for all runs, while the risk of falling below 400 kT is fairly low (less than 13% in all runs, for many runs <5%).

Table 2.2. Results of runs for various operating models and HCRs. Mean Biomasses and catches in 1000 tonnes.

	Y	Y	Y	Y	Y	Y 14-18	Y 14-23	Y 14-63	IA var yield%	Mean F	Mean SSB	prob2 < 800	prob2 < 800	prob2 < 800	prob2 < 400	prob2 <400	prob2 < 400
Run	2014	2015	2016	2017	2018	2014-2018	2014-2023	2014-2063	2014-2063	2014-2063	2014-2063	2014-2018	2014-2023	2024-2063	2014-2018	2014-2023	2024-2063
1	54	49	46	44	42	47	46	54	15	0.039	918	0.839	0.839	0.807	0.000	0.000	0.010
2	44	41	38	36	35	39	39	50	15	0.039	862	0.999	0.999	0.858	0.010	0.010	0.013
3	99	91	84	79	77	86	83	71	16	0.039	1192	0.001	0.001	0.713	0.000	0.000	0.007
4	53	49	46	44	42	47	46	56	16	0.039	964	0.837	0.837	0.962	0.000	0.000	0.090
5	44	41	38	36	35	39	39	53	16	0.039	909	1.000	1.000	0.964	0.009	0.009	0.130
6	53	49	46	44	42	47	46	54	4	0.039	916	0.841	0.841	0.806	0.000	0.000	0.011
7	71	64	58	54	51	59	57	60	15	0.052	798	0.945	0.945	0.964	0.000	0.000	0.091
8	41	38	36	35	34	39	37	47	16	0.029	1028	0.743	0.743	0.520	0.000	0.000	0.000
9	0	0	0	0	0	0	0	0	0	0.000	1640	0.543	0.543	0.000	0.000	0.000	0.000
10	46	41	38	37	38	40	43	52	29	0.036	944	0.824	0.824	0.783	0.000	0.000	0.000
11	48	43	40	38	39	42	44	52	24	0.037	936	0.829	0.830	0.795	0.000	0.000	0.000
12	49	45	42	40	39	43	45	53	21	0.037	935	0.840	0.840	0.791	0.000	0.000	0.000
13	50	45	42	40	40	43	45	55	23	0.036	984	0.837	0.837	0.955	0.000	0.000	0.007
14	53	49	46	44	42	47	46	54	16	0.039	919	0.841	0.842	0.806	0.000	0.000	0.009
15	53	49	46	43	42	47	46	54	16	0.039	920	0.846	0.846	0.805	0.000	0.000	0.010
16	53	49	46	43	42	47	46	54	16	0.039	919	0.850	0.850	0.813	0.000	0.000	0.012
17	54	49	46	44	42	47	46	56	16	0.039	966	0.841	0.842	0.959	0.000	0.000	0.085
18	29	26	24	24	26	26	46	48	18	0.034	896	0.998	0.998	0.821	0.007	0.007	0.000
19	34	30	28	28	29	30	34	49	26	0.035	888	0.998	0.998	0.826	0.005	0.005	0.000
20	37	33	31	30	30	32	35	49	22	0.036	884	0.999	0.999	0.834	0.007	0.007	0.000
21	44	40	38	36	35	39	39	50	16	0.039	861	1.000	1.000	0.862	0.009	0.009	0.012
22	44	40	38	36	35	39	39	50	15	0.039	862	1.000	1.000	0.860	0.010	0.010	0.014
23	44	40	38	36	35	39	39	50	15	0.039	861	0.999	0.999	0.858	0.009	0.009	0.011
24	54	50	47	44	42	47	46	54	16	0.039	919	0.845	0.846	0.806	0.000	0.000	0.013
25	53	50	47	44	42	47	46	56	12	0.039	968	0.852	0.852	0.961	0.000	0.000	0.097
26	47	45	44	44	45	44	48	54	16	0.039	915	0.803	0.803	0.780	0.000	0.000	0.005
27	53	50	47	44	42	47	46	56	12	0.039	968	0.849	0.849	0.959	0.000	0.000	0.101
28	47	45	44	44	44	45	48	54	11	0.039	916	0.797	0.797	0.786	0.000	0.000	0.005
29	47	45	44	44	44	45	48	56	11	0.040	955	0.804	0.804	0.947	0.000	0.000	0.052
30	53	49	46	43	42	47	46	52	20	0.035	1013	0.840	0.840	0.926	0.000	0.000	0.003
31	48	47	46	47	49	47	53	54	13	0.060	837	0.805	0.806	0.911	0.000	0.000	0.028
32	56	50	46	42	39	48	47	54	17	0.032	948	0.862	0.862	0.763	0.000	0.000	0.008

Effect of changing initial stock size (Runs 2–3)

We see that the highest initial stock size gives a considerably higher yield also in the 50-year period, while the risk of falling below 800 kT during the 50-year period does not decrease very much.

Effect of cyclic recruitment (Runs 4–5)

Although the mean catch and stock size is slightly higher for the runs with stochastic recruitment, the risk of falling below the trigger points of 800 and 400 kT is higher for these runs, which is reasonable because of the greater fluctuations in stock size induced by cyclic recruitment.

Effect of assuming no assessment error (Run 6)

This gives, as expected, hardly any change in the yield and risks. However, note that the average interannual variability is reduced from 15 to 4%. Thus, assessment error is the main factor influencing the interannual variability.

Effect of varying F (Runs 7–9)

The long-term gain in increasing F from 0.039 to 0.052 is low, while this increases the risk of falling below the trigger points considerably (e.g. 9% probability of falling below 400 kT compared to 1% in the base case). Also note the long-term average of SSB of 1640 kT in the case of no fishing.

Effect of varying trigger points (Run 10–23)

The difference between a $B_{trigger}$ of 400 kT and $B_{trigger}$=0 was very small, no matter which recruitment function and B_{stop} value was chosen. When $B_{trigger}$ is set to 800 kT, it has some effect, as the average F during the period 2014–2063 is decreased somewhat (lowest value is 0.034 in run 18) and the interannual variation in yield is increased due to the perceived stock size fluctuating around the trigger point. Also in this case the choice of the B_{stop} value has little effect.

Effect of stabilizers (Runs 24–29)

The effect of introducing stabilizers is small. However, note that a five year rule will decrease the catches in the years 2014–2016 compared to a fixed F rule.

Effect of reducing F for low incoming recruitment (Run 30)

This has some effect for the case with cyclic recruitment (compared to Run 4). The risk of falling below 400 kT is considerably lower, while the yield is slightly lower.

Effect of varying selection pattern (Run 31–32)

The selection patterns were scaled to give the same average yield for the period 2014–2063 as the base case. This gave an F(12–18) of 0.060 for the demersal selection pattern and 0.032 for the pelagic selection pattern. The pelagic selection pattern gives higher stock size and lower risks than the demersal selection pattern.

2.8 Age composition of spawning stock

The annual recruitment of new year classes to the *S. mentella* stock in Subareas I and II as observed in research surveys back to the 1970s (ICES 2013a), and indirectly from the cod diet (Yaragina and Dolgov, 2012), shows much variation. However, the fishery and stock development since the mid-1980s suggest that additional mechanism may have played a critical role in the severe recruitment failure during the 1990s and early 2000s. A stock component along the slope south of about 70N which was composed predominantly of old, mature specimens, continued to produce fairly strong year classes during 1985–1990 despite the reduction of the total spawning stock size to record low levels around 1990 (ICES 2013a). After 5–6 years with fishing on this elder stock component, the recruitment quickly failed after 1990.

The older component of the mature stock may hence be a securing factor for a successful reproduction, whilst the youngest “mature” individuals (as measured by their gonads) may be contributing less to the recruitment. This hypothesis is supported by several investigations on the reproductive potential and maternal effects in fish, including *Sebastes* species (e.g. Kjesbu, 1988; Drevetnyak, 1991; St-Pierre and Lafontaine, 1995; Marshall *et al*., 1998; Berkeley *et al*., 2004a,b; Sogard *et al*., 2008; Field *et al*., 2008; Rodgveller *et al*., 2011 and Spencer and Dorn, 2013). This is summarized in a working document by Nedreaas and Planque to the WKREDMP.

Assuming a population in equilibrium with constant recruitment and fixed natural mortality across all age groups and fecundity-at-age derived from research referred to above, it is possible to derive a proxy for the relative reproductive potential of each age group, and hence find the age range that contains the highest reproductive potential. The WKREDMP found it, however, premature and difficult for time being to incorporate this in a management plan for *S. mentella*. Neither was it requested by the stakeholders. One may also argue that keeping the exploitation rate at an appropriate level will secure a sound age composition of the spawning stock and hence take care of the reproductive potential of the stock. Nevertheless, the impact of demography and maternal effects on reproductive potential and maximum long-term yield should be further investigated for this stock. How this can be implemented in a future management plan should be considered.

During WKREDMP, the relationship between recruitment and "mature biomass of at least a given age" was examined with the data available. Since "19+" is the plus group reported in the current analytical assessment and is therefore available for the entire time period 1992–2012, we report this here. It can be seen in Figure 2.8 that for the most recent period using 19+ biomass (R^2=0.77) instead of "gonad based SSB" (R^2=0.42) gives a much clearer signal between adult biomass and recruitment, especially in the recent years, and with a linear relationship that could be projected back to close to the origin. It is also clear that only the most recent years gives a potential "spawning biomass-recruitment" relationship, but the time period is short.

At present the SSB is dominated by 19+ fish. However, Figure 2.9 shows that the proportion of the total SSB which consists of age 19+ will decrease in the coming years, increase again when the strong year classes from 2004 onwards recruits to the 19+ stock, and then stabilize. Thus the present very high proportion of age 19+ in the SSB is not a normal situation.

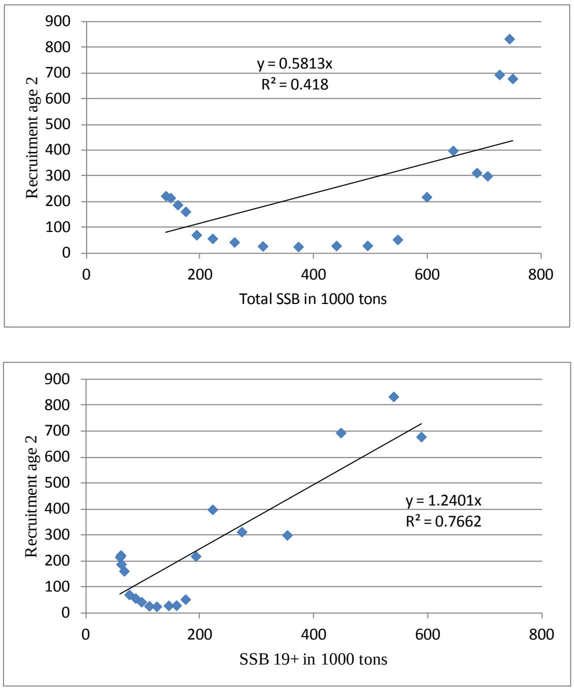

Figure 2.8. Spawning–stock biomass (SSB) all ages (left panel) and SSB age 19+ (right panel) vs. age 2 recruitment during 1992–2010 as estimated by the last ICES assessment (ICES 2013a).

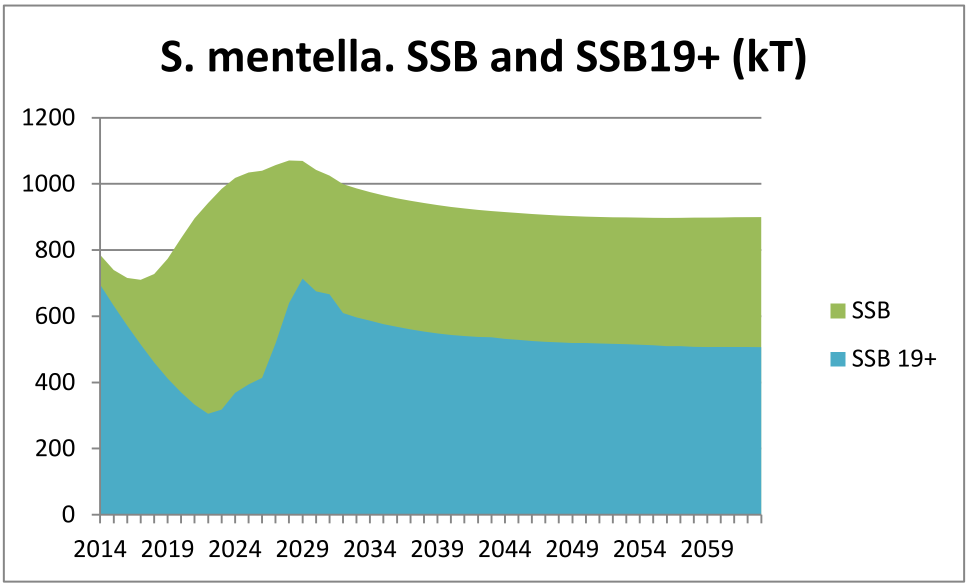

Figure 2.9. Total-stock biomass and SSB 19+ from the base case run.

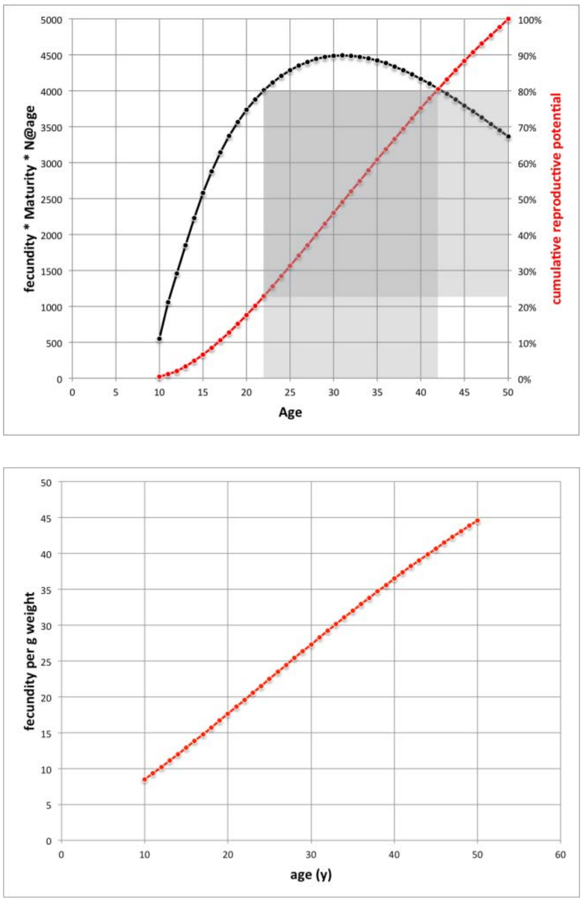

Figure 2.10. Reproductive potential of *S. mentella* in Subareas I and II, as a function of age. Left, estimated fecundity-at-age for the population (black line) and cumulated fecundity-at-age (red line) indicating that ages 22 to 42 years contribute most to fecundity when the population is at equilibrium. Right: Fecundity per unit weight for mature fish in age groups 10 to 50 years, showing that old individuals can contribute disproportionately to population fecundity.

2.9 Equilibrium projections

As contextual runs for Areas I & II reference points, projections to equilibrium were made at different values of constant F under different assumptions of the stock–recruitment relationship and natural mortality. From these projections it is possible to obtain equilibrium values of F_{MSY}, B_{MSY}, MSY and F_{crash}. It also gives an indication of the equilibrium catch curve.

Care needs to be exercised in the interpretation and use of these points from this method. The stock–recruitment data do not always show a positive relationship between stock size and recruitment, yet we have used functions which force this type of relationship. The sporadic recruitment behaviour of redfish makes fitting classical stock–recruitment functions problematic. The alternative, however, of fitting relationships which within certain ranges of stock size that show a negative association between recruitment and stock size could produce a deceptive view of the productivity dynamics of the stock.

Model

A simple age-based projection was constructed and has been used previously to estimate the F_{MSY} for Northern Gulf of St Lawrence cod (nGSL) in Canada (Duplisea, 2012). The advantage of this method over $F_{0.1}$ as a proxy for F_{MSY} is that, it is a true estimate of F_{MSY} which accounts for the long-term productivity dynamics which account for a stock–recruitment relationship. For stocks which are in a depressed biomass state and where natural mortality on older ages is high, $F_{0.1}$ tends to overestimate F_{MSY} as yield-per-recruit analysis will suggest hard fishing at young ages before they are removed by M, such is the case for nGSL cod. The long-term equilibrium relationship, because it accounts for the stock–recruitment relationship, will suggest a lower F_{MSY} which increases SSB to a point where the value for recruits per spawner is relatively large.

Projections for Area I & II Sebastes mentella

The population was projected to equilibrium (1000 years) under the following conditions:

- M= randomly sampled 0.03 to 0.07
- Weight-at-age= mean of 1990–2012
- Maturity ogive= mean of 1990–2012
- selectivity= mean of the demersal and the pelagic fleet

Three recruitment scenarios were explored (Figure 1): (A) a hockey-stick stock–recruitment function considering all the data (B) a hockey-stick stock–recruitment function considering only date from 2004–2010 (C) a hockey-stick stock–recruitment function where the breakpoint was set to minimum observed SSB and the geometric mean of all recruitment observations in fit A.

This stock has been assessed with a 19+ group but the method here has not been developed for a plus group. Therefore the data were extended to age 70 for the stock. This has no influence on the equilibrium projections here as at equilibrium the age structure is stable. The flat topped selectivity pattern found for ages <19 was extended out to age 70 for the purposes of these projections. The same expansion for maturity ogive and weight-at-age was also extended out to age 70. Numbers-at-age in 2013 were used for the projections but because it is a projection to equilibrium, it does not matter what numbers-at-age are used to start the runs.

Reference point definitions

MSY is the maximum long-term yield which can be taken from the stock.

F_{MSY} is the numbers weighted mean fishing mortality on ages 12–18 which will produce MSY in perpetuity.

B_{MSY} is the equilibrium SSB when the stock is fished at F_{MSY}.

F_{crash} is the numbers weighted mean fishing mortality on ages 12–18 which will crash (<1000 t SSB) the stock if fished indefinitely.

B_0 is the unfished equilibrium SSB (however there is an F of 0.001 applied to the stock at this point in the simulation).

Results

Stock–recruitment relationships

(A) The hockey-stick fitted to all years produced a breakpoint at the highest observed SSB and a recruitment near the arithmetic mean of all recruitments.

(B) The hockey-stick fitted to the stock–recruit data from 2004–2010 produced a breakpoint at the highest observed SSB but at a recruitment level about twice that of fit A.

(C) This hockey-stick relationship was not fitted but produced a recruitment equal to the geometric mean of all recruitments over all observed stock sizes.

These three relationships explore different productivity scenarios for the stock. (A) is the most pessimistic or is the recruitment scenario which requires the largest stock size to produce MSY (B) produces higher levels of recruitment for any stock size than (A). (C) is the scenario where mean recruitment is produced at most stock sizes and non-constant recruitment is only produced when stock size is very low. Scenario (C) can in some respects be considered the least conservative recruitment dynamics since even at the lowest observed stock size it will produce average recruitment.

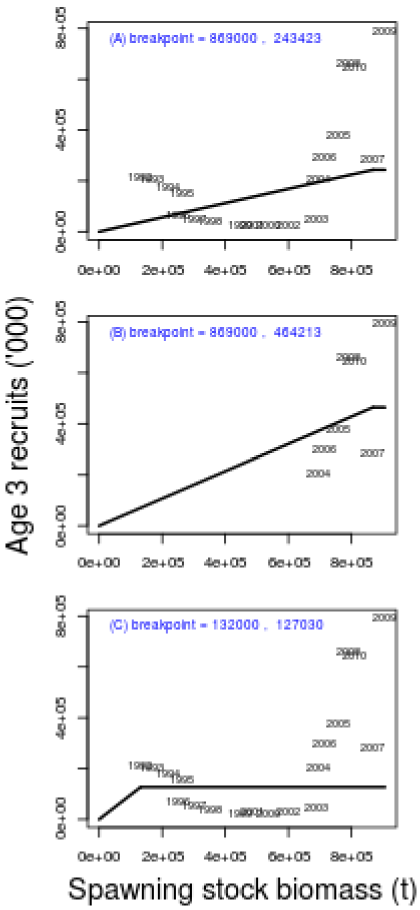

Figure 2.11. Stock–recruitment relationships used in three different projection scenarios: (A) fitted with all data years (B) fitted only with 2004–2010 data (C) breakpoint is at lowest observed spawning–stock size and geometric mean recruitment of all years.

Reference points

Scenario A: Hockey-stick fitted to all data (Figure 2.12 and Table 2.3, 1st column)

B_{MSY} under this recruitment assumption is near to 50% of B_0 with a median F_{MSY} of 0.037. The yield curve is relatively flat between about 0.025 and 0.04 however this is uncomfortably close to an F_{crash} of 0.048. Just over 50 000 t could be sustainably taken from this stock and annual basis if biomass were above 930 500 t assuming all population parameters and the fisheries selectivity remained constant.

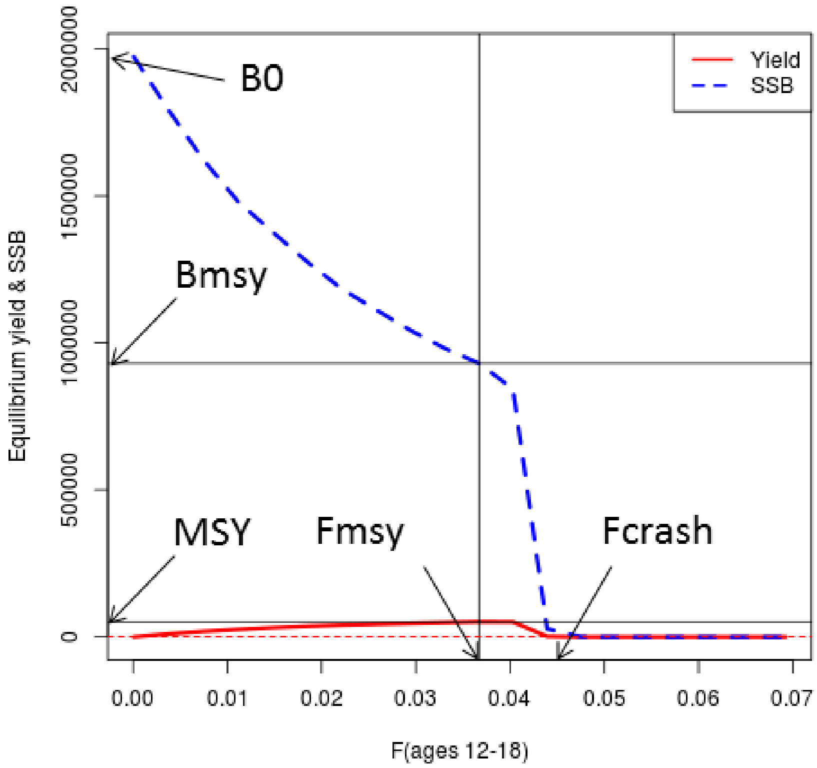

Figure 1.12. Results of the projections to equilibrium for Area I and II *S. mentella* using a hockey-stick recruitment function fitted to all data (scenario A).

Scenario B: Hockey-stick fitted to 2004–2010 data (Figure 2.13 and Table 2.3, 2nd column)

B_{MSY} under this recruitment assumption is about 25% of B_0 suggest a stock with greater specific production and stronger compensatory dynamics. The median F_{MSY} of 0.098 is more than double that of scenario A and likewise produces a sustainable yield about 2.5X higher than in scenario A when the biomass is larger than B_{MSY}. The yield curve is relatively flat between about 0.05 and 0.1; however, like in scenario A, F_{MSY} is relatively close to F_{crash}. Because the recruitment is higher for large stock sizes than in scenario A, the unfished equilibrium biomass is about 3.7 million tonnes.

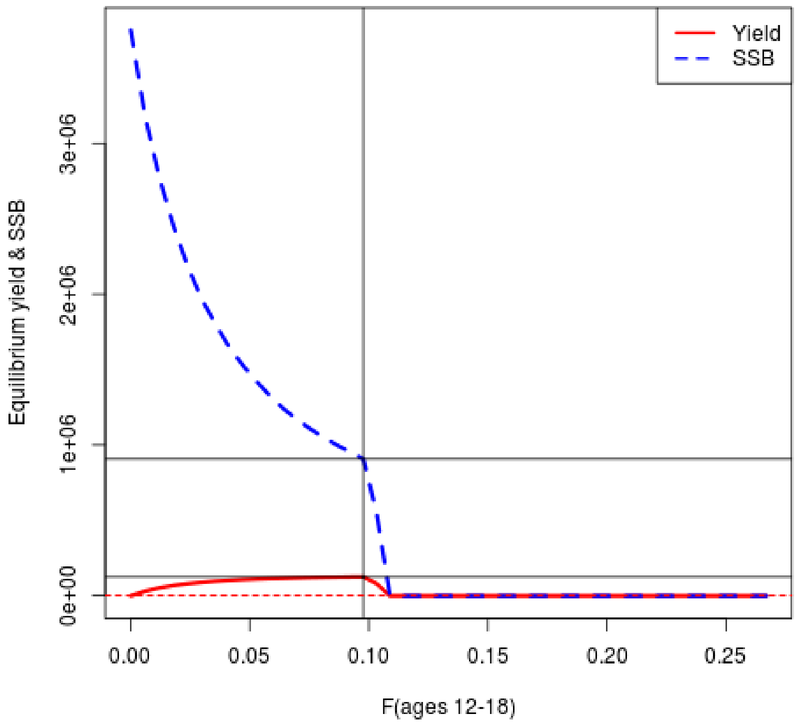

Figure 2.13. Results of the projections to equilibrium for Area I and II *S. mentella* using a hockey-stick recruitment function fitted to data from 2004–2010 (scenario B).

Scenario C: Hockey-stick with geometric mean recruitment over observed stock sizes (Figure 2.14 and Table 2.3, 3rd column)

This scenario produces the largest value for F_{MSY} (0.178) of three scenarios but again that F_{MSY} is close to F_{crash} (0.207). The yield curve for this scenario is near flat for F values from 0.05 to 0.20. The sustainable yield for this stock is smaller than the other scenarios (35 200 t) and likewise is B_{MSY} is much smaller (147 000 t) and unfished equilibrium biomass is about 1 million tonnes. B_{MSY}/B_0 suggests a much more resilient stock, however.

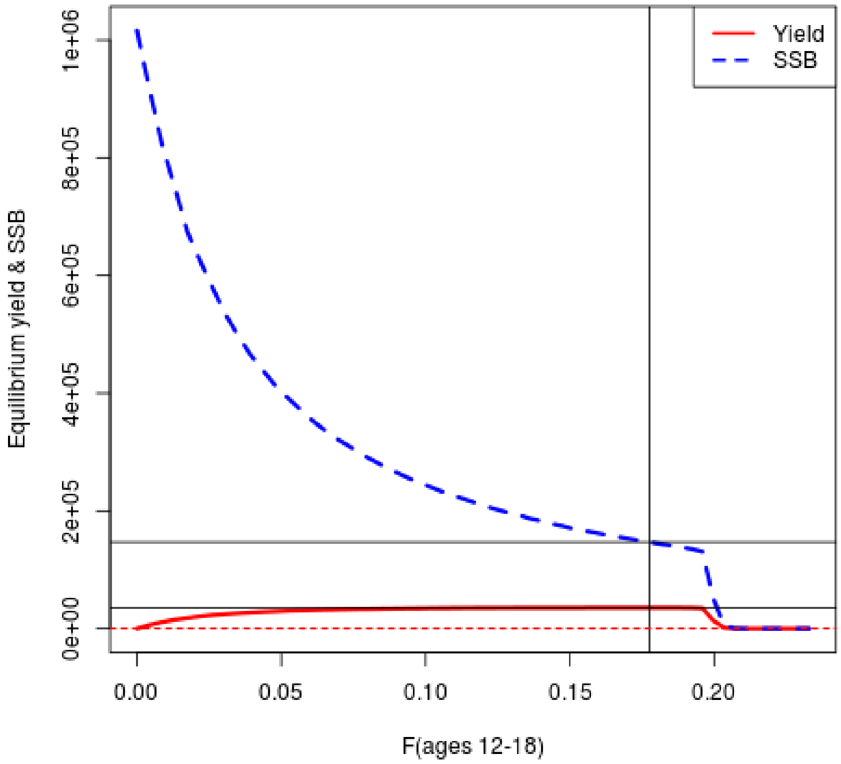

Figure 2.14. Results of the projections to equilibrium for Area I and II *S. mentella* using a hockey-stick recruitment function with a breakpoint and minimum observed spawner biomass and geometric mean recruitment (scenario C).

Table 2.3. Estimates of various reference points for Area I and II *S. mentella* result from projections to equilibrium under three different recruitment scenarios.

	SCENARIO A	SCENARIO B	SCENARIO C
Recruitment	**All years**	**2004–2010**	**Geomean**
MSY	51 300	125 900	35 600
F_{MSY}	0.037	0.098	0.178
B_{MSY}	930 500	907 300	147 000
F_{crash}	0.048	0.114	0.207
B_0	1 973 200	3 751 200	1 016 200

Discussion

The equilibrium project scenarios presented here are not meant to be used as strong management tools. What these projections are useful for is to play-out the implications of the full range of productivity parameters, fishing mortality and fishing selectivity in our observed range to see where they lead the stock. As such they can be considered a sort of consistency check on more realistic short-term non-equilibrium projection scenarios of fishing. A good example of this is provided by nGSL cod where $F_{0.1}$ tends to overestimate F_{MSY} as M on older fish has been at uncharacteristically high levels for more than the mean generation time of the stock. In addition, these scenarios highlight some of the productivity characteristics of the stock under different conditions such as B_{MSY}/B_0 which tells us about stock productivity at low stock size which has implications for recovery times.

The greatest uncertainty in these projections and in longer term projections for this stock concerns how recruitment is modelled. The consideration of three recruitment relationships which are all hockey-sticks presents a certain kind of limitation. One issue with hockey-stick models that becomes clear in this kind of analysis is the hard breakpoint between a density-dependent compensatory part (the slope) and a density-independent asymptote in R for larger stock sizes. In projections to steady-state, the model finds little reason to keep a stock size much larger than the biomass at the breakpoint. Therefore a hockey-stick model will always produce a B_{MSY} near the breakpoint biomass. Of course this will depend on what else is varying in the projections and by how much, but it is truism of the formulation in a deterministic sense. For this reason as well, F_{crash} will also tend to be very close to the breakpoint. The result of this is that F_{crash} and F_{MSY} will be close together, which is not an ideal scenario for managers. The hockey-stick is, however, one of the most parsimonious (conceptually if not mathematically) stock–recruitment models especially in the face of poor stock–recruitment data. The limitation of the hockey-stick do not invalidate the results however, as the yield curves from these projections (e.g. Figure 2.11, solid line) are quite flat and therefore, they offer little reason to fish near F_{MSY} because often fishing at an F which is considerably smaller than F_{MSY} in a proportional sense will give about the same yield. It must be kept in mind however, that these are projections to steady state and therefore F values near F_{MSY} or even above F_{crash} for a short period are unlikely to actually crash most stocks.

Comparison with current assessment and reference points

The results of the equilibrium analyses show that $F_{0.1}$ is a reasonable proxy for F_{MSY}, with the values being similar. In addition, the stock is probably above B_{MSY} at present with stock sizes significantly larger than 1 million tonnes unlikely to be sustained for long periods of time.

These projections are independent of the assumption of q for the ecosystem survey that is done in the assessment. Therefore they provide a certain amount of support for assuming q=1/3.5, as is currently used in the present assessment.

2.10 Discussion and conclusions

ICES considers that, for a long-lived, slow growing, late maturing stock any management action will take longer than five years before changes in the biomass are likely to be detected. Therefore, ten years seem to be a more sensible time span to assess the impact of a harvest control rule. The life-history characteristics of this stock also make it vulnerable to overfishing, and once overfished, the recovery might take decades. ICES therefore recommends applying a rather conservative management approach.

ICES evaluated 32 out of 72 potential combinations of settings provided by the requesting body, and has indicated which of the results are considered precautionary. The rationale for the evaluation of results was as follows: The biomass long-term equilibrium of the stock if harvested at $F_{0.1}$ (a proxy for F_{MSY}) is around 900 kt. If this is seen as a proxy for B_{MSY}, then a limit reference point B_{lim} could be half of it, around 450 kt. The request asked for the exploration of a $B_{trigger}$ or B_{stop} at 400 kt, so this value was used in the evaluation. ICES considers only those options precautionary which result in a low (<5%) probability of the biomass to fall below 400 kt in the next 50 years (time frame as requested).

Key results from the simulations indicate that:

- A trigger of 800 kt increases variability of TAC between years. Lower triggers have not been evaluated but should result in less variability at the same F. A biomass trigger of 600 kt seems to be a good starting point for future evaluations;
- The proposed F_{target} of 0.039 appears to be on the lower, 0.052 on the higher end of the range of F candidates resulting in a high long-term yield; the upper end of the range being at 0.052. There is however little long-term gain in yield if F_{target} is increased much above 0.039;
- A cyclic recruitment scenario requires the most conservative management approach. The stock and recruitment might benefit from a delayed or gradual implementation of a management plan, or a gradual increase of F (fishing at F_{target} only after the incoming stronger year classes have fully recruited to the fishery in 2017/2018); a low fixed TAC in the initial period or a stabilising element in the management plan might have a similar effect if implemented on the basis of recent catch;
- A pronounced decrease of F if weaker year classes are detected is considered sensible;
- Selectivity is different for different fleets (pelagic vs. demersal); the share of immature fish is higher in demersal fisheries. Management might want to consider a strategy that gives a higher share of the catch to pelagic fisheries as this would reduce F and increase SSB (if yield is fixed) or give a higher overall yield (if F is fixed). Other potential differences in environmental impact, e.g. on habitats, were not considered in the evaluation.

While a lot of effort has been spent to evaluate the full range of options provided, some of the assumptions in the evaluation appear to be unrealistic, namely the five-fold increase in yield in the first year (2014) although sum of the TACs set for that year is not yet known. That specifically holds if a stabilizer is implemented at these high assumed initial catches, since TACs will be maintained at a higher level for a longer period of time.

The catch advice should also be considered in light of the historical catch level – average since 1952 is 40 kT, ten year averages 1952–1961, 1962–1971 … 2002–2011: 30, 17, 121, 50, 12 and 13 kT respectively).

After next survey on mature *S. mentella* in the Norwegian Sea, which is planned for 2016, there should be more info on absolute stock size and it should be possible to include this survey in the assessment model, also it will be known whether the good year classes after 2003 have started recruiting to the mature stock. Thus the HCR should be re-evaluated in 2017.

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3 Evaluation of a proposed HCR for deep pelagic redfish (*Sebastes mentella*) in Irminger Sea and adjacent waters

The fishery for this stock only began in the early 1990s. No previous management plan evaluations or estimates of reference points have been made. An overview of the elements to be potentially included in the management plan was provided as part of the request. However, there are currently no analytical assessment or reference points available for this stock due to data uncertainties and the lack of reliable age data (WKRED; ICES, 2012). Advice is currently based on survey indices, catches, cpue and biological data.

At WKREDMP the trawl dataseries was re-evaluated and a simple production model was developed, solely for the purpose of comparing potential performance of candidate HCRs. The requested HCRs were evaluated as well as an alternative HCR form.

Updates following WKREDMP

Issue relating to the calculation of the 1999 and 2001 datapoints were identified following the WKREDMP. Once new value was recalculated for 1999, the final index for use in the HCR was created (Figure 8). Further analysis on the indices are more time consuming and require discussion at the WGIDEEPS meeting held in February 2015.

Following the revisions to the index new exploratory analyses were conducted for use as a basis for advice.

3.1 Current management and ICES advice

NEAFC is the responsible management body, and ICES the advisory body. Management of fisheries on pelagic redfish is based on setting total allowable catches (TAC) since 1996 and technical measures.

No harvest control rule exists for the stock and there has been no agreement on stock structure and the TAC and allocation key between contracting parties in NEAFC for several years. Some countries had set autonomous quotas. This has led to total annual catches far above the NEAFC TAC.

In March 2011, NEAFC agreed on interim measures for the deep pelagic beaked redfish fisheries until the end of 2014. These measures were agreed by all members of NEAFC except Russia who sets its own autonomous quota. The total catch has therefore exceeded the TACs in 2011–2013 set by NEAFC and is expected also to be above TAC in 2014. The objective of these measures was to gradually decrease the catches until they comply with the ICES advice, and to establish harvest control rule in the long term.

TAC and quota allocation between Contracting Parties for the deep-pelagic beaked redfish fishery in the Irminger Sea and adjacent waters 2011–2014 was fixed as follows: the TAC in 2011 was 38 000 tonnes, in 2012 it will be 32 000 tonnes, in 2013 26 000 tonnes, and in 2014 the TAC will be 20 000 tonnes. In addition to this an autonomous quota of 27 kt has been set by Russia for both the shallow and deep pelagic stocks in the Irminger Sea. Historically, approximately 87% of this catch is estimated to come from the deep pelagic component.

One of the objectives of these interim management measures was to establish a long-term management plan for redfish in the Irminger Sea and adjacent waters during the period, which includes appropriate harvest control rule.

ICES is advisory body. ICES has since 2008 advised that no more than 20 000 t should be fished and urged NEAFC to develop and implement management plan. The argument for this advice is that the stock is considered to have decreased over the last decade and the exploitation status is unknown.

3.2 The NEAFC Request

A request for the evaluation of a proposed Harvest Control Rule for deep pelagic redfish in the Irminger Sea and adjacent waters was submitted to ICES by NEAFC (Annex 4):

> As coastal states the Faroe Islands, Greenland and Iceland request ICES to evaluate their proposal on possible HCR under a management plan for redfish in the Irminger Sea and adjacent waters.
>
> **The request:** The coastal states aim to implement a management plan on redfish in the Irminger Sea and adjacent waters in 2015 in accordance with the MSY approach and ICES is requested to evaluate and elaborate on the suggestions for potential HCRs under such management plan as given in the attached document.
>
> **Justification:** The coastal states (Faroe Islands, Greenland and Iceland) aim to implement a permanent management plan in 2015 when the present management measures of reaching 20 000 tonnes in 2014 is running out.

Objective: The management plan should be in accordance with international agreements on sustainable harvest and the coastal states request ICES to comment on the proposed rules.

3.3 Stock structure and management units

The stock structure of redfish stocks in the North Atlantic is uncertain. Figure 1 shows the spatial distribution of pelagic beaked redfish at different stages of the life cycles in the Irminger Sea and adjacent waters. Redfish inhabit the pelagic habitats down to 1000 m depth, but the spatial and seasonal migration patterns of the stocks are still largely unidentified although it is known that adults undertake large migration between mating grounds, larval extrusion grounds and feeding grounds (Planque *et al*., 2013).

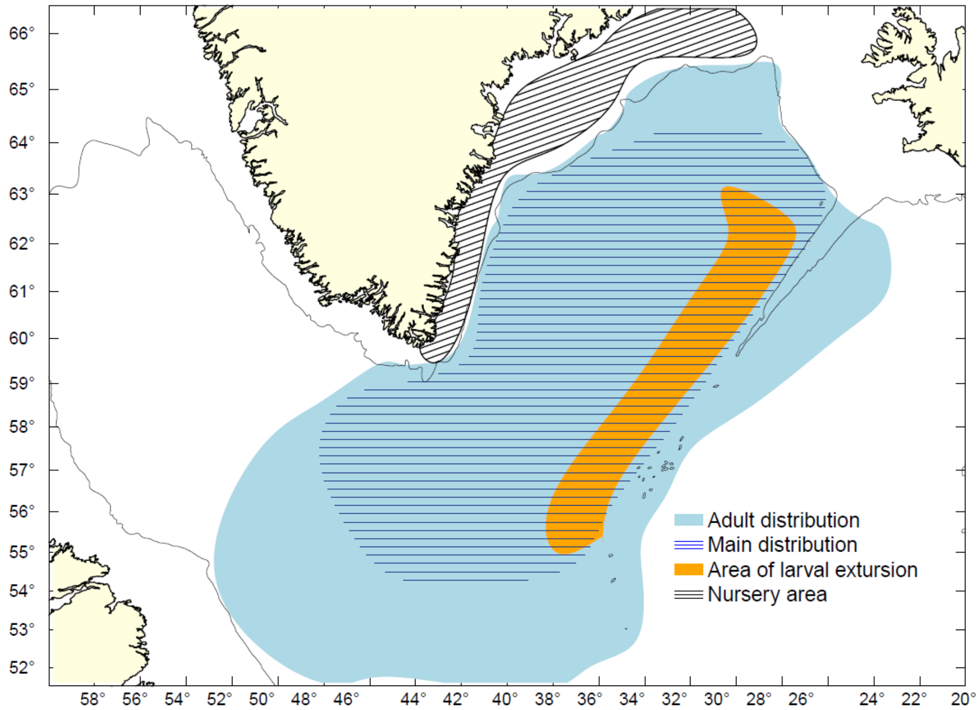


Figure 1. Distribution of pelagic redfish in the Irminger Sea and adjacent waters at different stages of the life cycle.

The Workshop on Redfish Stock Structure (WKREDS) in 2009 reviewed the stock structure of deep-water redfish in the Irminger Sea and adjacent waters (ICES, 2009b; Cadrin *et al*., 2010). ICES Advisory Committee (ACOM) concluded, based on the outcome of the WKREDS meeting, that there are three biological stocks of the species in the Irminger Sea and adjacent waters:

- a Deep Pelagic stock (NAFO 1–2, ICES V, XII, XIV >500 m) – primarily pelagic habitats, and including demersal habitats west of the Faroe Islands;
- a Shallow Pelagic stock (NAFO 1–2, ICES V, XII, XIV <500 m) - extends to ICES I and II, but primarily pelagic habitats, and includes demersal habitats east of the Faroe Islands;
- an Icelandic Slope stock (ICES Va, XIV) – primarily demersal habitats.

The East Greenland shelf is most likely a common nursery area for the three biological stocks.

The adult deep-water redfish on the Greenland shelf has traditionally been attributed to several stocks, and there remains the need to investigate the affinity of adults in this region.

Based on the stock identification information, ICES recommended three potential management units that are geographic proxies for biological stocks that were partly defined by depth and whose boundaries are based on the spatial distribution pattern of the fishery to minimize mixed-stock catches (Figure 2):

1) Management Unit in the northeast Irminger Sea: ICES Areas Va, XII, and XIV.
2) Management Unit in the southwest Irminger Sea: NAFO Areas 1 and 2, ICES Areas Vb, XII and XIV.

3) Management Unit on the Icelandic slope: ICES Areas Va and XIV, and to the north and east of the boundary proposed in the MU in the northeast Irminger Sea.

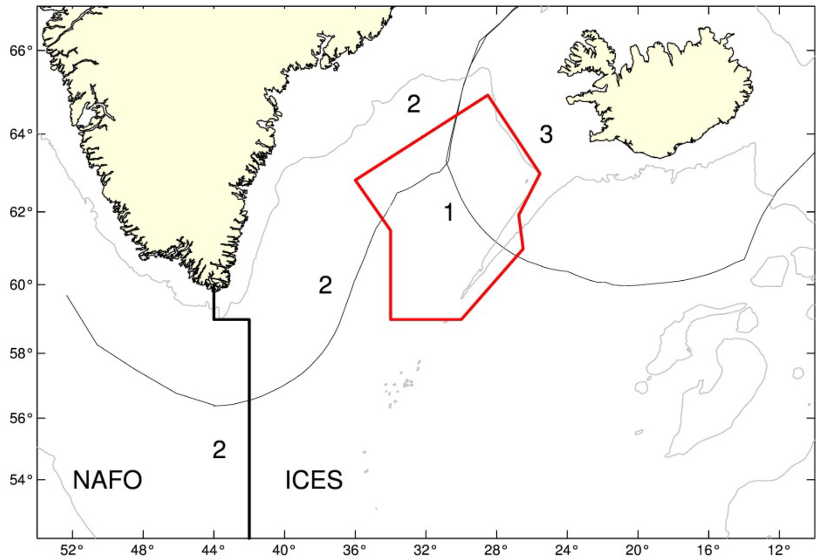


Figure 2. Management unit boundaries for beaked redfish in the Irminger Sea and adjacent waters. The polygon bounded by red lines, i.e. 1, indicates the region of the deep-pelagic management unit in the northwest Irminger Sea, 2 is the shallow pelagic management unit in the southwest Irminger Sea including within the NEAFC Convention areas, and 3 is the Icelandic slope management unit which is within the Icelandic EEZ.

The request to WKREDMP refers specifically to the deep-pelagic stock in the Irminger Sea (Area 1 in Figure 2). WKREDMP decided not to revisit any stock identity analyses, but rather to proceed with work on the request given the current management structure for redfish in this area.

The decision to advice on two stocks of pelagic redfish instead of one stock was not unanimous among ACOM members. The Russian Federation still maintains its point of view that there is only one stock of beaked redfish in the pelagic waters of the Irminger Sea. Russia reiterates its standpoint that studies of the redfish stock structure should be continued with the aim of developing agreed recommendations using all available scientific and fisheries data as a basis (ICES, 2013).

3.4 Available data

Deep-pelagic beaked redfish is a stock that is difficult to assess and is considered data poor although considerable data are available:

1) Catch data since 1991 (Section 4.4.1).

2) Cpue since 1991 from the commercial catches from key nations participating in the fishery (Section 4.4.1).

3) Survey indices since 1999 (Section 4.4.2)

4) Biological data:

   4.1) Length distribution from catches since 1991.

   4.2) Length distribution from the redfish surveys since 1999.

4.3) Few aged otolith samples, mostly from the commercial catch (Section 4.4.3.2).

4.4) Maturity samples from catches and surveys.

For a long-lived species such as redfish, the survey index is short. However, since the fishery is relatively new, the index time-series does not miss too much of the exploitation history. Trawl survey estimates in 2009 and 2011 are lower than the average for 1999–2003 and near the lowest observed. These indices in combination with a marked decrease in landings since 2004 suggest that the stock has been reduced in the past decade.

Commercial cpue indices are not used for tuning in assessing the stock. 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 benchmark workshop because the trends in the cpue may not be a reliable indicator of abundance and stock trends.

There is still a lack of basic information regarding the following aspects:

- population age structure;
- species identification of young individuals;
- magnitude and pattern of the recruitment are not known (despite existing 0-group surveys; Section 4.4.3.1);
- location of nursery and mating areas;
- estimation of natural mortality.

3.4.1 The fishery

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 tonnes in 1991 to nearly 140 000 t in 1996, stabilising at 85 000–105 000 t during the period 1997–2004, when some countries ceased fishing (Figure 3a). From 2005 onwards, annual landings have declined, being in the range 30 000 and 68 000 t. Landings are assumed to be fairly well reported. In the years 2002–2007 there were indications that reported effort (and consequently landings) could represent only around 80% of the real effort. This was mainly because of illegal, unregulated and unreported fishing (IUU) that occurred this period. Since 2007, IUU has stopped and misreporting assumed to be negligible.

The main fishing area is in the northwest Irminger Sea close to the Icelandic EEZ (north of 61°N and east of 32°W/ Figure 3b) from April to July at depths between 500 and 900 m).

Cpue from the commercial fleet has oscillated without trend since 1994 (Figure 3c). It is not known to what extent cpue reflects changes in the stock status of the deep pelagic *S. mentella* stock. The fishery targets pelagic aggregating fish. Therefore, stable or increasing cpues are not considered to reflect the stock status reliably, but decreasing cpues likely indicate a decreasing stock.

The fishery is targeting the adult part of the stock, so it is expected that the recruitment of juveniles is not negatively affected. It is a highly directed fishery, catching mainly redfish, very low bycatch and discard rates.

In 2002–2007, there were indications that reported effort (and consequently landings) could represent only around 80% of the real effort in certain years.

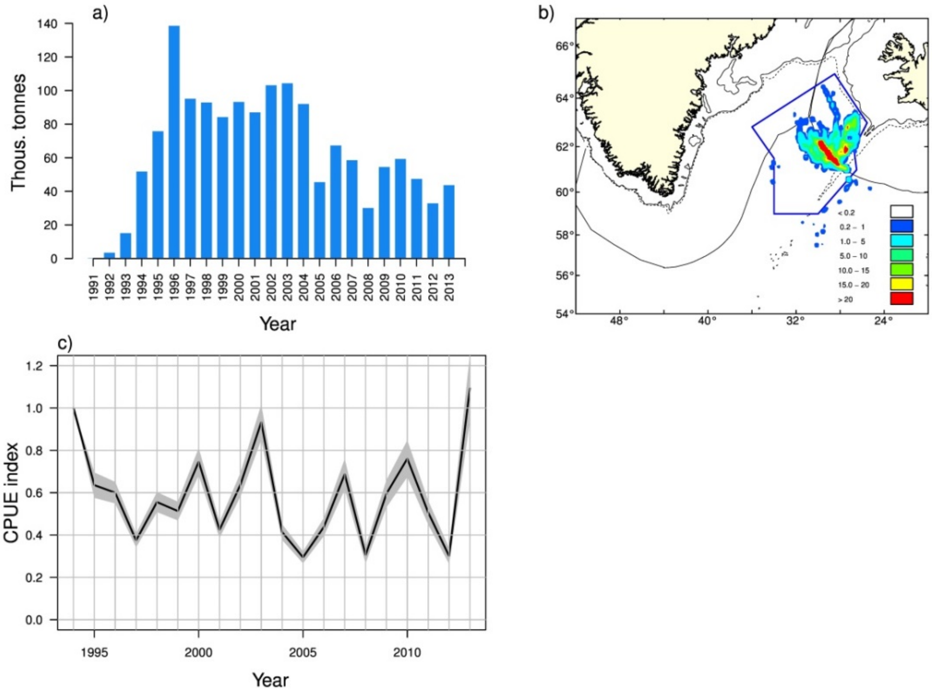


Figure 3. Deep-pelagic beaked redfish: a) Nominal landings 1991–2013. b) Fishing areas in the Irminger Sea adjacent waters 2005–2013 (all years combined) based on logbook data from Iceland, Faroe Islands, Germany, Greenland and Norway. c) Trends in standardized cpue based on logbook data from of the Icelandic fleet.

3.4.2 International redfish surveys

The international redfish surveys in the Irminger Sea and adjacent waters provide valuable information on the biology, distribution and relative abundance of oceanic beaked redfish, as well as on the oceanographic conditions of the surveyed area. Until 1999, only the shallow pelagic beaked redfish was surveyed by acoustics down to an approximate depth of 500 m. Attempts to obtain reliable stock size estimates and map the stock distribution below that depth did not succeed (Shibanov *et al.*, 1996; ICES, 1998; Sigurdsson and Reynisson, 1998), mostly due to the deep scattering layer (DSL), which is a mixture of many vertebrate and invertebrate species mixed with redfish (Magnússon, 1996; Sigurðsson *et al.*, 2002).

Since the fishery had moved towards the deep-pelagic beaked redfish at greater depths (500–1000 m) in the early 1990s it was very important to expand the vertical coverage of the survey. The 1999 survey provided for the first time an estimate on the abundance of the deep-pelagic beaked redfish stock with so-called trawl method (Section 8.1.1). Since then the survey has been conducted biennially. The surveys in 2005 and 2007 are not comparable with the other surveys because of changes in the depth range covered (see Section 8.1.3 where attempt is made to estimate the biomass for the deep-pelagic stock for those two years).

Table 1 gives an overview of the international trawl-hydroacoustic surveys on deep-pelagic beaked redfish conducted in the Irminger Sea and adjacent waters. The survey has been conducted by Iceland, Germany and Russia (with Norway participating in 2001) with two to five research vessels. The objective is to estimate biomass and distribution of the shallow and deep-pelagic stocks in the area. The results from the surveys are the bases for the ICES advice of the two stocks.

The survey is conducted in June/July and the survey area is the Irminger Sea and adjacent waters, covering area of approximately 350 000 NM (Figure 4).

In this survey, 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 only results presented are biomass indices and the length distribution of the catch. Otoliths are also sampled but have not been systematically age read.

Table 1. Redfish surveys on deep-pelagic beaked redfish carried out in the Irminger Sea and adjacent waters (depth 500–950 m in 1999–2003 and 2009–2013 and depth 350–950 m in 2005 and 2007). Th. nm2; square nautical miles surveyed, Country: IS - Iceland, DE - Germany, NO - Norway, RU - Russia.

Year	Country	Vessels	Th. nm^2	Depth range	References
1999	IS/DE/RU	3	296	500-950	Sigurdsson et al. (1999)
2001	IS/DE/RU/NO	5	420	500-950	ICES (2002)
2003	IS/DE/RU	3	405	500-950	ICES (2003)
2005	IS/DE/RU	3	386	350-950	ICES (2005)
2007	IS/RU	2	349	350-950	ICES (2007)
2009	IS/DE	2	360	550-900	ICES (2009a)
2011	IS/DE/RU	3	343	550-900	ICES (2011)
2013	IS/DE/RU	3	340	550-900	ICES (2013)

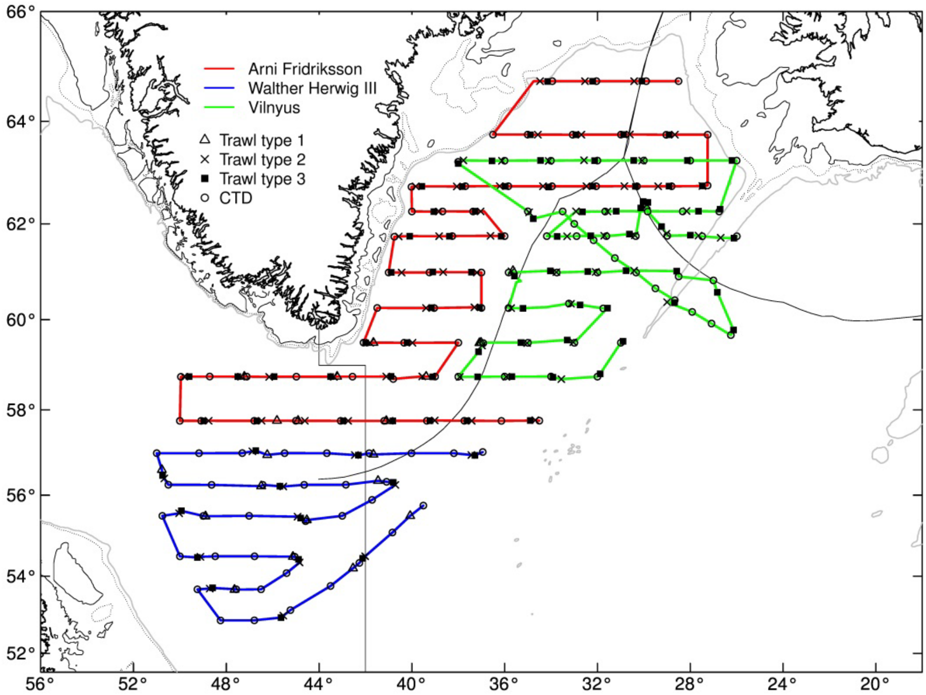


Figure 4. Cruise tracks and stations taken in the joint international redfish survey in the Irminger Sea and adjacent waters in June/July 2013.

3.4.2.1 Abundance estimation by the trawl method

The classic method of continuous echo integration deeper than 350 m (within and deeper than DSL) is applicable only under very specific conditions. Because of the increased influence of the vessel noise, as well as the mixing of redfish with various components of the DSL (Magnússon, 1996; Sigurðsson *et al.*, 2002) this is almost impossible. An additional difficulty is due to the decrease of the effective angle of the transducer beam, especially for single fish registration at great depths. This in particular demands for a lower SV-threshold, down to (-85)–(-90) dB for correct echo integration. For hullmounted transducers this may cause problems with noise. Therefore, acoustic estimation of redfish with a hull mounted transducer in depths exceeding 350 m is very difficult (Dalen *et al.*, 2003).

In the surveys in 1999–2013, a trawl-method was used to calculate abundance of deep-pelagic beaked redfish. The method is based on a combination of standardized survey catches and the hydroacoustic data, where the correlation between catch and acoustic values during trawling in the shallower layer is used to obtain acoustic values for the deeper layer, based on catches in the deeper layer. To be able to make the calculations, the hauls are carried out at different depth intervals, evenly distributed over the survey area.

Since 1999 (except in 2005 and 2007) the sampling with the trawl has been conducted as follows:

1) The depth zones shallower than the DSL, in which redfish could be acoustically identified. Trawling distance was 4 NM;

2) the depth zone shallower than 500 m, in which acoustic redfish registration was hampered by the deep scattering layer. The identification hauls covered the following layer (headrope of the net): from the top of the DSL down to 450 m. Trawling distance at each depth layer was 2 nautical miles;

3) the depth zones deeper than 500 m depth. The deep identification covered the following three depth layers (headline): 550 m, 700 m, 850 m. Trawling distance at each depth layer was 2 nautical miles.

In the 2005 and the 2007 surveys (ICES, 2005, 2007) the trawling was from 350 down to 950 m, i.e. within and deeper than the DSL. For this reason the abundance estimates by the trawl method are not comparable with the other years as both pelagic stocks were sampled simultaneously. In Chapter 8.1.3 a method is described how estimates below 500 m are calculated to be used in further analysis.

The catches were standardized by 1 NM. A linear regression model between the acoustic values and catches (in kg/NM) of type 1 trawls (shallower than the DSL and within redfish concentration) was applied to predict the acoustic values for each type 2 and 3 trawl. Because few type 1 trawls were taken in each survey (year), the type 1 trawls from all surveys since 2001 are combined. The results of the geometric mean linear regressions between the acoustic values and the catches recorded shallower than the DSL for each vessel are given in Figure 5.

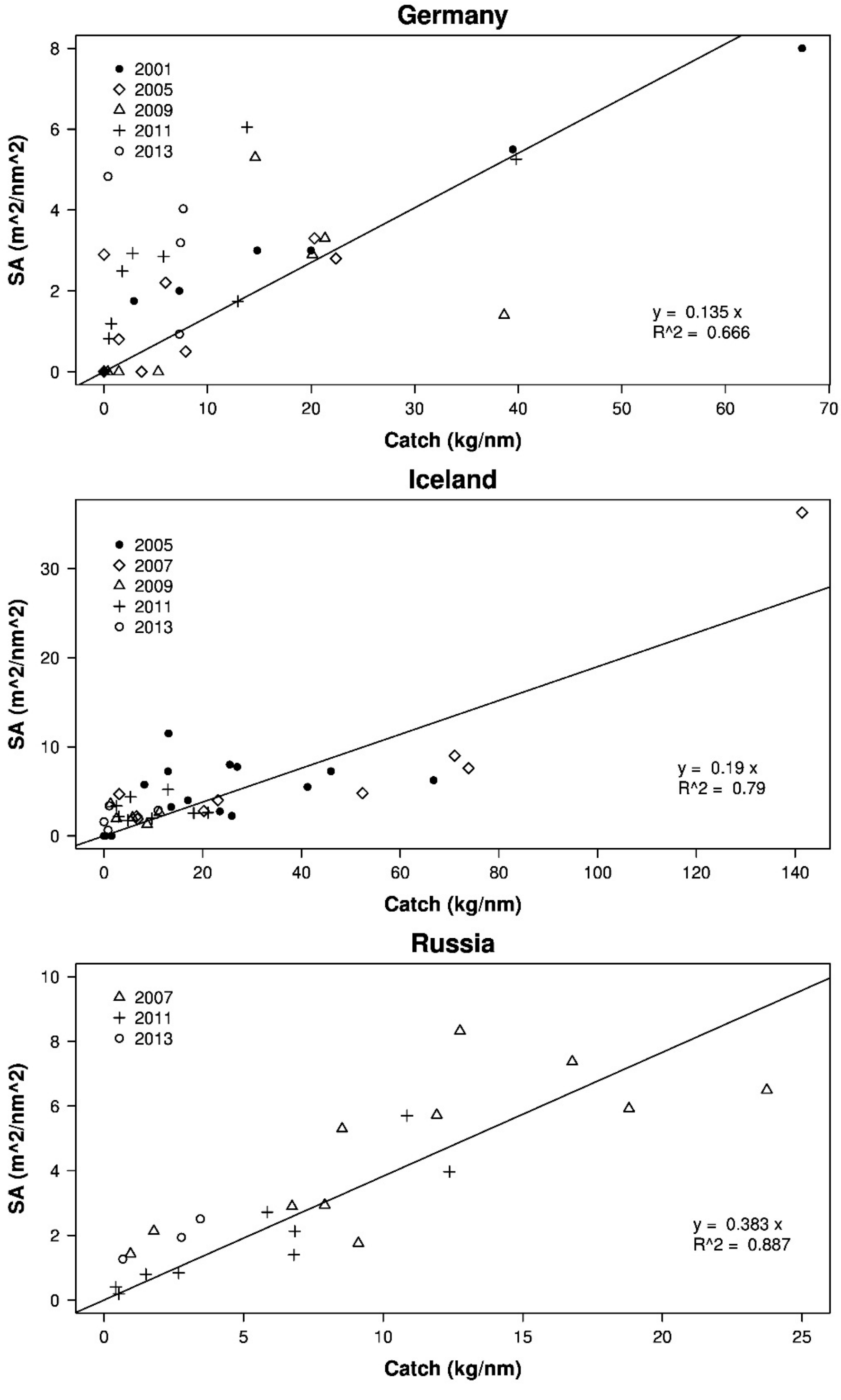


Figure 5. Regression between catches and observed hydroacoustic sA values, observed on the German, Icelandic and Russian vessels shallower than the DSL and used in the biomass calculation for deep-pelagic beaked redfish. For the German trawl types 1 the years 2001, 2005, 2009, 2011 and 2013 were used for the regression, the years 2005, 2007, 2011 and 2013 for the Icelandic vessel and 2007, 2011 and 2013 for the Russian vessel.

Estimation of redfish distribution by the trawl method for type 2 and 3 trawls was done by conversion of catches (catch in kg per NM) to equivalent acoustic estimates by predicting the sA values using the obtained correlation for each vessel. Further, the obtained *sA* values were then adjusted for the vertical coverage of the trawls and the depth range of each haul ($\Delta D/H_{tr}$ where ΔD is the difference between maximum and minimum depth of each haul and H_{tr} is the vertical opening during each tow). The s_A value for each trawl (s_{Atr}) is:

$$s_{Atr} = C * K * K_H$$

where C is the catch in kg per NM of each type 2 and 3 trawl, K is the coefficient of the trawl obtained from the linear regression of type 1 trawls for each vessel (see above), and K_H is the width of the depth range towed defined as:

$$KH = (H_{MAX} - H_{MIN} + dH_{TR}) = dH_{TR}$$

where H_{MAX} and H_{MIN} of the headline of the trawl during the tow and dH_{TR} is mean vertical opening of the trawl. For all vessels dH_{TR} was 50 m. For type 3 hauls (aimed at deep-pelagic beaked redfish) H_{MIN} was 550 m and H_{MAX} was 850 m.

Based on the regressions, confidence limits for the estimates were also calculated.

After having calculated the s_A values from the catches of each haul, the estimation of the abundance and biomass was calculated using the same target strength equation for redfish (20logL - 71.3) and the same algorithm as used for the acoustic estimation. The area coverage was considered to be the same as for the acoustic results.

3.4.2.2 Quality of the trawl biomass estimate

The quality of the trawl biomass estimate from the international trawl-acoustic surveys since 1999 has not been verified as the dataseries is relatively short and the survey is only conducted every second year. It is considered that the estimated abundance derived from the trawl data should be treated with great caution (ICES, 2002). Figure 6 shows the acoustic and trawl estimates of shallow pelagic stock. The trend in the trawl estimates within the DSL layer 2001–2013 shows similar trend as the acoustic estimate. This indicates that the trawl method, although uncertain, can be used to measure the abundance of the deep-pelagic stock.

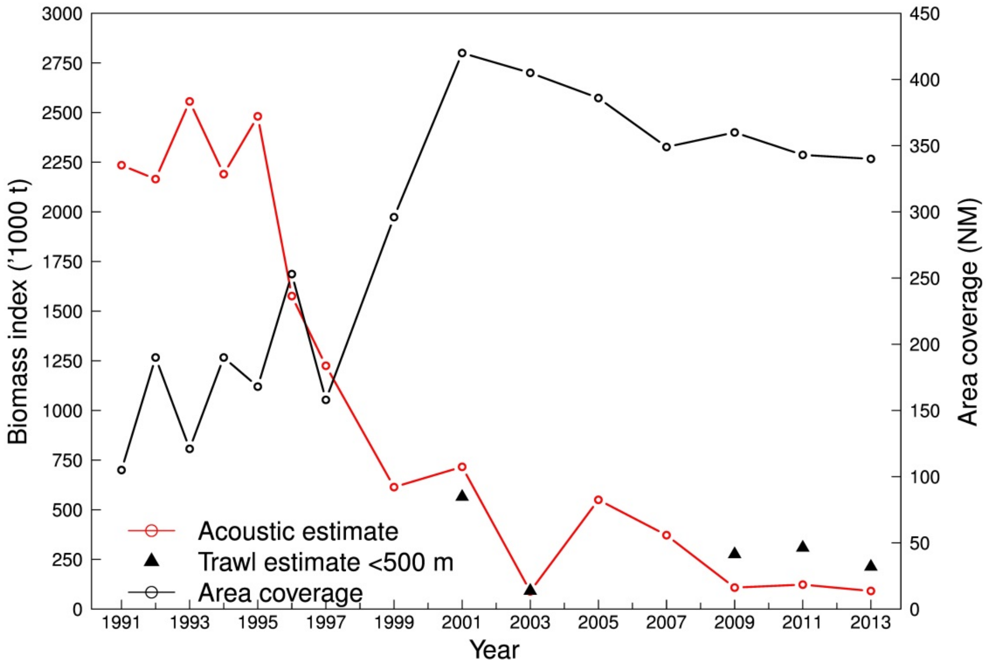


Figure 6. Overview of acoustic survey indices (thousand tonnes) from above scattering layer (red open circles, line), trawl estimates within the scattering layer and shallower than 500 m (black triangle), and aerial coverage (nautical miles squared, black open circle) in the Irminger Sea and adjacent waters 1991–2013.

3.4.2.3 Inclusion of the 2005 and 2007 surveys

Trawling was conducted differently in 2005 and 2007 than in 2001–2003 and 2009–2013. The difference is that in the 2005 and 2007 the trawling was from 350–950 m in a single tow. In the other surveys the trawling was in two separate tows, i.e. one tow from 350–500 m and one tow from 550 m down to 950 m (here defined T2 and T3 tows for the 350–500 m and 550–900 m respectively). This means that in 2005 and 2007 both pelagic stocks were sampled simultaneously.

To get an approximate biomass estimate of the deep-pelagic stock in 2005 and 2007 the following was done:

- Biomass indices are calculated after each survey for six areas shown in Figure 7 for both T3 tows (deep-pelagic stock, Table 2) and T2 tows (shallow-pelagic stock, Table 3).
- For the surveys conducted in 2001, 2009, 2011, and 2013 biomass estimates from the T2 and T3 tows were combined to get a total biomass estimate from 350-950 m depths (Table 4) and these are similar estimates as were done in 2005 and 2007. T2 tows in the 1999 and 2003 were not conducted.
- For each subarea and year a proportion of the deep-pelagic stock of the total biomass was calculated. Then, for each area a mean was calculated (Table 5).
- The mean for each subarea was finally multiplied with the 2005 and 2007 estimates (Table 6).
- This gives estimates of 420 and 554 thousand tonnes for 2005 and 2007 respectively (Table 6).

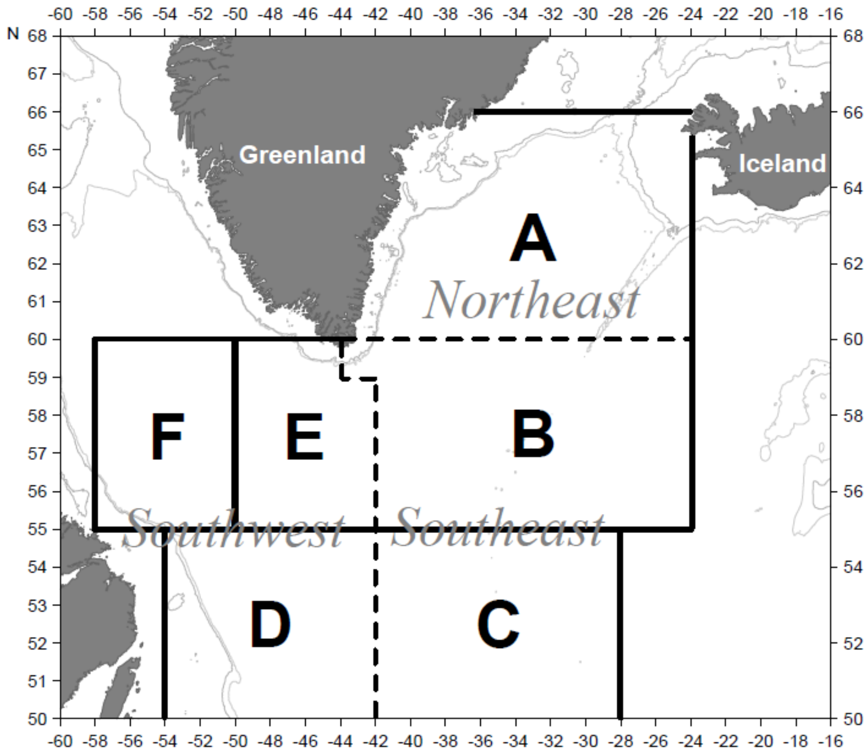


Figure 7. Defined subareas of the survey area in the Irminger Sea and adjacent waters.

Table 2. Biomass estimates (thousand tonnes) by subareas (Figure 7) of deep-pelagic beaked redfish (500–950 m depth) in the Irminger Sea and adjacent waters 1999–2003 and 2009–2013. Also shown are biomass estimates from the 2005 and 2007 surveys where sampling was done at 350–950 m and hence, both shallow- and deep-pelagic stock sampled.

Year	Area						Total	Depth range
	A	B	C	D	E	F		
1999	187	249	10	14	36	0	497	500–950
2001	497	316	28	79	64	18	1001	500–950
2003	476	142	20	13	27	0	678	500–950
2005	276	161	1	53	179	5	674	350–950
2007	345	283	2	32	172	19	854	350–950
2009	291	121	0	8	37	1	458	550–900
2011	342	112	0	1	18	0	474	550–900
2013	186	92	0	26	78	26	401	550–900

Table 3. Biomass estimates (thousand tonnes) by subareas (Figure 7) of shallow-pelagic beaked redfish (350–500 m depth) in the Irminger Sea and adjacent waters 2001, 2009, 2011 and 2013. Sampling in this depth layer was not conducted in 1999 and 2003.

Year	Area						Total
	A	B	C	D	E	F	
2001	23	40	45	399	54	5	565
2009	136	68	0	25	48	0	278
2011	69	185	1	30	76	0	361
2013	64	88	0	22	34	5	213

Table 4. Total biomass (thousand tonnes) by subareas (Figure 7) for combined T2 and T3 (see Tables 2 and 3) in 2001, 2009, 2011 and 2013.

Year	Area						Total
	A	B	C	B	E	F	
2001	520	356	73	478	118	23	1568
2009	427	189	0	33	85	1	735
2011	411	297	1	31	94	0	834
2013	250	180	0	48	112	31	621

Table 5. Proportion of deep-pelagic beaked redfish by subareas (Figure 7) for combined T2 and T3 tows (Table 4) in 2001, 2009, 2011 and 2013. Also shown is the average for each subarea for those four years.

Year	Area					
	A	B	C	B	E	F
2001	0,96	0,89	0,38	0,17	0,54	0,78
2009	0,68	0,64		0,24	0,44	1,00
2011	0,83	0,38		0,03	0,19	
2013	0,74	0,51		0,54	0,70	0,84
Average	0,80	0,60	0,38	0,25	0,47	0,87

Table 6. Biomass estimates of deep pelagic beaked redfish in 2005 and 2007 based on the average values given in Table 5.

Year	Area						Total
	A	B	C	B	E	F	
2005	222	97	0	13	83	4	420
2007	277	171	1	8	80	17	554

3.4.2.4 Survey index for use in the HCR

Trawl survey estimates have been relatively stable from 2005 to 2013, but are lower than the average for 1999–2003 (Figure 8 and the text table below). The 2013 estimate is the lowest and near the lowest observed. These indices in combination with a marked decrease in landings since 2004 suggest that the stock has been reduced in the past decade.

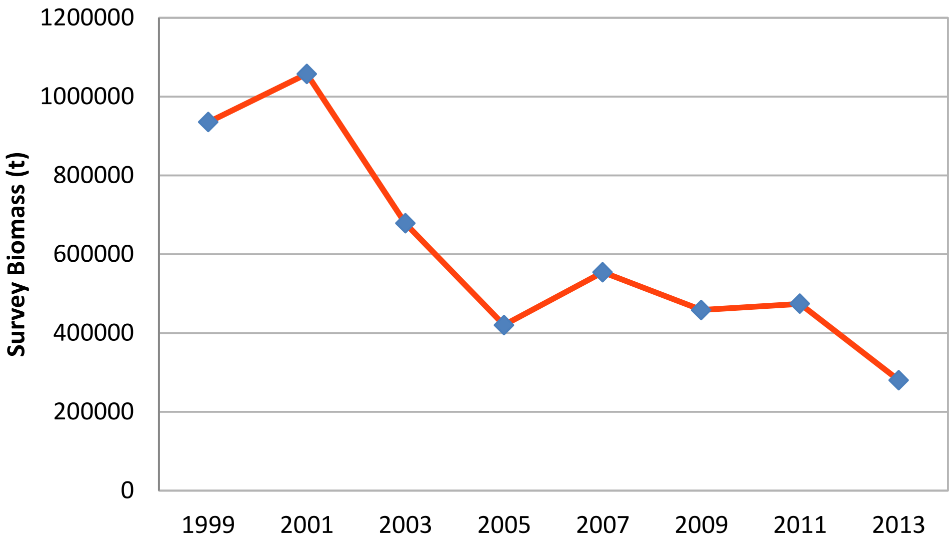


Figure 8. Survey index of deep-pelagic beaked redfish 1999–2013.

Year	Biomass
1999	935 000
2001	1 057 000
2003	678 000
2005	420 000
2007	554 000
2009	458 000
2011	474 000
2013	280 000

3.4.3 Other data

3.4.3.1 0-group surveys and juvenile research

The main nursery area for this species is located off East Greenland (Magnússon *et al.*, 1988, Saborido-Rey *et al.*, 2004). Abundance and distribution of 0-group redfish were measured in the Icelandic 0-group survey 1970–1995 in Icelandic and East Greenland waters (Magnússon and Magnússon, 1977; Magnússon and Jóhannesson, 1997; Sveinbjörnsson and Hjörleifsson, 2003) and juvenile abundance and biomass of redfish <17 cm from the German annual groundfish survey, conducted on the continental shelf and slope of West and East Greenland down to 400–500 m. In these surveys juvenile redfish were only classified to the genus *Sebastes* spp., as species identification of small specimens is difficult due to very similar morphological features. Furthermore, the German groundfish survey is designed for cod and does not cover the full distribution range of beaked redfish.

The purpose to of the 0-group survey was to obtain an indication of the relative year-class strength of larvae of commercially important fish species inhabiting these waters. The survey was discontinued in 2003.

The results from these surveys indicate that the distribution and abundance of 0-group redfish is variable (Figures 9a and 9b). Low abundance is found in Icelandic waters and the main distribution both at East Greenland and in the Central Irminger Sea (Magnússon and Jóhannesson, 1997). Above average year-class strengths were observed in 1972–1973, 1981, 1985–1991, and in 1995 (Figures 9a and 9b). It has, however, been difficult it is to use the 0-group survey indices as an indicator of year-class strength of different redfish species.

Biomass and abundance indices from the German annual groundfish survey show that juveniles were abundant in 1993 and 1995–1998. The 1999–2012 survey results indicate low abundance and are similar to those observed in the late 1980s. Observations on length distributions of *S. mentella* fished deeper than 400 m indicate that a part of the juvenile *S. mentella* on the East Greenland shelf migrates into deeper shelf areas (ICES, 2013) and into the pelagic zone in the Irminger Sea and adjacent waters (ICES, 2013; Stransky, 2000), with unknown shares.

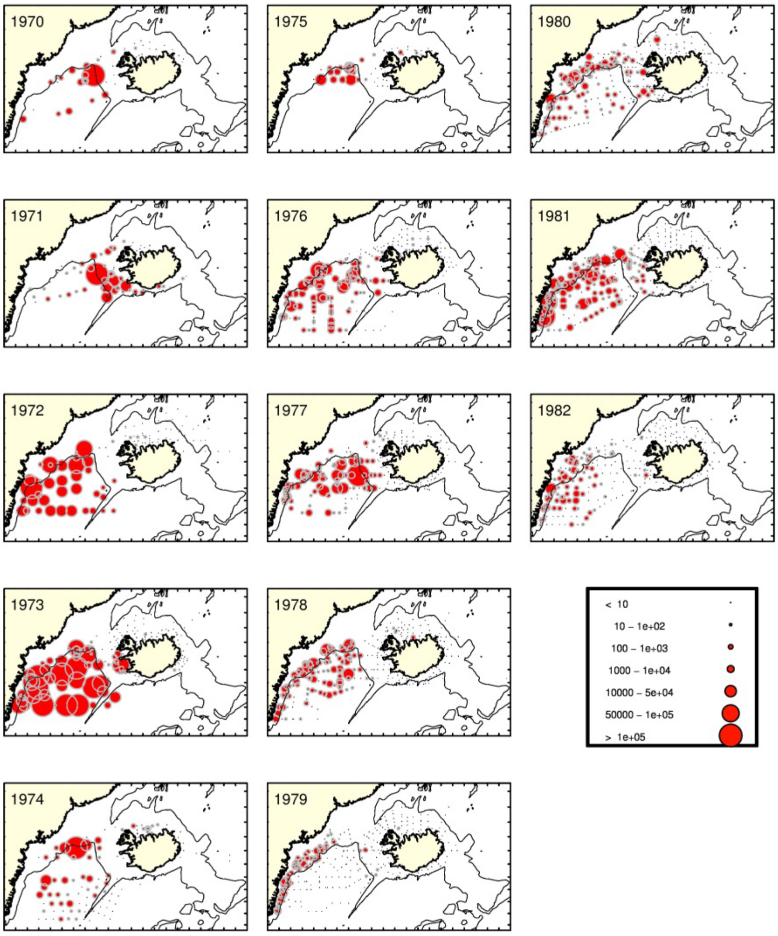


Figure 9a. Annual distribution and density (number/tow) of 0-group redfish 1970–1982.

