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Report of the Benchmark Workshop on Redfish (WKRED 2012)

1–8 February 2012

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Executive Summary

The WKRED 2012 Benchmark workshop met from 1–8 February 2012 at ICES Headquarters in Copenhagen, Denmark. The meeting was chaired by Invited External Expert Melissa Haltuch (USA) with ICES Coordinator Christoph Stransky (Germany). Doug Butterworth (South Africa), Tim Miller (USA) and Paul Spencer (USA) also participated in the meeting as a panel of Invited External Experts as well as 20 participants from nine countries. There were no stakeholder representatives in attendance. The objectives of the workshop were, for each stock under consideration:

1) to evaluate the appropriateness of data and methods to determine stock status;
2) to agree upon and document the preferred method for evaluating stock status and (where applicable) short-term forecasts and to update the associated Stock Annex as appropriate;
3) to evaluate the possible implications for biological reference points; and
4) to develop recommendations for future improvement of the assessment methodology and data collection.

The seven *Sebastes* stocks considered by the workshop were: Arctic *marinus*, Arctic *mentella*, Northwestern *marinus*, Icelandic *mentella*, Deep *mentella*, Shallow *mentella*, and Greenland *mentella*. The Benchmark workshop report presents the analyses undertaken during the workshop, identifies data and modelling concerns, and provides general recommendations from the workshop. The Stock Annexes are updated given the benchmark workshop outcomes. The report has sections dealing with data sources, data quality, environmental and ecosystem issues, stock assessment methods, forecasts, biological reference points, recommended modifications to the Stock Annexes, recommendations on the procedure for assessment updates and recommendations for future work for each species. The Stock Annexes follow the standard ICES format.

The Benchmark identified assessment models and configurations for Arctic *marinus* (GADGET), Arctic *mentella* (SCA), and Northwestern *marinus* (GADGET). This was the first Benchmark workshop review for the application of the models above to redfish. A biomass dynamic model was presented for Icelandic *mentella*, but not for the remaining three *mentalla* stocks (Greenland, Deep, and Shallow). The biomass dynamic model was extended to the remaining redfish stocks by the panel given the absence of quantitative models for the three remaining Northwestern *mentella* stocks and because the GADGET and SCA models covered relatively short time periods with respect to the exploitation history of the Arctic *marinus*, Arctic *mentella*, and Northwestern *marinus* stocks. The workshop agreed that the biomass dynamic models provide a useful cross-check of the GADGET and SCA model results. However, the workshop was unable to reach consensus regarding the utility of the biomass dynamic models as a step forward from the current trends based methods, which are not clearly defined in the current Stock Annexes for the four Northwestern *S. mentalla* stocks. Therefore, the workshop report details these analyses but the corresponding four Stock Annexes have not been agreed for the four Northwestern *S. mentella* stocks and this issue will need to be resolved at a higher level within ICES. In the interim the Stock Annexes offer two choices for proceeding, to maintain the current methods or to add the biomass dynamics model results. Issues requiring further work were identified for all stocks and included in the Benchmark Report. Issues regarding data quality and analysis, as well as assessment methodology were considered during the

meeting. Alternative assessment approaches were investigated for the three stocks with GADGET and SCA models. However time constraints allowed only for preliminary investigations to be conducted for the GADGET models due to long model run times. A large part of the workshop was dedicated to the GADGET models, which left little time to investigate the details of the TSA model as an alternative to the Northwestern *marinus* GADGET model.

General recommendations from the Benchmark include:

1) the use of preliminary workshop(s) to better prepare assessments for Benchmark workshops;

2) a series of workshops that would generally benefit the ICES Benchmark process on the following topics: reference points, harvest control rules and management strategy evaluations, data poor stock assessment methods, data weighting in stock assessment models, review of modelling packages, and review of survey methodology and data analyses;

3) standardization of survey data;

4) testing and documentation of stock assessment modelling platforms used in WKRED2012;

5) further investigation of discards; and

6) exploration of commercial cpue as tuning time-series for redfish assessments.

1 Introduction

This Benchmark workshop was convened according to guidance provided by ACOM with Draft Terms of Reference provided in the document 2011/2/ACOM49 (Annex 1). The objectives of the Workshop were, for each of the stocks considered:

1) to evaluate the appropriateness of data and methods to determine stock status;
2) to agree upon and document the preferred method for evaluating stock status and (where applicable) short-term forecasts and to update the associated Stock Annex as appropriate;
3) to evaluate the possible implications for biological reference points; and
4) to develop recommendations for future improvement of the assessment methodology and data collection.

Accordingly, the workshop reviewed data, provided an opportunity for input from stakeholders (though none availed themselves of this opportunity), and identified assessment issues. Most of the workshop was spent resolving the assessment issues to the extent possible, with a view to revising the Stock Annexes for adoption as standard approaches for application for the following 3–5 years.

The meeting was chaired by Invited External Expert Melissa Haltuch (USA) with ICES Coordinator Christoph Stransky (Germany). Doug Butterworth (South Africa), Tim Miller (USA) and Paul Spencer (USA) also participated in the meeting as a panel of Invited External Experts. Other participants included members of the ICES assessment groups (Northwestern Working Group and Arctic Fisheries Working Group), and members of the ICES Secretariat. A full list of participants is provided in Annex 2.

1.1 Implementing biomass dynamic models as a meta-analytical assessment approach for redfish

None of the stocks examined during the Benchmark workshop have reached the stage where a single definitive assessment can be proposed as the single “best” approach. In order to establish a common basis that could provide interim advice with respect to stock productivity, together with biomass and depletion levels for all stocks, the biomass dynamic models presented by Arni Magnusson for the Icelandic *mentella* stock, in Working Document 13 (WD13), were extended and applied to all stocks (see Appendices 1 and 2 for results). The reason for the joint assessment of all stocks at the simplest common level was to provide a basis for meta-analysis to provide further information on the values of productivity parameters, and biomass and depletion levels, for each stock. The outputs from such meta-analyses can inform not only the parameter estimates for biomass dynamics models, but also parameters for higher level assessments of these stocks. Biomass dynamic models fall into the level 3 category as defined by the ICES SISAM (Strategic Initiative for Stock Assessment Methods). For the stocks that did not have age structured models in place for the workshop, the biomass dynamic models are a quantitative basis for providing advice. However, it is preferable that in future these biomass dynamic models be, at a minimum, be extended to level 5 (Age Structured Production Models) as defined by the ICES SISAM.

Often more than one modelling approach was implemented for each stock at the workshop, and the outputs from each model, including the biomass dynamic models, can serve as a double check when formulating advice. This is particularly helpful in the case of the age structured models that cover relatively short time periods with respect to the exploitation history of the stocks. The biomass dynamic model results provide a common denominator and reasonable (though uncertain) estimates of the depletion of the resource since the start of the time-series of catches, rather than only over the period for which survey based abundance indices are available. In terms of sustainable yield estimation, the survey data are usually inadequate to provide precise estimates, particularly of stock productivity. However independent information can be used (Appendix Rockfish Productivity) to develop what could amount to a prior distribution for stock productivity. In the interests of simplicity, a range of results are presented across the values of stock productivity ($r = 0.05$ to 0.10). The choice of $r = 0.05$ to 0.10 was based on the information in Appendix Rockfish Productivity and was considered to be most appropriate to the redfish stocks being reviewed during the workshop. The estimates of precision associated with these results (displayed as CVs) are generally large and should be factored into decisions, with more conservative decisions for less precise estimates, in line with the precautionary approach. Also note that management quantities such as stock depletion and current sustainable yield (replacement yield, RY), are often relatively better estimated than MSY.

Workshop participants could not reach agreement regarding whether or not to include the biomass dynamic model results in the stock annexes for those stocks without age structured models (Icelandic, Greenland, Pelagic, and Deep *mentella*). The biomass dynamic model results are discussed in the workshop report and are offered by the panel as an alternative option to the current trends based methods in the stock annexes.

2 Glossary

2.1 Glossary

Regional organizations

ICES: International Council for the Exploration of the Sea (http://www.ices.dk)

NEAFC: Northeast Atlantic Fisheries Commission (http://www.neafc.org)

NAFO: Northwest Atlantic Fisheries Organization (http://www.nafo.int)

Geographical areas

(see http://geo.ices.dk, http://www.fao.org/fishery/area/Area27/en, EU Regulation 218/2009)

Subarea: geographical unit, e.g. Subarea II (Norwegian Sea, western Barents Sea, Spitsbergen and Bear Island)

Division: geographical unit, e.g. Division IIa (Norwegian Sea, southwestern Barents Sea)

Subdivision: geographical unit, e.g. Subdivision IIa1 (Norwegian Sea; NEAFC Regulatory Area)

Northeast Arctic area: Subareas I and II (acronym: NEA)

Northwestern area: Subareas V, XII and XIV (for pelagic redfish, also NAFO Subareas 1 and 2) (also 'GIF area': Greenland-Iceland-Faroes)

Species

Golden redfish: *Sebastes marinus* (Linnaeus, 1758), merely demersal distribution

Beaked redfish: *Sebastes mentella* (Travin, 1951) (also 'deep-sea redfish' or 'deep-water redfish'), demersal and pelagic distribution

Stocks

Acronym	Official stock name	WKRED stock name
smr-arct	Golden redfish (*Sebastes marinus*) in Subareas I and II	Arctic marinus
smn-arct	Beaked redfish (*S. mentella*) in Subareas I and II	Arctic mentella
smr-5614	Golden redfish (*S. marinus*) in Subareas V, VI and XIV	Northwestern marinus
smn-con	Beaked redfish (*S. mentella*) in Division Va and Subarea XIV (Icelandic slope stock)	Icelandic mentella
smn-sp	Beaked redfish (*S. mentella*) in Subeareas V, XII, XIV and NAFO 1 and 2 (Shallow Pelagic stock)	Shallow mentella
smn-dp	Beaked redfish (*S. mentella*) in Subareas V, XII, XIV and NAFO 1 and 2 (Deep Pelagic stock)	Deep mentella
smn-grl	Beaked redfish (*S. mentella*) in Subarea XIV (demersal on Greenland slope)	Greenland mentella

Expert groups

AFWG: Arctic Fisheries Working Group

NWWG: Northwestern Working Group

WGRS: Working Group on Redfish Surveys (formerly PGRS/SGRS; Planning/Study Group on Redfish Stocks/Surveys)

Surveys

Northeast Arctic area

Official survey name	Acronym	WKRED survey name	References
Joint Barents Sea survey – bottom-trawl	BS-NoRu-Q1 (BTr)	Winter survey	WD22
Joint Russian-Norwegian Ecosystem autumn survey – bottom-trawl	Eco-NoRu-Q3 (Btr)	Ecosystem survey	WD22
0-group survey	Eco-NoRu-Q3	0-group survey	WD22
Russian bottom-trawl survey	RU-BTr-Q4	Russian survey	WD22
Norwegian coastal survey	NOcoast-Aco-Q4	Coastal survey	WD22
Norwegian Sea pelagic survey	NS-PelAco-Q3	Pelagic survey	PGRS 2009
Redfish Survey in the Norwegian Sea and adjacent waters	REDNOR-Q3	??	PGRS 2009
Norwegian slope survey - south	NOslopeS-Aco-Q2	Slope south survey	
Norwegian slope survey - north	NOslopeN-Aco-Q3	Slope north survey	

Northwestern area

Official survey name	Acronym	WKRED survey name	References
German Greenland groundfish survey	GER(GRL)-GFS-Q4	German survey	Rätz, 1999
Greenlandic groundfish survey		Greenlandic survey	NWWG 2011 WD03
Greenland halibut survey		Greenland halibut survey	NWWG 2011 WD05
Icelandic bottom-trawl survey - spring	IS-SMB	Icelandic spring survey	WD 1
Icelandic bottom-trawl survey - autumn	IS-SMH	Icelandic autumn survey	WD 1
Faroese February-March groundfish survey	FO-GFS-Q1	Faroes spring survey	WD 1
Faroese August groundfish survey	FO-GFS-Q3	Faroes summer survey	WD 1
International Trawl-Acoustic Survey in the Irminger Sea and adjacent waters	TAS	Irminger Sea survey	WGRS 2011

Models

GADGET: The Globally Applicable Area Disaggregated General Ecosystem Toolbox is a toolbox for creating forward-simulation, process-based, fisheries models. See http://www.hafro.is/gadget

SCA: Statistical catch-at-age model, see e.g. Doubleday, W.G., 1976. A least-squares approach to analysing catch-at-age data. International Commission for Northwest Atlantic Fisheries, Research Bulletin 12: 69–81.

Schaefer: see e.g. Schaefer, M.B., 1954. Some aspects of the dynamics of populations important for the management of the commercial marine fisheries. IATTC (Inter-

American Tropical Tuna Commission) Bull. 1: 27–56. Or: Schaefer, M.B., 1957. Some consideration of population dynamics and economics in relation to the management of marine fisheries. Journal of the Fisheries Research Board of Canada 14: 669–681.

TSA: Time-Series Analysis, see e.g. Gudmundsson, G., 1994. Time-Series Analysis of Catch-at-age Observations. Appl. Statist. 43: 117–126.

Parameters

B: biomass

F: fishing mortality

SSB: spawning–stock biomass: biomass of the mature part of the stock

Statistics

MCMC: Markov Chain Monte Carlo methods (which include random walk Monte Carlo methods) are a class of algorithms for sampling from probability distributions based on constructing a Markov chain that has the desired distribution as its equilibrium distribution. The state of the chain after a large number of steps is then used as a sample of the desired distribution. The quality of the sample improves as a function of the number of steps. See e.g. Hastings, W.K., 1970: Monte Carlo Sampling Methods Using Markov Chains and Their Applications. Biometrika 57: 97–109.

3 Golden redfish (*S. marinus*) in Subareas I and II

3.1 Current assessment and issues with data and assessment

An experimental assessment model (GADGET) for *S. marinus* in Subareas I and II has been run during the AFWG since 2006 (ICES 2011). In brief, the model is a single-species, forward simulation, age–length structured model, split into mature and immature components. There are two commercial fleets (a gillnet fleet and a combined trawl and other gears fleet), and two surveys. Growth and fishing selectivity are assumed constant over time, and recruitment is estimated on an annual basis (no SSB–recruit relationship). Investigation is required into the changing signal from the coastal survey. In addition it is unclear to what extent the slight increase in recruitment in recent years is genuine *S. marinus* recruitment, and how much is due to species misidentification.

3.2 Compilation of available data

3.2.1 Catch and landings data

The landings statistics used by the Arctic Fisheries Working Group (AFWG) are those officially reported to ICES if not else reported by members of the Working Group. In cases where such reporting to ICES or AFWG do not exist, or are considered incomplete, reporting made directly to the Norwegian authorities during the demersal fisheries have been used as preliminary figures (see WD 21 for more details). In 2010, 43% of the total landings were taken by trawl, 38% by gillnet, 17% by longline, and 2% by other gears.

There are also cases where redfish (*Sebastes*) reporting to ICES exist, but not segregated by *Sebastes* species. The split of the national landings by species can be summarized as follows:

The national landings of redfish for Norway and Russia are split into species by the respective national laboratories. For other countries and ICES Divisions IIa and IIb, except for the pelagic fishery in international waters of the Norwegian Sea where most countries correctly are reporting this as *S. mentella*, the AFWG has split the demersal landings into *S. mentella* and *S. marinus* based on Working Documents, oral reports from country members at the AFWG or reports to the Norwegian fisheries authorities from different fleets fishing in the Norwegian Economic Zone (NEZ, IIa) and the Svalbard Fisheries Protection Zone (IIb). This species-splitting is documented for all years back to 1993 on http://groupnet.ices.dk/AFWG2011/Data/Smentella.

Landings statistics per year, split by redfish species, country and ICES area exist back to 1969 (ICES 2011; Anon. 2009). Based on the STATLANT database and species information in earlier ICES Working Group reports and Russian reports (Zakharov *et al*., 1977; Drevetnyak, 2003), the AFWG has been able to extend the total international *S. marinus* landings statistics back to 1908 (ICES 2011). Figure 3.1 shows the official landings statistics back to this year. See also Figure 3.3.

No discards are accounted for in the Northeast Arctic *Sebastes* stock assessments. The discarded bycatch in the shrimp fisheries is considered to be almost exclusively *S. mentella* (see Chapter 4.2.1), but the Norwegian coastal and fjord shrimp trawl fisheries caught some by catch of *S. marinus* before the sorting grid was introduced in 1992. Some of this were of consumable size and hence reported in the landings statistics.

PINRO, Russia, has developed a scheme for collecting biological and catch data by scientific observers on board fishing vessels (Gusev *et al.*, 2009). At-sea observer data are used to estimate discards by Russian fleet fishing for demersal species in the Barents Sea. Gusev *et al*. (2009) presents estimates of discards of golden redfish in the Russian demersal fishery during 1996–2006 which vary between 413 and 1935 tonnes per year.

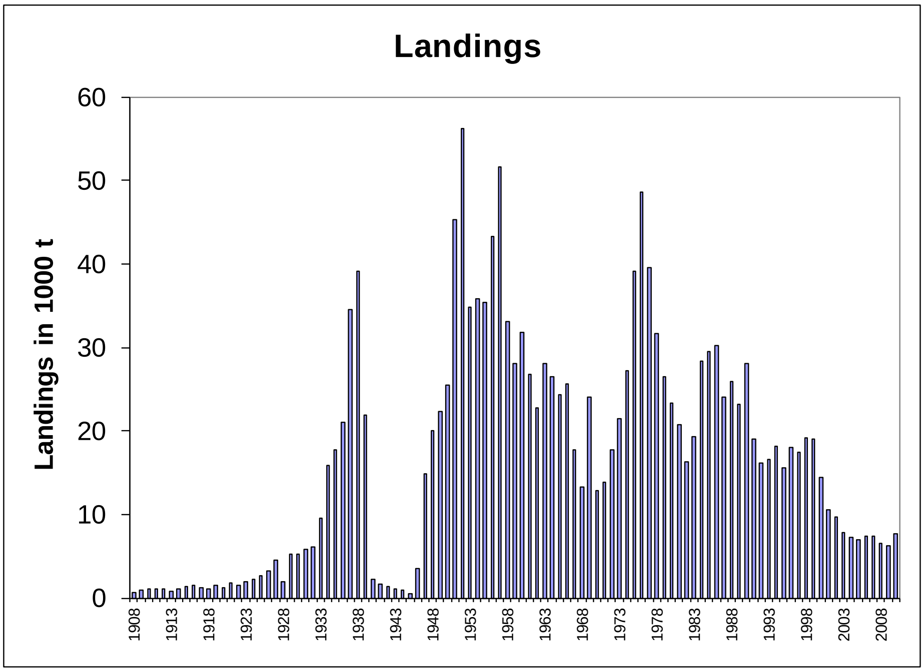


Figure 3.1. ***Sebastes marinus*** **in Sub-areas I and II. Total international landings 1908–2010 (thousand tonnes).**

3.2.2 Biological data

The Arctic *S. mentella* is long-lived (maximum age ca. 75 years), ovoviviparous, and inhabits pelagic and epibenthic habitats from 200–800 m in the Northeast Atlantic. The size and age at first maturity (50%) are 31 cm and 11 years, respectively.

In Norway, four different sampling platforms provide biological data (length, weight, age, sex, maturity) from the commercial catches. These are the Reference Fleet (self-sampling by trained fishers at sea), the Coastguard (upon inspections at sea), the Directorate of Fisheries' surveillance of the fisheries incl. temporary closure of juvenile fish areas, and some port sampling of redfish landings.

In Russia, one sampling platform provides all of the biological data (length, weight, age, sex, maturity) from the commercial catches. This is the scientific observer on board fishing vessels. A scientific observer is required to collect biological information on the major commercial species in each trawl. In catches of up to 500 kg, all fish are registered and measured. If the catch is greater than 500 kg, the length of 300 sp. of each species of fish is measured. For all Russian local fisheries areas, 50 fish are collected for estimating the age (otoliths).

For EU countries, *S. mentella and S. marinus* in ICES Subareas I and II are defined as "Group 1" species, i.e. species that drive the international management process including species under EU management plans or EU recovery plans or EU long-term multi-annual plans or EU action plans for conservation and management based on Council Regulation (EC) No 2371/2002. According to this regulation 125 specimens of each of the species per 1000 tonnes caught by each country should be age determined. In addition, individual weight, sex and maturity should be recorded and presented. For further details, see the Commission decision of 18 December 2009 adopting a multi-annual Community programme for the collection, management and use of data in the fisheries sector for the period 2011–2013 (2010/93/EU).