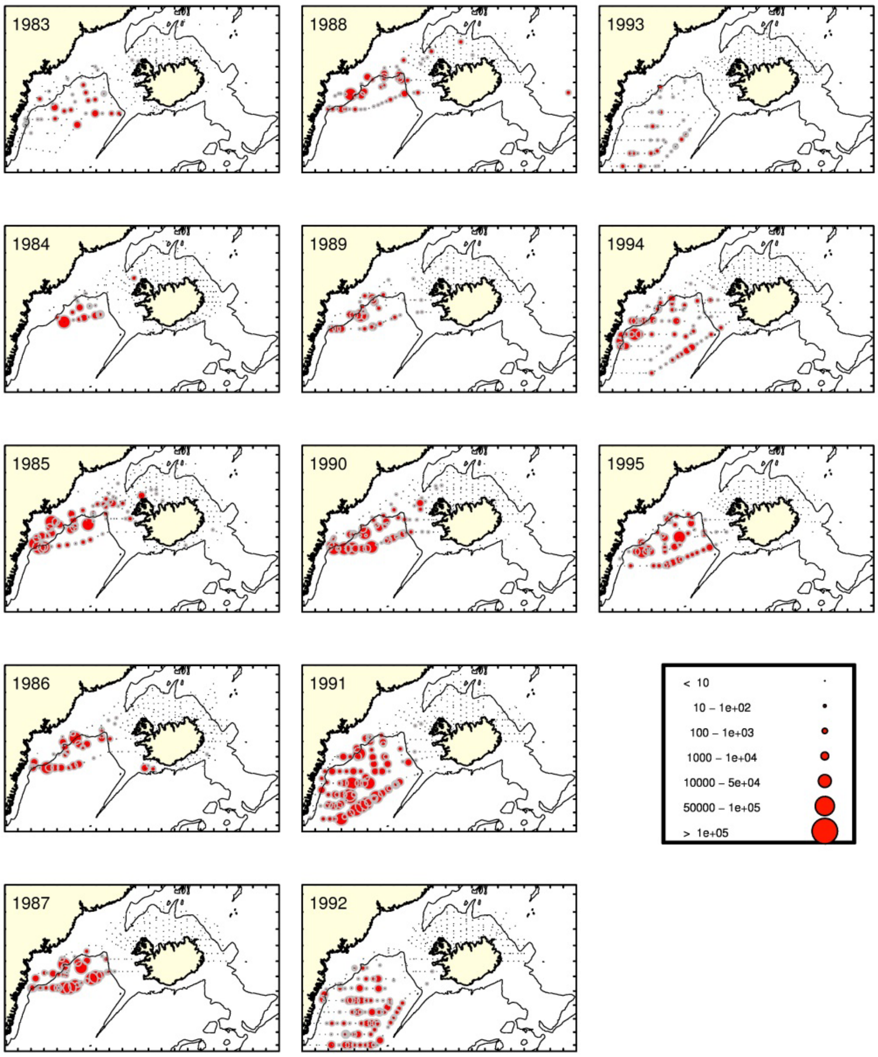


Figure 9b. Annual distribution and density (number/tow) of 0-group redfish 1983–1995.

3.4.3.2 Age data

Age reading of deep-pelagic beaked redfish in the Irminger Sea and adjacent waters and has not been systematic (Table 7). Most of the age reading has been in relation with various projects such as the EU project on redfish (Anon, 2004) and on population structure of deep-water redfish (Stefánsson *et al.*, 2009). This section describes the availability of age reading data of deep-pelagic beaked redfish.

Table 7. Available age data from the deep-pelagic beaked redfish in the Irminger Sea.

Year	Source	Nation	No. ageread
1999	Redfish survey	Iceland	719
1999	Commercial catch	Iceland	131
2001	Commercial catch	Iceland	117
2004	Commercial catch	Iceland	352
2006	Commercial catch	Iceland	188
2009	Commercial catch	Iceland	568
2012	Commercial catch	Norway	647
Total			2,722

The otolith samples show that beaked redfish become very old (Figure 10). It is a slow growing species (Figure 11a,b) but total mortality appears to be low, with Z close to 0.1 for the older fish (Figure 11c).

The age readings, although small, indicate that the fishery has been on an old population where recruitment has been little (Figures 9 and 10).

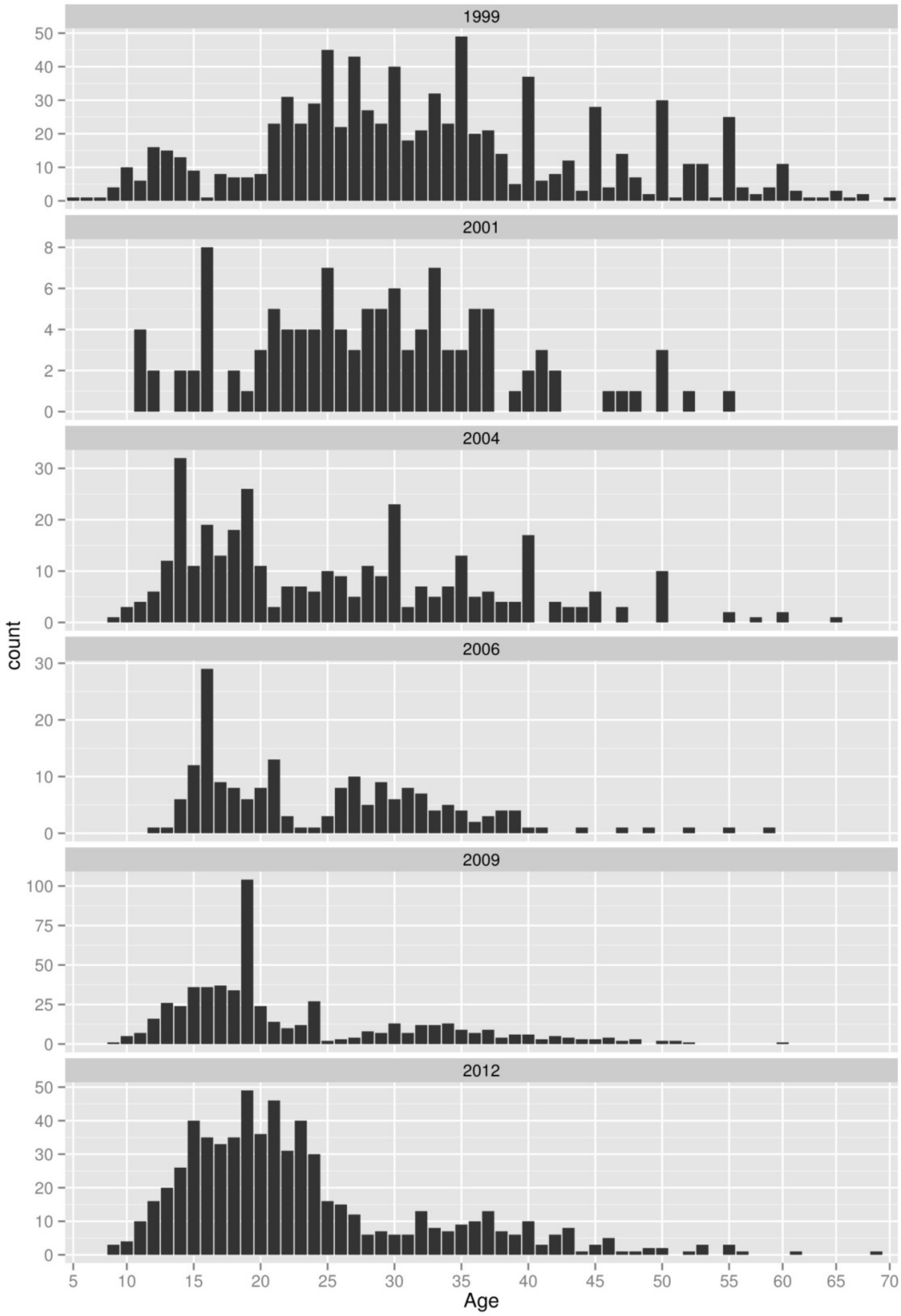


Figure 10. Age distribution of deep-pelagic beaked redfish based on age reading from the commercial catch (except 1999).

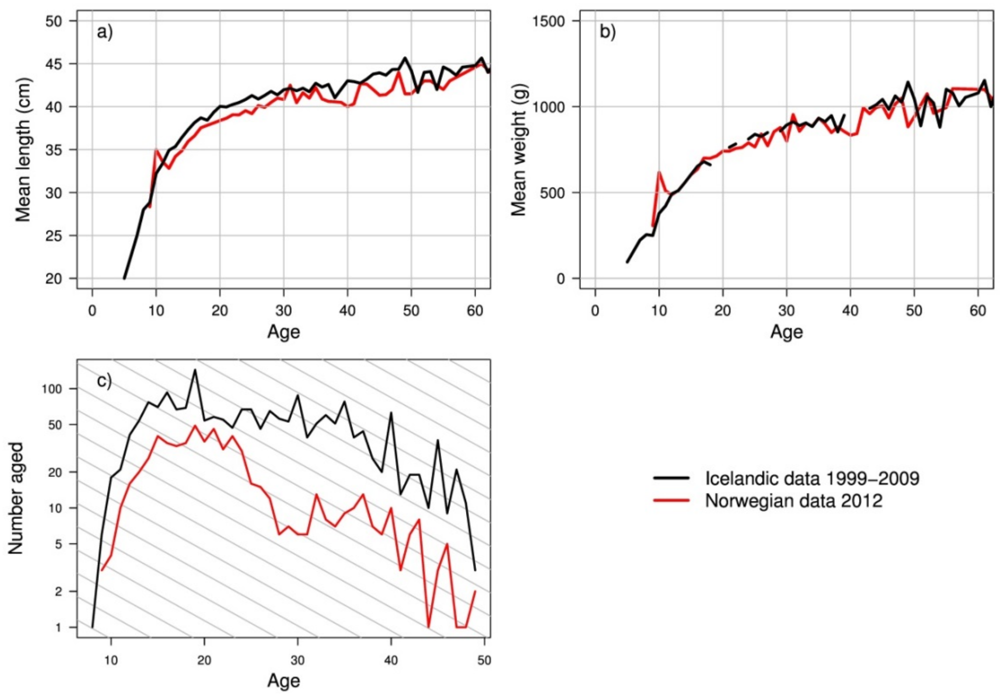


Figure 11. Deep-pelagic beaked redfish: a) Mean length-at-age from Icelandic data 1999–2009 (black line) and Norwegian data 2012 (red line). b) Mean weight-at-age from Icelandic data 1999–2009 (black line) and Norwegian data 2012 (red line). c) Numbers aged plotted on log scale from Icelandic data 1999–2009 (black line) and Norwegian data 2012 (red line). Grey lines correspond to Z = 0.1. See Table 7 for information on the age reading.

3.5 Candidate Harvest Control Rules

Despite the fact that the benchmark group did not suggest any alternatives to current assessment methods due to limited data and shortness of any dataseries, it was decided to continue with ideas on a management plan, based on survey indices alone. We recognize the limitation of such an approach but it is likely that this situation remain the case for the nearest future as surveys are only conducted every other year (hence the time-series will probably still be considered short after ten years or so), and there are no new appropriate analytical assessment methods foreseen for the deep-pelagic stock of redfish. Further, the available data do not allow defining reference points on the usual quantitative basis, but will require rough assumptions and therefore we provide the following ideas for discussion.

The request included three potential HCR forms, i) The Precautionary Approach as previously used as the 'default' basis by ICES, ii) the MSY approach as now used by ICES as the preferred basis and iii) the DLS (Data Limited Stock) approach (category 3.2 rule) as being developed and implemented by ICES for a number of so-called data poor stocks.

3.5.1 Reference point values

The suggestions are based on the facts that deep-sea redfish species are long-lived, slow-growing and late-maturing fish species and are thus highly vulnerable to overfishing. ICES has said that such species can only sustain low rates of exploitation and if depleted they have a long recovery period. Furthermore, if the natural mortality (M) is low (~0.05) as well as the harvest rate (here the suggested 0.05 as harvest rate is taken as equal to assumed M=0.05), one can argue that such conservative harvest rate could possibly be a conservative proxy for F_{MSY}. However, if catchability in the survey (q) is lower than we assume (q=1), such low harvest rate will have much lower probability of reducing the stock size than if the assumption is an overestimation on q, meaning the stock being smaller than the survey estimate indicates. ICES, during its evaluation of any proposals from NEAFC should also respond to these considerations and, if possible, make recommendations.

3.5.2 Proposed HCR types

The Coastal states requested ICES to evaluate a number of proposed HCRs (Annex 3).

3.5.2.1 Proposed 'PA' and 'MSY' style HCRs

The first two proposed approaches are illustrated in Figures 13–15. Both are functions whereby a target harvest rate is used above a certain biomass ($B_{trigger}$). Below this biomass, the harvest rate applied decreases as biomass approaches zero. The 'MSY-style' rule uses a single breakpoint and a linear decline in harvest rate, while the 'PA-style' rule uses two breakpoints.

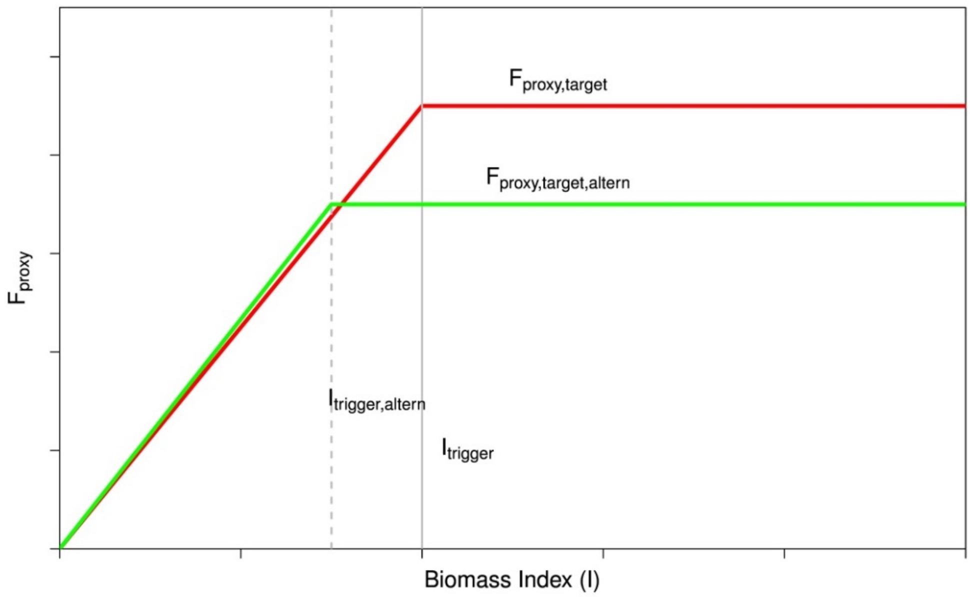


Figure 13. Deep-pelagic redfish in the Irminger Sea. Form of the standard F_{proxy} HCR.

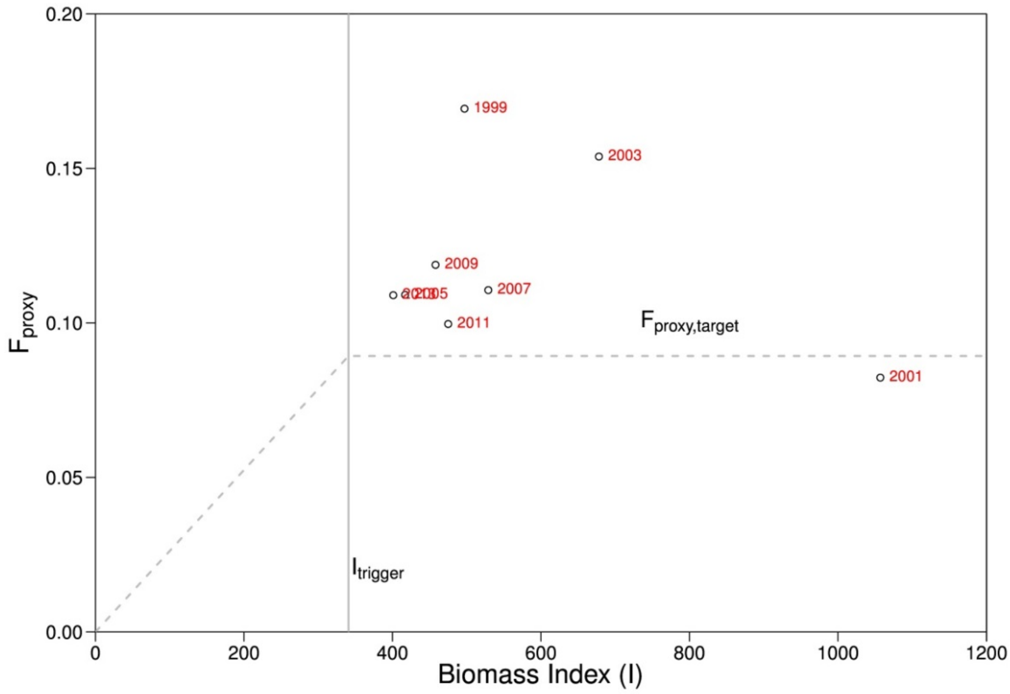


Figure 14. Deep-pelagic redfish in the Irminger Sea MSY HCR. Form of the standard F_{proxy} HCR with observed F_{proxy} values. F_{proxy};target = 0.75 * (F_{proxy};1999–2013) = 0.893 and $I_{trigger}$ = 0.85 * I2013 = 341.

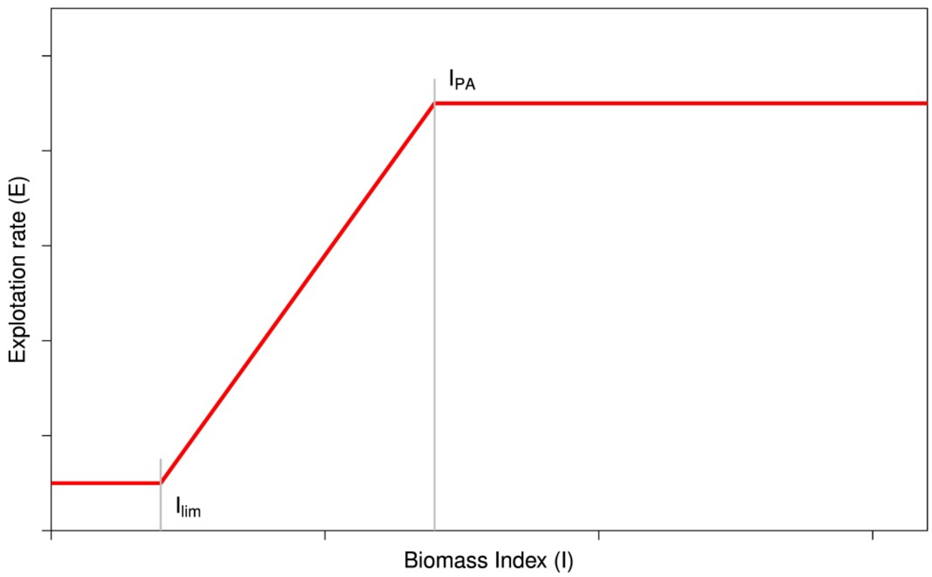


Figure 15. Deep-pelagic redfish in the Irminger Sea. Form of the standard precautionary approach HCR.

3.5.2.2 Proposal for a Data Limited Stock (DLS) Approach HCR

The third approach suggested in the request was to follow method 3.2.0 of the ICES approach for data-limited stocks (DLS; ICES 2012), or a variant thereof. The standard equation used in this method is presented below:

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

Essentially, this approach looks at the average index over a recent period (most commonly the last two years) compared to a period preceding this (most commonly the three years prior to the recent period). If the recent period shows an increase, the advised catch increases accordingly and vice versa. This is based on Russell's (1931) non-equilibrium definition of overfishing, in which if catch exceeds biological production this causes a reduction in the stock. Therefore, decreasing surveys suggest catch should be incrementally decreased and vice versa. The approach also recommends a 20% change limit in catch advice and, where deemed appropriate, the application of a 20% 'precautionary buffer' reduction in catch advice.

Of concern for applying this method to this stock is that the ICES DLS approach, and method 3.2.0, is largely untested for expected performance and its ability to satisfy precautionary and MSY objectives. The data available for this stock are insufficient to carry out a long-term evaluation that would be required to fully test the robustness of this method in this particular case. In 2013 the ICES methods working group (WGMG; ICES, 2013) examined the DLS approach and method 3.2.0 in some exploratory analyses. Amongst their conclusions was that the performance of the DLS framework deteriorates (in terms of being more precautionary as available data becomes more limited) when a well-managed stock becomes overexploited. A large part of this deterioration is caused by the 20% change limit imposed for catch advice in a particular year relative to some catch level two years earlier (effectively resulting in a constraint on changes in catch of only 10% per year). Though no well-defined reference points exist for this stock, the survey index suggests that the biomass has decreased since the early 2000s.

There are a number of difficulties in applying this ICES DLS approach to a long-lived stock such as redfish with the survey data available for it. Firstly, as pointed out in the request itself, the approach is determined for stocks where an annual survey is being carried out. This is not the case for the pelagic stocks in the Irminger Sea, which has a biennial survey. However, annual index values would be more important for shorter-lived, more dynamic species. Hence using a longer time period with fewer datapoints could be acceptable for a longer-lived species such as redfish. But the longer the time period examined to derive a trend in stock size, the slower reacting the HCR would be. The WGMG additionally noted that the 2 vs. 3 rule essentially examines the change in stock size (as indicated by the survey) between four years ago (average from five to three years ago) and 1.5 years ago (average of one and two years ago), a period of 2.5 years. This change over 2.5 years is then applied to recommend a change in catch over two years without correcting for this difference in time periods. This implies a potential over-reaction of the method. This problem increases if longer time periods are used, as would be required for a longer lived stock such as redfish.

A more important criticism of trend-based HCRs (such as the 2 vs. 3 rule) is that while they may arrest an increase in exploitation on the stock, they are likely to maintain stocks near to their current condition (which may be suboptimal). It was argued that target-based strategies (in terms of F_{MSY} proxies or index targets) could be preferable. While there is still uncertainty over exactly what the targets should be, they do at least allow for moving the stock in a more favourable direction than maintaining the current status for overexploited stocks.

3.5.2.3 An alternative HCR form

An alternative MSY Approach Harvest Control Rule (HCR) for pelagic *Sebastes mentella* in the Irminger Sea was presented and discussed. The proposed HCRs dealing with precautionary part of the traditional ICES approach imply a linear reduction in harvest rate when as SSB decreases below $B_{trigger}$. In the proposed rule, this linear decline is replaced with logistic like function (Figure newRule; Babayan, 2004).

This HCR has some positive features. A parameter describing logistic line could be a part of multivariate optimization and estimated during HCR evaluation. It is not necessary to evaluate a biomass limit reference point at that type of HCR. This rule provide a better stock protection in zone of low biomass and smooth crossing in target reference point compared to "traditional" one. The proposed HCR could be used on basis of any analytical assessment or to be a part of HCR which is based on survey index. It should be mentioned that such an approach could be applied for other stocks as well.

The principal point of this HCR is that, having a bizonal structure, it does not require a limit reference point for biomass and ensure acceptable protection of the stock when its biomass is low. This makes the above HCR similar to the classical three-zonal structure of the precautionary approach.

The above mentioned HCR is defined by a piecewise smooth function as follows:

If 0 ≤ B ≤ 0.5Btrigger	Frec = (0.5*Ftg)/(0.5*Btrigger)α*Bα
If 0.5 Btrigger < B ≤ Btrigger	Frec = Ftg-(0.5*Ftg)/(0.5*Btrigger)α*(Btrigger-B)α
If B > Btrigger	Frec=Ftg

where B is a stock biomass; $MSYB_{trigger}$ and Ftg are reference points for biomass and fishing mortality; Frec is a recommended level of fishing mortality; α is a crest factor of the logistic like curve (sigmoid curve).

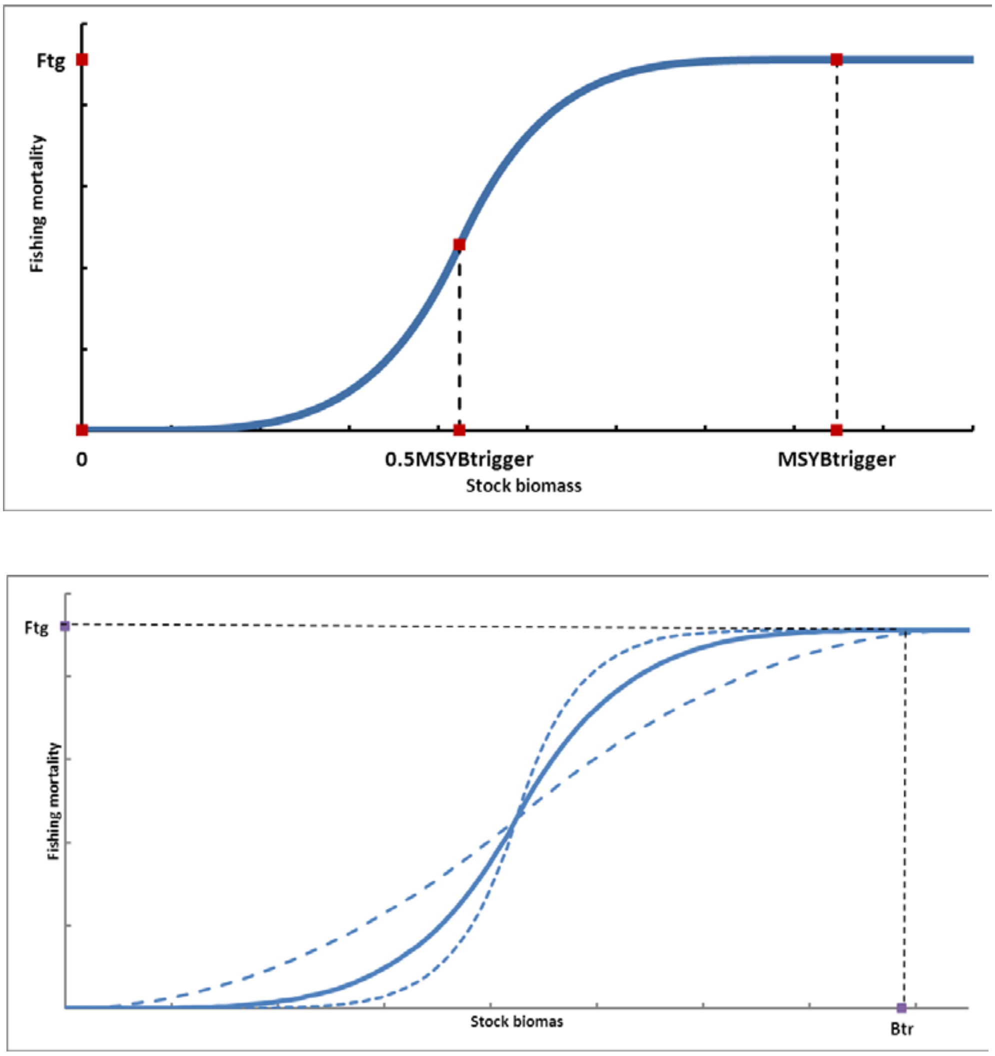


Figure newRule. An alternative HCR utilizing a logistic type function: basic structure (top) and various forms that can be obtained by varying the alpha parameter (bottom).

Taking into account possible errors in MSY characteristics estimators in the frame of HCR identification, it is advisable to use one of the following sets of reference points:

a) $F_{tg}=F_{0.1}$, $MSYB_{trigger}= B_{0.1}$;

b) $F_{tg} = (1-t\sigma_F)F_{MSY}$, $MSYB_{trigger}=(1+t\sigma_B)\ B_{MSY}$.

HCR optimization may be done with the help of the Monte Carlo method by simulating the stock management results for different values of the crest factor α. The advised crest factor by default is α=3.0.

3.5.2.4 Final HCRs checked

Nine candidate HCRs were evaluated by WKREDMP:

#	HCR Type	Ftar	Utrig
1	Linear, 2 breakpoints (‘PA’)	0.01; 0.05	20% Umax; 50% Umax
2	Linear, 1 breakpoint (‘MSY’)	0.05	85% Uloss
3	Linear, 1 breakpoint (‘MSY’)	0.07	85% Uloss
4	Linear, 1 breakpoint (‘MSY’)	0.09	85% Uloss
5	Linear, 1 breakpoint (‘MSY’)	0.05	50% Umax
6	Linear, 1 breakpoint (‘MSY’)	0.07	50% Umax
7	Linear, 1 breakpoint (‘MSY’)	0.09	50% Umax
8	Sigmoid	0.09	50% Umax
9	Sigmoid	0.05	85% Uloss

These rules were evaluated with and without the use of stabilizer (T, F).

3.6 Assessment

No analytical assessment is carried out on deep-pelagic beaked redfish 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 benchmark workshop on redfish in 2012 (ICES, 2012) some participants considered that at present the analytical assessment cannot be conducted because, for example, of little age data and the relative shortness of the time-series available. The external panel of WKRED 2012 put forward a Schaefer biomass dynamics model as an interim basis for assessment and the development of management advice (see Appendix 1 and 2 in ICES (2012)).

Some participants in the Working Group did not accept this Schaefer model approach. The external panel expressed reservations about the use of the trends based assessment approach (see Appendix 2). These issues are elaborated further in Section C of the Stock Annex (ICES, 2012).

3.7 Exploratory analyses

Note: The results in this section have been updated following the revision of the index values following the WKREDMP meeting. Analyses were rerun using the new indices as well as scaling the weights of catches and the stock so we get consistent uncertainty estimates and to use log(r) in the model rather than r to prevent estimating negative r values when sampling from the random multivariate normal to generate uncertainties in K and r.

Where previously to model scenarios were considered (with or without the 199 datapoint), the new 1999 (this datapoint still highly uncertain and will be revised at WGIDEEPS) survey estimate indicates a much higher biomass than the old estimate. This results in the two scenarios being extremely similar. Hence, only scenario B is now presented. Because the 1999 survey estimate is now much higher, and 2013 is lower, than previously calculated, the results are less promising as they were at WKREDMP.

Currently there is no agreed assessment for redfish in the Irminger Sea. There is however, a time-series of Biomass indices available, as well as a time-series of catches. The time-series for catches of this stock starting the early 1990s and the low catches in this period suggest that the fisheries started around that time.

Following the current assumption by the ICES working group we consider the time-series of catches and biomass index as coming from a single closed population. In order to evaluate the proposed management plan, we set up a simple Gordon Schaeffer assessment model that describes the development of the stock biomass B_t can be estimated for any time t from the Catches C_t, the carrying capacity K, the population growth rate r,. Because we assume our observations start when the fish stock is at the carrying capacity we can start with

$$B_1 = K,$$

and use

$$B_t = \max(0.01, B_{t-1} + B_{t-1} * r *(1- B_{t-1}/K)-C_{t-1}$$

for all $t>1$. The model is fit to data using MLE, assuming lognormal error distribution in the survey biomass index observations. Catchability is assumed to be 1. Uncertainty in parameters expressed using parametric bootstrapping using multivariate normal distribution with means being MLE parameter estimates, and variances from inverse of Hessian matrix (cf. Aarts and Poos, 2009).

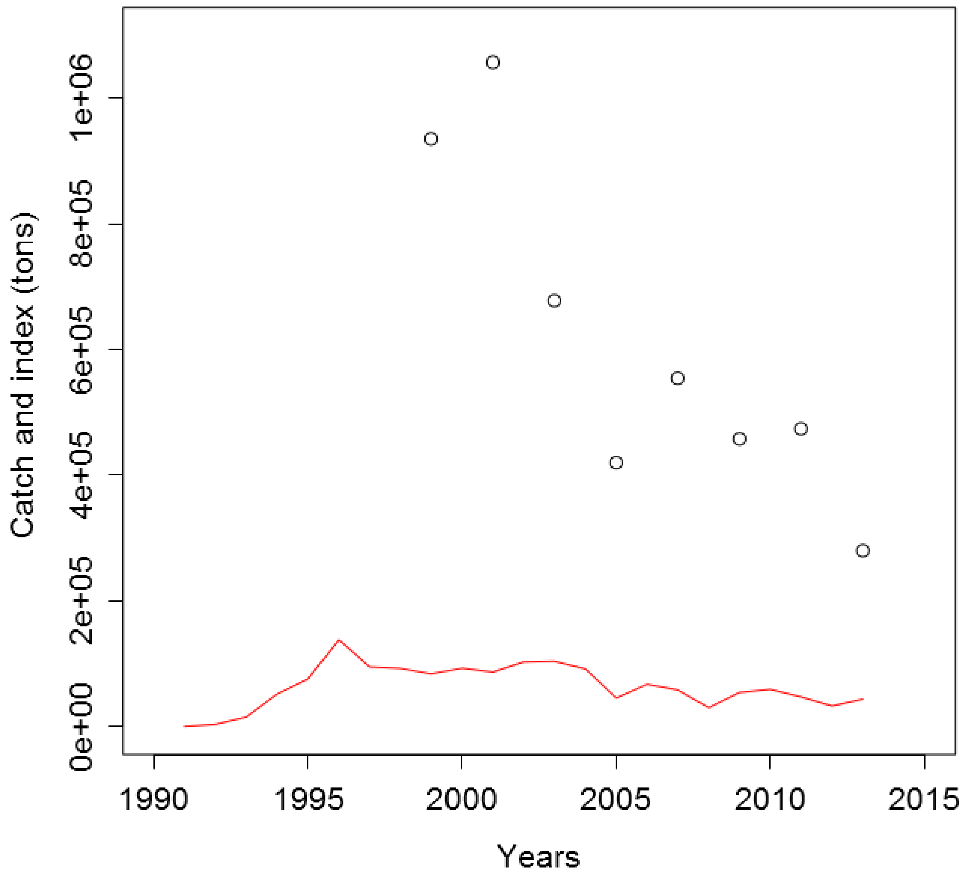


Figure 3.7.1. Catch (red line) and index values (points) for deep-pelagic Irminger Sea stock.

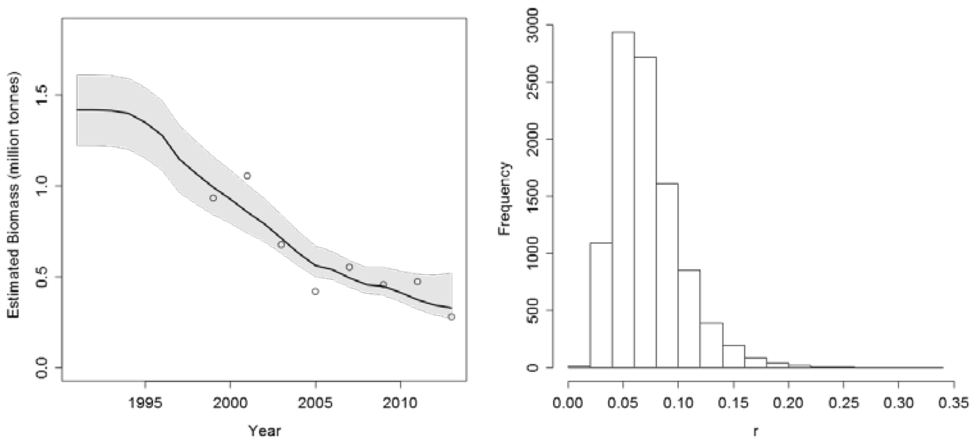


Figure 3.7.2. Assessment model SSB trajectory (left) and r estimates (right). Deterministic parameters: K=1400 kt, r=0.066.

3.7.1 The operating model

In the MSE we use the *r* and *K* parameters and the uncertainty in those as estimated by the assessment model to project the stock dynamics. This is called the "Operating Model" (see e.g. Kell *et al.*, 2007). 10 000 realizations sampled from uncertainty estimates are projected forward applying the chosen HCR. Projections are for the period 2014–2027. Future biomass indices are created from estimated sigma. TACs are set biennially.

TAC and Catches in 2014 and 2015 (biennial quota) are assumed to be (0.8*20 000 + 0.87 *27 000 tons ≈) 39 490 tons. These starting values, rather than the TAC of 20 kt, are required if we want the stabilizer to function appropriately.

3.8 Results

The results of the stochastic simulations are presented in Table Res, with detailed plots selected HCRs in Figures stochRes1–3. Median SSB and Catch values over the ten year simulation period are shown for rough comparisons of stock growth and yield between candidate rules. The biennial TAC variation is given since TACs only change every second year. In addition the probability of the stock being larger than current estimates in either 2020 or 2025 is shown. Since the index suggests that the stock has been in decline, a reasonable expectation of any HCR would be that it should allow for the recovery of the stock. Therefore, in the absence of any meaningful target reference points, HCRs could be considered as precautionary if they allow for a >95% probability of the stock in 2025 being larger than in 2014 (i.e. in ten years' time).

None of the HCRs examined have a >95% probability of the stock in 2025 being larger than in 2014. Without a stabiliser being applied, only two, HCR1 (the 'PA-style' rule) and HCR5 (the 'MSY-style' rule with the lowest target harvest rate and the highest $B_{trigger}$), have a >50% probability of $B_{2025} > B_{2014}$. This can be interpreted as at least preventing the stocks from declining further with a high probability, while not ensuring significant growth in the stock. However, when a stabiliser is applied, none of the HCRs tested have a >33% probability of $B_{2025} > B_{2014}$. The stock has been declining sharply and is currently estimated to be approximately a quarter of the size it was 15 years ago. This steep decline suggests indicates that the stock cannot sustain catches of the level observed in recent years. Though they do reduce biennial TAC variability, when a stabiliser is applied the TACs are not able to reduce rapidly enough to allow for a recovery of the stock in the short term.

Higher harvest rates lead to higher catches. However, this is a moot point since even the lowest target harvest rate examined (0.05) does not allow for a >95% probability of stock biomass growth.

Table Res. Performance statistics of the 9 HCRs examined.

#	HCR Type	Ftar	Utrig	SSB*	Catch*	Biennial TAC var*	P($B_{2020} > B_{2014}$)	P($B_{2025} > B_{2014}$)
#	**No stabilser**							
1	'PA'	0.01; 0.05	20% Umax; 50% Umax	298000	7000	0.5	0.37	0.71
2	'MSY'	0.05	85% Uloss	267000	14300	0.26	0.18	0.29
3	'MSY'	0.07	85% Uloss	249000	18800	0.27	0.08	0.11
4	'MSY'	0.09	85% Uloss	231000	22900	0.27	0.03	0.02
5	'MSY'	0.05	50% Umax	289000	8800	0.4	0.3	0.59
6	'MSY'	0.07	50% Umax	278000	11500	0.39	0.2	0.39
7	'MSY'	0.09	50% Umax	267000	13700	0.38	0.1	0.18
8	Sigmoid	0.09	50% Umax	265000	14300	0.45	0.07	0.13
9	Sigmoid	0.05	85% Uloss	266000	14300	0.24	0.18	0.29
#	**With stabiliser**							
1	'PA'	0.01; 0.05	20% Umax; 50% Umax	259000	12600	0.33	0.13	0.33
2	'MSY'	0.05	85% Uloss	239000	18700	0.22	0.09	0.16
3	'MSY'	0.07	85% Uloss	227000	22800	0.2	0.06	0.08
4	'MSY'	0.09	85% Uloss	214000	26500	0.18	0.03	0.02
5	'MSY'	0.05	50% Umax	253000	14100	0.29	0.11	0.27
6	'MSY'	0.07	50% Umax	246000	16400	0.26	0.08	0.17
7	'MSY'	0.09	50% Umax	239000	18600	0.24	0.05	0.07
8	Sigmoid	0.09	50% Umax	238000	19100	0.27	0.04	0.05
9	Sigmoid	0.05	85% Uloss	239000	18700	0.21	0.09	0.16

* **SSB (t), Catch (t) and biennial variation results are median from 2015–2025.**

HCR1 performs best in terms of stock recovery out of all the HCRs tested. In all the simulations, after landing the TAC in 2014, the biomasses in most of the realizations of the stock fall below B_{lim} and harvest rate declines to a very low 0.01 (Figure stochRes1). Due to a low *r*, the recovery of the stock is slow and average HR remains very low for the whole ten years. In the absence of a stabiliser, this leads to low catches (~7000 t/yr), which in 71% of the realizations allows for the stock to grow larger than in 2014. When a stabiliser is applied, catches reduce more gradually over time because the initial sharp drop is prevented by the TAC change limits (Figure stochRes2). This leads to on average larger catches (~12 600 t/yr) but in this case only 33% of the realizations allow the stock to recover to larger than in 2014.

HCR5 also allows a >50% probability of stock growth, without a TAC stabiliser (Figure stochRes3). This HCR has the same target harvest rate as HCR1 and only differs from HCR1 in terms of the degree to which harvest rate is reduce once the stock biomass falls below $B_{trigger}$. In HCR5 the harvest rate declines slower, allowing for higher average catches (~8800 t/yr) to be taken since HR does not drop as low as 0.01 (as in the case of HCR1). This also reduces the probability of stock biomass growth.

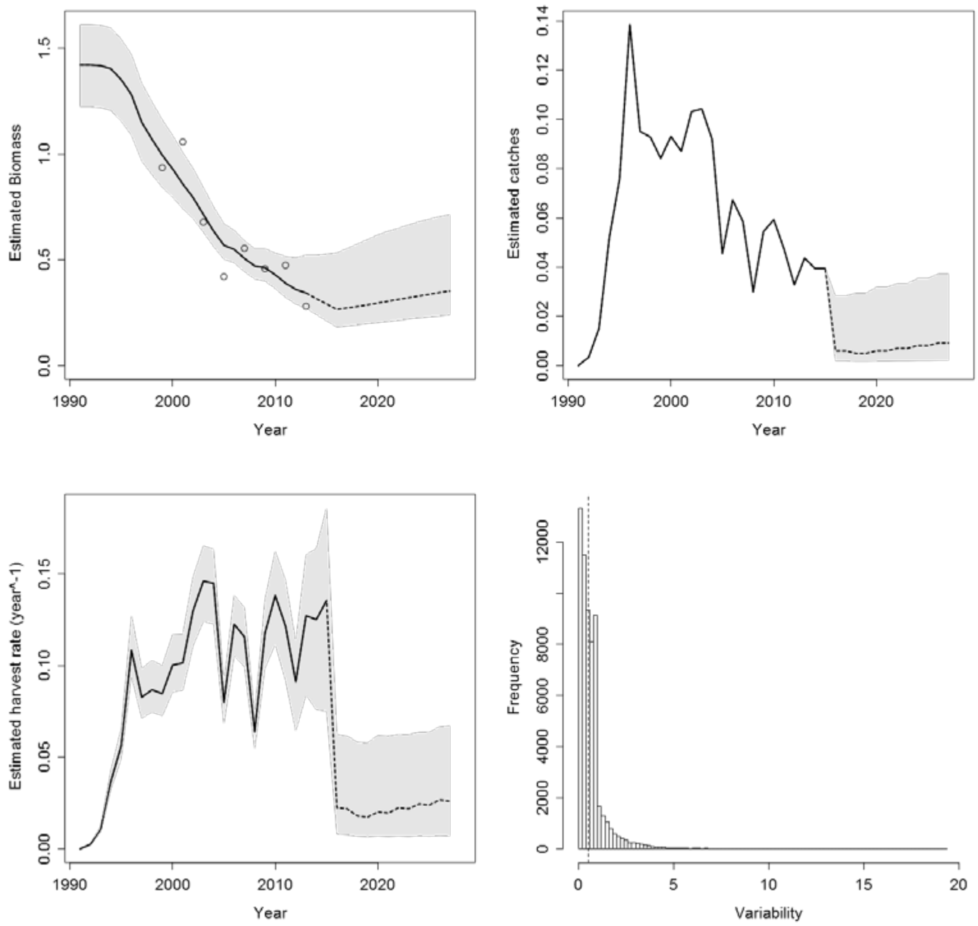


Figure stochRes1. Results of the stochastic simulations of HCR1 (the 'PA-style' rule, F_{target}=0.05, $B_{trigger}$ = 50%*U_{MAX}, B_{lim} = 20%*U_{MAX}, F_{low}=0.01) without a TAC stabiliser rule applied. Biomass (top left), catches (top right), harvest rate (bottom left) and TAC variability (bottom right). Grey areas denote 95% of runs, lines denote medians of runs.

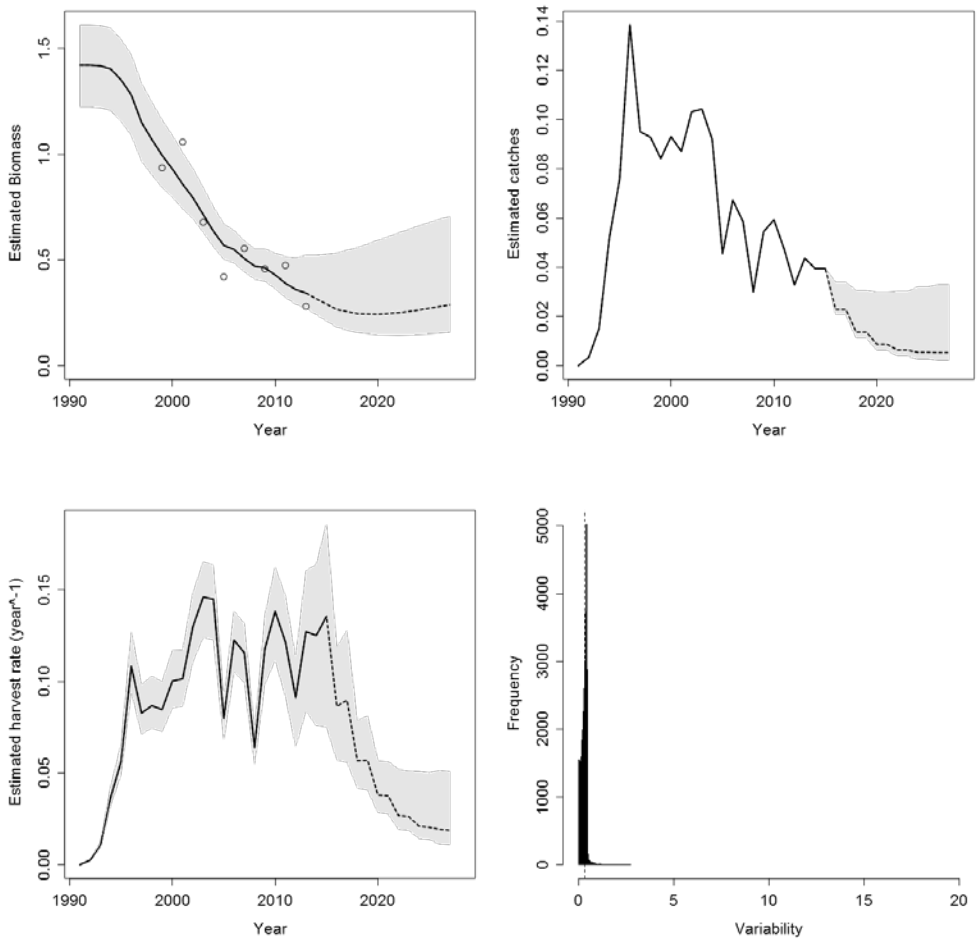


Figure stochRes2. Results of the stochastic simulations of HCR1 (the 'PA-style' rule, F_{target}=0.05, $B_{trigger}$ = 50%*U_{MAX}, B_{lim} = 20%*U_{MAX}, F_{low}=0.01) with a TAC stabiliser rule applied. Biomass (top left), catches (top right), harvest rate (bottom left) and TAC variability (bottom right). Grey areas denote 95% of runs, lines denote medians of runs.

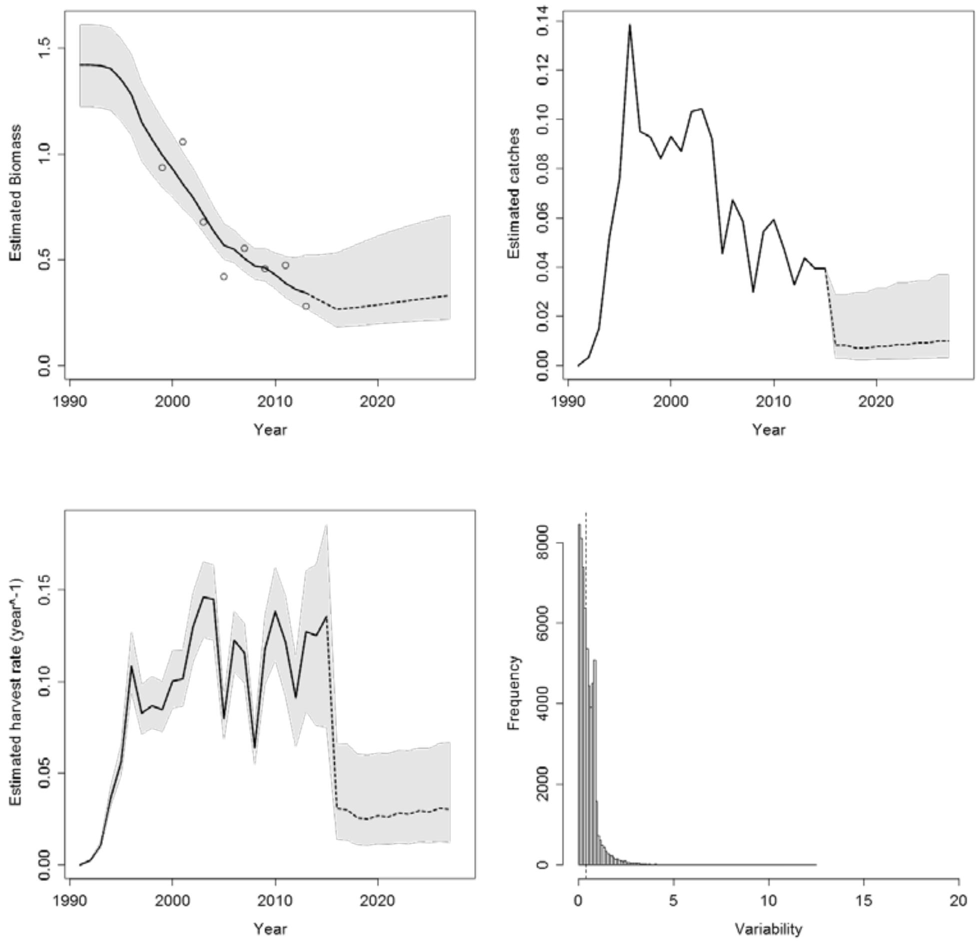


Figure stochRes3. Results of the stochastic simulations of HCR5 (the 'MSY-style' rule, F_{target}=0.05, $B_{trigger}$ = 50%*U_{MAX}) without a TAC stabiliser rule applied. Biomass (top left), catches (top right), harvest rate (bottom left) and TAC variability (bottom right). Grey areas denote 95% of runs, lines denote medians of runs.

3.9 Discussion and conclusions

Both during and following WKREDMP the method for calculating the index values was examined and tuned. This resulted in an almost completely changed index compared to the start of WKREDMP. New trawl values were proposed for 2005 and 2007, completing the fully biennial time-series from 1999. Following WKREDMP, the 1999 value, previously considered poorer quality estimates that the following years, was revisited and somehow improved. Though it is considered that the quality of the index time-series has improved, it is still recommended that these changes are examined further at the NWWG and WGIDEEPS meetings.

While the quality of the time-series improved, the signal it gives of stock development got worse. The current index time-series indicates a stock in sharp decline. Index stock biomass estimates have decreased by more than 75% in 15 years.

One reason for this decline could be overfishing, but this cannot be confirmed with the data currently available. The limited catch-at-age data gives mixed signals. While they suggest that total mortality (Z) on the stock has not been unusually high, the lack of older fish in current catches suggests that fishing pressure has been high.

A similar pattern would be observed if there were initially strong year classes entering into the stock followed by an extended period of poor recruitment prior to the start of the index time-series. If recruitment over the last two decades has indeed been low, stock recovery even under a very low harvest rate would be slow (though still quicker than recovery under a high harvest rate). This is especially true in the simulations conducted to evaluate the HCRs. If weaker than usual year classes were recruiting to the stock during the time measured by the index series in 1999–2013, then the biomass dynamics model fit to the data would estimate a lower intrinsic growth rate than the stock is actually capable of in the longer term. However, there are currently neither reliable sources of data on the level of recruitment to this stock nor on the longer term stock dynamic trends. The period of 14 years covered by the index time-series is less than a quarter of the maximum age attained by fish in this stock and is therefore a very short window of the stock development. This combined with insufficient aging data provides a very limited basis with which to gain a view of the long-term dynamics of the stock. So any simulations conducted at this stage necessitate a number of important assumptions.

Despite these limitations, an exploratory assessment was created in order to do some initial evaluations of candidate HCR performance. This model follows closely the trend observed in the raw index data (i.e. steady decline in biomass). The time-series of catches suggests that the fisheries on this stock started in the early 1990s, shortly before the start of the index time-series. This allowed for the simplifying assumption that at the start of the catches time-series the biomass of the stock was at carrying capacity (B0=K). However, given the long lifespan of redfish and potential sustained periods of low recruitment (often observed in redfish stocks), stock biomass is likely to fluctuate gradually over time, even in the absence of a fishery. From the data available it cannot be ascertained at what level the stock was in relation to carrying capacity (K) at the start of the catch time-series.

The exploratory model also assumes that the catchability of the survey index is equal to 1. The value of q has a significant impact on the estimated size of the stock and the intrinsic growth rate. If q<1, then the stock is larger than is estimated when assuming q=1, and vice versa. If q<1 then stock harvest rate is lower than the index harvest rate and the estimated value of *r* would be lower. Lower *r* values affect the ability of the stock to recover in the simulations, and are therefore an important parameter. Unfortunately the short time-series of data (for such a stock) does not provide enough data to estimate all parameters of the model simultaneously and there has been insufficient time to do a full sensitivity analysis of the impact of various assumptions on the value of *r*.

The results of the exploratory simulations are driven by the fact that the modelled stock, following the trend of the index, has declined sharply under the level of catches exerted in the past. Therefore only a sharp reduction in catches immediately followed by stable or slowly increasing catches for the next decade is likely to allow the stock to grow in size compared to its current size. Using a TAC stabiliser would slow the reduction in catches and in turn the slow the growth of the stock, or cause further decline (this stabilising effect is doubled since TACs are set biennially). Following an initial sharp reduction in TAC, variations in TACs using a low HR (e.g. <0.05) without a stabiliser would probably be low.

If an HCR was applied to this stock immediately, it would still take a long time before any discernible effects on the index biomass would be detected. The size of the next 10–15 year classes to enter the fishery, all of which are already present in the stock in unknown abundance, will to a large degree determine the future changes in the index biomass. Developing age structured indices for this stock would allow for a much improved basis to evaluate short-term trends under different harvest scenarios.

3.10 References

Babayan, V.K. 2004. Alternative methods to estimate the recommended exploitation rate in TAC calculations. Moscow, Rybnoe Khozyaistvo, 4: 23–25 (in Russian).

4 Evaluation of a proposed HCR for golden redfish (*Sebastes marinus*) in Subareas V, VI, XII and XIV

Information about available data, the assessment model and the HCR evaluations are all detailed in working document 2 (Kristinsson and Björnsson, 2014). This chapter focuses on the specific changes to the data and assessment and final conclusions on the HCR evaluations.

4.1 Current management and ICES advice

The Gadget model has been adopted as indicative of the trend (WKRED, 2102). ICES DLS approach, Category 2.1.1 is therefore used as basis for catch advice for this stock. Based on the prognosis of the GADGET model, the estimated landings for 2014 are 54 400 t, which is an increase of 26% compared to average landings in 2010–2012. This implies an increase of catches of at most 20% (uncertainty cap used) in relation to the average catch of the last three years, corresponding to catches of no more than 51 980 t. Considering that the current exploitation is not detrimental to the stock, the effort in the main fisheries has decreased significantly and biomass has increased, no additional precautionary reduction is needed.

4.2 The NEAFC Request

The request for golden redfish was made on behalf of the governments of lceland, The Faroe Islands and Greenland:

> The management strategy for golden redfish (*Sebastes marinus*) in Subareas V, VI, XII and XIV is to maintain the exploitation rate at the rate which is consistent with the precautionary approach and that generates maximum sustainable yield (MSY) in the long term.

The request suggests that the annual total allowable catch (TAC) will be set by applying the following harvest control rule (HCR):

> 1. The annual TAC will be set consistent with an average fishing mortality rate of 0.097 in the advisory year for age groups 9–19, when the spawning–stock biomass (SSB) in the assessment year (SSBy) is estimated to be above 220 000 tonnes ($B_{trigger}$).
>
> 2. Where the SSB in the assessment year is estimated to be below 220 000 tonnes ($B_{trigger}$), the TAC will be set consistent with a fishing mortality rate in the advisory year equal to 0.097 *(SSBy/$B_{trigger}$).

In addition, the evaluation should also include review of input data and the applied assessment methodology (Benchmark) and the appropriateness of values assigned to reference points.

Much work was conducted by the national experts and the NWWG prior to the drafting of the request. Hence the request has a very specific HCR formulation and suggests potential parameter values.

The full request is included in Annex 5.

4.3 Changes to the Assessment Model

The settings of the Gadget model in spring 2013 were unchanged from 2012, except that the survey data used in tuning were limited to 25–54 cm fish, compared to a range of 19–54 cm earlier. This was a part of a continuous development when small fish were gradually eliminated from the tuning fleet. When the 2012 data and the data from the 2013 March survey were added, estimates of the model changed by more than 20%, a seemingly large retrospective change for this type of model. Part of this change (3%) could be explained by the addition of the March 2013 survey data, but the main factor leading to this change was the age data from 2012 (mostly from the autumn survey). Some cohorts just recruiting to the fisheries appeared very strong in these data, leading to a revision of the estimate of the size of these cohorts. The model was of course more sensitive to these data, as data for small fish had gradually been removed from the tuning fleet in the model so there was no older cohort history to counter the new data indicating larger cohort sizes. In addition the age data from the 2011 autumn survey are missing as the survey was not conducted in this year.

Looking at numbers and mean weight by age there are indications that redfish is growing faster in recent years (Figures 1 and 2). Both the mean weight-at-age is increasing and the fish disappears earlier from the fisheries (Figure 2). For the latter observation year-classes 1996 and 1998 vs. the year class 1990 in the autumn survey was compared. As selection to the survey and catches is size based, faster growth will lead to cohorts recruiting earlier to the catches and fisheries and hence, leading to overestimation if changed growth was not taken into account.

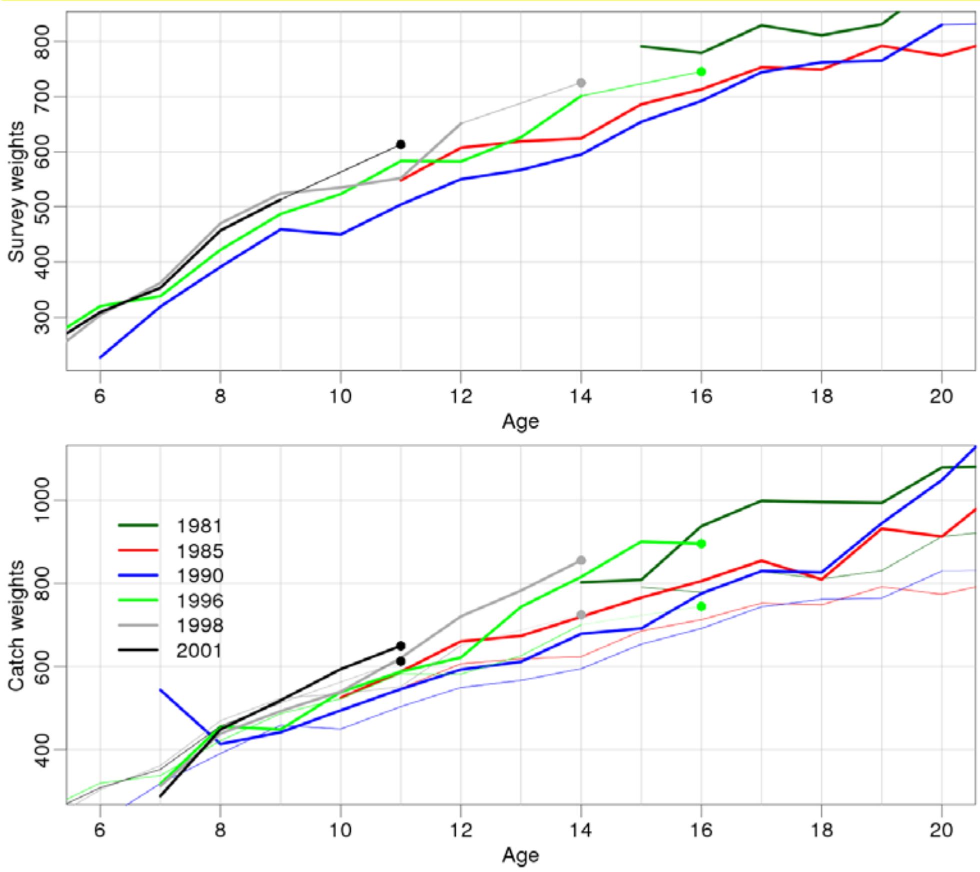


Figure 1. Mean weight-at-age of some cohorts in the autumn survey and catches.

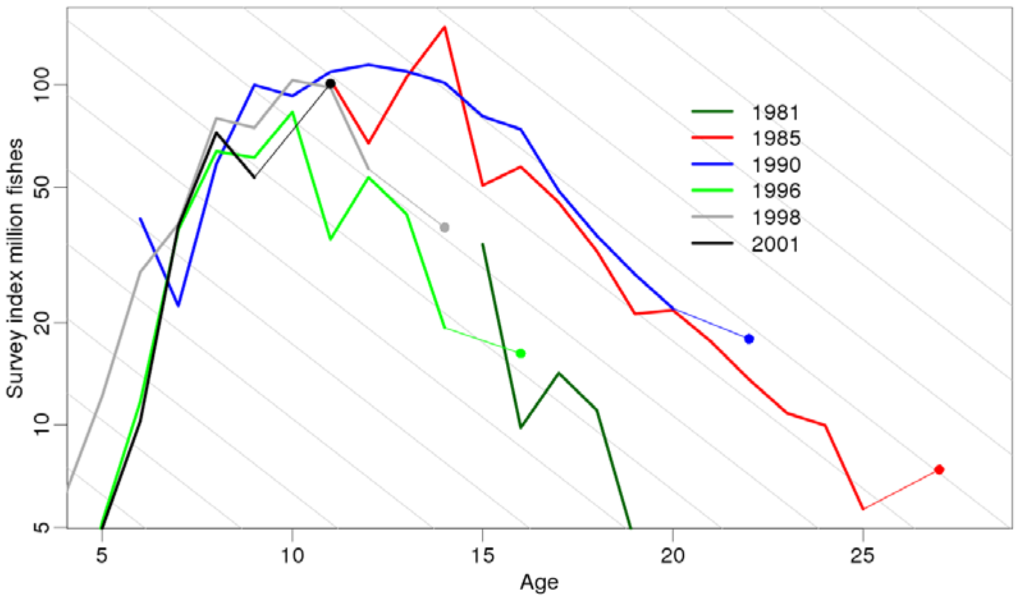


Figure 2. Age disaggregated indices from the Icelandic autumn survey plotted on log scale. The grey curves correspond to Z=0.2.

To account for this change in growth, mean length-at-recruitment (age 5) was estimated separately for year classes 1996 and later. This led to a more than 2 cm change and has a considerable effect on assessment (Figure 3).

The weighting of the individual datasets in the GADGET model is now calculated using an iterative re-weighing algorithm. Reweighting the run from 2013 (poor man's version of estimating standard error on likelihood components) did also have considerable effect on the model fit. This process essentially assigns weights to each input dataset on the basis of the inverse variance of the fitted residuals. This is done to reduce the effect of low quality input data. In all of the analysis done here re-weighting is applied.

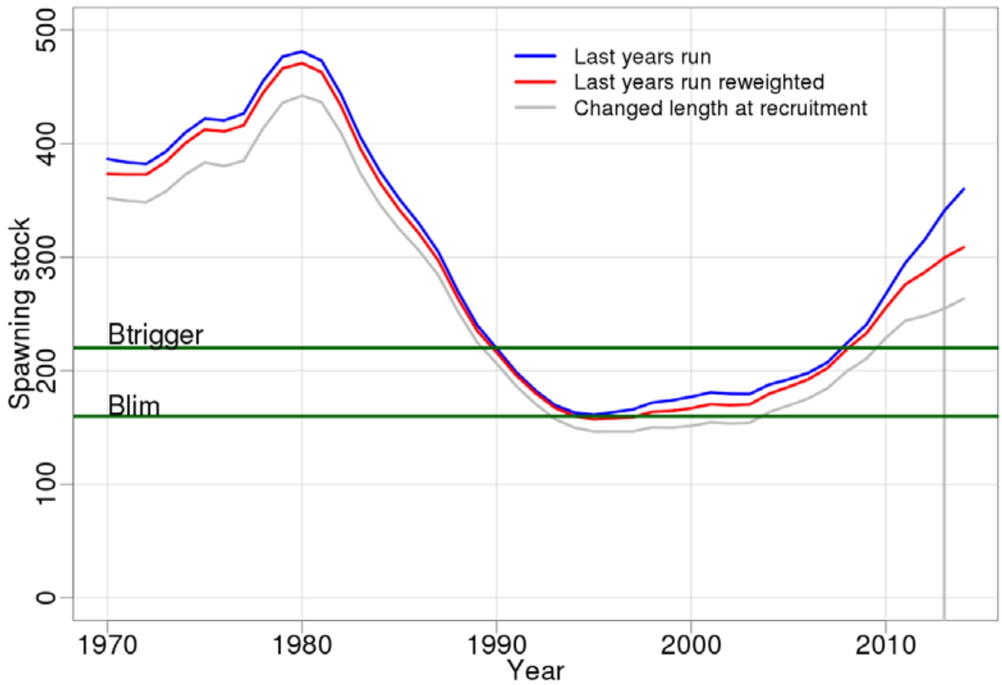


Figure 3. Comparison of the spawning stock from last year's run, last year's run reweighted and the where growth is allowed to change from the 1996 year class onwards.

Observed and predicted survey biomass in the assessment run from 2013 show a greater level of agreement than in other runs based only on Icelandic data. Lack of fit between observed and predicted survey biomass was one of the main critics of WKRED 2012. That lack of fit is caused by too narrow length distribution, with large fish and small fish missing but they weight much more in the tuning data than in the total biomass. This is best seen in Figure 4c that shows the abundance of 40 cm+ is still at a very low level taking into account that total biomass index has been very high for some time (Figure 4a). Possible explanations for this discrepancy include:

- Change in growth and earlier maturation (Figure 5) lead to fewer fishes reaching 40+ cm since growth decreases when the fishes become mature.
- Overestimation of intermediate fish in the survey. Part of the survey index in recent years comes from dense schools compared to the indices from the first years of the survey (seen by wider confidence intervals). Catchability in dense schools might be higher than in less dense schools. Surveying the most important redfish areas by acoustics was proposed two years ago but has not been done.

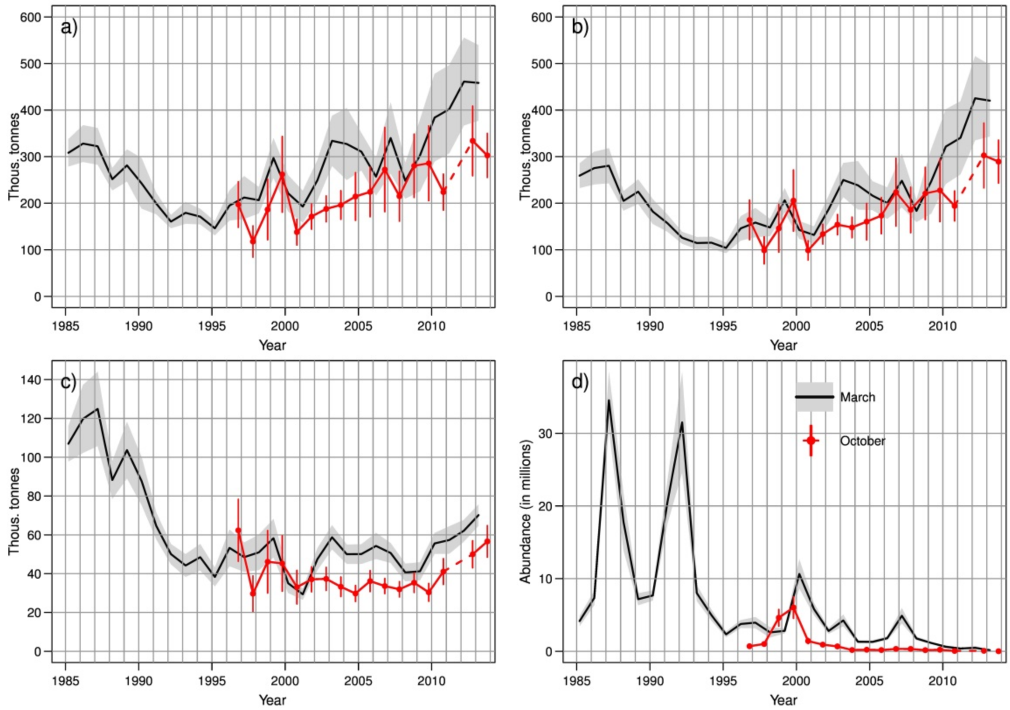


Figure 4. Indices from the Icelandic groundfish surveys. a) Total biomass. b) Biomass 33 cm +. c) Biomass 40 cm +. d) Abundance 11 cm and less.

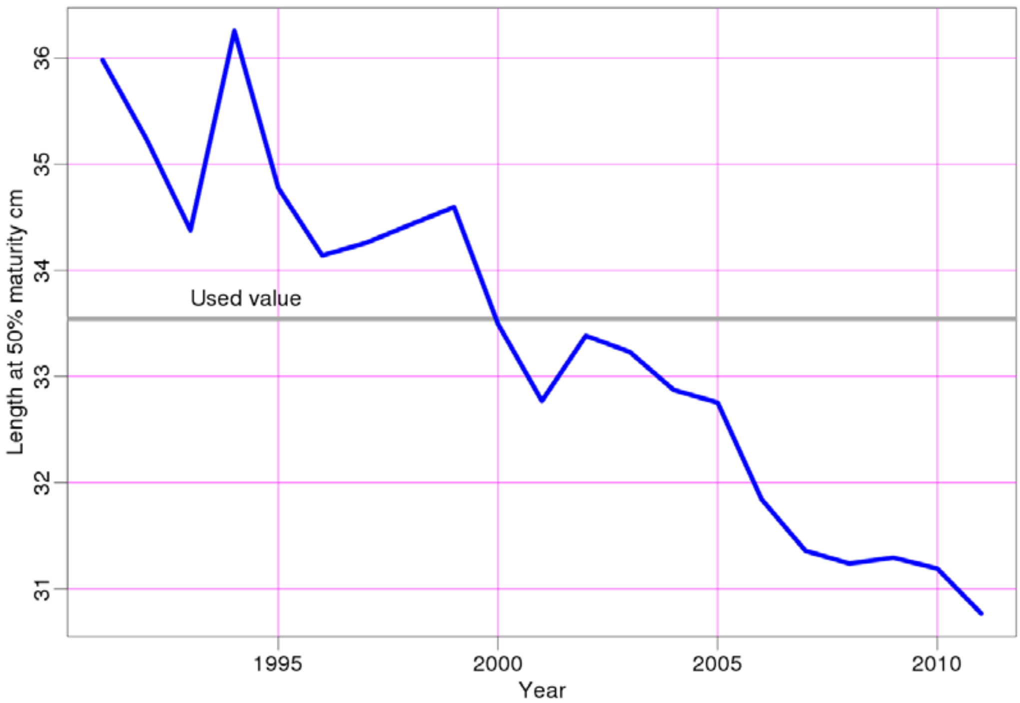


Figure 5. Development of length where 50% of redfish is identified as mature. L50 in the curve used shown for comparison.

Catch curves (Figure 6) do not strongly indicate that *Z* has been decreasing over the recent decade, which would be the case if the stock was increasing since the catches have been relatively unchanged for previous levels (with some interannual noise).

Age data from catches are part of the likelihood function and indicate a stable stock (green line, Figure 7). It should be noted that such data can be difficult to interpret when effort is slowly decreasing.

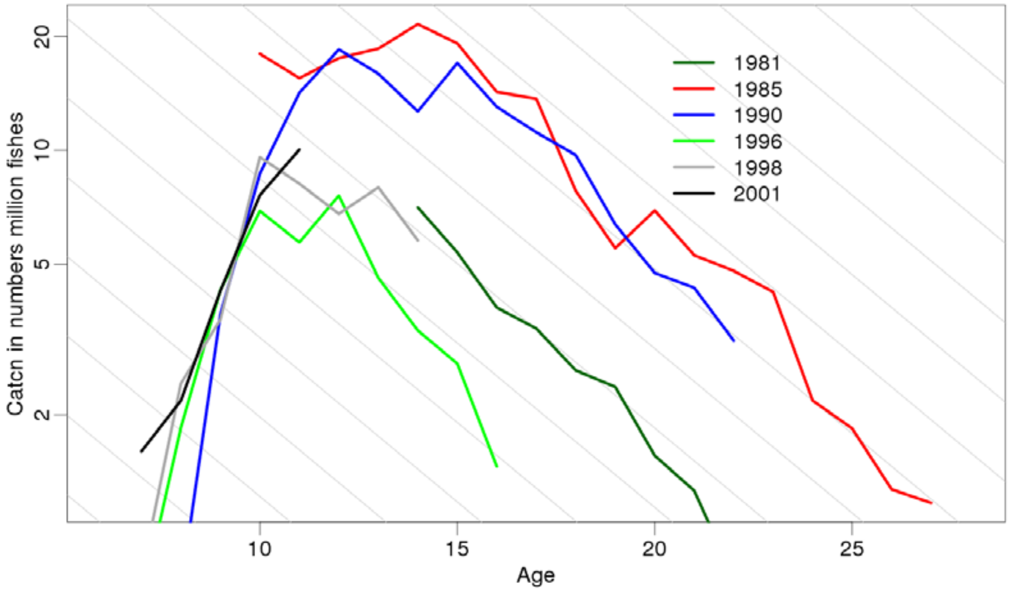


Figure 6. Catch in numbers from Icelandic waters in million fishes. Grey lines correspond to Z = 0.2.

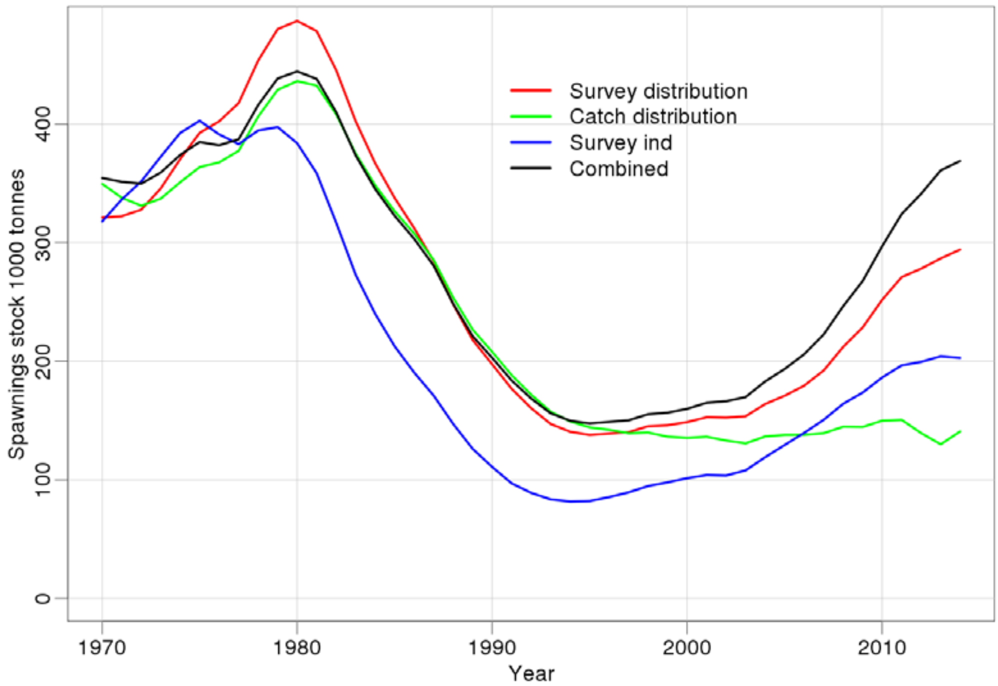


Figure 7. Development of spawning stock when various components are overweighted in run number 3. Each line corresponds to an assessment with one component of the likelihood function weighted heavily compared with the remaining components.

Based on the above results, model 4, where size at recruitment can vary is a candidate model based only on the Icelandic data. The retrospective pattern observed indicates that the model would provide results with a lower interannual variability (see Figure 22 in WD2). There are certainly limitations to the results from this model, but any solutions to these issues would require some additional biological and ecological research.

German survey data

The survey data shown in Figures 8 and 9 are calculated under the assumption of a survey area of 45 000 km^2, leading to the Greenland survey accounting for approximately 20% of the total biomass. For the Gadget model the survey data are based on a survey area of 22 500 km^2, which means that the Greenland survey accounts for 10% of the total biomass in recent years. This area (Figure 10) is selected to avoid extrapolation to areas not covered by the survey and not giving each individual survey station too much weight in comparison with each survey station in the Icelandic survey (which has more stations per unit area than the Greenland survey; Figure 11). Though the German survey only accounts for 10% of the total biomass, including it increases SSB estimated by the Gadget model by over 30% (Figure 14). The reason for this relatively large change is that large fish not found in Icelandic survey in recent years are found in the Greenland survey (Figure 9). Including the data from Greenland (survey biomass and age structure) leads to a model that matches the trend indicated by the survey biomass more closely, but the observed survey biomass is not significantly different from before.

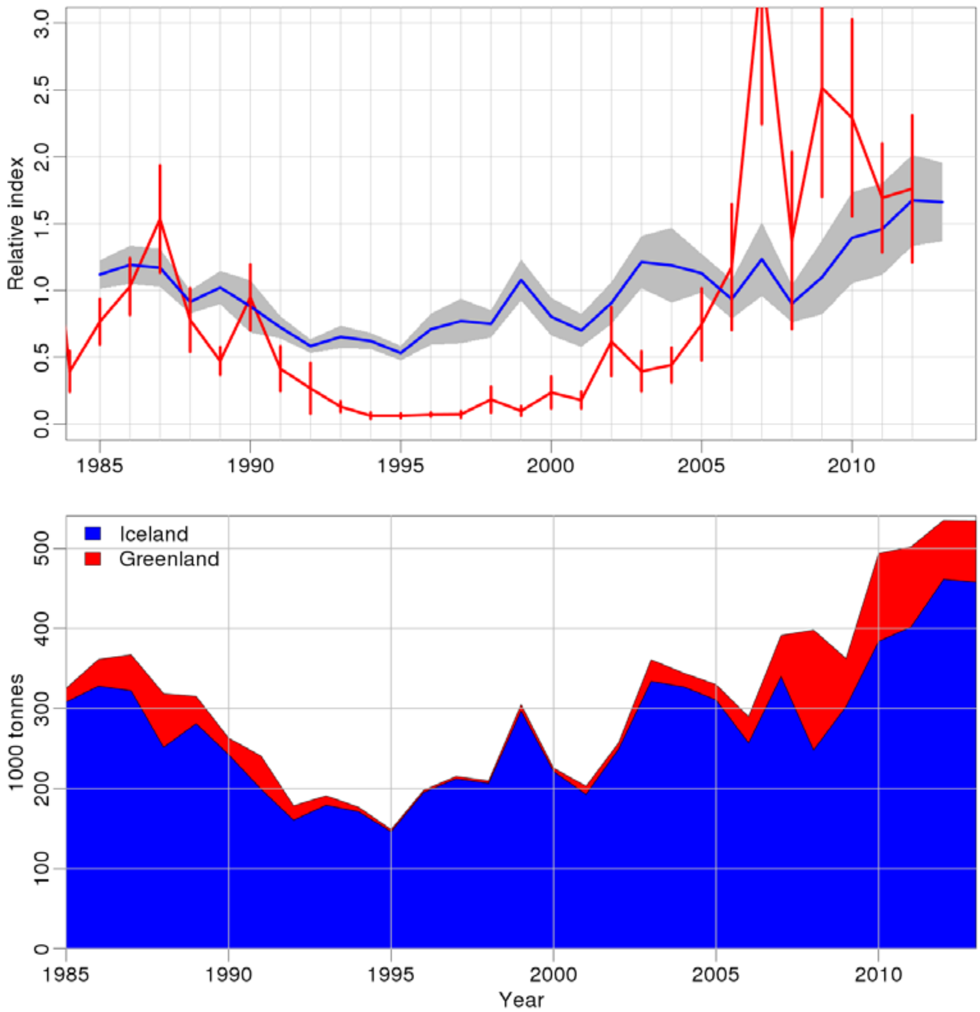


Figure 8. Relative survey indices (upper) and total biomass (lower) from the Icelandic March survey and the German survey in East Greenland waters.

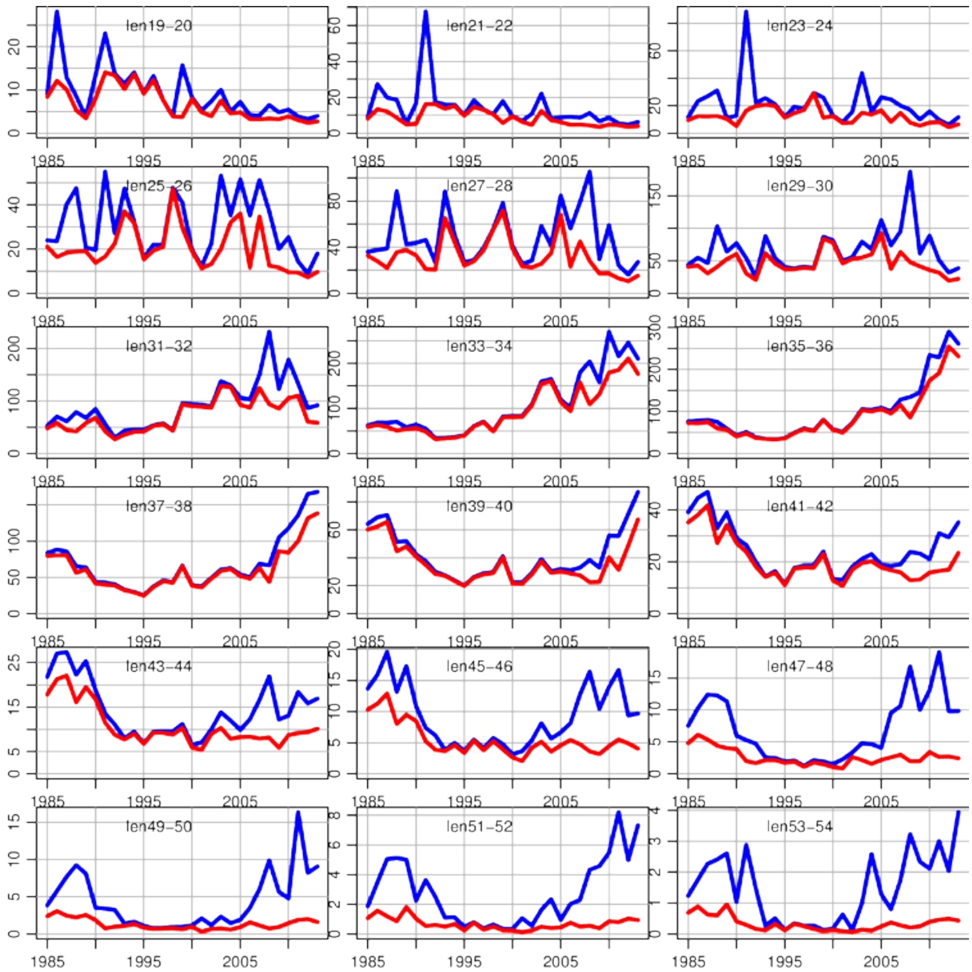


Figure 9. Survey indices by length from the Icelandic March survey (RED) and these combined with the German survey in East Greenlandic waters (BLUE).

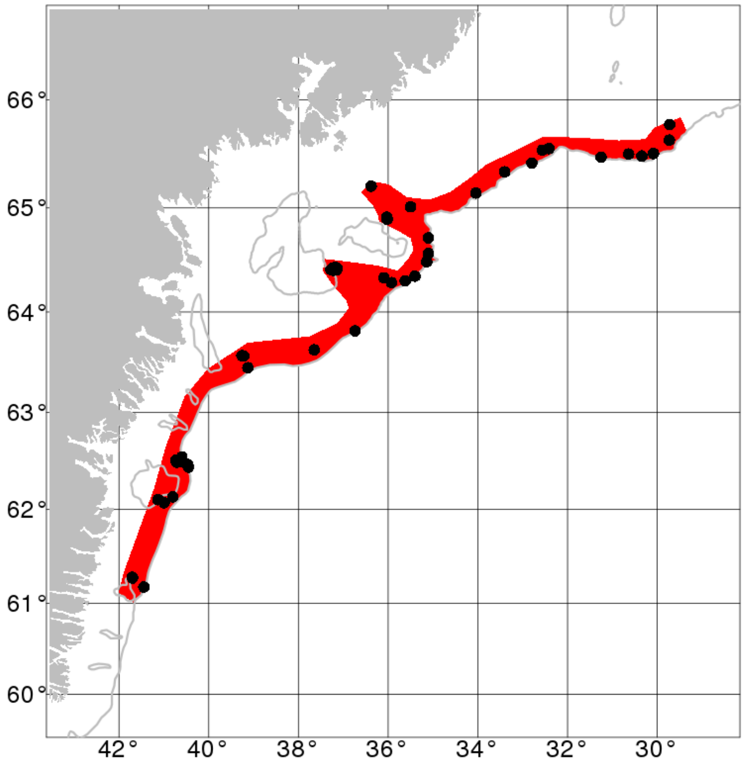


Figure 10. Stations in the German survey 2012. The red area is a candidate area (22 500 km²) used in compiling indices. Depth contours shown are 200 and 500 m.

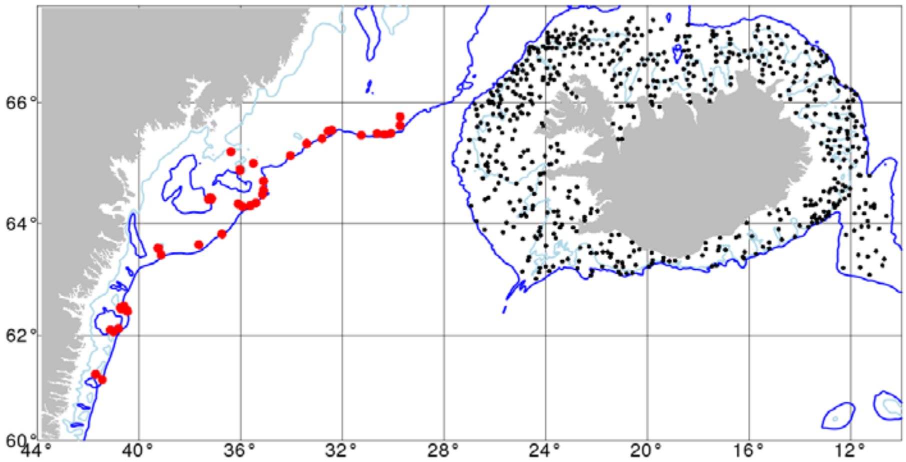


Figure 11. Location of stations in the Icelandic March survey 2013 and the German October survey 2012.

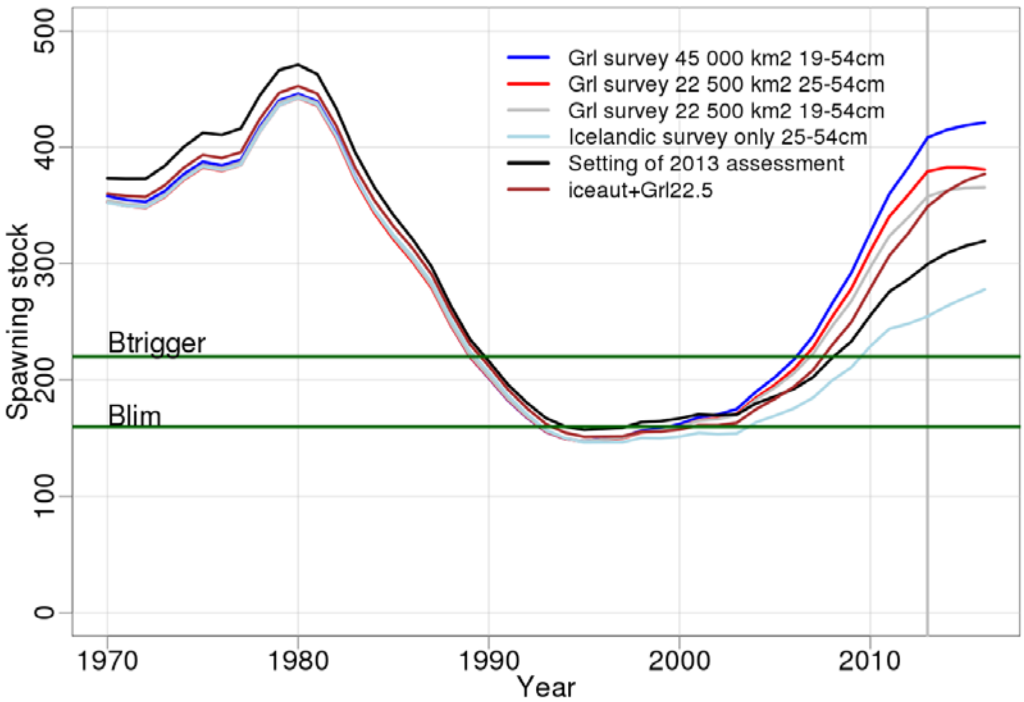


Figure 14. Spawning stock as estimated by different runs of the Gadget model.

4.4 Reference point values

Yield-per-recruit analysis show that when growth is allowed to change after 1996 $F_{9\text{–}19,MAX}$ changes from 0.097 to 0.114 (Figure 15). F_{MAX} of fully recruited fish or size based F_{MAX} does not change. This is a known phenomenon, for example taken into account in the management of Icelandic haddock and George bank haddock. The proposed fishing mortality of 0.097 is therefore around 85% of F_{MAX} with current settings. Stochastic simulations indicate that it leads to very low probability of spawning stock going below $B_{trigger}$ and B_{lim}, even with relatively large autocorrelated assessment error.

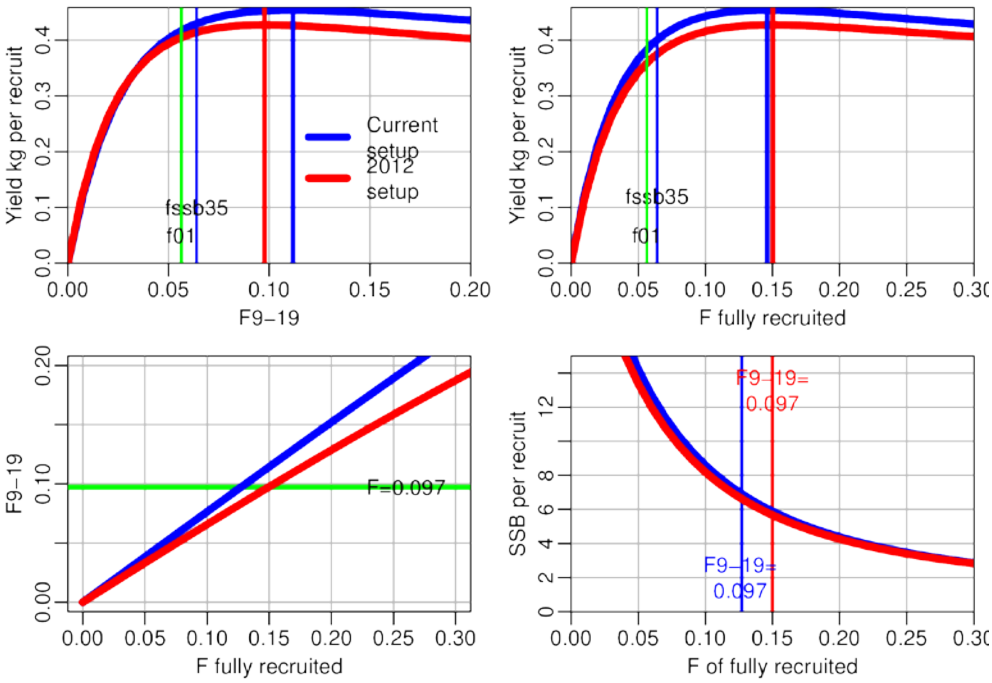


Figure 15. Yield-per-recruit as function of average fishing mortality of 9–19 years old fish, yield-per-recruit as function of fishing mortality of fully recruited fish, relationship between fishing mortality of fully recruited fish and F9–19 and Spawning stock per recruit as function of fishing mortality. The blue curves are based on run 3 (selected base run) but red on 2012 settings.

Yield-per-recruit reference points from the Gadget model (length-based) are not comparable to age based reference points. The proposed harvest ratio, 0.097, is well above $F_{0.1}$ and F_{ssb35} estimate from the Gadget model. These reference points have previously been proposed for this stock, but these points are also lower than from age based models. The proposed target harvest rate for this stock is rather high compared to what has been proposed to the Arctic *S. mentella* stock also dealt with by WKREDMP (Section 2). However, this is plausible since golden redfish grows at a faster rate.

The recruitment pattern observed from year-classes 1975–2003 (Figure 16) lacks long periods of poor recruitment often seen in redfish stocks. From a management perspective this is beneficial since overly cautious rules (i.e. low harvest rates) may not be needed to see the stock through sustained periods of very low recruitment. A spawning stock generated by poor recruitment and low fishing mortality has much broader, and hence resilient, age distribution than the same size spawning stock generated under higher fishing mortality and a few large recruitment events. Therefore, if poor recruitment lead to the stock declining towards B_{loss} after adoption of the HCR, 19+ biomass (or another measure of old fish) would still be relatively high, potentially benefitting the stock due the disproportionate reproductive output of older fish (see Section 2 for a discussion on maternal effects).

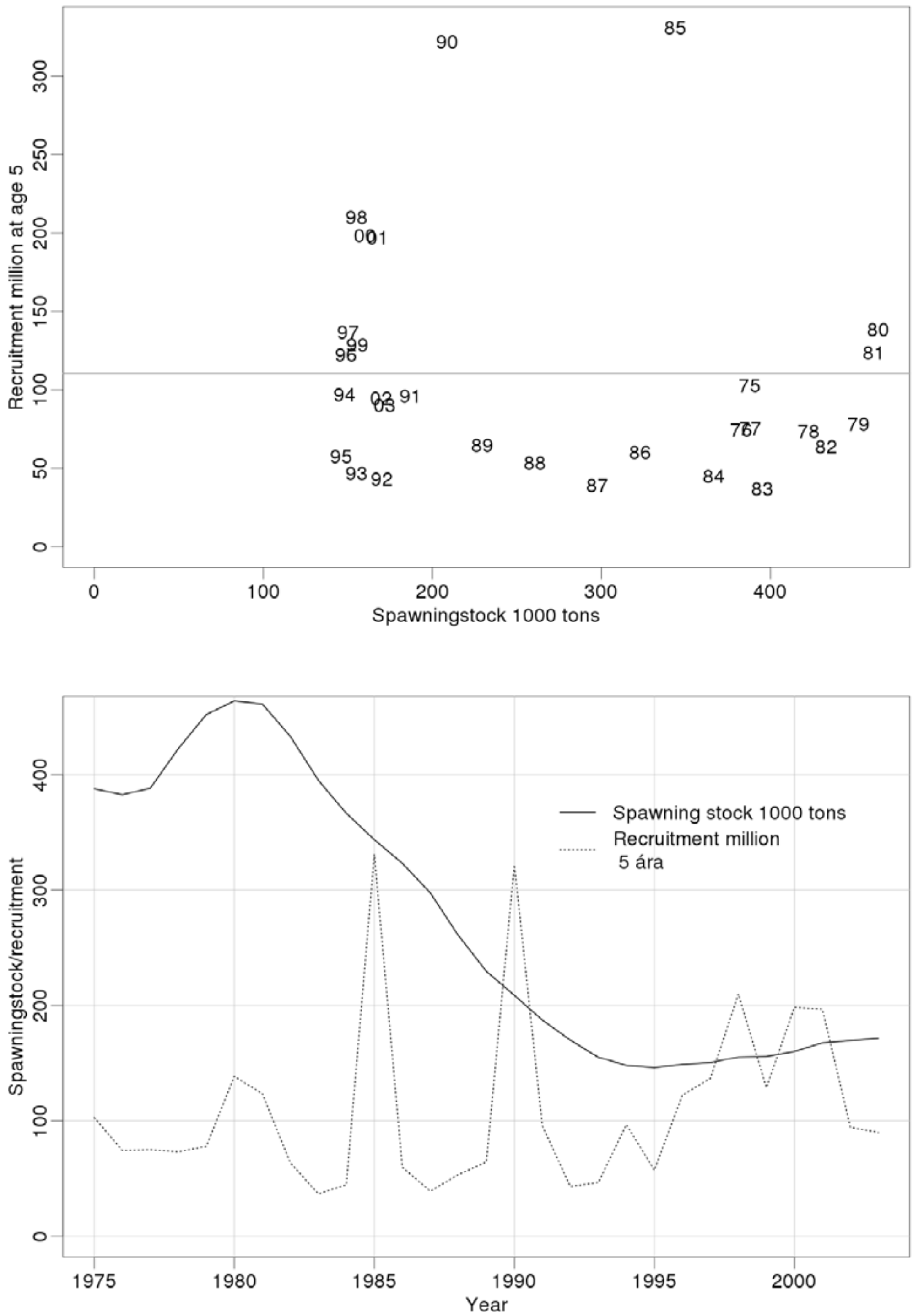


Figure 16. Spawning Stock–Recruitment pairs based on run 3 (top) and recruitment and spawning stock as function of time (bottom). See WD2 for further details.

$B_{trigger}$ was defined as 220 kt by adding a precautionary buffer to the proposed Blim of 160 kt: 160*exp(0.2*1.645). The probability of current SSB <$B_{trigger}$ is estimated as 2.7%. For simplicity, the action of $B_{trigger}$ is not included in the simulations since Gadget is not keeping track of "perceived spawning stock". Analysis of the stochastic prediction in R shows that if SSB is below $B_{trigger}$ it will only be noted in <15% of the cases. The reason is that the spawning stock is only likely to go below $B_{trigger}$ in periods of severe overestimation of the stock that occur due to the assumed high autocorrelation in assessment error. This situation differs from that of the stock going below $B_{trigger}$ due to poor recruitment (worse than observed in recent decades). In this case the spawning stock should still have a resilient age structure (as discussed above) and this could reduce the need to take further action below $B_{trigger}$.

Data on recruitment are still rather poor and data from other surveys at East Greenland than the German survey need to be investigated. The Icelandic surveys indicate that recruitment has been very poor for at least the last five years (Figure 4d). The applicability of the Icelandic surveys as measure of recruitment of redfish has been questioned but this is at least a negative signal and in long periods of poor recruitment a low harvest ratio is preferable.

Finally, it must be remembered that the F_{target} suggested implies a substantial reduction from the fishing mortality of last three decades. The stock is not considered to be in a very unhealthy state at present despite this three decade period of relatively high fishing pressure in relation to that proposed for the HCR. Still, the adoption of the HCR should not lead to major changes in the advice from recent years, which has partly been based on similar considerations.

The deliberations above offer some justification that the proposed harvest rate ($F_{9\text{–}19}$ = 0.097) is a sensible target for this stock. This of course depends also on the assumption that natural mortality for this stock is M=0.05.

4.5 Harvest Control Rule Evaluation

The proposed Harvest Control to be evaluated is:

$$F_{9-19} = 0.097max(\frac{SSB_y}{220}, 1)$$

where 220 = $B_{trigger}$ and the spawning stock, in kt, is compiled base on the maturity curve:

$$P_L = \frac{1}{1 + e^{-0.3122(L-33.54)}}$$

This maturity ogive was defined in 2005 and has been used since then. Length-at-maturity has on the other hand been decreasing in recent years (Figure 5) so the spawning stock in recent years is in fact larger than obtained using the maturity ogive defined above. The observed reduction in size when the fish becomes mature could be caused by increased temperature in the ocean. It might also be an artefact of fish growing up outside the Icelandic continental shelf (Greenland) and migrating over when mature.

The proposed F target in the harvest control rule was F_{MAX} from yield-per-recruit calculations done in 2012. F_{MAX} is not commonly used as a target. The Gadget model takes into account that the largest individuals of recruiting cohorts are removed by the fisheries, reducing the mean weight of the survivors, leading to lower estimated F_{MAX} than obtained from standard age based models. The M used for this stock is also relatively low (0.05), leading to relatively conservative estimate of F_{MAX}.

Recent observations have indicated that size at age for small redfish has been increasing. This is taken into account in the Gadget model by estimating length at recruitment (age 5) separately for cohorts 1996 and later. This result is an increase of 2.5 cm in estimated length at recruitment after 2005, leading to a higher age based F for the same size based F. F_{9-19}=0.097 is therefore lower than the F_{MAX} that is calculated assuming the increased growth. Both with the current settings and the 2012 settings, maximum yield occurs at F of fully recruited fish around 0.15 but $F_{MAX,9-19}$=0.116 with the current settings compared to 0.097 using the 2012 settings. Since selection by size has not changed significantly, to get F_{9-19}=0.097 with the current settings, F of fully recruited fish has to be reduced from 0.15 to 0.127, a 15% reduction in F.

Golden redfish is more than ten years old when estimation of the size of year classes is known. Regular age readings started in 1996 so basing the analysis on cohorts before 1975–1980 is questionable. Therefore investigation of spawning stock–recruitment relationship is based on cohorts 1975–2003, a short period for a long-lived fish such as this. No relationship between SSB and recruitment is observed from the relatively short available time-series (Figure 16). Therefore B_{loss} is proposed as candidate for B_{lim}. In the request B_{loss} is 160 kt, the value obtained in 2012, but the current estimate is 150 kt. It has to be evaluated if B_{lim} should be floating defined as B_{loss} or at a fixed value. Using a fixed value is preferable unless large changes in the assessment procedure occur.

An examination of the recruitment time-series (Figure 16) shows no autocorrelation. Therefore in stochastic simulations recruitment is drawn randomly from observed recruitment. Recruitment periods of less than ten years have a relatively small effect on this stock, since year classes last more than 15 years in the fishery. Longer periods than this may have an impact on management, but the dataseries are not long enough for evaluation of long-term variability in recruitment.

Assessment error is an important factor that needs to be included in stochastic simulations. Analysis based on TSA and the autumn survey indicated that uncertainty in stock size at the beginning of the assessment year was around 20% (25% in the advisory year, given intermediate year assumptions that need to be made). Analytical retrospectives (see WD2) show long-term patterns, especially when the Greenland survey data are included in the assessment. The magnitude of the assessment error is on the excessively high, though the pattern of bias is of concern.

The approach taken here was not to pretend that we have a good estimate of the assessment error but rather investigate the level of assessment error that the HCR could sustain. Assessment error was modelled as autocorrelated lognormal error with rho=0.9 and CV=0.3. This represents substantial error with long periods of over and underestimation (Figure 17). A lognormal distribution with a CV=0.3 also leads to a bias of approximately 0.045. The relatively high autocorrelation of the assessment error means that although uncertainty is high the interannual variability is relatively small.

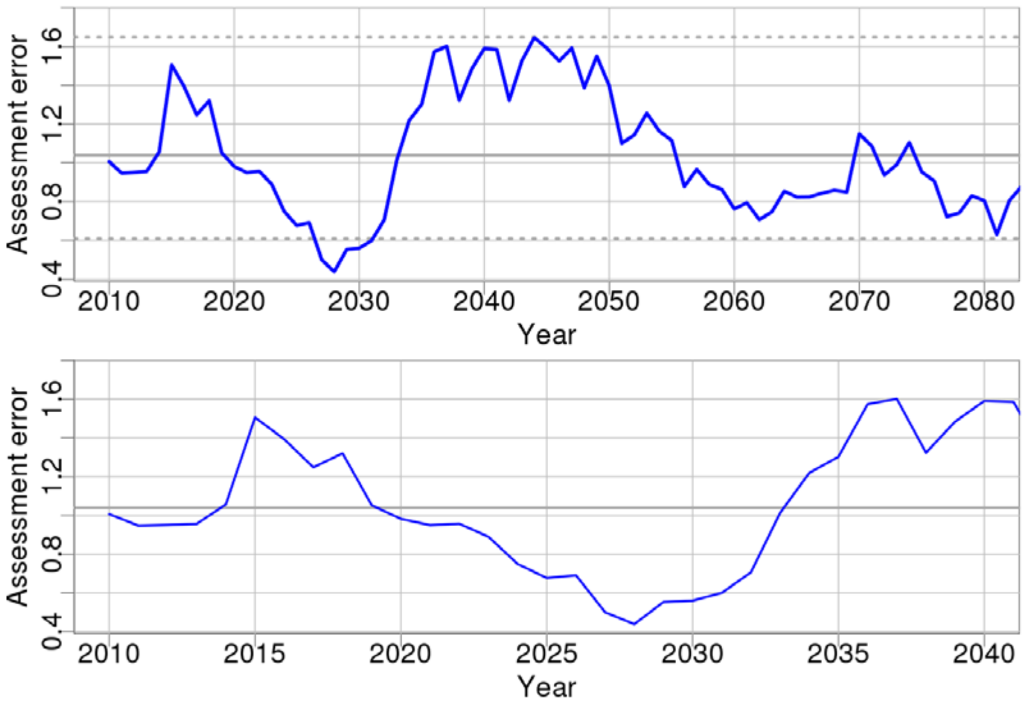


Figure 17. One realization of the Assessment error used in the stochastic predictions. The dashed lines show 5th and 95th percentile.

Another measure of the uncertainty in the advice is to look at the difference between models 3 (Iceland +Greenland) and 4 (Iceland only). The advice in 2014 based on the perception of the stock generated from model 3 would be 49 kt. This would correspond to an F_{9-19} = 0.14 if applied to the perception of the stock from model 4 (Icelandic surveys only for tuning). I.e. if the 'true' stock corresponds to the assessment only using Icelandic data, but advice was nevertheless based on the assessment using both Icelandic and Greenland data, a higher F would be exerted on the stock than intended. Simulations have been conducted using a higher F target to evaluate performance under this 'worst case scenario'.

The fifth percentile of the most recent estimate of spawning-stock biomass is 240 kt and the first percentile is 202 kt, indicating a very low probability of the stock currently being below $B_{trigger}$. The simulations did not include the trigger action when the spawning stock goes below 220 thousand tonnes. This action is could result from when perceived SSB dropping below $B_{trigger}$ due to assessment error. Likewise, the action may not be triggered although the stock is below $B_{trigger}$ is assessment error results in a perceived SSB greater than $B_{trigger}$. In general, excluding the trigger from the simulations results in a slightly higher average F over the duration of the simulations and therefore provides a harsher test of the proposed target HCR.

Uncertainty in the estimation of stock size could become a problem when approaching $B_{trigger}$, but a 10% change in estimated stock size when below $B_{trigger}$ could lead to a more than 20% change in advice. The current formulation leads to a 15% reduction in fishing mortality by size, so even if $B_{trigger}$ was reduced to B_{loss}, the HCR would be more precautionary than the rule proposed in 2012.

Performance of the plan

The proposed management plan should be effective in the long term, even with a relatively poor quality assessment (Figures 18–21). Given that more data will become available and another benchmark assessment is likely in the next five years, development of the stock under the management plan in the short term is important. The assessment proposed here includes data from East Greenland, an area where the abundance of *S. marinus* has been increasing and relatively more large fish are found there. The effect of including the indices from Greenland in the assessment is considerable but the connection between the areas is not clear. Will the stock in Greenland be used to fish down the stock in Iceland or will the fishing pressure be spread over the whole stock? Previously more large redfish were found in East Iceland and the Faroes. The distance from West Iceland to East Greenland is not larger than from West Iceland to East Iceland.

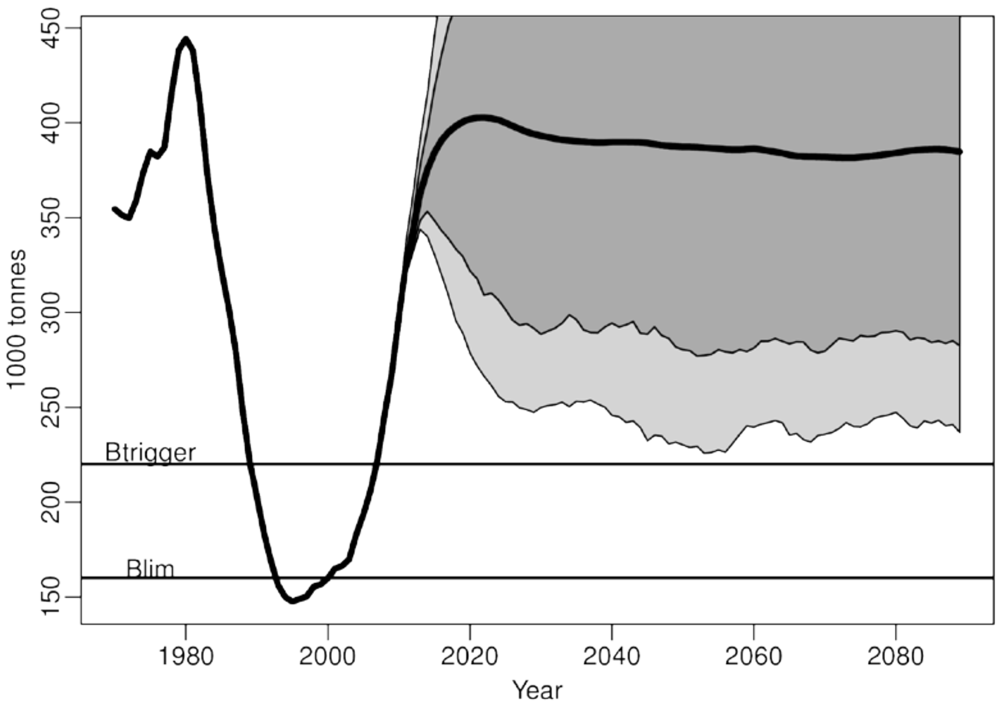


Figure 18. Development of the spawning stock according to run 3 (survey from Iceland and Greenland) if advice is given based on F_{9-19} = 0.097. The light grey area shows fifth and 95th quantile and the dark areas 16th and 84th quantile.

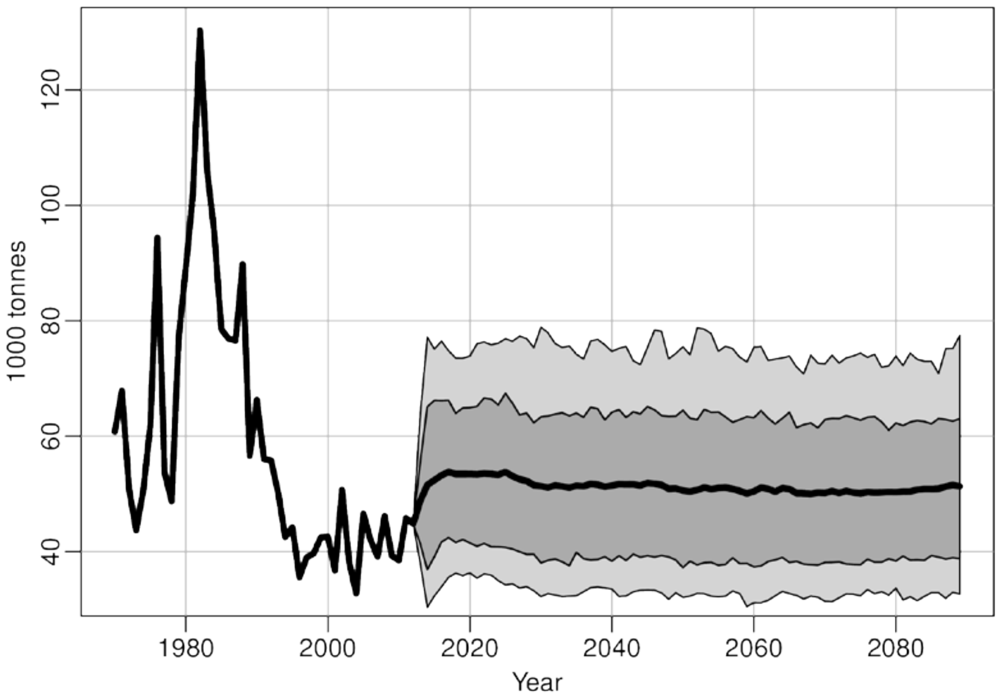


Figure 19. Development of the catches according to run 3 (survey from Iceland and Greenland) if advice is given based on $F_{9\text{–}19}$ = 0.097. The light grey area shows fifth and 95th quantile and the dark areas 16th and 84th quantile.

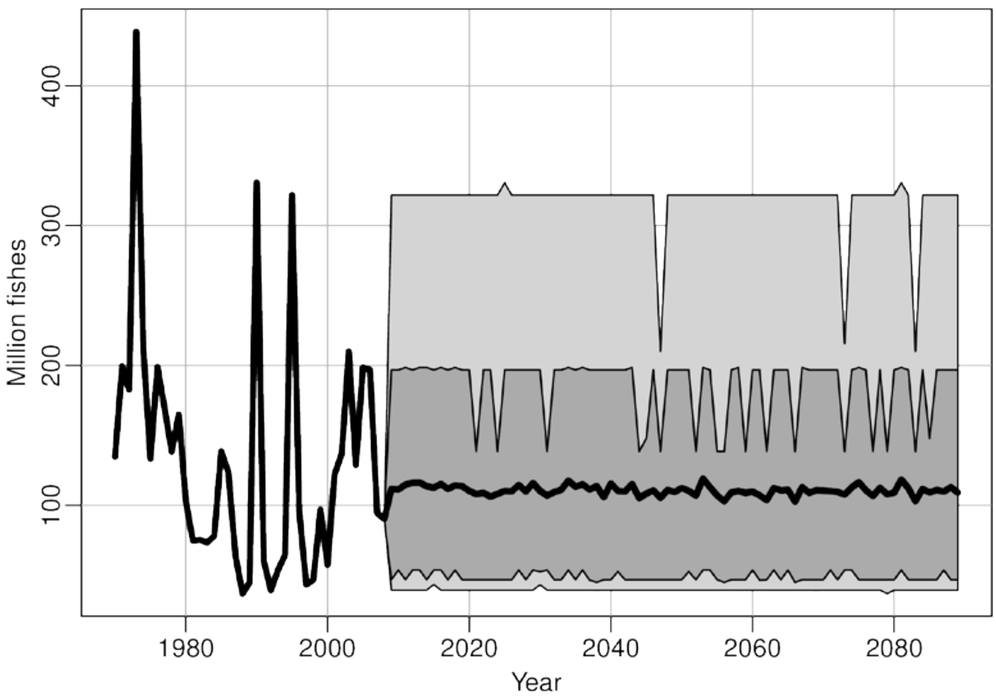


Figure 20. Development of recruitment according to run 3 (survey from Iceland and Greenland) if advice is given based on $F_{9\text{–}19}$ = 0.097. The light grey area shows fifth and 95th quantile and the dark areas 16th and 84th quantile.

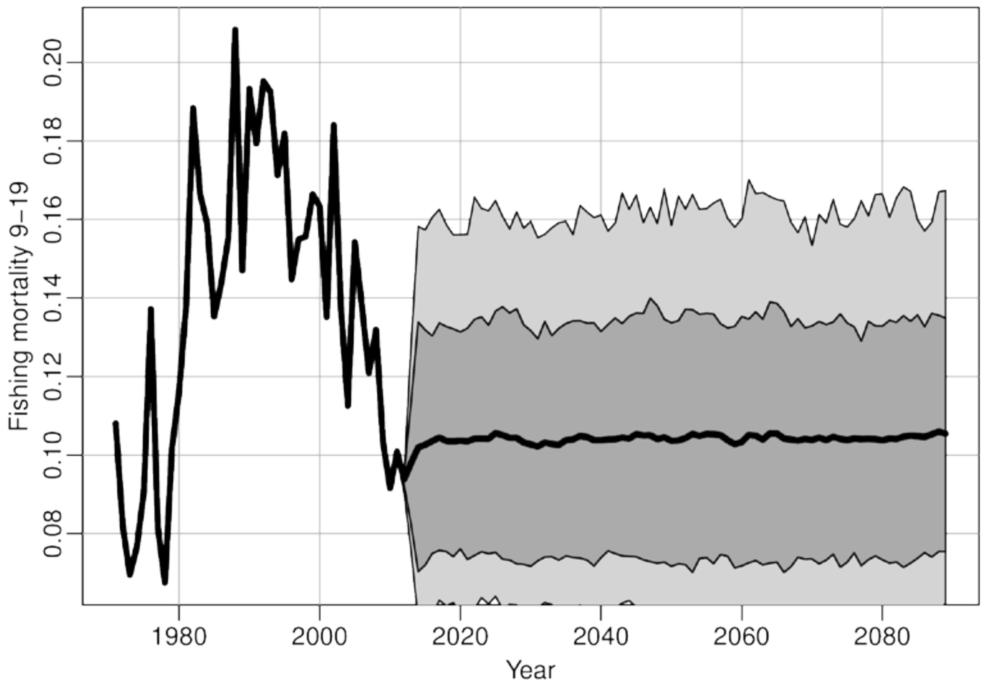


Figure 21. Development of F9–19 according to run 3 (survey from Iceland and Greenland) if advice is given based on F_{9-19} = 0.097. The light grey area shows fifth and 95th quantile and the dark areas 16th and 84th quantile.

Looking more closely at the development over the next five years, a number of scenarios are considered. Either the evaluation assumes the assessment is done including the Greenland survey but the 'true' population more closely resembles that from the assessment using only the Icelandic survey. This scenario leads to a higher realized F (0.14 vs. 0.097). Nevertheless, this level of fishing mortality will lead to relatively stable spawning stock above $B_{trigger}$, and stable catches and fishing mortality in coming years. (Figure 22).

Another scenario considers unusually poor recruitment. The recruitment of cohorts 2006–2013 is not estimated in this run, but rather replaced with the lowest observed recruitment over a five year period (corresponding to 50% of the average recruitment). This assumption of very poor recent recruitment leads to substantially worse development of the stock. In the 'worst case' scenario considering poor recruitment and an incorrect assessment, the stock is predicted to be going below $B_{trigger}$ in approximately five years (Figure 22, red line). F_{9-19}=0.14 is not far from average fishing mortality since 1990 (see WD 2). If we combine that with low recruitment or only half of the average, it is not surprising that the stock would go below levels seen earlier. However the stock is monitored, although the monitoring has some uncertainty. It is expected that in this case the trend in stock size would be noticed in the Icelandic data and action would be taken, perhaps revisiting the HCR should this occur.

The average catch in the future is estimated to be around 50 kt, or similar to the advice for 2014 (49 kt). Advice in 2014 would be 35 kt if only the Icelandic survey was used as basis for advice, lower than the catch in last 15 years.

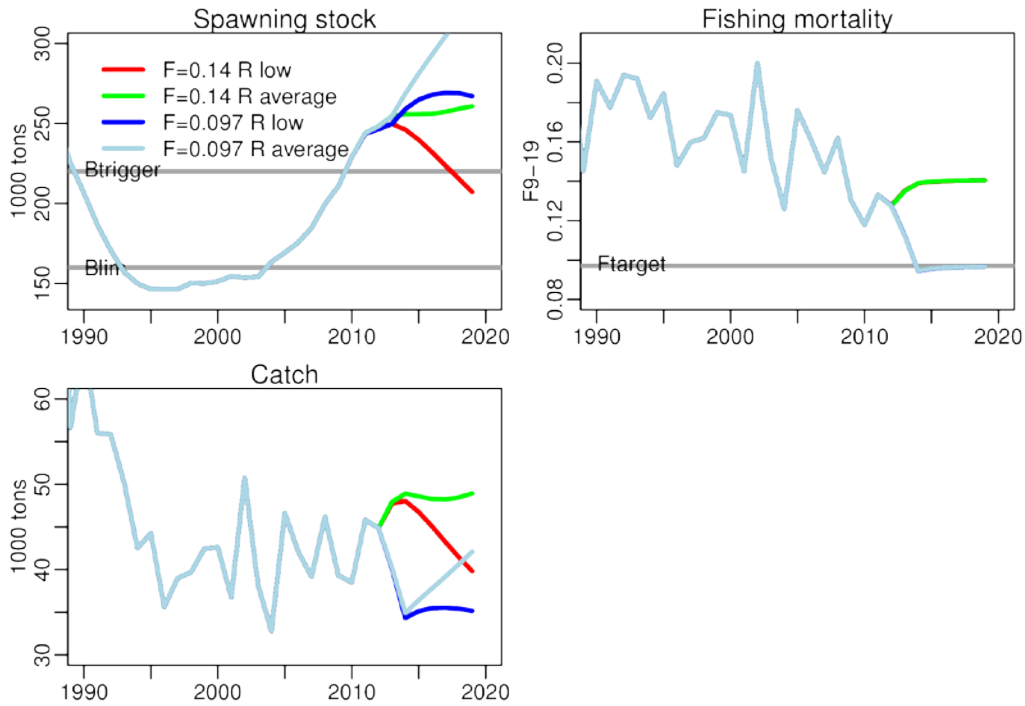


Figure 22. Development of the stock next six years for two values of fishing mortality and two recruitment levels. The higher level of fishing mortality corresponds approximately to what would be obtained if advice was given based on Icelandic + German survey but the run tuned with the Icelandic survey was giving the "true stock".

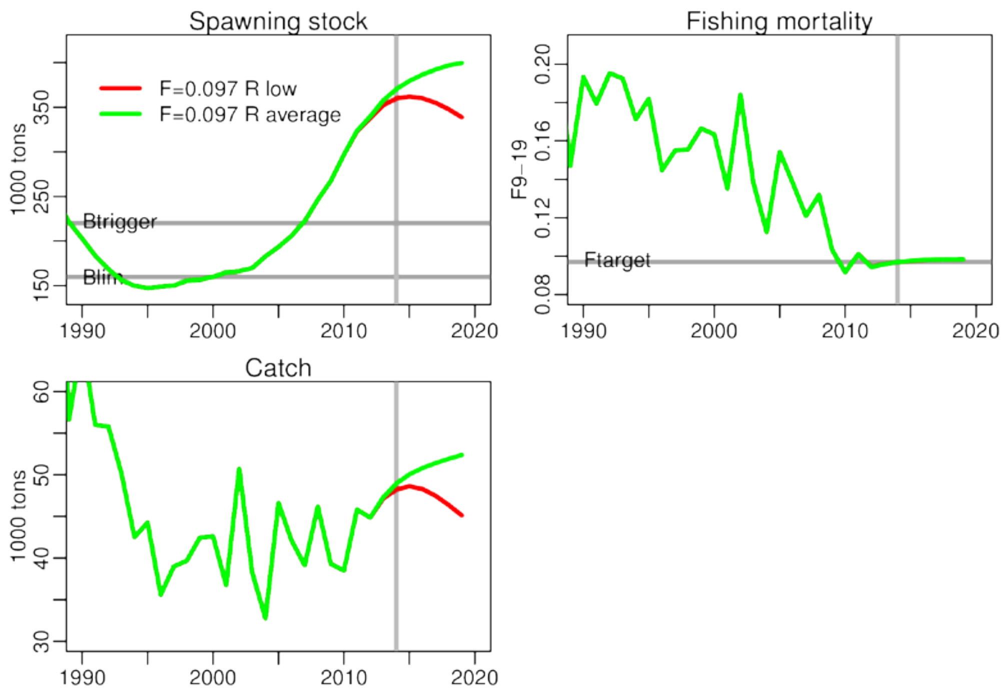


Figure 23. Development of the stock next six years for two recruitment levels and fishing at the target fishing mortality. The picture is based on run 3 tuned with Icelandic March survey + the German survey scaled to 22 500 km^2.

4.6 Discussion and conclusions

WKREDMP reviewed the assessment methodology for *Sebastes marinus* (in V VI XII XIV), and evaluated the proposed harvest control rule as part of a long-term management plan for this stock.

The stock assessment proposed is an extension of the assessment method used previously to evaluate trends ("GADGET: Globally applicable area-disaggregated general ecosystem toolbox"). The extension of the methodology encompasses three main issues:

1) To account for the change in growth, mean length at recruitment (age 5) was estimated separately for year classes 1996–2000 and for 2001–recent.

2) Addition of German Greenland Groundfish Survey in autumn (using a 22 500 km^2 area).

3) The weighting of the individual datasets in the GADGET model is now calculated using an iterative re-weighing algorithm.

These three changes to the assessment were made in response to an earlier benchmark for this redfish stock (ICES 2012). A new stock annex has been produced incorporating these changes and the resulting assessment is used as a starting point for the forecasts made to evaluate the proposed management plan.

The assessment results in a time-series of SSB and fishing mortality that is largely similar to the previous assessment, apart from a stronger increase in SSB in the most recent ten years. The assumptions chosen as the basis for the management strategy evaluation result in a current spawning–stock biomass estimate of about 360 kt in 2013, well above $B_{trigger}$.

The target fishing mortality of 0.097 in the proposed management plan is based on yield-per-recruit analyses giving a point estimate of F_{MAX} from the 2012 assessment. With a value of 0.114 year-1, the deterministic estimate of F_{MAX} from the new assessment is slightly higher than the target reference point in the plan.

The proposed HCR stabilises SSB above $B_{trigger}$ until at least 2020 under a wide range of assumptions on recruitment, assessment errors and stock definitions. Only if the recruitment was at the lowest observed level since 2006 and at the same time F is consistently underestimated (as could be caused by an inaccurate stock definition) would the biomass could fall below $B_{trigger}$ before 2020. This scenario is considered unlikely, and even if it should occur, signals in the data should indicate the decreasing trend.

It is anticipated that the HCR should lead to a reduction of F below that observed in the last 30 years. The proposed F_{target} (based on F_{MAX} calculated from the 2012 assessment) is slightly lower than the most recent estimate of F_{MAX}, which could be seen as a proxy for F_{MSY}. However, the difference in yield between F=0.097 and F=0.11 is minimal and well within the estimation error of the assessment model. Also, F_{MAX} does not include considerations of recruitment overfishing, so a slightly lower target is considered more precautionary.

The proposed HCR is considered an appropriate basis for management given the simulations conducted and the uncertainties involved in the assessment of this stock. Potential changes that could be investigated for future revisions to the management plan could be:

- Changing $B_{trigger}$ from 220 kt to 160 kt.
- Using the proportion of the spawning stock or exploitable biomass defined by any of the "logit" functions (see WD2). The proportion would be regression between $F_{9–19}$ and exploitable biomass.

Change to length based reference points, such as the proportion of spawning stock or proportion of catchable biomass as based on estimated selection curve, with the proportion selected to make $F_{9–19} \approx 0.097$ based on current settings. The group expects that there will be significantly better information on stock dynamics of this stock within the next five years. This will mainly be achieved by increased age reading from the survey and catch in Area XIV, and from attempts to improve the species separation of juvenile *Sebastes marinus* and *S. mentella* in the German Greenland Groundfish survey.

4.7 References

ICES. 2012. Report of the Benchmark Workshop on Redfish (WKRED 2012), 1–8 February 2012, Copenhagen, Denmark. ICES CM 2012/ACOM:48. 291 pp.

WKREDMP. 2014. Working Document No. 2. Material for assessment and Harvest Control Rule for Golden redfish (*Sebastes norvegicus*) Draft. Kristjn Kristinsson and Hskuldur Bjrnsson, Marine Research Institute, Reykjavk, Iceland.

Annex 1: List of participants

Name	Address	Phone/Fax	E-mail
Iliya Antonov	Russian Federal Research Institute of Fisheries & Oceanography (VNIRO) 17 Verkhne Krasnoselskaya 107140 Moscow Russian Federation	Phone +7 Fax +7	antonovI.VNIRO@ya.ru
Mette Bertelsen	ICES Secretariat		mette@ices.dk
Höskuldur Björnsson	Marine Research Institute PO Box 1390 121 Reykjavík Iceland	Phone +354 575 2000 Fax +354 575 2001	hoski@hafro.is
Bjarte Bogstad	Institute of Marine Research PO Box 1870 Nordnes 5817 Bergen Norway	Phone +47 92422352 Fax +47 55 23 86 87	bjarte.bogstad@imr.no
Jesper Boje	DTU Aqua – National Institute of Aquatic Resources Section for Fisheries Advice Charlottenlund Slot Jægersborg Alle 1 2920 Charlottenlund Denmark	Phone +45 358834 64 Fax +45 339 63333	jbo@aqua.dtu.dk
Daniel Duplisea External reviewer	Fisheries and Oceans Canada Institute Maurice-Lamontagne PO Box 1000 Mont-Joli QC G5H 3Z4 Canada	Phone +1 418 775-0881 Fax +1 418 775-1898	Daniel.duplisea@dfo-mpo.gc.ca
Heino O. Fock	Thünen Institute of Sea Fisheries Palmaille 9 22767 Hamburg Germany	Phone +49 40 38905 169 Fax +49 40 38905 263 fax	heino.fock@ti.bund.de
Yuri Kovalev	Knipovich Polar Research Institute of Marine Fisheries and Oceanography(PINRO) 6 Knipovitch Street 183038 Murmansk Russian Federation	Phone +7 8152 472 469 Fax +7 8152 473 331	kovalev@pinro.ru
Kristjan Kristinsson	Marine Research Institute PO Box 1390 121 Reykjavík Iceland	Phone +354 575 2000 Fax +354 575 2001	krik@hafro.is
David Miller Chair	Wageningen IMARES PO Box 68 1970 AB IJmuiden Netherlands	Phone +31 3174 853 69 Fax +31	David.miller@wur.nl
Kjell Nedreaas	Institute of Marine Research PO Box 1870 Nordnes 5817 Bergen Norway	Phone +47 55 238671 mobile +47 99 53 85 49	kjell.nedreaas@imr.no

Name	Address	Phone/Fax	E-mail
Benjamin Planque	Institute of Marine Research Tromsø PO Box 6404 9294 Tromsø Norway	Phone +47 77 60 97 21	benjamin.planque@imr.no
Jan Jaap Poos External reviewer	Wageningen IMARES PO Box 68 1970 AB IJmuiden Netherlands	Phone +31 317 487 189 / mob private + 31 6 22 79 44 89 Fax IMARES general +31 317 480 900	Janjaap.Poos@wur.nl
Jákup Reinert	Faroe Marine Research Institute PO Box 3051 110 Tórshavn Faroe Islands	Phone +298 35 353935 Fax +298 353901	jakupr@hav.fo
Aleksei Rolskiy	Knipovich Polar Research Institute of Marine Fisheries and Oceanography(PINRO) 6 Knipovitch Street 183038 Murmansk Russian Federation	Phone +7 8152450568 Fax +7 8152473331	rolskiy@pinro.ru
Henrik Sparholt	ICES Secretariat		henriks@ices.dk
Christoph Stransky	Thünen Institute of Sea Fisheries Palmaille 9 22767 Hamburg Germany	Phone +49 4038905228 Fax +49 4038905263	christoph.stransky@ti.bund.de

Annex 2: Recommendations

RECOMMENDATION	ADRESSED TO
1. As there is a clear lack of age data for the assessment of redfish, age determinations should be carried out on existing and newly collected otoliths from the following stocks in accordance with the latest age reading guidelines (WKADR 2006, 2008): Golden redfish (*Sebastes marinus*) in Subareas V, VI, XII, and XIV [primarily those from East Greenland]; Beaked redfish (*S. mentella*) in Subareas V, XII, and XIV and NAFO Subareas 1+2 (Deep pelagic stock > 500 m); Beaked redfish (*S. mentella*) in Division XIVb (Demersal). The minimum to be age-read and reported to NWWG should be 100 otoliths per stock per year. The interval between sampling years could be 2–3 years.	NWWG; WGIDEEPS; PGCCDBS; RCMs; Institutes collecting redfish otoliths from the listed stocks.
2. Russia reiterates its standpoint that studies of the redfish stock structure should be continued with the aim of developing agreed recommendations using all available scientific and fisheries data as a basis.	PGCCDBS, NWWG, Institutes collecting redfish otoliths from the listed stocks.

Annex 3: Harvest Control Rule for *Sebastes mentella* (in ICES Subareas I and II) – Request to ICES

ICES received two requests on the same topic, the evaluation of a harvest control rule for *Sebastes mentella* in Subareas I and II.

The first request was submitted by the Joint Norwegian–Russian Fisheries Commission (JNRFC)

"The parties responsible for managing the stock of *Sebastes mentella* seek to establish a Harvest Control Rule (HCR) for this fish stock. Before such an HCR is adopted the parties would request ICES to assess the consequences of a few alternative rules, in particular the following:

a) An HCR based on the ICES MSY-approach with a fishing mortality equal to $F_{0.1}$.

b) As a, but where the fishing mortality is set to ¾ of $F_{0.1}$.

c) As a, but where the fishing mortality is set to $^4/_3$ of $F_{0.1}$.

The fishing mortality indicated in the alternatives above should be the reference point for the annual TAC when the Spawning–Stock Biomass is at a level capable of producing maximum sustainable yield. Hopefully, setting the fishing mortality to one of these levels will also sustain the SSB at a productive level. We have, however, seen that due to natural conditions any fish stock may be reduced below such a productive level. An HCR for *Sebastes mentella* should specify pre-agreed actions if such development is seen in the future. The natural thing to do will be to reduce fishing mortality, and the parties would ask ICES to assess two different ways of doing this.

Reduction of F when SSB falls below $B_{trigger}$

$B_{trigger}$ is not known for this stock, but should be the reference point beneath which fishing mortality should be reduced. In lack of a precise figure for $B_{trigger}$, the Parties would ask ICES to assess the consequences of various levels of $B_{trigger}$. For each of the alternatives a, b or c above, $B_{trigger}$ should be set to either B_{MSY} or ¾ B_{MSY}. Should the SSB fall below $B_{trigger}$, fishing mortality should be reduced linearly with SSB. F should reach zero before SSB reaches zero, e.g. at B_{stop} = ½ B_{MSY} or B_{stop} = ¼ B_{MSY}. SSB refers to the Spawning–Stock Biomass assessed in the year of assessment.

Reduction of F when recruitment is reduced

To the extent that recruitment is measured to be low in a series of years, this may call for a reduced fishing mortality when setting the annual TAC. The Parties would therefore ask ICES to assess the consequences of cutting fishing mortality by 25 or 50% if the average strength at age 2 for the year classes which are 3–12 years old in the year for which the TAC advice is given is at or below 33 % of average recruitment at age 2 for the period 1992–1996.

ICES is requested to assess the consequences of the various rules with a) no modification of fishing mortality due to low SSB or recruitment, b) reduction of F when SSB falls below trigger points and c) reduction of F when recruitment is at a low level.

TAC stability

Some harvest control rules incorporates expected growth or decline of a fish stock, as well as stability elements, in the decision related to the annual TAC. An example of this is the HCR for Northeast Arctic Cod. The parties responsible for managing the stock of *Sebastes mentella* would ask ICES to assess an HCR with some of the same feature as the one for Northeast Arctic Cod, namely;

d) Estimate the average TAC level for the coming five years based on $F_{0.1}$. TAC for the next year will be set to this level as a starting value for the 5-year period. This procedure is to be repeated during the consecutive assessment, but the TAC should not deviate by more than +/-20% compared with the previous year's TAC.

For all simulations, ICES is asked to assess the consequences through calculating the following performance indicators (expected values):

- Annual yield during each of the next five years;
- Medium-term yield, represented as average yield during the next five and ten years;
- Long-term yield, represented as average yield during the next 50 years;
- Probability that SSB falls below $B_{trigger}$, in a five, ten and 50 year period.

Exploitation patterns

The medium to long-term consequences of various HCRs will also depend upon the exploitation pattern in the fishery. The parties would ask ICES to show which exploitation pattern is used in the simulations as well as to reflect upon how sensitive the results are for possible changes in the exploitation pattern.

Combinatorial of HCR explorations

Following the above, the total number of HCR explorations is 3 F's (1, $^3/_4$ and $^4/_3$ of $F_{0.1}$) x 2 $B_{trigger}$ (400 and 800 kt) x 2 B_{stop} ($^1/_2$ and ¼ B_{MSY}) x 3 recruitment reductions (0, 25 and 50%) x 2 TAC stability (on, off) = 72 combinations x 4 performance indices = 288 outputs."

The second request was submitted by NEAFC and was less specific

"Based on the advice for 2013, ICES is requested to explore possible long-term management plan options for redfish in ICES Subareas I and II. The objective of such a management plan shall be to establish levels of catches and fishing effort, which will result in the sustainable exploitation of pelagic redfish in ICES Subareas I and II, consistent with the precautionary approach and the principle of Maximum Sustainable Yield."

Annex 4: Management plan for deep-pelagic redfish (*Sebastes mentella*) in the Irminger Sea and adjacent waters – Discussion document and request

FISKIMÁLARÁÐIÐ

International Council for the Exploration of the Sea
H.C. Andersen Boulevard 44-46

1553 København V

Fiskivinnustovan
11. januar 2013
Mál: 12/00850-6
(at tilskila í svari)

Viðgjørt: AK

Tygara skriv:

Re: Request for evaluation of a proposed Harvest Control Rule for deep pelagic redfish in the Irminger Sea and adjacent waters

As coastal states the Faroe Islands, Greenland and Iceland request ICES to evaluate their proposal on possible HCR under a management plan for redfish in the Irminger Sea and adjacent waters.

The request : The coastal states aim to implement a management plan on redfish in the Irminger Sea and adjacent waters in 2015 in accordance with the MSY approach and ICES is requested to evaluate and elaborate on the suggestions for potential HCRs under such management plan as given in the attached document.

Justification : The coastal states (Faroe Islands, Greenland and Iceland) aim to implement a permanent management plan in 2015 when the present management measures of reaching 20.000 tonnes in 2014 is running out.

Objective : The management plan should be in accordance with international agreements on sustainable harvest and the coastal states request ICES to comment on the proposed rules.

Time frame : Before 30 September 2013.

Yours sincerely

Andras Kristiansen

Ministry of Fisheries
Bókbindaragøta 8 • P.O. Box 347 • FO-110 Tórshavn • Faroe Islands
Tel. (+298) 35 30 30 • Fax (+298) 35 30 35 • fisk@fisk.fo • www.fisk.fo

Discussion document – Redfish consultations October 12, 2012

Management plan for Deep-pelagic redfish (*Sebastes mentella*) in the Irminger Sea and adjacent waters – basis for discussion.

Introduction

As discussed during the consultation on redfish in the Irminger sea and adjacent waters on 28 September 2011, the Chair of the coastal State meeting had requested PECMAS to assist in developing a management plan for the Deep-pelagic management unit of *Sebastes mentella*. **It was agreed** that Þorsteinn Sigurðsson (Iceland) would formulate a first draft of a document, following ICES's conclusion of its benchmark assessment early 2012. All Contracting Parties who wished to take part in the PECMAS work on this issue were invited to nominate participants in the work of discussing and developing the draft. The aim of the exercise was to provide an overview over what elements should be in the management plan (building on previous work by ICES), but not to provide a final document with exact numbers. The document that would be created should provide a basis for discussion, rather than constitute a possible final product. It was agreed that the NEAFC Secretary would inform the Chair of the coastal States' meeting of this agreement.

The report of the the above mentioned benchmark assessment in February 2012 (ICES, 2012) stated that "For deep-pelagic redfish in the Irminger Sea and adjacent waters, no analytical assessment is carried out due to data uncertainties and the lack of reliable age data. The assessment is based on survey indices, catches, cpue and biological data. The quality of the trawl biomass estimate from the international trawl acoustic surveys since 1999 cannot be verified as the dataseries is relatively short and the survey is only conducted every second year. Therefore, the abundance estimates by the trawl method must only be considered a rough attempt to measure the abundance of the deep pelagic stock.
Trawl survey estimates in 2009 and 2011 are lower than the average for 1999–2003 and near the lowest observed. These indices in combination with a marked decrease in landings since 2004 suggest that the stock has been reduced in the past decade.

Furthermore it is stated in the ICES advice that commercial cpue indices are not used for tuning in assessing the stock. 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 benchmark workshop because the trends in the cpue may not be a reliable indicator of abundance and stock trends. "

No previous management plan evaluations or estimates of reference points have been made. In the absence of long time-series of surveys on the mature stock, it is difficult to establish reference point values of high precision **and the benchmark group recommends a dialogue with the managers about harvest control rules should be initiated as soon as possible**".

Despite the fact that the benchmark group did not suggest any alternatives to current assessment methods due to limited data and shortness of any data series, it was decided to continue with ideas on a management plan, based on survey indices alone. We recognize the limitation of such an approach but it is likely that this situation remain the case for the nearest future as surveys are only conducted every other year (hence the time series will probably still be considered short after 10 years or so), and there are no new appropriate analytical assessment methods foreseen for the deep- pelagic stock of redfish. Further, the available data do not allow to define reference points on the usual quantitative basis, but will require rough assumptions and therefore we provide the following ideas for discussion.

We identify three possibilities as basis for a potential HCR, i) The Precautionary Approach as previously used as the 'default' basis by ICES, ii) the MSY approach as now used by ICES as the preferred basis and iii) the DLS (Data Limited Stock) approach as being developed and implemented by ICES for a number of so-called data poor stocks. Below are some reflections on each of the three approaches.

The suggestions are based on the facts that deep-sea redfish species are long-lived, slow-growing and late-maturing fish species and are thus highly vulnerable to overfishing. ICES has said that such species can only sustain low rates of exploitation and if depleted they have a long recovery period. Furthermore, if the natural mortality (M) is low (~0.05) as well as the harvest rate (here the suggested 0.05 as harvest rate is taken as equal to assumed M=0.05), one can argue that such conservative harvest rate could possibly be a conservative proxy for F_{msy}. However, if catchability in the survey (q) is lower than we assume (q=1), such low harvest rate will have much lower probability of reducing the stock size than if the assumption is an overestimation on q, meaning the stock being smaller than the survey estimate indicates. ICES, during it's evaluation of any proposals from NEAFC should also respond to these considerations and, if possible, make recommendations.

Proposal for a Precautionary Approach HCR

The Coastal states request ICES to evaluate the following proposal for the harvest control component of a long-term management plan for Deep-pelagic management unit of Sebastes mentella in the Irminger Sea and adjacent waters and in particular to consider whether the plan is consistent with the precautionary approach and will provide for the sustainable harvesting of the stock.

1. The NEAFC Parties agree to implement a long term management plan for the fisheries on the Deep-pelagic redfish stock, which is consistent with the precautionary approach, aiming at ensuring harvest within safe biological limits and designed to provide for fisheries consistent with maximum sustainable yield, in accordance with advice from ICES.

2. The Parties recognise the fact that no biological reference points based on an analytical approach are available for the stock.

3. For the purpose of this long term management plan, in the following text, "TAC" means the sum of the all TAC set by NEAFC Parties.

4. In the absence of biological reference points, Parties agree to use trawl survey indices as a proxy for such reference points

- As a proxy for $B_{\mathbf{lim}}$, the Parties agree to use $U_{\mathbf{lim}}$ (survey index)
  - $U_{\mathbf{lim}}$=0.2 X $U_{\mathbf{max}}$ (or any other value recommended by ICES)
- As a proxy for B_{PA}, the Parties agree to use U_{PA} (survey index)
  - U_{PA}=0.5 X $U_{\mathbf{max}}$ (or any other value recommended by ICES)

5. The parties recognise the fact that no reference points have been provided but requests ICES to evaluate the proposed values for $U_{\mathbf{lim}}$ and U_{PA} based on the survey results.

6. Based on the assumption under item 4, NEAFC requests ICES to evaluate a HCR based on biennial recommendation on total allowable catch (given in the autumn of the years when survey is conducted and will apply until the next survey is available, unless there are indications that the status of the stock has changed significantly to the worse).

The proposed HCR is as follows:

(1) For U below U_{lim}. TAC = 0.01*survey Index (or any other appropriate value, lower or higher recommended by ICES)

(2) For U between U_{lim} and U_{PA}: The following formula will apply

$TAC = U*(E_{lim} + [(U-U_{lim})*(E_{PA}-E_{lim})/(U_{PA}-U_{lim})])$; Where E means exploitation ratio (% of the survey biomass index) and U means survey index

(3) For U being above U_{pa}, the TAC will be 0.05*U (or any other appropriate value recommended by ICES).

As the variation in the survey index is expected to be high, there might be a need for buffering the calculated TAC based on the approach above. Therefore ICES is also requested to evaluate whether the following approach is in accordance with the precautionary approach to managing the resource.

(4) For U being below U_{lim}: $TAC_{\mathbf{i}} = (TAC_{\mathbf{i-1}} + 0.01*U)/2$

(5) For U being between U_{lim} and U_{PA}, following formula will apply:

$TAC_{\mathbf{i}} = (TAC_{\mathbf{i-1}} + U*(E_{lim} + [(U-U_{lim})*(E_{PA}-E_{lim})/(U_{PA}-U_{lim})]))/2$

(6) For U being above U_{PA}, the $TAC_{\mathbf{i}} = (TAC_{\mathbf{i-1}}+0.05*U)/2$.

Proposal for a MSY Approach HCR

[SIMILAR TO ABOVE PA APPROACH BUT WITHOUT THE ‘LIM’ BREAK, IE. DIRECTLY FROM B-TRIGGER TO ZERO HOWEVER WITH A SPECIAL ATTENTION RULE AREA WHEN NEAR ZERO. BUT FOR BOTH APPROACHES WE NEED TO JUSTIFY THE BREAKPOINT ESTIMATE OF 50% OF MAX VALUE]

Proposal for a Data Limited Stock (DLS) Approach HCR

In 2012 ICES has developed a quantitative approach for data limited stocks, i.e. stocks for which data are insufficient to perform a full analytical assessment and forecast. This approach is based on a stock categorization based on data availability, and a subsequent catch rule. This will, contrary to previous advice from ICES, provide the clients with absolute catch advice.

In the present DLS approach it is suggested to categorize pelagic redfish (both stocks) as category 3, where “surveys are reliable indicators of trends, but no quantitative assessment is available”. Within this category the suggested method is 3.2.0. which is “If there are survey data on abundance (e.g. CPUE over time), but there is no survey-based proxy for MSY. $B_{trigger}$ and F values or proxies are not known.“ This means that the algorithm

$$C_{y+1} = C_{y-1}\left(\frac{\sum_{y-1}^{y-x} I/2}{\sum_{y-3}^{y-z} I/3}\right)$$

should be the basis for the catch advice, i.e. the proportional change in survey indices the last two years compared to the previous three years. Also, according to the approach, the estimated catch advice could be capped by a 20% uncertainty cap and/or a precautionary buffer as described in the ICES DLS approach.

The approach is determined for stocks where an annual survey or regular surveys is being carried out. This is not the case for the pelagic stocks in the Irminger Sea, and the implementation of the approach therefore has to be examined further.

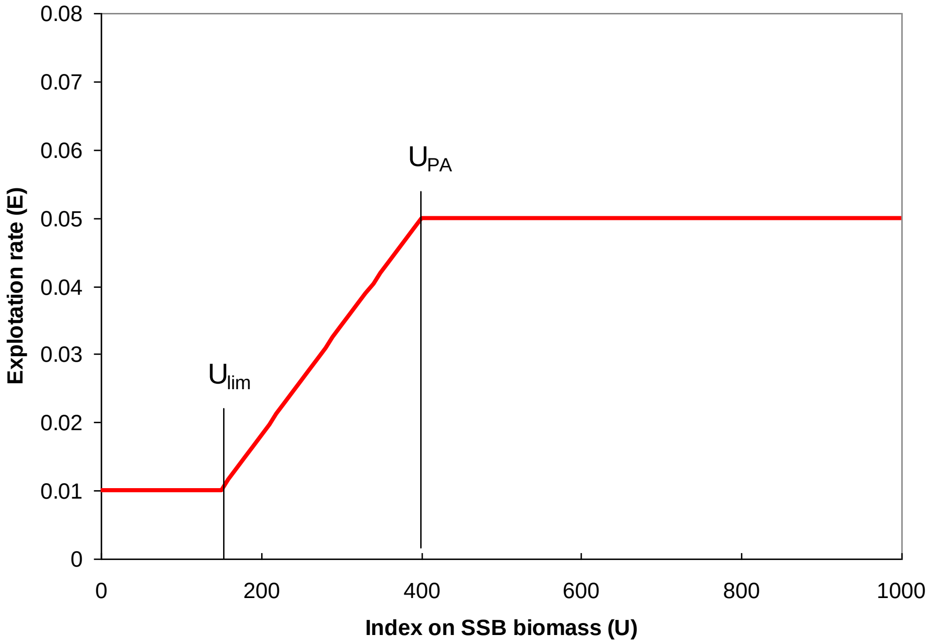


Figure illustrating the suggested HCR for the deep stock of pelagic redfish in the Irminger Sea and adjacent waters using the PA approach. The X axis illustrates the size of the spawning stock biomass as measured in the international survey and Y axis is exploitation rate (% of the biomass value).

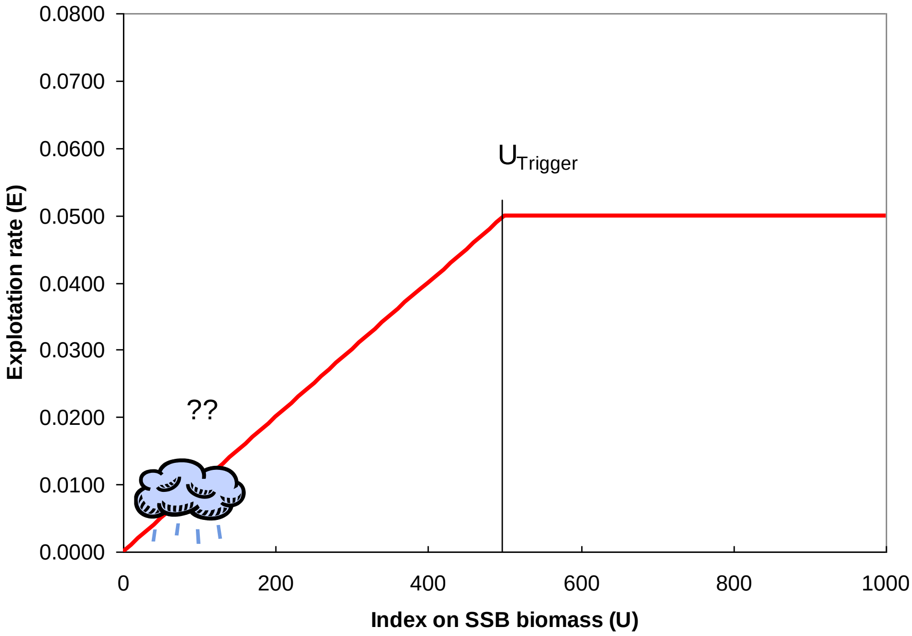
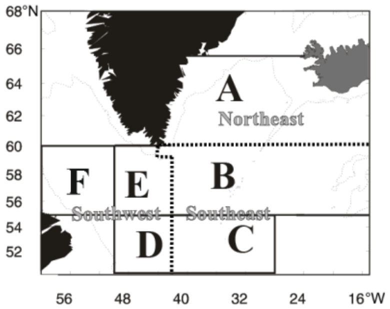


Figure illustrating the suggested HCR for the deep stock of pelagic redfish in the Irminger Sea and adjacent waters using the MSY approach. The X axis illustrates the size of the spawning stock biomass as measured in the international survey and Y axis is exploitation rate (% of the biomass value).

Table.

Available survey data on deep stock of pelagic redfish in the Irminger Sea and adjacent waters by different areas shown below the table (from ICES NWWG report 2012).

Year	A	B	C	D	E	F	Total	Depth (m)
1999	187	249	10	14	36	0	497	500–950
2001	497	316	28	79	64	18	1001	500–950
2003	476	142	20	13	27	0	678	500–950
2005	276	161	1	53	179	5	675	350–950
2007	345	283	2	32	172	19	853	350–950
2009	291	121	0	8	37	1	458	550-900
2011	342	112	0	1	18	0	474	550–900



Annex 5 Request for evaluation of a proposed long-term management plan and harvest control rule for golden redfish (*Sebastes marinus*) in Subareas V, VI, XII and XIV

11 FEB. 2013

International Council for the Exploration of the Sea
H.C. Andersen Boulevard 44-46
DK-1553 Copenhagen V
Danmark

ATVINNUVEGA- OG
NÝSKÖPUNARRÁÐUNEYTIÐ

Ministry of Industries and Innovation

Skúlagötu 4 150 Reykjavík Iceland
tel.: + (354) 545 9700 postur@anr.is www.anr.is

Reykjavík February 5, 2013
Reference: ANR12090104/11.2.3

Subject: Request for evaluation of a proposed long-term management plan and harvest control rule for golden redfish (Sebastes marinus) in Subareas V, VI, XII and XIV

The Governments of Iceland, Faroe Islands and Greenland propose the following management plan for golden redfish (Sebastes marinus) in Subareas V, VI, XII and XIV:

The management strategy for golden redfish (Sebastes marinus) in Subareas V, VI, XII and XIV is to maintain the exploitation rate at the rate which is consistent with the precautionary approach and that generates maximum sustainable yield (MSY) in the long term.

In accordance with this strategy, the annual total allowable catch (TAC) will be set by applying the following harvest control rule (HCR):

1. The annual TAC will be set consistent with an average fishing mortality rate of 0.097 in the advisory year for age-groups 9-19, when the spawning stock biomass (SSB) in the assessment year (SSBy) is estimated to be above 220,000 tonnes (Btrigger).

2. Where the SSB in the assessment year is estimated to be below 220,000 tonnes (Btrigger), the TAC will be set consistent with a fishing mortality rate in the advisory year equal to 0.097 *(SSBy/Btrigger).

These HCR formulations are based on work of national experts and the NWWG and have been considered to be in accordance with the ICES MSY advisory framework.

The evaluation should also include review of input data and the applied assessment methodology (Benchmark) and the appropriateness of values assigned to reference points.

The Governments of Iceland, Faroe Islands and Greenland request ICES to evaluate whether this proposed harvest control is in conformity with its objectives.

ICES is also invited to propose alternative rules or modified rules on its own initiative and to evaluate these.

On behalf of the government of Iceland, The Faroe Islands and Greenland.

On behalf of the Minister

Kristján Skarphéðinsson

Ingvi Már Pálsson

Cc: Emanuel Rosing, Department of Fisheries, Hunting and Agriculture, Greenland,
Andras Kristiansen, Fiskimálaráðið, The Faroe Islands

Annex 6: WKREDMP Working Documents

Harvest Control Rule for deep pelagic beaked redfish (*Sebastes mentella*) in the Irminger Sea and adjacent waters

Kristján Kristinsson, Höskuldur Björnsson and Þorsteinn Sigurðsson
Marine Research Institute, Reykjavík, Iceland
⟨krik@hafro.is⟩ ⟨hoski@hafro.is⟩ ⟨steini@hafro.is⟩

Contents

1 Introduction

This working document describes harvest control rule (HCR) scenarios for deep pelagic beaked redfish (*Sebastes mentella*) in the Irminger Sea and adjacent waters. Current management measures implemented by NEAFC in March 2011 will end after the 2014 fishing year. Therefore, the coastal states within NEAFC asks ICES to evaluate HCRs for the stock.

The objective of the HCR is to reverse the downward trend in the survey indices since 2001. Commercial catched has in the past been high and well above ICES advice and recommended TAC.

Deep pelagic beaked redfish is considered data limited stock where no analytical assessment is conducted. The stock status has been assessed based on trends in survey biomass indices from the international redfish survey in terms of the ICES trends based assessment approach. Supplementary data used includes relevant information from the fishery and length distributions from the commercial catch and the international redfish survey.

2 The NEAFC Request

Request for evaluation of a proposed Harvest Control Rule for deep pelagic redfish in the Irminger Sea and adjacent waters

As coastal states the Faroe Islands, Greenland and Iceland request ICES to evaluate their proposal on possible HCR under a management plan for redfish in the Irminger Sea and adjacent waters.

The request: *The coastal states aim to implement a management plan on redfish in the Irminger Sea and adjacent waters in 2015 in accordance with the MSY approach and ICES is requested to evaluate and elaborate on the suggestions for potential HCRs under such management plan as given in the attached document.*

Justification: *The coastal states (Faroe Islands, Greenland and Iceland) aim to implement a permanent management plan in 2015 when the present management measures of reaching 20,000 tonnes in 2014 is running out.*

Objective: *The management plan should be in accordance with international agreements on sustainable harvest and the coastal states request ICES to comment on the proposed rules.*

3 Geographical distribution

Figure 1 shows the spatial distribtuion of pelagic beaked redfish at different stages of the life–cycles in the Irminger Sea and adjacent waters. The two stocks (see Section 4 about the stock structure) inhabit the pelagic habitats down to 1,000 m depth, but the spatial and seasonal migration patterns of the stocks are still largely unidentifed aothough it is known that adults undertake large migration between mating grounds, larval extrusion grounds and feeding grounds (Planque et al., 2013).