Apart from Norway, responsible for ca. 85% of the catches, Russia and Germany frequently provide length information about their landings. In those cases, Russian and German length compositions have been applied on the Russian and German landings, respectively, using an age–length-key (ALK) and weight-at-age data from the Norwegian trawl landings. Catches from the other countries are usually assumed to have the same age composition and weight-at-age as the Norwegian trawl landings.

A maturity ogive has previously not been available for *S. marinus*, and knife-edge maturity-at-age 15 (age 15 as 100% mature) has hence been assumed. The improved maturity ogive modelled by the GADGET model, and based on maturation data (by length and age) collected from Norwegian surveys and landings, is presented in Figure 3.2. This analysis demonstrates that 50% of the fish are mature at age 12.

Live weight-at-age is estimated from length-at-age (Figure 3.3) from both research survey data and commercial data as we assume the length- and weight-at-age in the catch to be the same as in the stock. The length-at-age is converted to weight by using the relationship $W=\alpha L^3$, where α=0.015. According to WD19 the best fit for the years 1999 through 2009 is the log-linear relationship $W=\alpha L^\beta$ $W = \alpha L^{\beta} e^{\varepsilon}$ where logα=-4.676 and β=3.125. Age–length relationships for redfish are typically non-linear and a natural choice of a simple model is the von Bertanlanffy growth model: $L=L_\infty(1-e^{-KAge})e^{\varepsilon}$, where L_∞ is the mean maximum length, K the growth rate, and ε a zero mean error term with variance σ^2.

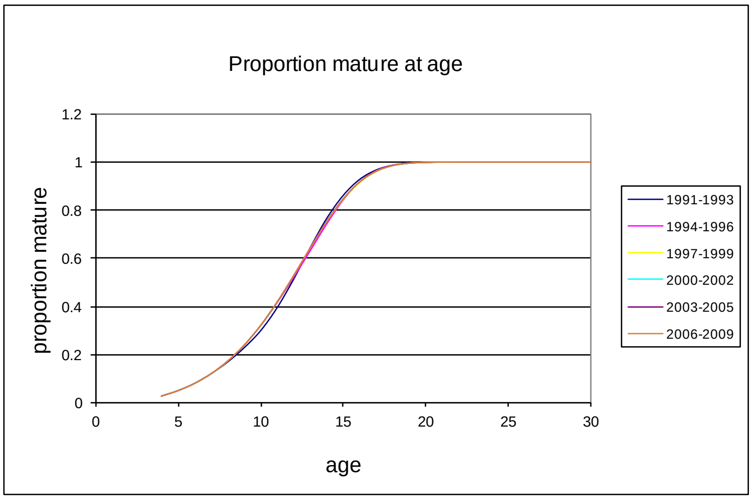


Figure 3.2. Maturity-at-age of *Sebastes marinus* in ICES Subareas I and II as estimated from research survey and commercial data (ICES 2011).

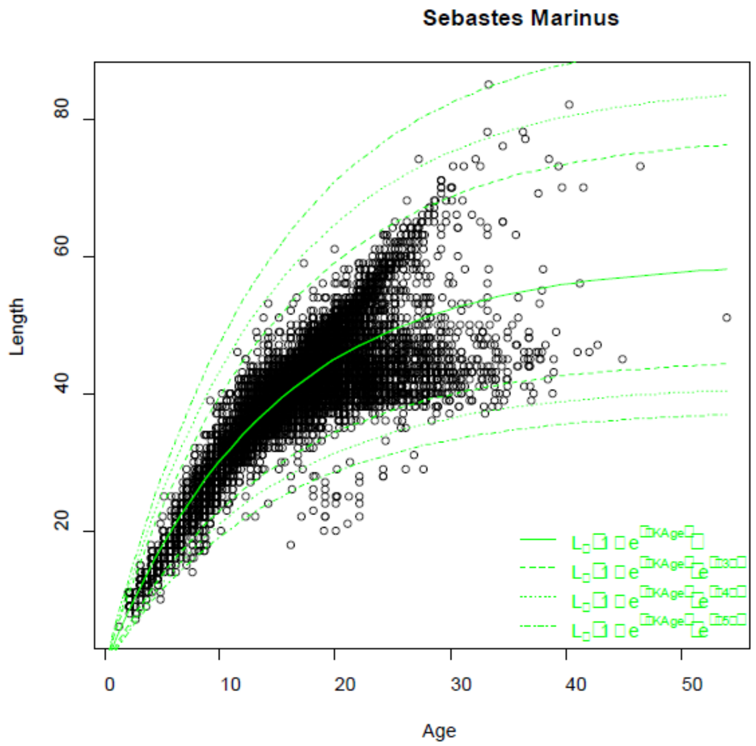


Figure 3.3. Length *vs.* age for Arctic *Sebastes marinus* for data available from IMR's database (Norway) for the years 1999 through 2009. The estimated mean using von Bertanlanffy's growth model is shown by the solid green line, and distances from the mean measured as number of standard deviations from the mean are shown by the dotted lines (ref. WD19). Note that some 20 cm specimens have been aged to 20 years, these are most likely *S. viviparus* that have been misidentified as *S. marinus*. The two branches of growth beyond age 25 need further investigation and explanation.

3.2.3 Survey tuning data

A description of the available and used surveys in the assessment models are given in WD18 and WD24. A schematic illustration of these survey-series is given below in Figure 3.4.

3.2.4 Commercial tuning data

The cpue series for *S. marinus* from Norwegian 32–50 meter freezer trawlers and factory trawlers (>53 m) has been available since 1992. Only data from days with more than 10% *S. marinus* in the catches (in weight) are included in the annual averages. This cpue series is not used as input to the present GADGET assessment model, but is used by the Arctic Fisheries WG as independent and supplementary information. The commercial landings by length and age, by quarter and by two fleets are hence the only commercial tuning data used in the current GADGET assessment.

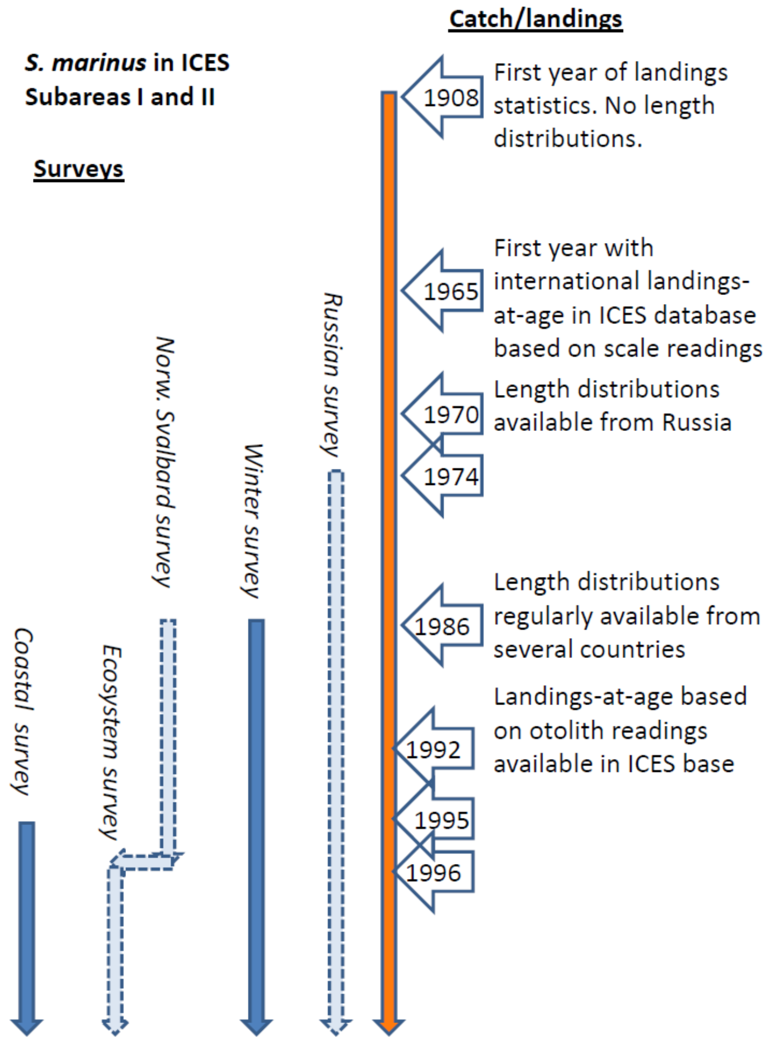


Figure 3.4. Illustration of the available time-series of surveys and catch/landings data. Solid blue arrows show the scientific surveys currently used in the GADGET model, while the dotted light blue arrows show available surveys currently not used.

3.2.5 Industry/stakeholder data inputs

None.

3.2.6 Environmental data

No environmental data are currently used in the stock assessment.

3.3 Stock identity, distribution and migration issues

A thorough description of the distribution and migration of the Arctic *S. marinus* can be found in Drevetnyak *et al*. 2011. The species is distributed in the Barents Sea from the northwest coast of Norway along the continental slope up to the Bear Island and further to the West Spitsbergen slope (Figure 3.5), but not so far into the southern Arctic Sea as beaked redfish. To the east, the golden redfish reaches as far as the North Kanin, Goose and Novaya Zemlya Banks. The limits of its distribution depend on the spatial extent of warm water of Atlantic origin. Golden redfish are also found over most of the continental shelf and in the Norwegian fjords southwards beyond 62°N, although more scattered south of this latitude. Important areas of larval extrusion are outside Lofoten and Vesteralen, the Halten Bank area, outside Möre and probably in many of the Norwegian fjords, but the migration patterns linked to these areas are not known.

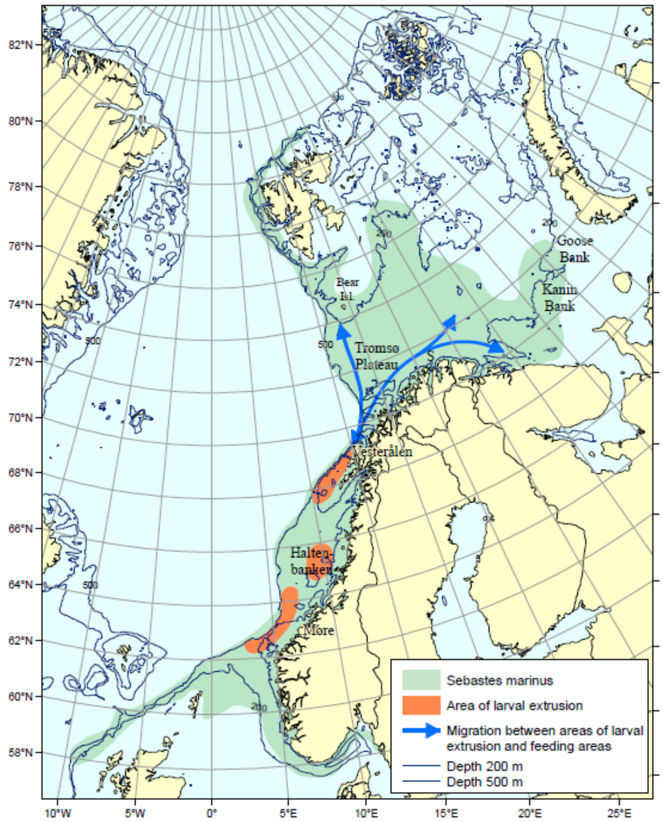


Figure 3.5. Arctic *S. marinus*; distribution, area of larval extrusion, larval drift and migration routes (source: Drevetnyak *et al.*, 2011).

3.4 Influence of the fishery on stock dynamics

It has hitherto not been observed any direct influences of the fishery on maturation and growth of Arctic *S. marinus*. The fact that the recruitment to the stock has been very low for more than a decade has, however, resulted in a continuously older spawning stock. A time-limited moratorium has been enforced in the conventional fisheries (gillnet, longline, handline, Danish seine) except for handline vessels less than 11 meters. Since 2007 this moratorium has been during five months, this is now (2012) extended to more than eight months. Many fishermen now report about more concentrations of golden redfish and hence catch rates. Biological samples collected from these fisheries show no new recruitment, but rather an increasing age of the catches. Temporal and spatial closures therefore seem to have an effect by at least giving the fish a better chance to aggregate. This was also reported from Iceland during the meeting (e.g. WD2).

3.5 Influence of environmental drivers on stock dynamics

There has hitherto not been documented any environmental drivers on the golden redfish stock dynamics in ICES Subarea I and II.

3.6 Role of multispecies interactions

3.6.1 Trophic interactions

Predation by cod on redfish.

See Chapter 4.6.1 for more information. Some of the redfish found in cod stomachs are identified to species, but most are only recorded as *Sebastes*. Based on the species composition of redfish in the sea, most of the redfish found in cod stomachs are probably *S. mentella*, but redfish identified as *S. marinus* and *S. viviparus* has also been recorded.

3.6.2 Fishery interactions

At present, the only directed fishery for golden redfish is a fishery with conventional gears in the Norwegian Economic Zone during four months of the year (no quota limitations). Bycatches are mainly taken in the demersal saithe/cod/haddock fisheries, and to a lesser extent, juveniles in the shrimp trawl fisheries. The levels of redfish by-catch and discards in the demersal fisheries are given in Chapter 4.2.1.

3.7 Impact of the fishery on the ecosystem

There is currently no specific study on the current impact of the arctic *S. marinus* fishery on the ecosystem. Possible impacts from the demersal fishery are described in Section 1.3 of the Arctic Fisheries Working Group report (p. 35–37, ICES 2011) and mostly concern degradation of benthic habitats and associated fauna.

3.8 Stock assessment methods

3.8.1 Models

Two different models have been examined for *S. marinus* in the Northeast Arctic, a detailed age–length structured "GADGET" model and a simpler surplus-production based Schaefer model. The GADGET model is able to give details of the recent stock history, but is not able to be extended back in time to assess virgin biomass. There is also a high degree of uncertainty about recent recruitment, which renders forward projections with this model problematic. The lack of reliable SSB-recruitment and virgin biomass estimates also precludes estimating B_{MSY}. The Schaefer model is able to produce estimates of the degree of depletion of the stock, and the virgin biomass. However it is reliant on setting the productivity, *r*, of the stock, which is poorly known. Consequently it gives ranges of possible values for stock status, which can be used to provide a validation for the GADGET models. The ability of the Schaefer model to estimate virgin biomass also gives the future possibility to evaluate recovery plans and estimate F_{MSY}.

3.8.1.1 GADGET

A *Sebastes marinus* GADGET model has been employed as an exploratory assessment model at the AFWG since 2005. The model has proven stable over that time, with a consistent reconstruction of declining stock, with possible, though uncertain, improved recruitment in recent years. The model presented here is based on the AFWG model, although the base case selected here has a lower natural mortality and only a single survey (the winter survey).

The GADGET model is length structured, and thus able to use length data directly, reducing the impact of ageing errors on the model. However age–length data are still required in order to estimate growth rates.

The GADGET model is closely related to the model that currently has been used by the ICES North Western WG on *S. marinus* (Björnsson and Sigurdsson, 2003). The functioning of a GADGET model, including parameter estimation, is described in Bogstad *et al*. (2004). The model has been run from 1986 to 2010, with quarterly time-steps. The main model period has been considered to be from 1990, with earlier years acting as a lead-in period to the model. The *S. marinus* has been modelled with a single-species, single-area model, with mature and immature fish considered separate single population groups. The fish were modelled in 1 cm length categories. The age and length ranges were defined as 3–30+ and 1–59+ cm, respectively. The *S. marinus* was considered to have von Bertanlanffy growth, with estimated parameters comparable to those in Nedreaas 1990 (model estimates *K*=0.093, *L-inf*=55.5, similar to the *K*=0.11, *L-inf*=50.2, and *t0*=0.08 from Nedreaas, 1990). The length–weight relationship $W=0.000015*L^{3.0}$ (where *W* is in kilogramme and *L* in cm) was used and kept constant between seasons and years. There has been no cannibalism or modelled predation, and mortality has been exclusively due to fishing and residual natural mortality. Recruitment was handled as a number of recruits estimated per year, and no attempt at closure of the life cycle via a SSB–recruitment relationship was made.

It is often not possible to reliably estimate natural mortality within the model, and consequently the natural mortality *M* was set externally. In the base case model a fixed value of *M*=0.05 was used for all ages, although the impact of using *M*=0.1 was examined via a sensitivity test. In Section 4.6.1 it is demonstrated that for *S. mentella,* cod predation can impose a variable, but sometime high, mortality on young fish. It is possible that similar processes are operating on *S. marinus*. If this is the case then the model would underestimate these young ages. It should be noted that this underestimation would only be on the youngest ages and would not affect the fishable biomass of the stock. However if data were available to inform this predation level then the fit to the youngest ages in the survey might be improved.

Estimation is conducted by minimizing a negative log likelihood derived from a weighted sum of the negative log likelihoods (misfits) for each of the available datasets (listed below), using a wide area search (Simulated Annealing) followed by a local search algorithm (Hooke and Jeeves, 1961). No assumptions about the likelihood surface being either smooth or continuous are required by either algorithm. Sensible initial recruitment values were provided from trial XSA-runs carried out previously by the Arctic Fisheries WG. This is purely for the purposes of ensuring efficient convergence during optimization. There are no priors in the estimation, and the estimation process was iterated after convergence in order to gain confidence in the final solution. Ranges were set for each estimable parameter; again this was to speed the optimization process, with bounds being chosen outside the range considered feasible. The bounds also serve as a check on the estimation process; none of the estimated parameters lie on their bounds.

The following parameters are estimated within the model:

- Three growth parameters (two for mean growth, one for distribution of annual updates);
- Annual recruitment one per year;
- Four parameters governing commercial selectivity (two per fleet);

- Two parameters governing survey selectivity;
- Initial population numbers for mature and immature fish;
- Growth, natural mortality and fishing pattern are considered to be constant over time. The flexibility exists within GADGET to allow for stepwise or gradual changes over time, however we do not consider this to be required for this stock.

Data used for fitting the model are:

- Quarterly length distribution of the landings from two commercial fishing fleets;
- Quarterly age–length keys from the same fishing fleets;
- Length disaggregated and aggregated survey indices from the winter Norwegian Barents Sea bottom-trawl survey (February) from 1990 to 2010 (joint with Russia since 2000);
- Age–length keys from the winter Barents Sea bottom-trawl survey;
- Maturity-at-age data

The fishing was handled as two main, and two subsidiary fleets. The Norwegian trawl- and gillnet fleets were both fully modelled, with selectivity estimated for each, accounting for about 70–80% of the total catch in tonnes in 2003. The amount fished in each time-step of one quarter of the year was input from catch data as a fixed amount. No account of possible errors in the catch-in-tonnes data was made. Two additional fleets have been considered; the international trawl fleet and a fleet made up by combining all other minor Norwegian fishing methods. Both these fleets have quarterly catch-in-tonnes specified, and are assumed to have the same selectivity as the Norwegian trawl fleet. In addition to catch-in-tonnes, quarterly numbers caught at length, and age–length keys have been used. The format of the selectivity (a logistic curve) was selected and assumed to remain constant over time for each fleet. In order to account for possible errors in age reading the data were split into age–length keys, and purely length based distributions. Both datasets were input to the model, with weights set so that each gave an approximately equal contribution to the overall negative log likelihood score.

Survey data were used as age–length keys giving the age–length distribution within a single year, and as a purely length based survey index giving year-to-year variations in numbers by length. Prior to 1992 only length and weight data were recorded. The time period 1990–2003 was used. In the absence of direct data, the age–length key for 1992 was also used as age–length key for 1990–1991 (although the external panel commented that this practice should be avoided). The form of the selectivity was selected, using a logistic curve for the survey and allowing the model sufficient freedom that it could approximate a flat selectivity if that best fitted the data. The fitted curve that was flat, with a selectivity of one, for all lengths in the stock. This can be seen as supporting the assumption that the survey indices represent a relative measure of the stock abundance, unbiased by selectivity changes with length or age. This model was then adopted as the standard one for which results presented.

Results

Stock trends

Figure 3.6 shows the overall patterns for the stock development predicted by the model. The years immediately after 1990 are characterized by overall falling stock numbers, from 300 million in 1990 to below 50 million by 2010. Stock biomass is initially stable around 110 000 tonnes, but begins to fall from the late 1990s, reaching around 30 000 tonnes by 2010. The mature part of the stock was relatively stable until 2005, with fishing being balanced by the entry of maturing fish. However the declining number of immature fish means that by 2005 there are few fish left to mature, and the spawning stock consequently falls. It should be noted that the immature and mature stock trends are different, and the overall biomass is a combination of these two, time-lagged, trends.