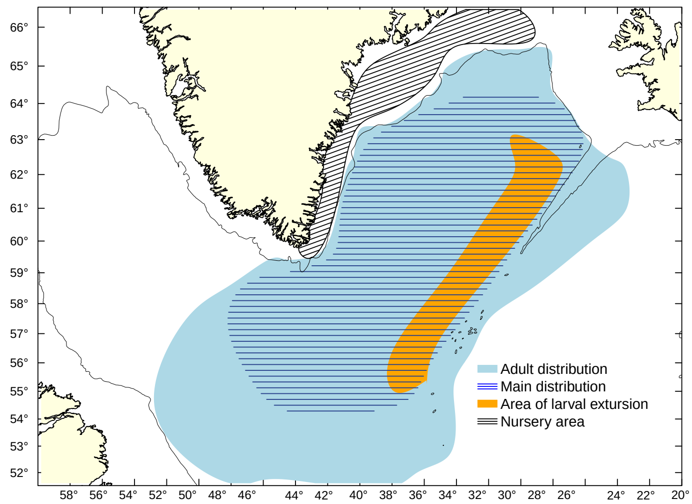


Figure 1: Distribution of pelagic redfish in the Irminger Sea and adjacent waters at different stages of the life-cycle.

4 Stock structure and management units

The Workshop on Redfish Stock Structure (WKREDS) in 2009 reviewed the stock structure of deep-water redfish in the Irminger Sea and adjacent waters (ICES, 2009b; Cadrin et al., 2010). ICES Advisory Committee (ACOM) concluded, based on the outcome of the WKREDS meeting, that there are three biological stocks of the species in the Irminger Sea and adjacent waters:

- a **Deep Pelagic stock** (NAFO 1-2, ICES V, XII, XIV >500 m) - primarily pelagic habitats, and including demersal habitats west of the Faroe Islands;
- a **Shallow Pelagic** stock (NAFO 1-2, ICES V, XII, XIV <500 m) - extends to ICES I and II, but primarily pelagic habitats, and includes demersal habitats east of the Faroe Islands;
- an **Icelandic Slope** stock (ICES Va, XIV) - primarily demersal habitats.

The East-Greenland shelf is most likely a common nursery area for the three biological stocks.

The adult deep-water redfish on the Greenland shelf has traditionally been attributed to several stocks, and there remains the need to investigate the affinity of adults in this region.

Based on the stock identification information, ICES recommended three potential management units that are geographic proxies for biological stocks that were partly defined by depth and whose boundaries are based on the spatial distribution pattern of the fishery to minimize mixed stock catches (Figure 2):

1. Management Unit in the northeast Irminger Sea: ICES Areas Va, XII, and XIV.
2. Management Unit in the southwest Irminger Sea: NAFO Areas 1 and 2, ICES areas Vb, XII and XIV.
3. Management Unit on the Icelandic slope: ICES Areas Va and XIV, and to the north and east of the boundary proposed in the MU in the northeast Irminger Sea.

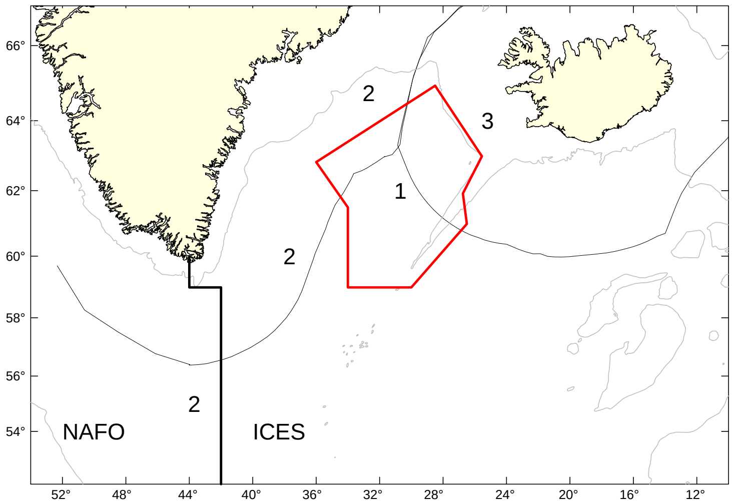


Figure 2: Management unit boundaries for beaked redfish in the Irminger Sea and adjacent waters. The polygon bounded by red lines, i.e. 1, indicates the region of the deep-pelagic management unit in the northwest Irminger Sea, 2 is the shallow pelagic management unit in the southwest Irminger Sea including within the NEAFC Convention areas, and 3 is the Icelandic slope management unit which is within the Icelandic EEZ.

5 Current management and ICES advice

NEAFC is the responsible management body, and ICES the advisory body. Management of fisheries on pelagic redfish is based on setting total allowable catches (TAC) since 1996 and technical measures.

No harvest control rule does exists for the stock and there has been no agreement on stock structure and the TAC and allocation key between contracting parties in NEAFC for several years. Some countries had set autonomous quotas. This has led to total annual catches far above the NEAFC TAC.

In March 2011, NEAFC agreed on interim measures for the deep pelagic beaked redfish fisheries until the end of 2014. These measures were agreed by all members of NEAFC except Russia who sets its own autnomous quota. The total catch has therefore exceed the TACs in 2011-2013 set by NEAFC and is expected also to be above TAC in 2014. The objective of these measures was to gradually decrease the catches until they comply with the ICES advice, and to establish harvest control rule in the long term.

TAC and quota allocation between Contracting Parties for the deep-pelagic beaked redfish fishery in the Irminger Sea and adjacent waters 2011-2014 was fixed as follows: the TAC in 2011 was 38,000 tonnes, in 2012 it will be 32,000 tonnes, in 2013 26,000 tonnes, and in 2014 the TAC will be 20,000 tonnes.

One of the objective of these interim management measures was to establish a long-term management plan for redfish in the Irminger Sea and adjacent waters during the period, which includes appropriate harvest control rule.

ICES is advisory body. ICES has since 2008 adviced that no more than 20,000 t should be fished and urged NEAFC to develop and implement management plan. The argument for this advice is that the stock is considered to have decreased over the last decade and the exploitation status is unknown.

6 The fishery

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 tonnes in 1991 to nearly 140,000 t in 1996, stabilising at 85,000-105,000 t during the period 1997-2004, when some countries ceased fishing (Figure 3a). From 2005 onwards, annual landings have declined, being in the range 30,000 and 68,000 t.

The main fishing area is in the north-west Irminger Sea close to the Icelandic EEZ (north of 61°N and east of 32°W) (Figure 3b) from April to July at depths between 500 and 900 m).

The fishery is targeting the adult part of the stock, so it is expected that the recruitment of juveniles is not negatively affected. It is a highly directed fishery, catching mainly redfish, very low bycatch and discard rates.

In 2002-2007, there were indications that reported effort (and consequently landings) could represent only around 80% of the real effort in certain years.

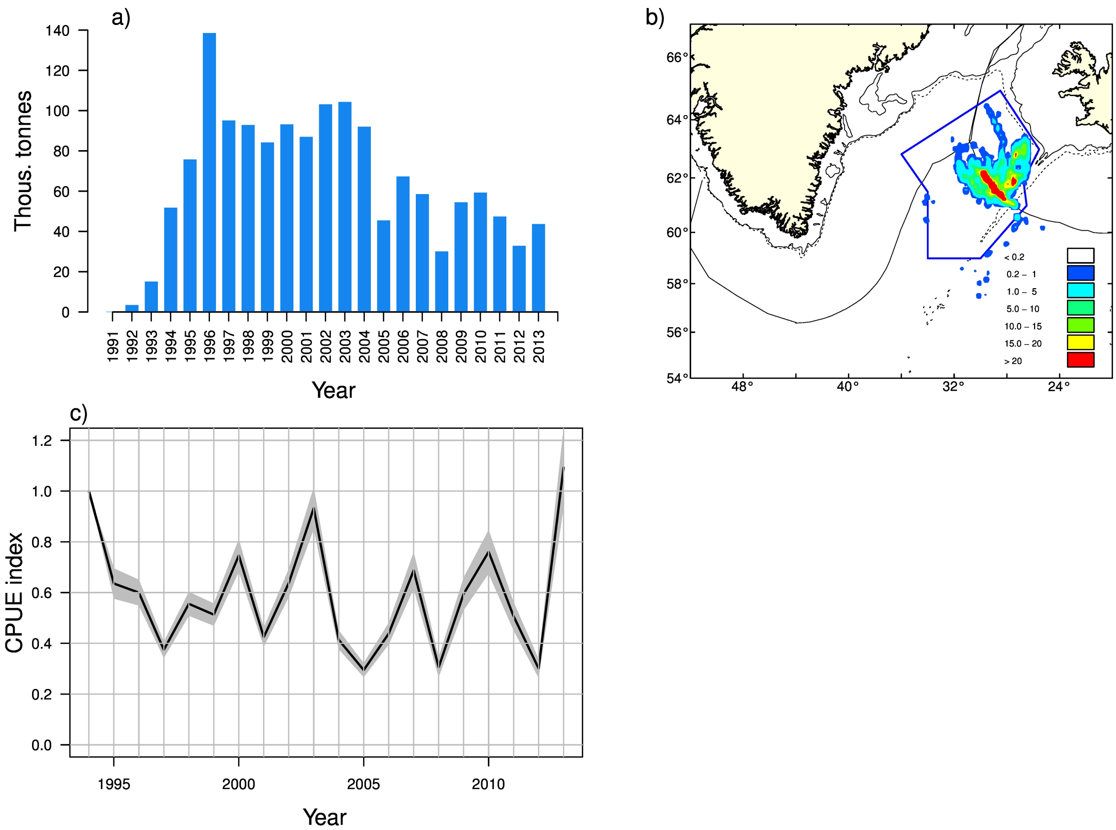


Figure 3: Deep pelagic beaked redfish: a) Nominal landings 1991-2013. b) Fishing areas in the Irminger Sea adjacent waters 2005-2013 (all years combined) based on log-book data from Iceland, Faroe Islands, Germany, Greenland and Norway. c) Trends in standardised CPUE based on log-book data from of the Icelandic fleet.

7 Assessment

No analytical assessment is carried out on deep pelagic beaked redfish 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 benchmark workshop on redfish in 2012 (ICES, 2012) some participants considered that at present the analytical assessment cannot be conducted because, for example, of little age data and the relative shortness of the time–series available. The external panel of WKRED 2012 put forward a Schaefer biomass dynamics model as an interim basis for assessment and the development of management advice (see Appendix 1 and 2 in ICES (2012)).

Some participants in the Working Group did not accept this Schaefer model approach. The external panel expressed reservations about the use of the trends based assessment approach (see Appendix 2). These issues are elaborated further in Section C of the Stock Annex (ICES, 2012).

8 Data

Deep pelagic beaked redfish is a stock that is difficult to assess and is considered data poor although considerable data is available:

1. Catch data since 1991 (Section 6).
2. CPUE since 1991 from the commercial catches from key nations participating in the fishery (Section 6).
3. Survey indices since 1999 (Section 8.1)
4. Biological data:
    (a) Length distribution from catches since 1991.
    (b) Length distribution from the redfish surveys since 1999.
    (c) Few aged otolith samples, mostly from the commercial catch (Section 8.2.2).
    (d) Maturity samples from catches and surveys.

There is still a lack of basic information regarding the following aspects:

- population age structure;
- species identification of young individuals;
- magnitude of the recruitment and the patterns are not known (but see Section 8.2.1);
- location of nursery and mating areas;
- estimation of natural mortality (Section 8.2.3).

8.1 International redfish surveys

The international redfish surveys in the Irminger Sean and adjacent waters provide valuable information on the biology, distribution and relative abundance of oceanic beaked redfish, as well as on the oceanographic conditions of the surveyed area. Until 1999, only the shallow pelagic beaked redfish was surveyed by acoustics down to an approximate depth of 500 m. Attempts to obtain reliable stock size estimates and map the stock distribution below that depth did not succeed (Shibanov et al., 1996; ICES, 1998; Sigurdsson and Reynisson, 1998), mostly due to the deep scattering layer (DSL), which is a mixture of many vertebrate and invertebrate species mixed with redfish (Magnússon, 1996; Sigurðsson et al., 2002).

Since the fishery had moved towards the deep pelagic beaked redfish at greater depths (500–1000 m) in the early 1990s it was very important to expand the vertical coverage of the survey. The 1999 survey provided for the first time an estimate on the abundance of the deep pelagic beaked redfish stock with so-called trawl method (Section 8.1.1). Since then the survey has been conducted biennially. The surveys in 2005 and 2007 are not comparable with the other surveys because of changes in the depth range covered (see Section 8.1.3 where attempt is made to estimate the biomass for the deep pelagic stock for those two years).

Table 1 gives an overview of the international trawl-hydroacoustic surveys on deep pelagic beaked redfish conducted in the Irminger Sea and adjacent waters. The survey has been conducted by Iceland, Germany and Russia (with Norway participating in 2001) with two to five research vessels. The objective is to estimate biomass and distribution of the shallow and deep pelagic stocks in the area. The results from the surveys are the bases for the ICES advice of the two stocks.

The survey is conducted in June/July and the survey area is the Irminger Sea and adjacent waters, covering area of aproximately 350,000 NM (Figure 4).

In this survey, 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 only results presented are biomass indices and the length distribution of the catch. Otolith are also sampled but have not been systematically age read.

Table 1: Redfish surveys on deep pelagic beaked redfish carried out in the Irminger Sea and adjacent waters (depth 500-950 m in 1999-2003 and 2009-2013 and depth 350-950 in 2005 and 2007 m). Th. nm^2; square nautical miles surveyed, Country: IS - Iceland, DE - Germany, NO - Norway, RU - Russia.

Year	Country	Vessels	Th. nm^2	Depth range	References
1999	IS/DE/RU	3	296	500-950	Sigurdsson et al. (1999)
2001	IS/DE/RU/NO	5	420	500-950	ICES (2002)
2003	IS/DE/RU	3	405	500-950	ICES (2003)
2005	IS/DE/RU	3	386	350-950	ICES (2005)
2007	IS/RU	2	349	350-950	ICES (2007)
2009	IS/DE	2	360	550-900	ICES (2009a)
2011	IS/DE/RU	3	343	550-900	ICES (2011)
2013	IS/DE/RU	3	340	550-900	ICES (2013)

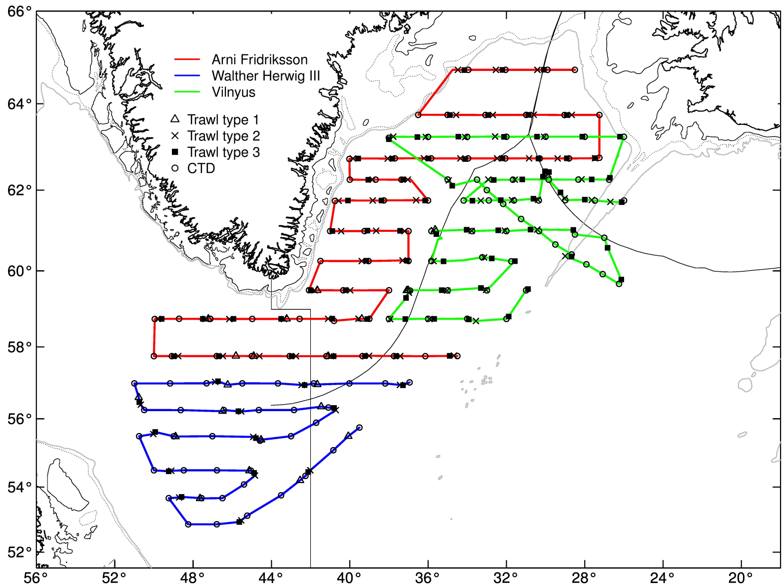


Figure 4: Cruise tracks and stations taken in the joint international redfish survey in the Irminger Sea and adjacent waters in June/July 2013.

8.1.1 Abundance estimation by the trawl method

The classic method of continuous echo integration deeper than 350 m (within and deeper than DSL) is applicable only under very specific conditions. Because of the increased influence of the vessel s noise, as well as the mixing of redfish with various components of the DSL (Magnússon, 1996; Sigurðsson et al., 2002), this is almost impossible. An additional difficulty is due to the decrease of the effective angle of the transducer beam, especially for single fish registration at great depths. This in particular demands for a lower SV-threshold, down to (-85) – (-90) dB for correct echo integration. For hull-mounted transducers this may cause problems with noise. Therefore, acoustic estimation of redfish with a hull mounted transducer in depths exceeding 350 m is very difficult (Dalen et al., 2003).

In the surveys in 1999-2013, a trawl-method was used to calculate abundance of deep pelagic beaked redfish. The method is based on a combination of standardized survey catches and the hydroacoustic data, where the correlation between catch and acoustic values during trawling in the shallower layer is used to obtain acoustic values for the deeper layer, based on catches in the deeper layer. To be able to make the calculations, the hauls are carried out at different depth intervals, evenly distributed over the survey area.

Since 1999 (except in 2005 and 2007) the sampling with the trawl has been conducted as follows:

1. The depth zones shallower than the DSL, in which redfish could be acoustically identified. Trawling distance was 4 NM;

2. the depth zone shallower than 500 m, in which acoustic redfish registration was hampered by the deep scattering layer. The identification hauls covered the following layer (headrope of the net): from the top of the DSL down to 450m. Trawling distance at each depth layer was 2 nautical miles;

3. the depth zones deeper than 500 m depth. The deep identification covered the following 3 depth layers (headline): 550 m, 700 m, 850 m. Trawling distance at each depth layer was 2 nautical miles.

In the 2005 and the 2007 surveys (ICES, 2005, 2007) the trawling was from 350 down to 950 m, i.e. within and deeper than the DSL. For this reason the abundance estimates by the trawl method are not comparable with the other years as both pelagic stocks were sampled simultaneously. In Chapter 8.1.3 a method is described how estimates below 500 m are calculated to be used in further analysis.

The catches were statndardized by 1 NM. A linear regression model between the acoustic values and catches (in kg/NM) of type 1 trawls (shallower than the DSL and within redfish concentration) was applied to predict the acoustic values for each type 2 and 3 trawl. Because few type 1 trawls were taken in each survey (year), the type 1 trawls from all surveys since 2001 are combined. The results of the geometric mean linear regressions between the acoustic values and the catches recorded shallower than the DSL for each vessel are given in Figure 5.

Estimation of redfish distribution by the trawl method for type 2 and 3 trawls was done by conversion of catches (catch in kg per NM) to equivalent acoustic estimates by predicting the s_A values using the obtained correlation for each vessel. Further, the obtained s_A values were then adjusted for the vertical coverage of the trawls and the depth range of each haul ($\Delta D/H_{tr}$ where ΔD is the difference between maximum and minimum depth of each haul and H_{tr} is the vertical opening during each tow). The s_A value for each trawl (s_{Atr}) is:

$$s_{Atr} = C * K * K_H \tag{1}$$

where C is the catch in kg per NM of each type 2 and 3 trawl, K is the coefficient of the trawl obtained from the linear regression of type 1 trawls for each vessel (see above), and K_H is the width of the depth range towed defined as:

$$K_H = (H_{MAX} - H_{MIN} + dH_{TR})/dH_{TR} \tag{2}$$

where H_{MAX} and H_{MIN} of the headline of the trawl during the tow and dH_{TR} is mean vertical opening of the trawl. For all vessels dH_{TR} was 50 m. For type 3 hauls (aimed at deep pelagic beaked redfish) H_{MIN} was 550 m and H_{MAX} was 850 m.

Based on the regressions, confidence limits for the estimates were also calculated.

After having calculated the s_A values from the catches of each haul, the estimation of the abundance and biomass was calculated using the same target strength equation for redfish (20logL - 71.3) and the same algorithm as used for the acoustic estimation. The area coverage was considered to be the same as for the acoustic results.

8.1.2 Quality of the trawl biomass estimate

The quality of the trawl biomass estimate from the international trawl-acoustic surveys since 1999 has not been verified as the data series is relatively short and the survey is only conducted every second year. Figure 6 shows the acoustic and trawl estimates of shallow pelagic stock. The trend in the trawl estimates within the DSL layer 2001-2013 shows smiliar trend as the acoustic estiame. This indicates that the trawl method, although uncertain, can be used to measure the abundance of the deep pelagic stock.

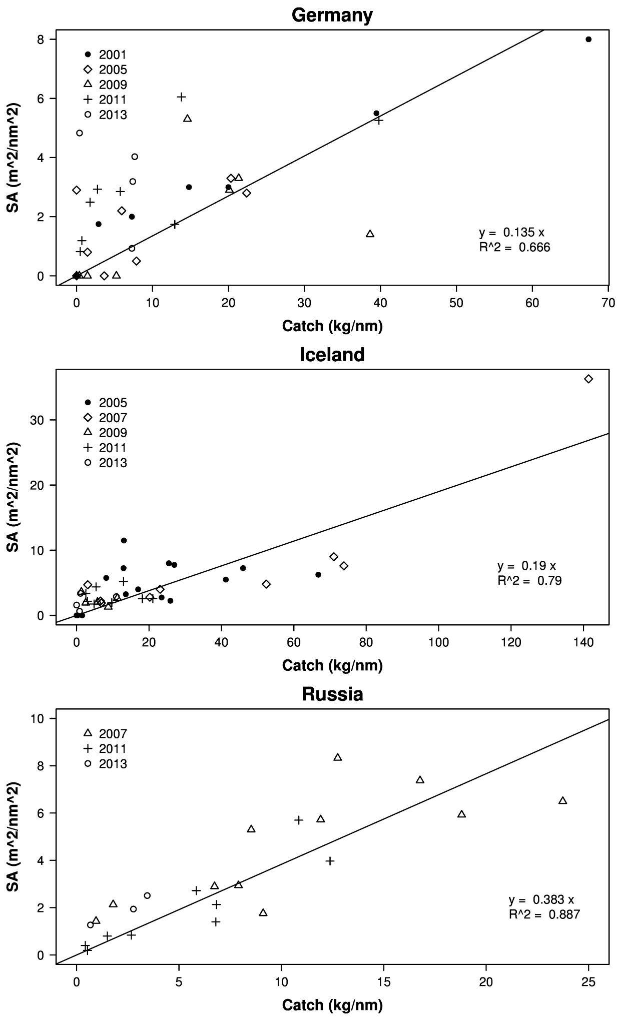


Figure 5: Regression between catches and observed hydroacoustic s_A values, observed on the German, Icelandic and Russian vessels shallower than the DSL and used in the biomass calculation for deep pelagic beaked redfish. For the German trawl types 1 the years 2001, 2005, 2009, 2011 and 2013 were used for the regression, the years 2005, 2007, 2011 and 2013 for the Icelandic vessel and 2007, 2011 and 2013 for the Russian vessel.

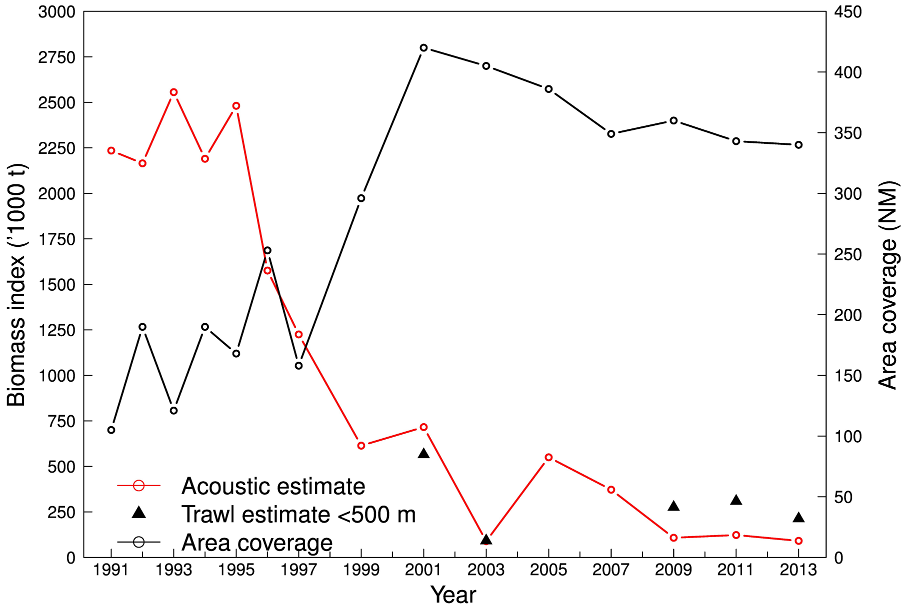


Figure 6: Overview of acoustic survey indices (thoushand tonnes) from above scattering layer (red open circles, line), trawl estimates within the scattering layer and shallower than 500 m (black triangle), and aerial coverage (nautical miles squared, black open circle) in the Irminger Sea and adjacent waters 1991-2013.

8.1.3 Inclusion of the 2005 and 2007 surveys

As described in Chapter 8.1 the trawling was conducted differently in 2005 and 2007 than in 2001-2003 and 2009-2013. The difference is that in the 2005 and 2007 the trawling was from 350-950 m in a single tow. In the other surveys the trawling was in two separate tows, i.e. one tow from 350-500 m and one tow from 550 m down to 950 m (here defined T2 and T3 tows for the 350-500 m and 550-900 m respectively). This mean that in 2005 and 2007 both pelagic stocks were sampled simultaneously.

To get an approximate biomass estimate of the deep pelagic stock in 2005 and 2007 the following was done:

- Biomass indices are calculated after each survey for six areas shown in Figure 7 for both T3 tows (deep plagic stock, Table 2) and T2 tows (shallow pelagic stock, Table 3).
- For the surveys conducted in 2001, 2009, 2011, and 2013 biomass estimates from the T2 and T3 tows were combined to get a total biomass estimates from 350-950 m depths (Table 4) and are similiar estimates as were done in 2005 and 2007. T2 tows in the 1999 and 2003 were not conducted.
- For each sub-area and year a proportion of the deep pelagic stock of the total biomass was calculated. Then, for each area a mean was calculated. (Table 5)
- The mean for each sub-area was finally multiplied with the 2005 and 2007 estimates (Table 6).
- This gives estimates of 420 and 554 thousand tonnes for 2005 and 2007 respectively (Table 6).

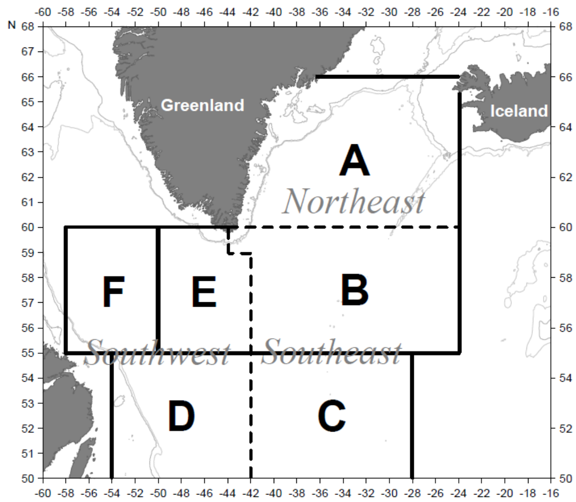


Figure 7: Defined subareas of the survey area in the Irminger Sea and adjacent waters.

Table 2: Biomass estimates (thousand tonnes) by sub-areas (Figure 7) of deep pelagic beaked redfish (500-950 m depth) in the Irminger Sea and adjacennt waters 1999-2003 and 2009-2013. Also shown are biomass estimates from the 2005 and 2007 surveys were were sampling was done at 350-950 m and hence, both shallow and deep pelagic stock sampled.

	Area							
Year	A	B	C	D	E	F	Total	Depth range
1999	187	249	10	14	36	0	497	500–950
2001	497	316	28	79	64	18	1001	500–950
2003	476	142	20	13	27	0	678	500–950
2005	276	161	1	53	179	5	674	350–950
2007	345	283	2	32	172	19	854	350–950
2009	291	121	0	8	37	1	458	550–900
2011	342	112	0	1	18	0	474	550–900
2013	186	92	0	26	78	26	401	550–900

Table 3: Biomass estimates (thousand tonnes) by sub-areas (Figure 7) of shallow pelagic beaked redfish (350-500 m depth) in the Irminger Sea and adjacennt waters 2001, 2009, 2011 and 2013. Sampling in this depth layer were not conducted in 1999 and 2003l.

	Area						
Year	A	B	C	D	E	F	Total
2001	23	40	45	399	54	5	565
2009	136	68	0	25	48	0	278
2011	69	185	1	30	76	0	361
2013	64	88	0	22	34	5	213

Table 4: Total biomass (thousand tonnes) by sub-areas (Figure 7) for combined T2 and T3 (see Tables 2 and 3) in 2001, 2009, 2011 and 2013.

	Area						
Year	A	B	C	B	E	F	Total
2001	520	356	73	478	118	23	1568
2009	427	189	0	33	85	1	735
2011	411	297	1	31	94	0	834
2013	250	180	0	48	112	31	621

Table 5: Proportion of deep pelagic beaked redfish by sub-areas (Figure 7) for combined T2 and T3 tows (Table 4) in 2001, 2009, 2011 and 2013. Also shown is the average for each sub-area for those four years.

	Area					
Year	A	B	C	B	E	F
2001	0,96	0,89	0,38	0,17	0,54	0,78
2009	0,68	0,64		0,24	0,44	1,00
2011	0,83	0,38		0,03	0,19	
2013	0,74	0,51		0,54	0,70	0,84
Average	0,80	0,60	0,38	0,25	0,47	0,87

Table 6: Biomass estimates of deep pelagic beaked redfish in 2005 and 2007 based on the average values given in Table 5.

Year	Area A	B	C	B	E	F	Total
2005	222	97	0	13	83	4	420
2007	277	171	1	8	80	17	554

8.1.4 The 1999 survey estimate

The 1999 survey provided for the first time an estimate on the abundance of the deep pelagic beaked redfish stock with the trawl method (Sigurdsson et al., 1999). However, the method was considered as an experimental attempt to estimate the deep pelagic stock. Also, the method to estimate the stock is different than in the other years.

No Type 1 and Type 2 tows were combined in the survey, whereas in other years T1 were conducted where redfish could be acoustically detected and then with a simple regression catches were converted to sa values

Formula used to estimate s_A values

8.1.5 Results

Trawl survey estimates have been relativel stable from 2005 to 2013, but are lower than the average for 1999-2003 (Figure 8). The 2013 estimate is the lowest and near the lowest observed (Figure 8). These indices in combination with a marked decrease in landings since 2004 suggest that the stock has been reduced in the past decade.

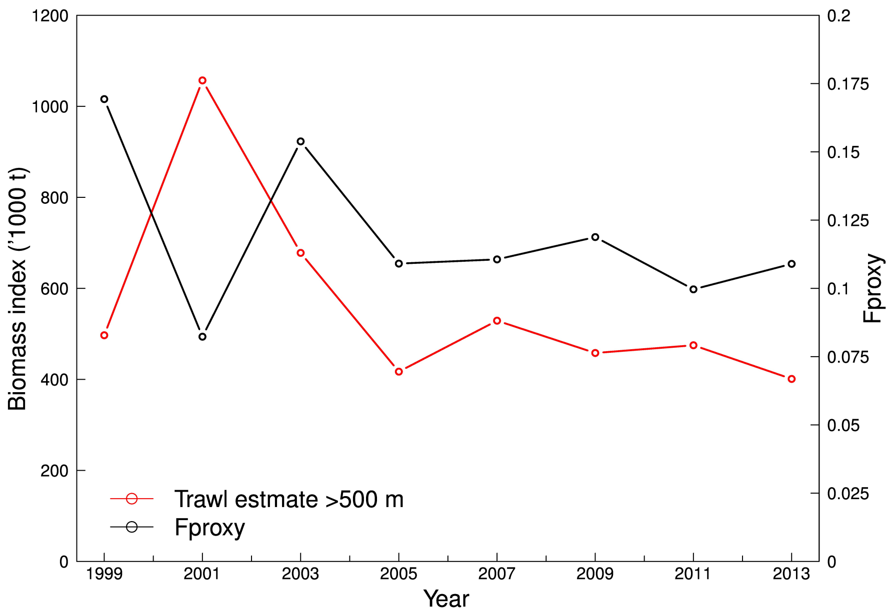


Figure 8: Survey index of deep pelagic beaked redfish 1999-2013 and F_{proxy}.

8.2 Other data

8.2.1 0-group surveys

The distribution and abundance 0-group fish in Icelandic and East Greenland waters was investigated annually in August in a 0-group survey 1970-2003 (Magnússon and Magnússon, 1977; Magnússon and Jóhannesson, 1997; Sveinbjörnsson and Hjörleifsson, 2003). The purpose to of the survey was to obtain an indication of the relative year-class strength of larvae of commercially important fish species inhabiting these waters. The survey was discontinued in 2003.

One problem regarding these larvae research on redfish was that it was difficult to distinguish the golden redfish and deep-water fish larvae from each other although attempts were made (Magnússon and Magnússon, 1977; Magnússon, 1981).

The results from these surveys indicate that the distribution and abundance of 0-group redfish is variable (Figures 9a and 8b). Low abundance is found in Icelandic waters and the main distribution both at East Greenland and in the Central Irminger Sea (Magnússon and Jóhannesson, 1997). It has, however, been difficult it is to use the 0-group survey indices as an indicator of year class strength of different redfish species.

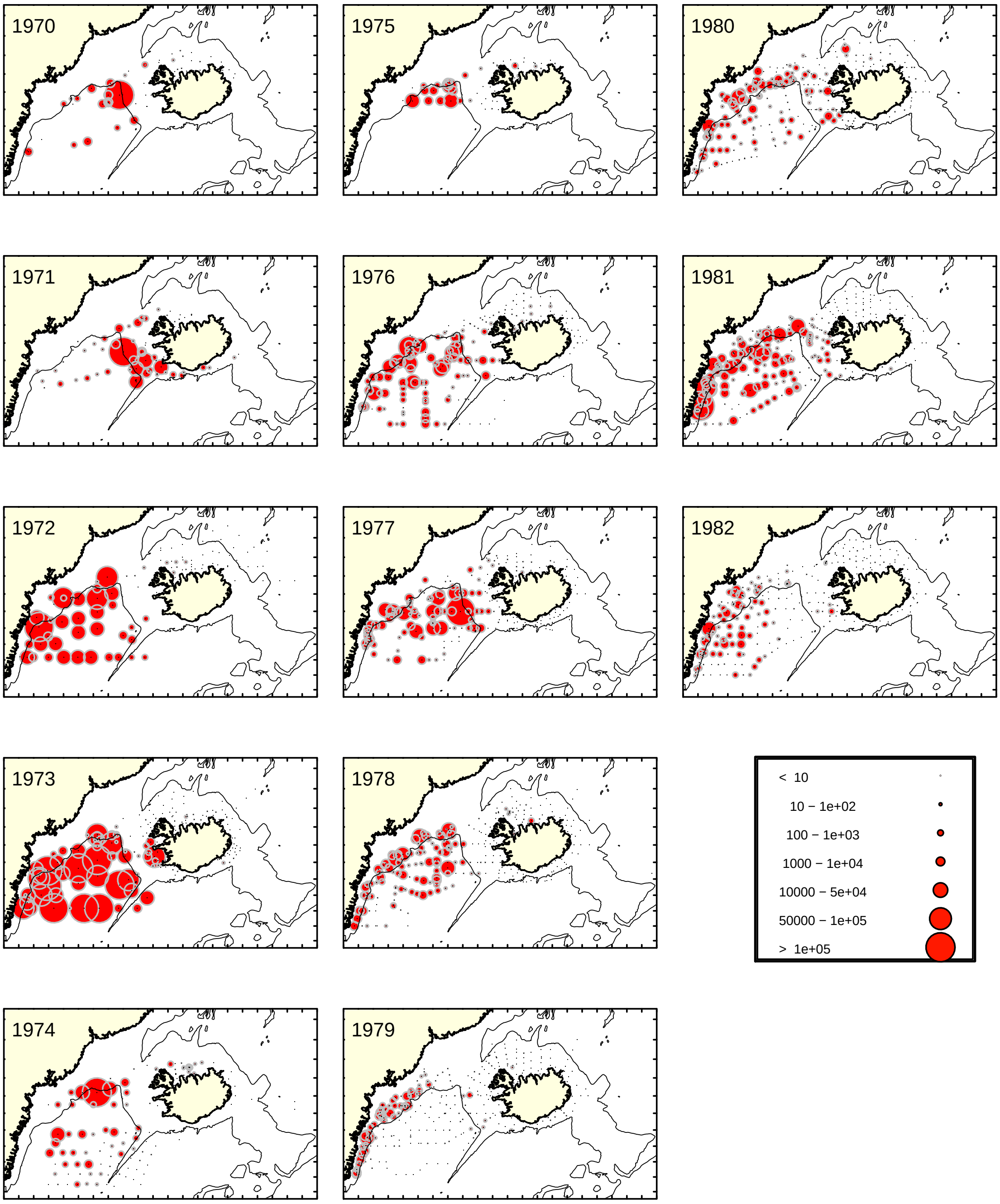


Figure 9a: Annual distribution and density (number/tow) of 0-group redfish 1970-1982.

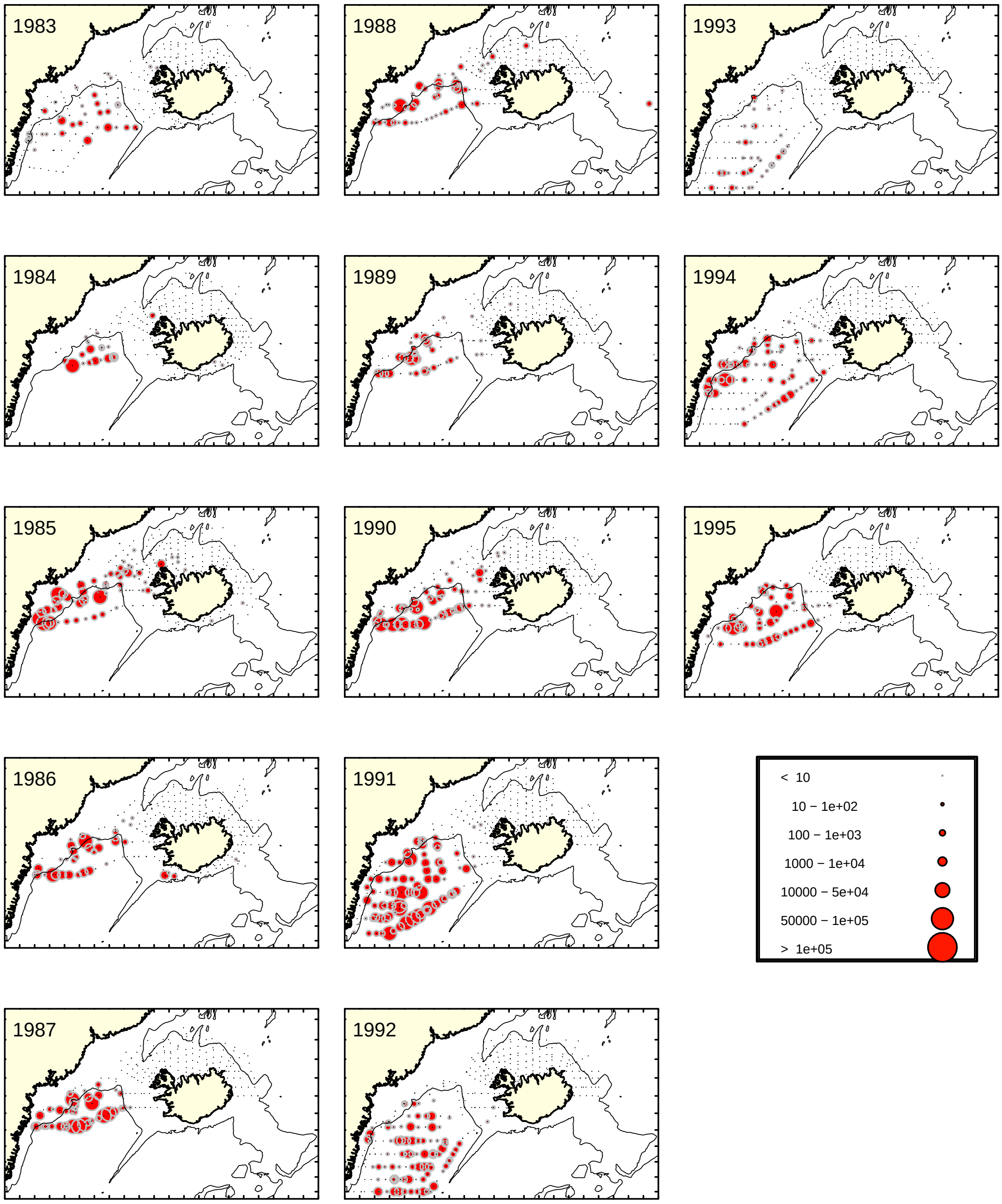


Figure 8b: Annual distribution and density (number/tow) of 0-group redfish 1983-1995

8.2.2 Age data

Age reading of deep pelagic beaked redfish in the Irminger Sea and adjacent waters and has not been systematic. Most of the age reading has been in relation with various projects such as the EU project on redfish (Anon, 2004) and on population structure of deep-water redfish (Stefánsson et al., 2009). This section describes the availability of age reading data of deep pelagic beaked redfish.

The otolith samples show that beaked redfish become very old (Figure 9). It is a slow growing species (Figure 11a,b) but total mortality appears to be low, with Z close to 0.1 for the older fish (Figure 11c).

The age readings, although small, indicate that the fishery has been on an old population (Figures 9 and 10) where recruitment has been little.

Table 7: Available age data from the deep pelagic beaked redfish in the Irminger Sea.

Year	Source	Nation	No. ageread
1999	Redfish survey	Iceland	719
1999	Commercial catch	Iceland	131
2001	Commercial catch	Iceland	117
2004	Commercial catch	Iceland	352
2006	Commercial catch	Iceland	188
2009	Commercial catch	Iceland	568
2012	Commercial catch	Norway	647
Total			2,722

8.2.3 Natural mortality

Natural mortality, M, for beaked redfish unknown. Based on regression equations that related instantaneous mortality from unexploited populations to the maximum age observed (t_{max}) (Hoenig, 1983), M values for beaked redfish were estimated within the range of 0.05 to 0.10, depending on t_{max} of 50, 70 and 90 years and is shown in the table below.

	t_{max}		
	50	70	90
Hoenig regression, fish species	0.083	0.059	0.046
Hoenig regression, all species	0.091	0.065	0.051

For further detail, see Appendix 1 in the 2012 WKRED report (ICES, 2012)).

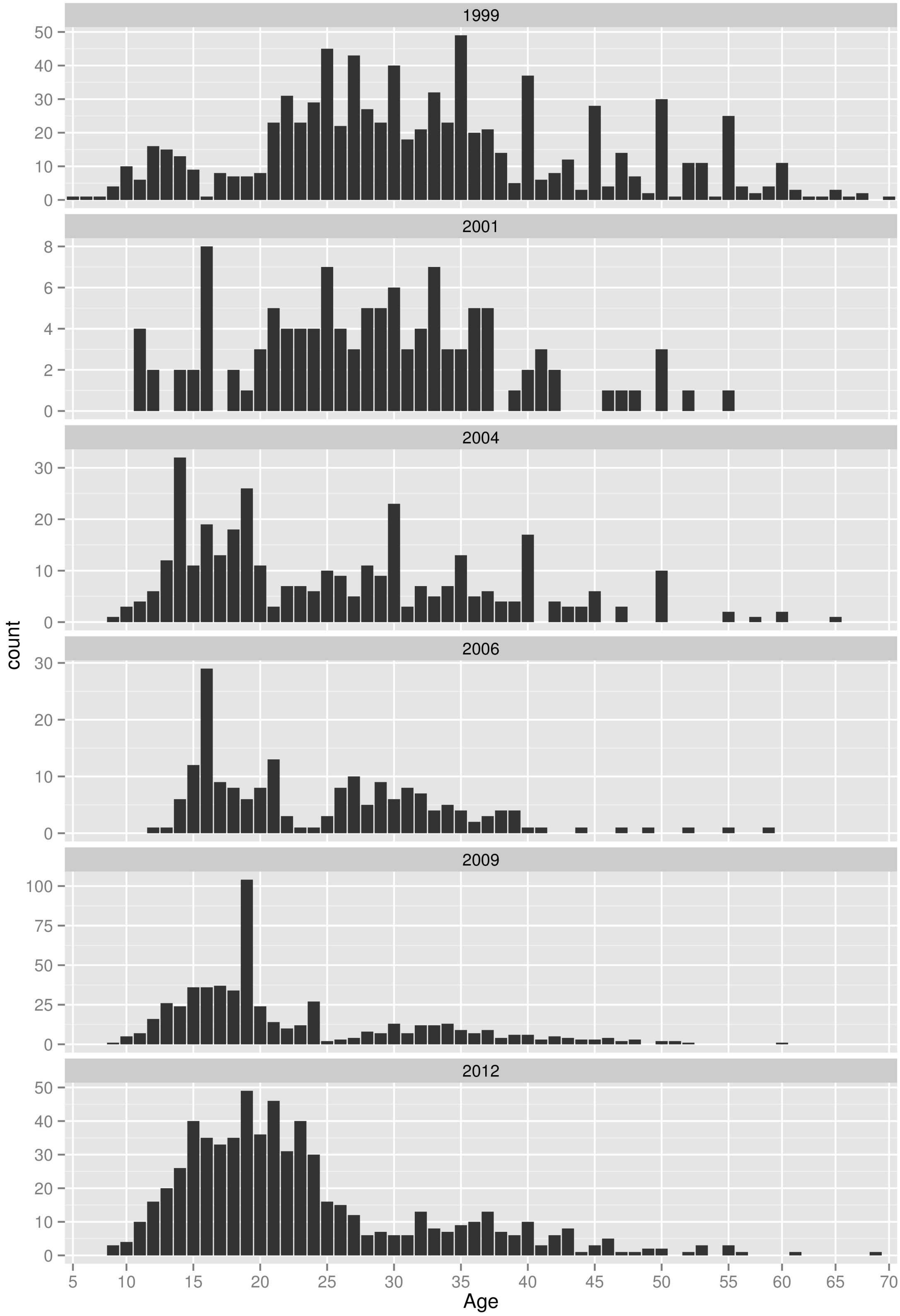


Figure 9: Age distribution of deep pelagic beaked redfish based on age reading from the commercial catch (except 1999).

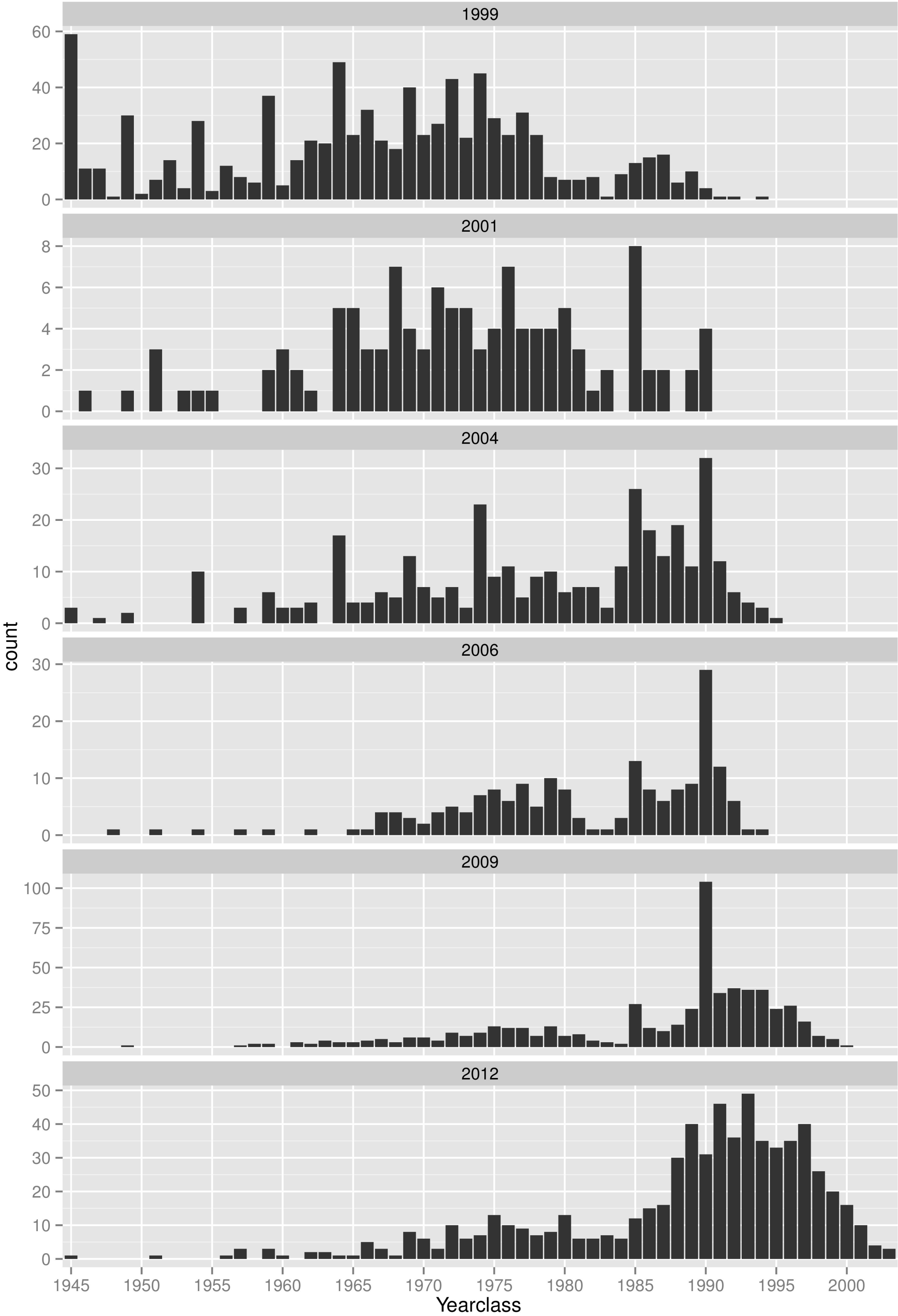


Figure 10: Yearclass distribution of deep pelagic beaked redfish based on age reading from the commercial catch (except 1999).

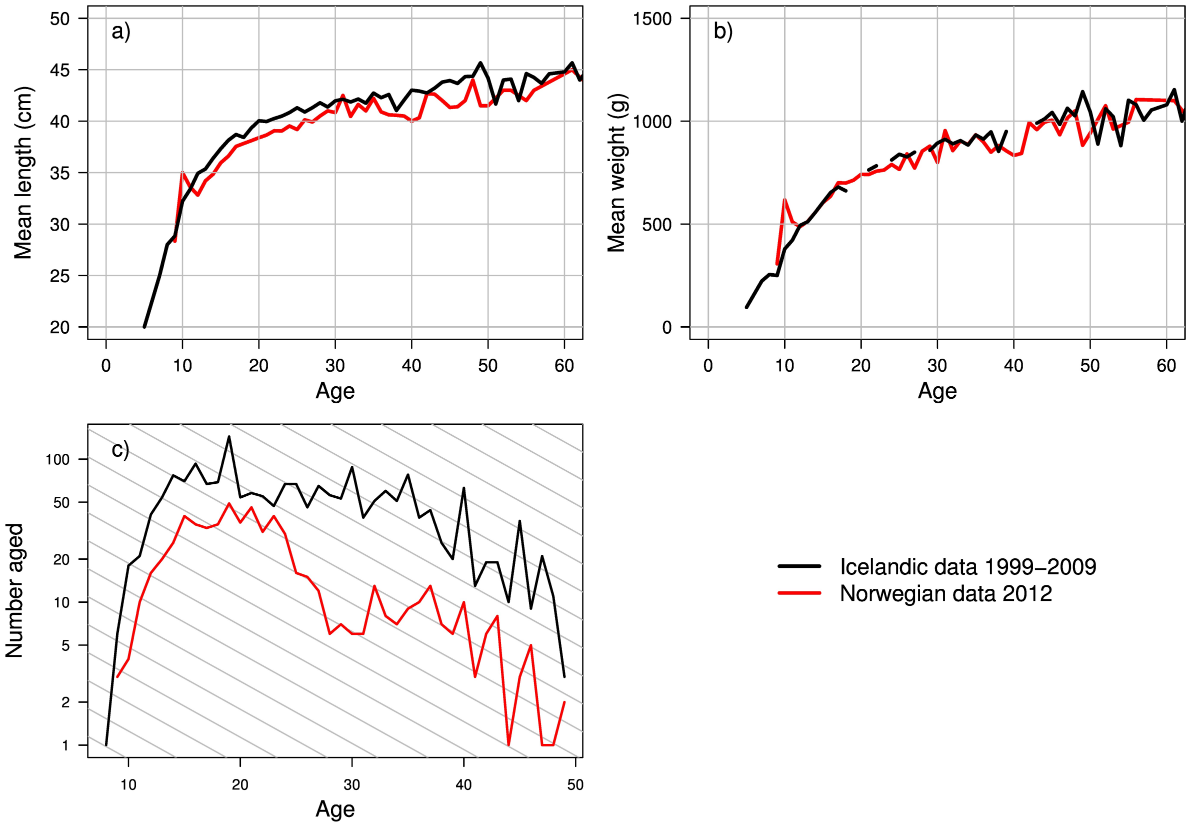


Figure 11: Deep pelagic beaked redfish: a) Mean length at age from Icelandic data 1999-2009 (black line) and Norwegian data 2012 (red line). b) Mean weight at age from Icelandic data 1999-2009 (black line) and Norwegian data 2012 (red line). c) Numbers aged plotted on log scale from Icelandic data 1999-2009 (black line) and Norwegian data 2012 (red line). Grey lines correspond to $Z = 0.1$. See Table 7 for information on the age reading.

9 Harvest Control Rule (HCR)

In this section, three HCR options for deep pelagic redfish are discussed and evaluated.

9.1 MSY Approach HCR

The formulation of the MSY approach will here be based on the proxy version of the standard ICES MSY approach, but developed where no formal assessment is conducted because of insufficient data.

As most often is the case F_{MSY} and $B_{trigger}$ are not easily defined so they will have to be defined provisionally until more data are available or an appropriate MSY probe is defined. In this document, we propose a provisional values for MSY to be used for the next 5-10 year. It is a short time for redfish, but the goal is to observe some recorvery of the stock during this period and to collect more data, especially on age distribution.

9.1.1 Assumptions and formulations

Assumptions:

1. Landings are correct (Section 6 and Table 8).
2. The survey index reflects the stock size (Section 8.1 and Table 8).
3. Assuming $F = M$, which means values within the range of 0.05 to 0.10 (Section 8.2.3).

Table 8: Nominal landings (t), survey index, and F_{proxy} (catch divided by survey index).

Year	Catch	Survey index	F_{proxy}
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	497,000	0.169
2000	93,113		
2001	86,993	1,057,000	0.082
2002	103,128		
2003	104,296	678,000	0.154
2004	91,954		
2005	45,485	420,000	0.109
2006	67,288		
2007	58,516	554,000	0.111
2008	30,045		
2009	54,406	458,000	0.119
2010	59,288		
2011	47,333	475,000	0.100
2012	32,802		
2013	43,698	401,000	0.109

The abundance index from the international redfish survey in the Irminger Sea will be used as an index of biomass. The size distribution of the redfish caught in the survey indicates that the the index is a measure of spawning stock.

The maximum of the survey index was observed in 2001. The development shows a downward trend and the index has decreased by 62% since 2001. Since 2001 the indices have haved decreased at the rate of 0.072 (standard error 0.014) per year (Figure 12). In the regression the 1999 value is omitted.

F_{proxy} (catch divided by index, Equation 3) was on the average 0.122 in 1999-2013 (Table 8) but note there there are only 6 data points (Figure 8). F_{proxy} was on average higher in 1999-2003 than in 2009-2013, where in the latter period F_{proxy} was on average 0.109. If M is equal to F (see Section 8.2.3 on natural mortality), the reduction in F to get 7.2% change in Z is 14.4%. Uncertainty is high so to have a reasonably high probability to stop the trend the reduction required would be at least 50-100% higher than this value.

If $F_{proxy,target}$ will be based on the whole survey period then $F_{proxy,target} = 0.122 * 0.75 = 0.092$. If on the other hand $F_{proxy,target}$ is based on the most recent period, that is, 2009-2013, then it gives $F_{proxy,target} = 0.109 * 0.75 = 0.082$.

The lowest value of the index is $I_{2013} = 401{,}000$ t in 2013 and $I_{trigger}$ could be set to 401,000 t $*$ 0.85 $=$ (the 0.85 value is an *ad hoc* value and could be something else). Higher $F_{proxy,target}$, for example 0.1, and $I_{trigger} = I_{2013}$ could also be used but it would lead to more variable advice as the probability of being below the $I_{trigger}$ is higer (Figure 13).

The HCR applied is as followed. After each new survey (every second year), a new TAC is calculated based on the following equations:

$$F_{proxy,ys} = \frac{C_{ys}}{I_{ys}} \tag{3}$$

where C_{ys} is the commerical catch at the assessment year and I_{ys} is the survey index at the assessment year. $F_{proxy,target}$ will be 75% of the average of the 1999-2013 (or 2009-2013):

$$F_{proxy,target} = 0.75 * (\bar{F}_{proxy,1999-2013}) \tag{4}$$

Finally $I_{trigger}$ will be 85% of the lowest survey index observed, in the case in 2013 (the 85% value is an *ad hoc* value and could be something else):

$$I_{trigger} = 0.85 * I_{2013} \tag{5}$$

The TAC for next year would be with a buffer:

$$\text{TAC}_{y+1} = \min\left(\frac{I_{ys}}{I_{trigger}}, 1\right)\left(\frac{\text{TAC}_y + F_{proxy,target} I_{ys}}{2}\right) \tag{6}$$

9.1.2 TAC for 2014

The advice/TAC should be given every second year. The TAC for 2014, based on the MSY approach would then be:

$$F_{proxy,2013} = \frac{43,698}{401,000} = 0.109 \tag{7}$$

Based on the average of 1999-2013

$$F_{proxy,target} = 0.75 * (0.122) = 0.0893 \quad (8)$$

$$I_{trigger} = 0.85 * 401,000 = 341,000 \quad (9)$$

With catch buffer:

$$\text{TAC}_{2014} = \min\left(\frac{401,000}{341,000}, 1\right)\left(\frac{26,000 + 0.0915 * 401,000}{2}\right) = 31,375 \text{ t} \quad (10)$$

Another catch buffer is to use an uncertainty cap and limit the increase or decrease of the TAC by 10% each year. Since the advice will be given every second year (the survey is conducted biennially) then the TAC will not increase or decrease by no more than 20% compared with previous TAC. Then the final equation will be:

$$\text{TAC}_{2014} = \min\left(\frac{401,000}{341,000}, 1\right)(0.0915 * 401,000) = 36,692 \text{ t} \quad (11)$$

This is an increase of 41.1% in TAC in 2014 compared to the 2013 TAC which was 26,000 t. This implies an increase of catches of at most 20% (uncertainty cap used) in relation to the 2013 TAC, corresponding to TAC of no more than 31,200 t in 2014 and 2015.

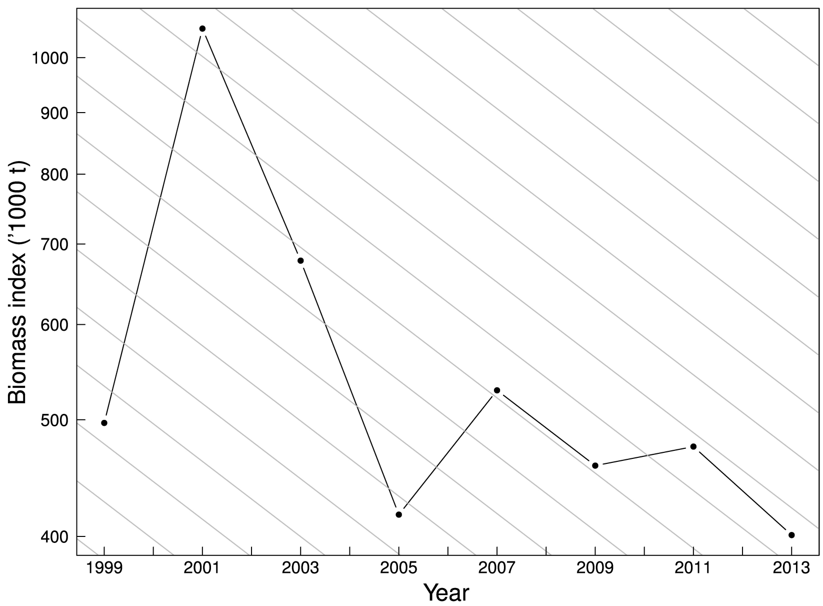


Figure 12: Indices of deep pelagic redfish since 1999 and a trend line through them (nod data points for 2005 and 2007). The trendlines correspond to slop of -0.072 on logscale (the 1999 value is not included in the regression).

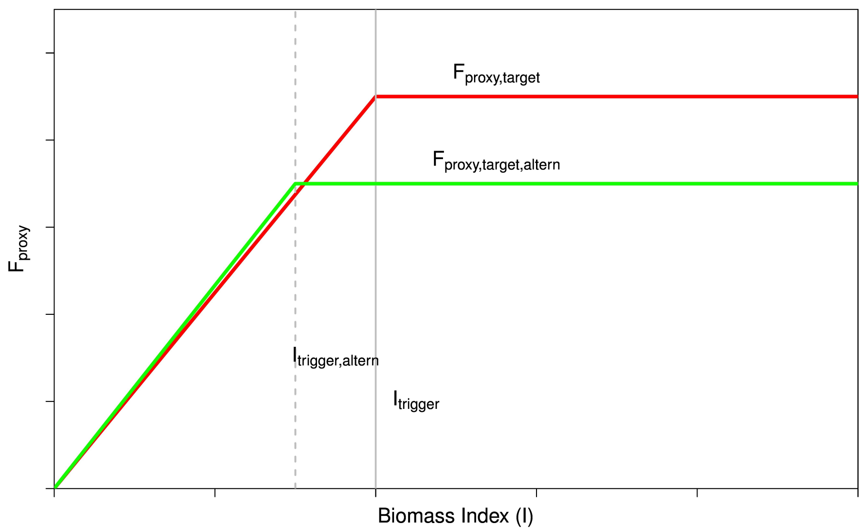


Figure 13: Deep pelagic redfish in the Irminger Sea. Form of the standard F_{proxy} HCR.

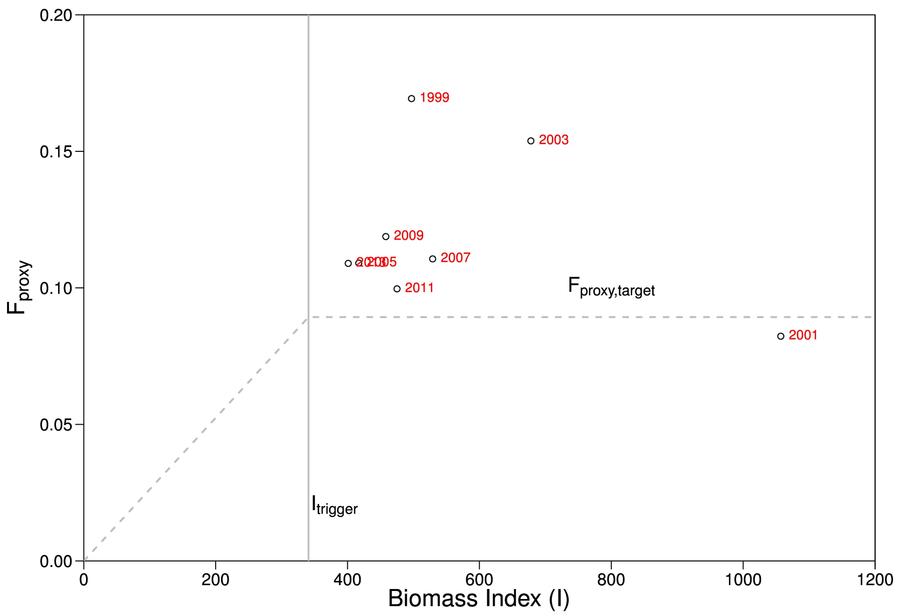


Figure 14: Deep pelagic redfish in the Irminger Sea MSY HCR. Form of the standard F_{proxy} HCR with observed F_{proxy} values. $F_{proxy,target} = 0.75 * (\bar{F}_{proxy,1999-2013}) = 0.893$ and $I_{trigger} = 0.85 * I_{2013} = 341$.

9.2 Precautionary Approach HCR

The ICES Precautionary Approach is the old ICES method before shifting to the MSY approach.

9.2.1 Assumptions

As for the MSY HCR then the assumptions about the catch statistics and survey indices are the same.

In the PA HCR, the reference points (B) are based on the survey index (I): For a proxy for B_{lim} and B_{PA}, I_{lim} and I_{PA} are defined as:

$$I_{lim} = 0.2 \times I_{max} \tag{12}$$

$$I_{PA} = 0.5 \times I_{max} \tag{13}$$

where I_{max} is the maximum observed survey value. The 0.2 and 0.5 values are *ad hoc* values and could be something else. These values have been used for golden redfish (*S. norvegicus*) in V and XIV when status of the stock was based on the precautionary approach and survey indices.

By decreasing for example the value to 0.4, I_{PA} will be lower and hence the variability in in TAC will be lower when I_y is between I_{PA} and I_{lim} (see Figure 15).

9.2.2 Formulation

Proposed HCR:

1. For I_{ys} (observed survey index at the assessment year) being above I_{PA},

$$\text{TAC} = E_{PA} \times I_{ys}. \tag{14}$$

   where E_{PA} is the exploitation ratio (% of the survey biomass index) when the stock is above I_{PA}.

2. For I_{ys} being below I_{lim}

$$\text{TAC} = E_{lim} \times I_{ys}. \tag{15}$$

   where E_{lim} is the exploitation ratio (% of the survey biomass index) when the stock is below I_{lim}

3. For I_{ys} being between I_{lim} and I_{PA},

$$\text{TAC} = I_{ys} \times \left(E_{lim} + \frac{(I_{ys} - I_{lim}) \times (E_{PA} - E_{lim})}{I_{PA} - I_{lim}} \right) \tag{16}$$

E_{PA} and E_{lim} (similar to F_{PA} and F_{lim}) are *ad hoc* values and are here predefined as 0.05 and 0.01 respectively. The 0.05 value is assumed natural mortality, M, for redfish.

They could also be based on the reference points based on the survey index I, that is, similar as in the MSY aprroach.

PA HCR with catch buffer:

1. For I_{ys} above I_{PA},

$$\text{TAC}_i = (\text{TAC}_{i-1} + E_{PA} \times I_{ys})/2. \tag{17}$$

2. For I_{ys} below I_{lim},

$$\text{TAC}_i = (\text{TAC}_{i-1} + E_{lim} \times I_{ys})/2. \tag{18}$$

3. For I_{ys} between I_{lim} and I_{PA},

$$\text{TAC}_i = \left(\text{TAC}_{i-1} + I_{ys} \times \left(E_{lim} + \frac{(I_{ys} - I_{lim}) \times (E_{PA} - E_{lim})}{I_{PA} - I_{lim}}\right)\right)/2 \tag{19}$$

where TAC_{i-1} is the TAC of the previous year.

9.2.3 TAC for 2014

This example is based on following reference points:

$$\text{I}_{lim} = 0.2 \times 1,057,000 = 211,400 \tag{20}$$

$$\text{I}_{PA} = 0.5 \times 1,057,000 = 528,500 \tag{21}$$

and $E_{PA} = 0.05$ and $E_{lim} = 0.01$. I_{2013} is 401,000 t and hence between I_{lim} and I_{PA} then following equation applies:

$$\text{TAC}_{2014} = 401,000 \times \left(0.01 + \frac{(401,000 - 211,400) \times (0.05 - 0.01)}{528,500 - 211,400}\right) = 13,624 \text{ t} \tag{22}$$

and with catch buffer:

$$\text{TAC}_{2014} = \left(26,000 + 401,000 \times \left(0.01 + \frac{(401,000 - 211,400) \times (0.05 - 0.01)}{528,500 - 211,400}\right)\right)/2 = 19,812 \text{ t} \tag{23}$$

Table 9 and Figure 16 show TAC based on different trigger points (I_{PA}), exploitation ratio (E_{PA} and E_{lim}), and whether to use catch buffer or not. By having a lower trigger (I_{PA}) there will be lower variability in the TAC with different exploitation patterns.

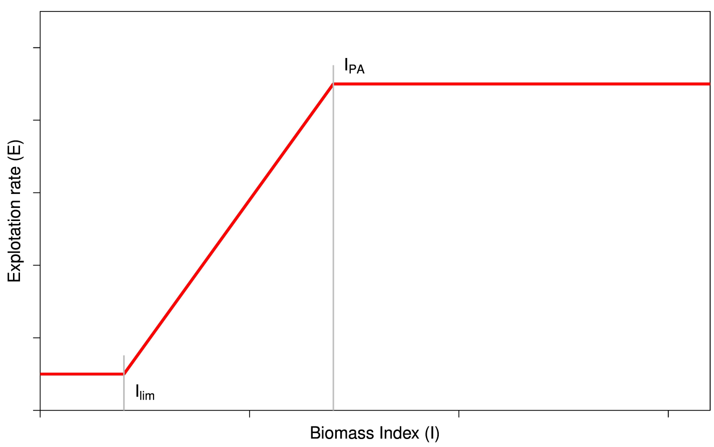


Figure 15: Deep pelagic redfish in the Irminger Sea. Form of the standard precautionary approach HCR.

Table 9: TAC based on various scenarios.

E_{PA}	$E_{lim} = 0.01$		$E_{lim} = 0.02$		$E_{lim} = 0.03$	
	No catch buffer	Catch buffer	No catch buffer	Catch buffer	No catch buffer	Catch buffer
$I_{lim} = 0.2 \times I_{max}$, $I_{PA} = 0.5 \times I_{max}$						
0.050	13.624	19.812	15,230	20,615	16.837	21.418
0.075	19.633	22.816	21.239	23.620	22.846	24.423
0.100	25.641	25.821	27,248	26,624	28.854	27.427
$I_{lim} = 0.2 \times I_{max}$, $I_{PA} = 0.4 \times I_{max}$						
0.050	18.385	22.193	18.802	22.401	19.218	22.609
0.075	27.370	26.685	27.786	26.893	28.202	27.101
0.100	36.355	31.177	36.771	31.385	37.187	31.594

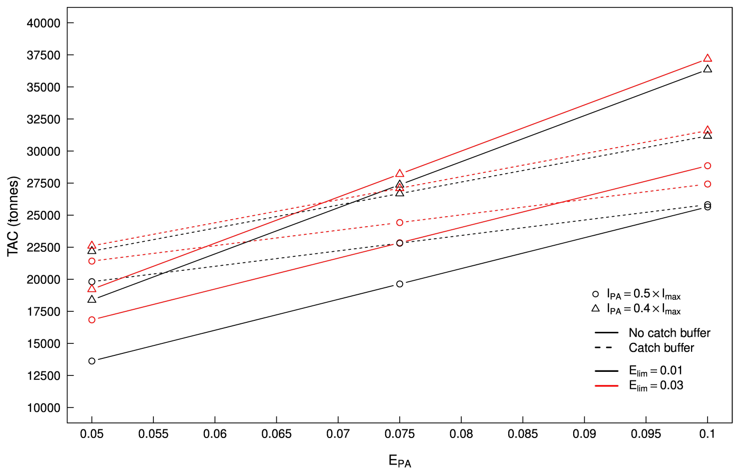


Figure 16: TAC based on various PA scenarios.

9.3 Data Limited Stock (DLS) Approach HCR

Based on ICES Data Limited Stock (DLS) scenario

$$C_{y+1} = C_{y-1} \left(\frac{\sum_{y-1}^{y-x} I/2}{\sum_{y-3}^{y-z} I/3} \right) \tag{24}$$

The question is whether this method can be used with a survey conducted every second year, short time series, and gap in the time series.

9.3.1 From the ICES advice sheet in 2013

For data-limited stocks (DLS) for which a biomass/abundance index is available, ICES uses as harvest control rule an index-adjusted status quo catch. The advice is based on a comparison of the three most recent index values (2009- 2013 as the survey is conducted biennially) with the three preceding values (1999 2003, no surveys conducted in 2005 and 2007), combined with recent catch or landings data. Knowledge about the exploitation status also influences the advised catch.

For this stock the biomass is estimated to have decreased by 40% between the years 1999-2003 (average of three indices) and 2009-2013 (average of three indices). This implies a decrease in catches of at most 40% in relation to the average catch of the last three years, corresponding to a catch of no more than 27,776 t. Additionally, considering that exploitation is unknown, the DLS approach implies that catch should decrease by a further 20% as a precautionary buffer. This results in catch/landings of no more than 22,221 t in 2014. All catches are assumed to be landed. Given the data available and the history of the ICES advice for this stock, there is no basis for ICES to change its previous advice.

10 Conclusion

Survey indices from the international redfish survey show that deep pelagic beaked redfish in the Irminger Sea and adjacent waters has decreased substantially since 2001. The few age readings also indicate that the fishery is on an old population with little recruitment in the past two decades.

In this working document we have explored three HCR for this stock, which no analytical assessment is conducted because of little data. We recommend that the MSY approach to be used for the next 5-10 years, and the PA approac and the DLS approach ignored.

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Material for assessment and Harvest Control Rule for Golden redfish (*Sebastes norvegicus*) - Draft

Kristjn Kristinsson and Hskuldur Bjrnsson
Marine Research Institute, Reykjavk, Iceland
⟨krik@hafro.is⟩ ⟨hoski@hafro.is⟩

Contents

1 Introduction

Golden redfish in East-Greenland, Icelandic, and Faroes waters is considered as on stock and ICES advice is based on that. In recent decades large majority of catches have been taken in Icelandic waters (Figure 3).

This document describes the settings of the gadget model with inclusion of survey data from East–Greenland.

Description of the Gadget model is found in the Stock Annex for the species in the 2013 NWWG report (ICES, 2013) and results of the 2013 run in Chapter 17 in the same report.

Description of the two Icelandic bottom trawl surveys conducted in Icelandic waters and the German bottom trawl survey conducted in East–Greenland waters are found in the Stock Annex for golden redfish in the 2013 NWWG report (ICES, 2013).

2 Age data

Regular age readings of golden redfish have been conducted since 1995 from the commercial catches of the Icelandic bottom trawl fleet and from 1996 from the Icelandic autumn survey. The sampling of otoliths has also been sufficiently extensive to compile catch in numbers and survey abundance by numbers from the Icelandic autumn survey. The age readings have been verified by comparison with other readers. The age reader was also tested by reading samples from unspecified years to check that the knowledge about the dominant yearclasses was not affecting the results.

Data from the Icelandic groundfish surveys (spring and autumn) and also from the deep-water shrimp survey indicate that the 1985 and 1990 yearclasses were much larger than neighbouring cohorts (Figure 1). Age readings also show that these two year classes were dominating in the fisheries from 1994 to 2005.

Catch in numbers plotted on log scale indicates that total mortality, Z, of golden redfish in Icelandic waters has been close to 0.2 since 1995 (Figure 2). Catches have been relatively stable during this period (Figure 3), but fishing effort has decreased in recent decade.

The following Shephard–Nicholson model on catch in numbers 1995–2012 for 10–22

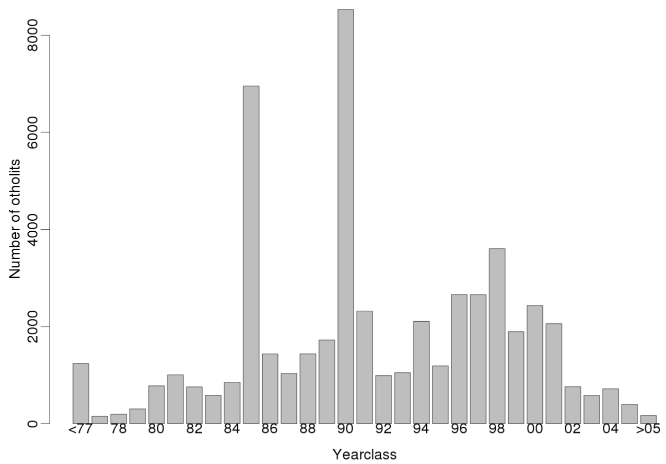

Figure 1: Number of otoliths aged of each cohort from 1995–2012.

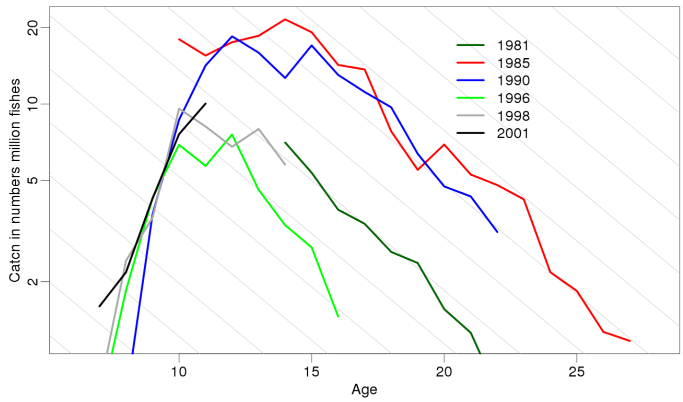

Figure 2: Catch in numbers from Icelandic waters in million fishes. Grey lines correspond to $Z = 0.2$.

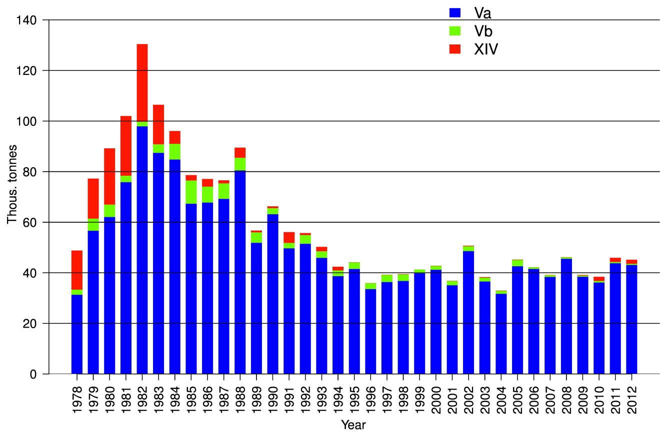

Figure 3: Landings of golden redfish from East-Greenland (XIV), Iceland (Va) and the Faroe Islands (Vb) waters.

year old fish was used to calculate total mortality:

$$\log(C_{ay}) = \delta_{yc} + \log(a) \tag{1}$$

where yc refers to yearclass. The model was fitted by the *glm* function in R statistical package, limited to 15 years and older redfish that is considered fully recruited to the fisheries. The result is $Z = 0.21$. Splitting the data in three periods gives similar estimate for each period.

The Shephard–Nicholson model gives a CV of 0.27. This is a similar value as obtained for 3–9 year old haddock in Icelandic water during the same years. The Icelandic haddock stock is a stock where age reading is not considered to be problematic and yearclass contrast is high.

Age data from the autumn survey gives similar results as the catch in numbers ($Z = 0.21$, Figure 4)

The result is that fishing mortality, F, is low, but how low depends on the value of natural mortality, M. The catch curve analysis only give us information about cohorts that have 18–20 years and older fish as the analysis are confined to fish 15 years and older.

In 2012, the 1985 yearclass still accounted for over 3% of the commercial catches

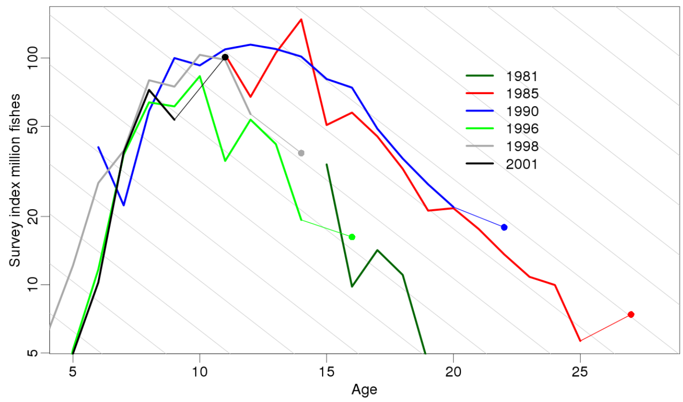

Figure 4: Survey index in numbers in million fishes from the autumn survey. Grey lines correspond to $Z = 0.2$.

and the 1990 yearclass over 8%. From 1997 to 2001 the share of the 1985 yearclass was around 35%, but older cohorts were rather depleted in those years.

Results from stock assessment indicate that L_{50} in the Icelandic commerical fisheries is 33–34 cm and can be seen by looking at the length distributions (Figure 5). The surveys catch smaller fish, but the availability of the the smalles fish (less than 12 cm) to the surveys is little in most years (Figure 5). The fisheries in the Faroe Islands catch larger fish than in Iceland but the fisheries in Greenland both smaller and larger fish (Figure 5).

Looking at the age data, approximately 50% of 10 year old fish is larger than 33 cm, both in the autumn survey and in the commercial catches. The percentage is 11% for age 8, 90% for age 13 and 95% for age 15. The proportion in the stock is of course lower as both the survey and the catches have size rather than age based selection. These

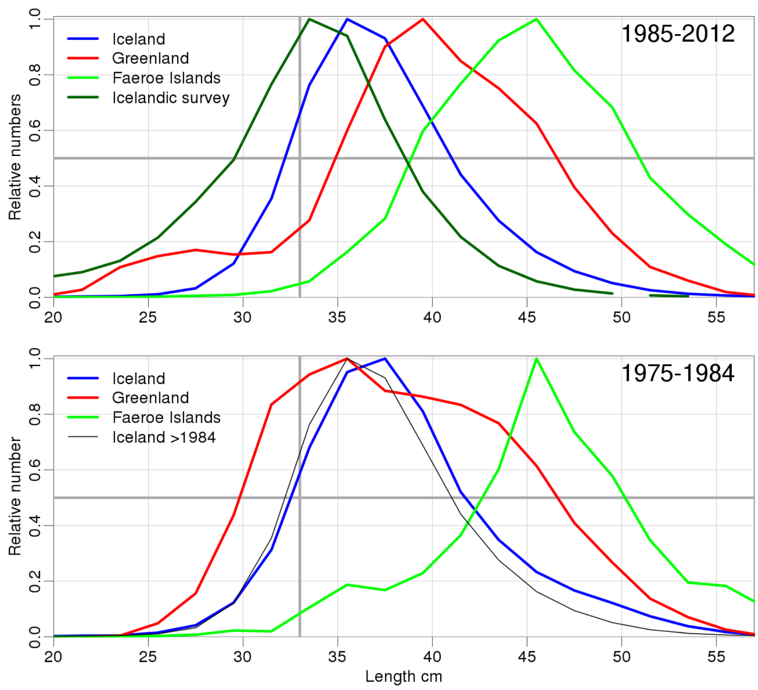

Figure 5: Length distributions from commercial catches in Iceland, Greenland, and the Faroe Islands, and the Icelandic spring survey.

numbers do though confirm that a catch curve analysis for 15 years old fish and older is a reasonable proxy for “fully recruited fish”.

3 Survey data

This section describes survey data in the area Iceland, East Greenland, Faeroes ((Kristinsson et al., 2012)). The Faeroese surveys does only haf a biomass index in ther range 4000-6000 tonnes, only 1-2% of the Icelandic surveys and the series are only available since 1994 and 1996. Therefore the Faeorese surveys are not included in the following combination of surveys in the area, but it might be noted that they show downward trend.

The Icelandic groundfish survey in March commenced in 1985. The index of total biomass (Figure 6) shows a sharp decline from 1985 to 1995, an increase since 1995–2006, and rapid increase from 2008 to 2013. In recent years the index is much higher than in the period 1985–1987 but with considerably higher CV. The Icelandic autumn survey that commenced in 1996, shows similar trend (Figure 6).

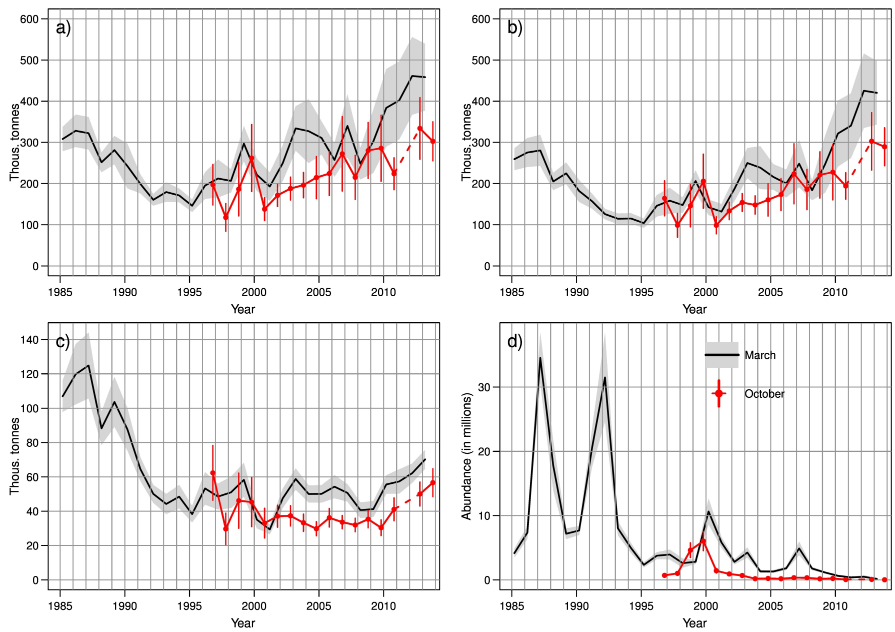

Figure 6: Indices from the Icelandic groundfish surveys. a) Total biomass. b) Biomass 33cm +. c) Biomss 40cm +. d) Abundance 11cm and less.

The German survey conducted off eastern Greenland since 1981, shows rapid increase in the biomass of golden redfish in recent years (Figure 7) and this increase is more than observed in the Icelandic survey. If the German survey is not included in the stock assessment it will lead to underestimation of the stock. As can be seen, the German survey accounts for approximately 18% of the total biomass but there are some reservations about this number depending on how the survey indices are compiled, i.e how large area the survey is considered to represent (see later in this working document).

The Icelandic March survey covers the Icelandic continental shelf down to 400–500 m while the Icelandic autumn survey extends to deeper waters (Figure 8). The autumn survey indicates the distribution of golden redfish is between 0 and 450 m while beaked redfish (*S. mentella*) is from 350 to 800 m (Figure 9). The area between 300 and 600 m is rather small (slopes of the continental shelf) so the the Icelandic March survey, with very dense grid of stations between 0 and 450 m, has good coverage of the golden redfish in Icelandic waters. The area covered is approximately 200 thous. km^2.

The German survey does not cover the East-Greenland continental shelf very well

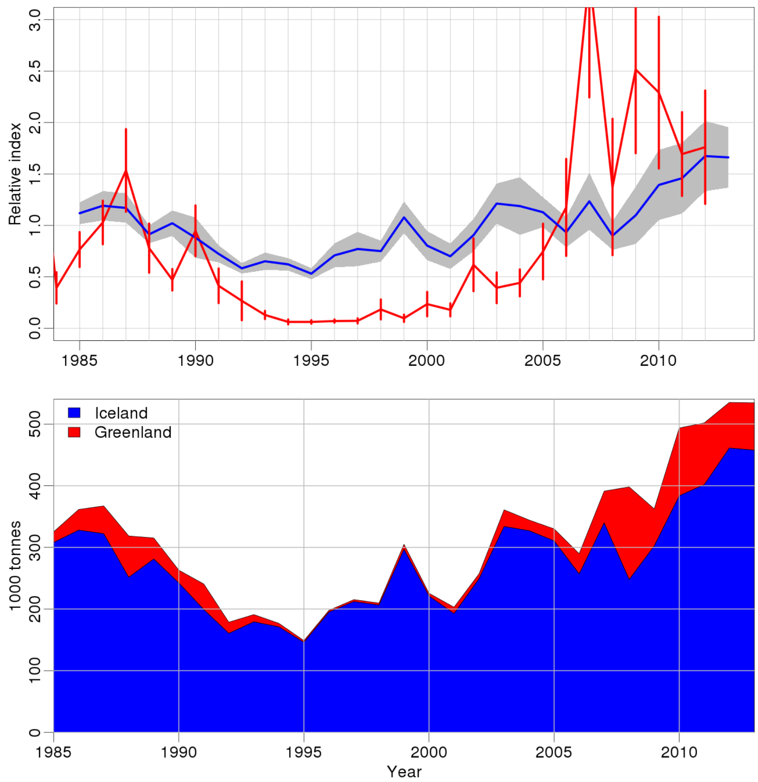

Figure 7: Relative survey indices (upper) and total biomass (lower) from the Icelandic March survey and the German survey in East Greenland waters.

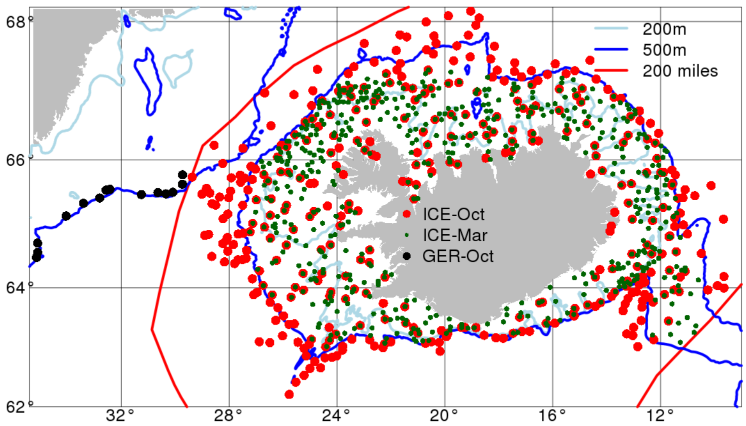

Figure 8: Location of stations in the Icelandic March and October surveys. Stations in the German survey 2012 shown for comparison.

and only the edges of the continental shelf from 150–450 m are covered (Figure 10). Both beaked redfish and golden redfish are caught in the survey, but the survey does not cover the distributional area of the species. Distribution of golden redfish extends closer to shore but deep water redfish in deeper waters. Redfish smaller than 18 cm is not identified to species in the survey.

Length distribution of golden redfish from the German survey (Figure 11) indicate that most of the small redfish found is deep water redfish. This can be seen by the

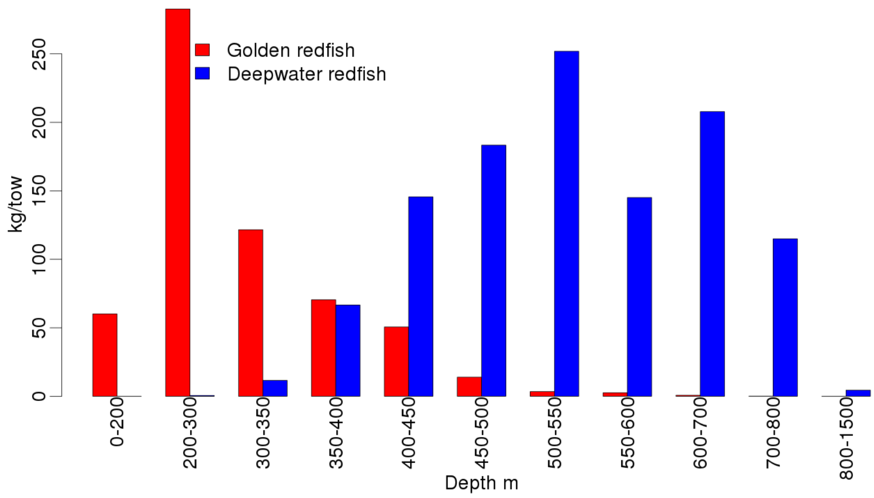

Figure 9: Catch of redfish by species and depth range in the Icelandic autumn survey.

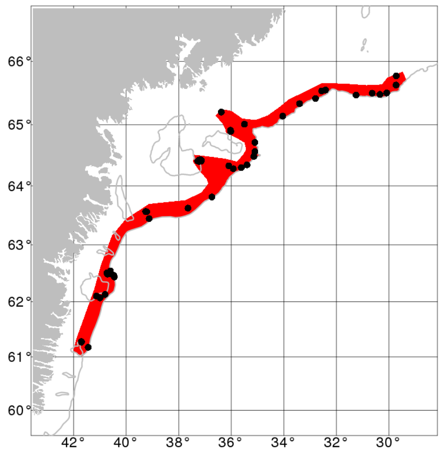

Figure 10: Stations in the German survey 2012. The red area is a candidate area (22,500 km^2) used in compiling indices. Depth contours shown are 200 and 500 m.

sudden drop in numbers between 17 cm juveniles not identified to the species and 19 cm golden redfish. The difference should be deep water redfish but the data for deep water redfish are at the moment not available.

The nursery areas of golden redfish are not covered but they might be in untrawled or untrawlable areas on the Greenland continental shelf. Those areas are most likely rather cold but large quantities of small redfish (5-15 cm) have been found in the deep water shrimp survey in Icelandic waters, in waters between -1– 3°C, while large redfish is not common in those cold waters.

The East Greenlandic continental shelf south of 66°N between 100 and 500 m is around 90,000 km^2. The area used to compile abundance indices from the survey is 45,000 km^2, a rather large area when looking at the coverage of the survey. A region to use in compilation of survey indices is shown (Figure 10). The size of the region is 22,500 km^2. Outer boundary of the region follows the 500 m contour while the inner boundary is more *ad-hoc*. As mentioned earlier results from the Icelandic autumn survey

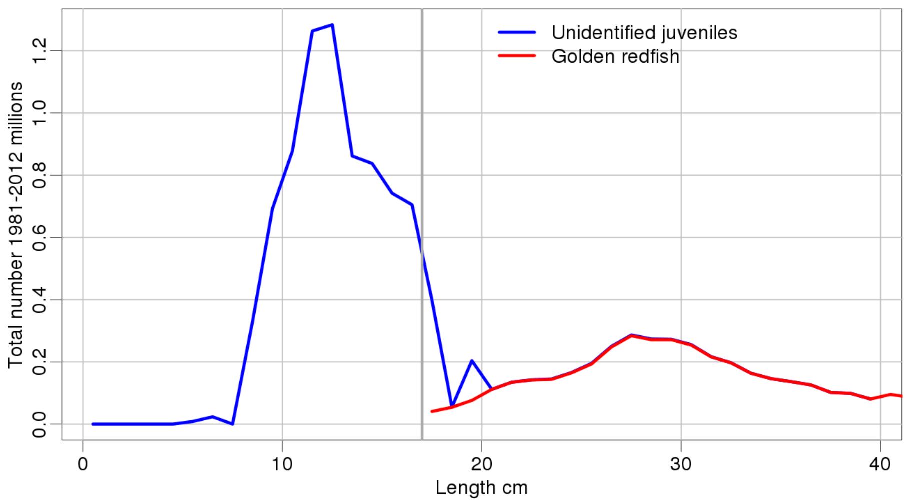

Figure 11: Total number of unidentified redfish 18 cm and smaller and golden redfish larger than 18 cm in the German survey of East Greenland.

indicate that golden redfish is not common below 500 m depth. Using larger areas in compilation of survey indices leads to substantial extrapolation to areas not covered by the survey. Redfish might inhabit those areas, but they are most likely nursery areas. Combining the Icelandic March survey and the German survey in East Greenland show the relatively large areas are missing, both in shallow waters off eastern Greenland and even in the area north of 66°N on the Greenland continental shelf (Figure 12).

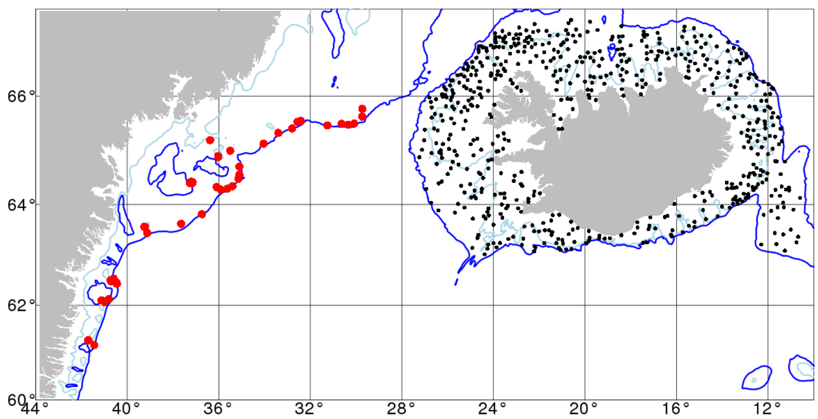

Figure 12: Location of stations in the Icelandic March survey 2013 and the German October survey 2012.

4 Compiling combined survey index for golden redfish in Iceland and East Greenland

Assessment of golden redfish has in recent years been based on length disaggregated abundance indices from the Icelandic groundfish surveys in March that are available since 1985. The German survey in East Greenland has been conducted since 1981 but the coverage is poor in some years, especially in 1992 and 1994 when only 6 stations were done for each year. Abundance was very low in this period (Figure 7), so the lack of coverage in those years does not matter. In the last two decades the average number of stations has been around 40, compared to 560 stations for the Icelandic March survey. The total area used for the Icelandic March survey is around 200 thous. km^2, so an area of 14 thous. km in East Greenland waters should be used to get comparable density of stations.

The Icelandic data are converted to abundance by assuming 17 m width of the survey trawl. Also diurnal variability is taken into account and the results calibrated to the average of day and night but the survey is conducted 24 hours per day. Results from the German survey are converted to abundance per km^2 by assuming 22 m width of the survey trawl but not correcting for time of day as the German survey is only conducted during the day.

The Icelandic indices are compiled using stratified mean as described in Stock Annex for the species in ICES (2013). The Greenland indices are compiled taking the average over the abundance/km at the stations multiplying by $\frac{22}{16}$ to account for different trawl width in the surveys and then by the survey area.

The German survey in Greenland waters is conducted in the autumn (September–October) or 5–6 months later than the Icelandic March survey. The German survey in year y is added to the Icelandic March survey in the year $y+1$ or the year after. During this period of 5–6 months between the surveys, the fish grows and also it might migrate between areas. The former problem is taken care of by adding 1 cm to the length of all fish caught in the German survey but the latter problem is not considered specifically.

Using an area coverage of 45,000 km^2 of the German survey in Greenland waters, which has been used in the survey compilation of the data, leads to the Greenland survey accounting for 18% of the total biomass (Figure 7).

The size distribution in the German survey is quite different from the Icelandic survey (Figure 13). Relatively little part of 33–40 cm fish is found in East Greenland waters while more than 50% of the large fish (43 cm and larger) has often been observed near Greenland. The signal for the small fish contains much noise. As described earlier the German survey does not seem to cover the nursery areas of golden redfish.

The large proportion of large fish in East Greenland waters is in line with what has been observed earlier in the commercial catches (Figure 5). In recent years, the lack of large fish in Icelandic waters compared to what has been seen of intermediate size fish few years earlier has lead to lower estimated stock. Inclusion of survey data from East Greenland might lead to more increase in estimated stock size than what would be obtained by the percent increase in survey biomass **(er ekki alveg a skilja etta).**

Inherent in the combination of data from Greenland and Iceland is therefore migration of redfish between Iceland and Greenland when it becomes large **(???)**. This theory has not been veryfied or supported by for example tagging.

The Icelandic autumn survey can also be used in the assessement, but the time series is still relatively short for redfish (long lived where it may take one yearclass up to 40 years to go through the fishery) and there are questions if the survey will be continued

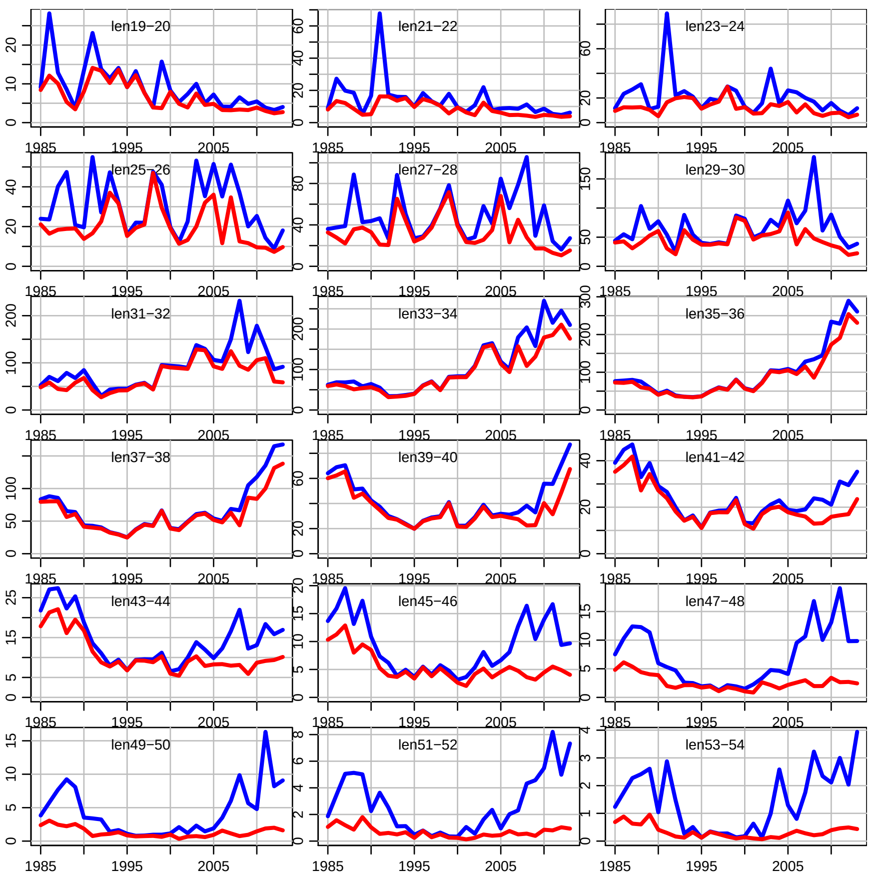

Figure 13: Survey indices from the Icelandic March survey and the German survey in East Greenlandic waters by length. The red line shows the results from Iceland, the blue line the sum.

(the survey will be conducted in 2014).

Combining the Icelandic autumn survey and the German autumn survey is another option. The disadvantage is shorter timeseries of the Icelandic autumn survey compared to the Icelandic March survey, fewer stations taken in the autumn survey compared to the March survey, and uncertinty about future of the autumn survey (the survey will be conducted in 2014). The advantage is contemporary surveys, something that matters if seasonal migrations between the areas are suspected.

5 Assessment

This section is not finished but mostly be an update of what was presented at the annual science conference last year. Hope

Assessment has been done for golden redfish in Icelandic waters since 1999 using the length based Gadget model (Bjrnsson and Sigursson, 2003). The assessment has not been approved by ICES as basis for advice although it has been used for comparison when formulating advice. Results from the Gadget assessment have been relatively consistent (Figure ??) but the model settings have changed through time.

In the Gadget model for redfish the following data is used:

- Catch data from Iceland, Greenland and the Faeroe Island;
- length disgaggregated survey index from the Icelandic groundfish survey in March;
- length disgaggregated survey index from the German groundfish survey in October (btti vi);
- length distributions from catches in Iceland, Greenland and the Faroe Islands;
- age length keys and mean length at age from the Icelandic autumn survey since 1996 and catches since 1995.

The difference in the setting presented here compared to the assessment in 2013 is that data from the German survey conducted on the continental shelf of East Greenland has been added.

Growth of the redfish is modelled by the von Bertalanffy growht function. Selection of the fishing fleet in the model is size based rather than age based so the fleet targets the largest individuals of recruiting age groups, reducing mean at age in the population. Natural mortality, M, used is low or 0.05. The "correct" natural mortality is not known, but it is at least well below 0.2 for the fish kept by the fisheries where $Z = 0.2$. Low M and size based model lead to relatively conservative value of F_{max} that can possibly be used as a target F in assessment using the same low M. Using higher M will change the problem of appropriate F_{target} to a precautionary evaluation. But the main point is that the assessment is a tool to generate useful advice rather than presenting the truth about amount of redfish in the area.

The Gadget assessment was originally tuned with length disaggregated from 5–50 cm, but 5–10 cm redfish was very abundant in Icelandic waters from 1987–1994 and the large cohorts identified in the surveys (1985 and 1990 year classes) were also identified by the age readings as the most imortant in fisheries and surveys 7–20 years later. The 1996–2001 year classes were much less abundant (figure 6d) while assessment indicate that each of them is close to 50% of the 1985 and 1990 yearclasses. Therefore it seems likely that only small part of recent recruits originate from Icelandic waters. The trend in recent assessments settings has therefore been to gradually exclude smaller fish in the tuning. In 2012 and 2013 assessments, 24 cm and smaller fish was excluded from the tuning fleet. The fishes grow 2–3 cm per year. Golden redfish recruit to the fisheries at the size of about 30 cm and last in the fisheries for more than 10 years, so lack of recruitment data is not considered a major problem, having them would though be desirable if looking more than 2-3 years ahead. Figure 14 is based on average recruitment after the 2005 yearclass that is the last one estimated. Effect of recruitment assumption will be explored in the section on short term prognosis. Work on getting better idea on recruitment (exploration of the Greenland continental shelf) should be started.

Another problem observed in recent assessment is the lack of large redfish (larger than 40 cm) in the survey compared to what the model predicts (Figure 17). Two plausible explanations have been proposed:

1. The Icelandic surveys have been overestimating the abundance of 30–38cm redfish in recent years. Few tows with large abundance of redfish account for most of the total biomass index. Fishing mortality is much lower than it was from 1985–1989 and large areas west of Iceland is closed for fishing. This allows fish to aggregate in dense schools. The question is if "catchability" in those dense schools is comparable to less dense schools observed in the late 1980's.

2. Length at maturity has decreased in recent years. This could possibly reduce L_{inf} and therefore the number of fishes that reach 40 cm and larger.

3. Reduced fishing effort and larger protected area has lead to increased survival of small redfish, that might be sensitive to mesh penetration.

With inclusion of the Greenland survey, alternative assessment extending the size range of the survey down to 19 cm was also investigated but redfish larger than 18 cm is identified to species in the German survey.

The original idea with the inclusion of the German survey was that the survey covered the nursery areas of the golden redfish. As seen in previous section (Figures 11 and 13) the German survey does not give much additional information on recruitment. The index of large redfish (40 cm and larger) is on the other hand similar or higher than in Icelandic waters and has increased rapidly since 2005. Index of total biomass from the German survey has also increased (Figure 7) and is now close to 20% of the total biomass index for the East Greenland–Iceland area (when the calculations of the index is based on an area of 45 thous. km^2.

The alternative model runs in addition with the 2013 run are presented below. In all cases the indices are length disaggregated in 2 cm intervals.

1. Indices from the Icelandic March survey and the German survey in East Greenland scaled to 45,000 km^2 added. Size of fish included 19-54 cm.

2. Indices from the Icelandic March survey and the German survey in East Greenland scaled to 22,500 km^2 added. Size of fish included 25-54 cm.

3. Indices from the Icelandic March survey and the German survey in East Greenland scaled to 22,500 km^2 added. Size of fish included 19-54 cm.

4. Indices from the Icelandic March survey. Size of fish included 25-54 cm.

5. Settings used last spring. Similar to alternative 4 but changes in growth not allowed.

6. Indices from the Icelandic Autumn survey and the German survey in East Greenland scaled to 22,500 km^2 added. Size of fish included 19-54 cm. Time range of tuning series 1996-2012 but contemporary surveys added.

Inclusion of the German survey has a large effect on results of the assessment (Figure 14). The spawning stock in 2013 was estimated around 400 thous. tonnes if the the Greenland survey scaled to 45,000 km^2 is used compared to 265 thous. tonnes if only the Icelandic survey is used. Using the Greenland survey scaled to 50% of the full area

(Figure 10) leads to results in between and could be argued to be the area covered by the survey. Using a larger area leads to extrapolation to areas not covered by the survey. Redfish is most likely to be found in those areas but has not been measured. The difference between last years assessment and the assessment using only the Icelandic survey is estimation of different length at recruitment of cohorts 1996 and later, that are estimated to be 2 cm larger at age 5 than earlier cohorts. Also what is presented here as last years assessment is a reweighted version of it that reduced inference about stock size somewhat.

Another aspect is that the number of stations in the German survey is only around 40 and scaling them to an area of 45,000 km^2 increases noise, as the area covered by each station increases.

Selecting the weight of the German survey based on the objective function does not help (Figure 15). Ignoring the German survey minimizes the objective function, but that is not the correct way. This problem is also seen in analytical retrospective pattern (Figures 21 vs. 22. The run including the Greenland survey has much more apparent pattern in the retro analysis and higher variability. This pattern might partly be caused by the inclusion of smaller fish (19-24cm) that has been below predictions in recent years. The run utilizing the German survey does on the other hand follow trends in survey biomass better (Figure 16) though it is below predictions.

There is lot of variability in the data from Greenland and there is no age data available, but the age structure there does not need to be identical to what is observed in Icelandic waters. Increasing number of stations and expanding the survey is of course the obvious solution, but expensive and difficult to implement as the knowledge of trawlable areas on the Greenland continental shelf is limited and redfish is not limited to trawlable area.

Inclusion of the German survey does not change the residual pattern much. There is still the problem of too low survey biomass in recent years (Figure 16) and positive blocks for medium size redfish and negative for larger redfish (Figure 17.) The problem with the survey biomass is though somewhat reduced compared to the run based only on the Icelandic March survey.

Looking at individual runs in the reweighting operations shows that the age and length distribution in the catches indicates stable stock while the surveys indicate increase (Figures 18 and 19) - Size and age distribution of the catches does on the other hand control historical stock size.

The suggestion is to use run 3 (Figure 14) as basis for advice in next until next benchmark. In this setting the German survey is weighted to the area covered by the survey (Figure 10) which is about half the “official” area This is a precautionary measure and does not include any inference about the proportion of the stock in Greenland waters, at least the recruitment areas are unknown and difficult to imagine other location than areas on the Greenland continental shelf not covered by the survey. The suggested assessment setup is based on using survey data for 17 cm and larger fish. Survey residuals from this run are shown in Figure 20 showing relatively poor fit of the smallest fish to indices.

The problem is apparent from the analytical retrospective pattern (Figure 21). The retros are based on reweighting of the likelihood each year. There is a change in historical stock size when more data are added, more otoliths are added and the weight of different likelihood components changes. The retrospective pattern shown ends in the beginning of the advisory year and is reflective of uncertainty in advice given based on the model.

Looking at the spawning stock as proportion of SSB_{1980} a negative bias can be seen for more than a decade. This "long term" behaviour is possible when cohorts last in the stock for 15–20 years.

The retrospective patterns show that model results do not change much between years as expected when fishing mortality is low and old data depreciate slowly. This is a desirable property in management but can in some cases be dangerous as if variability in M and other biological parameters were put in data would depreciate faster. The main point is though that no additional stabilisation should be put in a proposed havrvest control rule as discussed in next section.

One thing that does not change much from one run to another is the selection of the Icelandic fisheries (Figure 23). This is to be expected as the length distribution of the fisheries has remained very similar (at least the left end) for the last 2-3 decades, even though the age structure has been changing. This observation is one of the reasons for using a size based model.

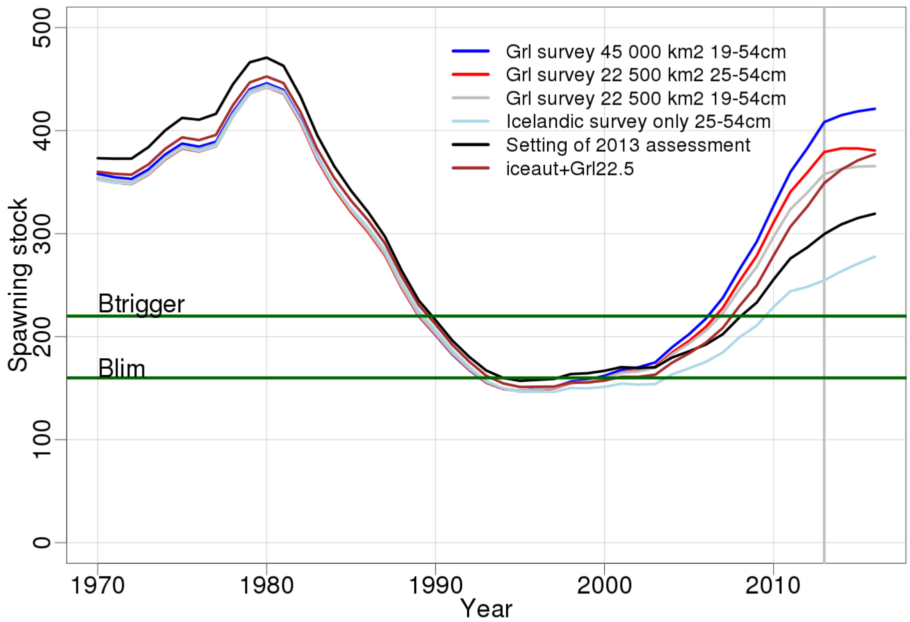

Figure 14: Spawning stock as estimate by equation 2. The difference between different runs is described in the list above.

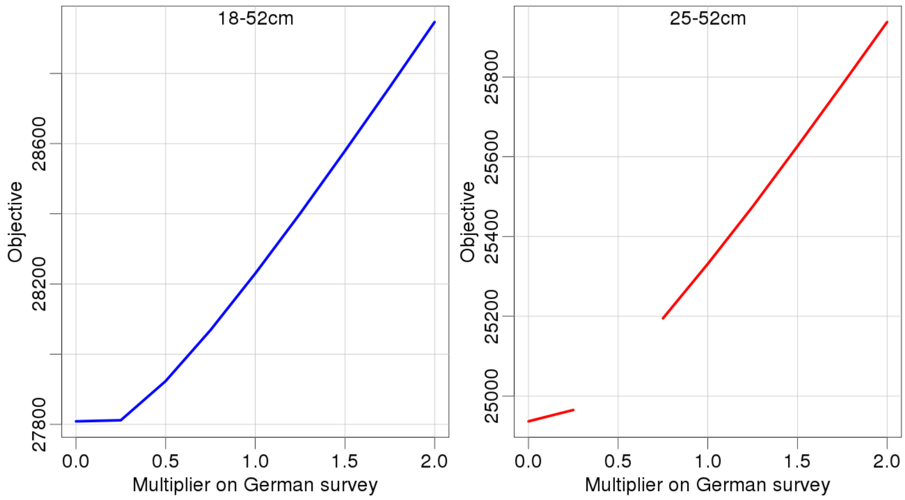

Figure 15: Value of the objective function against the multiplier on the German survey (multiplier of 1 means 45,000 km^2.

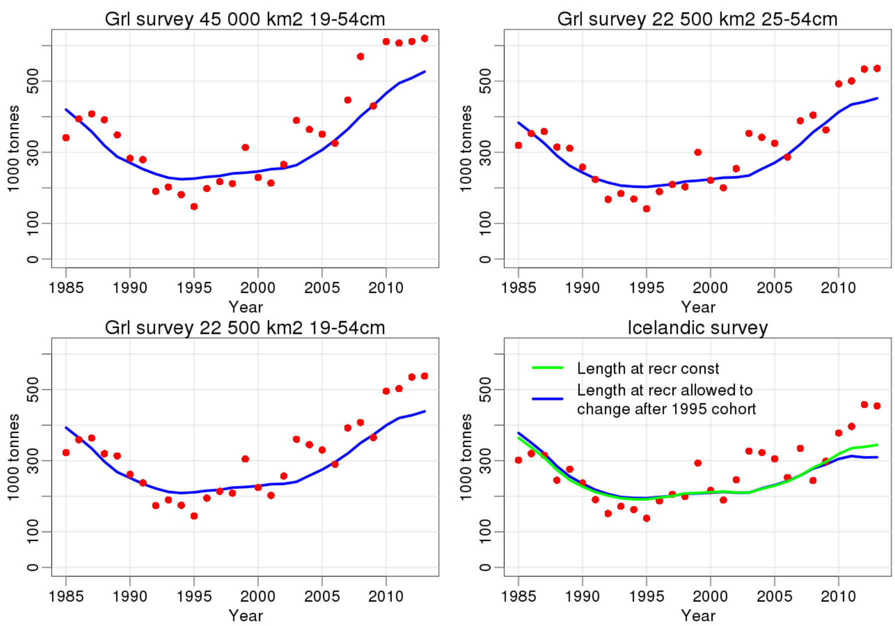

Figure 16: Observed and predicted survey biomass different runs. See figure 14 for meaning of labels.

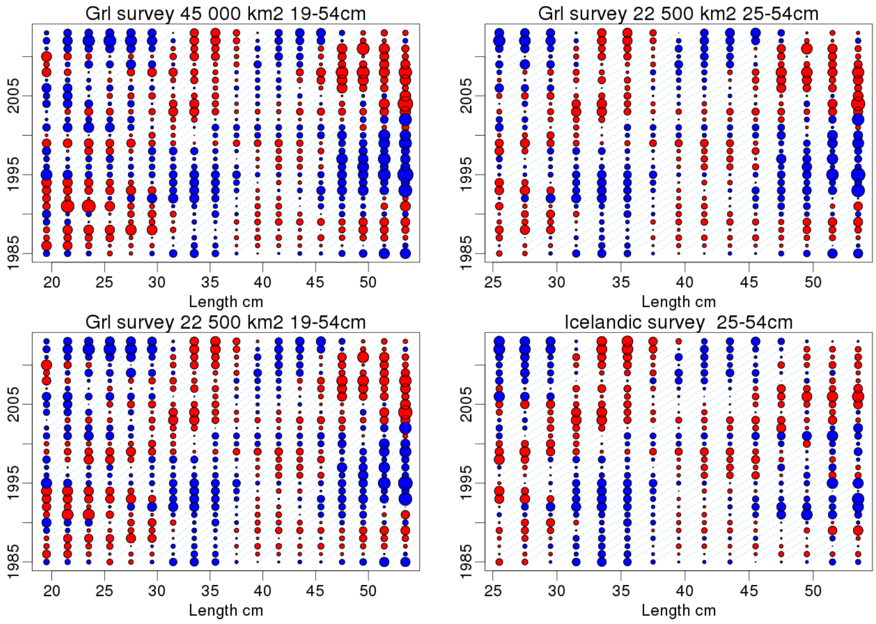

Figure 17: Survey residuals from the different runs. See figure 14 for meaning of labels.

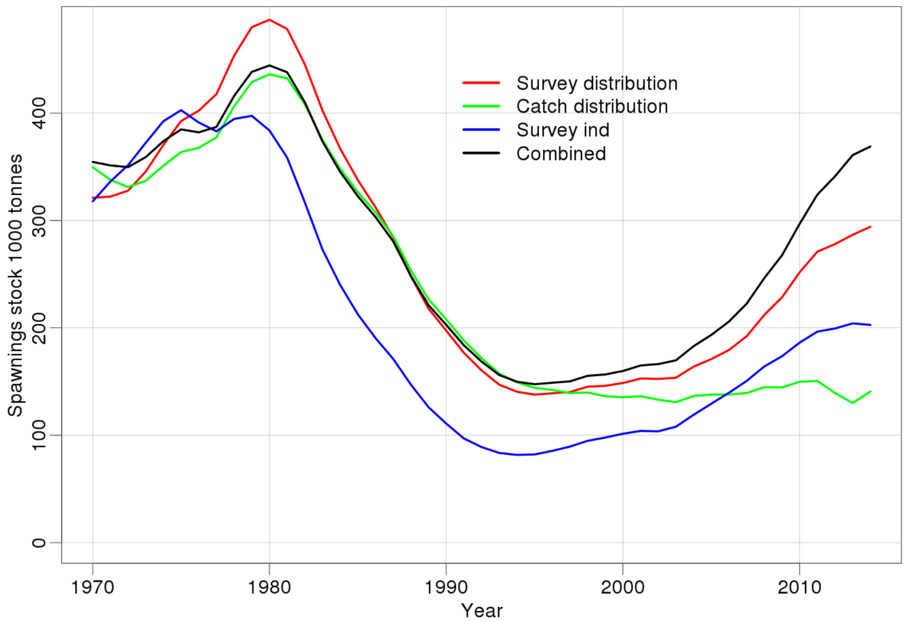

Figure 18: Development of spawning stock when various components are overweighted in run number 3. See figure 14 for meaning of labels.

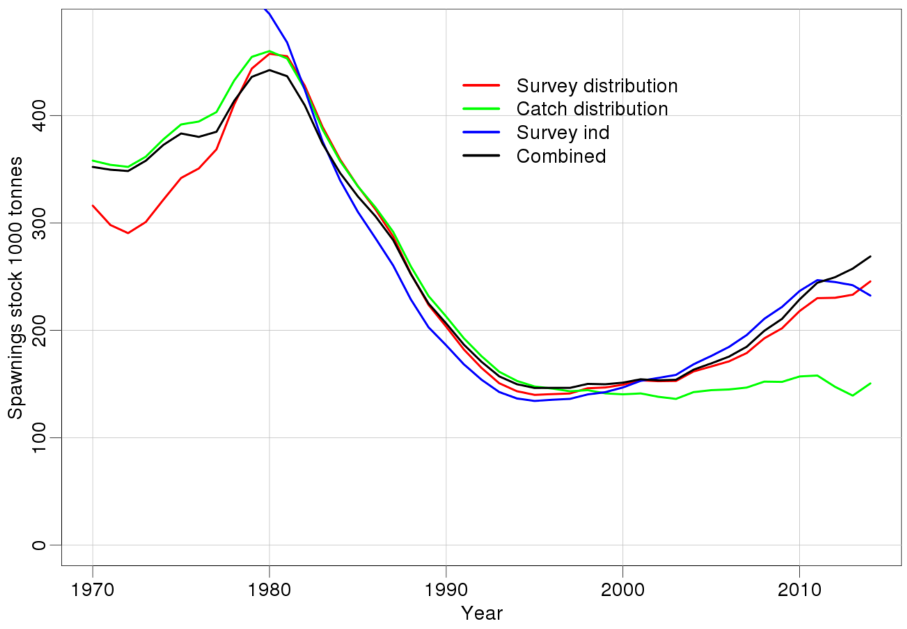

Figure 19: Development of spawning stock when various components are overweighted in run number r using Icelandic March survey for tuning. See figure 14 for meaning of labels.

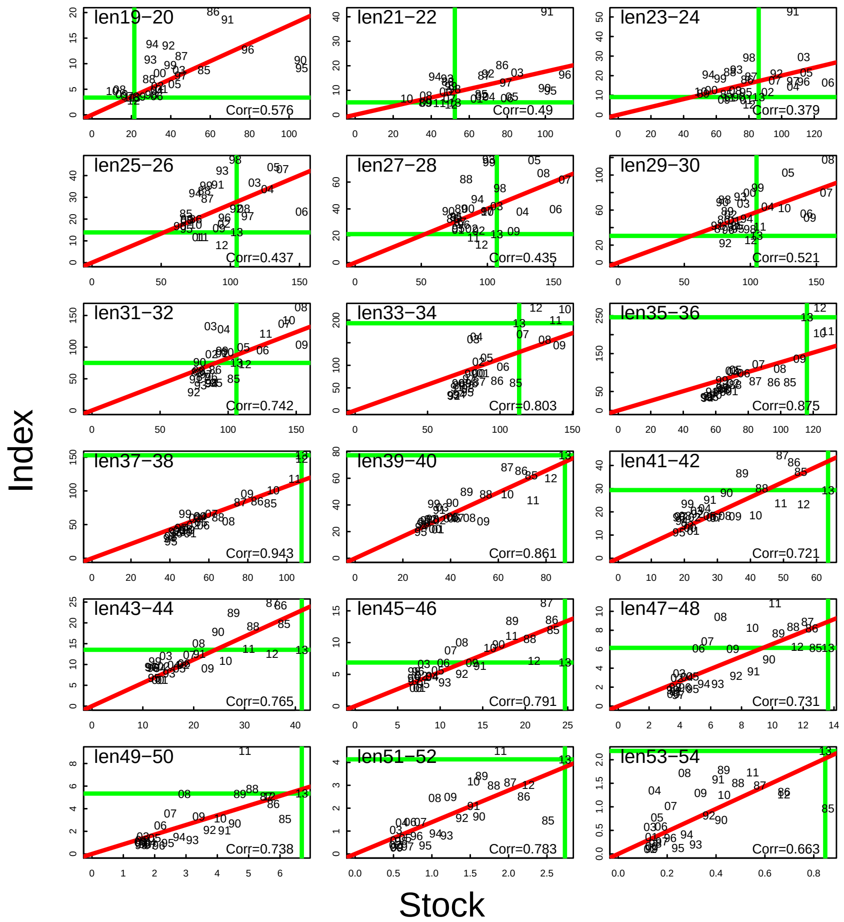

Figure 20: Fit between model and survey indices using the model settings suggested for the next years.

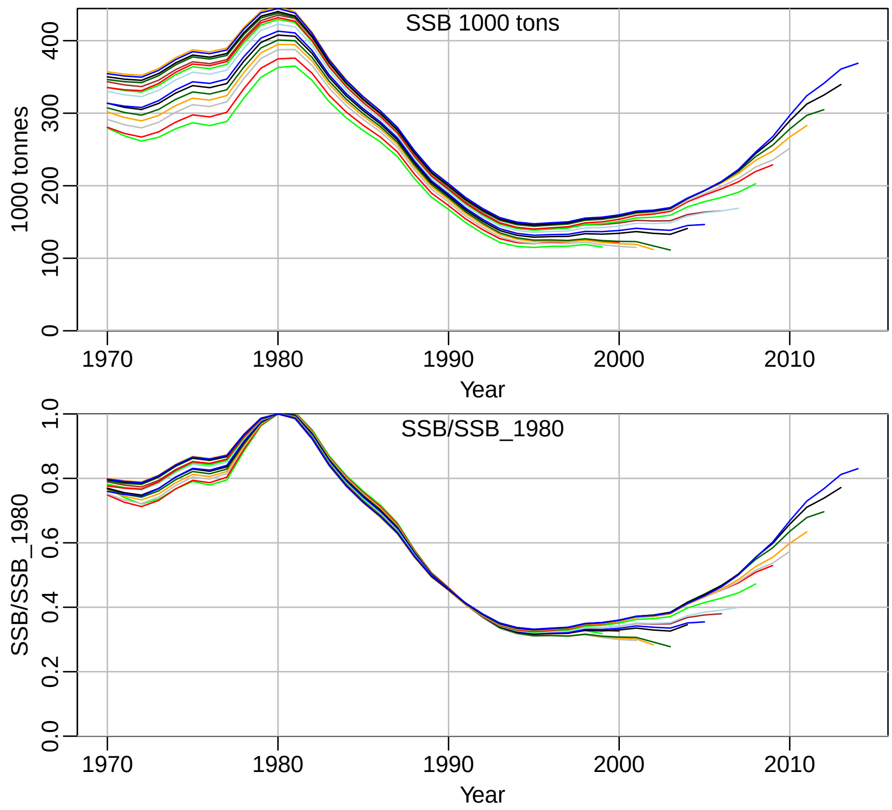

Figure 21: Retrospective pattern of the spawning stock in run 3, ((figure 14). Each retro ends a year after the assessment year.

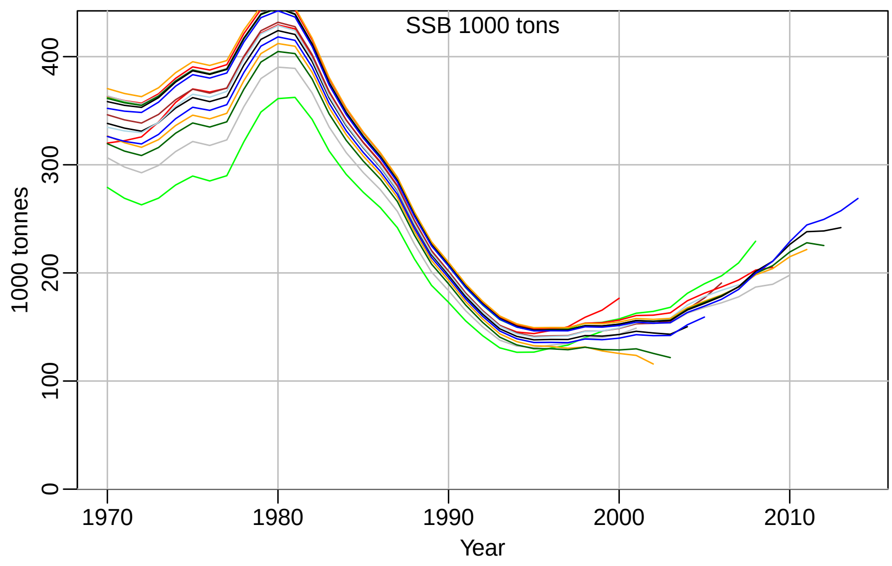

Figure 22: Retrospective pattern of the spawning stock in run 4 tuned only with the Icelandic survey (figure 14). Each retro ends a year after the assessment year.

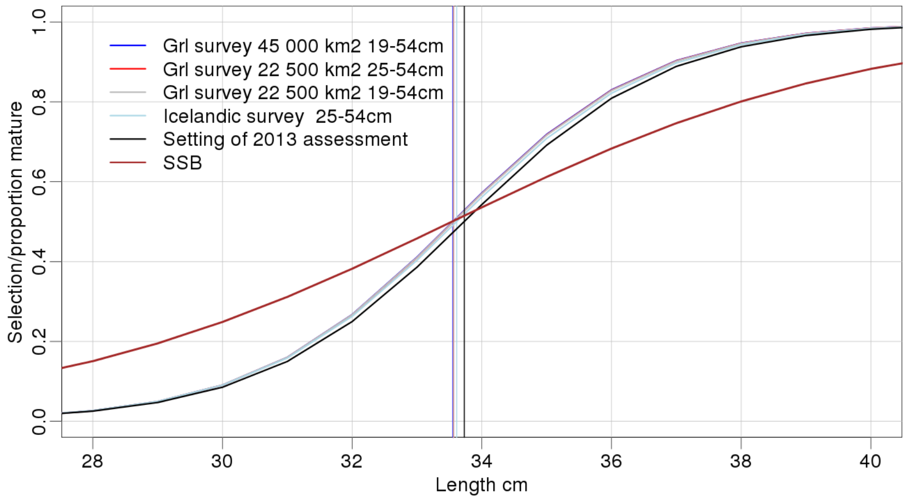

Figure 23: Estimated selection pattern from the runs shown in figure 14. Maturity ogive used to compile SSB shown for comparison).

6 Harvest Control Rule

The section presented here is not quite finished but the material will be and update of what was presented at the annual science conference last year. (http://community.ices.dk/ExpertGroups/WKRED2014/Evaluation%20of%20a%20proposed%20HCR%20 The update is mostly to take into account new assessment presented in last section.

The proposed Harvest Control to be evaluated is $F_{9-19} = 0.097max(\frac{SSB_y}{220}, 1)$ where the spawning stock is compiled base on the maturity curve

$$P_L = \frac{1}{1 + e^{-0.3122(L-33.54)}} \tag{2}$$

B_{lim} is defined as B_{loss} or 160 thous. tonnes and $B_{trigger}$ as 220 thous. tonnes.

This maturity ogive was defined around 2005 and has been used since then. Length at maturity has on the other hand been decreasing in recent years (Figures 27 and 23) so the spawning stock is larger than obtained using the maturity ogive defined by Equation 2. The observed reduction in size when the fish becomes mature could be real, for example caused by increased temperature in the ocean. It might also be an artifact of fish growing up outside the Icelandic continental shelf (Greenland), migrating over when mature.

The F_{target} proposed in the harvest control rule was F_{max} from yield per recruit calculations done in 2012. (Figure 24). F_{max} is generally not used as a target. The Gadget model takes into account that the largest individuals of recruiting cohorts are removed by the fisheries, reducing the mean weight of the survivors, leading to lower estimated F_{max} than obtained from standard age based models. The M used here is also relatively low (0.05) leading to relatively conservative estimate of F_{max}.

As mentioned in last section recent observation have indicated that size at age for small redfish has been increasing. This is taken into account in the Gadget model by estimating length at recruitment (age 5) sepereately for cohorts 1996 and later. The result is an increase of 2.5cm in estimated length at recruitment after 2005leading to **higher age based F for the same size based F** (figure 24. $F_{9-19} = 0.097$ is therefore below F_{max} with the increased growth. Both with the current settings and the 2012 settings maximum yield occurrs at F of fully recruited fish around 0.15 but $F_{max,9-19} = 0.116$ with the current settings compared to 0.097 2012. To get $F_{9-19} = 0.097$ with the current settings F of fully recruited fish has to be reduced from 0.15 to 0.127, 15% reduction in F as selection by size has not changed much (23.

Golden redfish is more than 10 years old when estimation of the size of yearclasses is known. Regular agereadings started in 1996 so basing the analysis on cohorts before 1975-1980 is questionable. Therefore investiation of spawningstock-recruitment relationship is based on cohorts 1975-2003, short period for this fish.

No relationship between SSB and recruitment is observed from the relatively short available time series (figure 25. Therefore SSB_{loss} is proposed as candidate for B_{lim}. In the request SSB_{loss} is 160. tonnes, the value obtained in 2012, but the current estimate is 150 thous. tonnes. It has to be evaluated if B_{lim} should be floating defined as B_{loss} or at a fixed value. Using a fixed value (160 kt) is fine execpt large changes in the assessement procedure occurr. Also with the recent changes in length at maturity B_{lim} is not a measure of the spawning stock but following the changes observed in size at maturity questionable for this purpose and the “spawning stock” will be based on the ogive shown in figure 23.

Looking at the recruitment as a timeseries (figure 26 no autocorrelation is observed.

Therefore in stochastic simulations recruitment is drawn randomly from observed recruitment. Recruitment of less than 10 years haver relatively small effect for this stock where yearclasses last 15 years in the fishery. Longer periods do on the other hand matter but the dataseries are not long enough for evaluation of long term variability in recruitment.

Assessment error is an important factor that needs to be included in stochastic simulations. Analysis based on TSA and the autumn survey indicated that uncertainty in stock size in the beginning of the assessment year was around 20% (25% in the advisory year). Analytical retros (figures 21 and 22) show long term patterns, especially the retro including the Greenland survey. The magnitude of the assesment error is on the other not very high.

Another measure of the uncertainty in the advice is to look at the difference between models 3 (Iceland +Greenland) and 4 (Iceland only). The advice in 2014 obtained by model 3 is 49 thous tonnes that would lead to $F_{9-19} = 0.14$ if model 4 (Icelandic surveys only for tuning) was the truth.

The approach taken here was not to pretend that we have a good estimate of the assessment error but rather investigate the level of assessment error that the HCR could sustain. Assessment error was modelled as autocorrelated lognormal with $\rho = 0.9$ and $CV = 0.3$, substantial error with long periods of over and underestimation (figure 28. Lognormal distribution with $CV = 0.3$ lead also to a bias of 0.045. The relatively high autocorrelation of the assessment error means that even though uncertainty is high the interannual variability is relatively small.

The simulations did not include the trigger action when the spawning stock goes below 220 thous. tonnes. This action is onesided and can happen when $SSB > B_{trigger}$ due to assessment error, that also causes the action not to be guaranteed when $SSB < B_{trigger}$. The trigger does therefore cause reduced average fishing mortality.

The fifth percentile of the spawning stock are 240% thous. tons (figure 29 and the first percentile 202 thous. tonnes. The risk of being below $B_{trigger}$ and B_{lim} is therefore low.

Doing the same analysis based on the run tuned with the Icelandic survey only leads to similar results. Recruitment from most yearclasses but the most recent is similar so the spawning stock is similar, the fifth percentile is 223 thous. tonnes and the first percentile 180 thous. tonnes. (Figure 33). The problem is that if this setup decribes the stock, assessment using the Greenland survey leads to consistent overestimation of the stock.

Uncertainty is estimation of stock size could become a problem when approaching $B_{trigger}$, but 10% change in estimated stocksize when below $B_{trigger}$ will lead 20 over 20% change in advice. Current formulation leads to 15% reduction in $Fishingmortalitybysize$ so even though $B_{trigger}$ was reduced to B_{loss} the Harvest Control Rule would be more precautionary than the rule proposed in 2012.

Another change that might be done was to change to length based references, like proportion of spawning stock or proportion of catchable biomass as based on estimated selection curve (figure 23) with the proportion selected to make $F_{9-19} = 0.097$ based on current settings.

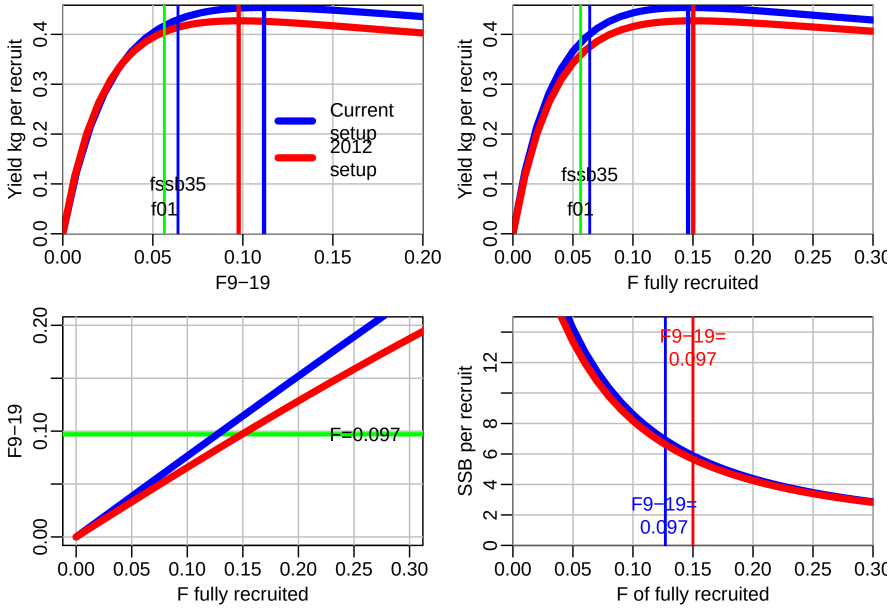

Figure 24: Yield per recruit as function of average fishing mortality of 9-19 years old fish, yield per recruit as function of fishing mortality of fully recruited fish, relationship between fishing mortality of fully recruited fish and F_{9-19} and Spawning stock per recruit as function of fishing mortality. The blue curves are based on run 3 (selected base run) but red on 2012 settings

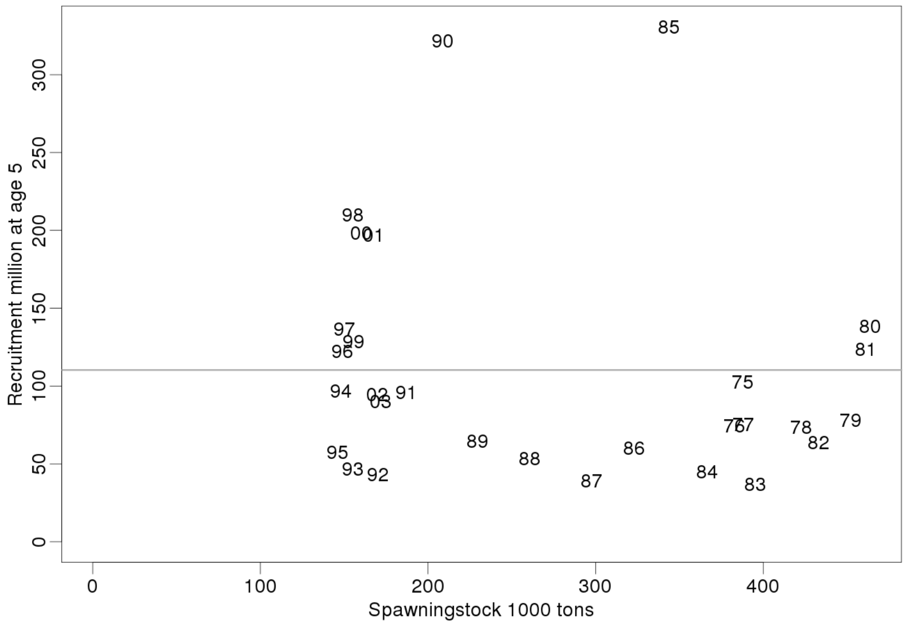

Figure 25: Recruitment as function of spawning stock based on run 3. The labels show yearclasses

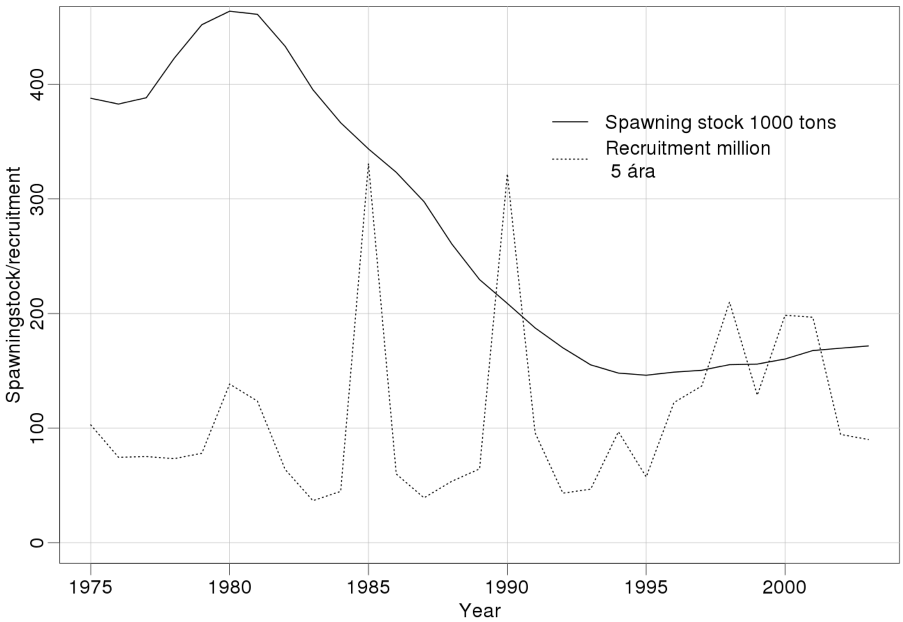

Figure 26: Recruitment and spawning stock as function of time based on run 3

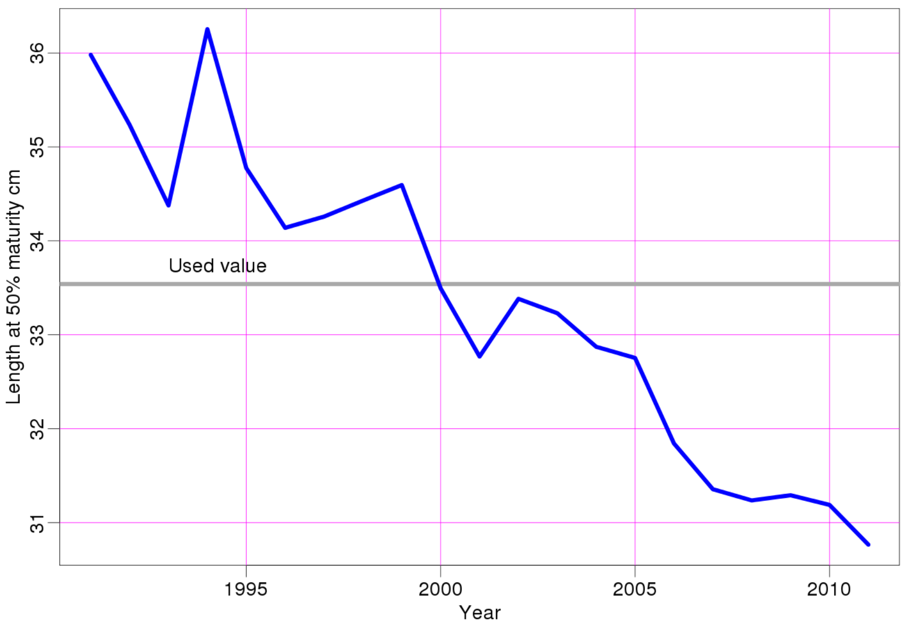

Figure 27: Development of length where 50% of redfish is identified as mature. L_{50} in the curve used (equation 2) shown for comparison.

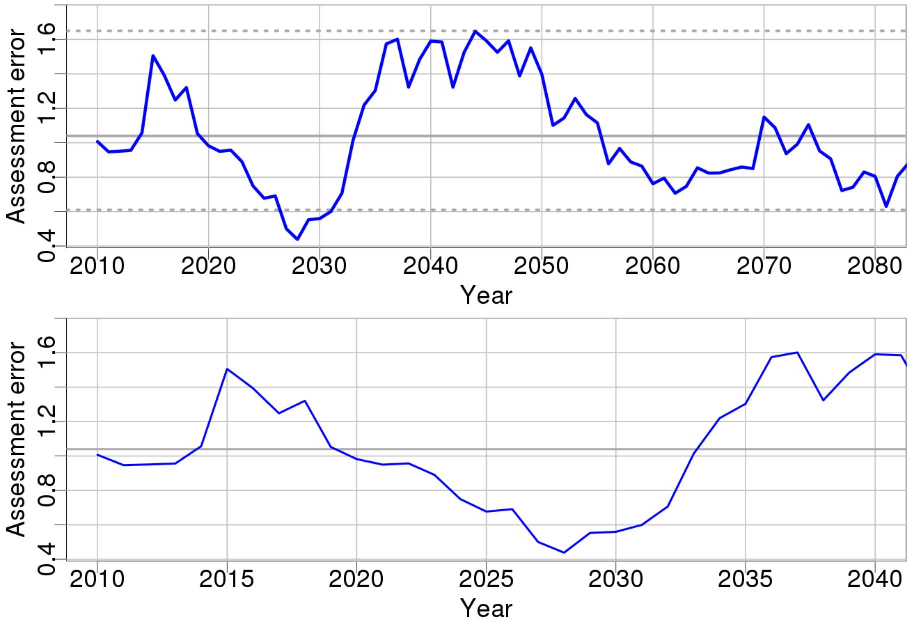

Figure 28: One relisation of the Assessment error used in the stochastic predictions. The dashed lines show 5th and 95th percentile.

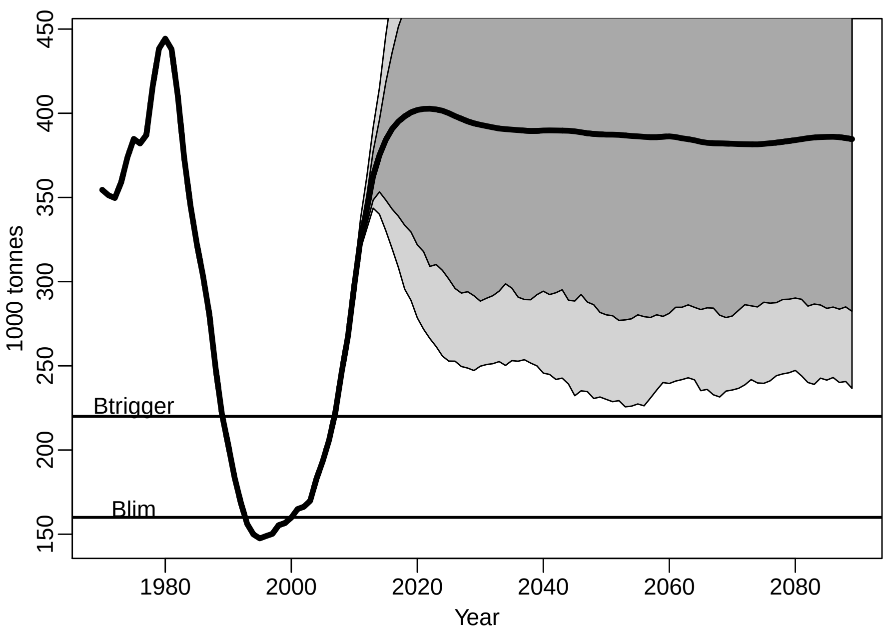

Figure 29: Development of the spawning stock according to run 3 (survey from Iceland and Greenland) if advice is given based on $F_{9_1 9} = 0.097$ The light grey area shows fifth and 95th quantile and the dark areas 16th and 84th quantile

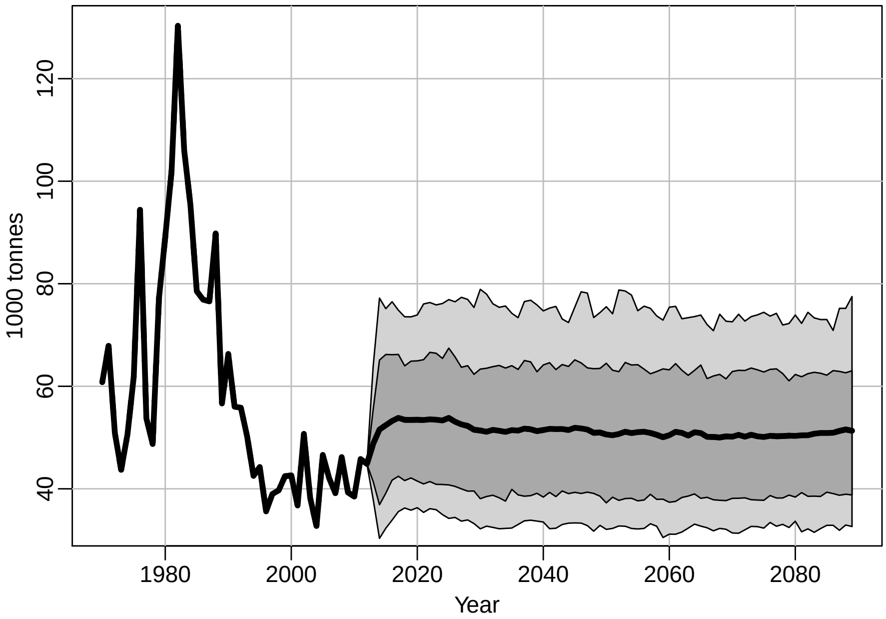

Figure 30: Development of the catches according to run 3 (survey from Iceland and Greenland) if advice is given based on $F_{9_19} = 0.097$ The light grey area shows fifth and 95th quantile and the dark areas 16th and 84th quantile

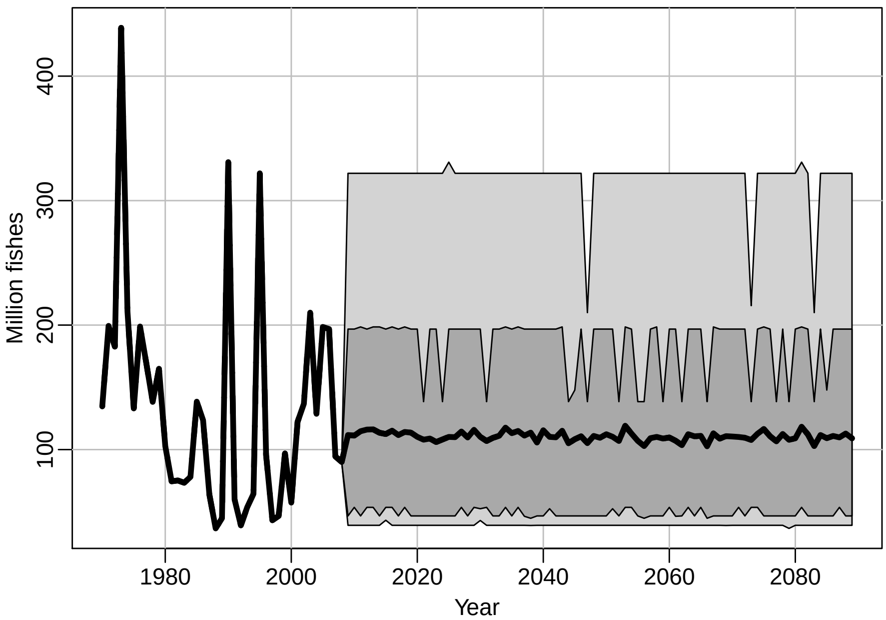

Figure 31: Development of recruitment according to run 3 (survey from Iceland and Greenland) if advice is given based on $F_{9_19} = 0.097$ The light grey area shows fifth and 95th quantile and the dark areas 16th and 84th quantile

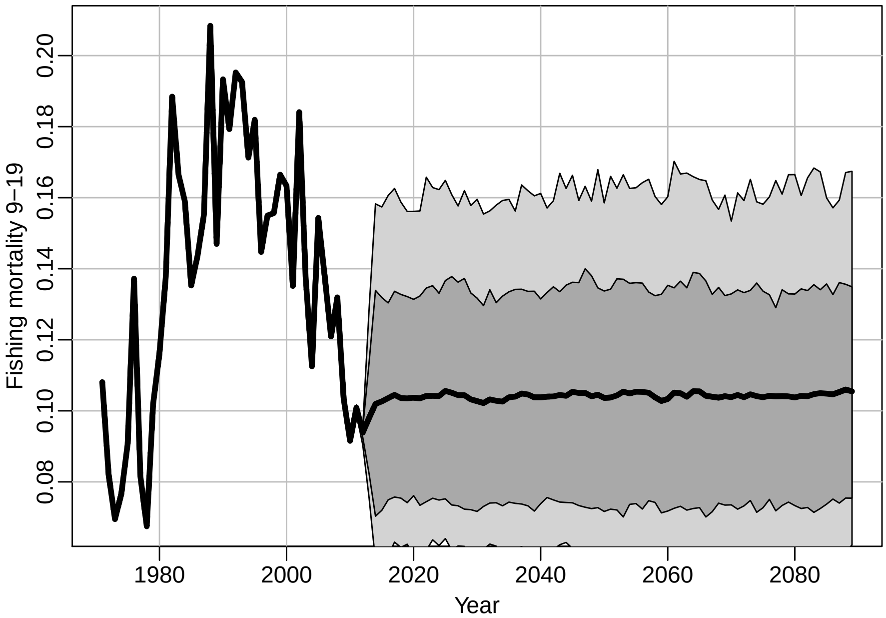

Figure 32: Development of F_{9-19} according to run 3 (survey from Iceland and Greenland) if advice is given based on $F_{9_19} = 0.097$ The light grey area shows fifth and 95th quantile and the dark areas 16th and 84th quantile

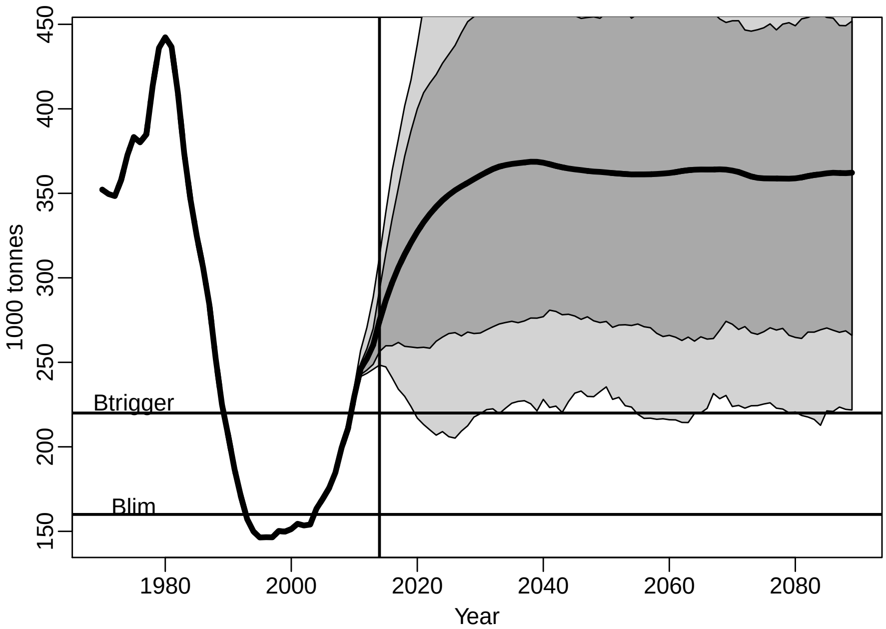

Figure 33: Development of the spawning stock according to run 4 (survey from Iceland and only) if advice is given based on $F_{9_19} = 0.097$ The light grey area shows fifth and 95th quantile and the dark areas 16th and 84th quantile

7 Short term considerations

The proposed management plan should work quite well in the long term, even with relatively poor assessment (figure 28). The benchmark part is more about looking at the next 5+ years and possible development in that period. The assessment proposed here includes data from East Greenland, an area where the abundance of Marinus has been increasing and relatively much large fish is found there. The effect of including the indices from Greenland in the assessment are considerable but the connection between the areas are not clear. Will the stock in Greenland be used to fish down the stock in Iceland or do they come over. Earlier more large redfish was found in East Iceland and the Faeroes. The distance from West Iceland to East Greenland is not larger than from West Iceland to East Iceland (figure 12).

What is done here is to look at the development in the next 5 years, assuming that the assessment is done including the Greenland survey but the assessment based on the Icelandic survey is giving the “truth”. Advice in 2014 based on including the Greenland survey 49 thous. tonnes, increasing by 2 thous. tonnes over the text years. This advice will lead to fishing mortality of 0.14 if the “truth” was the run based on the Icelandic survey . This level of fishing mortality will lead to relatively stable spawning stock, catches and fishing mortality in coming years. (figure 35).

Recruitment of cohorts 2006 and later is not estimated in this run (ending in 2013) and average recruiment is estimated for cohorts 2006 onwards. Putting the lowest observed recruitment over 5 years period (50% of the average) leads to substantially worse development of the stock that is predicted to be go below $B_{trigger}$ during the simulation period (figure 35.

If the worst scenario shown would be noticed in the Icelandic data and action taken.