Survey index comparison

The model tracks the overall Barents Sea winter survey index reasonably well (Figure 3.7), with the model replicating the overall downward trend of the stock. The model also fits the survey length distributions reasonably well, except for the younger fish since 2007 (Figure 3.8). The survey shows a signal of somewhat abundant young fish in 2008 and 2010, but this signal is absent in 2007 and 2009. It is therefore not clear what the actual recruitment signal in the index is. In addition there is a potential difficulty in species identification at young ages. There has been recent good recruitment in the much more numerous stock of *S. mentella*, and a relatively small level of misidentification of young *S. mentella* as *S. marinus* could completely account for the perceived signal of recruitment in *S. marinus.* These fish have not yet entered the fishery, so there are currently no data against which to validate this signal.

Recruitment

Figure 3.9 shows the number of recruits at age 3.

The model estimates falling recruitment through to around 2000, which then remained at a low level except for improved recruitment values in 2004 and 2006. These recruitment estimates are rather uncertain, as mentioned above. Note that the fall in recruitment from 1990 to 2000 is not due to reducing SSB, which is estimated to be relatively constant over this period. Thus, attempts to use long-term averages for recruitment and/or productivity of the stock in modelling may prove problematic and high uncertainty in estimates of recent recruitment only compound this difficulty.

Modelled fishing mortality

The model shows a fully selected fishing mortality falling from around F=0.25 or higher in the 1990s to F=0.15 shortly after 2000 (Figure 3.10). However the model also indicates that F has increased since that low, and is now around F=0.20 again.

Maturity

Maturity is modelled as an age-dependant process, with a chance for an immature fish to mature each year according to its age. The maturity ogive arising from the model has the age of 50% maturity at around age 12.

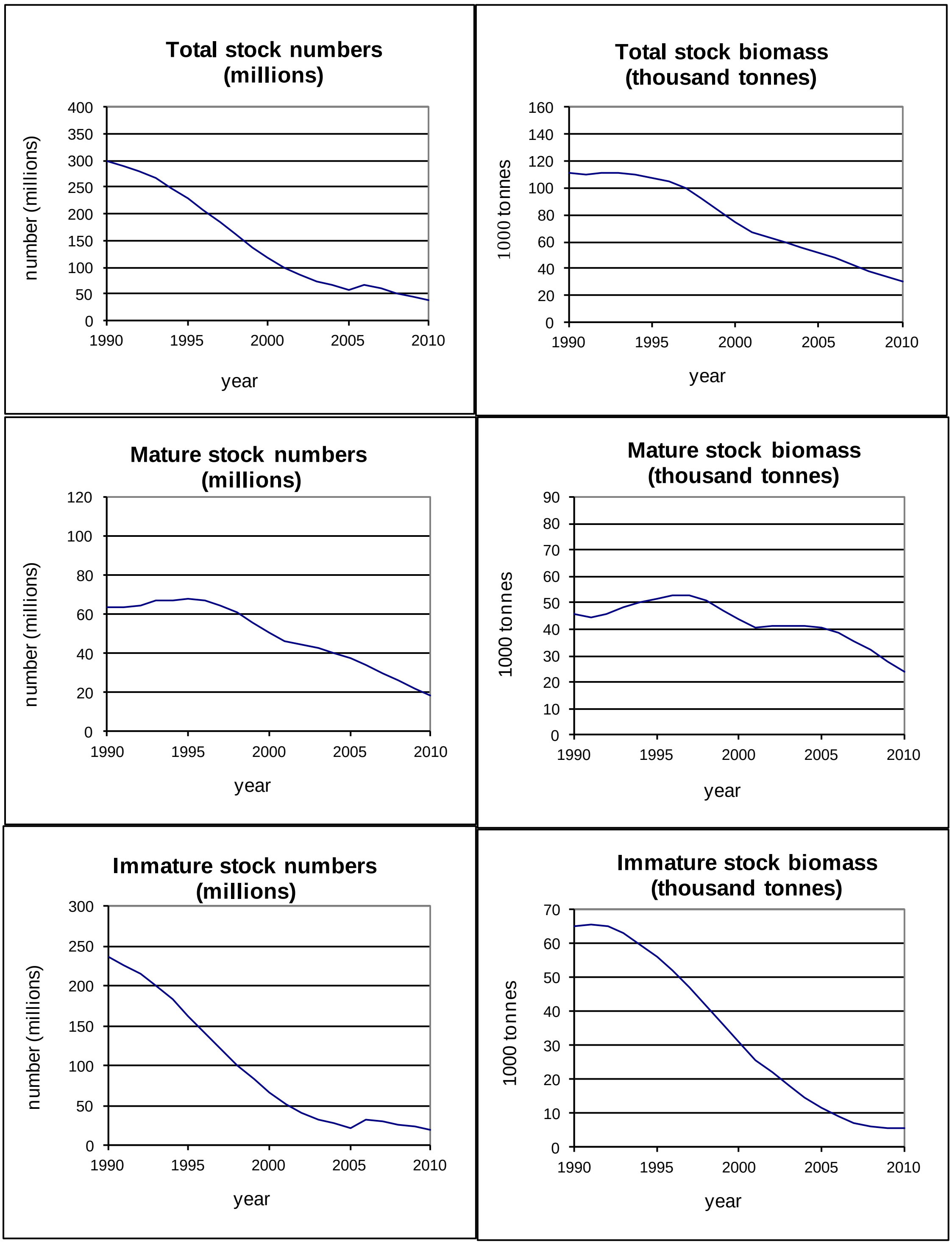


Figure 3.6. Stock trends for the GADGET *S. marinus* model base case.

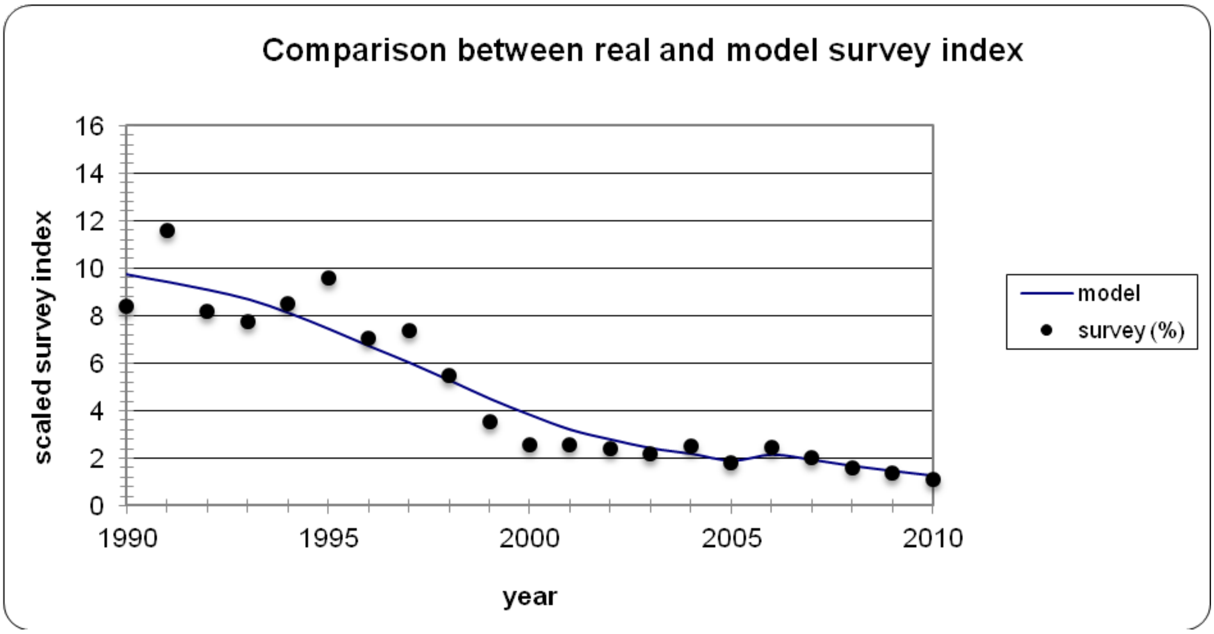


Figure 3.7. Comparison between model and winter survey.

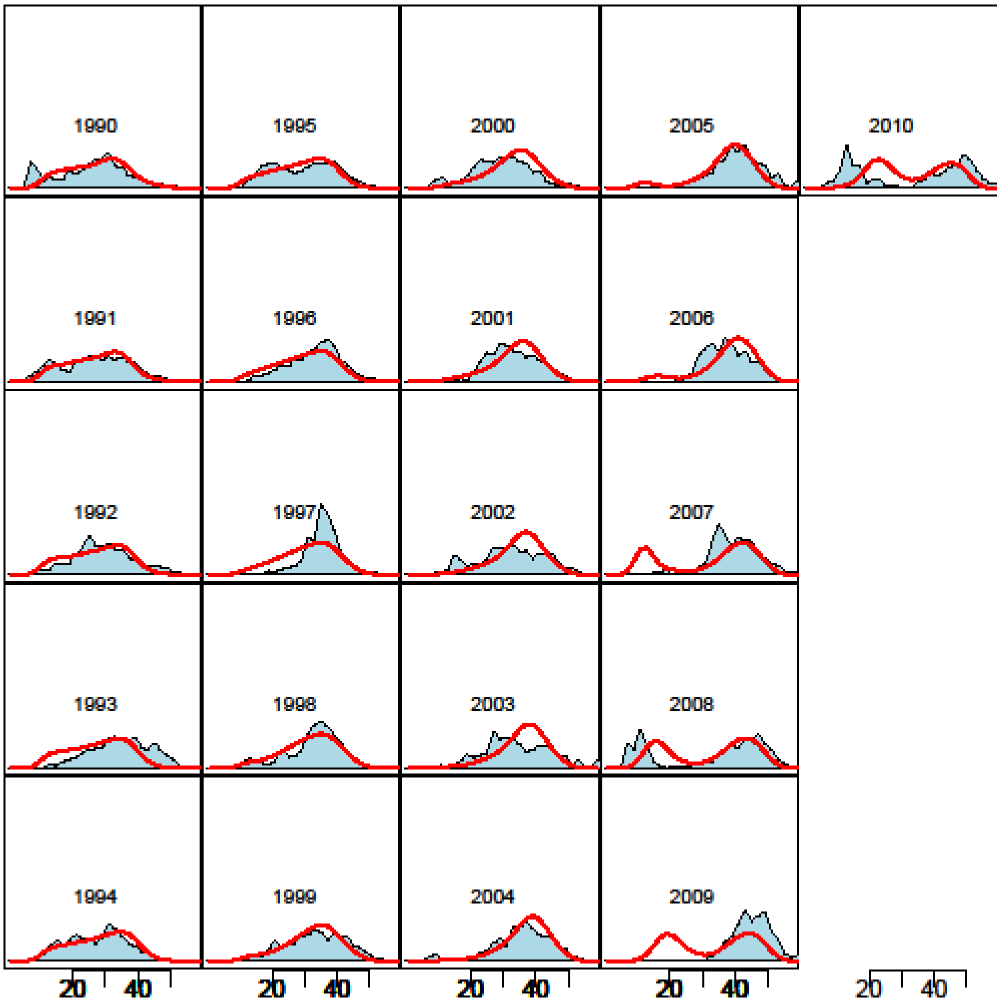


Figure 3.8. Annual fit the length distribution in the winter survey between model (red line) and survey (blue area).

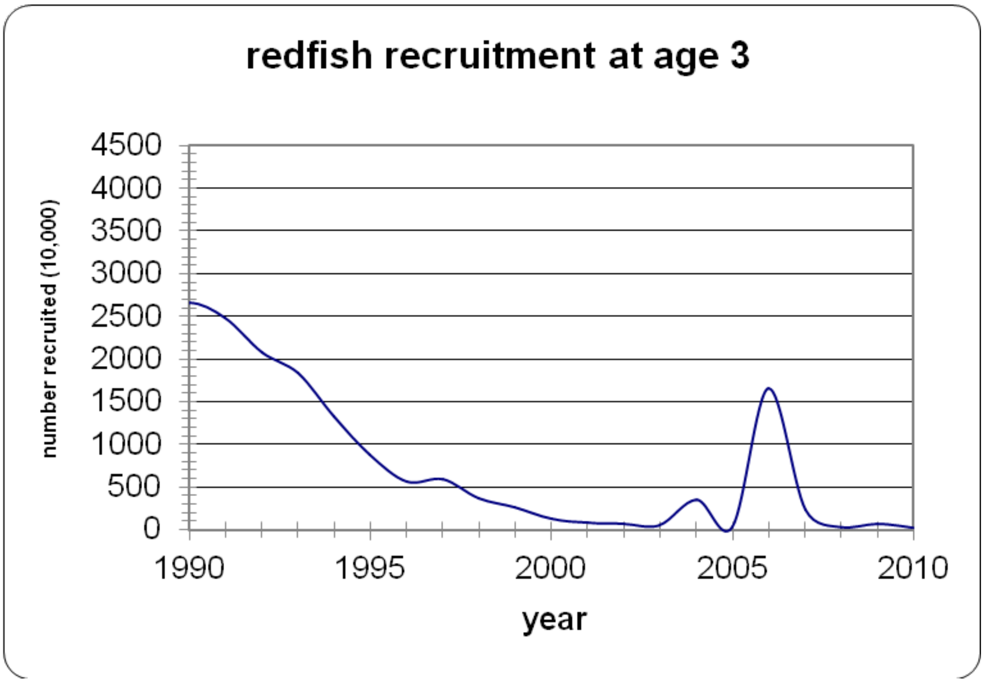


Figure 3.9. Modelled stock–recruitment.

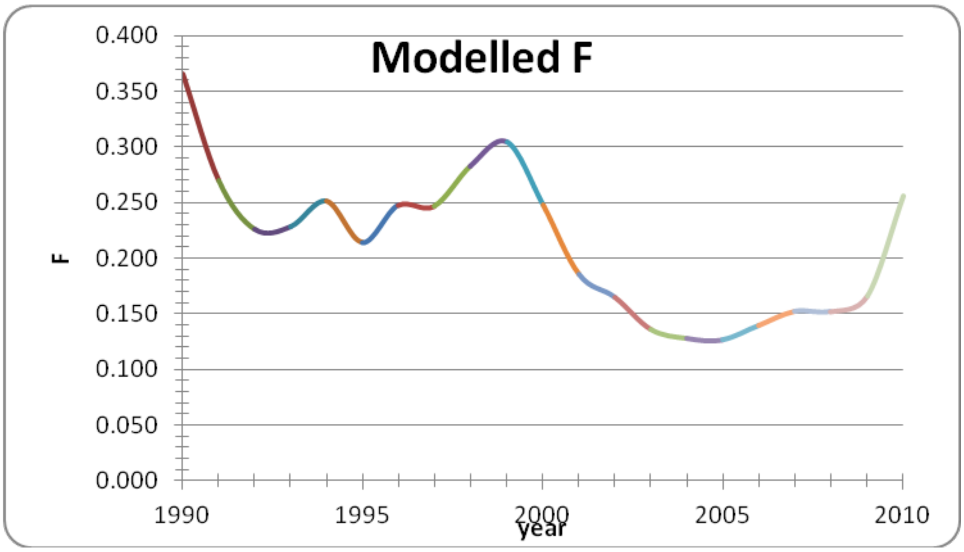
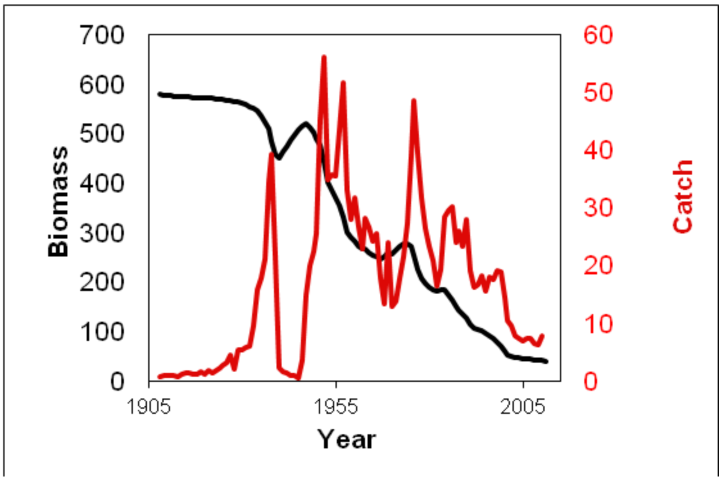


Figure 3.10. Modelled fishing mortality.

3.8.1.2 Biomass dynamics modelling

A Schaefer model was developed for the arctic *S. mentella* stock. The model rationale and structure are presented in Appendix 1. The model was coded and run during the workshop using ADMB. Runs were performed with different assumptions on r (intrinsic growth rate): 0.02, 0.05, 0.10 and 0.15.

Schaefer model outputs can be used as a reality/sanity checks for other models. Model fitting performance is not sensitive to the choice of growth parameter value. All runs indicate a relatively stable stock biomass from 1908 to the early 1930s, followed by a nearly continuous decrease until present (Figure 3.11). Current depletion level is below 10% in all model runs. The carrying capacity estimates vary from $K = 1{,}4$ to $K = 0.6$ million tonnes for $r = 0.02$ and $r = 0.15$ respectively and corresponding biomass estimates range from 39 to 87 thousand tonnes. These estimates are greater than the stock biomass estimated by GADGET (30 thousand tonnes).



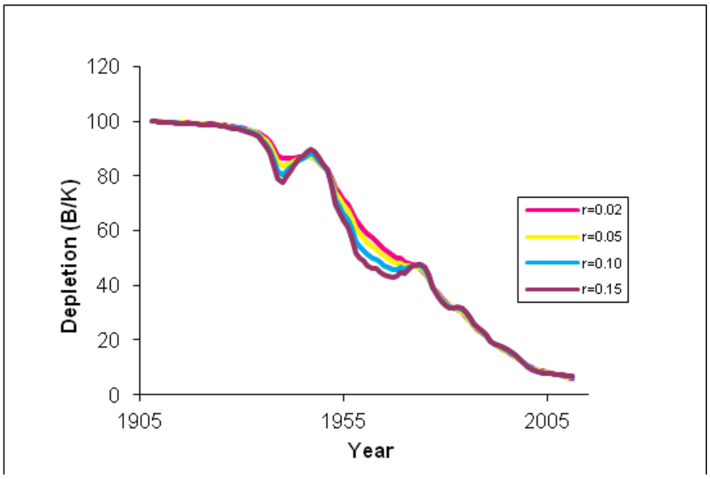


Figure 3.11. Top: The reported catches (red) and estimated stock biomass (black), in thousand tonnes, for the period 1965–2010 and for intrinsic growth rate *r* = 0.15. Bottom: the ratio of biomass (*B*) over carrying capacity (*K*) for the period 1965-2010 and four levels of intrinsic growth rate (*r*).

3.8.2 Sensitivity analysis

Sensitivity analysis was conducted for the biomass production model (reported in Section 3.8.1.2). A series of sensitivity test were conducted to compare the base case GADGET model with different alternate model formulations. The scenarios and key differences and similarities to the base case are described below.

Winter survey selectivity

One issue raised was that the winter survey might be less effective at catching the largest fish. If this was the case then there would be a model misspecification because the modelled survey selectivity was constrained to be a logistic curve (which was in practice estimated to be flat overall length ranges in the model). An attempt at using a dome-shaped selectivity failed, and so the model was run using a logistic selectivity curve set to go down with oldest age. The fitted curve was flat, identical with the base case. This does not rule out the possibility of such declining selectivity, but does suggest that there was no signal of this in the data employed here.

Coastal survey

The coastal survey has been included previously in fitting the AFWG model. However, the survey has proven problematic (as noted in the data section), with high values in 2008, 2009 and 2010 seemingly incompatible with previous years' coastal survey and the continuing downward trend seen in the other data sources. As a coastal survey with limited area coverage, and one which is not designed for redfish, this survey could have issues with variable coverage of the stock between years. As a result it was decided at the Working Group that, until the dynamics of the survey coverage are better understood, the survey should be removed from the model. Two different sensitivity tests were conducted on this survey to examine the sensitivity of model outcomes to decisions about handling this survey, described below.

Partial inclusion of the coastal survey

The base case described above has the survey excluded in fitting the model. At the AFWG the survey from 1995–2007 has been included, with later datapoints excluded. This option was tested here and it was found that the biomasses estimated by the model were similar to the base case. Immature biomass estimates were very similar between the two models, and mature biomass was slightly lower by 2010 (20 000 tonnes *vs*. 24 000 tonnes). The Working Group therefore considers that the base case presented here is compatible with the population dynamics as estimated previously, and that the decision to drop the coastal survey has not materially affected the assessment results (Figure 3.12).