Similar situation would be observed in Icelandic waters we have two different stocks or stock components with limited connection and the part in Greenland will be used to generate advice on catches that will be taken in Icelandic waters. In that case reduction might be noticed in Icelandic waters and increase in Greenland. Similar happen with stocks that change their distribution but there is inertia to change fishingareas (Example Icelandic haddock).

Effect of assumption about recent cohorts has more effect when fishing mortality is high, as the adult stock becomes larger (figure 35) Effect of recruitment “assumptions” can also be noted in the selected base run (figure 34) . **They do though have small effect on next years advice .**

$F_{9-19} = 0.14$ **is not far from average fishing mortality since 1990 32. If we combine that with low recruitment or only half of the average the stock is in the end going to go below what we have seen earlier. The stock is though monitored so action will hopefully be taken before anything serious happens, even though the monitoring has some uncertainty.**

The advice obtained for 2014 would have been 49 thous. tonnes, lower than the advice given but higher than the landings in last 15 years that are 42 thous. tonnes on the average. The average catch in the future is estimated to be around 50 thous. tonnes, or similar to the advice for 2014 (30). Advice in 2014 would be 35 thous. tonnes if only the Icelandic survey was used as basis for advice (figure 35). This is lower than the catch in last 15 years but appropriate value if the run tuned with the Icelandic is giving the truth.

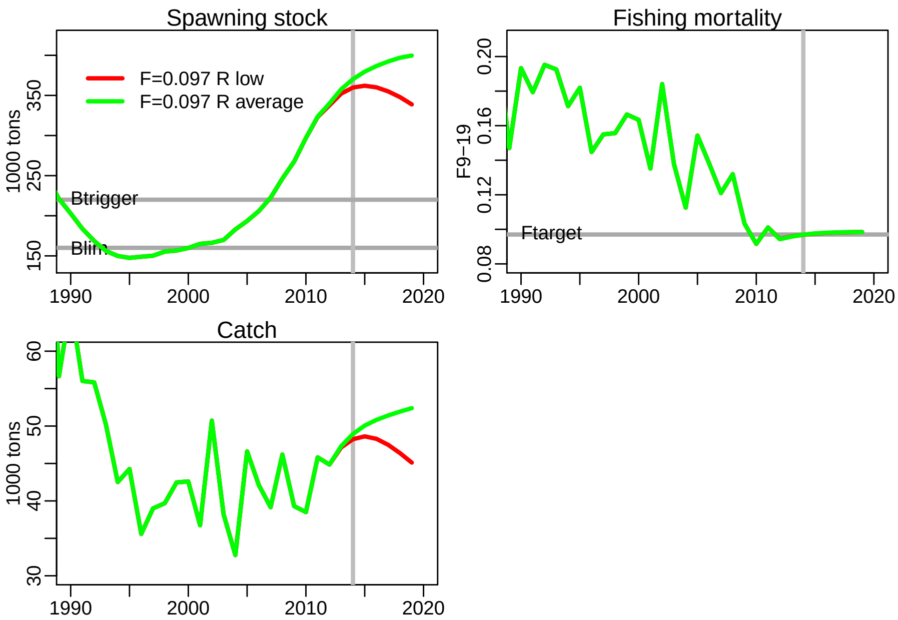

Figure 34: Development of the stock next 6 years for two recruitment levels and fishing at the target fishingmortality. The picture is based on run 3 tuned with Icelandic March survey + the German survey scaled to 22500 km2..

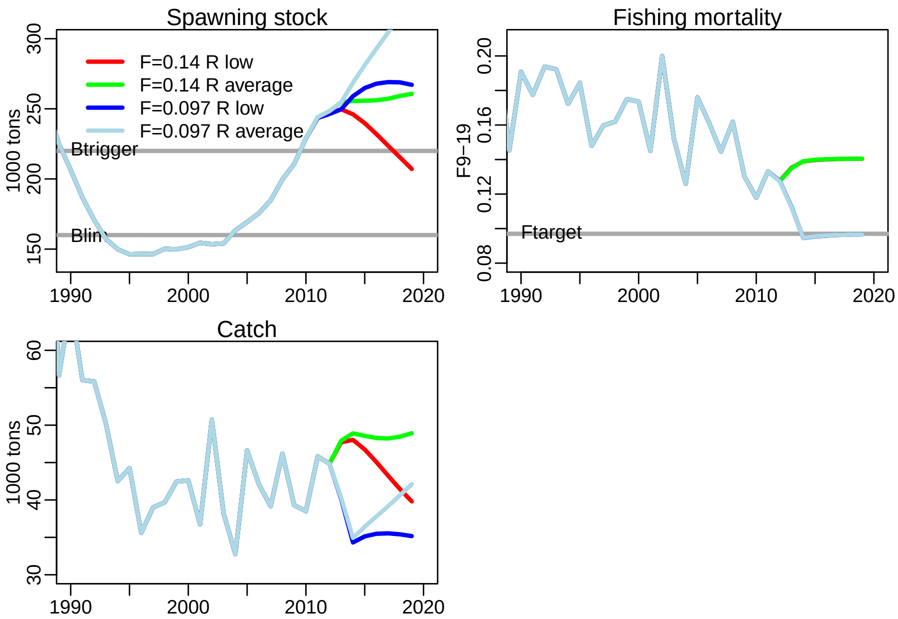

Figure 35: Development of the stock next 6 years for 2 values of fishing mortality and two recruitment levels. The higher level of fishing mortality corresponds approimately to what would be obtained if advice was given based on Icelandic + German survey but the run tuned with the Icelandic survey was giving the "true stock".

8 Complications

A number of things have happened in recent decades that could have increased survival of redfish, making more adult fish out of each recruit. Among those factors are.

A shrimp survey has been conducted in Icelandic water since 1987 (figure 36. The area covered by the shrimp survey is large or $\approx 80000 km^2$. Since 1997 redfish has been measured at all the stations, where it is found but few reffish were measured before 1993.

The numbre of redfish per hour was over 150 in 1987 when the 1985 yearclass was going through but 100 on the average when the 1990 yearclass was going through but for some reason the 1990 yearclass lasted longer in the area. If the number of redfish caught per hour is scaled by the hours traswled the total number caught of the 1990 yearclass from 1991-1994 is 80 million fishes. The recruitment of the 1990 yearclass at age 5 is estimated to be 300 million so the calculated discard could be 15-20 percent of the yearclass. Yield per recruit of age 5 fish is approximately 450g (figure 24) but assuming 300g the catch lost from the 1990 yearclass might be 25 000 tonnes.

Sorting grids were made mandatory in the shrimp in 1994 but since relatively few redfish have been observed in the area since then. As the assessment is done today, starting at age 5 the discard in the shrimp fisheries would not have major effect on the assessment as most of it happened at age 1-4.

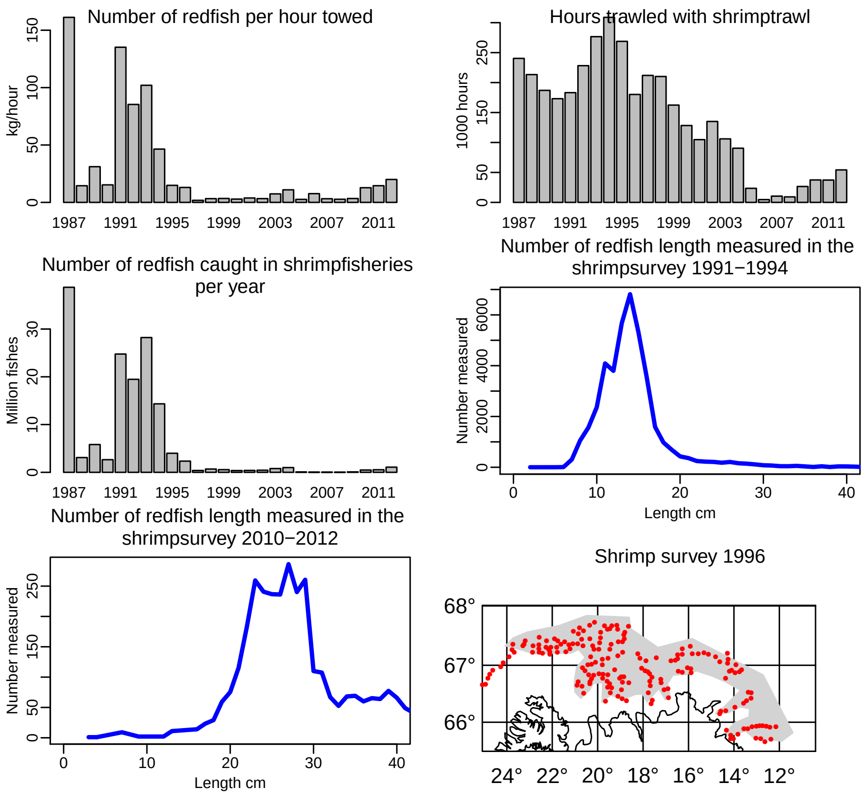

Figure 36: Collection of information from the deep water shrimp survey and the shrimp fisheries

One problem not looked at here is possibly better survival of redfish below 30cm due to decreased fishing effort and closed areas west of Iceland since 1994?

9 Other measures from the survey

As shown earlier survey indices have been relatively high in recent years (Figure 6) mostly caused by few relatively large tows and demonstrated by the relatively high estimated uncertainty. The indices have though been realtively consistent from year to year.

Other measures that are not as dependent on few large hauls but rather a measure of the extent of distribution are surprisingly variable (figure 37) but are at their highest level in 2013. The average number of stations in the March survey is 570 and redfish is found in 95% of the stations. The high values seen in 2013 might be caused by increase in the North west where the density of stations is highest but this area is closest to Greenland.

Other interesting division is between East and West and greater than and less than 40cm (figure 38). Amount in the west is considerably greater but the proportion of large fish is higher in the east.

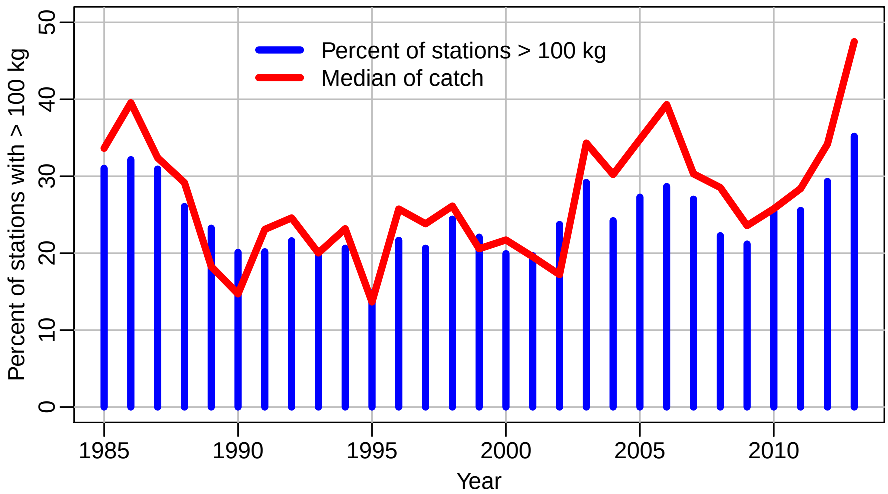

Figure 37: Percent of stations in the Icelandic March survey with ¿ 100 kg of redfish and median of redfish catch per station

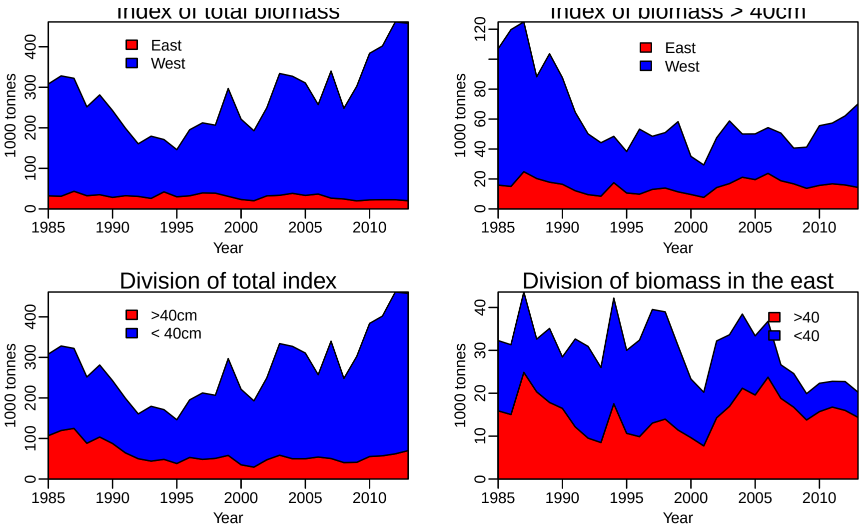

Figure 38: Division of the March survey biomass index between east and west and ¿ 40cm and ¡ 40cm

References

Bjrnsson, H., and Sigursson, T. 2003. Assessment of golden redfish (*Sebastes marinus* L) in Icelandic waters. Scientia Marina 67(Suppl. 1): 301–314.

ICES 2013. Report of the North Western Working Group (NWWG). ICES CM 2013/ACOM:07. 1538 pp.

Kristinsson, K., Fock, H., and Reinert, J. 2012. Golden Redfish *(*Sebastes marinus) in ICES SubareaV and Division XIVb as observed in groundfish surveys. ICES CM 2012/ACOM:48 Working Document No. 1 WKRED 2012.

Evaluation of management plans for S. mentella in ICES areas I and II.

WD3, WKREDMP, Copenhagen 20-25 January 2014

Bjarte Bogstad, Daniel Howell, Kjell Nedreaas and Benjamin Planque, Institute of Marine Research, Norway

Version dated 15 January 2014

Background

This WD describes the evaluation of management plans for *S. mentella* in ICES areas I and II carried out in advance of the WKREDMP meeting in January 2014, based on a request from the Parties responsible for managing this stock. Analyses of the stock-recruitment relationship to be used are given in another document (Howell, WD1). We are aware of the guidelines for Management Strategy Evaluation given in the ICES WKGMSE report (ICES, 2013). However, we have so far only taken into account some of the sources of uncertainty in simulations, but we have tried to follow the minimum standards for simulations given by WKGMSE. We have used the "short-cut" approach (i.e. assuming some uncertainty level on the annual assessment, rather than doing a full assessment within the simulation loop).

Choice of software

The PROST software (Åsnes, WD2), which previously has been used for evaluation of HCRs for Northeast Arctic cod, haddock and saithe (see description in ICES 2006), was used for the simulations. Some new features had to be added before WKREDMP to accommodate for the features in the HCRs to be tested.

Tests have been conducted to confirm that projections with PROST give the same results as projections with the catch at age model used at AFWG, for the period 1992-2012.

Clarifications and amendments to request

The request is given at the end of this WD.

Reference and trigger points: F0.1=0.039 for age range 12-18 (AFWG 2013). B_{msy} (and B_{lim} and B_{pa}) are not defined for this stock at the moment. Thus $B_{trigger}$ and B_{stop} in harvest control rules should be given as numerical values, and no references should be made to B_{msy} in the harvest control rules:

In order to get a text which is internally consistent and implementable, we thus suggest changing the wording in the request on reduction of F when SSB falls below $B_{trigger}$:

"Reduction of F when SSB falls below $B_{trigger}$

For each of the alternatives A, B or C above, $B_{trigger}$ should be set to either 800, 500 or 0 kt. Should the SSB fall below $B_{trigger}$, fishing mortality should be reduced linearly with SSB. F should reach zero before SSB reaches zero, e.g., at B_{stop} = ½ $B_{trigger}$ or B_{stop} = ¼ $B_{trigger}$. SSB refers to the Spawning Stock Biomass assessed in the year of assessment. Using the 19+ biomass for SSB (as described in WD1), 500kT represents a level below which recruitment could start to be impaired (estimated breakpoint in recruitment at 535kT, which to 1 significant figure is 500kT). The 800kT level is chosen to be 50% higher than the recruitment breakpoint, to provide a buffer against a high level of uncertainty in the recruitment.

Fishing pattern: The request says: "The parties would ask ICES to show which exploitation pattern is used in the simulations as well as to reflect upon how sensitive the results are for possible changes in the exploitation pattern." We decided to first make runs only with the recent (average of last 5 years) exploitation pattern, and then we will reflect on which additional runs are needed with other exploitation patterns. This is done to limit the total number of simulations made, not only to save time and effort, but also in order not to overload the recipients with information. The recent exploitation pattern is primarily driven by the pelagic fleet, so simulations should mainly reflect variations in exploitation from this fleet rather than from the demersal fleet.

Reduction of F when recruitment is reduced: "cutting fishing mortality with 25 or 50% if the average strength at age 2 for year classes which are 3-12 years old in the year for which the TAC advice is given is at or below 33 % of average recruitment at age 2 for the period 1992-1996". The 1992-1996 average is 293 million, so we suggest using 100 million as the threshold here since that is very close to 33% of the average. If SSB< $B_{trigger}$, the reduction in F due to weak incoming year classes is applied to the F after it has been adjusted for SSB<$B_{trigger}$ (this issue was not dealt with in the request).

Concerning TAC stability, we suggest that limits on annual variability of TAC should be suspended when the SSB is below $B_{trigger}$, in the same way as in the HCR for NEA cod.

Performance criteria:

Performance criteria according to the request: Yield in each of the years 2014-2018, mean yield 2014-2018, 2014-2023 and 2014-2063. Also the probability of SSB being (not falling) below 500 kT (close to the breakpoint in the hockey stick SSB-recruitment relationship) during the periods 2014-2018, 2014-2023 and 2014-2063 is calculated. This probability is calculated as *the proportion of years with* SSB_{19+} *less than 500 kT, averaged over all simulations*. (Prob1 in WKGMSE terminology). We also calculate the mean SSB_{19+} and total stock biomass (TSB) for the last 20 years of the period (2044-2063), which should be close to the mean long-term values (20 year average used because 20 year period for cyclic recruitment used in some runs). This value and the yield should be compared to stock biomasses and yields obtained from other sources (e.g. Schaefer model, see Fig 6.9 in ICES (2013).

Prediction input:

Initial stock size is taken from the 2013 assessment, and 2013 is considered an intermediate year with the same fishing mortality by age as estimated for 2012 (catches and fishing pattern in 2013 are known to be approximately the same as in 2012). Thus the harvest control rule is implemented from 2014 onwards. Concerning recruitment, survey data indicate that the 2011-2013 year classes, which are age 2 in 2013-2015, are somewhat weaker than the preceding year classes. Thus a value of 500 million (close to the 2006-2012 average in SCAA of 491 million) at age 2 is used for these three year classes. The uncertainty in the abundance in the initial year as well as in the annual assessment is assumed to be normally distributed with a CV of 0.2, corresponding to a 90% confidence interval ranging from 426 to 827 thousand tonnes for $SSB_{19+.}$ Uncertainty of number at age is independent between ages. This approximately corresponds to the uncertainty in the scaling coefficient for the swept area estimate from the Joint Norwegian-Russian ecosystem survey (3.5 is used but likely values span from 3 to 6, AFWG 2013 section 6.4).

For weight at age in the stock and catch (these are equal), the historic average for the period 2008-2012 is used. Note that for age 18 the 2009-2012 average is used because the 2008 value is unrealistically low. Natural mortality is set to 0.05 for all ages. It is assumed that all 19+ fish are “mature” while all younger fish are “immature”. Note that this is based on an analysis of the relationship between stock biomass and recruitment, rather than gonad development (Howell, WD1). It is not mentioned in the request which values should be used for weight, maturation and natural mortality, but an historic average seems sensible.

For the exploitation pattern we used the historic average for the period 2008-2012 as the default. Sensitivity tests on fishing pattern have not yet been performed, but should be done. In this period the distribution of the catch on the two fleets (pelagic and demersal fishery) was approximately constant. (Note: We can only use a single fleet in PROST, while the SCAA model currently uses two fleets).

Analyses of the stock-recruitment relationship were made by Howell (WD1). He suggests basing this on $SSB_{19+,}$ and to use a hockey stick stock-recruitment relationship with a slope of 1.3627 (unit: number of age 2 recruits/kg SSB) and a breakpoint at 535 thousand tonnes. Using the same method to determine the uncertainty in the recruitment function as for cod, haddock and saithe (see e.g. Kovalev and Bogstad 2005) gave a slope of 1.29 and a breakpoint at 540 thousand tonnes, with a cv on log scale of 0.252. These estimates are based on data from 2004 onwards, so they are based on only 7 data points. In the preceding period (1996-2003) recruitment at given SSB was significantly below the level predicted from this relationship. It therefore appears possible that this stock may have extended periods of good and poor recruitment, and any management rule should be robust to this possibility. Therefore, in order to investigate the performance of various HCRs if long periods of low recruitment occur, we also used a cyclic recruitment where the mentioned hockey stick function is multiplied by the term $0.25*\exp(1.75*\sin(2\pi(T-2005)/20))$. The period of 20 years is chosen to produce periods of low recruitment of similar length to that observed e.g. for the year classes 1996-2003. The amplitude is chosen to give the same ratio between the minimum and maximum year class strength as observed for the period 1992-2012. The factor 0.25 gives an average recruitment which is about 50% of that obtained with the hockey stick stock-recruitment function from WD1.

1000 simulations were run for each HCR.

Table 1. Number at age in initial year (2013), weight at age and exploitation pattern at age used in the simulations.

Age	Number 1 January 2013 (million, rounded)	Weight at age (kg)	Exploitation pattern
2	500	0.005	0.00000
3	645	0.013	0.00000
4	754	0.024	0.00000
5	598	0.052	0.00000
6	246	0.154	0.00034
7	244	0.170	0.00087
8	295	0.300	0.00213
9	154	0.436	0.00491
10	35	0.516	0.00929
11	19	0.526	0.01420
12	17	0.510	0.01793
13	14	0.564	0.02018
14	15	0.598	0.02157
15	21	0.624	0.02266
16	27	0.630	0.02366
17	32	0.638	0.02458
18	68	0.645	0.02536
19+	998	0.638	0.02707

Number of runs to be made

F values: 3 ($F_{0.1}$, $F_{0.1}$*4/3, $F_{0.1}$*3/4)
$B_{trigger}$: 3 (800, 500, 0 kT)
B_{stop}: 2 ($B_{trigger}$/2, $B_{trigger}$/4)

Stability : 2 (max 20%/no limit)
Reduction in F if low incoming recruitment: 3 (0, 25, 50%)
5-year rule: 2 (yes/no)
Cyclic recruitment: 2 (yes/no)

Total: 3x3x3x2x2x2x2=432 runs, however, if $B_{trigger}$=0 the B_{stop} value is irrelevant so in total this gives 360 runs.

Concerning the uncertainty in initial stock size, assessments with survey scaling coefficients of 3 and 6 (see above and ICES 2013) will be available by the time WKREDMP starts so they could be used as a basis for simulations.

We decided first to do a few runs with the least conservative harvest control rule in the range suggested (i.e. highest F=$F_{0.1}$*4/3, $B_{trigger}$=0). We ignore the stability and 5-year rule issue (i.e . assume no limit on annual variation, and no 5-year rule) in this first round as we believe that this has relatively little impact on the outcome for such a long-lived stock.

Thus we did these 4 runs:
Run 1: $F_{0.1}$*4/3, hockey-stick recruitment, no reduction in F if low incoming recruitment
Run 2: $F_{0.1}$*4/3, hockey-stick recruitment, 50 % reduction in F if low incoming recruitment
Run 3: $F_{0.1}$*4/3, hockey-stick*cyclic recruitment, no reduction in F if low incoming recruitment
Run 4: $F_{0.1}$*4/3, hockey-stick*cyclic recruitment, 50 % reduction in F if low incoming recruitment

Table 2 Simulation results (thousand tonnes and proportions)

	Run 1	Run 2	Run 3	Run 4
Yield 2014	40	40	40	40
Yield 2015	40	40	40	40
Yield 2016	42	42	42	42
Yield 2017	45	45	45	45
Yield 2018	50	50	50	50
Mean yield 2014-18	44	44	44	44
Mean yield 2014-23	56	56	56	56
Mean yield 2014-63	105	105	60	57
Prop years SSB_{19+} < 500 2014-18	0.391	0.368	0.386	0.391
Prop years SSB_{19+} < 500 2014-23	0.677	0.676	0.674	0.681
Prop years SSB_{19+} < 500 2014-63	0.209	0.210	0.515	0.456
Mean TSB 2044-63	3399	3413	1624	1720
Mean SSB_{19+} 2044-63	1066	1070	561	633

Run 2 gives results equal to run 1 (recruitment in 10 years prior to intermediate year not low enough to affect F, also R/SSB function does not give very low recruitments for the SSB values experienced in those runs).

For runs 1 and 2, the mean yield is 105 thousand tonnes and the mean SSB and TSB at the end of the period is 1.1 and 3.4 million tonnes, respectively. Both the mean yield and the mean TSB seems to be on the high side, as the maximum biomass in the Schaefer model run about 2.2 million tonnes, while catches generally have been considerably lower (10-year averages 1952-1961, 1962-1971 … 2002-2011: 30, 17, 121, 50, 12 and 13 thousand tonnes). The mean yield in runs 3 and 4 seems to be closer to a level the stock can sustain based on historical catches. It is thus likely that the recruitment estimated from recent years represents a "good" period of recruitment rather than reflecting the long term development of the stock, and that some means of accounting for this (such as the cyclic pattern employed here) is required.

These results suggest that if recruitment (or recruits per unit SSB) is stable then the reduction in F with periods of poor recruitment has no impact, as that part of the HCR then never come s comes into effect. If, however, there are periods of poor recruitment, then a reduction in F gives a long term improvement in SSB and reduces the chance of dropping below 500kT, at the cost of only a small reduction in catch. Such a feature may thus be considered a precautionary part of any management rule for this stock.

The way forward

The ratio of total catch over total stock biomass is very low for this stock, which should be expected for a long-lived species, and one direct consequence of this is the impossibility to derive robust absolute estimates of the stock size. For this reason, the SCAA assessment model relies on one of the surveys to set the absolute biomass level. This solution is not optimal and generates additional uncertainty in the model outputs. Given these large uncertainties in present stock size and the limited knowledge of recruitment dynamics, any harvest control rule for this stock should be re-evaluated within a few years. In the SCAA assessment model presently used, surveys on the mature stock in the Norwegian Sea are not included. Such trawl-acoustic surveys were carried out in 2008, 2009 and 2013, and the next survey is planned for 2016. Such surveys also provide some information on the range of absolute stock levels in addition to indicating trends.

The spawning stock-recruitment relationship is also a key issue. In addition to getting more years of data and experimenting with other relationships than those given in this WD, this relationship could also be improved by including data on redfish by-catch in the shrimp fishery and predation by cod on redfish. Although age data are available only back to 1992, it should be possible to get knowledge about recruitment also in the 1980s given that bottom trawl survey data on length are available back to 1986, pelagic 0-group survey data are available back to1980 and that data on predation by cod on redfish are available back to 1984. It is important to keep in mind that the stock-recruitment relationship may remain evasive even with additional data, given 1) the longevity and late maturity of *S. mentella* (which implies that many years of data are necessary) and 2) that long-lived fish species tend to display greater recruitment variability while their SSB varies slowly (Longhurst 2002).

Instead of deciding on some $F/B_{trigger}$ type harvest control rule, it could be considered to agree on some fixed catch level for a period of 3-5 years until more data are available. This catch level should be set so that the risk of decreasing the SSB during that period is low.

Furthermore, it should be noted that this stock at the moment is managed by two different fisheries commissions (NEAFC and Joint Norwegian-Russian Fisheries Commission), and that there is no agreement on how to split the TAC between areas or countries.

References:

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Appendix

Harvest Control Rule for *Sebastes mentella* – Request to ICES

The advice on catch levels for *Sebastes mentella* in ICES sub-areas I and II for 2013 was based on the ICES MSY-approach. As an approximation to the reference point F_{msy}, ICES used the reference point $F_{0.1}$.

The parties responsible for managing the stock of *Sebastes mentella* seek to establish a Harvest Control Rule (HCR) for this fish stock. Before such an HCR is adopted the parties would request ICES to assess the consequences of a few alternative rules, in particular the following:

A. An HCR based on the ICES MSY-approach with a fishing mortality equal to $F_{0.1}$.

B. As A, but where the fishing mortality is set to ¾ of $F_{0.1}$.

C. As A, but where the fishing mortality is set to 4/3 of $F_{0.1}$.

The fishing mortality indicated in the alternatives above should be the reference point for the annual TAC when the Spawning Stock Biomass is at a level capable of producing maximum sustainable yield. Hopefully, setting the fishing mortality to one of these levels will also sustain the SSB at a productive level. We have, however, seen that due to natural conditions any fish stock may be reduced below such a productive level. An HCR for *Sebastes mentella* should specify pre-agreed actions if such development is seen in the future. The natural thing to do will be to reduce fishing mortality, and the parties would ask ICES to assess two different ways of doing this.

<u>Reduction of F when SSB falls below $B_{trigger}$</u>

$B_{trigger}$ is not known for this stock, but should be the reference point beneath which fishing mortality should be reduced. In lack of a precise figure for $B_{trigger}$, the Parties would ask ICES to assess the consequences of various levels of $B_{trigger}$. For each of the alternatives A, B or C above, $B_{trigger}$ should be set to either B_{MSY} or ¾ B_{MSY}. Should the SSB fall below $B_{trigger}$, fishing mortality should be reduced linearly with SSB. F should reach zero before SSB reaches zero, e.g., at B_{stop} = ½ B_{MSY} or B_{stop} = ¼ B_{MSY}. SSB refers to the Spawning Stock Biomass assessed in the year of assessment.

<u>Reduction of F when recruitment is reduced</u>

To the extent that recruitment is measured to be low in a series of years, this may call for a reduced fishing mortality when setting the annual TAC. The Parties would therefore ask ICES to assess the consequences of cutting fishing mortality by 25 or 50% if the average strength at age 2 for the year classes which are 3-12 years old in the year for which the TAC advice is given is at or below 33 % of average recruitment at age 2 for the period 1992-1996.

ICES is requested to assess the consequences of the various rules with a) no modification of fishing mortality due to low SSB or recruitment, b) reduction of F when SSB falls below trigger points and c) reduction of F when recruitment is at a low level.

<u>TAC stability</u>

Some harvest control rules incorporates expected growth or decline of a fish stock, as well as stability elements, in the decision related to the annual TAC. An example of this is the HCR for Northeast Arctic Cod. The parties responsible for managing the stock of *Sebastes Mentella* would ask ICES to assess an HCR with some of the same feature as the one for Northeast Arctic Cod, namely;

D. Estimate the average TAC level for the coming 5 years based on $F_{0.1}$. TAC for the next year will be set to this level as a starting value for the 5-year period. This procedure is to be repeated during the consecutive assessment, but the TAC should not deviate by more than +/-20% compared with the previous year's TAC.

For all simulations, ICES is asked to assess the consequences through calculating the following performance indicators (expected values):

- Annual yield during each of the next 5 years
- Medium term yield, represented as average yield during the next 5 and 10 years
- Long term yield, represented as average yield during the next 50 years
- Probability that SSB falls below $B_{trigger}$, in a 5, 10 and 50 year period

<u>Exploitation patterns</u>

The medium to long-term consequences of various HCRs will also depend upon the exploitation pattern in the fishery. The parties would ask ICES to show which exploitation pattern is used in the simulations as well as to reflect upon how sensitive the results are for possible changes in the exploitation pattern.

<u>Combinatorial of HCR explorations</u>

Following the above, the total number of HCR explorations is 3 F's (1, 3/4 and 4/3 of $F_{0.1}$) x 2 $B_{trigger}$ (400 and 800 kt) x 2 B_{stop} (1/2 and ¼ B_{MSY}) x 3 recruitment reductions (0, 25 and 50%) x 2 TAC stability (on, off) = 72 combinations x 4 performance indices = 288 outputs.

Prost Users Guide

Morten N. Åsnes *
Bjarte Bogstad <bjarte.bogstad@imr.no>
IMR, Bergen, Norway

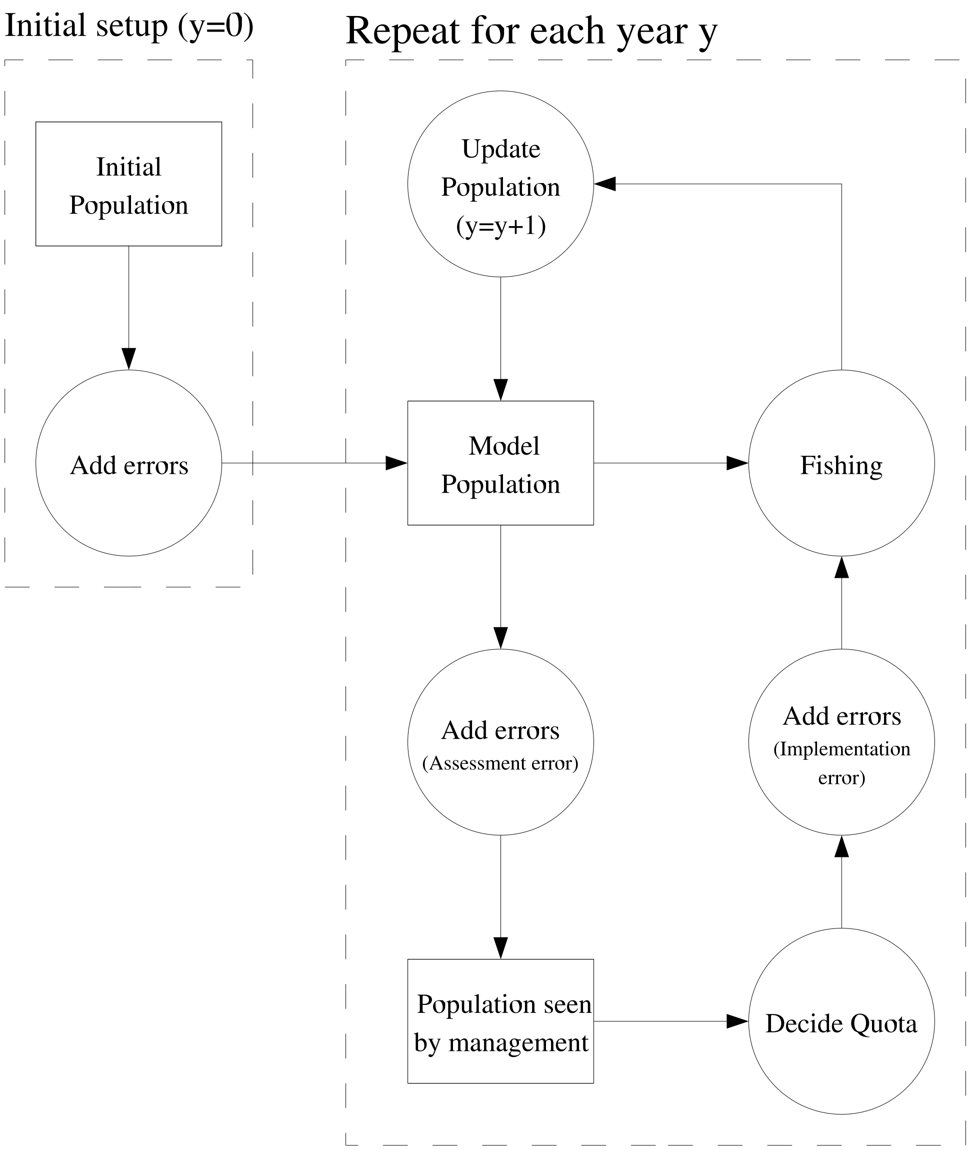
January 14, 2014

Contents

*No longer at IMR, please contact bjarte.bogstad@imr.no for questions regarding Prost

1 Introduction

This document describes the prognosis program Prost (Projections Stochastic), version 0.1. The purpose of the program is to perform stochastic projections using an age structured population model, for given management rules. The program starts with a given population, which is then projected into the future and subjected to natural mortality and fishing. Fishing level is given by a management rule. Stochastic errors can be added to the initial starting population (numbers, weight, maturity, etc.), and to the recruitment. In addition errors can be added to the population before it is seen by the management rule (assessment error), and to the decided quota (implementation error). Each model simulation will thus give a different realization of the projection. The model works as described in Skagen et al. (2003). A yearly time step is used. The following figure illustrates a single realization of the model.



The program was developed for use in the evaluation of the proposed harvest control rule for Northeast Arctic cod (Bogstad et al. 2004), but is generally applicable for making single-species, single-fleet, single-area stochastic projections using an age-structured population model. Weight at age and maturity at age can be density-dependent, and a variety of harvest control rules can be applied. It is easy to add more options for density-dependent weight/maturity at age as well as additional harvest control rules.

The ICES Study group on Long term Advice (ICES 2004a) as well as the ICES Methods Working group (ICES 2004b) have discussed existing tools similar to Prost. Such tools include WGMTERM, ICP, STPR and CS5.

The model does not assume any specific unit in the input and output files. It is up to the user to make sure that units for numbers and weight match up. In the manual we assume that numbers are in thousands and weights are in tons.

2 Installation

Prost is written in Java, and can therefore run on any platform where a Java runtime version is available.

If you're not developing Java software yourself, it is sufficient to download the JRE (Java Runtime Environment). Verify that you have a suitable Java installation by typing `java -version` in a Dos or Terminal window. The output should be something like this:

```
java version "1.7.0_45"
Java(TM) SE Runtime Environment (build 1.7.0_45-b18)
Java HotSpot(TM) 64-Bit Server VM (build 24.45-b08, mixed mode)
```

Please notice that the Java Browser Plugin is not sufficient for running Java Applications like Prost.

An up to date JRE can be downloaded at http://www.oracle.com/technetwork/java/javase/downloads/jre7-downloads-1880261.html. The download should be named *jre-7u45-windows-i586.exe* or similar for the 32 bit version, or *jre-7u45-windows-x64.exe* or similar for the 64 bit version. The download consists of a setup program, which must then be run to install Java on your computer.

After running the installer try to run `java -version` from a DOS windows again to verify that the correct Java version is found.

If for some reason Windows can still not find the installed Java version, you will have to configure your the windows *Path* environment variable to include the path where `java.exe` is installed. First, locate directory where `java.exe` is in installed. It should typically be something like `c:\Program Files\Java\jre7\bin`. Now, to add this directory to the system path, click *Start*, then *Control Panel*, then *System*. Then click *Advanced* and *Environment Variables*. Now edit the *Path* under *System Variables*, and add the java directory to the end, separated from the previous entry by a semicolon. The new path should be in effect when you open a new command window.

As an alternative, it is possible to change the path temporarily in a single command window. In a command windows, type the following: `set path=%path%;c:\Program Files\Java\jre7\bin` (but change the path to reflect where Java is installed on your machine). Now the new path will be in effect only in the current window until it is closed.

Prost comes packaged as a single file called `prost.jar`. It is most convenient to place this file together with the input files in the directory where you intend to run the program.

3 Running Prost

To run Prost, type `java -jar prost.jar`. This will read the file `stock.dat`, and start a run. Output will appear in various text files (`.csv` files which can be read into Excel). See Section 5 for more detail on the output files.

3.1 Command Line Options

To control how many simulations to perform, add the command line option `-i nr_of_simulations`. For example; to run 1000 simulations you type: `java -jar prost.jar -i 1000`. The default is 100 simulations. The option `-o` produces very detailed output to the file `out.csv`. When doing many simulations this file will become very large. It is usually only needed for debugging.

To specify a seed for the random number generator, use the option `-r seed` where seed is an integer.

The option `-v` will print some more information to the screen as the input files are read in. This will be helpful in tracking down any mistakes in the input files.

It is possible to set the fishing level on the command line with the option `-f flevel`. If this option is used, the given value will override the `FaboveBpa` parameter from the management file (Section 4.4).

When this option is used, all output files will have a prefix added to their name, to distinguish output files from different runs. For instance; if the option `-f 0.4` is used the summary file will be named `F0.4-summary.csv`.

This option can be useful when one wants to automate the task of running Prost with different fishing levels. The script `prost.js` can do this on Windows. See Section 3.2 for details on how to use the `Prost.js` script.

The option `-s portnr` specifies that Prost should communicate with an external program on the specified port. During the simulation Prost will then read data from this socket each year,

The data read from the socket is weight in stock, weight in catch, maturity, and natural mortality. Prost will then write the number of the start of the next year back over the socket.

3.2 Scripting

A script is provided with the Prost distribution, for doing multiple runs, with different fishing levels. The script will accept all the usual Prost arguments, but the `-f` option is handled differently. This option is now followed by three values: The smallest fishing level to use, the largest fishing level, and a step-value. The script will run Gadget multiple times, starting with the smallest fishing level, increasing the level by the step value each time, up to and including the given max level. The script is called `prost.js`, and it will only work on the Windows platform. The complete syntax is as follows:

```
prost.js -f minf maxf stepf <ordinary prost options>
```

The script expects the Prost program (`prost.jar`) to be in the same directory as the script is running from, or the directory above it. If `prost.jar` can not be found, the script will exit with an error message.

4 Prost Input Files

All input files are pure text files. They generally consist of keyword – value pairs, in a predefined order. Comments can be introduced with a semicolon. The rest of the line following the semicolon is treated as a comment.

4.1 Control file

The control file must reside in the directory where Prost is started, and it must be named `stock.dat`. This file specifies the age range and time span to run the model for. It also lists all the other input files. An example of the file:

```
name                Torsk
firstyear           2003          ; intermediate year
lastyear            2028          ; last prediction year
extrayears          5             ; extra years after lastyear
minage              3             ; recruitment age
maxage              13            ; +group
fbarmin             5
fbarmax             10
bpa                 460000
blim                220000
flim                0.49
maxthreshold        20
minthreshold        20
maxf                0.9
summarystart        2004
summaryend          2028
population          pop.dat
recruitment         rec.dat
management          manage.dat
weightandmaturity   density
file                density.dat
```

The keywords are explained in Table 1.

The model will start some years before the intermediate year because data from earlier years might be needed for the recruitment function. And because the management rule may look several years into the future when setting the quota, the model may also run for several years after the last year.

The numbers of years to run before $firstyear$ is determined by the minimum age in the model. Thus if $minage = 2$, the program will require data for two years before $startyear$. The number of years to run after $lasteyear$ depends on several things. Firstly, the model must run at least $minage$ years after $lastyears$, this is because of the way the recruitment function is implemented. Then, if the *lookahead* management rule is used, the model must run as many years after *lastyear* as the *lookahead* management rule is set to look into the future. Lastly, there is the keyword *extrayears* in the control file, where the user can specify how many years after *lastyear* of data are in certain input

Table 1: Keywords in control file

Keyword	Type	Description
name	string	Name of the stock
firstyear	integer	Intermediate year (assessment year)
lastyear	integer	Last year that a quota will be given for
extrayears	integer	Extra years needed (for management rule) after *lastyear* **(optional)**
minage	integer	Minimum age
maxage	integer	Maximum age
fbarmin	integer	Minimum age for reference F calculation
fbarmax	integer	Maximum age for reference F calculation
bpa	double	B_{pa} value
blim	double	B_{lim} value
flim	double	F_{lim} value
maxthreshold	double	Threshold for counting a year as having a big increase in quota
minthreshold	double	Threshold for counting a year as having a big decrease in quota
maxf	double	Maximum fishing mortality
summarystart	integer	First year in summary output
summaryend	integer	Last year in summary output
population	string	Filename for population data
recruitment	string	Filename for recruitment function definition
management	string	Filename for management rule definition
weightandmaturity	string	Option for weight and maturity
file	string	Filename for density dependent, or historic weight and maturity **(optional)**

files. Thus the number of years to run after *lastyear* will be the largest value of *minage*, *extrayears*, and *years* (in the *lookahead* rule). We will call this last year of the model Y_N in the discussion below.

The B_{pa} value is used only as a trigger point in the constant F rule (Section 4.4.1) and the lookahead rule (Section 4.4.2). The B_{lim} value is only used for calculating $P(SSB < B_{lim})$ in the summary output. The values F_{lim}, *maxthreshold*, and *minthreshold* are also used only for printing.

4.1.1 Weight And Maturity option

The keyword *weightandmaturity* indicates how weights and maturity are modeled. The option must be one of *initial*, *density*, or *historic*. If the option is *initial*, the weight and maturity comes from the population file, in the format specified below. If the option *density* or *historic* is given, the next line of the file must give a filename where these options are further specified. The format for the *density* option is specified in Section 4.5 The *historic* option is described in Section 4.6. Note that even if the *density* or *historic* option is given, the initial population file must still contain weight and maturity.

4.2 Population File

The name of the population file is given in the control file. As mentioned above, all data given here must start in the year $firstyear - minage$, but depending on which recruitment function is used, the data before *firstyear* might not be used. The following sets of data must be given (Table 2). Y_i is the intermediate year (*firstyear*), Y_0 is $firstyear - minage$, and Y_N is the last year of the model run as defined above.

Table 2: Input data type keywords and ranges

Keyword	**Range**	**Description**
[numbers]	$Y_0 \rightarrow Y_i$	Population numbers up to and including intermediate year
[fishingmortality]	$Y_0 \rightarrow Y_i$	Fishing mortality up to and including intermediate year
[naturalmortality]	$Y_0 \rightarrow Y_N$	Natural mortality for the whole time period
[stockweight]	$Y_0 \rightarrow Y_N$	Stock weight for the whole time period
[catchweight]	$Y_0 \rightarrow Y_N$	Catch weight for the whole time period
[maturity]	$Y_0 \rightarrow Y_N$	Maturity for the whole time period

Each set of data has the following general format:

```
[keyword]
expected
<age vector of expected values 1>
...
<age vector of expected values N>
distortion <distortion 1>
...
distortion <distortion N>
```

The keyword identifies the type of data. Each age vector gives the expected value for each age in a given year. Each distortion then specifies how to draw a random value around the expected. The distortion format can be one of the following:

4.2.1 No distortion

```
distortion none
```

This will use the expected value directly, no error is added.

4.2.2 Normally distributed distortion

```
distortion normal
cv <cv age vector>
[bias <Optional bias age vector>]
trunk <truncation>
```

This will draw from a normal distribution with expected value as above, and standard deviation $sd = cv\hat{X}$ where $\hat{X}$ is the expected value.

Optionally bias can be included. This will give a normal distribution with mean $\hat{X} + \hat{X} \cdot \text{bias}$.

4.2.3 Multivariate lognormally distributed distortion

```
distortion multivariate
covariance <covariance matrix>
```

This will draw from a multivariate lognormal distribution with expected value as above, and the given covariance matrix with dimension $(maxage - minage + 1) * (maxage - minage + 1)$.

4.3 Recruitment File

The recruitment functions are defined in a file given by the control file. Several recruitment functions can be listed, so that for example a fixed recruitment can be used for the years where data on recruits are available, and a stock-recruit relationship can be used for other years. Here is an example of such a file.

```
[Recruitment]
generators 2

[RecruitmentGenerator]
firstyear 2004
type fixed
years 2
;       2004    2005
numbers 308000  664000
error   none

[RecruitmentGenerator]
firstyear 2006
type  ockham
a     529104
b     224482
error normal
sd    0.2
trunk 2.0
```

The keyword generators gives the number of recruitment functions. The recruitment functions are then listed in order. The format is as follows:

```
[RecruitmentGenerator]
firstyear <year>
type <function type>
<function specific input>
<error distribution>
```

4.3.1 Recruitment Functions

The recruitment type can be one of the following:

Fixed recruitment

This reads the recruitment numbers from a file. The recruitment is then:

$$R_y = N_y$$

The file format is:

```
type fixed
years <nr of years>
numbers <n_1 n_2 ... n_N>
```

Here N is the number of years that this recruitment function applies to (see above).

Beverton-Holt

Beverton-Holt gives recruitment according to the following function:

$$R = \frac{a \cdot SSB}{b + SSB}$$

where *SSB* is the spawning stock biomass. The file format for this function is:

```
type bevertonholt
a    <parameter a>
b    <parameter b>
```

Cyclic Beverton-Holt

The cyclic beverton-holt function has this format:

```
type      bevertonholt-cyclic
a         <parameter a>
b         <parameter b>
amplitude 0.43
period    6.57
phase     -1.92
k         0.19
w         4.29
```

This gives the same recruitment as the beverton-holt function above, but with a cyclic term included. The recruitment function is thus:

$$R = f(SSB)e^{amplitude \cdot \sin(\frac{2\pi(year-1946+phase)}{period})+k(\bar{w}-w)}$$

where $f(SSB)$ is the normal beverton-holt function:

$$R = \frac{a \cdot SSB}{b + SSB}$$

Ricker

The Ricker recruitment function gives recruitment according to the following function:

$$R = a \cdot SSB \cdot e^{-b \cdot SSB}$$

The file format is as follows:

```
type ricker
a    <parameter a>
b    <parameter b>
[ssb-cutoff <optional parameter ssb-cutoff>]
```

The parameter `ssb-cutoff` is optional. If this parameter is given, it is used as a maximum SSB. If the stock SSB is higher than `ssb-cutoff`, the value of `ssb-cutoff` will be used instead of SSB in the recruitment formula above.

Ockham

The ockham recruitment function gives recruitment according to the following function:

$$R = \begin{cases} a & \text{if} \quad SSB \geq b \\ \frac{a \cdot SSB}{b} & \text{if} \quad SSB < b \end{cases}$$

The file format is then:

```
type ockham
a    <parameter a>
b    <parameter b>
```

Cyclic Ockham

The cyclic ockham function has the following format:

```
type       ockham-cyclic
a          <parameter a>
b          <parameter b>
amplitude  0.43
period     6.57
phase     -1.92
k          0.19
w          4.29
```

This gives the same recruitment function as Ockham, with a cyclic term included.

$$R = f(SSB) e^{amplitude \cdot \sin(\frac{2\pi(year-1946+phase)}{period}) + k(\bar{w}-w)}$$

Where $f(SSB)$ is the same as the standard Ockham function.

$$f(SSB) = \begin{cases} a & \text{if} \quad SSB \geq b \\ \frac{a \cdot SSB}{b} & \text{if} \quad SSB < b \end{cases}$$

$\bar{w}$ is here the mean weight in the spawning stock.

This recruitment function is further described in Bogstad et al. (2004).

4.3.2 Recruitment Error

For all recruitment functions an error distribution must be specified (it can be set as *none* if no error is to be added). The error distribution is specified using one of the following formats.

Normal distribution

```
error normal
cv    <coefficient of variance>
[bias <Optional bias age vector>]
trunk <truncation>
```

This gives an error (ε) drawn from a normal distribution with $mean = 0.0$ and $sd = cv$. ε is truncated to be in the range $[-trunk \cdot cv \rightarrow trunk \cdot cv]$. If R is one of the recruitment functions in Section 4.3.1 the number of recruits is then $R' = R + R \cdot \varepsilon$.

Optionally bias can be included. This gives the number of recruits as $R' = R + R \cdot \text{bias} + R \cdot \varepsilon$.

Lognormal distribution

```
error lognormal
cv    <cv on a log scale>
[bias <Optional bias age vector>]
trunk <truncation>
```

This gives an error (ε) drawn from a lognormal distribution with $mean = 0.0$ and $sd = cv$. ε is truncated to be in the range $[-trunk \cdot cv \rightarrow trunk \cdot cv]$. The number of recruits is then $R' = R \cdot e^{\varepsilon}$.

Optionally bias can be included. This gives the number of recruits as $R' = R \cdot \text{bias} + R \cdot e^{\varepsilon}$.

No error

```
error none
```

This gives no error added to the recruitment. $R' = R$.

4.3.3 Special recruitment functions

In this section we list ad-hock recruitment functions which have been added for specific situations. They are not meant to be general.

Cyclic Haddock

This is a special recruitment function intended used for haddock. It gives recruitment according to the following 7-year cycle:

- Four years with *low* recruitment.

- One year with *good* recruitment.
- Probability p of a year with *outstanding* recruitment,
  or a year with *good* recruitment with probability $1 - p$.
- One year with *good* recruitment.

For the years with low recruitment a Ricker function is used. A ricker function is also used for the good years, and an Ockham function is used for the outstanding year. Thus three sets of recruitment parameters must be given; for the Ricker function in low years, for the ricker function in good years, and for the Ockham function in Outstanding years. In addition and error function must be specified after each of these recruitment functions. The Input formats are the same as described for the Ricker function, Ockham function, and error functions described in the previous sections. The complete format for the cyclic haddock recruitment is thus as follows:

```
type haddock-cyclic
low-recruitment
  a <parameter a for ricker>
  b <parameter b for ricker>
  [ssb-cutoff <optional parameter ssb-cutoff for ricker>]
  error <error type>
  <parameters for error>
good-recruitment
  a <parameter a for ricker>
  b <parameter b for ricker>
  [ssb-cutoff <optional parameter ssb-cutoff for ricker>]
  error <error type>
  <parameters for error>
outstanding-recruitment
  p <probability of outstanding recruitment>
  a <parameter a for ockham>
  b <parameter b for ockham>
  error <error type>
  <parameters for error>
```

4.4 Management File

The management file defines the management rule to use for setting the fishing quota. It also specifies how the real model is distorted before the managers see it, and how the decided quota is distorted before it is fed back to the real model. The format is as follows:

```
[ManagementDistortions]
ImplementationError distortion none
InputNumbers        distortion none
InputFishing        distortion none
Recruitment         distortion none
```

```
[ManagementRule]
type <management rule>
<input for management rule>
```

The format for distortion is the same as for the population file (Section 4.2). The rule type can be one of *constantf*, *tac*, or *lookahead*. Let F be the *reference* F (arithmetic average over the age range $fbarmin - fbarmax$) and S_a the selection age vector. The *fishing mortality* for age a is then given by:

$$F_a = F \cdot S_a \cdot \frac{\sum_{a=\text{fbarmin}}^{\text{fbarmax}} S_a}{(\text{fbarmax} - \text{fbarmin} + 1)}$$

All the rules will calculate a quota in tons for year $y+1$. We then use the selection pattern (from the input file) to find the appropriate fishing level that gives this quota. We then use this fishing level to calculate catch in numbers for year $y+1$. This catch in numbers is then fed back to the model and used for fishing in year $y+1$ after possibly being distorted. The ImplementationError above decides how the quota is distorted before it is fed back into the model as fishing mortality.

4.4.1 Constant F Rule

For the *constant F rule* the format is:

```
type         constantF
Selection    <selection age vector>
FaboveBpa    <F level above Bpa>
[Fmin        <Optional minimum F level>]
[FlowRec     Optional keyword enable adjustment of F at low recruitment>]
[LowRec      <LowRec> Recruitment belowe this number is considerd poor.]
[LowYears    <years> How many years of recruitment to consider]
[Freduction  <factor> At low recruitment multiply F by this factor]
[HistoricRec <recruitment vector> Historic recruitment before first year]
Maxinc       <Max increase in quota from last year>
Maxdec       <Max decrease in quota from last year>
MaxTAC       <Max allowed catch in weight>
FirstYearTAC <quota for intermediate year>
FbelowBpa    <function type>
```

The *fbelowpa* function is one of the keyword *flat*, *low*, or *linear*. The formats are:

```
flat
```

Which gives $F = F_{target}$ when $SSB < B_{pa}$

```
low
Flow <flevel>
```

Which gives $F = F_{low}$ when $SSB < B_{pa}$

```
linear
Bzero <Bzero>
```

Which gives $F = \frac{(SSB - B_{zero}) \cdot F_{aboveBpa}}{B_{pa} - B_{zero}}$ when $B_{zero} < SSB < B_{pa}$ and $F = 0$ when $SSB < B_{zero}$.

If $SSB(y+1) > B_{pa}$ and $SSB(y) > B_{pa}$, the quota is constrained by the limits on year-to-year change indicated by the keywords *maxinc* and *maxdec*: If the quota is more than *maxinc* percent larger than last years quota, or more than *maxdec* percent less, we adjust the quota to be within *maxdec* and *maxinc* percent of last years quota.

If *firstyeartac* is -1 the *maxinc* and *maxdec* values are not used for setting the quota in year $y+1$. If *firstyeartac* is positive the value is used when applying the *maxinc* and *maxdec* check in year $y+1$.

The $MaxTAC$ parameter makes it possible to use this option to apply a constant F rule with a catch ceiling.

If the *FlowRec* is present, the following keywords must also be present in this exact order:

```
FlowRec
LowRec      <LowRec>
LowYears    <years>
Freduction  <factor>
HistoricRec <recruitment vector>
```

This option will reduce F when the stock goes through several consecutive years with poor recruitment. The value Lowrec gives the level the average recruitment has to fall below to be considered poor. The value LowYears specifies over how many years this average recruitment is calculated.' The value *Freduction* gives a factor by which the target F level will be multiplied in case of poor recruitment. The recruitment vector gives recruitment values for the years before the intermidiate year in the model. There must be $LowYears - 1$ values given.

If the optional *Fmin* is given, it must be followed by an F value. Whenever there is a year where the fishing level is below this *Fmin* level, except in years where $SSB < Bpa$, F will be adjusted up to the Fmin level. Because the *constantF* rule applies a constant F level, the *Fmin* option is only useful if some other constrains that can potentially reduce F are also in use.

It is not advised to use both the FlowRec *and* Fmin *options at the same time. A warning will be given if you do so.*

4.4.2 Lookahead Rule

The Lookahead rule is a generalization of the 3-year rule. The 3-year rule was suggested by the Joint Norwegian-Russian Fisheries Commission in 2002, as a way of stabilizing the quota for the Northeast Arctic cod and haddock stocks by looking more than one year into the future.

The format for the lookahead rule is similar to the format for the *constantF* rule (4.4.1) with a few changes:

```
type         lookahead
[years       <N> Optional specification of how many years to simulate]
selection    <selection age vector>
FaboveBpa    <F level above Bpa>
[Fmin        <Optional minimum F level>]
[FlowRec     Optional keyword enable adjustment of F at low recruitment>]
[LowRec      <LowRec> Recruitment below this number is considered poor.]
[LowYears    <years> How many years of recruitment to consider]
[Freduction  <factor> At low recruitment multiply F by this factor]
[HistoricRec <recruitment vector> Historic recruitment before first year]
Maxinc       <max increase in quota from last year in percent>
Maxdec       <max decrease in quota from last year in percent>
MaxTAC       <max allowed catch in weight>
Firstyeartac <quota for intermediate year>
[MaxChangeRuleVariant <Optional keyword>]
Fbelowpa     <function type>
```

The Optional keyword *years* specifies how many years to simulate forward when deciding on the quota. If this keyword is omitted, it will be set to 3 years.

When the *Lookahead Rule* is used in year y to set the fishing quota for year $y+1$, we first simulate N years forward from these starting values, with a fishing level dependent on SSB(y+1) in the same way as in the *constant F rule.*

We set the quota for year $y+1$ as the average of the catch in tons in the years $y+1$, $y+2$, ... ,$y+n$ from the simulation we did.

If $SSB(y+1) > B_{pa}$ and $SSB(y) > B_{pa}$, the quota is constrained by the limits on year-to-year change in the same way as for the *constant F rule.* But if the optional keyword *MaxChangeRuleVariant* is specified, the year-to-year change is only constrained if $SSB(y') > B_{pa}$ for all the years y, $y+1$, $y+2$ and $y+n$.

If weight in catch is density-dependent (4.5) and the *3-year rule* is used, The *weight at age in the catch* used by the rule in year $y+1$ is also used int the remaining years.

The options *Fmin* and *FlowRec* work as for the *constantF* rule, and are described in section 4.4.1

4.4.3 3-year Rule

The 3-year rule has been deprecated, please use the lookahead rule instead.

The 3-year rule is a way of stabilizing the quota by looking more than one year ahead. It was suggested by the Joint Norwegian-Russian Fisheries Commission in 2002, for the Northeast Arctic cod and haddock stocks.

The format for the 3-year rule is:

```
type         3year
selection    <selection age vector>
```

```
FaboveBpa     <F level above Bpa>
Maxinc        <max increase in quota from last year in percent>
Maxdec        <max decrease in quota from last year in percent>
MaxTAC        <max allowed catch in weight>
Firstyeartac <quota for intermediate year>
[MaxChangeRuleVariant <Optional keyword>]
Fbelowpa      <function type>
```

When the *3-year Rule* is used in year y to set the fishing quota for year $y+1$, we first simulate 3 years forward from these starting values, with a fishing level dependent on SSB(y+1) in the same way as in the 3-year rule.

We set the quota for year $y+1$ as the average of the catch in tons in year $y+1$,$y+2$, and $y+3$ from the simulation we did.

If $SSB(y+1) > B_{pa}$ and $SSB(y) > B_{pa}$, the quota is constrained by the limits on year-to-year change in the same way as for the *constant F rule*. But if the optional keyword *MaxChangeRuleVariant* is specified, the year-to-year change is only constrained if $SSB(y') > B_{pa}$ for all the years y, $y+1$, $y+2$ and $y+3$.

If weight in catch is density-dependent (4.5) and the *3-year rule* is used, The *weight at age in the catch* used by the rule in year $y+1$ is also used for the years $y+2$ and $y+3$.

4.4.4 Tac Rule

For the *Tac Rule* the format is:

```
type tac
Selection <selection age vector>
maxF      <maximum F level>
TAC
<y_1> <Tac_1>
<y_2> <Tac_2>
.     .
.     .
.     .
<y_n> <Tac_n>
```

With this rule you simply specify in the input file the quota in tons for each year. The *maxF* parameter makes it possible to use this option to apply a fixed F rule with a catch ceiling.

4.5 Density dependent processes

In this file, you can specify that various processes in the model will be density dependent. The processes are growth (stock weights and catch weights), maturity, and cannibalism. In all cases the age range the process will apply to can be restricted to a subrange of the full age range in the stock. There is also an option to give minimum and maximum values for each age group.

The functional forms for growth, and the first maturity variant are described in Bogstad et al. (2004). All the functions are further described below.

The format for density dependent processes is:

```
stockweight <yes or no>
<if yes, additional input for stockweight>

catchweight <yes or no>
<if yes, additional input for catchweight>

maturity <yes or no>
<if yes, additional input for maturity>

cannibalism <yes or no>
<if yes, additional input for cannibalism>
```

4.5.1 Growth (stockweight and catchweight)

The following function is used for weight in the stock:

$$ws_{a,y} = \alpha_a TSB_{y-1} + \beta_a$$

For weight in the catch this function is used:

$$wc_{a,y} = \alpha_a ws_{a,y} + \beta_a$$

Both *stockweight* and *catchweight* uses the following format:

```
minage      <minage>
maxage      <maxage>
alpha       <alpha parameter age vector>
beta        <beta parameter age vector>

limit                          ; optional limit
  min  x1 ... xn               ; minimum value for each age (optional)
  max  y1 ... yn               ; maximum value for each age (optional)
```

4.5.2 Maturity

The maturation process can use one of two different functions. The *function* keyword followed by *densitydependent* or *weightdependent* selects which function to use.

The *densitydependent* function is:

$$P_{a,y}(TSB) = \frac{1}{1 + e^{-\alpha(\gamma a - \kappa - TSB_{y-1})}}$$

Where TSB denotes total stock biomass.

The *weightdependent* function is:

$$P_{a,y}(ws_{a,y}) = \frac{1}{1 + e^{-\lambda_a(ws_{a,y} - w_{50,a})}}$$

The format for the *densitydependent* function is:

```
function    densitydependent
minage      <minage>
maxage      <maxage>
alpha       <alpha parameter>
kappa       <kappa parameter>
gamma       <gamma parameter>

limit                         ; optional limit
  min  x1 ... xn              ; minimum value for each age (optional)
  max  y1 ... yn              ; maximum value for each age (optional)
```

The format for the *weightdependent* function is:

```
function    weightdependent
minage      <minage>
maxage      <maxage>
lambda      <lambda parameter age vector>
w50         <w50 parameter age vector>

limit                         ; optional limit
  min  x1 ... xn              ; minimum value for each age (optional)
  max  y1 ... yn              ; maximum value for each age (optional)
```

4.5.3 Cannibalism

The cannibalism process can use one of two different functions. The *function* keyword followed by *ssblag3* or *biomass6and7* selects which function to use. The *ssblag3* function is:

$$M2_{y,a} = \alpha_a SSB_{y-3} + \beta_a$$

Where SSB denotes spawning stock biomass. The *biomass6and7* function is:

$$M2_{y,a} = \alpha_a (N_{y,6} W_{y,6} + N_{y,7} W_{y,7}) + \beta_a$$

Both the *ssblag3* and *biomass6and7* function uses the following input format:

```
function    <ssblag3 or biomass6and7>
minage      <minage>
maxage      <maxage>
alpha       <alpha age vector>
beta        <beta age vector>

limit                         ; optional limit
  min  x1 ... xn              ; minimum value for each age (optional)
  max  y1 ... yn              ; maximum value for each age (optional)
```

4.6 Historic weight and maturity

In this file, you can specify how stock weights, catch weights, and maturity are drawn from historic time series. The format is:

```
numberofyears <n>

stockweight <yes or no>
file <file with historic stockweights>

catchweight <yes or no>
file <file with historic catchweights>

maturity <yes or no>
file <file with historic maturities>
```

Each of these files has the following format:

```
historicdata
d1,1 ... d1,a
 ...
dy,1 ... dy,a
```

where y is the number of years with historic data, and a is the number of age groups.

5 Prost Output Files

Summary output is written to the file `summary.csv`. More detailed output for individual variables can be found in `fishing.csv`, `distortedfishing.csv`, `recruit.csv`, `catch.csv`, `ssb.csv`, and `tsb.csv`. On the file `rule.csv` it is indicated how often the various segments of a HCR are activated.

The file `out.csv` gives very detailed output, and can become quite large. It is most useful for diagnostic purposes. All the output files are written as comma separated values (`.csv`) and can thus be imported into *Excel* or other spreadsheets for further processing.

6 Suggested extensions

- Extend the *linear* option in the *fbelowpa* function with a new parameter $Fzero$. The formula for F will then be: $F = Fzero + \frac{(SSB - B_{zero}) \cdot F_{aboveBpa}}{B_{pa} - B_{zero}}$ when $B_{zero} < SSB < B_{pa}$ and $F = Fzero$ when $SSB < B_{zero}$.
- Extending the historic option so that fishing pattern and natural mortality also can be drawn from historic times series.
- Allow for a non-zero proportion of F and M before spawning.
- Allow for the maximum increase/decrease in TAC from year to year to be given in biomass in addition to as a percentage.

7 References

Bogstad, B., Aglen, A., Skagen, D. W., Åsnes, M.N., Kovalev, Y., Yaragina, N. A. 2004. *Evaluation of the proposed harvest control rule for Northeast Arctic cod.* Pp. 396-417 in Report of the ICES Arctic Fisheries Working Group, Copenhagen 4-13 May 2004. ICES C.M. 2004/ACFM:28, 483 pp.

ICES 2004a. *Report of the ICES Study Group for Long Term Advice*, Copenhagen 23-27 February 2004. ICES C.M. 2004/ACFM:16, 38 pp.

ICES 2004b. *Report of the ICES Working Group on Fish Stock Assessment Methods*, Lisbon 11-18 February 2004. ICES C.M. 2004/D:03, 232 pp.

Skagen, D. W., Bogstad, B., Sandberg, P., and Røttingen, I. 2003. *Evaluation of candidate management plans, with references to North-east Arctic cod.* ICES C.M. 2003/Y:03, 19pp.

ICES WKREDMP, 20-25 January 2014

Working Document

Historic recruitment and spawning stock-recruitment relationship

By Kjell Nedreaas and Benjamin Planque, Institute of Marine Research, Norway

Historic development of recruitment

Drevetnyak et al. (2011) give an outline of the *Sebastes mentella* stock in the ICES areas I and II, its biology, distribution and fishery. Several exploratory analytical assessments confirm that the stock began to decline after the mid 1970ies, and the commercial stock reached a minimum in the early or mid 1990ies. The latter is further confirmed by recent assessments. The Barents Sea population (north of about 70N) reached its minimum abundance some years earlier, and the fishery in the Barents Sea reached the low level of 10,500 t in 1987. Despite the low stock level in the Barents Sea the population continued to produce good year classes for some years, up to about 1990. A likely reason for this was that the stock component along the slope south of about 70N which is composed predominantly of old, mature specimens, acted as a reproductive buffer for the entire stock. This component had never been harvested before and norwegian fishermen started fishing in this area in the mid and late 1980ies. After 5-6 years with fishing on this stock component, the recruitment quickly failed after 1990.

Poor recruitment has been observed in surveys from 1991 to 2005, with a recruitment failure during 1996-2003. The spawning stock in the near future is hence fully dependent on year classes that were born prior to the early 1990s, before the period of recruitment failure. Year classes born after this period will not significantly contribute to the spawning stock for at least 4-5 years, and the biomass of mature fish will depend on how well today’s adult stock is protected.

Figs. 1-3 show the historic recruitment of year classes at an early stage (0-group and/or juvenile *S. mentella* at age 1-2) from different surveys, and indirectly from the cod diet (Fig. 4).

Spawning stock-recruitment relationship in current assessment model

The Working Document by Daniel Howell presents an attempt to construct a SSB-recruitment relationship for *Sebastes mentella* in the Barents Sea/Norwegian Sea, which can be used for management strategy evaluations. It does not deal with attempting to understand all of the complexity and uncertainties surrounding the recruitment, but rather focuses on attempting to isolate a usable recent signal between spawners and recruits.

As can be seen in Fig 5 (recruitment at age 2 from the SCAA assessment model since 1992), there are clear time dependent trends, with three distinct phases of recruitment in the *S.mentella* stock in the Barents Sea/Norwegian Sea, an early phase of moderate recruitment, a middle phase of poor recruitment, and a recent phase of moderate and good recruitment. When plotted against modelled SSB in the year of spawning, there is no clear relationship, and a time-dependent pattern dominates. Even if one excludes the early and middle periods, there is still the problem of a dominant time dependent trend. (see the most recent years in Fig 5).

One limitation of the current SCAA assessment model is that the numbers-at-age data is limited to ages 2-18 after which all individuals are merge in a 19+ group. Using the population matrix it is possible to reconstruct the population biomass- and numbers-at-age for ages 2-19+ in 1992 (the starting year of the model), ages 2-20+ in 1993, ages 2-21+ in 1994 and so on. The resulting biomass/numbers in 2012 for ages 2-38+ (Fig. 6) indicate that 2/3rd of the biomass is included in the current plus group. However, such age-disaggregated stock information, i.e. beyond 30+, is currently only available for the most recent years. The SCAA model should be expanded to include separate age groups up to 30 years to cover most year classes appropriately. The ICES AFWG urge every nation to follow the ICES recommendations for the age reading of mature fish of 20 years or more (WKADR, ICES CM 2006/RMC:09, ICES CM 2009/ACOM:57). The sample size of aged *S. mentella* should be increased to ensure that reliable age-length-keys can be estimated.

During the current management plan work we therefore examined the relationship between recruitment and “mature biomass of at least a given age”. Since “19+” is the plus group reported in the current analytical assessment and is therefore available for the entire time period 1992-2012, we report this here. Similar investigations have been conducted for other ages, and the overall relationships presented here are robust to small changes in the choice of plus group to use. It can be seen in Fig. 7 that for the most recent period using 19+ biomass instead of “gonad based SSB” gives a much clearer signal between adult biomass and recruitment, especially in the recent years, and with a linear relationship that could be projected back to close to the origin. It is also clear that the three periods described above are still distinctly different from each other, and that only the most recent years gives a potential “spawning biomass-recruitment” relationship, but the time period is short.

Input recruitment to model projections

The short-, medium- and long-term projections and simulations done during the workshop for *S. mentella* in ICES areas I and II take into account the recruitment of age 2 from the most recent assessment (ICES 2013). This include the year classes from 1990 until 2010 which all are taken from the 2013 assessment, while information about the strength of the 2011-2013 year classes were taken from recent research surveys and projected as 2 year olds. There is currently no information on the abundance of the 2011-2013 year classes by age except at the 0-group stage. Abundance by length groups exists from the annual winter surveys (February) and ecosystem surveys (August-September), the latter, however, not being so simple to use due to overlapping lengths of 1 and 2 year olds. The Workshop therefore decided to estimate the abundance of the 2011-2012 year classes at age 2 from the linear regression of the historic (back to 1992) relationship between 0-group and 2-year olds from the assessment, and likewise between 5-9 cm fish during the winter survey and 2-year olds from the assessment. The average abundance estimated from these two regressions resulted in 210 millions and 322 millions at age 2 of the 2011 and 2012 year classes, respectively. For the most recent year class (2013), only one data point currently exist, i.e. as 0-group, and this was likewise projected to about 100 millions as 2 year old.

References

Drevetnyak K., Nedreaas, KH, and Planque, B. 2011. Redfish. Pp 292-307 in Jakobsen, T. and Ozhigin, VK (editors), The Barents Sea – Ecosystem, Resources, Management. Half a century of Russian-Norwegian cooperation. Tapir Academic Press, Trondheim, Norway.

ICES. 2013. Report of the Arctic Fisheries Working Group (AFWG), 18 - 24 April 2013, ICES Headquarters, Copenhagen. ICES CM 2013/ACOM:05. 682 pp.

Figures

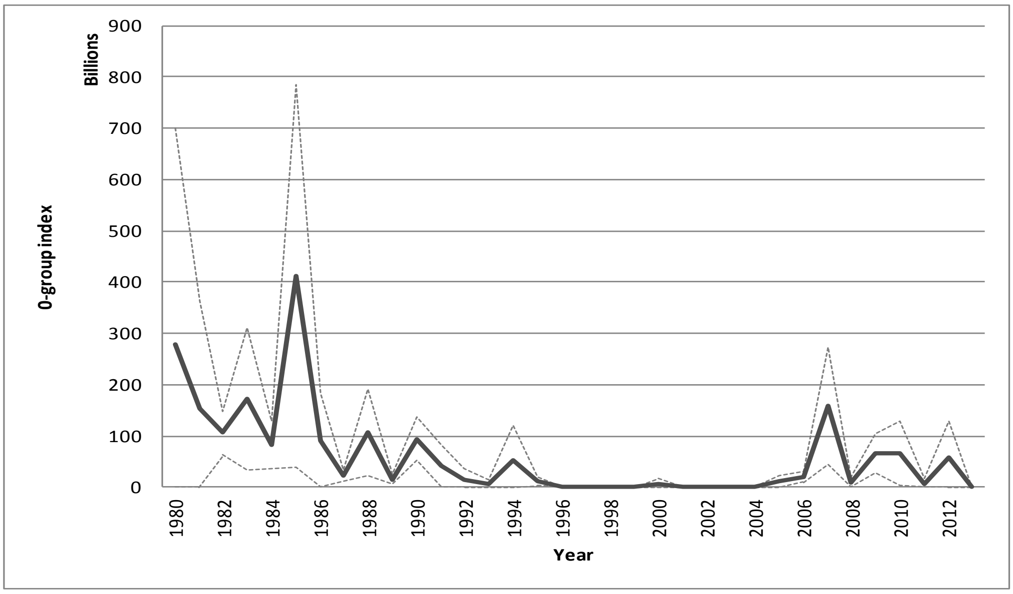


Figure 1. *Sebastes mentella* in Subareas I and II. Abundance indices (in millions) with 95% con-fidence limits of 0-group redfish (believed to be mostly S. mentella) in the international 0-group survey in the Barents Sea and Svalbard areas in August-September 1980-2013.

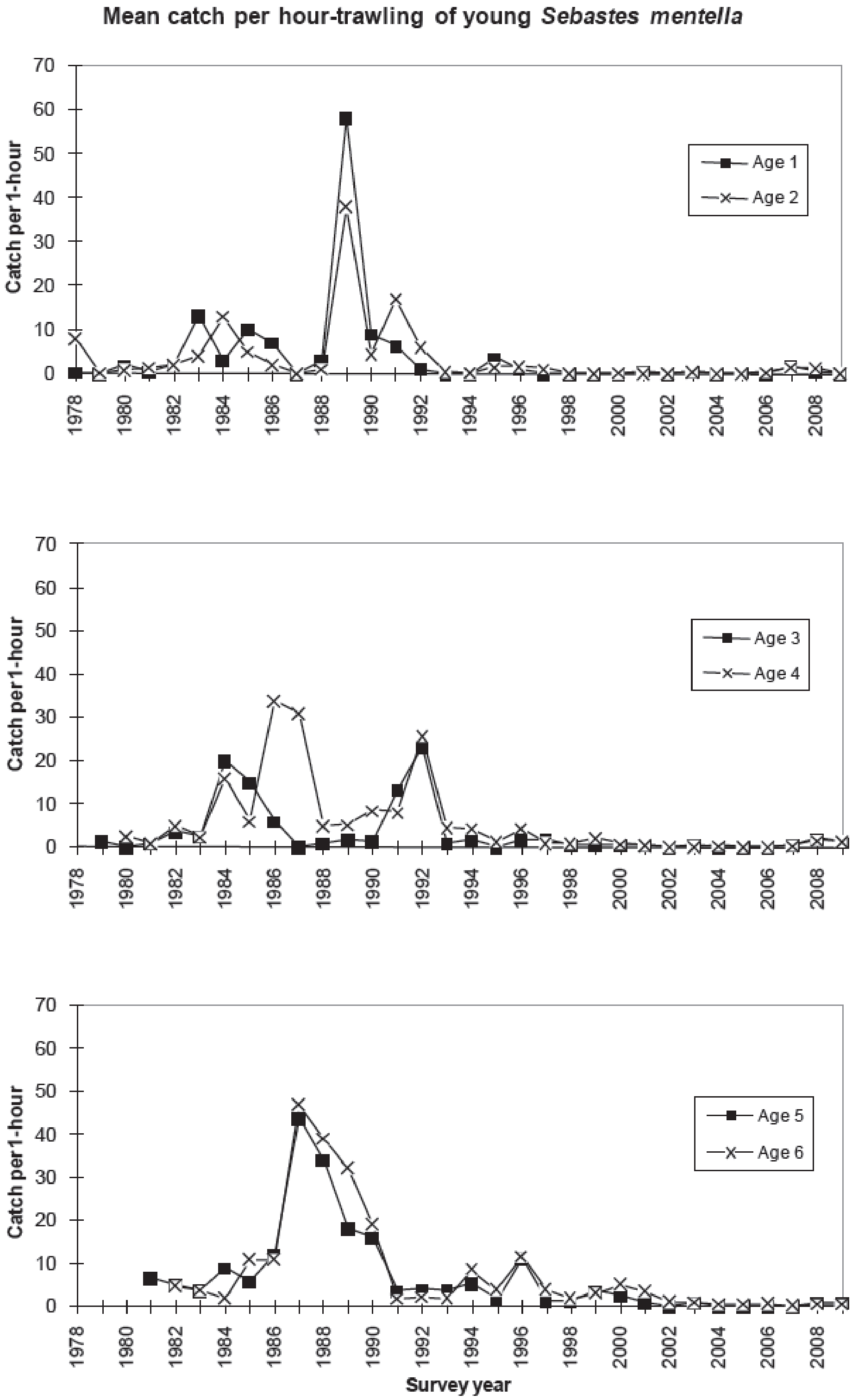


Figure 2. *Sebastes mentella* in Sub-areas I and II. Catch (numbers of specimens) per hour trawling of different ages of S. mentella in the Russian groundfish survey in the Barents Sea and Svalbard areas (from ICES AFWG).