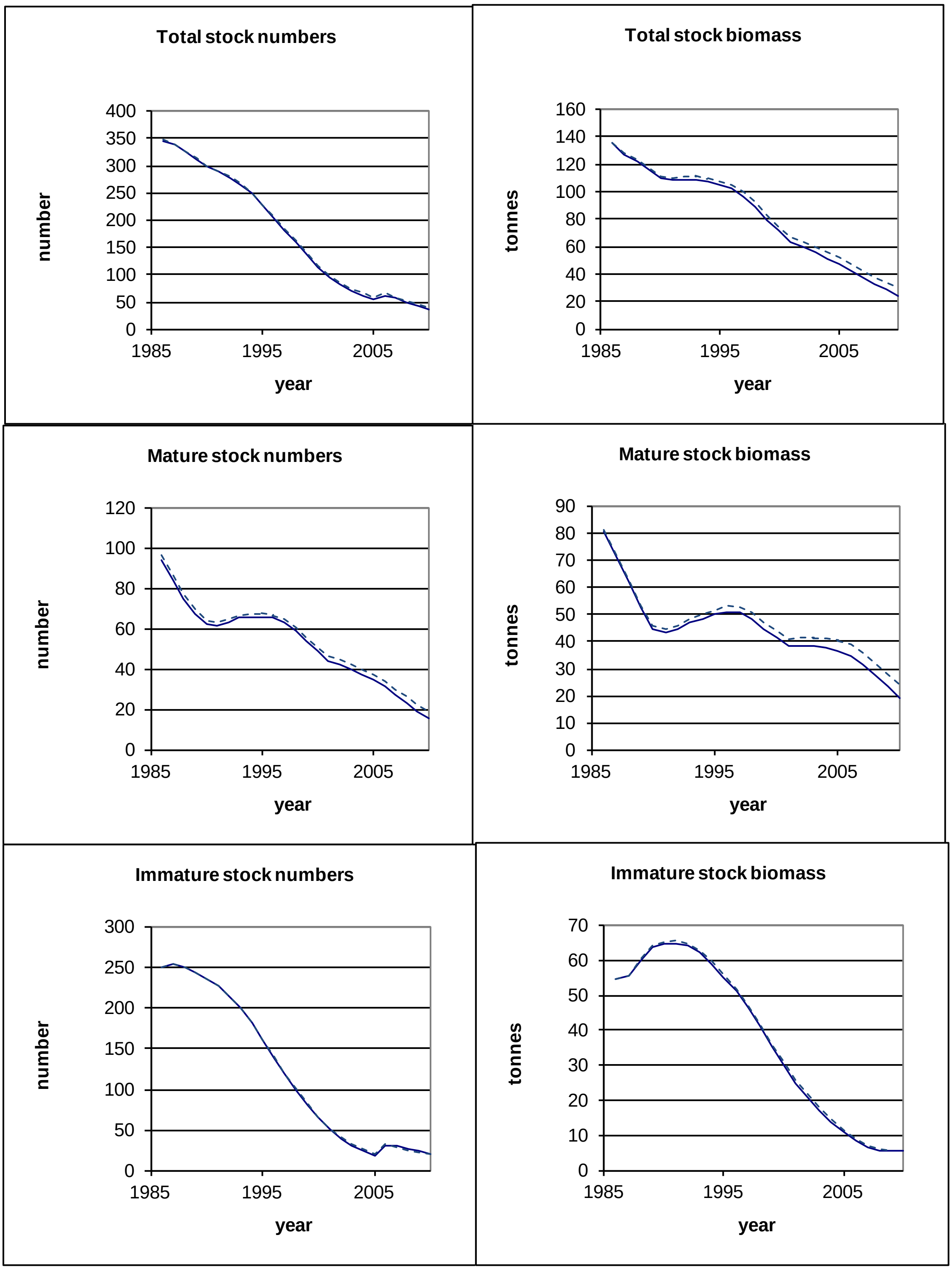


Figure 3.12. Comparison between stock dynamics excluding (dotted line, the base the case described above) and including (plain line) the coastal survey for the period 1995–2007.

Complete inclusion of the coastal survey

A further sensitivity test was conducted including the coastal survey from 1995–2010. In this case the last three datapoints are higher than the long-term trend, and the model responds by adding more large fish, with the mature biomass estimated increased from 24 000 tonnes to 37 000 tonnes by 2010. There is no impact on recruitment or small fish, since these are not covered by the survey (Figure 3.13).

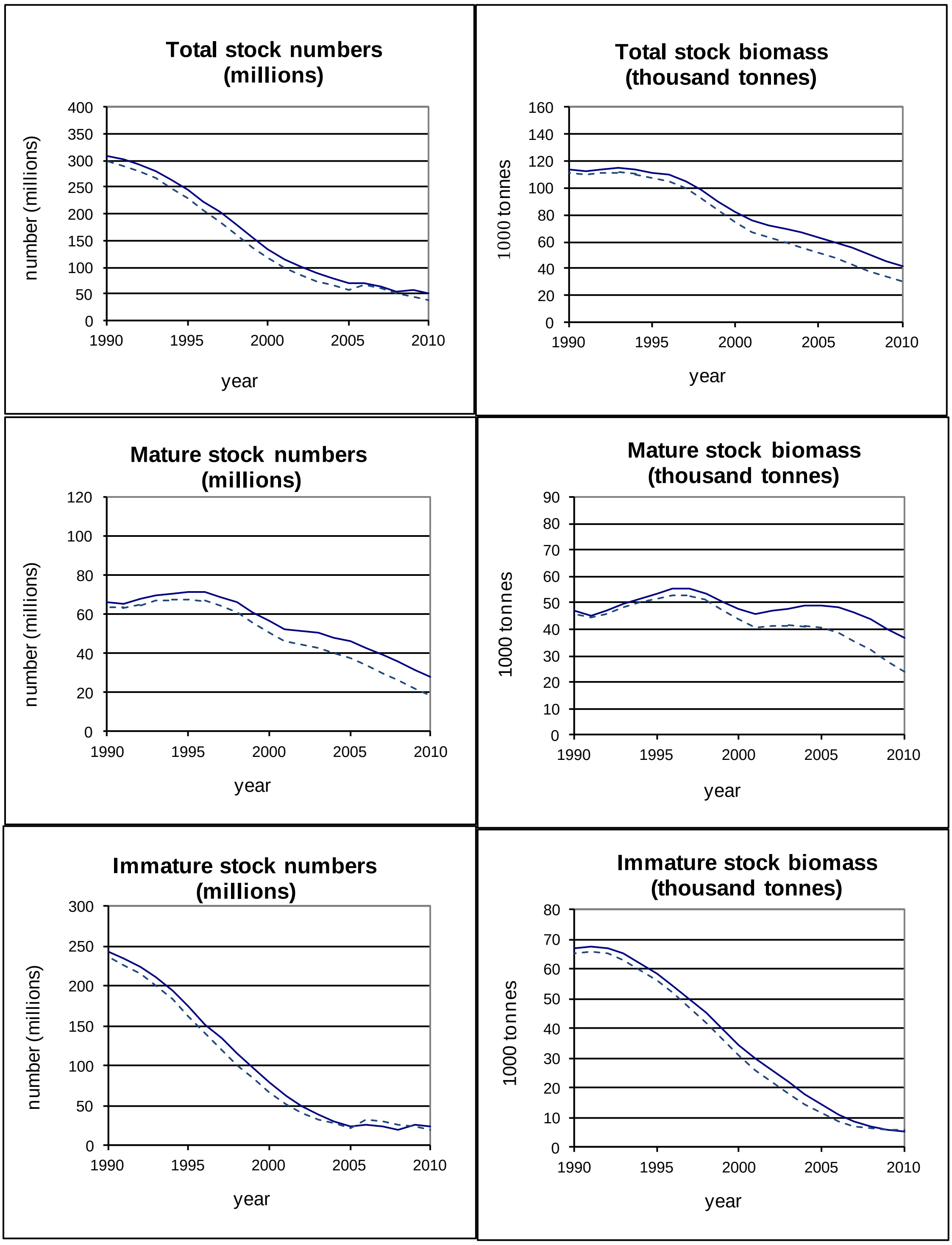


Figure 3.13. Comparison between stock dynamics exluding (dotted line, the base the case described above) and including (plain line) the coastal survey from 1995–2010.

The conclusion from these sensitivity tests is that the coastal survey from 1995–2007 is broadly consistent with the other data used to fit the model; however after 2007 the coastal survey is giving a different signal which is not consistent with the other data used to fit the model. Furthermore the results are rather sensitive to this altered signal. This is taken as a justification of the decision to exclude the dataseries until the behaviour of this survey for *S. marinus* is better understood.

M=0.1

It was considered by the Working Group that *M*=0.05 was an appropriate estimate of natural mortality across the redfish stocks examined, although with the caveat that at the youngest ages there may be a variable component induced by predation. A sensitivity test was run to examine the effects of increasing mortality to *M*=0.1. In this case the higher natural mortality required high recruitment to offset the higher death rate, and the resulting abundances were appreciably larger than in the base case (Figure 3.14) although the trends were very similar.

It should be noted that the estimate of equilibrium catch was rather insensitive to the choice of *M* (Section 3.9) in the models examined here. Thus, uncertainty around the best value of *M* may give uncertainties around the overall level of the stock, but trends in stock development and levels of sustainable catches are rather more robust to this uncertainty.

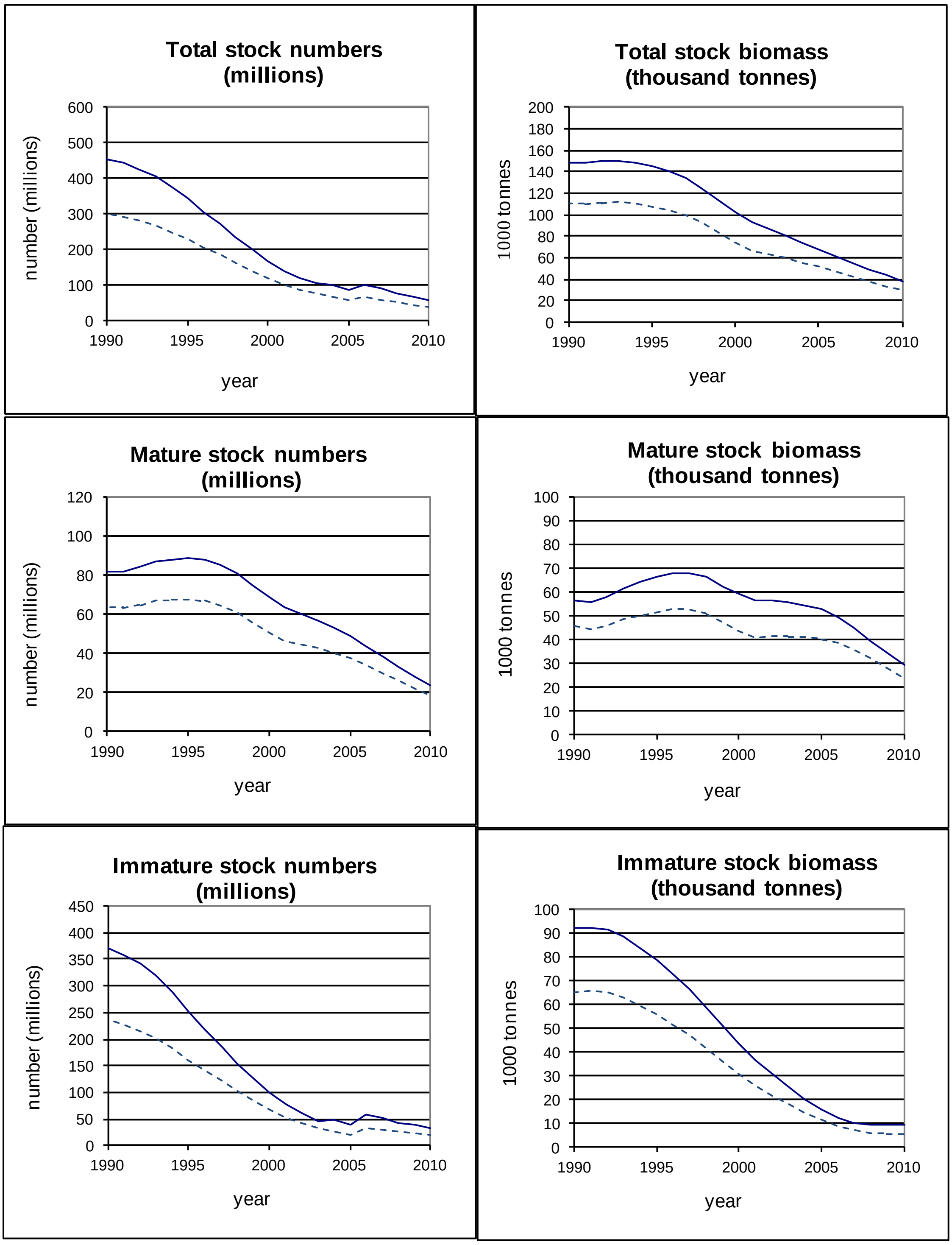


Figure 3.14. Comparison between stock dynamics for *M*=0.1 (solid line) and the base case model with *M*=0.05 (dotted line).

3.8.3 Retrospective patterns

Retrospective patterns for the GADGET model for running the model to 2005–2010 are presented in Figure 3.15. The largest pattern occurs in the years 2005–2007 in the mature stock biomass, which has an impact on the total-stock biomass. In these years an initially low estimate for mature biomass at the end of the model in 2005 is revised upwards in 2006 and again in 2007. Since 2007 the model has been largely stable, with numbers and biomass consistent year-to-year. There has however been a notable retrospective pattern in recruitment since 2000. Initial relatively high estimates of recruitment between 2003 and 2006 have been revised downwards in subsequent years (Figure 3.16). This reinforces concerns raised elsewhere in this document about the accuracy of this recruitment estimate.

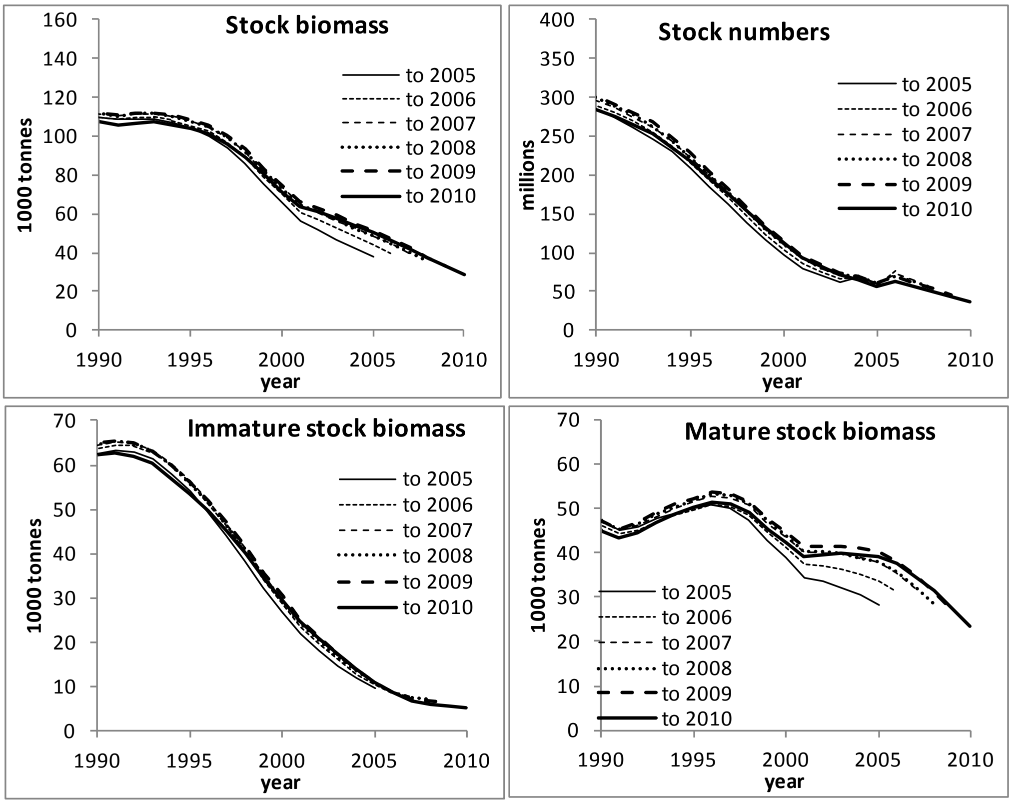


Figure 3.15. Retrospective plots for the Gadget model, showing stock biomass, stock numbers, immature and mature stock biomass.

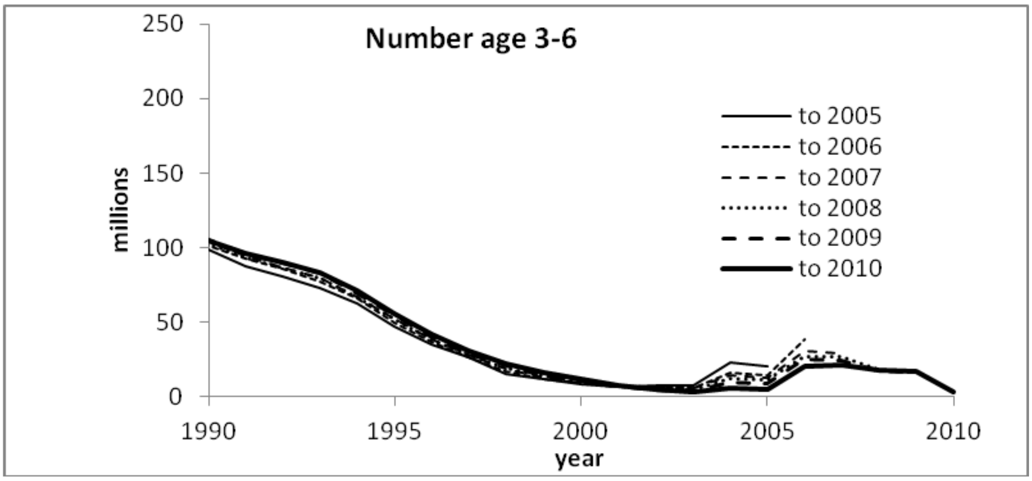


Figure 3.16. Retrospective plot for young fish (age 3–6).

3.8.4 Evaluation of the models

The Working Group considered that the overall recent *S. marinus* stock dynamics are captured by the GADGET model. The base case presented above is considered to represent the best available configuration, given the state of knowledge of the stock and dataseries.

It is noted however, that the results for the youngest age classes (only) may be distorted by the absence of predation-induced mortality within the model. There is also an uncertain signal regarding recruitment arising from the winter survey, the survey itself gives erratic estimates, and there are also concerns over the possible influence of species misidentification.

The results from the GADGET model are broadly compatible with those from the Schaefer model for *S. Marinus* in terms of trend and level. Both models indicate a clear declining trend in stock biomass; the level of the Schaefer model is generally higher, but comparable, to that estimated by GADGET (Section 3.8.1.2). The Schaefer model (see Appendix 1) has the limitation of not taking account of delay effects linked to age structure in this long-lived resource. It suggests that the current depletion (ratio of current to pristine abundance) of the stock is about 6%.

3.8.5 Conclusions

The WG considers that is appropriate to use the GADGET model for evaluation of population dynamics and current stock status of *S. marinus* in Areas I and II, but that the uncertainties surrounding recent recruitment preclude the ability to conduct reliable medium-term forecasts. The model can, however, be used to appropriate catch levels from recruitment averaged over time, and thus give a medium-term target yield for this fishery.

In the absence of a reliable SSB-recruit relation, the GADGET model is unable to estimate the depletion level or the virgin biomass from the relatively short time-series of detailed data available. Any attempt to place the current stock levels in such a historical perspective (for example to construct a rebuilding plan for this stock or compute a long-term MSY) must therefore be informed by other models able to run over a longer time-series of data (such as the Schaefer surplus production model presented here, see the depletion estimate from this model quoted above).

The final GADGET model configuration is the base case presented here, with two fleets (trawl and gillnet) and one survey (Barents Sea winter survey), and natural mortality set to M=0.05. The natural mortality has been changed and the coastal survey excluded compared to the specification in the previous stock annex.

Based on concerns over the coastal survey coverage of the *S. marinus* stock it has been decided to exclude this dataseries in its entirety when fitting the model compared to the previous version. The Working Group notes that the choice to include or exclude this survey has only minor changes on the modelled dynamics and thus the recommendations arising from the model. Further effort is required to investigate this series in order to be able to use it. Consequently only the Barents Sea winter survey is used in optimizing the model, and this is given a logistic (S-shaped) selectivity curve (which in practice becomes flat during optimization). The choice of value for natural mortality (between M=0.1 and M=0.05) has a greater effect on modelled population dynamics. The Working Group decided that M=0.05 was more appropriate to this stock based on the biological characteristics (particularly the longevity) of the fish than the previously used value of 0.1. It should be noted that although the choice of M had an appreciable impact on population dynamics, it has little effect on the evaluation of a sustainable catch at current recruitment and stock abundance (see Section 3.9).

Two areas of further research into the data in order to improve the modelling were highlighted. The first is the apparent variable coverage of the coastal survey. The second is the potential impact of species misidentification on the recruitment signal.

3.9 Short-term and medium-term forecasts

The key difficulty in making short and medium-term forecasts for the Arctic *S. marinus* stock is the uncertainty about recent recruitment arising from erratic signal (described above) in the survey and possible species misidentification. Attempting to obtain medium-term predictions of sustainable catch by projecting the model forward in time would be highly sensitive to the poorly known recruitment values for the large year classes in the model. Instead the modelled population dynamics were used to calculate sustainable yield-per-recruit (YPR) and hence the sustainable yield if the average recruitment over the last ten years were to be repeated in future. Dependant on the fishing mortality associated with the underlying management strategy, this gives a target yield for the fishery in order to produce sustainable catches over the medium term. If, in future, recruitment was to improve, then the target would need to be revised. In the absence of a SSB–recruitment relationship, no attempt was made to estimate the catch required to rebuild reproductive potential; rather the estimates reflect the appropriate levels utilization for current recruitment levels.

Predictions based on hypothetical future recruitment could be conducted, as done in Section 4.9 for Arctic *S. mentella*, but there was not sufficient time to explore these during the workshop.

3.9.1 Model and software

The model used to compute yield-per-recruit is the GADGET base case model described in Section 3.8.1. The model was fitted to the fisheries and population dynamics parameters, conditioned on the historical data as described above, and with natural mortality fixed at M=0.05. These parameters were then used with a simplified model using a single fleet based on the Norwegian trawl fleet, and a background of zero initial population and zero annual recruitment.

The yield-per-recruit (YPR) was calculated by adding recruitment in a single year. Repeat runs were made using a range of values for F, with the results shown in Figure 3.17. It should be noted that there is no spawning–stock–recruitment relationship in the model; rather these calculations assume a constant annual recruitment. Consequently the model may over-predict yield at higher fishing levels, because these levels will lead to a larger reduction in SSB than in overall stock. The yields presented here should therefore be considered an upper bound (especially at higher fishing levels).

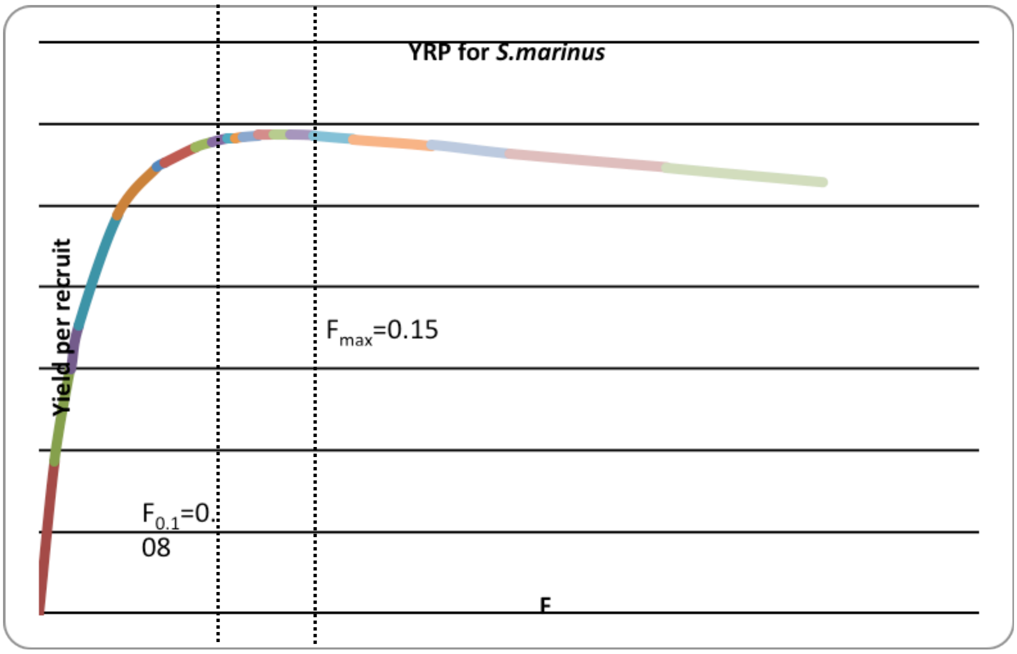


Figure 3.17. Yield-per-recruit for *S. marinus*, computed from the base case GADGET model presented in this document.

The highest yield obtained is at F_{max} = 0.15, but from a rather flat topped curve. $F_{0.1}$ (the point at which the slope is 10% of the slope at the origin, a typical precautionary proxy for F_{msy}) is around $F_{0.1}$ = 0.08. Other proxy values are certainly possible. Average recruitment-at-age 3 is modelled for the last ten years (including high recruitment spike) is estimated to be 2.6 million individuals. Assuming a constant recruitment, running the model to stability gives an estimate of long-term yields under a particular fishing mortality. Using a constant annual recruitment of 2.6 million individuals with the above fishing mortalities gives the corresponding sustainable yields.

For F_{max} = 0.15 the sustainable yield at current recruitment is 1500 tonnes per year;

For $F_{0.1}$ = 0.08 the sustainable yield at current recruitment is 1400 tonnes per year.

Two sensitivity tests were conducted. The first examined the effect of using natural mortality fixed at *M*=0.1. As described above, this resulted in rather higher recruitment to offset the greater mortality. The model with *M*=0.1 gives an average 5.4 million recruits over the last ten years, and $F_{0.1}$ = 0.14. The highest point on the YPR curve is at F_{max} = 0.4, however this is considered unrealistic because this results in few mature fish (there is no penalty on this in the model since recruitment is assumed to remain constant however low the spawning–stock biomass).

The higher natural mortality means that although the *F* values are computed to be higher, the sustainable yields are similar to those for the preferred model, at 1400 tonnes at $F_{0.1}$, and a maximum of around 1600 tonnes at the unrealistic F_{max} = 0.4. The higher levels of mortalities (*F* and *M*) are offset by the higher recruitment, giving similar catches.

A similar exercise has been conducted for fishing using the selectivity pattern of the gillnet fishery, with a natural mortality of M=0.05, giving slightly higher yields (1550 tonnes for F=0.15, and 1450 tonnes for F=0.08).

In the most recent AFWG (ICES 2011) report it is noted that a maximum exploitation rate of removing 5% of the fishable biomass per year had been suggested as suitable for similar long-lived species (Dorn, 2002). This is similar to (although slightly more conservative than) the $F_{0.1}$ = 0.08 calculated here.

The Working Group consider that the *M*=0.05 model represents the most plausible model, and suggest that $F_{0.1}$ is the maximum fishing level that would prevent further decline in the stock , giving a yield of 1400 tonnes. It should be noted that this level does not allow for stock rebuilding, merely for stabilizing the current decline. We also note that this estimate is rather insensitive to variations in choice of F_{msy} proxy or natural mortality level, and is in line with biological knowledge of the species.

3.9.2 Conclusions

The base case model described above, with recruitment fixed at the average over the last ten years, has been chosen as the final model for producing forecasts. It is the one that fits best with the data, as described in Section 3.8. This choice is reinforced by the resulting sustainable catch being relatively insensitive to assumptions about natural mortality. The results from this analysis suggest that the model gives a basis for stating that current catches are above those the stock can sustain at current levels of recruitment. If the current recruitment were to be continued then the stock could sustain a fishery of not more than around 1500 tonnes without experiencing further decline in stock numbers.

It should be noted that the calculations conducted here ignored any SSB effects of recruitment, and are do not present a recovery strategy. Rather they estimate the maximum catch possible from constant recruitment at the current low average level. The virgin biomass, the productivity level r, and the SSB–recruitment relationship are all unknown for this stock. As a result it is difficult to quantify the catch required to lead to rebuilding of the stock. Thus the assessment can produce equilibrium catches from the GADGET model, but cannot give F_{MSY}.

3.10 Biological reference points [see WKFRAME and WKFRAME2 reports]

The WG did not consider it possible to produce biological reference points for this stock. The estimates for catches under the F_{max} and $F_{0.1}$ presented above are reliant on empirical values for recruitment, rather based on stock biology. Furthermore there is considerable uncertainty in these values, both from the erratic signal in the survey and the possible misidentification of young *S. mentella* as *S. marinus*. Consequently the estimate of sustainable yield based on recent recruitment gives a short to medium-term target for the fishery, but *biological* reference points are not currently available.

3.11 Recommendations on the procedure for assessment updates and further work

Assessment updates

The WG considers that is appropriate to use the GADGET model presented here for evaluation of population dynamics and current stock status of *S. marinus* in Areas I and II, with the Schaefer model results used as a “sanity check” on the model results.

In the absence of the ability to produce reliable medium-term forecasts, the GADGET model should be used to produce estimates of yield-per-recruit and hence advice on sustainable catch under recent average recruitment levels. Again, the Schaefer model provides bounds on the range of plausible solutions to cross-check the GADGET model.

Monitor recent recruitment

It is important to continue to monitor the data on recent recruitment, through both the survey and the commercial catches. The recent signal of recruitment comes from a single survey, and has a number of caveats (inconsistent signal, species identification issues). These years of recruitment will be entering the fishery in the coming years, and therefore additional data will become available to refine the recruitment estimates.

Model effects of species misidentification

It may be possible with the GADGET model to identify the impacts of different levels of species identification on modelled stocks. This should be explored.

Data sources

Further investigations of the potential data sources not included in the model should be conducted. The stock coverage of the coastal and fjord survey needs to be re-examined, but other data sources (e.g. cpue indices) could also be considered.

Rebuilding plan

In the longer term it is desirable to devise a rebuilding plan to recover the stock from its current low level.

3.12 Implications for management (plans) [previous management plans evaluations, new ref. points]

The major implication for management is that the current fishing level (ca. 7000 tonnes) is substantially above the estimates of sustainable yield derived during this Working Group. Given the poor recruitment over the last decade, the current sustainable yield is around 1500 tonnes.

An important fact is that estimates of recruitment from surveys have proven problematic. These estimates cannot be refined until the fish enter the fishery. Consequently the management implication is a need to be able to react rapidly to fisheries-based data which suggests that the earlier survey-based estimates need to be refined up or down.

3.13 References

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4 Beaked redfish (*S. mentella*) in Subareas I and II

4.1 Current assessment and issues with data and assessment

ACFM (now ACOM) had considered it not necessary to assess this stock every year since the status of the stock can clearly be deduced from the surveys, and no analytical assessment has been conducted since 2003 (ICES 2003). Qualitative assessments have been based on the age composition of catches and survey trends (Barents Sea bottom-trawl surveys and 0-group surveys, Norwegian Sea pelagic surveys).

4.2 Compilation of available data

4.2.1 Catch and landings data

The landings statistics used by the Arctic Fisheries Working Group (AFWG) are those officially reported to ICES if not else reported by members of the Working Group. In cases where such reports to ICES or AFWG do not exist, or are considered incomplete, reports made directly to the Northeast Atlantic Fisheries Commission (NEAFC, concerning the international pelagic trawl fishery for *S. mentella* in the international waters of the Norwegian Sea) and the Norwegian authorities during the demersal fisheries have been used as preliminary figures (see WD 21 for more details).

There are also situations where redfish (*Sebastes*) reports to ICES exist, but not by individual species. In such cases, the split of the national landings by species can be summarized as follows:

The national landings of redfish for Norway and Russia are split into species by the respective national laboratories. For other countries and ICES Divisions IIa and IIb, except for the pelagic fishery in international waters of the Norwegian Sea where most countries correctly are reporting this as *S. mentella*, the AFWG has split the demersal landings into *S. mentella* and *S. marinus* based on working documents, oral reports from country members at the AFWG or reports to the Norwegian fisheries authorities from different fleets fishing in the Norwegian Economic Zone (NEZ, IIa) and the Svalbard Fisheries Protection Zone (IIb). This species splitting is documented for all years back to 1993 on http://groupnet.ices.dk/AFWG2011/Data/Smentella.

Landings statistics per year, split by redfish species, country and ICES area exist back to 1969 (ICES 2011; Anon. 2009). Based on the STATLANT database and species information in earlier ICES Working Group reports and Russian reports (Zakharov *et al*., 1977; Drevetnyak, 2003), the NEAFC Working Group on collating information on the distribution of *Sebastes mentella* in ICES Subareas I and II and distribution of catches from the stock succeeded, however, in extending the total landings statistics back to 1952 (Anon., 2009). Figure 4.1 shows the official landings statistics back to 1952. See also Figure 4.3.

No discards are accounted for in the Northeast Arctic *Sebastes* stock assessments. Numbers and weights of redfish (fully dominated by *S. mentella*) taken as bycatch in the Norwegian shrimp fishery (and raised to the total international shrimp catches) in the Barents Sea during two decades (1983–2002) have previously been presented to the AFWG (e.g. ICES 2007). The results show that shrimp trawlers removed substantial numbers of juvenile redfish during the beginning of the 1980s with two peaks during 1985 and 1989 amounting to about 200 million individuals. As sorting grids became mandatory in 1993, and with effective additional temporal area closures to prevent bycatches of the smaller juveniles, bycatches of redfish reduced drastically during the 1990s. PINRO, Russia, has developed a scheme for collecting biological and catch data by scientific observers on board fishing vessels (Gusev *et al*., 2009). At-sea observer data are used to estimate discards by Russian fleet fishing for demersal species in the Barents Sea. Gusev *et al*. (2009) presents estimates of discards of beaked redfish in the Russian demersal fishery during 1996–2006, which vary between 25 and 609 tonnes per year.

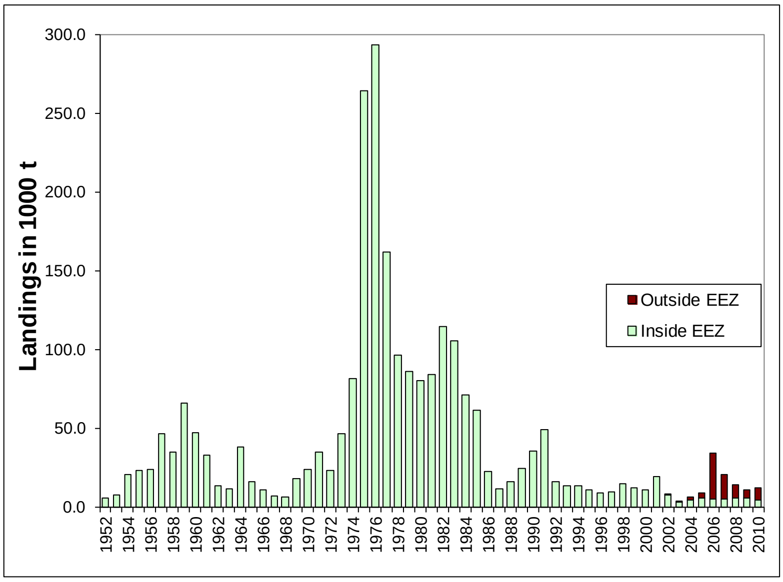


Figure 4.1. *Sebastes mentella* in Subareas I and II. Total international landings 1952–2010 (thousand tonnes).

4.2.2 Biological data

The Arctic *S. mentella* is long-lived (maximum age about 75 years), ovoviviparous, and inhabits pelagic and epibenthic habitats from 200–800 m in the Northeast Atlantic. The size and age at first maturity (50%) are 31 cm and eleven years, respectively.

In Norway, four different sampling platforms provide biological data (length, weight, age, sex, maturity) from the commercial catches. These are 1) the Reference Fleet (self-sampling by trained fishers at sea), 2) the Coastguard (upon inspections at sea), 3) the Directorate of Fisheries' surveillance of the fisheries incl. temporary closure of juvenile fish areas, and 4) some port sampling of redfish landings.

In Russia, one sampling platform provides all of the biological data (length, weight, age, sex, maturity) from the commercial catches. This is the scientific observer on-board fishing vessels. A scientific observer is required to collect biological information on the major commercial species in each trawl. In catches of up to 500 kg, all fish are registered and measured. If the catch is greater than 500 kg, the length of 300 sp. of each species of fish is measured. For all Russian local fisheries areas, 50 fish are collected for estimating the age (otoliths).

For EU countries, *S. mentella and S. marinus* in ICES Subareas I and II are defined as "Group 1" species, i.e. species that drive the international management process including species under EU management plans or EU recovery plans or EU long-term multi-annual plans or EU action plans for conservation and management based on Council Regulation (EC) No 2371/2002. According to this regulation 125 specimens of each of the species per 1000 tonnes caught by each country should be age determined.

In addition, individual weight, sex and maturity should be recorded and presented. For further details, see the Commission decision of 18 December 2009 adopting a multi-annual Community programme for the collection, management and use of data in the fisheries sector for the period 2011–2013 (2010/93/EU).

Since 1991, the catch in numbers-at-age of *S. mentella* from Russia is based on otolith readings. The Norwegian catch-at-age is based on otoliths back to 1990. Before 1990, when the Norwegian catches of *S. mentella* were smaller, Russian scale-based age–length keys were used to convert the Norwegian length distribution to age. Despite the fact that both laboratories base the age reading on otoliths, there are still severe discrepancies in the age readings of *S. mentella* collected in the same area at about the same time. As the difference is related to the ability of reading age of fish of 20 years and more, the problem is believed to be related to the fact that the proximal zone of the otolith sections is not considered by the Russian readers.

Maturity-at-age of *S. mentella* in ICES Subareas I and II is estimated from research survey data (Figure 4.2). Live weight-at-age is estimated from length-at-age (Figure 4.3) from both research survey data and commercial data as we assume the length- and weight-at-age in the catch to be the same as in the stock. The length-at-age is then converted to weight by using the relationship $W=\alpha L^3$, where α=0.0125. According to WD19 the best fit for the years 1999 through 2009 is the loglinear relationship $W = \alpha L^{\beta}$ where log α=-4.545 and β=3.051. Age–length relationships for redfish are typically non-linear and a natural choice of a simple model is the von Bertanlanffy growth model: $L=L_{\infty}(1-e^{-KAge})$, where L_{∞} is the mean maximum length and K the growth rate.

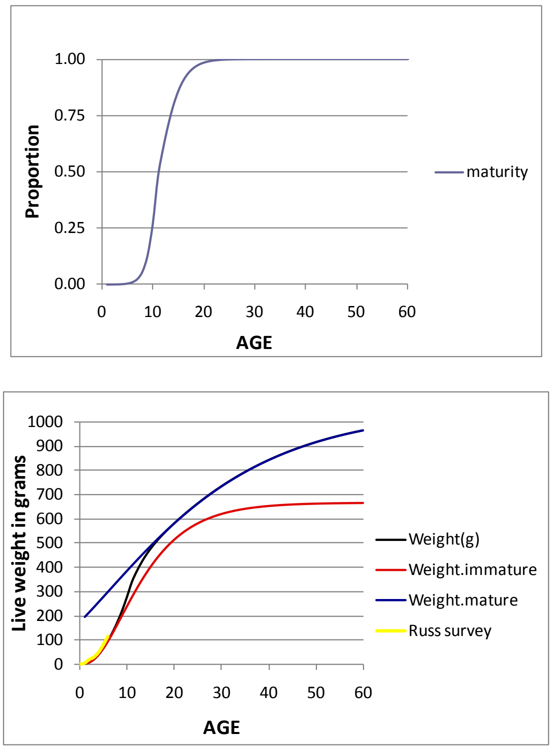


Figure 4.2. Maturity-at-age (left panel) and live weight-at-age (right panel) of *Sebastes mentella* in ICES Subareas I and II as estimated from research survey data (Anon., 2009).

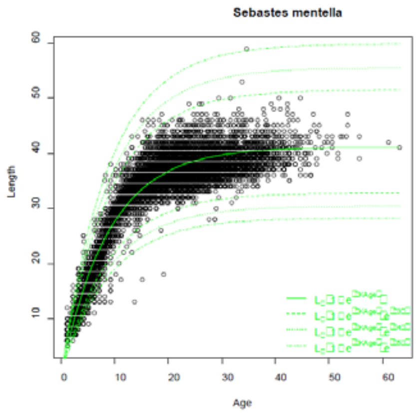


Figure 4.3. Length vs. age for Arctic *Sebastes mentella* for data available from IMR's database (Norway) for the years 1999 through 2009. The estimated mean using von Bertanlanffy's growth model is shown by the solid green line, and distances from the mean measured as number of standard deviations from the mean are shown by the dotted lines (ref. WD19).

4.2.3 Survey tuning data

A description of the available and used surveys in the assessment models are given in WD18 and WD24. A schematic illustration of these survey-series is given below in Figure 4.4.