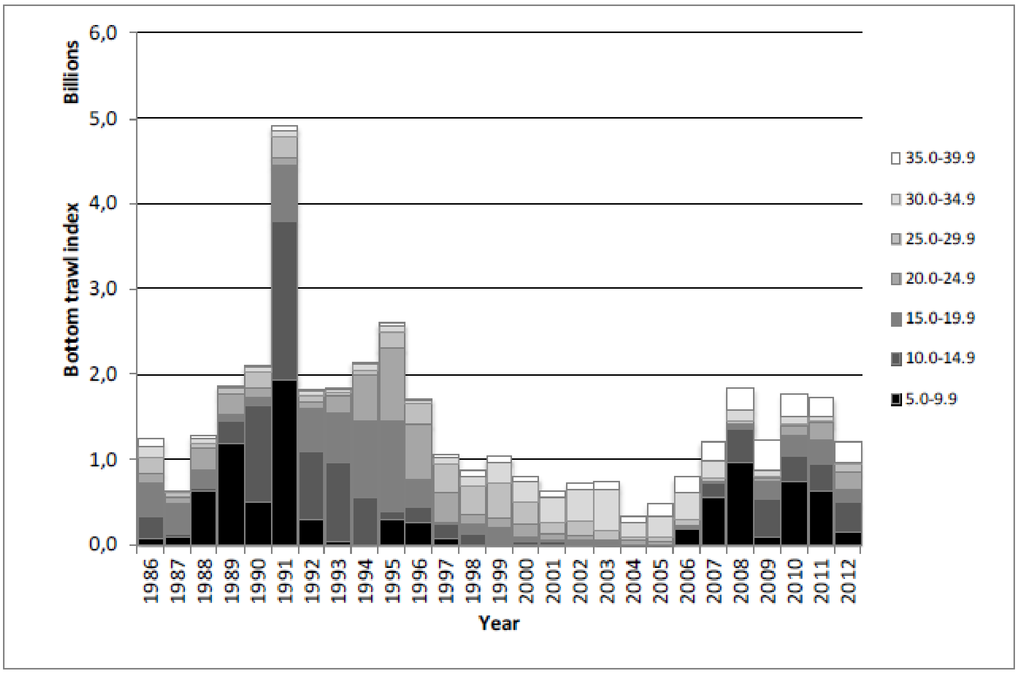


Figure 3. *Sebastes mentella* in Subareas I and II. Abundance indices disaggregated by length when combining the Norwegian bottom trawl surveys 1986-2012 in the Barents Sea (winter) and at Svalbard (summer/fall) (from ICES AFWG).

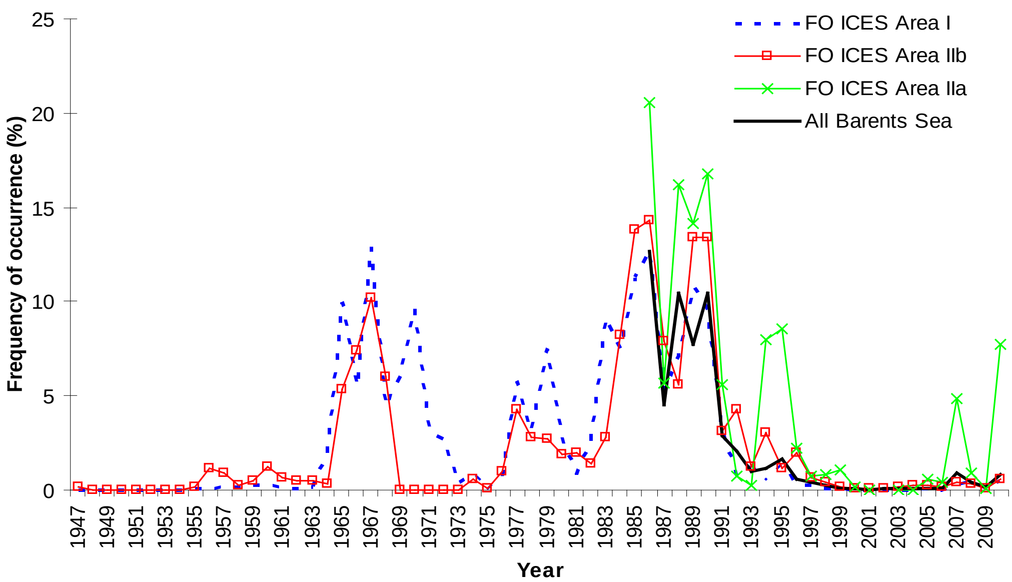


Figure 4. Frequency of redfish occurrence in NEA cod diet in the southern Barents Sea (ICES area I), along the Norwegian coast (ICES subarea IIa) and in the Bear Island-Spitsbergen area (ICES subarea IIb) in 1947-2010 due to the PINRO qualitative database (from Yaragina and Dolgov 2012)

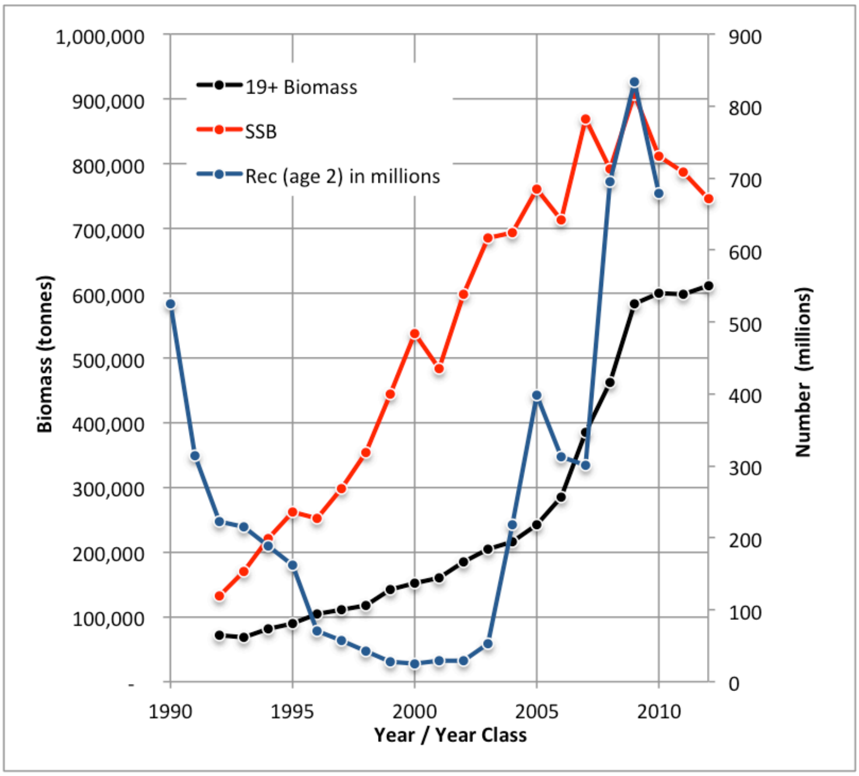


Figure 5. Recruitment at age 2 from the SCAA assessment model since 1992 and the corresponding total SSB and the SSB 19+ biomass (ICES 2013).

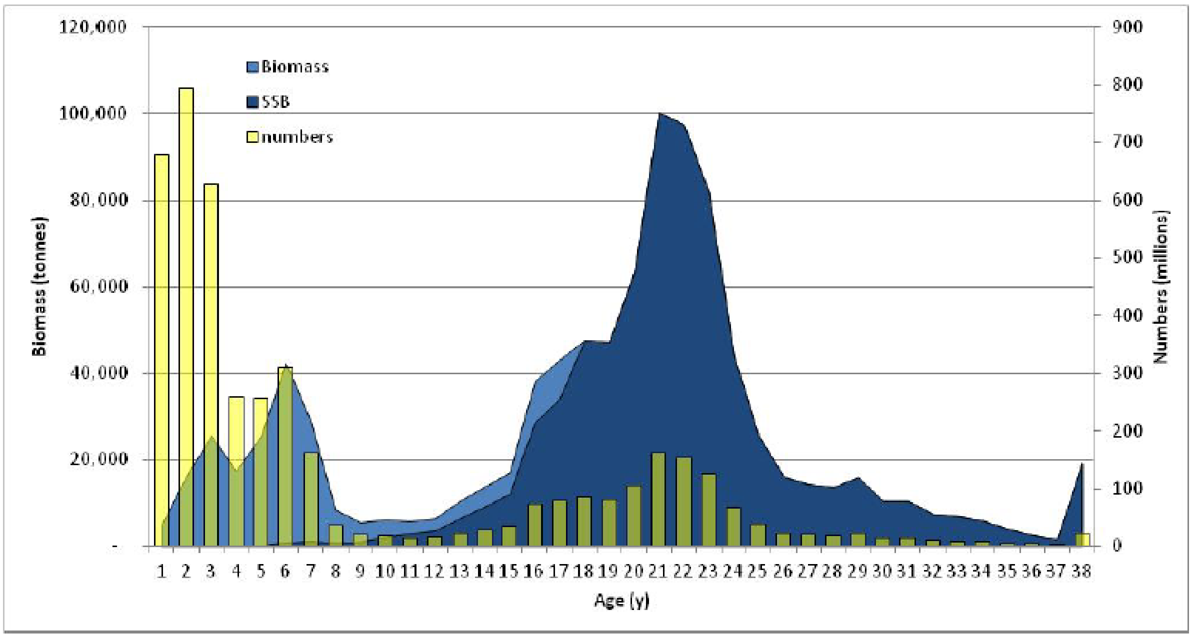


Figure 6. Modelled distribution of numbers, biomass and spawning stock biomass at age 2-38+ in 2012 (from ICES 2013).

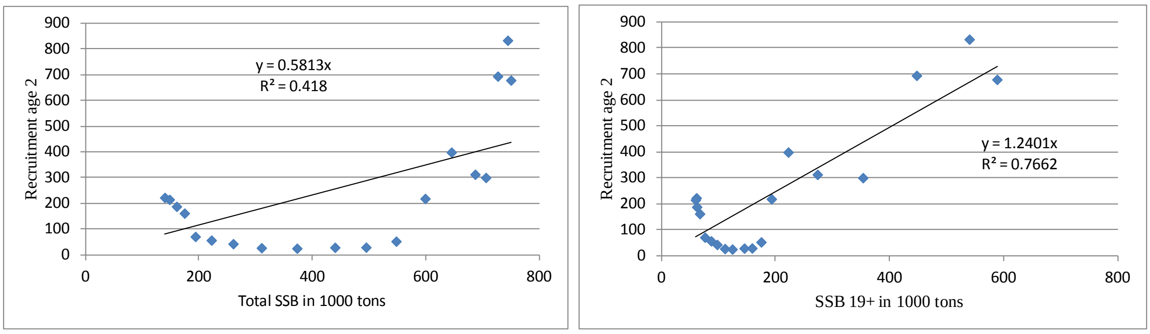


Figure 7. Spawning stock biomass (SSB) all ages (left panel) and SSB age 19+ (right panel) versus age 2 recruitment during 1992-2010 as estimated by the last ICES assessment (ICES 2013).

WD 6: *Sebastes mentella* recruitment in the Barents Sea
Daniel Howell

This document presents an attempt to construct a SSB-recruitment relationship for *Sebastes mentella* in the Barents Sea which can be used for management strategy evaluations. As such it does not deal with attempting to understand all of the complexity and uncertainties surrounding the recruitment, but rather focuses on attempting to isolate a usable recent signal between spawners and recruits.

As can be seen in figure 1 (recruitment at age 2 from the SCAA assessment model), there are clear time dependent trends, with three distinct phases of recruitment in the *S.mentella* stock in the Barents Sea, an early phase of moderate recruitment, a middle phase of poor recruitment, and a recent phase of moderate and good recruitment. When plotted against modelled SSB in the year of spawning, there is no clear relationship, and a time-dependent pattern dominates. The fact that the pattern is time dependent can be clearly seen in figure 2, where recruitment is simply plotted against year of spawning. Even if one excludes the early and middle periods, there is still the problem of a dominant time dependent trend. (see the most recent years in figure 2).

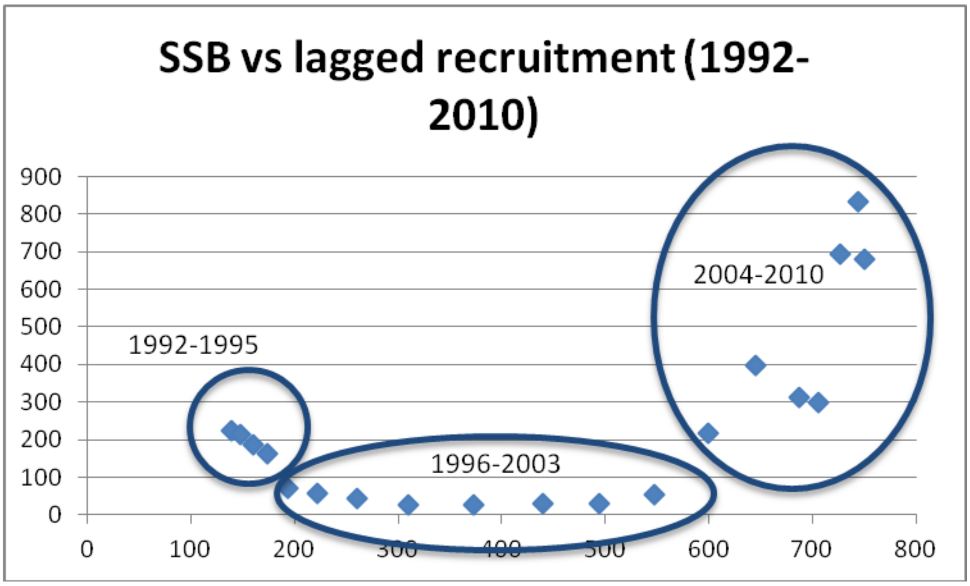


Figure 1. Recruitment at age 2 (in millions) on the y axis, against SSB in the year of spawning in 1000 tonnes on the x axis

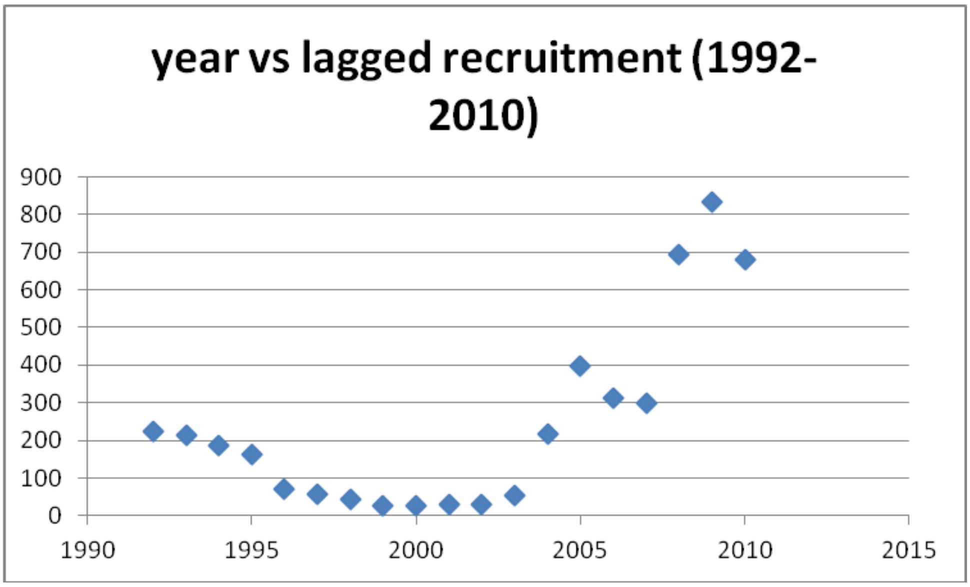


Figure 2. Recruitment at age 2 (in millions) on the y axis, against the year of spawning

There are reasons for believing that the early period may not be comparable to the later years. This represents a period before the heaviest fishing, when there were still relatively unfished populations, and the data suggests a higher growth rate for the older fish than has been observed more recently. The middle period represents a period with extremely low recruitment despite increasing SSB. The most recent period shows a generally increasing trend of recruitment as SSB, but fitting a slope through this period would suggest that there is zero recruitment below around 500,000-550,000 tonnes of SSB. From this is not clear how to proceed with constructing the SSB-recruitment relationship required for a management strategy evaluation.

It is of course possible that the recruitment trends are driven largely by environmental conditions. However, an alternate hypothesis is that older fish are dominant in the recruitment, and the youngest “mature” individuals (as measured by their gonads) are contributing little to the recruitment. We therefore examined the relationship between recruitment and “mature biomass of at least a given age”. Since “19+” is the plus group in much of the data, we report this here. Similar investigations have been conducted for other ages, and the overall relationships presented here are robust to small changes in the choice of plus group to use. It can be seen in figure 3 that for the most recent period using 19+ biomass instead of “gonad based SSB” gives a much clearer signal between adult biomass and recruitment, especially in the recent years, and with a linear relationship that could be projected back to close to the origin. It is also clear that the three periods described above are still distinctly different from each other, and that only the most recent years gives a potential “spawning biomass-recruitment” relationship.

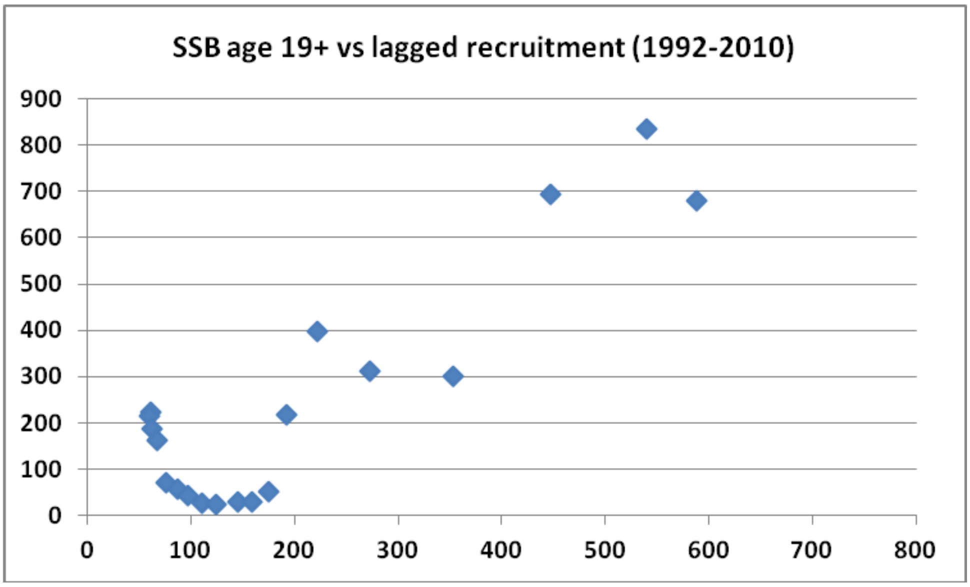


Figure 3. Recruitment at age 2 (in millions) on the y axis, against the 19+ biomass in the year of spawning in 1000 tonnes on the x axis

We therefore attempt to construct a SSB-recruitment relationship using the years 2004-2010. This is obviously a rather short time series, and there will inevitably be considerable uncertainty in the results, especially the unquantifiable uncertainty arising for not being certain how representative this short period is of the entire stock dynamics. However since this is all that is available, we proceed on this basis, and note that it is possible to apply addition periodic forcing functions to the recruitment during the management strategy evaluation in order to ensure that the final HCR is robust to a wider range of variability.

There is obviously no evidence here to support estimating a Ricker relationship, as we do not evidence for a descending limb to the recruitment curve. Nor is there clear evidence that the recent recruitment at age 2, between 700-800 million individuals, represents the maximum to the distribution. Again, in order to proceed we will assume, if necessary, that this is at or close to the maximum recruitment. We examine two possible functional forms, a Beverton-Holt relationship and a “hockey stick” relationship, and use the Excel solver to minimize the sum of square misfit for both approaches. As can be seen in figure 4, the available data strongly supports a linear relationship in this time period, with both estimated functions approximating a linear increase over the observed period, and both being consistent with zero recruitment at zero spawning biomass.

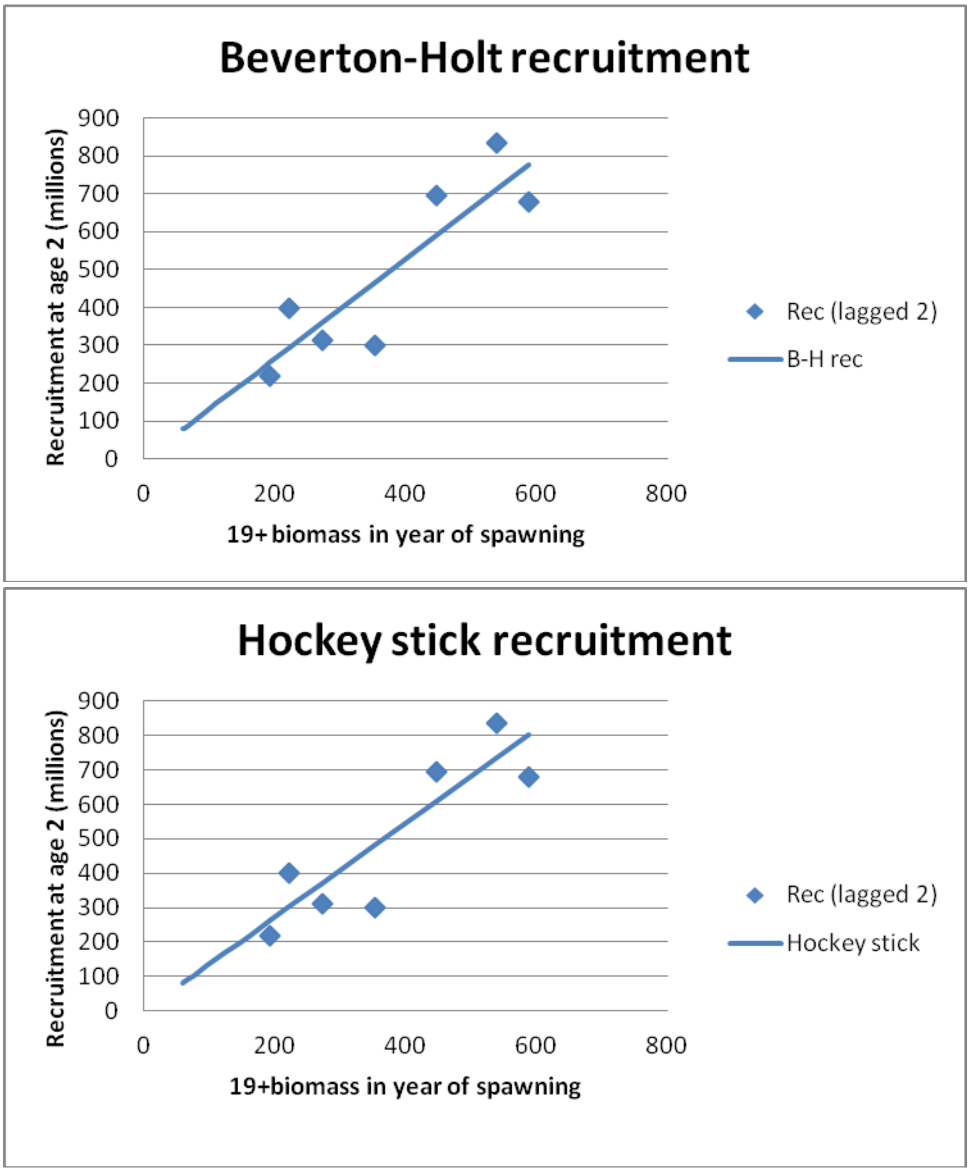


Figure 4. Excel optimisation of the Beverton-Holt (top) and Hockey stick (bottom) recruitment functions using the 2004-2010 19+ biomass.

Obviously such a recruitment relation cannot be applied "as is" to a forward simulation model, as the result would eventually be an infinite population. We therefore take the average of the most recent three years to represent the maximum recruitment (735 million) at a 19+ biomass of 535,000 tonnes. This may seen as a precautionary figure in the context of the MSE, as we know that recruitment can go at least that high. There is also some support from the 0-group survey, which extends back to 1980, when the SSB is believed to have been much higher. Only three times in that time series is a higher 0-group observed than in period 2004-2010), suggesting that recruitment above this assumed level is rather uncommon, even at high levels of SSB. Using a Beverton-Holt relationship with a fixed maxima gives a poor fit to the recruitment for moderate 19+ biomass, and we therefore use the hockey stick relationship with this breakpoint. The parameters for the estimated relationship are given in table 1, and the results are presented in figure 5. Figure 6 shows the fit of this relationship to the entire data, indicating that it is a relatively poor fit to the early years of the data series, underpredicting the recruitment at the start of the timeseries, and overpredicting in the middle.

Parameter	Value
Slope	1.3627
Breakpoint (19+biomass)	535

Table 1. Hockey stick parameters, assuming recruitment at age 2 in millions and 19+biomass in thousand tonnes.

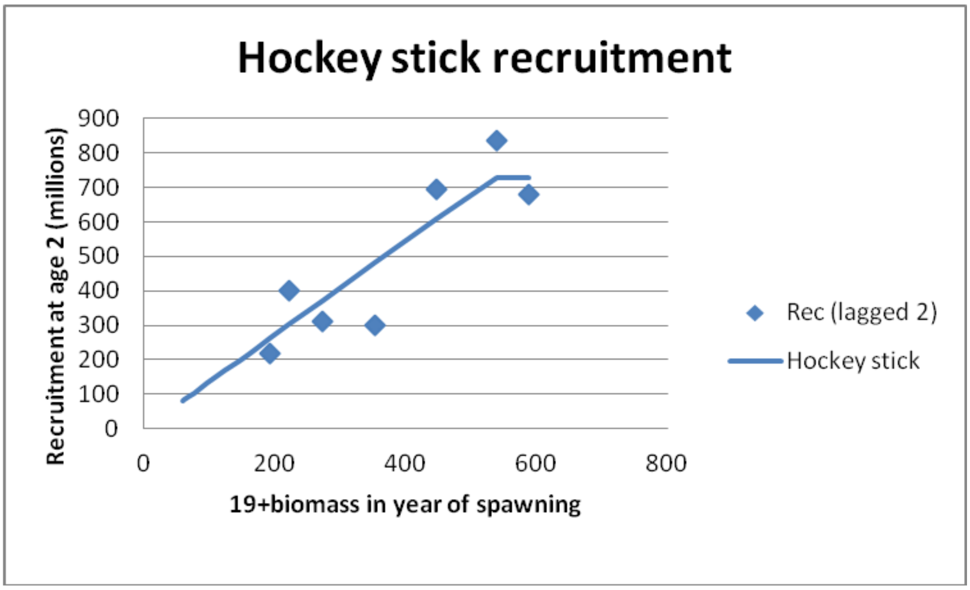


Figure 5. Excel optimisation of the Hockey stick recruitment functions using the 2004-2010 19+ biomass, with a break point imposed at 535 thousand tonnes.

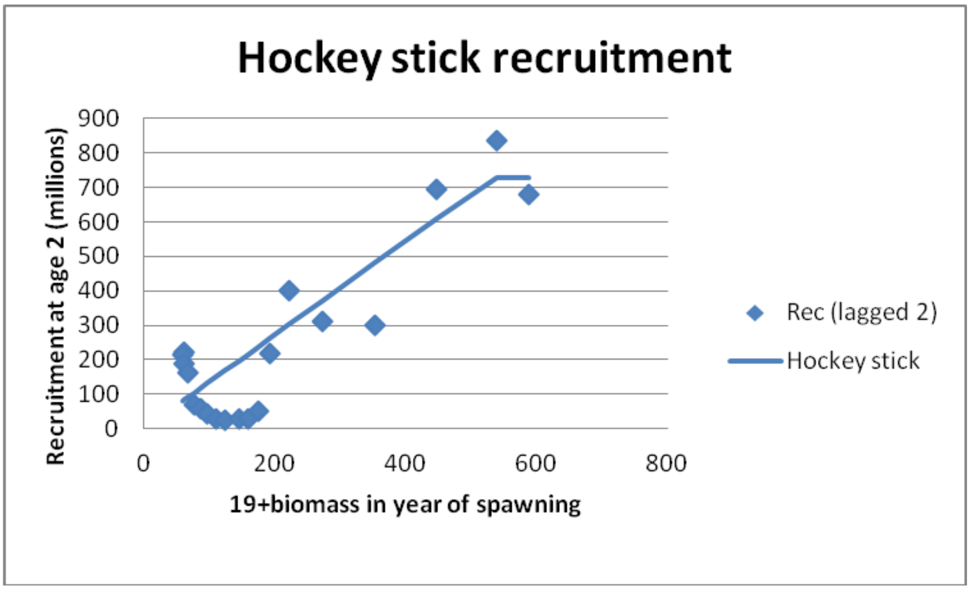


Figure 6. Optimised hockey stick recruitment functions using the 2004-2010 19+ biomass, with a break point imposed at 535 thousand tonnes, plotted against the entire 1992-2010 datas series.

As discussed above this a rather speculative relationship, with a rather short time period and an imposed maximum. Furthermore it does fully represent the recruitment in the earlier time periods. If one assumes that the situation at the start of the time period (with extensive unfished populations) is unlikley to reoccur in the foreseeable future, then the problem is that the recruitment function overestimates the recruitment in the middle (1996-2003) period. The possibility of periods of recruitment substantially below that predicted by the function examined here needs to be accounted for in the managment strategy evaluations.

ICES WKREDMP, 20-25 January 2014

Working Document

Possible maternal effects on the recruitment in *Sebastes spp.*

By Kjell Nedreaas and Benjamin Planque, Institute of Marine Research, Norway

Decadal variations in recruitment may be driven by environmental conditions. The great variability seen in the historic recruitment of new year classes at an early stage (0-group and/or juvenile *S. mentella* at age 1-2) from surveys and indirectly from the cod diet can support this (see Working Document on recruitment). However, the fishery and stock development since the mid 1980ies suggest that additional mechanism may have played a critical role. In particular, that the older component of the mature stock may be important for a successful reproduction, whilst the youngest "mature" individuals (as measured by their gonads) may be contributing less to the recruitment. This hypothesis is supported by several investigations on the reproductive potential and maternal effects in fish, including *Sebastes* species (e.g. Kjesbu 1988; Marshall et al., 1998; Berkeley et al. 2004a; Sogard et al., 2008; Field et al., 2008)

Drevetnyak (1991) collected data and estimated the fecundity for 9-19 years old *S. mentella* during 1966-1989. He concludes that population fecundity of *Sebastes mentella* does not only depend on abundance, but also on the age structure of the spawning population.

St-Pierre and Lafontaine (1995) found that for *S. mentella* in the Gulf of St. Lawrence, the absolute fecundity was significantly ($P<0.001$) related to fish length (Fig. 5; $r^2=0.65$) and fish weight ($r^2=0.67$). The slope coefficients of the log-log relationship were 4.165 and 1.423 for length and weight, respectively, and were both significantly ($P<0.001$) greater than 1.0. This indicates that redfish fecundity varies as a power function of length and weight.

According to Berkeley et al. (2004a), larvae from the oldest females in their experiments with rockfishes (*Sebastes* spp.) had growth rates more than three times as fast and survived starvation more than twice as long as larvae from the youngest females (Figs. 6-7). In this study, female age was a far better predictor of larval performance than female size. The apparent underlying mechanism is a greater provisioning of larvae with energy-rich triacylglycerol (TAG) lipids as female age increases. The volume of the oil globule (composed primarily of TAG) present in larvae at parturition increases with maternal age and is correlated with subsequent growth and survival.

Furthermore, Berkeley et al. (2004b) found evidence that older, larger female rockfishes (*Sebastes* spp.) produce larvae that withstand starvation longer and grow faster than the offspring of younger fish, that stocks may actually consist of several isolated reproductive units, and that recruitment may come from only a small and different fraction of the spawning population each year. None of these phenomena is accounted for in current management programs. They examined alternative management measures that address these specific issues and conclude that the best and perhaps only way to ensure old-growth age structure and complex spatial structure in populations of groundfish is through interconnected networks of marine reserves.

Although maternal effects were expressed somewhat differently across the different species and varied in their degree of expression, Sogard et al. (2008) conclude that maternal effect on larval quantity, quality or extrusion time is prevalent across a range of rockfish (*Sebastes* spp.) species. As females grow older and larger, they are presumably able to invest proportionately more energy into reproduction and produce greater relative numbers of larvae, which are often also of higher quality. Furthermore, by releasing larvae on an age dependent temporal schedule, females spread the reproductive effort of their maternal lineage across the spawning season. The importance of maternal size and/or age to a suite of critical reproductive traits in these fishes suggests that the removal of older and/or larger females from a local population may have disproportionately detrimental consequences for total larval survival and subsequent recruitment.

In all cases the maternal effects showed increasing lipid provisioning of larvae, greater weight-specific fecundity, and earlier timing of parturition in the spawning season with increasing maternal age or size. No effect of maternal age or size on larval size was, however, observed. Their results confirmed that older and larger females in rockfish populations may contribute disproportionately to larval recruitment by producing higher quality larvae and more larvae per unit biomass, and releasing them at a different time than younger and smaller females. A shift in timing of parturition with female age may constitute a diversified bet-hedging strategy, providing a temporal spread of spawning effort within a maternal lineage, whereby successive female progeny release larvae at different times within the same year.

Rodgveller et al. (2011) found that older, longer, and heavier females develop embryos earlier than younger, shorter, or lighter *Sebastes maliger*. Oil globule diameter and maternal length and weight were statistically linked, but weight-specific fecundity did not increase with maternal size or age, suggesting that reproductive output does not increase more quickly as fish age and grow. Age or size truncation of a rockfish population, in which timing of parturition is related to age and size, could, however, result in a shorter parturition season. This shortening of the parturition season could make the population vulnerable to fluctuating environmental conditions.

Spencer and Dorn (2013) examined the influence of maternal effects and weight-specific relative fecundity on stock status (defined as reproductive potential and measured as eggs, larvae, or spawning stock biomass), Fmsy, and the statistical fit of stock–recruitment curves estimated within the Bering Sea/Aleutian Islands Pacific ocean perch (Sebastes alutus) (Fig. 8). The results of this study illustrate how estimates of depletion and Fmsy depend on the choice of index for reproductive potential, and demonstrate how processes such as weight-specific fecundity, maternal effects in larval survival, and temporal trends in growth can interact to produce complex changes in estimated stock status and productivity. The Fmsy range for Pacific ocean perch from three indices of reproductive potential was 0.079–0.084. In future studies, the "signal to noise" properties of reproductive data should be explored more thoroughly, particularly in the context of the other input data to stock assessments. For example, incorporation of the uncertainty associated with reproductive information into assessments would allow evaluation of the relative gain obtained by improved sampling of reproductive information relative to other inputs such as abundance surveys. Additionally, management strategy evaluations can be used to evaluate the risk to yield and stock abundance associated with imprecise information on reproductive biology. The two examples demonstrate the influence of reproductive biology upon stock productivity even in cases where residual recruitment variation is relatively unaffected, and motivate the ongoing monitoring of reproductive status and its incorporation in estimation of fishing rate reference points.

The current assessment model used for *S. mentella* in ICES areas I and II relies mostly on research survey and fisheries catch data on fish between 2 and 18y old. Beyond this age, data is combined into a 19y+ group. This results in a simpler model for analytical assessment and constitutes an approach that is robust to errors in age reading for old individuals. However, the demographic structure of *S. mentella* beyond 18y, which may play a critical role for the reproductive output potential of the population, is not apparent in the results of the assessment model. To illustrate this we present below estimates of 'reproductive potential-at-age' for the population of *S. mentella* with no fishing, and emphasize the importance of the demographic structure of *S. mentella* beyond 18y (Fig. 5).

The calculations are similar to those presented in the NEAFC report of the zonal attachment working group (Anonymous, 2009). The population is assumed to be at equilibrium with constant recruitment and fixed natural mortality across all age groups, M=0.05. For each age group, it is possible to derive the number of individuals $Na = N1e^{-aM}$, with *Na* the number of fish of age *a*, *N1* the number of fish of age 1, and *M* the natural mortality. The maturity-at-age (*Mat*) is derived from Anonymous (2009) and the fecundity-at-age (*Fec*) is derived from the equation in St. Pierre and de Lafontaine (1995). By multiplying these three quantities it is possible to derive a proxy for the relative reproductive potential of each age group.

Figure 5 shows the reproductive potential as a function of age (black line) and the cumulated reproductive potential (red line). From this figure, it appears that at equilibrium, age groups between 22 y and 42y contribute most to reproduction and account for nearly 60% of the reproductive potential. While age groups up to 18y account for only 13% of the reproductive potential. Using the same data source it is possible to derive estimates of fecundity per unit weight as a function of age (Figure 6). This indicates that, for a given reproductive biomass (SSB) fish aged 42y can potentially produce twice as much offsrpings than fish aged 22y. The demographic composition of the 19+ group can therefore greatly influence the reproductive potential of the *S. mentella* population and should be considered in addition to the biomass estimate for this group. This could be done by using proxies for reproductive potential other than SSB, which is the only one considered at present in the assessment and advice (ICES, 2013).

The maternal effects on larval growth and survival were not considered in the above analysis. If considered, these effects would likely reinforce the importance of old individuals for the recruitment potential.

We believe that decreased robustness of the spawning stock, both in abundance and demography, by reducing the abundance of old spawners beyond a critical limit was an important factor that led to the reduced and subsequent collapsed recruitment during 1992-2003 (Fig. 6). And likewise, that the new promising recruitment after 2003 has been dependent on the re-establishment of a critical mass of older spawners in the spawning stock.

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Figures

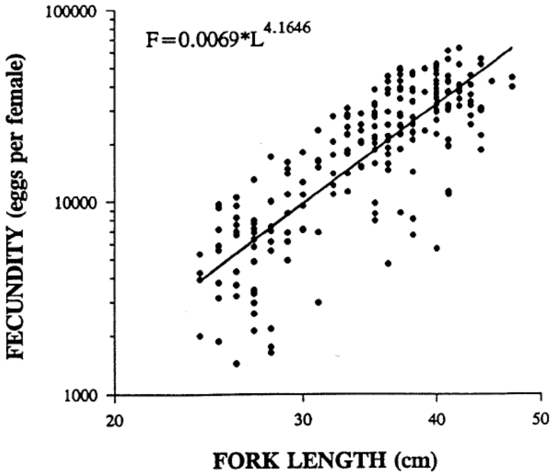

Figure 1. Logarithmic relationship between number of eggs and length for "mentella" type redfish (*S. mentella*) in the Gulf of St. Lawrence (from St-Pierre and Lafontaine 1995).

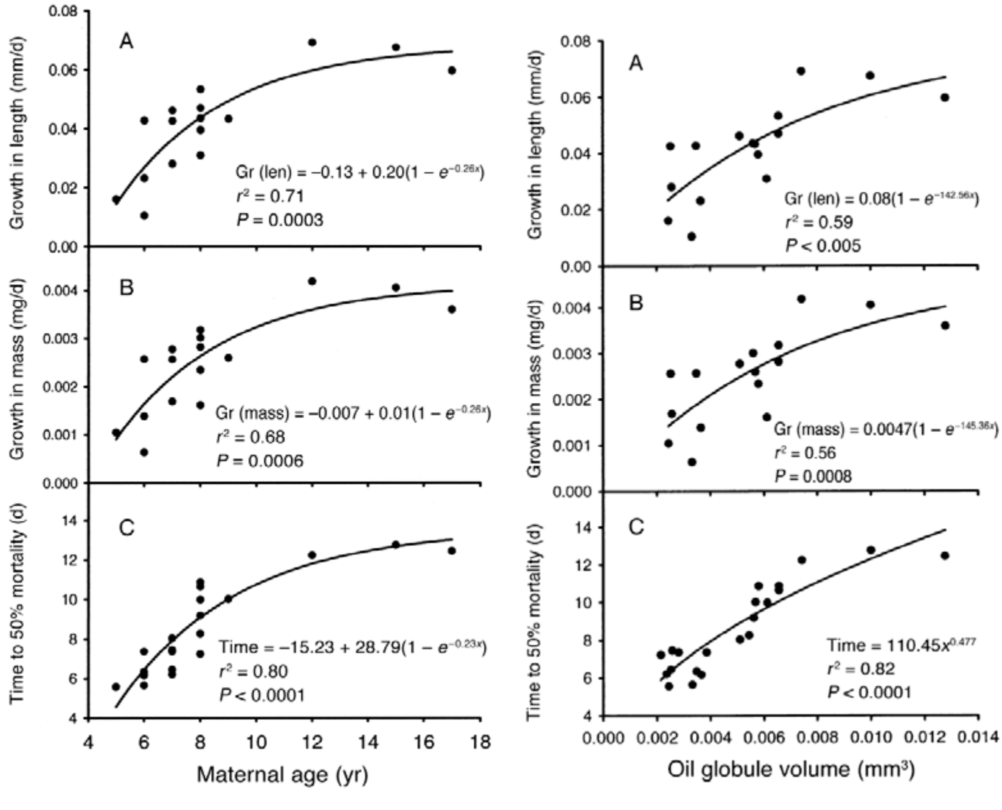

Figure 2. Left panel: relationships in black rockfish (*Sebastes melanops*) between maternal age and (A) growth in length, (B) growth in mass, and (C) median time to starvation. Right panel: Relationships in black rockfish between larval oil globule volume and (A) growth in length, (B) growth in mass, and (C) median time to starvation (from Berkeley et al (2004a)

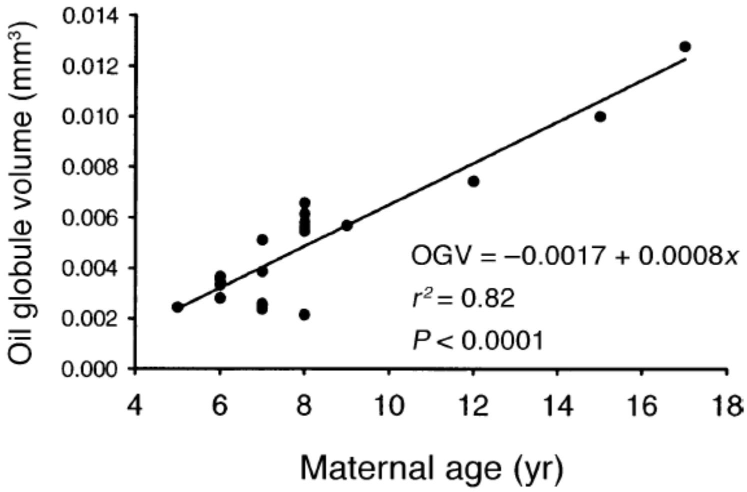

Figure 3. Relationship between larval oil globule volume (OGV) and maternal age in black rockfish (Berkeley et al. 2004a).

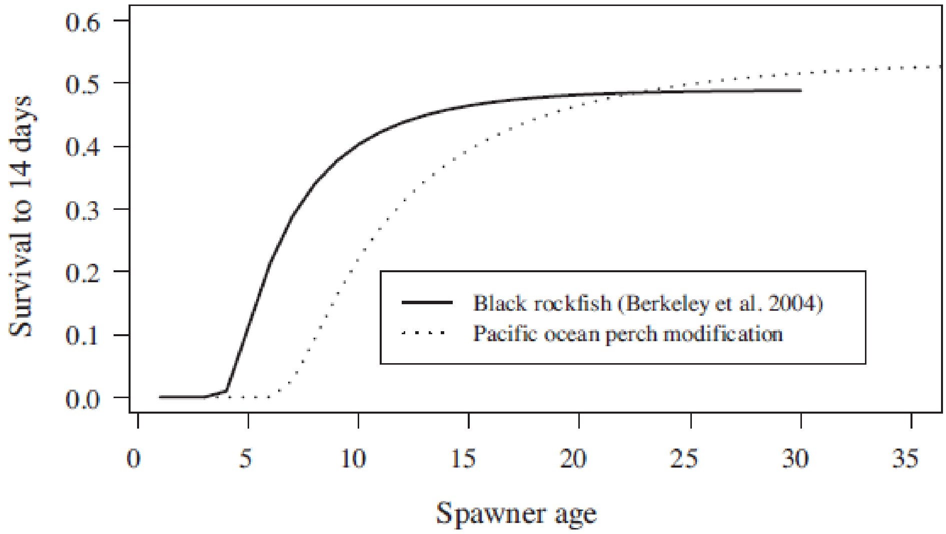

Figure 4. Survival to viable larvae as a function of spawner age for black rockfish (from Berkeley et al., 2004) and a hypothesized curve for Pacific ocean perch (Spencer and Dorn 2013).

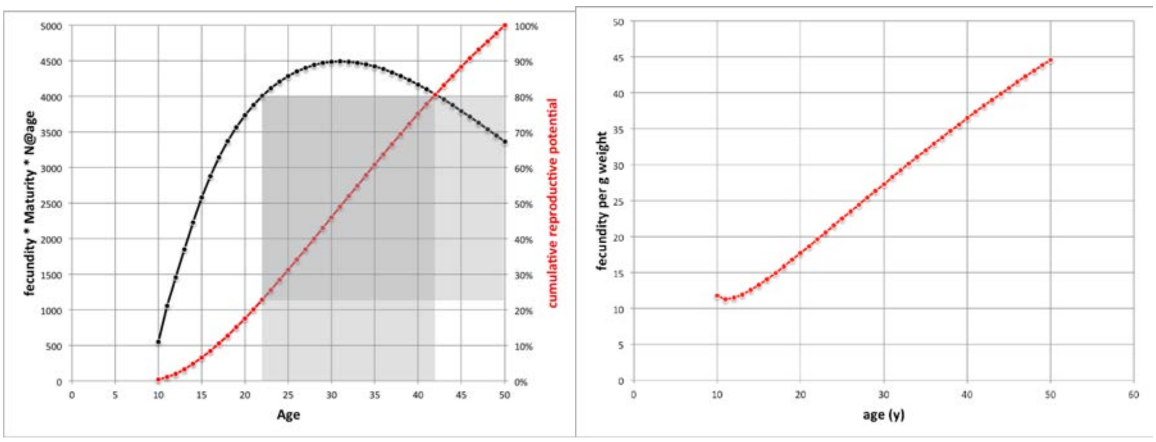

Figure 5. Left: reproductive potential-at-age (black line) and cumulated reproductive potential (red line) for unfished (F=0) populations of *S. mentella*. Right: fecundity per gram weight as a function of age.

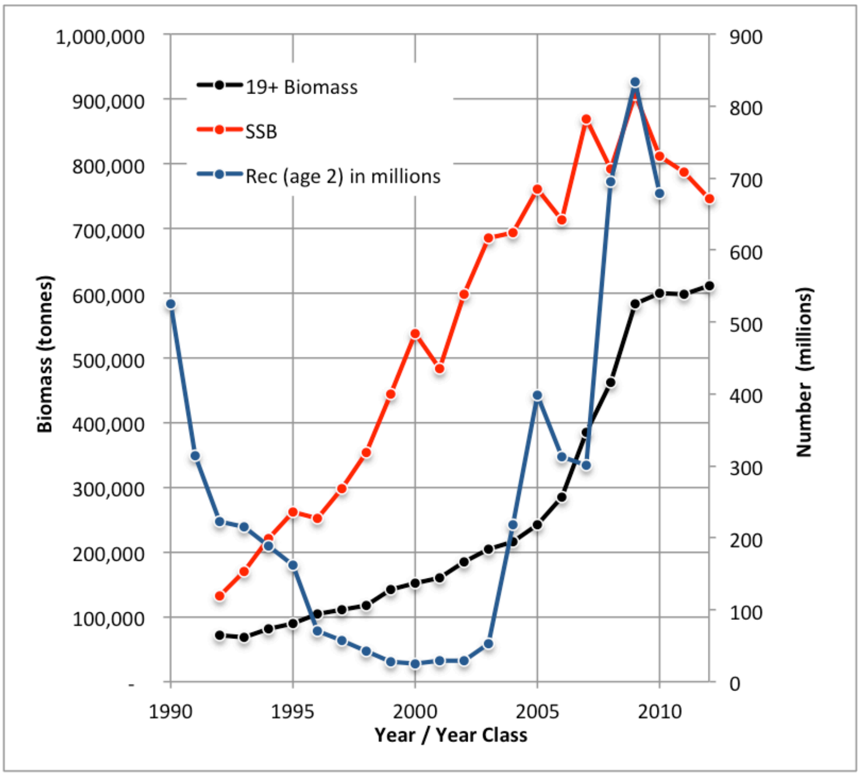

Figure 6. Recruitment at age 2 from the SCAA assessment model since 1992 and the corresponding total SSB and the SSB 19+ biomass (ICES 2013).

Annex 7: Stock Annex golden redfish (Subareas V and XIV)

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Golden redfish (*Sebastes marinus*) in ICES Subareas V and XIV
Working Group	NWWG
Date	February 2014
Revised by	Kristján Kristinsson, Höskuldur Björnsson

A. General

A.1. Stock definition

Golden redfish (*Sebastes marinus*) on the continental shelves of East Greenland, Iceland and Faroe Islands (ICES Subareas V and Division XIVb) is considered one stock. This stock definition is based on the location of copulation and extrusion area (Magnússon and Magnússon, 1977; Magnússon, 1980; ICES, 1983). The few population genetic studies that have been conducted do not provide definitive results (Nedreaas *et al*., 1994; Pampoulie *et al*., 2009).

Geographical range of golden redfish in the East Greenland/Iceland/Faroe Islands region is shown in Figure A.1.1. Golden redfish is most abundant in Icelandic waters (ICES Division Va) and where most of the commercial catches are taken. Golden redfish is found all around Iceland, but the areas of the highest abundance are west, southwest, south and southeast of Iceland at depths of 100–400 m. The main nursery areas are off East Greenland and Iceland. In Icelandic waters they are found all around the country, but are mainly located off the west and north coasts at depths between 50 m and 350 m. No nursery grounds are known in the Faroese waters (ICES, 1983; Einarsson, 1960; Magnússon and Magnússon, 1975; Pálsson *et al*., 1997). As they grow, the juveniles migrate along the north coast towards the most important fishing areas off the west and southwest coast, but also to the Southeast fishing areas and to Faroese fishing grounds in ICES Division Vb.

A.2. Fishery

Exploitation of golden redfish of the East Greenland/Iceland/Faroe Islands stock (EGIF stock) started in the mid-1920s in Icelandic waters, and after the Second World War in the two other areas (Figure A.2.1).

The landings from the EGIF stock peaked in 1955 to 160 000 t (Figure A.2.1.), in the same year the fishery started in East Greenland waters. Between 1956 and 1978 the landings gradually decreased in all areas to 50 000 t but then increased again, especially in Icelandic waters. The total annual landings rose to a peak of 130 000 t in 1982. In the late 1980s the fishery collapsed in East Greenland waters and decreased in the two other areas. For the past 20 years the annual landings have been around 40 000 t and a 95–98% has been taken in Icelandic waters.

Annual landings and overview of the major fleet

Iceland

The fishery for golden redfish in Icelandic waters started in the early 1920s but annual landings started to increase in the late 1930s (Figure A.2.1). Annual landings in

1936–1939 varied between 40–65 thousand tonnes, compared to an average of 10 thousand tonnes in 1922–1935. During the interwar period redfish was mainly caught by foreign vessels operating in Icelandic waters. This fishery was unimportant during World War II but increased rapidly after the war and to a record high of 140 thousand tonnes in 1951. Annual landings in 1956–1977 ranged between 60–115 thousand tonnes. The majority of the catches were taken by foreign vessels, mainly from West-Germany. Since 1977, with the expansion of the EEZ to 200 nautical miles, mainly Icelandic vessels have fished for golden redfish in Icelandic waters. Landings declined from about 98 000 t in 1982 to 39 000 t in 1994. Since then, landings have oscillated between 32 000 and 49 000 t. Average annual landings in 2000–2011 have been around 40 000 tonnes.

The fishery for golden redfish in Icelandic waters is directed and predominantly conducted by the Icelandic bottom-trawl fleet, and accounts for more than 90% of the total catch. The rest is partly caught as bycatch in the gillnet, longline, and lobster fisheries. The most important fishing grounds are southwest and west of Iceland at 200–400 m depth.

The fishing fleet operating in Icelandic waters consists of diverse boat types and sizes, operating various types of gear. Golden redfish is mostly caught by the same vessels that are fishing for the pelagic and Icelandic slope *S. mentella* stocks. These are trawlers larger than 40 BRT equipped with bottom trawls.

Greenland

The fishery for golden redfish in East-Greenland waters (ICES Subarea XIV) started in the early 1950s and annual landings have been more variable than in the other areas (Figure A.2.1). Until early 1980s the fishery was mainly conducted by West-Germany, except in 1976 when the former USSR exceeded the catches of West-Germany.

The landings peaked in 1955 to about 80 000 t shortly after the fishery commenced in the area. The annual landings then declined and ranged between 8000 and 41 000 t during the period 1957 to 1975, being on average 27 000 t. In 1976 the landings increased suddenly to 54 000 t mainly because of increased redfish fishery of the former Soviet Union. The annual landings immediately dropped to 15 000 t and were at that level for the next few years. After the landings reached 31 000 t in 1982, the golden redfish fishery drastically declined within the next three years. During the period 1985–1994, the annual landings from Subarea XIV varied between 600 and 4200 t, but from 1995 to 2008 there has been little or no direct fishery for golden redfish and landings were 200 t or even less, mainly taken as bycatch in the shrimp fishery. In 2009, a fishery targeting redfish was initiated in ICES XIV. In 2010, landings of golden redfish increased considerable and were 1600 t, similar to early 1990s levels. This increase is mainly due to increased directed redfish fishery in the area.

Faroe Islands

Directed fishery for golden redfish in Faroese waters (ICES Division Vb) was very little until 1978 (Figure A.2.1.). Landings rose to 9000 tonnes in 1985 but dropped gradually to 1500 t in 1999. Between 1999 and 2005 annual landings varied between 1500 and 2500 t, but afterwards they have oscillated between 460 to 690 t. Annual landings had never been so low.

The majority of the golden redfish caught in Division Vb is taken by pair and single trawlers (vessels larger than 1000 HP), mainly as bycatch in other fisheries.

Management and regulations

Iceland

The Ministry of Fisheries and Agriculture in Iceland is responsible for the management of all Icelandic fisheries and law enforcement within the Icelandic Exclusive Economic Zone (EEZ). The Ministry issues regulations for commercial fishing for each fishing year (from September 1st to August 31st the following year), including allocation of the TAC for each of the stocks subject to such limitations. Below is a short account of the main features of the management system, with emphasis on golden redfish when applicable. Further and detailed information on the management and regulations can be found at http://www.fisheries.is/.

A system of transferable boat quotas was introduced in 1984, but was changed to an individual transferable quota (ITQ) system in 1990. The fisheries are subjected to vessel catch quotas. The quotas represent shares in the national total allowable catch (TAC). Since the 2006/2007 fishing season, all boats operate under the TAC system. Until 1990, the quota year corresponded to the calendar year but since then the quota, or fishing year, starts on September 1 and ends on August 31 the following year. The agreed quotas are based on the Marine Research Institute's TAC recommendations, taking some socio-economic effects into account.

Within this system, individual boat owners have substantial flexibility in exchanging quota, both among vessels within the same company and among different companies. The latter can be done via a temporary or permanent quota transfer. In addition, some flexibility is allowed to individual boats regarding the transference of allowable catch of one species to another. These measures, which can be acted on more or less instantaneously, are likely to reduce initiative for discards (which is effectively banned by law) and misreporting than can be expected if individual boats are restricted by TAC measures alone. They may, however, result in fishing pressures of individual species to be different than intended under the single species TAC allocation.

Furthermore, a vessel can transfer some of its quota between fishing years. There is a requirement that the net transfer of quota between fishing years must not exceed 10% of a given species (was changed from 33% in the 2010/2011 fishing year). This may result in higher catch in one fishing year than the set TAC and subsequently lower catches in the previous year.

Landings in Iceland are restricted to particular licensed landing sites, with information being collected on a daily basis time by the Directorate of Fisheries (the native enforcement body). All fish landed has to be weighted, either at harbour or inside the fish processing factory. The information on landings is stored in a centralized database maintained by the Directorate and is available in real time on the Internet (www.fiskistofa.is). Between 5–10% of the golden redfish caught annually in Icelandic waters is landed in foreign ports. The accuracy of the landings statistics are considered reasonable although some bias is likely.

All boats operating in Icelandic waters have to maintain a logbook record of catches in each haul. For the larger vessels (for example vessels using bottom and pelagic trawls) this has been mandatory since 1991. The records are available to the staff of the Directorate for inspection purposes as well as to the stock assessors at the Marine Research Institute.

Redfish (golden redfish (*S. marinus*) and Icelandic slope *S. mentella*) has been within the ITQ system since the beginning. Icelandic authorities gave a joint quota for these two species until the fishing year 2010/2011, although the MRI has provided a separate advice for the species since 1994. The separation of quotas was implemented in the fishing year that started September 1, 2010. Since the 1994/1995 fishing year, the total annual landings of golden redfish have exceeded the recommended TAC in most years.

Regulations

With some minor exceptions, it is required by law to land all catches. For golden redfish there is no formal harvest control rule. 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.

The minimum legal catch size for golden redfish is 33 cm for all fleets, with allowance to have up to 20% undersized (i.e. <33 cm) specimens of golden redfish (in numbers) in each haul. If the number of redfish <33 cm in a haul is more than 20%, fishing is prohibited for at least two weeks in those areas. Below is a sort description of area closures in Icelandic waters.

REAL-TIME AREA CLOSURE: A quick closure system has been in force since 1976 to protect juvenile fish. Fishing is prohibited up to two weeks in areas where the number of small fish in the catches has been observed by inspectors to exceed certain percentage (for example 25% or more of <55 cm cod and saithe, 25% or more of <45 cm haddock, and 20% or more of <33 cm redfish). If there are several consecutive quick closures in a given area the Minister of Fisheries can close the area for longer time with regulations, forcing the fleet to operate in other areas. Inspectors from the Directorate of Fisheries supervise these closures in collaboration with the Marine Research Institute.

PERMANENT AREA CLOSURES: In addition to allocating quotas on each species, there are other measures in place to protect fish stocks. Based on knowledge of the biology of various stocks, many areas have been closed temporarily or permanently aiming at juvenile protection. Figure 1 shows the map of such area closures that was in force in 2006. Some areas have been closed for decades.

TEMPORARY AREA CLOSURES: The major spawning grounds of cod, plaice and wolfish are closed during the main spawning period of these species. This measure was partly initiated by the fishermen.

Since 1991, when the first redfish closure took place, there have been another 68 quick closures in golden redfish fishing grounds (Table A.2.1 and Figure A.2.2). Quick closures have been fewer for small golden redfish since 2001, or three every year on average, because large areas southwest and west of Iceland are permanently or temporarily closed to trawling to protect juvenile golden redfish (Figure A.2.3). These areas were closed partly because quick closures on redfish fisheries happened very often during the period 1991–1995 (Schopka, 2007).

Faroe Islands

Management measures and regulations

Since 1 June 1996, a management system based on a combination of area closures and individual transferable effort quotas in days within fleet categories has been in force for the Faroese demersal fisheries. The individual transferable effort quotas apply to all fleets (from 2010), except for gillnetters fishing for Greenland halibut and monkfish, which are regulated by a fixed number of licences, by fishing depth and technical measures like maximum allowed number of nets, mesh size and maximum fishing time for each set. Pelagic fisheries for herring, blue whiting and mackerel are regulated by TACs. Trawlers are in general not allowed to fish within the 12 nautical mile limit and large areas on the shelf are closed to them. Inside the 6 nautical miles limit only longliners less than 110 GRT and jiggers less than 110 GRT are allowed to fish. The Faroe Bank shallower than 200 m is closed to all trawl and gillnet fisheries.

Technical measures such as area closures during the spawning periods, to protect juveniles and young fish, and mesh size regulations are a natural part of fisheries regulations.

Vessels from other nations are licensed to fish in Faroese waters through bilateral and multilateral agreements, regulated by TACs. Only Norway and EU have permission to fish deep-water species, but since no agreement has been reached in the negotiations on mutual fishing rights between the Faroese and Norway/EU since 2010, these parties, for the moment, are not allowed to fish in Faroese waters.

Greenland

Management measures and regulations

Management of golden redfish in the Greenland EEZ is managed by the Greenland Ministry of Fisheries, Hunting and Agriculture. There was no redfish directed fishery for more than a decade in east Greenland, but in 2009 an experimental fishery was successful, and the fishery was reopened. The fisheries are subjected to vessel catch quotas, which represents a share of the total allowable catch (TAC). The TAC is set by the Ministry of Fisheries, Hunting and Agriculture and is based on a mixed fishery, with no distinction being made between *S. marinus* and *S. mentella*. Hence, the mixed species TAC for 2010 was 6000 t, and this increased to 8500 t in 2011–2012 (assuming an 80:20 split between *S. mentella* and *S. marinus*).

All vessels are required to fill out logbooks records of the catch in each haul, and the information is made available to the Greenland Institute of Natural Resources. The fishery has since 2009 also been obligated to provide frozen samples of whole fish to the Greenland Institute of Natural Resources, with the objective to provide a species splitting factor and the collection of samples for a genetically based stock assignment study. Continued sampling from catches is necessary to allow for a continued monitoring of shifts in the species composition.

Catches of Golden redfish in the redfish directed fishery reached approximately 1700 t in 2011 (estimated from an 80:20 split of 8381 t mixed catches of *S. mentella* and *S. marinus*). The catches are taken in a small area just east of Kleine Banke (64°N 36°W and just northeast from here at 64°30′ N–65°N and 35°W). The fishery contracted from 2009–2011, and it appears that the fishery is taking place on a large local aggregation of redfish.

Greenland opened an offshore cod fishery on the east coast of Greenland in 2008. To protect spawning aggregations of cod present management measures in Greenland EEZ prohibits trawl fishery for cod north of 63°N latitude. In 2009 and 2010 in this area was extended to 62°N. In 2012 this area closure was annulled, and instead all fishing directed for cod must take place after July 1st. This is done to protect spawning aggregations of cod in the Greenland EEZ. Due to the depth distribution of *S. marinus* (Hedeholm and Boje, 2012, WD#9) it is vulnerable to bycatch in the cod fishery, however, the current level of bycatch is considered insignificant (<1.5 t).

The introduction of grid separators in the shrimp fishery has reduced bycatch to very small amounts, and is not considered significant, especially since the shrimp fishery in the East Greenland area is limited (Sünksen, 2007).

A.3. Ecosystem aspects

Golden redfish is ovoviviparous, meaning that eggs are fertilized, develop and hatch internally. The male and female mate several months before the female extrudes the larvae. The females carry sperm and non-fecundated eggs for months before fertilization takes place in winter. Females are thought to have a determinate fecundity. Golden redfish produce many, small larvae (37–350 thousand larvae) that are extruded soon after they hatch from eggs and disperse widely as zooplankton (Jónsson and Pálsson, 2006). The extrusion of larvae may take place over several days or weeks in a number of batches. Knowledge of the biology, behaviour and dynamics of golden redfish reproduction is very scarce.

Growth and maturity

Golden redfish is, like most redfish species, long-lived, slow-growing and late-maturing. Males mature at age 8–10 at size 31–34 cm, whereas females mature age 12–15 at size 35–37 cm (Jónsson and Pálsson, 2006).

Diet

The food of golden redfish consists of dominant plankton crustaceans such as amphipods, copepods, calanoids, and euphausids (Pálsson, 1983).

B. Data

B.1. Commercial catch

The text table below shows landings data supplied from each area.

	KIND OF DATA				
Country/area	Caton (Catch in weight)	Canum (catch-at-age in numbers)	Weca (weight-at-age in the catch)	Matprop (proportion mature-by-age)	Length composition in catch
Iceland (Va)	x	x	x	x	x
Faroe Islands (Vb)	x				x
Greenland (XIV)	x				x

B.1.1. Iceland

Icelandic commercial catch data, in tonnes by month, area and gear, are obtained from Statistical Iceland and the Directorate of Fisheries. The geographical distribution of catches (since 1991) is obtained from the logbooks, where location of each haul, effort, depth of trawling and total catch of golden redfish are recorded.

B.1.1.1 Splitting the redfish catches in ICES Division Va between *S. marinus* and Icelandic slope *S. mentella*

Until the 2010/2011 fishing season, Icelandic authorities gave a joint quota for *S. marinus* and Icelandic slope *S. mentella* in ICES Division Va. Icelandic fishermen were not required to divide the redfish catch into species. This was a problem when catch statistics of those two species were determined. Since 1993, a so-called *split–catch* method has been used to split the Icelandic redfish catches between the two species.

B.1.1.1.1. Data

The following data were used:

4) Data from logbooks of the Icelandic fleet (information on the location of each haul, how much was caught of redfish, and if available, the species composition of the catch).

5) Information on landed products from Icelandic factory (freezer) trawlers.

6) Biological samples from the Icelandic fresh-fish trawlers sampled by MRI and Icelandic Catch Supervision (ICS) personnel.

7) Landing statistics from Germany and UK if available.

8) Landing statistics from foreign vessels fishing in Icelandic waters.

9) Official landings by gear type provided by Directorate of Fisheries in Iceland.

B.1.1.1.2. Splitting the redfish catch from freezer trawlers

The redfish landings data of the freezer fleet are divided into species in landing reports and considered reliable. However, the official landings for each fishing trip are not divided by gear type if more than one was used (in this case bottom trawl and pelagic trawl), but set on one gear type (usually bottom trawl). The freezer trawlers mainly use bottom trawl in the redfish fishery, but in some years, especially in the 1990s, they also used pelagic trawls. Based on logbooks, the redfish caught with pelagic trawl was Icelandic slope *S. mentella*.

To get reliable species composition of the bottom-trawl catch, the total catch of the freezer trawler for each species was estimated. If for a given year redfish was caught with pelagic trawl (total catch was based on logbooks) the catch was subtracted from the total *S. mentella* catch.

B.1.1.1.3. Splitting the redfish catch from the fresh fish trawlers

The catch is first divided into defined strata and split into species according to the ratio of *S. marinus*/*S. mentella* observed in biological samples from each strata. Each stratum is a 15′ Latitude x 30′ Longitude rectangle.

1) **For each year:** The redfish catch from each year was divided into strata and scaled to the total un-split catch of the two species for each rectangle. It is assumed that the distribution of catch not reported in logbooks was the same as the reported catch. Catch taken by other gears was included (it usually represented about 2% of the total catch).

2) **For each stratum and each year:** The biological samples taken from the commercial catch were used to split the catch in each stratum into species. In this step, the average species composition in the samples in each stratum is estimated and then applied to the total catch of the fleet in that stratum (see previous step). If no information on species composition in a stratum for any given year was available, the species composition one year before was used if available. If not, then the species composition two years before was applied, and so forth up to a maximum of five years before a given year. If no samples were available in a five year period, the splitting

was done according to depth and the captain's experience. Only a small proportion of the catch was split into species using this last criterion.

3) The split into species of redfish landings in Germany and UK (containers or fresh landings) is based on landings reports and considered reliable.

4) For other nations operating in ICES Division Va, the catches are split according to information given by those nations. In 2009, only Faroe Islands and Norway operated in ICES Division Va.

B.1.1.1.4. Other gears

Between 92–98% of the annual redfish catch is caught with bottom trawls. The redfish caught with other gear types, i.e. longline, gillnet, hook and line, Danish seine, and lobster trawl is assumed to be *S. marinus*, because boats using these gear types mainly operate in shallow waters were only *S. marinus* is found.

B.1.2. Greenland

The Greenland authorities operate the quota uptake with three types of redfish:

- fish caught by bottom trawl and longlines on the bottom are named *Sebastes marinus*;
- fish caught pelagic in the Irminger Sea are named *Sebastes mentella*;
- fish caught as bycatch in the shrimp fishery are named *Sebastes* sp.

From the Greenland and German surveys we know that the demersal redfish found in the area is a mixture of *S. marinus* and *S. mentella*. All surveys report that *S. mentella* dominates the catch. According to survey background and one sample of fish from the commercial fishery, the amount of *S. mentella* caught in XIVb in 2009 and 2010 is estimated as 80% of the reported catch of demersal redfish derived from logbooks. This separation has been conducted with different proportions of *S. mentella* in years with significant catches (e.g. 1986), but it remains uncertain what have been done through the years with low catches.

B.1.3. Faroe Islands

Faroese commercial catch data are in tonnes by month, area and gear, and supplied by Statistics Faroe Islands and the Directorate of Fisheries. The geographical distribution of catches is obtained from the logbooks, where location of each haul, effort, depth of trawling and total catch of redfish are recorded.

Since golden redfish is landed just as redfish, there is a need to use all available information to split the catches into *S. marinus* and *S. mentella*, respectively.

For the Faroese catches, this split is based on data from Research Vessels surveys on horizontal and vertical distribution of the two species, from regular biological sampling of the redfish landings by fleet, and from logbooks (information on the location of each haul, effort, depth of trawling and how much redfish was caught).

For the catches from other nations, official landings statistics (STATLANT) and information from national laboratories are used to split catches into the two species.

B.1.4. Biological data from the commercial catch

Sampling from the Icelandic fleet

Biological data from the commercial catch were collected from landings by scientists and technicians of the Marine Research Institute (MRI) in Iceland and directly on board on the commercial vessels (mainly length samples) by personnel of the Directorate of Fisheries in Iceland. The biological data collected are length (to the nearest cm), sex, maturity stage and otoliths for age reading.

The general process of the sampling strategy by the MRI since 1999 is to take one sample of golden redfish for every 500 tonnes landed. Each sample consists of 200 individuals: otoliths are extracted from 30 fish which are also length measured, weighed, and sex and maturity determined; 70 fish are length measured, weighted, sex and maturity determined; the remaining 100 are length measured and sex and maturity determined.

Sampling data of size composition from the bottom-trawl fleet are available from 1956–1966 and 1970–2010, but sampling before 1976 is rather limited. Since 1999, 219–434 samples are taken annually and 35 000–74 000 individuals are length measured annually (Table B.1.2.1).

Sampling of age composition from the bottom-trawl fleet only started in 1995. For the first two years, age reading was scarce, but since 2000 the annual number of samples has been between 45 and 50 and 1600–1800 otoliths are age determined (Table B.1.2.1).

The data are stored in a database at the Marine Research Institute and are used to generate an age–length key (ALK) and as input data for the GADGET model.

Sampling from the Faroese fleet

Length samples from the Faroese fleet are available from 2001 and there are a few samples from the early 1990s.

Sampling from East Greenland

Length samples are available from the German commercial fleet operating in East Greenland waters 1975–1991, 1999, 2002 and 2004. Few length samples are available from the newly started Greenland fishery.

B.2. Biological

The total catch-at-age data in Va from 1995 is based on Icelandic otolith readings.

B.3 Surveys

Icelandic surveys in Va

Two bottom-trawl surveys, conducted by the Marine Research Institute in ICES Division Va, are considered representative for golden redfish: the Icelandic Groundfish Survey (IGS or the Spring Survey) and the Autumn Groundfish Survey (AGS or the Autumn Survey). The Spring Survey has been conducted annually in March since 1985 on the continental shelf, at depths shallower than 500 m, and it has a relatively dense station-grid (approximately 600 stations). The Autumn Survey has been conducted in October since 1996 and covers larger area than the Spring Survey. It is conducted on the continental shelf and slopes and extends to depths down to 1500 m. The number of stations is about 380 so the distance between stations is often larger.

The text in the following description of the surveys is mostly a translation from Björnsson *et al*. (2007). The emphasis has been put on golden redfish where applicable. The report, written in Icelandic with English abstract and English text under each table and figure, can be found at the MRI website under the following link: http://www.hafro.is/Bokasafn/Timarit/rall_2007.pdf. An English version of the survey manual can be found at http://www.hafro.is/Bokasafn/Timarit/fjolrit-156.pdf.

B.3.1. Spring Survey in Va

The stated aim of the Spring Survey has been since the beginning the estimation of abundance of demersal fish stocks, particularly the cod stock, with increased accuracy and thereby strengthening the scientific basis of fisheries management. That is, to get fisheries-independent estimates of abundance that would result in increased accuracy in stock assessment relative to the period before the Spring Survey. Another aim was to start and maintain dialogue with fishermen and other stakeholders.

To help in the planning, experienced captains were asked to map out and describe the various fishing grounds around Iceland and then they were asked to choose half of the tow-stations taken in the survey based on their fishing experience. The other half was chosen randomly by the scientists at the MRI, but the captains were asked to decide the towing direction for all the stations.

B.3.1.1. Timing, area covered and tow location

It was decided that the optimal time of the year to conduct the survey would be March, or during the spawning of cod in Icelandic waters. During this time of the year, cod is most easily available to the survey gear as diurnal vertical migrations are at minimum in March (Pálsson, 1984). Previous survey attempts had taken place in March and for possible comparison with those data it made sense to conduct the survey in the same month.

The total number of stations was decided to be 600 (Figure B.3.1), to decrease variance in indices and keep the survey within the constraints of what was feasible in terms of survey vessels and workforce available. With 500–600 tow-stations the expected CV of the survey would be around 13%.

The survey covers the Icelandic continental shelf down to 500 m and to the EEZ-line between Iceland and Faroe Islands. Allocation of stations and data collection is based on a division between northern and southern areas. 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 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 allocated in the colder northern area and 175 stations were allocated in the southern area. The two areas were then divided into ten strata, four in the south and six in the north.

Stratification of the survey area and the allocation of stations were based on pre-estimated cod density patterns in different "statistical squares" (Pálsson *et al*., 1989). The statistical squares were grouped into ten strata depending on cod density. The number of stations allocated to each stratum was in proportion to the product of the area of the stratum and cod density. Finally, the number of stations within each stratum was allocated to each statistical square in proportion to square size. There are up to 16 stations in each statistical square in the Northern area and up to seven in the southern area.

B.3.1.2. 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 1972–1973 to conduct the survey. Each year, up to five trawlers have participated in the survey, each in a different area (NW, N, E, S, SW). 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 had some modifications since the start of the survey, most of them in 1986–1988.

The survey gear is based on the trawl that was the most commonly used by the commercial trawling fleet in 1984–1985. It has a 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 at 4 nautical miles and towing speed at approximately 3.8 nautical miles per hour. The minimum towing distance so that the tow is considered valid for index calculation is 2 nautical miles. Towing is stopped if wind is more than 17–21 m/sec, (8 on Beaufort scale).

B.3.1.3. Later changes in vessels and fishing gear

The trawlers used in the survey have been changed somewhat since the beginning of the survey. The changes include alteration of hull shape (bulbous bow) and size (hull extended by several meters), larger engines, and some other minor alterations. These changes have most likely changed ship performance, but they are very difficult to quantify.

The trawlers are now considered old and it is likely that they will be decommissioned soon, so the search for replacements has started. In recent years, the MRI research vessels have taken part in the Spring Survey after carrying out elaborate comparison studies. The RV Bjarni Sæmundsson has surveyed the NW-region since 2007 and RV Árni Friðriksson has surveyed the Faroe–Iceland Ridge in recent years and will survey the SW area in 2010.

The trawl has not changed since the start of the survey. The weight of the otterboards has increased from 1720–1830 kg to 1880–1970 kg, which 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 otterboards is unchanged.

B.3.1.4. Later changes in trawl stations

Initially, the numbers of trawl stations surveyed was expected to be 600 (Figure B.3.1). However, this number was not covered until 1995. The first year 593 stations were surveyed but in 1988 the stations had been decreased down to 545 mainly due to bottom topography (rough bottom that was impossible to tow), but also due to drift ice that year. In 1989–1992, between 567 and 574 stations were surveyed annually. In 1993, 30 stations were added in shallower waters as an answer to fishermen's critique.

In short, until 1995 between 596 and 600 stations were surveyed annually. In 1996, 14 stations that were added in 1993 were omitted. Since 1991 additional tows have been taken at the edge of the survey area if the amount of cod has been high at the outermost stations.

In 1996, the whole survey design was evaluated to reduce costs. The number of stations was decreased to 532 stations. The main change was to omit all of the 24 stations from the Iceland–Faroe Ridge. 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 1996 have been surveyed.

In the early 1990s there was a change from Loran C positioning system to GPS. This may have slightly changed the positioning of the stations as the Loran C system was not as accurate as the GPS.

B.3.2. Icelandic Autumn Groundfish Survey

The Icelandic Autumn Groundfish Survey has been conducted annually in October since 1996 by the Marine Research Institute (MRI). 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 conducted annually in March since 1985 does not cover the distribution of these deep-water species. The second 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.

B.3.2.1. 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 (EEZ) 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.

B.3.2.2. 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 were 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 location of those stations was, therefore, based on distribution and pre-estimated density of the species.

Because MRI was not able to finance a project of this magnitude, it was decided to focus the deep-water part of the survey on the Greenland halibut main distributional area. Important deep-water redfish areas south and west of Iceland were omitted. The number and location of stations in the shallow-water area were unchanged. For this reason, only the years from 2000 onwards can be compared for Icelandic slope *S. mentella*.

The number of stations in the deep-water area was reduced to 150, 100 of which 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 the logbook database of the bottom-trawl fleet fishing for Greenland halibut 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 1996–1999 (Figure B.3.2).

In addition, 14 stations were randomly added in the deep-water area in areas where great variation had been observed in 1996–1999. Because of rough bottom, which made it impossible to tow, five stations have been omitted. Finally, 12 stations were added in 1999 in the shallow water area, making the number of stations in the shallow water area 162. The total number of stations taken in 2000–2009 has been around 381 (Table B.3.1).

In 2010, 16 stations were omitted in the deep-water area and the total number of stations in the area reduced from 219 to 203. All these stations have in common that they are in areas where stations are many and dense (close to each other), and with little variation. Four stations, aimed at deep-water redfish, were omitted southeast of Iceland. The rest or 12 stations were omitted west and northwest of Iceland, stations originally aimed at Greenland halibut.

B3.2.3. Vessels

The RV "Bjarni Sæmundsson" has been used in the shallow water area from the beginning of the survey. 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" (Table B.3.1).

B3.2.4. 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 is 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).

B.3.5. Data sampling

B.3.5.1. Length measurements and counting

All fish species are length measured. For the majority of species, including golden redfish, 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 (Spring Survey) or five (Autumn Survey) times the length interval of golden redfish. Example: If the continuous length distribution of golden redfish at a given station is between 15 and 45 cm, the length interval is 30 cm and the number of measurements needed is 120. If the catch of golden redfish at this station exceeds 120 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.