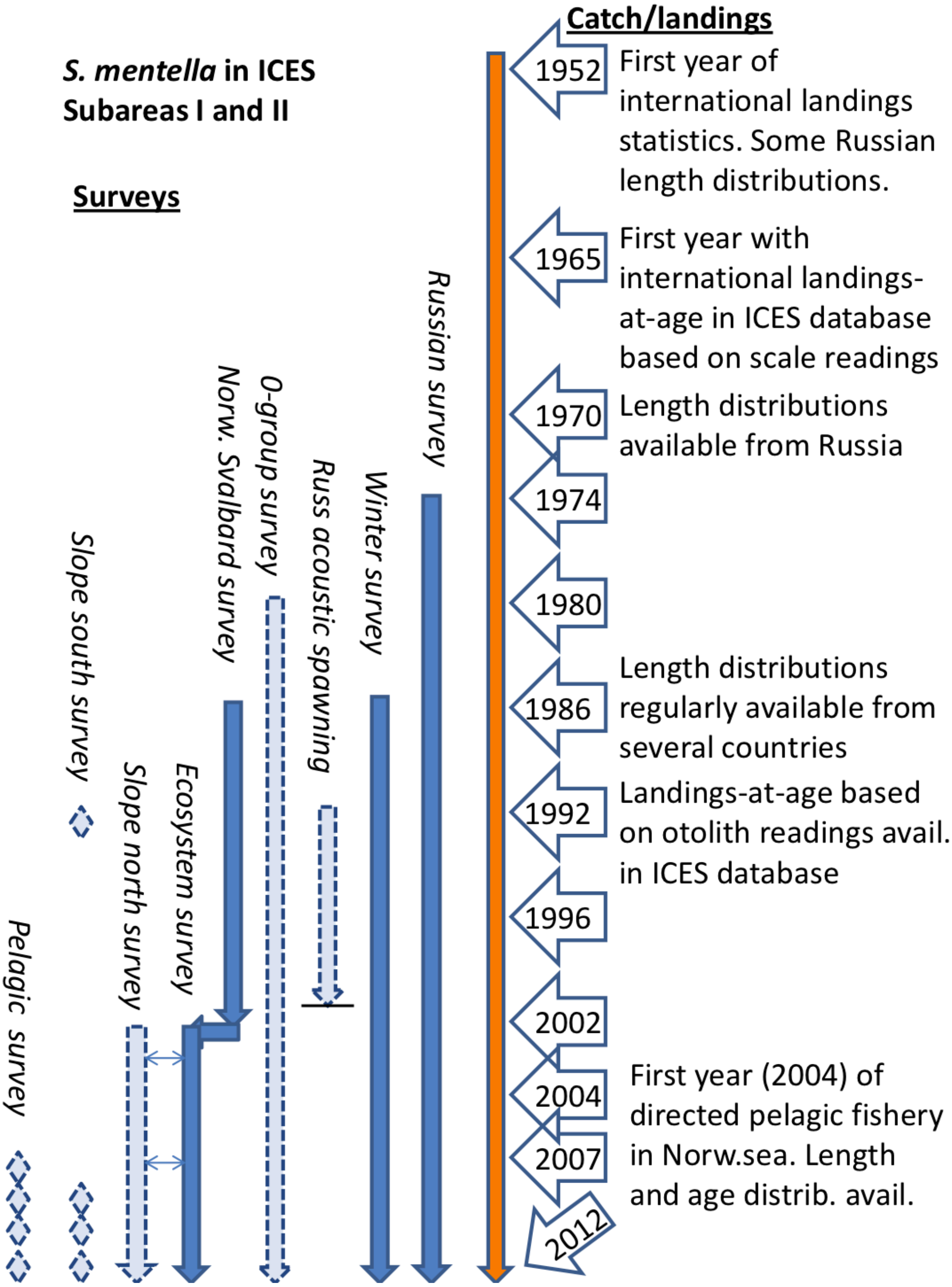


Figure 4.4. Illustration of the available time-series of surveys and catch/landings data. Solid blue arrows show the scientific surveys currently used in both the SCAA and Gadget models, while the dotted light blue arrows show available surveys currently not used.

4.2.4 Commercial tuning data

Catch-per-hour-trawling data for the *S. mentella* fishery have been available from Russian PST- and BMRT-trawlers fishing in ICES Division IIa in March–May 1975–2002, representative for the directed Russian fishery accounting for 60–80% of the total Russian catch. The AFWG has previously concluded that the Russian trawl cpue series do not represent the trend in stock size but is more a reflection of stock density. This is because the fishery on which these data are based since 1996 was carried out by one or two vessels on localized concentrations in the Kopytov area southwest of Bear Island. Due to a change in fishing behaviour/effort, these cpues are only comparable for the period after 1991. This cpue series are not used as input to the present SCAA or Gadget assessment models. The commercial landings by length and age, by quarter and by two fleets are hence the only commercial tuning data used in the assessments.

4.2.5 Industry/stakeholder data inputs

None.

4.2.6 Environmental data

As 0-group and juvenile this stock is an important plankton eater in the Barents Sea, and when this stock was healthy, 0-group were observed in great abundance in the upper layers, feeding on the plankton production. During the first five–six years of life *S. mentella* is also preyed upon by other species. Its contribution to the cod diet is well documented (see Chapter 4.6.1). Hydrographic data are collected during the surveys conducted in the Barents and Norwegian Seas. These data are reported to the Arctic Fisheries Working Group (Chapter 1 of the AFWG reports) but they are not directly used in the assessment.

4.3 Stock identity, distribution and migration issues

The most recent description of the distribution and migration of Arctic beaked redfish (*S. mentella* in Subareas I and II) is found in Drevetnyak *et al*. (2011). The main features of its distribution are illustrated in Figure 4.5. Adult beaked redfish are distributed from about 62°N in the south to the Arctic ice north and east of Svalbard (Spitsbergen), with a spatial distribution confined to water masses of Atlantic origin. On continental shelves and slopes, adult beaked redfish can be found close (<10 m) to the bottom but also in the pelagic layers above. Acoustic registrations during scientific surveys have demonstrated that the portion of redfish inhabiting the pelagic water column, i.e. above the 10 m near bottom layer, may be 80–90% of the total abundance (Anon., 2009). The central Barents Sea and the Svalbard (Spitsbergen) shelf are primarily nursery areas. Although it aggregates in the Bear Island Channel, the Hopen Trench and on the Bear Island slope, the characteristic behaviour of beaked redfish is to seasonally migrate west- and southwestwards towards the continental slope and out into the pelagic layers of the Norwegian Sea as it grows to adulthood.

In the Norwegian Sea and along the slope south of 70°N few specimens less than 28 cm are observed, and on the shelf south of this latitude beaked redfish are found only along the slope at depths of about 450 to 650 m. The southern limit of its distribution is not well defined, but is believed to be somewhere on the slope northwest of Shetland. In the Barents Sea region there is no record of adult beaked redfish east of 35°E and north of 81°18′N. Adult fish in the Barents Sea occur at depths of 300 to 500 m. Preferred water temperature while wintering is 4–5 °C and for feeding, about 2°C.

Larvae are transported by warm currents from the spawning grounds on the continental slope to nursery grounds in the Barents Sea, especially towards the Svalbard (Spitsbergen) area, where the juveniles settle. Juveniles thus tend to be found further to the east and north than adult fish. The warm Atlantic currents are believed to be the most important influence on the distribution of juvenile fish, while adult distribution is controlled primarily by bottom habitat, depth, temperature and food availability. During the first autumn the 0-group redfish descend to near-bottom habitats and may then interfere with the shrimp trawling and cause some of the shrimp-trawling fields to be closed, although the vast majority of this young and small redfish live semi-pelagic above the bottom. Beaked redfish inhabit the nursery areas of the Barents Sea until they are four years of age. At the age of five, six or more, they begin to migrate against the current to sites along the continental slope where the mature part of the population aggregate.

Copulation between males and females takes place several months before mature females aggregate along the continental slope from north of Shetland to the Tromsø Plateau and the Bear Island, where larvae are extruded in spring, mainly from mid-March to late April. In recent years, adult and mature beaked redfish have also extended their feeding into the Norwegian Sea, and have inhabited the international waters in the middle of the Norwegian Sea from late May until mid-November when most of the redfish migrate back to the slope area.

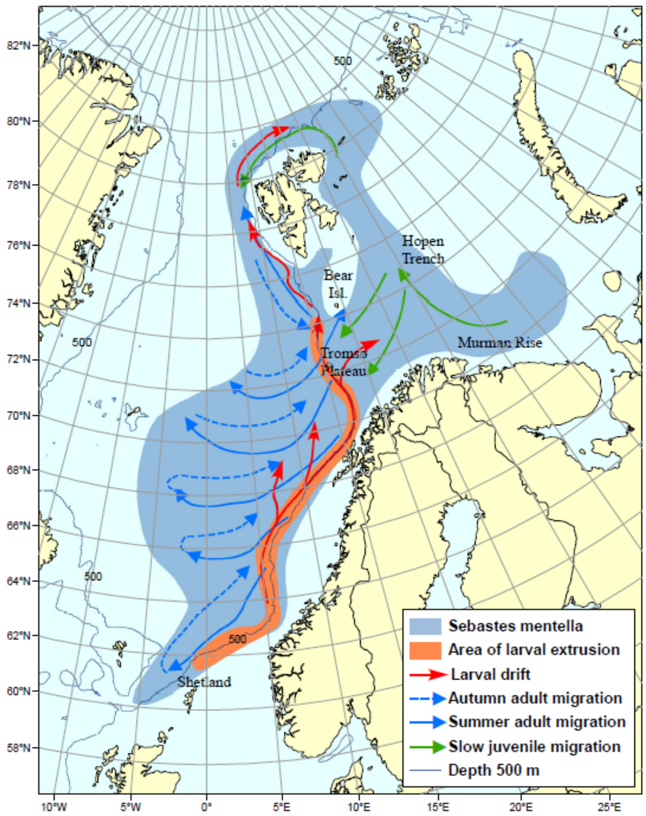


Figure 4.5. Arctic *S. mentella* distribution, area of larval extrusion, larval drift and migration routes (source: Drevetnyak *et al.*, 2011).

4.4 Influence of the fishery on stock dynamics

No influences of the fishery on maturation and growth of Arctic *S. mentella* have been observed to date. The severe stock decline until about 1990 can, however, clearly be seen as a result of a fishery that was too high and unsustainable, and included large amounts of juvenile discarding. Up to the middle of the 1980s, former USSR and GDR were the two countries taking most of the Arctic *S. mentella* catches in Subareas I and

II (Anon., 2009). The fishery was mostly going on in the western part of the Barents Sea between the Malangen Bank and Bear Island (the Kopytov area), and the international fishery reached a peak in 1976 of 293 000 tonnes. Many years with directed catches in the order of 80 000–200 000 tonnes, huge bycatches in other fisheries, not the least of juveniles in the shrimp fishery, resulted in a severe decrease in the stock towards the late 1980s. However, the stock continued to produce new good year classes. It was not until the fishery in 1985–1990 started fishing on old and mature fish on new fishing grounds never harvested before along the continental slope, at around 500 m depth, south of Malangen Bank (69°N) towards Møre that a sudden reduction in larvae and 0-group became apparent on the nursery areas in the Barents Sea.

In order to rebuild the stock, different fisheries regulations have been implemented, e.g. mandatory use of sorting grid and temporal area closures in the shrimp fishery since 1992, a ban on all trawl fisheries in some areas (2000), and finally a ban on the directed demersal trawl fishery for *S. mentella* since 2003 (see WD 20). Putting these restrictions on the fishery has likewise contributed to the rebuilding of the spawning stock and a subsequent improved recruitment.

4.5 Influence of environmental drivers on stock dynamics

No environmental drivers on the beaked redfish stock dynamics in ICES Subarea I and II have been documented to date, but the apparently sudden aggregations of fishable concentrations of beaked redfish far out in parts of the Norwegian Sea in August–October may partly have been caused by environmental drivers. The distribution of the *S. mentella* population is confined to Atlantic water masses. Changes in the circulation and distribution patterns of Atlantic water masses in the Norwegian and Barents Sea could potentially affect stock distribution and productivity.

4.6 Role of multispecies interactions

4.6.1 Trophic interactions

4.6.1.1 Predation by cod on redfish

Since 1984, stomach content data for cod in the Barents Sea have been collected by Norway and Russia and included in a joint database (Dolgov *et al*., 2007). The cod's annual consumption of various prey groups has been calculated for 1984–present (ICES, 2011), based on stomach content data, a temperature-dependent model for stomach evacuation rate (dos Santos and Jobling, 1995), cod abundance estimates from assessments (ICES, 2011) and geographical distribution of cod based on survey data. Consumption estimates have been calculated separately by Norway and Russia, using the same database and evacuation rate models, but different spatial and temporal resolution. The Norwegian calculations are made by half-year and three areas (west, east and north), while the Russian calculations are made by quarter but without spatial resolution. Both countries calculate the consumption by predator age groups and prey length groups. The methods are described in Bogstad and Mehl (1997) and Dolgov *et al*. (2011). The total annual consumption of redfish is shown in Table 4.1, and the consumption divided on length groups (Norwegian data only) is shown in Table 4.2. Some of the redfish found in cod stomachs are identified to species, but most are only recorded as *Sebastes*. Based on the species composition of redfish in the sea, most of the redfish found in cod stomachs are probably *S. mentella*, but redfish identified as *S. marinus* and *S. viviparus* has also been recorded. Bycatch estimates are also small compared to consumption by cod, the highest estimated value for the bycatch in the period 1983–2002 was 18 000 tonnes in 1984, with values <1000 tonnes for all years from 1993 onwards (Ajiad *et al*., 2005).

There are many uncertainties in these calculations. However, the total consumption seems to indicate that the food conversion efficiency is at a reasonable level (Bogstad and Mehl, 1997), and there is no obvious reason for these calculations to give a large over- or under- estimate of redfish abundance in cod stomachs compared to abundance of other prey. The proportion of redfish found in cod stomachs where the size is registered, has been variable, so the total consumption of redfish is more reliable than the consumption divided on length groups. Redfish is eaten by all age groups of cod, with the proportion of redfish in the diet increasing slightly with cod age. The redfish consumed by cod is smaller/younger (<25 cm/eight years) than the fishable stock. Note that the size distribution fluctuates in a way consistent with variation in abundance of young redfish, first the small redfish disappeared from the cod stomachs, then the larger redfish disappeared, and now the small redfish are coming back. Also, the abundance of redfish in the 5–14 cm length group in the Norwegian winter survey and in the stomachs seems to be closely correlated (Figure 4.6). The discrepancy in that relationship between the recent years and the 1980s may be due to gear changes in the survey in the early 1990s, which have increased the survey catchability for small fish (Jakobsen *et al*., 1997).

PINRO, Murmansk, have collected qualitative (frequency of occurrence-FO) stomach content data for the period 1947–present (see Yaragina and Dolgov (WD29) and references in Dolgov *et al*., 2007). The trends in frequency of occurrence of redfish in cod stomachs in these data are shown in Figures 4.7 and 4.8. There is a fairly good correspondence between the trends in frequency of occurrence and in weight percentage during the period 1984–2010, where both data sources are available. Areas of the highest redfish FO values in cod stomachs coincide with the areas of immature *Sebastes mentella* dwelling (Shestova, 1982; Drevetnyak, 1995). Young redfish may be found in the deep waters (channels or troughs) dependent upon warm Atlantic currents. Analyses show that portion (FO values) of cod preyed on redfish increases 1–2 years afterwards appearance of strong year classes of *Sebastes*. Thus, the strong year classes of *Sebastes mentella* registered in the Barents Sea were born in 1964, 1966, 1969, 1982–1983 and 1991–1992 (Shestova, 1982; Drevetnyak, 1995). It coincides with the fact that juvenile redfish were most frequently consumed by cod in the middle 1960s, 1970, the middle 1980s, and early 1990s. Since 1996 a drastic decrease in redfish FO values in cod stomachs were observed, which most likely reflect the failure of redfish recruitment in the area during the period 1996–2003 (Planque *et al*., 2012).

4.6.1.2 Predation by other predators on redfish

Redfish is also preyed upon by other species such as Greenland halibut (*Reinhardtius hippoglossoides*, Dolgov *et al*., 2011). However, it does not seem to be a major part of the diet of any predator, and since the biomass of other predatory fish in the Barents Sea is much smaller than the cod biomass, predation by other fish species on redfish is probably negligible compared to the predation by cod. One could probably assume that the predation by other predators on *S. mentella* is of the same order of magnitude as the proportion of the total consumption of redfish by cod, which consist of other redfish species than *S. mentella*.

Table 4.1. Consumption of redfish by cod according to Norwegian and Russian consumption calculations (1000 tonnes).

Year	Norway	Russia
1984	364	195
1985	225	97
1986	315	158
1987	323	118
1988	223	127
1989	228	157
1990	243	232
1991	312	144
1992	188	121
1993	100	41
1994	78	56
1995	190	112
1996	97	71
1997	36	31
1998	9	15
1999	16	13
2000	8	4
2001	6	4
2002	1	3
2003	3	2
2004	3	7
2005	3	7
2006	12	16
2007	40	22
2008	51	44
2009	29	24
2010	147	143

Table 4.2. Redfish consumption by cod (1000 tonnes, Norwegian calculations) by redfish length group.

Year	0-4 cm	5-9 cm	10-14 cm	15-19 cm	20+ cm
1984	22.7	243.2	69.7	8.1	19.9
1985	16.2	100.5	79.5	8.3	20.3
1986	23.8	91.4	80.3	119.2	0.0
1987	2.6	39.0	56.1	211.5	14.0
1988	36.8	112.5	22.6	50.2	0.9
1989	19.4	182.1	8.1	8.2	10.5
1990	1.5	104.7	125.7	11.5	0.0
1991	0.3	77.4	90.1	25.2	118.7
1992	0.5	34.9	45.6	100.0	7.0
1993	0.0	17.8	42.4	38.7	0.9
1994	0.3	6.0	37.3	17.8	16.8
1995	0.9	47.9	26.4	78.7	36.6
1996	0.5	21.0	5.0	29.7	40.3
1997	0.0	0.5	3.1	1.5	30.4
1998	0.0	0.0	3.0	1.4	4.4
1999	0.1	0.0	4.0	6.7	5.1
2000	0.2	0.1	1.7	1.6	4.5
2001	0.0	0.0	0.2	0.1	5.6
2002	0.0	0.0	0.4	0.0	0.3
2003	0.0	0.0	0.2	0.6	2.4
2004	0.0	0.3	0.0	0.2	2.4
2005	0.0	0.3	0.0	1.3	1.0
2006	0.0	3.1	0.1	6.7	2.0
2007	0.0	34.1	1.6	1.5	2.5
2008	0.3	39.1	6.5	2.7	2.5
2009	0.0	15.2	13.0	1.2	0.0
2010	9.9	115.1	18.4	3.4	0.4

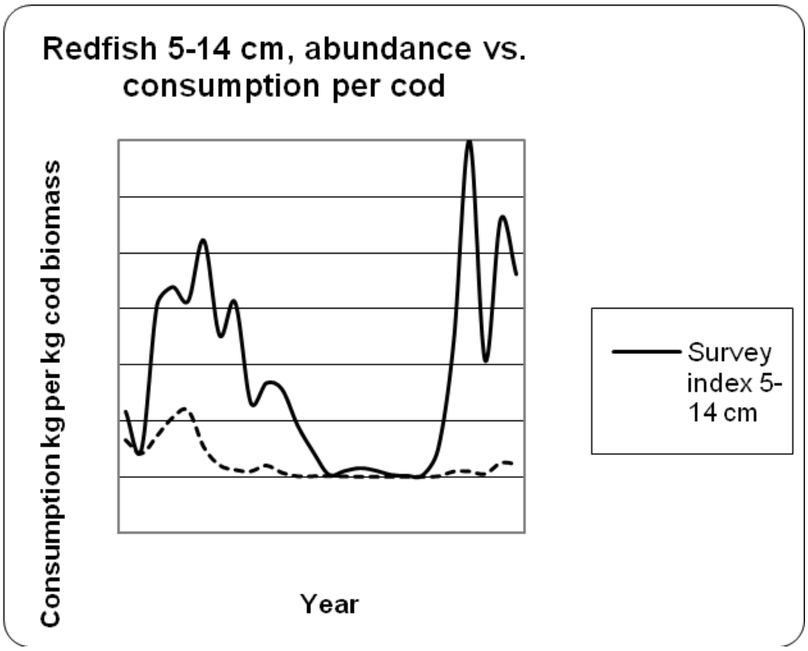


Figure 4.6. Development in redfish consumption per cod.