B.3.5.2. Otolith sampling

Otolith sampling of golden redfish only started in 1998 in the Spring Survey. Annually 3100–3800 otoliths are taken but, only otoliths from the year 2010 have been age read. Otolith of golden redfish from the Autumn Survey has on the other been sampled since the beginning of the survey in 1996. Annually 1000–1600 otoliths are sampled and all of them have been age read.

For golden redfish, a minimum of five are collected in both surveys, but the maximum differ between the surveys. In the Spring Survey the maximum number of otoliths collected are ten but 15 in the Autumn Survey. Otoliths are sampled at a 20 fish interval in the Spring Survey and ten fish interval in the Autumn Survey. This means that if in total 200 golden redfish are caught in the Autumn Survey in a single haul, 20 otoliths are sampled.

Each golden redfish taken in the otolith sampling is sex and maturity determined, weighed ungutted, and the stomach content is analysed onboard.

B.3.5.3. 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.

Tow information:

General: Station, Vessel registry no., Cruise ID, Day/Month/Year, Statistical Square, Subsquare, Tow number, Gear type no., Mesh size, Briddles length (m).

Start of haul: Position North, Position West, Time (hour:min), Tow direction in degrees, Bottom depth (m), Towing depth (m), Vertical opening (m), Horizontal opening (m).

End of haul: Position North, Position West, Time (hour:min), Warp length (fm), Bottom depth (m), Tow length (nautical miles), Tow time (min), Tow speed (knots).

Environmental factors:

Wind direction, Air temperature (°C), Windspeed, Bottom temperature (°C), Sea surface, Surface temperature (°C), Cloud cover, Air pressure, Drift ice.

B.3.6. Data processing

Abundance and biomass estimates at a given station.

As described above, the normal procedure is to measure at least four 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:

$$P = \frac{n_{measured}}{n_{counted} + n_{measured}}$$

$$n_{L_1-L_2} = \sum_{i=L_1}^{i=L_2} \frac{n_i}{P}$$

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:

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

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

B.3.6.1. Index calculation

For calculation of indices the Cochran method is used (Cochran, 1977). The survey area is split into strata (see Section B.3.6.2). 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 estimate from the strata.

A “tow-mile” is assumed to be 0.00918 NM^2. That is the width of the area covered is assumed to be 17 m (17/1852=0.00918).

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

$$\overline{Z}_i = \frac{\sum_i Z_i}{N_i}$$

where $\overline{Z}_i$ is the mean catch (number or biomass) 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:

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

And the sample variance in the *i*-th stratum:

$$\sigma_i^2 = \left(\frac{\sum_i (Z_i - \overline{Z}_i)^2}{N_i - 1} \right) \left(\frac{A_i}{A_{tow}} \right)^2$$

where A_i is the size of the *i*-th stratum in NM² and A_{tow} is the size of the area surveyed in a single tow in NM².

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

and the variance is

$$\sigma_{strata}^2 = \sum_{region} \sigma_i^2$$

and the coefficient of variation is

$$CV_{region} = \frac{\sigma_{region}}{I_{region}}$$

B.3.6.2. Stratification

The strata used for survey index calculation for golden redfish in the Spring Survey are shown in Figure B.3.3 and for the Autumn Survey in Figure B.3.4. The stratification is the same in both surveys, but the area is larger in the Autumn Survey. The stratification is in general based on depth stratification and similar oceanographic conditions within each stratum.

The survey stratification and subsequent survey indices for golden redfish were recalculated for the Autumn Survey in 2008 and for the Spring Survey in 2011. This was done because the majority of the total catch of golden redfish comes in few but large tows leading to high uncertainties in the estimates of the biomass/abundance indices (high CV). Many of these hauls are in a region with relatively long intervals between stations and gaps in the station grid can be seen near these hauls (Figures B.3.3 and B.3.4). After the changes, fewer and larger strata were used and the strata with the holes in the station net reduced. The aim of this revision was to reduce the weight of certain tows, to reduce the area weight and hence, to reduce CV in the indices.

The numbers of strata in the Autumn Survey were reduced from 74 to 33. Figure B.3.5 shows the stratification of the survey area that was used before 2008. The average size of stratum subsequently increased and number of tows within stratum increased. It should also be noted that some strata at the edge of the survey area were reduced in size. The number of strata in the Spring Survey went from 45 to 24. Figure B.3.6 shows the stratification of the survey area that was used before 2011.

Diurnal variation

Golden redfish is known for its diurnal vertical migration showing semi-pelagic behaviour. Usually the species is in the pelagic area during the night-time and close to the bottom during the daytime. There may also be a size or age difference in this pelagic behaviour. This causes great diurnal variation in the catch rates of golden redfish in both the spring and autumn bottom-trawl surveys conducted in Icelandic waters, and it has a large effect on the abundance indices.

The surveys are conducted both during the day and the night (24 hours). Few stations in a limited area account for a large part of the total catches of golden redfish. Besides, interannual variability caused by the time of day when the stations are taken becomes large and hence, can greatly influence the results.

The general model without taking into account length is a generalized model (GML):

$$\log(catch) = \alpha_{year} + \beta_{station} + \gamma_{time}$$

The model uses quasi family with log link and variance proportional to the mean. The factor α_{year} could be interpreted as abundance index. The factor γ_{time} does on the other hand describe the development during the day.

The data were divided into 17 length groups and fitted for each length group.

$$\log(catch) = \alpha_{year} + \beta_{station} + ps(time, df = 7)$$

where is the periodic spline with seven degrees of freedom.

Scaled predictions for each length group in the Spring and Autumn Surveys by the model are shown in Figure B.3.7. As may be seen the smallest redfish has opposite diurnal vertical migration compared to the usual one of larger fish. The model results do also show that much less is caught of the smallest redfish in the survey compared to medium size. This scaled diurnal variation by length as seen in Figure B.3.7 was used for calculating Cochran index for redfish. The only difference from the traditional method is that the numbers caught in each length group at each station will be divided by the appropriate multiplier shown in Figure B.3.7.

Comparison of total biomass index for golden redfish based on the old and new stratification, and taking into account the diurnal variation is shown in Figure B.3.8 for the Spring Survey and Figure B.3.9 for the Autumn Survey. In general, the measurement errors of the indices based on the new stratification and taking into account diurnal variation are lower than the ones based on the old stratification.

Faroese surveys in Vb

Two annual groundfish surveys are conducted on the Faroe Plateau by the Faroe Marine Research Institute, the Spring Survey carried out in February–March since 1994 (100 stations per year down to 500 m depth, Figure B.3.10), and the Summer Survey in August–September since 1996 (200 stations per year down to 500 m depth, Figure B.3.11). Both surveys are bottom-trawl surveys and the same bottom trawl with 40 mm mesh size in the codend is used. Effort for both surveys is recorded in terms of minutes towed (60 min).

All stations are fixed stations. Half of the stations in the Summer Survey were the same as in the Spring Survey. The surveyed area is divided into 15 strata defined by depth and environmental conditions. For index calculation same method was applied as described in Section 2.4.3. The 'tow-mile' is assumed to be 0.0108 NM^2 and the width of the trawl is assumed to be 22 m. The tow length is set to 4 NM. It was not possible to calculate the sampling variance since the catch was aggregated by stratum, that is, only the total catch and number of tows per stratum was available.

Surveys in Greenland waters

Survey design

Abundance, biomass estimates and length structures have been derived using annual German groundfish surveys covering shelf areas and the continental slopes off West and East Greenland during 1982–2012. The survey was primarily designed for the assessment of cod, but it covers the entire groundfish assemblage down to 400 m depth (Rätz, 1999). Designed as a stratified random survey, the hauls are allocated to the strata off West and East Greenland according to both the area and the mean historical cod abundance at equal weights. Stations are randomly selected from successfully trawled grounds. Because of favourable weather and ice conditions and to avoid spawning concentrations, autumn was chosen for the time of the surveys.

The surveys were carried out by the research vessel RV Walther Herwig (II) 1982–1993 (except 1984 throughout RV Anton Dohrn was used) and since 1994 by RV Walther Herwig III.

Up to 2012, the surveyed area is the 0–400 m depth that is divided into seven geographical strata and two depth zones (0–200 m; 200–400 m, Figure B.3.12). The numbers of hauls were initially ca. 200 per year but were reduced from the early 1990s to 80–100 per year.

In 2013, the survey was re-stratified, with four strata in West Greenland resembling NAFO subarea structure, and five strata in East Greenland. Depth zones considered are 0–200 m and 200–400 m (Figure B.3.13). The time-series was recalculated accordingly.

For historical reasons strata with less than five hauls were not included in the annual stock calculations op to 2008. From 2009 on, all valid hauls have been included and the entire time-series have been corrected. For strata with less than five samples, GLM and quasi-likelihood estimates are recalculated based on year and stratum effects from the time-series. In some years (notable 1992 and 1994) several strata were not covered due to weather conditions/vessel problems, implying that the survey estimate implicitly refers to varying geographical areas.

Re-stratification of the survey in NWWG 2013 (NWWG WD 25)

The new stratification refers to 31 607 nm^2 excluding in particular areas for which no data were available (Table B.3.2), whereas the old stratification covered 37 463 nm^2 (Table B.3.3).

Stratification is undertaken to optimize sampling effort and design to obtain highly reliable estimates of a population, i.e. under minimizing sample variance.

Stratification on species level for Atlantic cod, golden redfish and deep-sea redfish was carried out according to the cumulative squared root frequency method by Dalenius and Hodges (Cochran, 1977, p.127–131; Dalenius and Hodges, 1959) based on average biomass per ICES rectangle.

Following the approach undertaken by Cornus (1986), survey samples were assigned to ICES rectangles prior to calculating stratum affiliations. Within ICES rectangles, the amount of trawlable area was estimated according to Cornus (1986).

Stratification on community level was undertaken with Ward's minimum variance method by means of clustering. Many simulation studies comparing various methods of cluster analysis have been performed. In these studies, artificial datasets containing known clusters are produced using pseudo-random number generators. The datasets are analysed by a variety of clustering methods, and the degree to which each clustering method recovers the known cluster structure is evaluated. See Milligan (1981) for a review of such studies. In most of these studies, the clustering method with the best overall performance has been either average linkage or Ward's minimum variance method. The method with the poorest overall performance has almost invariably been single linkage. However, in many respects, the results of simulation studies are inconsistent and confusing.

A six stratum design was analysed for community structure.

For each species, five strata were determined in terms of their assortment of ICES rectangles (Figure B.3.13). In a further step, adjacent ICES rectangles were combined into one stratum both defined through density level and geographic coherence.

Species stratification schemes were cross-checked with community schemes to outline general distribution patterns on the shelf.

In a third step, sampling frequency was checked, and strata 5 and 6 were joined to reach sufficient sample coverage.

Fishing gear

The fishing gear used was a standardized 140 feet bottom trawl, its net frame rigged with heavy groundgear because of 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 at 300 m depth, the vertical net opening being 4 m. In 1994, smaller Polyvalent doors (4.5 m^2, 1500 kg) were used for the first time to reduce net damages due to overspread caused by bigger doors (6 m^2, 1700 kg), which have been used earlier.

Index calculation

All calculations of abundance and biomass indices were based on the modified 'swept-area' method using 22 m horizontal net opening as trawl parameter, i.e. the constructional width specified by the manufacturer, and standardized to a towing time of 30 minutes, yielding a distance swept of 2.25 nm as derived from a speed of 4.5 knots. Hauls, which received net damage or became hang-up after less than 15 minutes, were rejected. Some hauls of the 1987 and 1988 surveys were also included although their towing time had been intentionally reduced to ten minutes because of the expected large cod catches as observed from echosounder traces.

Stratified abundance estimates calculated from catch-per-tow data using the stratum areas as weighting factor (Cochran, 1977). Strata with less than five valid sets were included but are indicated. The coefficient of catchability was set at 1.0, implying that estimates are fair indices of abundance and biomass. Respective confidence intervals (CI) were set at the 95% level of significance of the stratified mean. The length–frequency distributions (LFDs) were compiled by stratum and year and raised to the respective abundance.

The assumption of the swept-area approach are certainly overestimating abundance, since herding effects through trawl doors and bridles are not considered (Dickson, 1993a; Dickson, 1993b). According to measurements undertaken with rock-hopper equipped BT140, door spread is about 60 m, and applying extension factors derived from nets of similar size, 0.5 of the door spread effectively contributes to the herding effect and thus to catch (Dickson, 1993b). This indicates that the naïve swept-area estimate based on the horizontal net opening only realistically overestimates catch by a factor of two.

Fitted SI

Following Venables and Dichmont (2004), a quasi-likelihood model was applied with loglink function and negative binomial-distributed errors.

Biological measurements

Fish were identified to species or lowest taxonomic level, and the catch in number and weight was recorded. Redfish inhabiting the survey area close to the bottom are believed to belong to the traditional stocks off Greenland, Iceland and the Faroe Islands (ICES, 1995). In the German surveys off Greenland, fish (>17 cm) were separated into *S. marinus* L. and *S. mentella* Travin, whereas juvenile redfish (<17 cm) were classified as *Sebastes* spp. due to difficult - and in most cases impossible - species identification. Total fish lengths were measured to cm below.

Stratification, index calculation, and inclusion of the German Survey in East Greenland in the GADGET model

Area definition

The German Survey does not cover the East Greenland continental shelf very well and only the edges of the shelf from 150–450 m are covered. The area used to compile abundance indices from the survey is approximately 45 000 km^2 (Figure B.3.13), a large area looking at the coverage.

For inclusion of the German Survey in East Greenland waters in the GADGET model (See Chapter C for the description and setup of the GADGET model) the survey area was reduced. Instead of using the five defined strata proposed in 2013 and shown in Figure B.3.13, only one stratum was used around the stations taken (Figure B.3.14). This approach was taken to avoid extrapolation to areas not covered by the survey and hence, to reduce the weight of each station. After the changes the area behind each station in the German Survey is 75% larger than of an average station in the Icelandic Spring survey.

The size of this region is 22 500 km^2. Outer boundary of the region follows the 500 m contour while the inner boundary is more *ad hoc*. Results from the Icelandic autumn survey indicate that golden redfish is not common below 500 m depth. Using larger areas in compilation of survey indices leads to substantial extrapolation to areas not covered by the survey.

Survey indices calculations

The Icelandic data are converted to abundance by assuming 17 m width of the survey trawl. Also diurnal variability is taken into account and the results calibrated to the average of day and night but the survey is conducted 24 hours per day. Results from the German survey are converted to abundance per km^2 by assuming 22 m width of the survey trawl but not correcting for time of day as the German survey is only conducted during the day.

The Icelandic indices are compiled using stratified mean as described in Chapter B.3.6. The Greenland indices used in the GADGET setup are compiled by taking the average over the abundance/km^2 of the stations each year multiplied by $\frac{22m}{16m}$ (to account for different trawl width in the German and the Icelandic Spring Surveys respectively) and then by the size of the survey area, in this case 22 500 km^2.

Combination of the Icelandic Spring Survey and the German East Greenland Survey

The German survey in East Greenland waters is conducted in the autumn (September–October) or 4–5 months earlier than the Icelandic Spring survey the following year. When the survey indices were combined, the German survey in year *y* was added to the Icelandic Spring Survey conducted the year after (*y+1*). During this period of 4–5 months between the surveys, the fish grows. Furthermore, it might also migrate between areas. The former problem is taken care of by adding one cm to the length of all fish caught in the German survey but the latter problem is not considered specifically.

B.4. Commercial cpue

Iceland

Catch per unit of effort is routinely calculated during the annual assessment process. Data used to estimate cpue for golden redfish in Division Va since 1978 were obtained from logbooks of the Icelandic bottom-trawl fleet. Only those hauls were used that were taken above 450 m depth (combined golden redfish and Icelandic slope *S. mentella*) and that were comprised of at least 50% golden redfish (assumed to be the directed fishery towards the species; between 70–80% of the total annual catch were from those hauls). Non-standardized cpue and effort is calculated for each year:

$$E_y = \frac{Y_y}{CPUE_y},$$

where *E* is the total fishing effort and *Y* is the total reported landings.

Cpue indices were also estimated from this dataset using a GLM multiplicative model (generalized linear models). This model takes into account changes in vessels over time, area (ICES statistical square), month and year effects:

glm(log(catch) ~ log(effort) + factor(year) + factor(month) + factor(area) + factor(vessel), family=gaussian())

C. Modelling framework (historical stock development)

C.1. Description of GADGET

GADGET is shorthand for the "Globally applicable Area Disaggregated General Ecosystem Toolbox", which is a statistical model of marine ecosystems. GADGET, previously known as BORMICON and Fleksibest, has been used for assessment of golden redfish in ICES Division Va since 1999 (Björnsson and Sigurdsson, 2003).

GADGET is an age–length structured forward-simulation model, coupled with an extensive set of data comparison and optimization routines. Processes are generally modelled as dependent on length, but age is tracked in the models, and data can be compared on either a length and/or age scale. The model is designed as a multispecies, multiarea, multifleet model, capable of including predation and mixed fisheries issues; however it can also be used on a single species basis. Worked examples, detailed manual, and further information on GADGET can be found on www.hafro.is/gadget. In addition the structure of the model is described in Björnsson and Sigurdsson (2003), Begley and Howell (2004), and a formal mathematical description is given in Frøysa *et al*. (2002).

GADGET is distinguished from many stock assessment models used within ICES that it is length based and takes into account the fact that fisheries are often targeting the largest individuals of age groups partly recruited to the fisheries thereby reducing the mean weight of the survivors.

Setup of a GADGET run

There is a separation of model and data within GADGET. The simulation model runs with defined functional forms and parameter values, and produces a modelled population, with modelled surveys and catches. These surveys and catches are compared against the available data to produce a weighted likelihood score. Optimization routines then attempt to find the best set of parameter values.

Growth

Growth is modelled by calculating the mean growth for fish in each length group for each time-step, using a parametric growth function. In the golden redfish model a von Bertalanffy function has been employed to calculate this mean growth. At each time-step the length distributions are updated according to the calculated mean growth by allowing some portion of the fish to have no growth, a proportion to grow by one length group and a proportion two length groups, etc. How these proportions are selected affects the spread of the length distributions but these two equations must be satisfied:

$$\sum p_{il} = 1$$

and

$$\sum i p_{il} = \mu_i$$

Here μ is the calculated mean growth and p_{il} is the proportion of fish in length group l growing i length groups. The proportions are selected from a beta-binomial distribution, that is a binomial distribution $f(n,p)$ where n is the maximum number of length groups that a fish can grow in one time interval. The probability p in the binomial distribution comes from a beta distribution described by α and β (Stefansson, 2001). As in all discrete probability distributions the condition $\sum p_{il} = 1$ is automatically satisfied. The mean of the distribution is given by:

$$\mu_l = \frac{n\alpha}{\alpha + \beta} = \sum_{i=0}^{n} p_{il} i$$

For a given value of β, a value of α is selected so that $\mu_l = G_l$ where G_l is the calculated mean growth from the parametric growth equation. β, which can either be estimated or specified in the input files, affects the spread of the length distribution.

Fleets

All fleets or predators in the model work on size. To be specific the predators have size preference for their prey and through predation can affect mean weight and length-at-age in the population. A fleet (or predator) is modelled so that either the total catch or the total effort in each area and time interval is specified. In the golden redfish assessment described here the commercial catch is given in weight but the survey is modelled as a fleet with a constant effort.

The first step in estimating catch in numbers by age and length in the model is to calculate the 'modelled cpue' for each fleet:

$$CPUE_{\mathrm{mod}} = \sum_{prey} \sum_{l} S_{prey,l} N_{prey,l} W_{prey,l}$$

where $S_{prey,l}$ is the selection of prey length l, $N_{prey,l}$ is the number of fish and $W_{prey,l}$ is the mean weight of prey of length l. The total catch of each length group of each prey is then calculated from:

$$C_{prey,l} = C \frac{S_{prey,l} N_{prey,l} W_{prey,l}}{CPUE_{\mathrm{mod}}}$$

where $C_{prey,l}$ is the amount caught by the predator of length group l of prey (in this case golden redfish) and C is the total amount caught by the fleet, either specified or calculated from:

$$C = E \times CPUE_{\mathrm{mod}}$$

where E is the specified effort.

In the golden redfish assessment described here the commercial catches are set (in kg per six months), and the survey is modelled as fleet with small total landings. The total catch for each fleet for each six month period is then allocated among the different length categories of the stock according to their abundance and the catchability of that size class in that fleet.

Likelihood data

A major advantage of using an age–length structured model is that the modelled output can be compared directly to a wide variety of different data sources. It is not necessary to convert length into age data before comparisons. GADGET can use various types of data that can be included in the objective function. Length distributions, age–length keys, survey indices by length or age, cpue data, mean length and/or weight-at-age, tagging data and stomach content data can all be used.

Importantly this ability to handle length data directly means that the model can be used for stocks such as golden redfish where time-series of age data is relatively short compared to the lifespan of the species). Length data can be used directly for comparison to model output. The model is able to combine a wide selection of the available data by using a maximum likelihood approach to find the best fit to a weighted sum of the datasets.

Optimization

The model has three alternative optimizing algorithms linked to it: a wide area search Simulated Annealing (Corona *et al.*, 1987), a local search Hooke-Jeeves algorithm (Hooke and Jeeves, 1961) and finally one based on the Boyden-Fletcher-Goldfarb-Shanno algorithm hereafter termed BFGS (Bertsekas, 1999).

The simulated annealing and Hooke-Jeeves algorithms are not gradient based, and there is therefore no requirement for the likelihood surface to be smooth. Consequently neither of these two algorithms returns estimates of the Hessian matrix. Simulated annealing is more robust than Hooke-Jeeves and can find a global optimum where there are multiple optima, but needs about 2–3 times the number of iterations compared to the Hooke-Jeeves algorithm.

BFGS is a quasi-Newton optimization method that uses information about the gradient of the function at the current point to calculate the best direction in which to look for a better point. Using this information the BFGS algorithm can iteratively calculate a better approximation to the inverse Hessian matrix. Compared with the two other algorithms implemented in GADGET, BFGS is very local search compared to simulated annealing and more computationally intensive than the Hooke-Jeeves algorithm. However the gradient search in BFGS is more accurate than the stepwise search of Hooke-Jeeves and may therefore give a more accurate estimate of the optimum. The BFGS algorithm used in GADGET is derived from that presented by Bertsekas (1999).

The model is able to use all three algorithms in a single optimization run, attempting to utilize the strengths of all. Simulated annealing is used first to attempt to reach the general area of a solution, followed by Hooke-Jeeves to rapidly home in on the local solution, and finally BFGS is used for fine-tuning the optimization. This procedure is repeated several times to attempt to avoid converging to a local optimum.

Likelihood weighting

The total objective function to be minimized is a weighted sum of the different components. Selection of the weights follows the procedure laid out by Taylor *et al*. (2007) where an objective re-weighting scheme for likelihood components is described for GADGET models using cod as a case study. The iterative re-weighting heuristic tackles this problem by optimizing each component separately in order to determine the lowest possible value for each component. This is then used to determine the final weights. The iterative re-weighting procedure has now been implemented in the R statistical language as a part of the **rgadget** package (***rgadget***.*r-forge.r-project.org/*) which is written and maintained by B. Th. Elvarsson at MRI.

Conceptually the log-likelihood components can roughly be thought of as residual sums of squares (SS), and as such their variances can be estimated by dividing the SS concerned by the associated degrees of freedom. Then the optimal weighting strategy is the inverse of the variance. The variances, and hence the final weights are calculated according the following algorithm:

1) Calculate the initial SS given the initial parameterization. Assign the inverse SS as the initial weight for all log-likelihood components. With these initial weights the objective function will start off with a value equal to the number of likelihood components.

2) For each likelihood component, perform an optimization with the initial score for that component set to 10 000. Then estimate the residual variance using the resulting SS of that component divided by the effective number of datapoints, that is, all non-zero data-points.

3) After the optimization set the final weight for that all components as the inverse of the estimated variance from step 3 (weight = (1/SS) * df*).

The effective number of datapoints (df*) in 3) is used as a proxy for the degrees of freedom determined from the number of non-zero datapoints. This is viewed as a satisfactory proxy when the dataset is large, but for smaller datasets this could be a gross overestimate. In particular, if the survey indices are weighed on their own while the yearly recruitment is estimated they could be over-fitted. If there are two surveys within the year Taylor *et al*. (2007) suggest that the corresponding indices from each survey are weighed simultaneously in order to make sure that there are at least two measurements for each yearly recruit. In general problems such as those mentioned here could be solved with component grouping, that is, in step 2) above likelihood components that should behave similarly, such as survey indices, should be heavily weighted and optimized together.

Another approach for estimating the weights of each index component, in the case of a single survey fleet, would be to estimate the residual variances from a model of the form:

$$\log(I_{lt}) = \mu + Y_t + \lambda_l + \varepsilon_{lt}$$

where *t* denotes year, *l* length-group and the residual term, ε_{lt}, is independent normal with variance σ_s^2 where *s* denotes the likelihood component referenced. The inverses of the estimated residual variances are then set as weights for the survey indices. In the rgadget routines, this approach is termed **sIw** as opposed to **sIgroup** for the former approach.

C.2. Settings for the golden redfish assessment in GADGET

Below is the description of the GADGET settings for the golden redfish assessment as accepted by WKREDMP 2014. Changes from the previous settings are described.

Age and length range and growth: In the assessment one cm length groups are used, 10.5–68.5 cm. The year is divided into two time-steps. The age range is five to 30 years, with the fish 30 years and older treated as a plus group. The length at recruitment (age 5) is estimated and mean growth is assumed to follow the von Bertalanffy growth function. Mean length at recruitment (age 5) was estimated separately for year classes before 1996, for year classes 1996–2000 and year classes 2001 and later. This was done to take into account increase in mean weight-at-age that has been observed since year class 1996. As selection to the survey and catches is size based, faster growth will lead to cohorts recruiting earlier to the surveys and the fisheries and hence, leading to overestimation if changed growth was not taken into account. Weight–length relationship is obtained from spring survey data. Before the 2012 assessment, age range in the model was 0–30 years old but the youngest age groups were excluded from the model as recruitment data were not considered usable in assessment due to changes in spatial distribution of recruits.

Natural Mortality (*M*): Natural mortality for this long-lived species is assumed to be low but has to be guessed like for most other stock. Since the 2012 assessment, *M* of all age groups, except the plus group, is 0.05 but 0.1 for the plus group. Before that *M* for 0 years old was 0.20 and then reducing gradually to 0.05 for age 5. *M* for age 5–29 was 0.05 but 0.1 for the plus group (30+). Changing *M* for ages 0–4 does not affect the results as they do not appear in the fisheries.

Time-Steps: The model starts in 1970 and the time-step is six months. The last tuning and catch data used are for the first half of the assessment year. Short-term predictions 5–8 years ahead are done with fixed effort and fixed catch. Landings data are available for all the period but biological data are scarce before 1985 and scarcer the further back in time we go. In the model all available data are used for tuning. One reason for starting the model so early is to have the burn in period of the model before the most important tuning data are sampled, but also try to have the time period comparable to the lifespan of the species.

Commercial Landings: The commercial landings are since the spring 2012 modelled as three fleets (Greenland, Iceland and the Faroese), each with selection patterns described by a logistic function and the total catch in tonnes specified for each six month period.

Surveys: Two surveys are used, the Icelandic Spring Survey (IS-SMB) and the German autumn groundfish survey in East Greenland waters (GER(GRL)-GFS-Q4). The indices are combined into one survey index.

The German autumn groundfish survey is conducted in the autumn (September–October) or 4–5 months earlier than the Icelandic Spring Survey (March) the following year. When the survey indices were combined, GER(GRL)-GFS-Q4 in year *y* was added to the IS-SMB conducted the year after (*y+1*). To compensate for growth during the period of 4–5 months that are between the surveys, one cm was added to the length of all fish caught in GER(GRL)-GFS-Q4. The length groups division used in the tuning are two cm length groups from 19 to 54 cm.

The combined surveys (1985-onwards) are modelled as one fleet with constant effort and a nonparametric selection pattern that is estimated for each length group.

In previous settings only the Icelandic Spring Survey (IS-SMB) was used.

General changes

Changes made in 2012

Some important changes have been done to the model setup in recent years, most of them due to problems with recruitment estimation but reasonably large year classes seen in recent years were not seen in Icelandic surveys as small fish. This has led to consistent underestimation of recruiting year classes in recent years.

Changes made in 2014

- Changes in growth, now modelled for three periods, before 1996 year class, 1996–2000 year class and 2001 and later year classes.
- Inclusion of the German Groundfish Survey in East Greenland waters (GER(GRL)-GFS-Q4). The survey biomass of the German survey at year *y* was added to the Icelandic spring survey the year after or *y+1*.
- Length range of tuning data 19–54 cm.

In addition development of the model has been ongoing. Among the things developed in 2011–2014 is the likelihood weighting that was changed somewhat in the latter half of 2012.

Current setup

Data/constraints used in the objective function to be minimized are as follows:

Data used for tuning are:

- Length distributions from the commercial catches (Greenland, Iceland and the Faroese) and the surveys (the Icelandic Spring survey (IS-SMB) and German Groundfish Survey in East Greenland combined) in two cm length groups, using multinomial likelihood functions.
- Length disaggregated survey indices in two cm length group 19–54 cm using lognormal errors.
- Age–length keys and mean length-at-age from the Icelandic groundfish survey in October (IS-SMH): 1996–recent year. Based on two cm length groups using multinomial likelihood function.
- Age–length keys and mean length-at-age from the Icelandic commercial catch 1995–recent year. Based on two cm length groups using multinomial likelihood function.
- Mean length-at-age in IS-SMH. Based on sum of squares.
- Mean length-at-age in Icelandic commercial catches. Based on sum of squares.
- Landings by six month period.
- Understocking, i.e. too small biomass to cover the specified catch in tonnes.
- Bounds, a penalty function restricting the optimizing algorithms to the bounds specified for the estimated parameters.

The total objective function to be minimized is a weighted sum of the different components. Understocking and bounds are zero in the final solution they are only tools for guidance during the optimization process. Weights for the various log-likelihood components are assigned according to the reweighting procedure described above.

The parameters estimated are:

- The number of fish when simulation starts.
- Recruitment each year.
- Two parameters for the growth equation.
- Parameter β of the beta-binomial distribution controlling the spread of the length distributions.
- The selection pattern of the commercial catches. Two parameters for each fleet.
- Average size at recruitment. Three parameters estimated separately for year classes before the 1996 year class, year classes 1996–2000 and year classes 2001 and onwards.

The estimation can be difficult because some groups of parameters are correlated, and therefore the possibility of multiple optima cannot be excluded.

DESCRIPTION	PERIOD	HALF-YEAR	AREA	LIKELIHOOD COMPONENT
Length distribution of landings	1970+	YES	Iceland East Greenland Faroese	ldist.catch
Combined survey length distribution of IS-SMB and GER(GRL)-GFS-Q4	1985+	-	Iceland East Greenland	ldist.survey
Abundace index of IS-SMB and GER(GRL)-GFS-Q4 of 19–24 cm individuals	1985+	-	Iceland	si1924
Abundace index of IS-SMB and GER(GRL)-GFS-Q4 of 25–54 cm individuals	1985+	-	Iceland	si2524
Age–length key of the landings	1995+	-	Iceland	alkeys.catch
Age–length key of the IS-SMH	1996+	-	Iceland	alkeys.survey
Mean length by age of landings	1995+	-	Iceland	meanl.catch

The **diagnostics** considered when reviewing the model's results are:

- Likelihood profiles plot. To analyse convergence and check for problematic parameters.
- Plots comparing observed and modelled proportions by fleet (catches). To analyse how estimated population abundance and exploitation pattern fits observed proportions.
- Plots of residuals in catchability models. To analyse precision and bias in abundance trends.
- Retrospective analysis. To analyse how additional data affects the historical predictions of the model.

Model setup

This file contains some information about the GADGET setup for golden redfish.

The selected base run is stored in the directory Baserun2014_2019. The most important files are:

TIME (first and last year of simulation and the number of time-step). Last year's file looked like. (In GADGET; means comment in similar way as # is used in R. # is on the other hand used to identify estimated variable in GADGET.)

;Optimisation Time file for the redfish example in 2013 assessment
;
firstyear 1970
firststep 1
lastyear 2013
laststep 1
notimesteps 2 6 6
;

The simulation time ends in first half of the assessment year to be able to use the tuning data in that quarter (Icelandic Spring survey). Catches in the first half of the assessment year are gestimated and part of the input to the model.

Another time file **TIME.SIMU** is used for prognosis six years ahead.

;
; Simulation Time file for the redfish example
;
firstyear 1970
firststep 1
lastyear 2019
laststep 2
notimesteps 2 6 6
;

The final year in those file is incremented by 1 each year.

AREA is a file required by the program. The file contains size of each area and temperature. These data are not needed in the redfish example so the values in this file do not matter, but the file must be there with the right "number of numbers". This file is in the directory and does not need to be updated.

Description of the stock is in the file **SMARINUS** and that file is not changed between years while same settings are used.

Three files are with the name **sebmar.rec, sebmar.init** and **sebrefw.dat** are stored in the directory InitFiles. Of those sebmar.rec is the only one that needs to be changed each assessment year.

Initial conditions are stored in the file **sebmar.init**. In this file there are ten estimated parameters but the data are not sufficient to estimate the number in each age group in 1970. This file will not be changed annually if the assessment settings are not changed.

The file **sebrefwt.dat** stores the length–weight relationship used in the simulations.

The file **sebmar.rec** contains information about recruitment. Recruitment is at age 5 in step 1. Recruitment is estimated for each year from 1970. Mean length-at-age is estimated separately for three time periods, 1970–2000, 2001–2005 and 2006 onwards. The last year class estimated is the year class that is eight years old in the assessment year. In the 2013 assessment year it is the year class 2005. In simulations other year classes are assumed as average (the name of the switch is #**recfuture** and the average value **0.8** and the minimum over five years is **0.45**). Assumptions about these year classes do not have much effect on the advice but substantial on short-term simulations (six years). Next year the first line with #**recfuture** will be replaced with #**rec2011**. Every year possible changes in growth should be investigated. This investigation is similar to checking if selection pattern has changed in separable age-based model but changes in growth do often lead to change in selection by age.

The file **FLEET** in the top directory describes the fleets catching the fish. Each fleet has a type, specified catches in kg (totalfleet) or specified effort (linearfleet). Each fleet also has a name, selection function and a multiplier that can be used to scale up or down the effort or catches. Data files where catch or effort data are stored are also specified.

The directory **DataFiles** contains a number of files that will all have to be changed (or appended) every year. The files are:

FarCommLD.dat
IceCommLD.dat
GreenCommLD.dat
sebmar.meanlength.catch
fleet.data
IceMarGrlOctIndices.dat
sebmar.meanlength.surveys
fleet.predict
IceMarGrlOctLdr.dat
sebmar.surveys.alkeys
sebmar.catch.alkeys

The files **IceMarGrlOctIndices.dat** and **IceMarGrlOctLdr.dat** contain the combined survey indices for Iceland and Greenland. The difference between those files is just one column with the fleet name that is not in **IceMarGrlOctIndices.dat.** These files describe the use of the same data in two different ways.

All of the files in the **DataFiles** directory can be read in **R** with the command

read.table(file,comment.char=";")

fleet.data contains the catch per time period and fleet. There are four fleets defined, three commercial fleets and one survey, contains the landings in kgs per time-step (six months).

The three commercial fleets (column 4) used in this assessment are **Faroe, Greenland, Iceland.** The last catch data of those fleets are in the first half of the assessment year. The catch after that should be zero. A missing line is interpreted as 0. Each year, catch for the year before the assessment year is entered. The catch for the first half is already there, but as it was an estimate it has to be updated. An estimate for the first half of the assessment year will then be added. The exact division between the year halves does not matter as long as the total catches are correct.

The fourth fleet is the survey **IcelandMarchSurvey** with small amount caught every time-step (10 tons). When the Greenland survey data are added the fleet is still called **IcelandMarchSurvey**. Nothing needs to be changed for **IcelandMarchSurvey** for the next six years in the file **fleet.data**.

The file **fleet.predict** contains information about prediction with fixed effort. The effort is one but a multiplier is specified in the file **FLEET** in the top directory. There it is also specified that the fleet future is with specified effort and is called **linearfleet** but the others where the catch is specified are called **totalfleet**. The proposed HCR corresponds to the multiplier being *0.127.* Care should be taken to have the effort 0 in all time intervals where commercial catch in kg is given, **step 1 2013** and earlier in the **2013** assessment.

Other files in the folder **DataFiles** are likelihood data, all of them specified in the file **LIKELIHOOD** in the base directory where they are related to certain likelihood types (penalty, understocking, surveyindices, catchdistribution, catchstatistics). So-called aggregation files specify how the data are aggregated. Possible methods for aggregation are large, both across lengths, ages and areas. For example, the length distribution from the Icelandic commercial fleet, the file **LIKELIHOOD** looks like:

[component]
name Ice.CommLD
weight 0.0421227197
type catchdistribution
datafile DataFiles/IceCommLD.dat
function multinomial
overconsumption 1
minimumprobability 20
areaaggfile AggFiles/allarea.agg
ageaggfile AggFiles/allage.agg
lenaggfile AggFiles/len.agg
fleetnames Iceland
stocknames sebmar
;

Below are few lines from the file **IceCommLD.dat**. Order does not matter in that file

2011	**1**	**allareas**	**allages**	**len19–20**	**2**
2012	**1**	**allareas**	**allages**	**len19–20**	**22**

What does len19–20 and allages mean? For that we look at the files **AggFiles/allage.agg** and **AggFiles/len.agg**

allage.agg
.agg
;
; Age aggregation file - all ages aggregated together
;
allages 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

len.agg one line

;name	*minl*	*maxl*
len19–20	*18.5*	*20.5*

The number **weight** is what is later changed by the reweighting algorithm.

Generation of the likelihood data files will not be described here but the Icelandic data are generated by **R** scripts accessing the Icelandic databases. The German survey data from East Greenland are provided on cm basis for every station. Generation of the data file is just summing up available length and age measurements by length, age, and time interval, compiling survey indices by length or calculating mean length-at-age, standard deviation and number of aged fishes per age group and time interval. The only complication in the generation of likelihood data is the combination of the survey indices from Iceland and Greenland. Generally compiling data for GADGET is simpler than calculating, catch in numbers per age and survey indices by age.

After running the program large number of files will be generated as specified in **PRINTFILE**. The **rgadget** library (http://r-forge.r-project.org/projects/rgadget/) has a number of functions to read and plot these files.

The last thing to be done before starting a new run is to add the switch corresponding to the most recruitment to the most recent parameter file. This step can also be skipped but then the parameter starts with the value 0 and wide bounds, for example from **-9999** to **9999**. The negative bound might become a problem in optimization so setting the line in manually is recommended. Not starting from the best solution from the last year is recommended procedure if time allows. This can be achieved by randomly changing some of the value in the starting parameter file (**params.in** is the default name).

The order of things is as follows.

- Set up the data and likelihood files.
- Run the model with the final parameter file from last year *gadget -s -i params.final.*
- Look at the file *params.out* generated in each gadget run. If the data entered are correct the likelihood value (line 2) in *params.out* should not have increased by more than 50%.
- Copy *params.final* to *params.in*. Add the line with the most recent recruitment.
- Run the reweighing script. See below this list.
- Copy the file params.final from the **WGTS** directory and change #**recfuture** to the average value (0.8). Change the multiplier of the future fleet in the file FLEET to 0.127.
- Run the simulations with *gadget -s -i params.final -main main.simu*. The catch obtained for the year after the assessment year is the advice for that year.
- Plot results.

In reweighting data from the same source are combined so the command used is:

grouping<-list(sind=c("si1924","si2548"),survey=c("alkeys.sur","IceSurMar.LD","meanl.sur"),comm=c("Ice.CommLD","meanl.catch","alkeys.catch"),foreign=c("Far.Co

mmLD","Green.CommLD"))

gadget.iterative(rew.sI=TRUE,grouping=grouping)

gadget.iterative is obtained from the rgadget package.

D. Short-term projection

Short and medium-term forecasts for golden redfish in Va and XIV can be obtained from GADGET using the settings described below.

Model used: Age–length forward projection

Software used: GADGET (script: run.sh)

Initial stock size: abundance-at-age and mean length for ages 5 to 30+

Maturity: Fixed maturity ogive.

F and M before spawning: NA

Weight-at-age in the stock: modelled in GADGET with VB parameters and length–weight relationship

Weight-at-age in the catch: modelled in GADGET with VB parameters and length–weight relationship and selection by size

Exploitation pattern:

Landings: logistic selection parameters estimated by GADGET for the Icelandic fleet.

Intermediate year assumptions: First half, TAC constraint based on the TAC left from last year. Second half, F according to the Harvest Control Rule

Stock–recruitment model used: None

Procedures used for splitting projected catches: driven by selection functions and provide by GADGET.

E. Medium-term projections

See Section D.

F. Long-term projections

Model used: Age–length forward projection

Software used: GADGET

Initial stock size: one year class of 1 million individuals

Maturity: Fixed maturity ogive by size

F and M before spawning: NA

Weight-at-age in the stock: modelled in GADGET with VB parameters, length–weight relationship and selection of the fisheries

Weight-at-age in the catch: modelled in GADGET with VB parameters and length–weight relationship

Exploitation pattern:

Landings: logistic selection parameters estimated by GADGET for the Icelandic commercial fleet

Procedures used for splitting projected catches:

Driven by selection functions and provided by GADGET.

Yield-per-recruit is calculated by following one year class started at age 5 in 2002 of million fishes for 53 years through the fisheries calculating total yield from the year class as function of fishing mortality of fully recruited fish. Yield-per-recruit is then the total amount caught divided by the initial number of fish at age 5. In the model, the selection of the fisheries is length based so only the largest individuals of recruiting year classes are caught reducing mean weight of the survivors, more as fishing mortality is increased.

G. Biological reference points

Investigation of spawning stock–recruitment data do not show any apparent relationship from 1975–2003 that is approximately the period where reasonable estimates on those data can be obtained. Therefore B_{loss} was suggested in 2012 as candidate for B_{lim}. Then B_{loss} was 160 thousand tonnes that while it is now closer to 150 thousand tonnes due to changes in parameter settings. Still the proposed B_{lim} is 160 thousand tonnes, but will be revisited is changes are done to the assessment that lead to major change in stock size. (Changes in M).

$B_{trigger}$ was defined as 220 thousand tonnes in 2012 (160*exp(0.2*1.645)) where 0.2 was at that time estimated standard error of the biomass in the assessment year from a TSA assessment. This point does not have any biological meaning, it is just a trigger point in the harvest control rule and according to the simulations probability of SSB $<B_{trigger}$ should be low and in the simulations the trigger action is not included but it will lead small reduction in average fishing mortality. Without any $B_{trigger}$ the probability of SSB $<B_{lim}$ is still very low (<1%). Long periods of poor recruitment (not observed in those 30 years where data on recruitment are available) would be the scenario most likely leading to SSB $<B_{trigger}$. 30 years is short time for redfish so things not seen there are relatively likely to happen in the near future.

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Table A.2.1. Number of quick closures on golden redfish in Icelandic waters 1991–2011. See text for further description.

Year	Number of Closures
1991	1
1992	1
1993	2
1994	8
1995	3
1996	0
1997	0
1998	3
1999	6
2000	12
2001	3
2002	3
2003	1
2004	1
2005	6
2006	3
2007	4
2008	5
2009	2
2010	2
2011	2
Total	68

Table B.1.2.1. Biological sampling of golden redfish from the commercial catch in Icelandic waters 1995–2011. The table shows number of samples, how many individuals were sampled for length measurement and age determination.

	Length Measurements		Age Determination	
Year	# Samples	# Measured	# Samples	# Age Read
1995	177	38,403	7	596
1996	100	19,747	3	209
1997	172	38,990	23	1424
1998	174	35,336	26	1404
1999	253	52,407	37	1218
2000	323	73,965	49	1611
2001	269	52,833	46	1600
2002	341	62,926	48	1627
2003	260	45,568	48	1676
2004	219	35,741	48	1669
2005	434	71,681	44	1629
2006	336	52,873	46	1681
2007	311	49,673	45	1723
2008	327	47,122	48	1704
2009	283	46,995	52	1838
2010	328	56,807	47	1721

Table B.3.1. Vessels used in the Autumn Groundfish Survey in ICES Division Va, their survey area, and the number of station taken.

Year	Shallow waters		Deep waters		Total stations
	Vessel name	No.Stations	Vessel name	No.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	163	r/v Árni Friðriksson	219	382
2001	r/v Bjarni Sæmundsson	161	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	162	r/v Árni Friðriksson	219	381
2009	r/v Bjarni Sæmundsson	162	r/v Árni Friðriksson	219	381
2010	r/v Bjarni Sæmundsson	162	r/v Árni Friðriksson	203	365

Table B.3.2. The survey area (nm²) based on the old stratification (used up to 2012) in the German Greenland groundfish Survey by stratum (see Figure B.3.12).

	Depthstrata (m)	Area (nm2)
1.1	1–200	6805
1.2	201–400	1881
2.1	1–200	2350
2.2	201–400	1018
3.1	1–200	1938
3.2	201–400	742
4.1	1–200	2568
4.2	201–400	971
5.1	1–200	2468
5.2	201–400	3126
6.1	1–200	1120
6.2	201–400	7795
7.1	1–200	92
7.2	201–400	4589
Total		37 463

Table B.3.3. The survey area (nm²) based on the new stratification (applied in 2013) in the German Greenland groundfish Survey by stratum (see Figure B.3.13).

In West GLD stratification equals NAFO stratification, in East GLD based on assignment to ICES rectangles, therefore geographic boundaries given as ca. values.

STRATUM	BOUNDARIES					DEPTH	AREA
	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	4615
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	2173
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

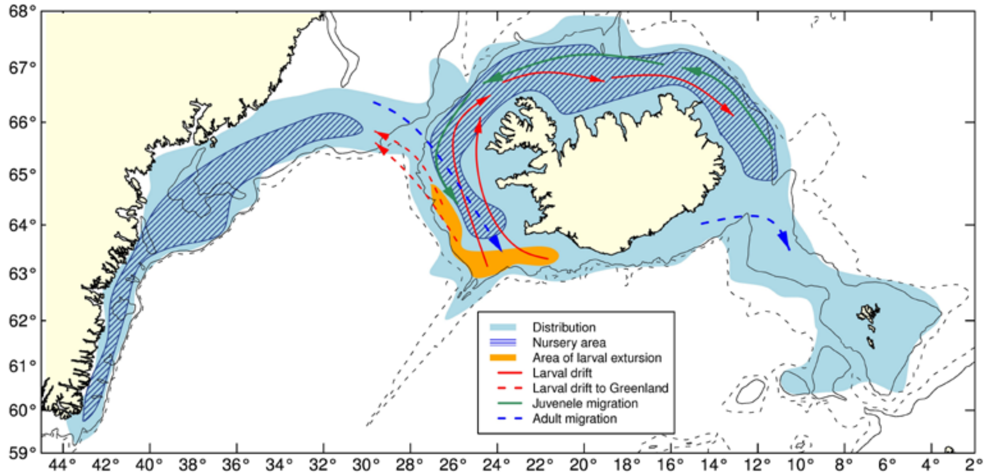

Figure A.1.1. Geographic range of golden redfish (*Sebastes marinus*) in East Greenland, Icelandic and Faroese waters, area of larval extrusion, larval drift and possible migration routes. The solid and dashed lines indicate the 500 m and 1000 m depth contour respectively.

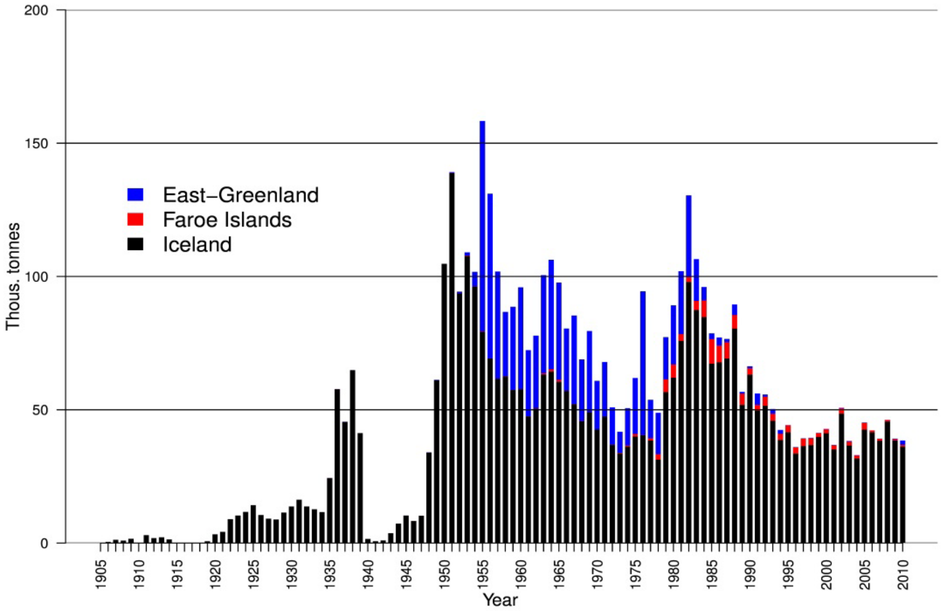

Figure A.2.1. Nominal landings (in tonnes) of golden redfish from Icelandic waters (ICES Division Va), Faroese waters (ICES Division Vb) and East-Greenland waters (ICES Division XIV) 1906–2010.

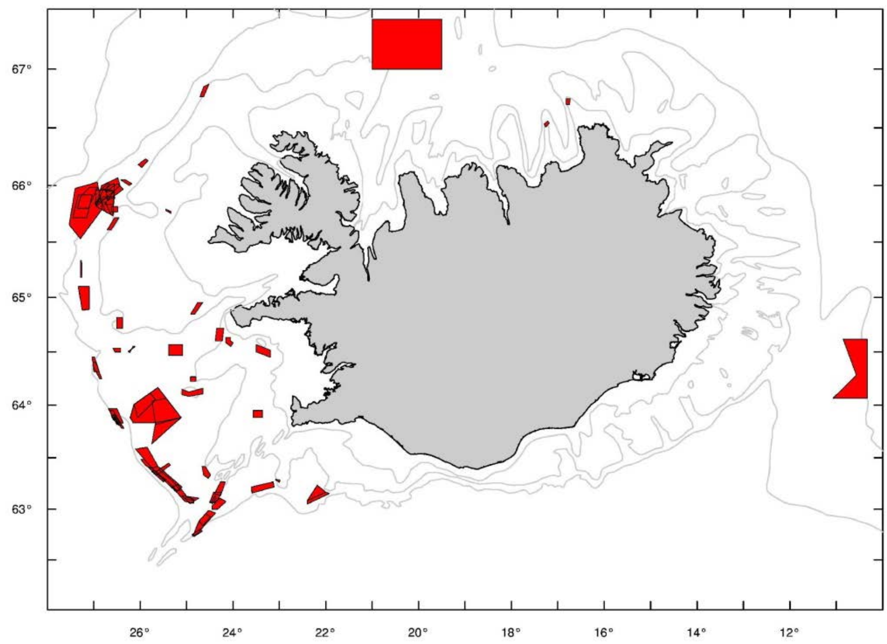

Figure A.2.2. Schematic overview of quick closures on golden redfish in Icelandic waters (ICES Division Va) 1991–2011.

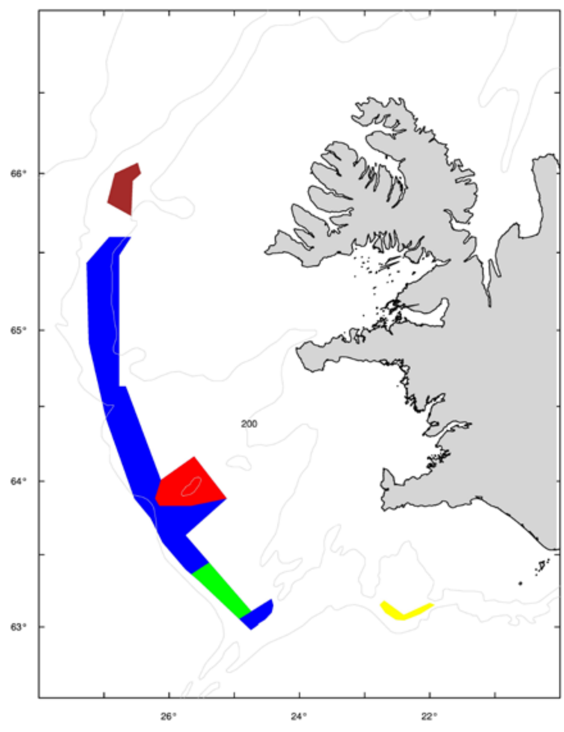

Figure A.2.3. Schematic overview of closed areas for protection of juvenile *S. marinus* in Icelandic waters (ICES Division Va). These areas are either closed permanently or temporarily. During closure bottom trawling is prohibited. The blue area is closed all year long; the red area is only open during the night or from 20:00–08:00 from October 1 to April 1 to allow fishing for saithe; the brown area is open for bottom trawling during the night or from 20:00 to 08:00; the green area is open for bottom trawling February 1 to April 15; the yellow area is closed for bottom-trawl fishery from June 1 to October 31.

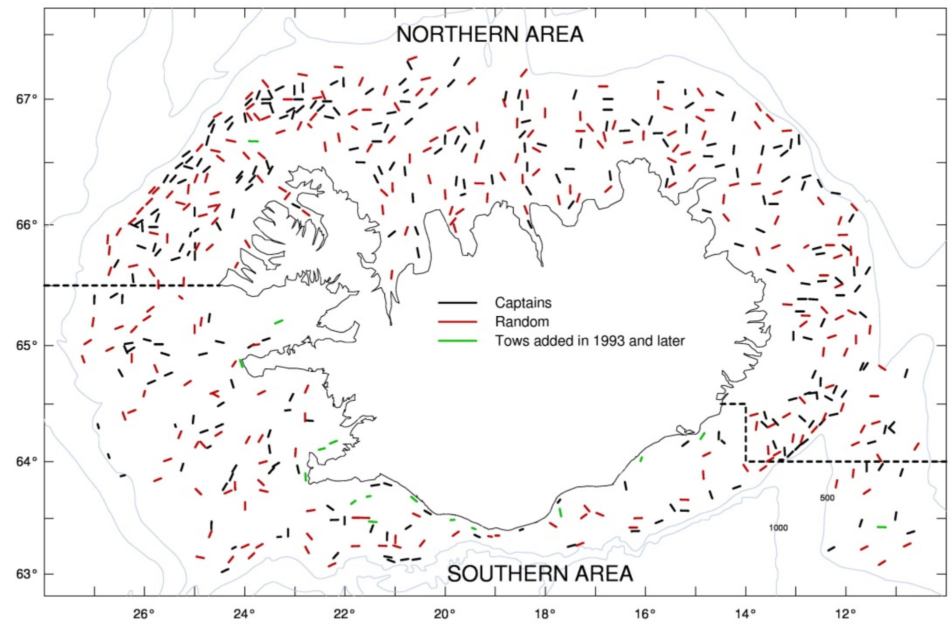

Figure B.3.1. Stations in the Spring Survey in March. Black lines indicate the tow-stations selected by captains of commercial trawlers, red lines are the tow-stations selected randomly, and green lines are the tow-stations that were added in 1993 or later. The broken black lines indicate the original division of the study area into Northern and Southern area. The 500 and 1000 m depth contours are shown.

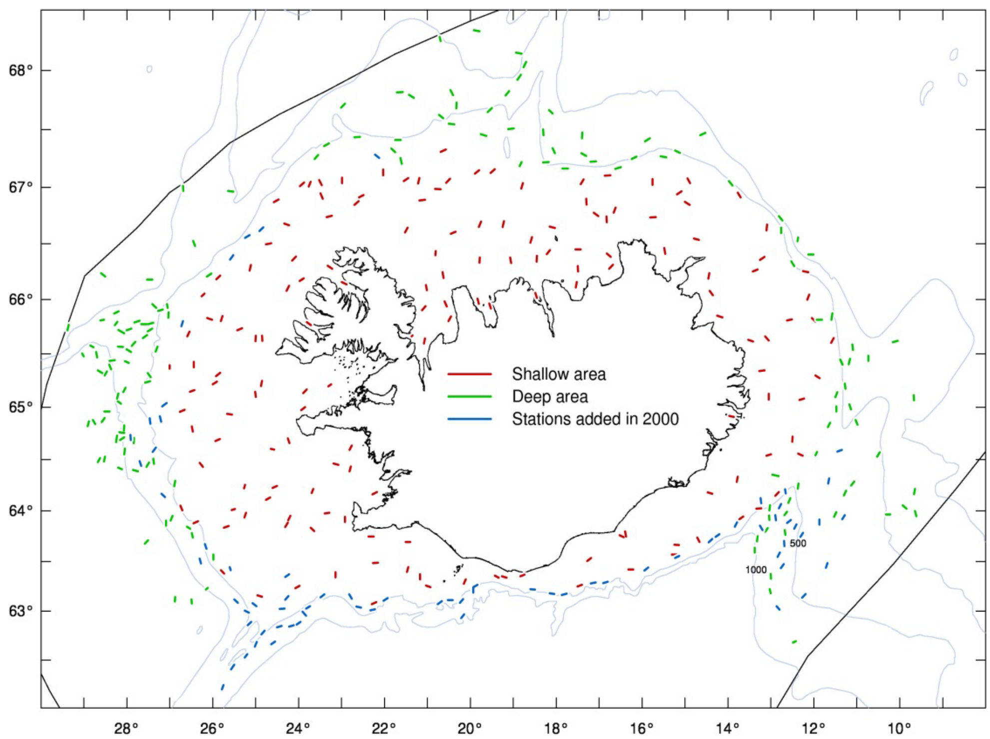

Figure B.3.2. Stations in the Autumn Groundfish Survey (AGS). RV "Bjarni Sæmundsson" takes stations in the shallow-water area (red lines) and RV "Árni Friðriksson" takes stations in the deep-water areas (green lines), the blue lines are stations added in 2000.

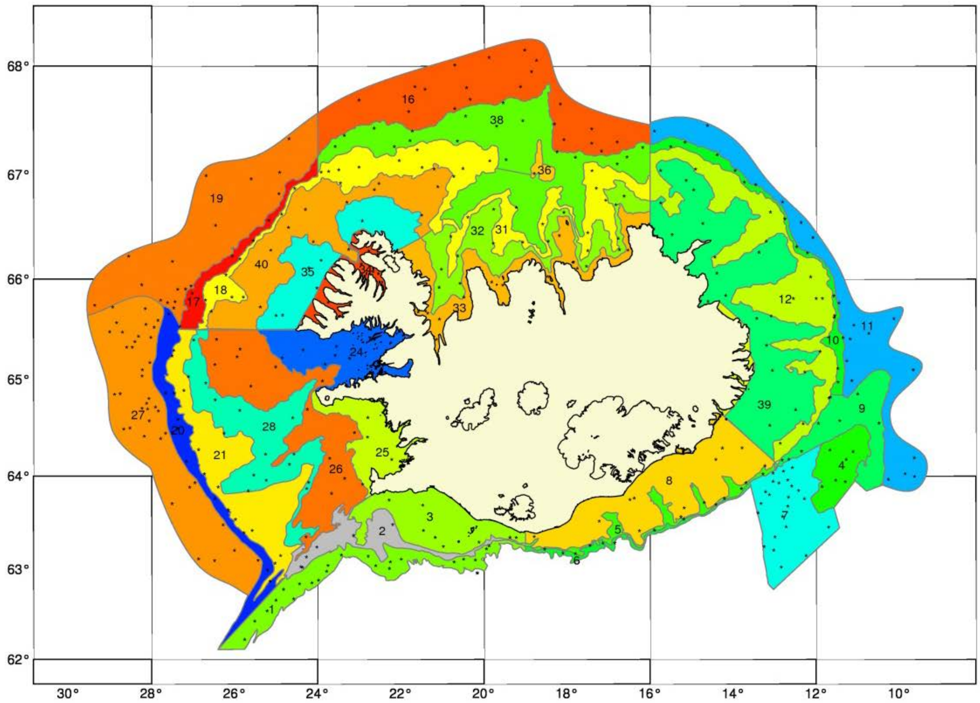

Figure B.3.3. Subareas or strata used for calculation of survey indices for golden redfish from the Autumn Survey in Icelandic waters. This stratification was applied in 2008.

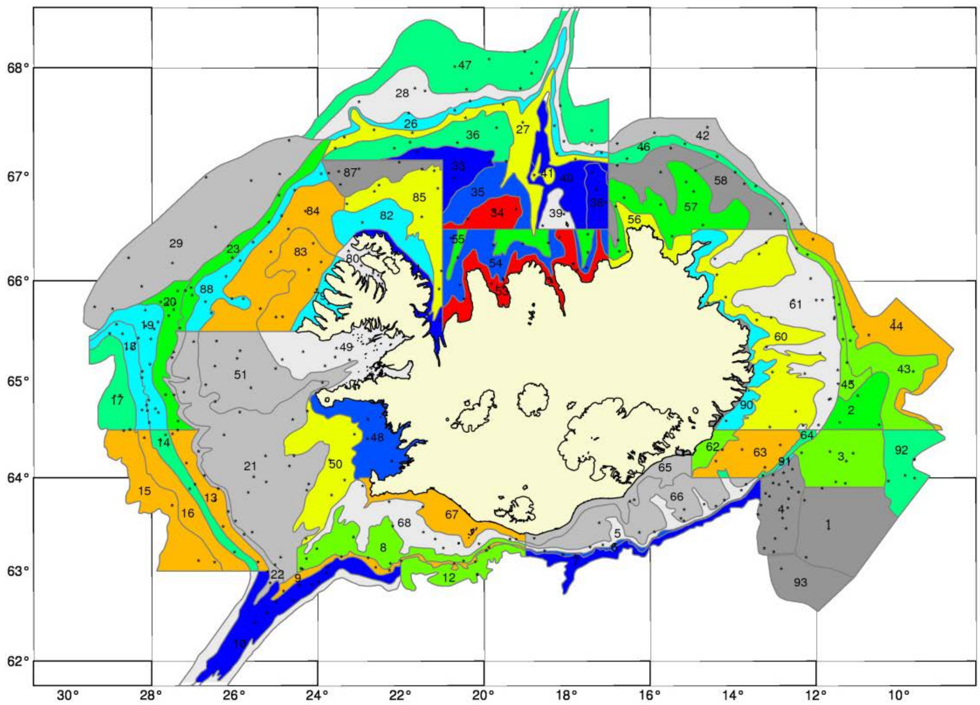

Figure B.3.4. The old stratification (before 2008) that was used for calculation of golden redfish indices from the Autumn Survey in Icelandic waters.

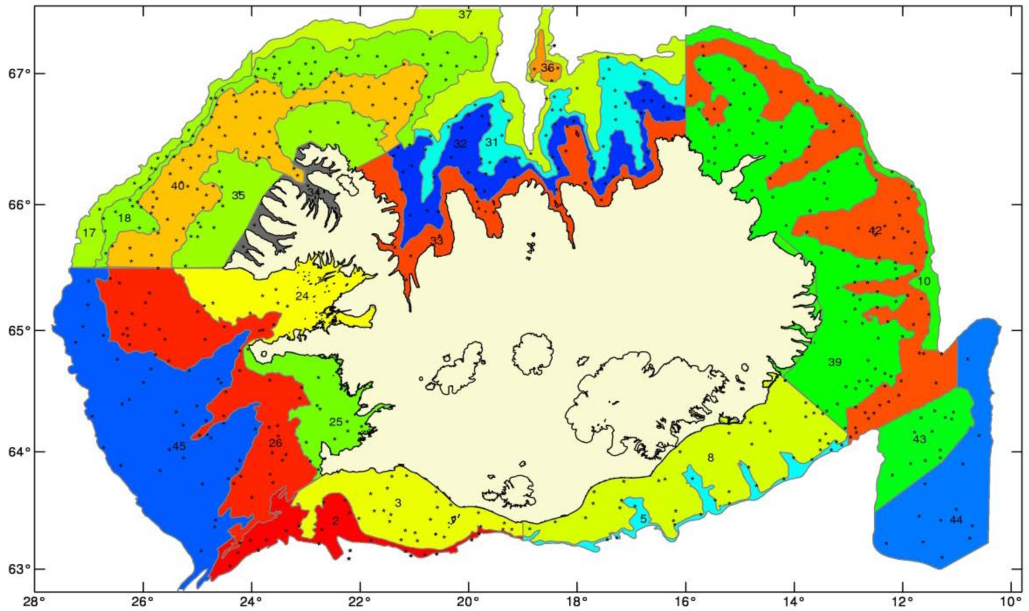

Figure B.3.5. Subareas or strata used for calculation of survey indices for golden redfish from the Spring Survey in Icelandic waters. This stratification was applied in 2011.

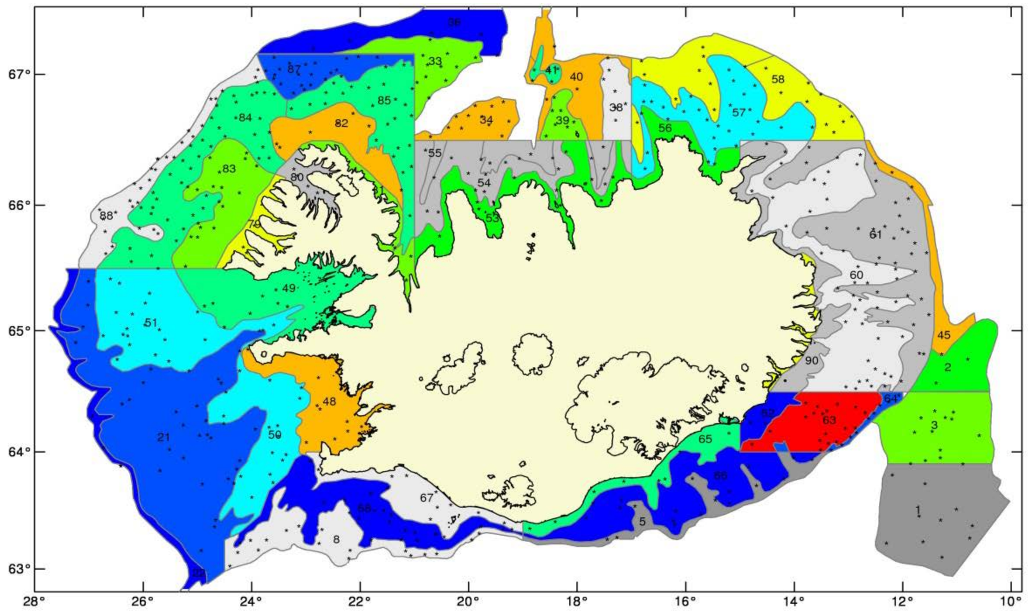

Figure B.3.6. The old stratification (before 2011) that was used for calculation of golden redfish indices from the Spring Survey in Icelandic waters.

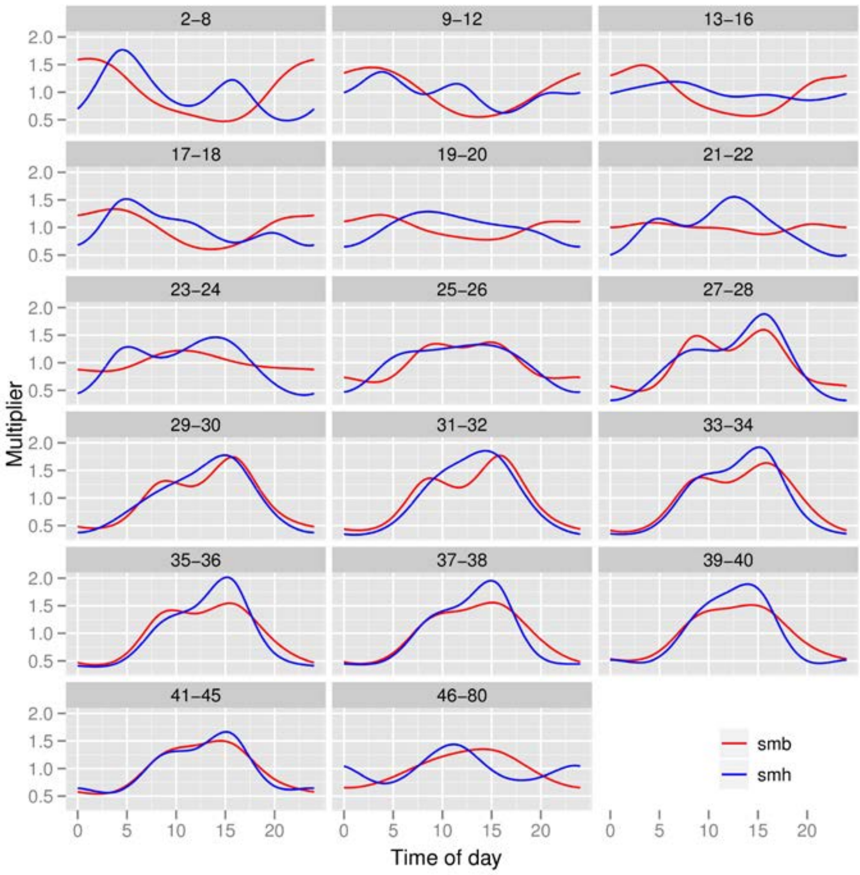

Figure B.3.7. Scaled multiplier for each length group in the Spring Survey (smb - red line) and the Autumn Survey (smh - blue line) based on the glm model with smoother applied to each length group.

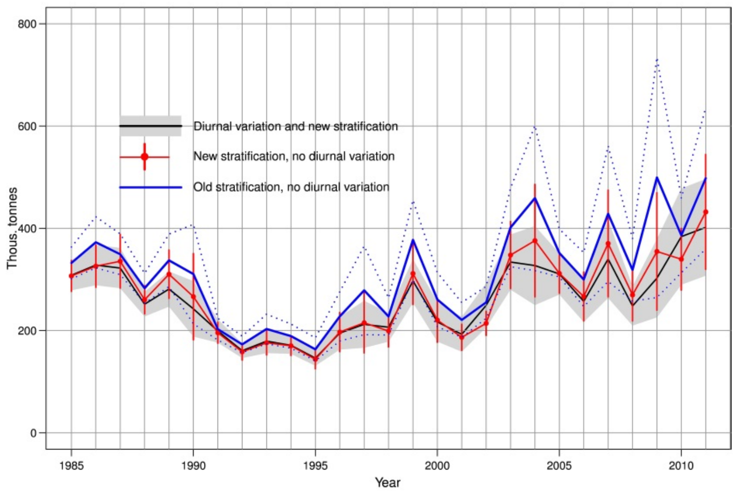

Figure B.3.8. Comparison in survey indices of golden redfish in the Spring Survey 1985–2011, calculated using the new stratification scheme (Figure 3) with and without diurnal vertical migration, and the old stratification scheme (Figure 4).

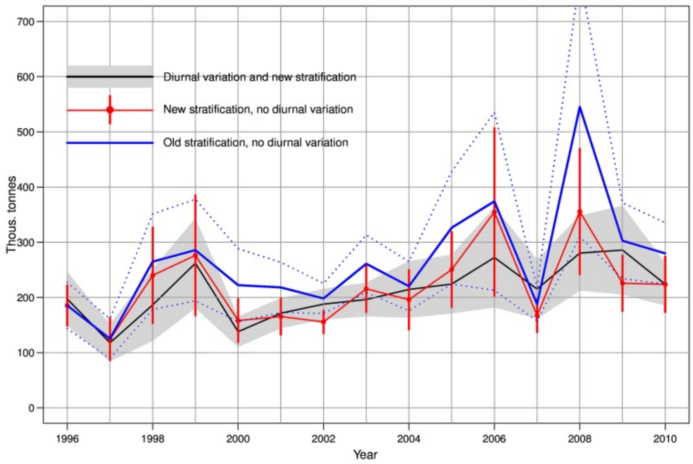

Figure B.3.9. Comparison in survey indices of golden redfish in the Autumn Survey 1996–2010, calculated using the new stratification scheme (Figure 3) with and without diurnal vertical migration, and the old stratification scheme (Figure 4).

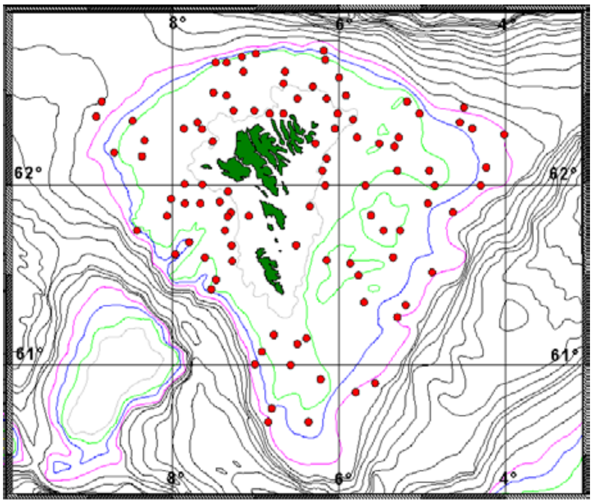

Figure B.3.10. Stations in the Spring Survey on the Faroe Plateau in March 2011.

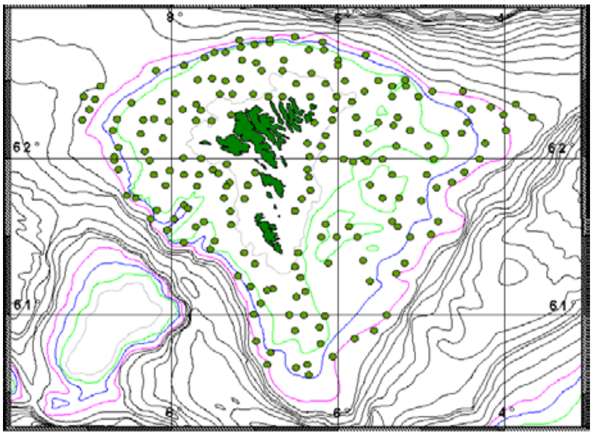

Figure B.3.11. Stations in the Summer Survey on the Faroe Plateau in August 2011.

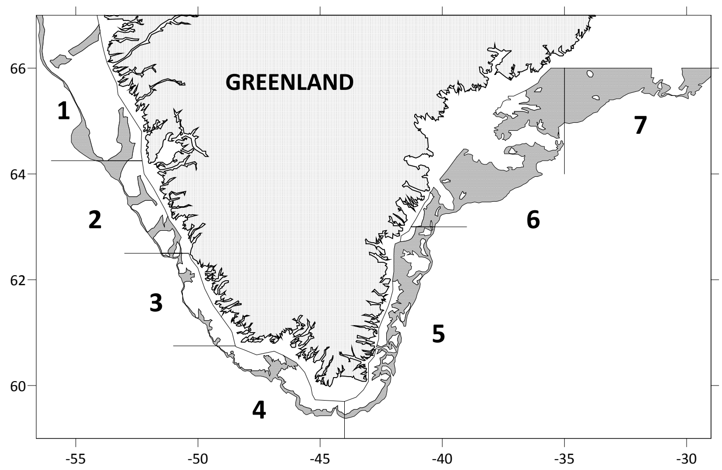

Figure B.3.12. Old stratification used for calculation of golden redfish survey indices of the German groundfish survey conducted on the Greenland shelf until 2012. Only strata off the East Greenland were used (strata 5–7).

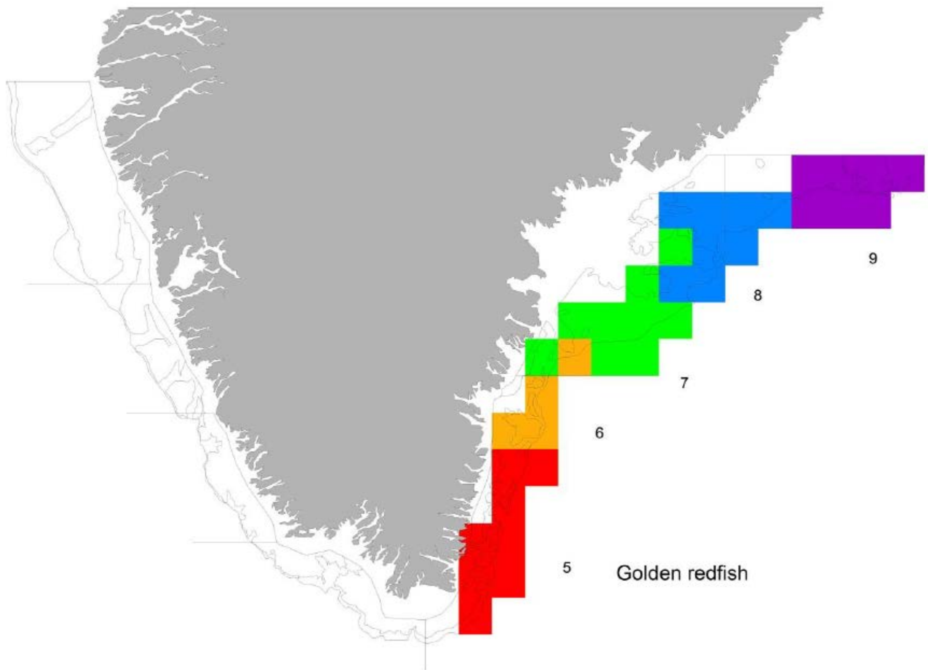

Figure B.3.13. The re-stratification in East Greenland undertaken in 2013. West Greenland strata remain unchanged. Each stratum is divided into two depth zones, 1–200 m and 201–400 m.

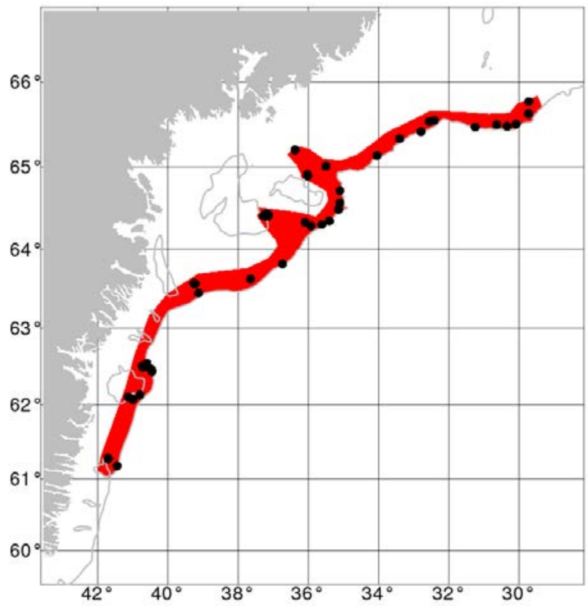

Figure B.3.14. The stratification of the German Survey conducted in East Greenland and used for calculation of survey indices of golden redfish to be used in the GADGET setup. The red area represents the proposed stratum (size = 22 500 km²) and the black points are the stations taken in the 2012 survey.