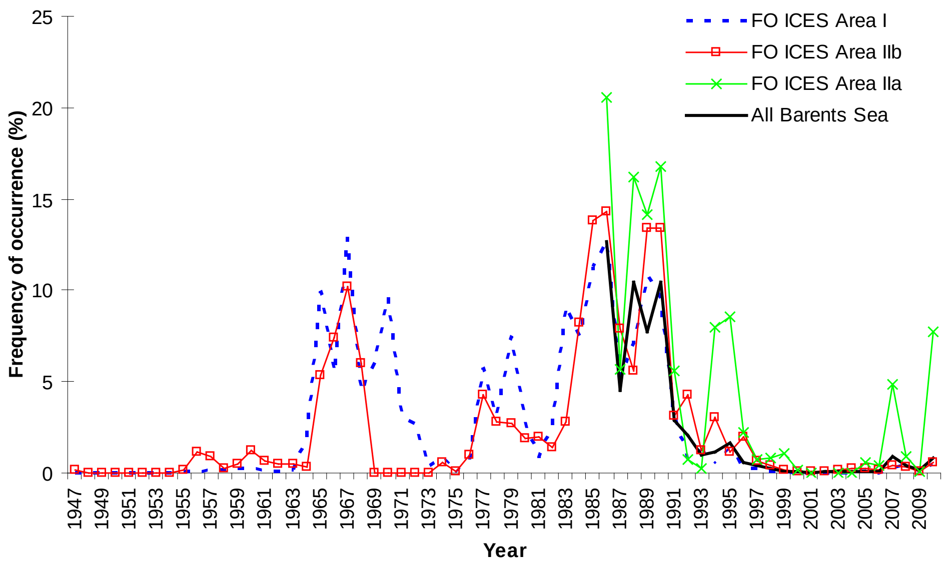


Figure 4.7. Frequency of redfish occurrence in NEA cod diet in the southern Barents Sea (ICES area I), along the Norwegian coast (ICES Subarea IIa) and in the Bear Island-Spitsbergen area (ICES Subarea IIb) in 1947–2010 due to the PINRO qualitative database.

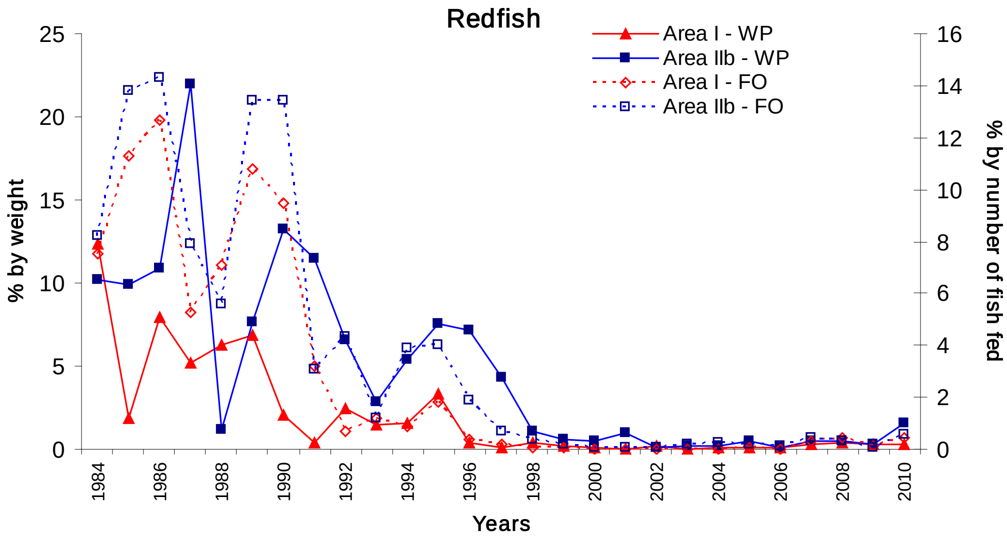


Figure 4.8. Frequency of occurrence (FO) and weight percent (% W) of redfish in cod diet in the southern Barents Sea (ICES area I) and the Bear Island–Spitsbergen area (ICES Subarea IIb).

4.6.2 Fishery interactions

At present, the only directed fishery for beaked redfish is a pelagic trawl fishery in international waters of the Norwegian Sea, which is restricted by a quota (7900 tonnes and 7500 tonnes in 2011 and 2012, respectively). Bycatches are taken in demersal cod/haddock/Greenland halibut fisheries, as juveniles in shrimp trawl fisheries, and occasionally in the pelagic blue whiting and herring fisheries in the Norwegian Sea. The levels of redfish bycatch and discards in the shrimp and demersal fisheries are given in Chapter 4.2.1.

4.7 Impacts of the fishery on the ecosystem

There is currently no specific study on the current impact of the arctic *S. mentella* fishery on the ecosystem. Possible impacts from the demersal bycatch fishery are described in Section 1.3 of the Arctic Fisheries Working Group report (p. 35–37, ICES 2011) and mostly concern degradation of benthic habitats and associated fauna. There are no studies on the ecosystem impact of the pelagic fishery in the Norwegian Sea.

4.8 Stock assessment methods

4.8.1 Models

4.8.1.1 Statistical Catch-at-age Model (SCAA)

4.8.1.1.1 Model description

A statistical catch-at-age model was developed for the Arctic *mentella* stock. The SCAA consists of three main entities: an age-structured population dynamics model, a catch numbers-at-age model, and an observation model for survey indices of numbers-at-age in the population. With this structure, when provided with reasonably accurate data on catches in numbers-at-age and survey indices in numbers-at-age, the model can estimate the parameters necessary to reconstruct population dynamics. The SCAA was developed for the period 1992–2010, with catch-at-age from the pelagic and demersal fisheries and survey numbers-at-age from winter, ecosystem and Russian surveys. Details of the model input and parameters are provided in Table 4.3. The model is further detailed in Working Document 24.

Obtaining estimates in absolute terms from the SCAA requires that one of the surveys is used as an absolute index of numbers-at-age. For this purpose, the ecosystem survey level was assumed to provide such absolute estimates. Based on hydroacoustic observations conducted during surveys in the Barents Sea (ecosystem 2004, winter 2007–2009), it is estimated that the proportion of *S. mentella* in the bottom layer-accessible to bottom trawling-represents $^{1}/_{5}$ of fish abundance in the whole water column (measured as sA) (Anon., 2009). For the base-case model, the ecosystem survey catchability was set so that the absolute numbers-at-age in the Barents Sea are five times the swept-area estimates from the ecosystem survey. Natural mortality was set to 0.05.

The selectivity-at-age in Norwegian surveys, which was originally modelled by a Gompertz sigmoid (WD24), was replaced by an exponential decline. This was done to improve the residuals from the winter and ecosystem survey numbers-at-age. The sigmoid function was kept for the Russian survey. An additional likelihood component was added to the SCAA in order to track closely the reported total catches in biomass. This component is excluded from the negative loglikelihood values (nll) reported in the results.

The SCAA was run in ADMB. No priors were set on the distribution of parameters. Empirical distributions of parameters were obtained using MCMC sampling, with 1 million samples. The first 100 000 were discarded and only $^{1}/_{100}$ of the remaining samples were retained to draw the empirical distributions.

Table 4.3. Specification of the SCAA assessment model. GADGET specifications are provided for comparative purposes.

	SCA	GADGET
Year-span	1992–2010	(1986) 1990–2009
Population characteristics		
Maximum age	19+	30+
Genders	1	1
Maturity stages	2	2
Population lengths	N/A	1–60+
Summary biomass (mt)	SSB/Total	Immature/SSB/Total
Data characteristics		
Data lengths	N/A	1–60+
Data ages	2–19+	2–30+/2–19+
First mature age	From annual ogives	Estimated age-based maturation
Starting year of estimated recruitment	1992	1986
Fishery characteristics		
Fishery timing	Annual	Quarterly
Fishery ages	6–19+	6–30+
Winter survey timing	0.12	Q1
Winter survey ages	2–15	3–15
Ecosystem survey timing	0.75	Q3
Ecosystem survey ages	2–15	3–15
Russian survey timing	0.90	Q4
Russian survey ages	2–11	3–11
Fishing mortality	Separable, age x year	Match reported catches
Fishery selectivity	Gompertz sigmoid	exponential
Winter & ecosystem survey selectivities	Exponential decline	exponential
Russian groundfish survey selectivity	Gompertz sigmoid	exponential

4.8.1.1.2 Model results–base case

For the base-case scenario, a total of 74 parameters was estimated. The model is formulated on the logscale (see WD 24) and the estimated values are reported in Table 4.4, together with the untransformed estimates. The natural mortality was set to 0.05 and the catchability coefficient for the ecosystem survey was set to q=1/3.5. When the selectivity-at-age for the ecosystem survey is taken into account this is equivalent to assuming that the absolute abundance of *S. mentella* is five times greater than the swept-area estimate from the survey.

Table 4.4. Estimated parameters in the base case assessment model.

Parameter	Initial Value	Number estimated	Sd	Unlogged parameter estimate
Initial population				Numbers in thousands
logN@age 2 in 1992	17	20.22	0.14	606 710
logN@age 3 in 1992	17	20.21	0.14	596 920
logN@age 4 in 1992	17	20.09	0.15	530 510
logN@age 5 in 1992	17	19.59	0.15	322 540
logN@age 6 in 1992	17	19.09	0.16	195 680
logN@age 7 in 1992	17	18.64	0.16	124 900
logN@age 8 in 1992	17	18.59	0.17	118 370
logN@age 9 in 1992	17	18.63	0.18	123 020
logN@age 10 in 1992	17	18.92	0.19	165 280
logN@age 11 in 1992	17	18.49	0.21	107 610
logN@age 12 in 1992	17	18.57	0.23	116 300
logN@age 13 in 1992	17	18.27	0.25	85 613
logN@age 14 in 1992	17	18.32	0.26	90 678
logN@age 15 in 1992	17	18.03	0.28	67 950
logN@age 16 in 1992	17	17.43	0.31	36 950
logN@age 17 in 1992	17	16.83	0.35	20 328
logN@age 18 in 1992	17	16.38	0.49	12 966
logN@age 19+ in 1992	17	18.93	0.17	166 380
Recruitment				Numbers in thousands
logN@age 2 in 1993	18	19.76	0.14	380 790
logN@age 2 in 1994	18	19.42	0.14	271 910
logN@age 2 in 1995	18	19.36	0.14	255 060
logN@age 2 in 1996	18	19.18	0.14	214 190
logN@age 2 in 1997	18	19.06	0.14	189 910
logN@age 2 in 1998	18	18.25	0.15	84 263
logN@age 2 in 1999	18	18.20	0.15	80 089
logN@age 2 in 2000	18	17.72	0.15	49 619
logN@age 2 in 2001	18	17.27	0.16	31 667
logN@age 2 in 2002	18	17.01	0.17	24 316
logN@age 2 in 2003	18	17.24	0.18	30 760
logN@age 2 in 2004	18	16.96	0.20	23 183
logN@age 2 in 2005	18	17.54	0.22	41 548
logN@age 2 in 2006	18	19.29	0.23	239 410
logN@age 2 in 2007	18	20.07	0.27	519 820
logN@age 2 in 2008	18	19.80	0.32	398 670
logN@age 2 in 2009	18	18.99	0.40	176 120
logN@age 2 in 2010	18	19.50	0.61	294 140

Fishing mortality - Demersal				Mortality coefficient
logF in 1992	-2	-3.05	0.16	0.047
logF in 1993	-2	-3.45	0.16	0.032
logF in 1994	-2	-3.55	0.16	0.029
logF in 1995	-2	-3.85	0.15	0.021
logF in 1996	-2	-4.38	0.15	0.012
logF in 1997	-2	-4.31	0.15	0.013
logF in 1998	-2	-3.94	0.15	0.019
logF in 1999	-2	-4.34	0.15	0.013
logF in 2000	-2	-4.53	0.14	0.011
logF in 2001	-2	-3.96	0.14	0.019
logF in 2002	-2	-5.07	0.14	0.006
logF in 2003	-2	-6.15	0.13	0.002
logF in 2004	-2	-5.41	0.13	0.004
logF in 2005	-2	-4.99	0.13	0.007
logF in 2006	-2	-4.98	0.17	0.007
logF in 2007	-2	-6.03	0.17	0.002
logF in 2008	-2	-5.89	0.16	0.003
logF in 2009	-2	-5.62	0.16	0.004
logF in 2010	-2	-5.89	0.16	0.003
Fishing mortality - Pelagic				Mortality coefficient
logF in 2006	-2	-3.68	0.16	0.025
logF in 2007	-2	-4.09	0.15	0.017
logF in 2008	-2	-4.61	0.15	0.010
logF in 2009	-2	-5.28	0.17	0.005
logF in 2010	-2	-4.81	0.15	0.008
Fishing selectivity – Demersal				
age@50% selectivity	11	10.12	0.26	
Slope of selectivity sigmoid	0.90	0.83	0.07	
Fishing selectivity – Pelagic				
age@50% selectivity	14	14.20	0.58	
Slope of selectivity sigmoid	0.90	0.83	0.18	
Observation errors (in log)				Variance of log-catches/numbers
Demersal fleet catches@age	-	-1.34	0.07	0.26
Pelagic fleet catches@age	-	-0.62	0.15	0.54
Winter survey numbers@age	-	0.04	0.09	1.04
Ecosystem surv. numbers@age	-	-0.23	0.10	0.79
Russian survey numbers@age	-	-0.62	0.11	0.54

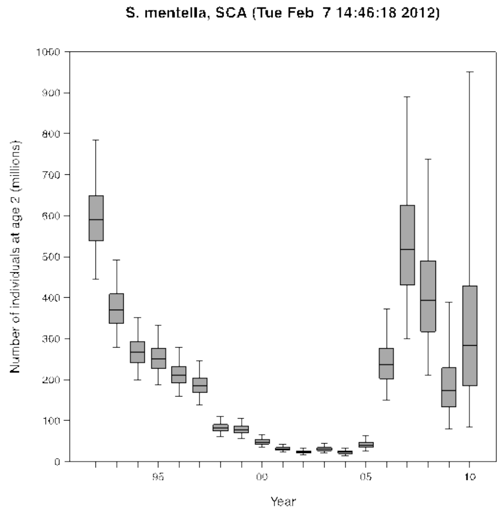
Survey scaling coefficients				Catchability
Log q winter survey	-8.00	-8.42	0.09	1/4.55
Log q ecosystem survey	-8.16	-8.16	0.00	This parameter value is fixed. 1/3.5
Log q Russian survey	-18.00	-17.97	0.13	1/68,847,000
Survey selectivities				
Winter and ecosystem surveys exponential decline (log S)	-10	-2.88	0.21	
Russian survey age@50% selectivity	4.57	3.98	0.36	
Russian survey slope of selectivity sigmoid	0.96	0.94	0.17	
Natural mortality				
Log M	-3	-3	0.00	This parameter value is fixed. M=0.05

The main features of the stock and fishery dynamics are (Figures 4.9–4.11):

- a decline in recruitment-at-age 2 from 1992 to 1998, followed by a period of very low recruitment until 2005 and a subsequent increase to high, but also highly uncertain recruitment levels.
- An gradual increase in spawning–stock biomass from around 200 thousand tonnes in 1992 to around 1.1 million tonnes in 2005 followed by a period of relative stability around the 2005 level.
- A gradual decline in the demersal fleet fishing mortality from 0.05 in 1992 to 0.004 in 2006–2010 and an average (and declining) pelagic fleet fishing mortality of 0.013 in 2006–2010.

The S-shaped selectivity curves for the demersal and pelagic fleets are consistent with the known size/age of reported catches. The older age at 50% maturity in the pelagic fleet (14y) in comparison with the demersal fleet (10y) is explained by the fact that the pelagic fleet is operating in the international waters of the Norwegian Sea where the population is primarily composed of mature individuals, whereas the demersal fleet primarily operates on the shelves and Barents Sea where juveniles are abundant.

The selectivity patterns for the surveys are modelled by an exponential decline for the Norwegian surveys (winter and ecosystem) and Gompertz sigmoid for the Russian survey. These were chosen to minimize residual patterns in survey numbers-at-age indices. There was little time to investigate how the choice of these shapes can alter the model results and this would need to be investigated further. In particular, dome-shaped selectivity functions should be explored. Residuals for the numbers-at-age for the two fleets and the three surveys are indicated in Figures 4.12–4.16.



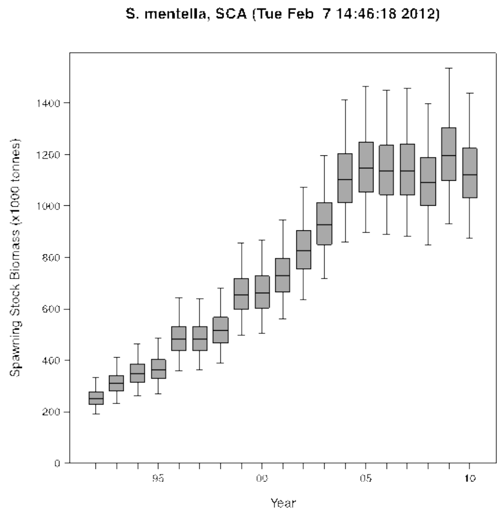
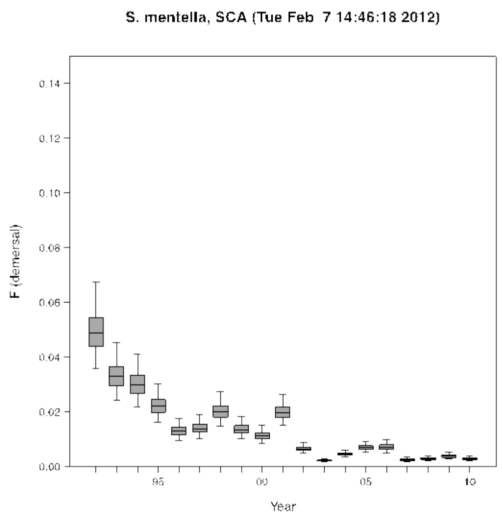


Figure 4.9. Estimated recruitment-at-age 2 (left panel) and spawning–stock biomass (right panel) for the period 1992–2010.



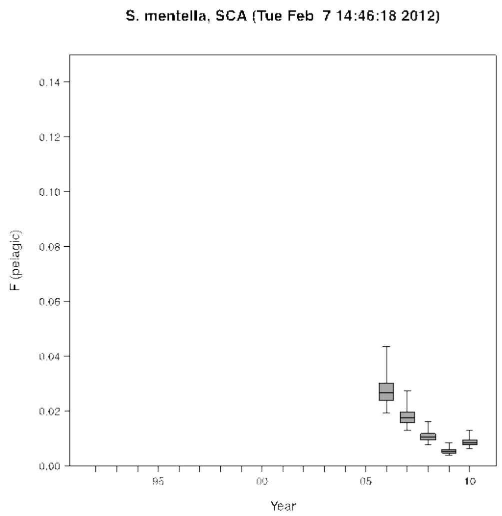
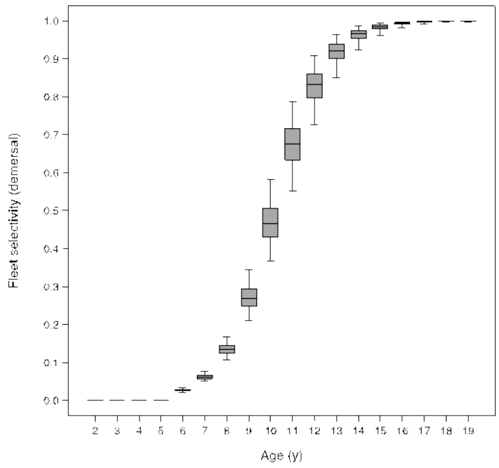
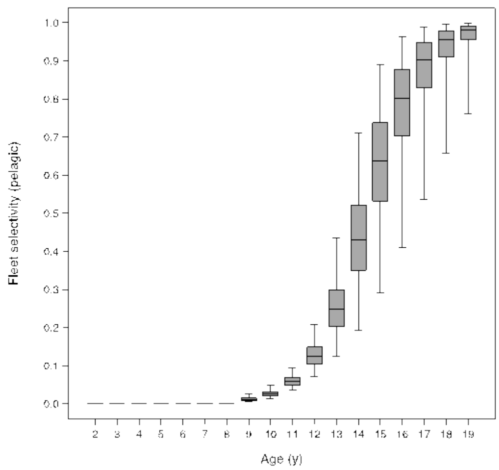


Figure 4.10. Estimated fishing mortality for the demersal (left panel) and pelagic (right panel) fleets for the period 1992–2010. The pelagic fleet catch-at-age data are available only from 2006 onwards.

S. mentella, SCA (Tue Feb 7 14:46:18 2012)



S. mentella, SCA (Tue Feb 7 14:46:18 2012)



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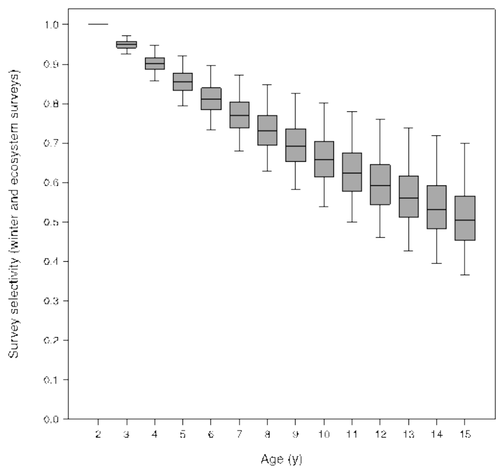


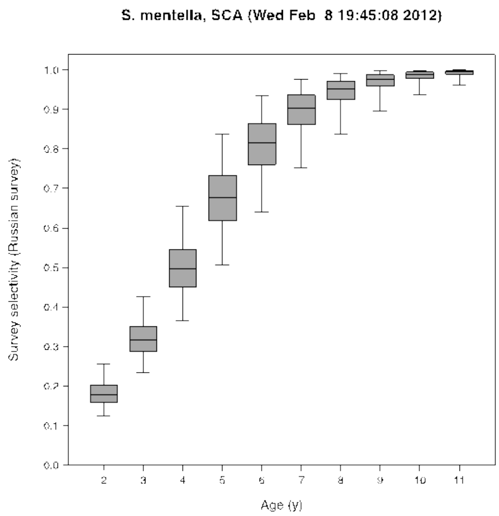


Figure 4.11. Selectivity-at-age for the demersal fleet (top left), the pelagic fleet (top right), the winter and ecosystem surveys (bottom left) and the Russian survey (bottom left).

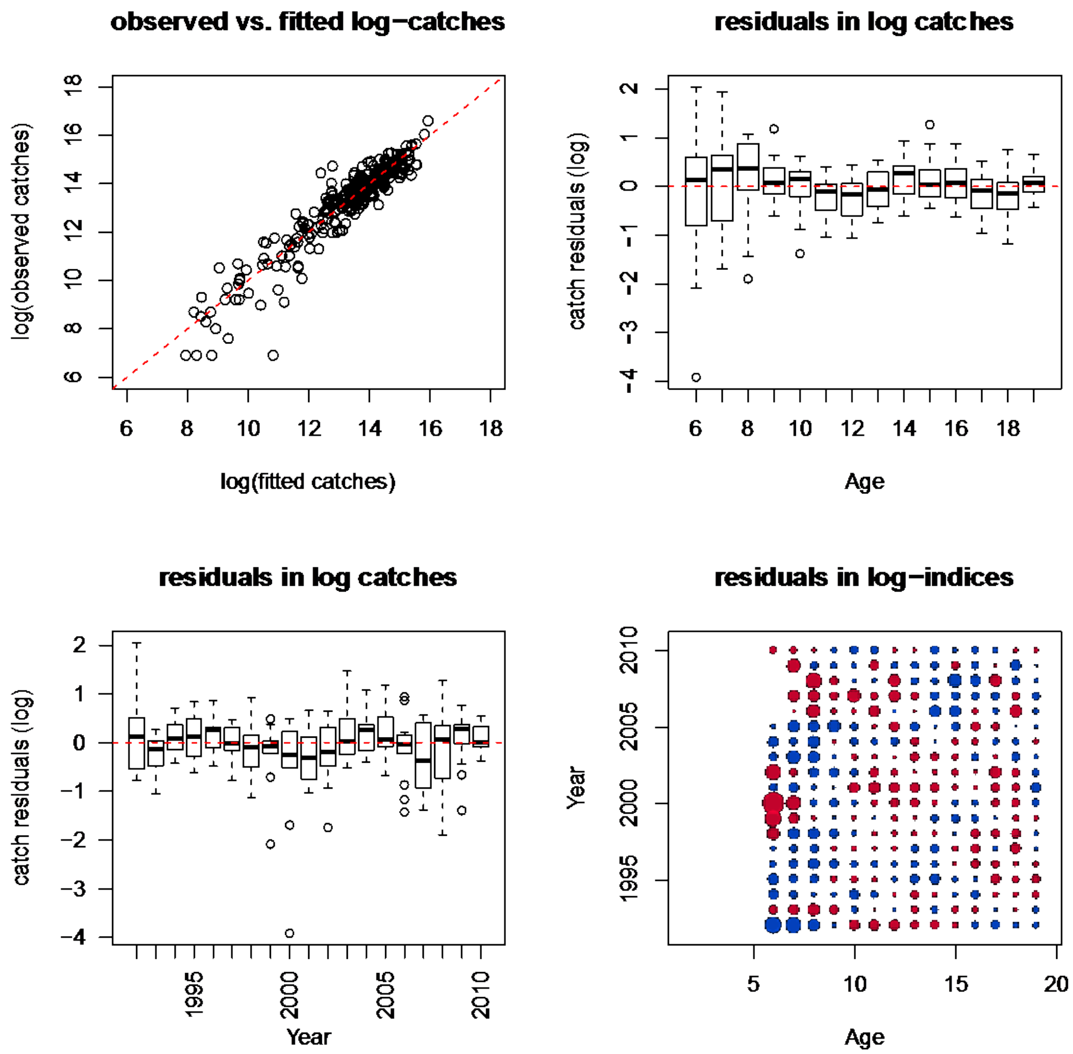


Figure 4.12. Diagnostic plots for the demersal fleet catch-at-age data. Top left: scatterplot of observed vs. fitted indices, the dotted red line indicates 1:1 relationship. Top right: boxplot of residuals (observed less fitted) for each age. Bottom left: boxplot of residuals for each year. Bottom right: bubbleplot of residuals for each age/year combination, bubble size is proportional to mean residuals, blue are positive and red are negative residuals.

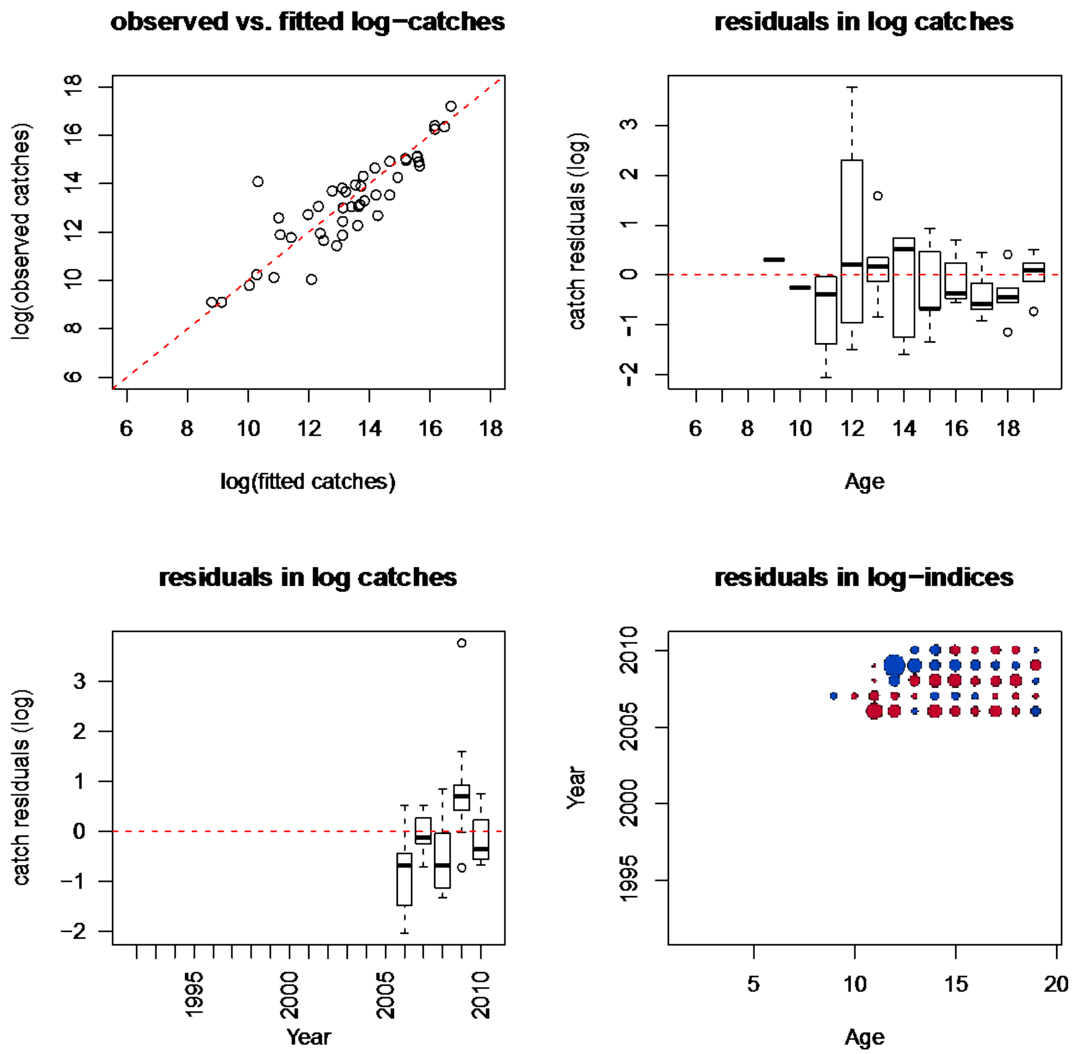


Figure 4.13. Diagnostic plots for the pelagic fleet catch-at-age data. See legend from Figure 4.12.

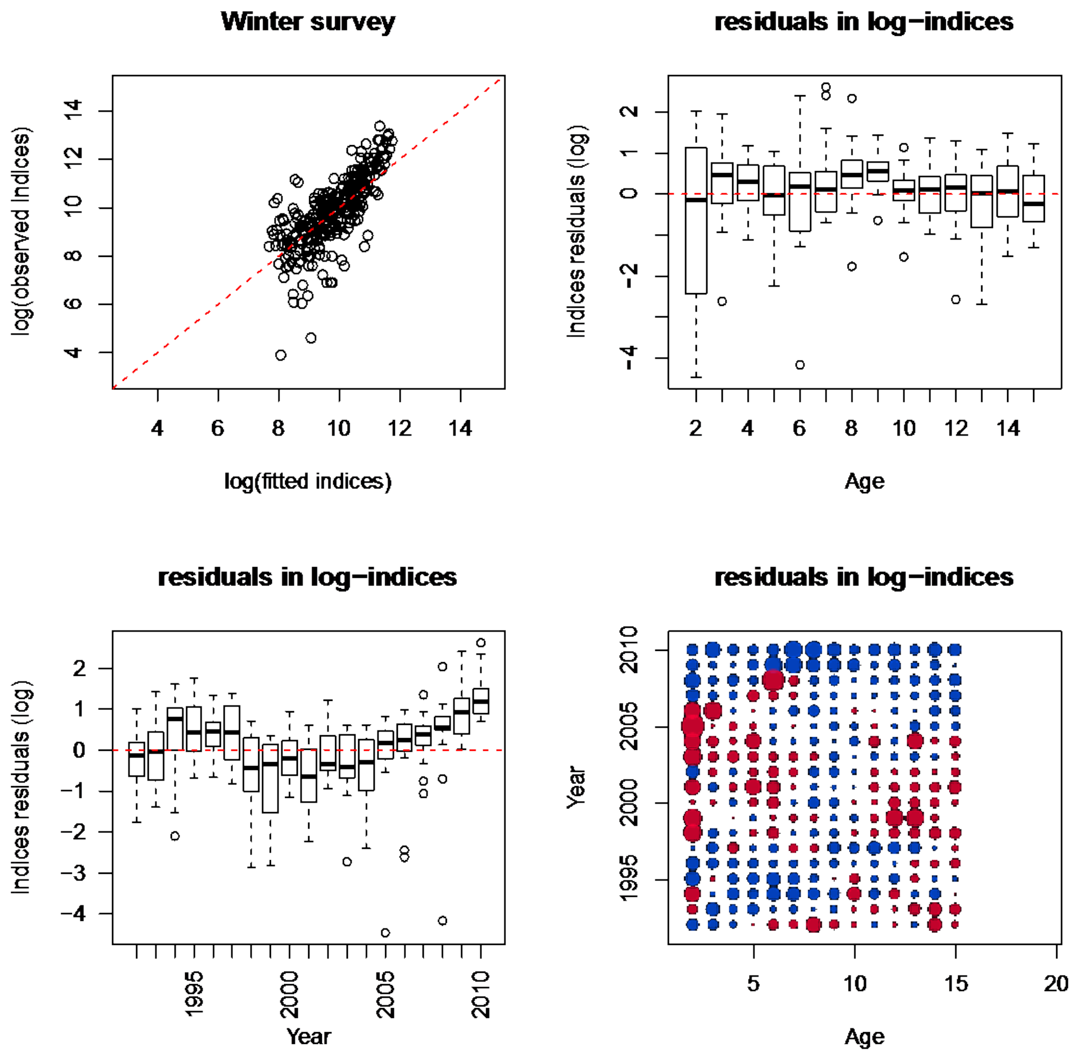


Figure 4.14. Diagnostic plots for the winter survey numbers-at-age data. See legend from Figure 4.12.

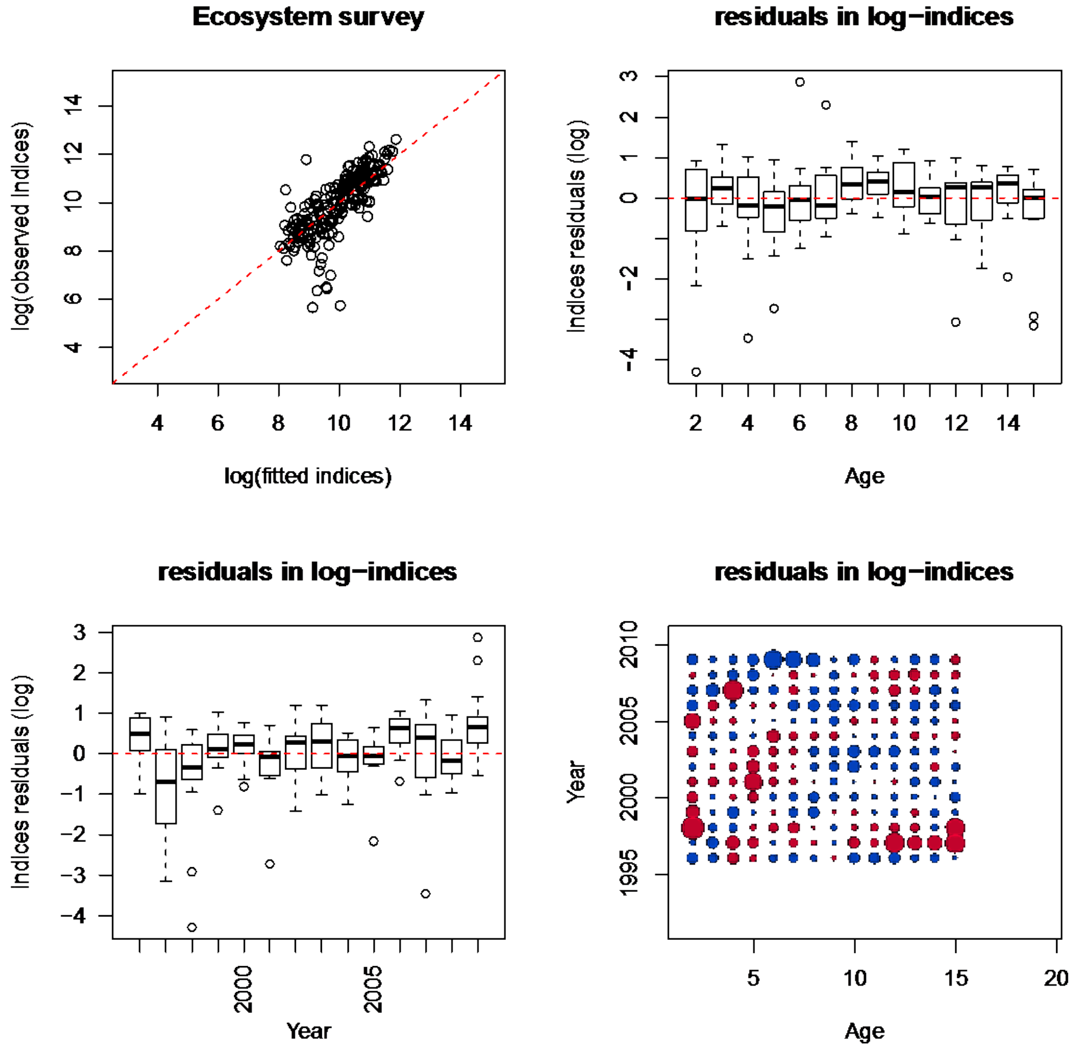


Figure 4.15. Diagnostic plots for the ecosystem survey numbers-at-age data. See legend from Figure 4.12.

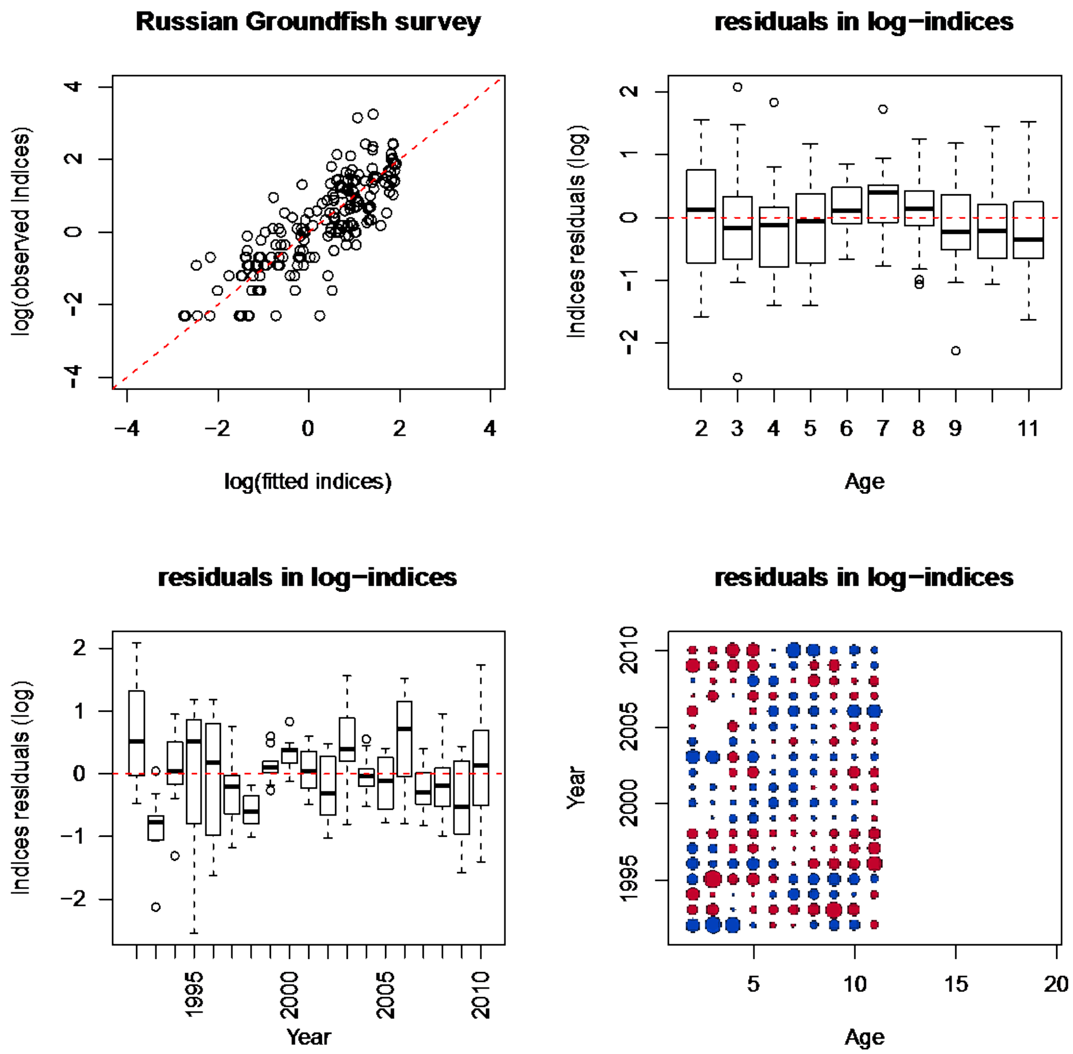


Figure 4.16. Diagnostic plots for the Russian survey numbers-at-age data. See legend from Figure 4.12.

4.8.1.2 Gadget model

4.8.1.2.1 Model description

As an addition to the SCAA model, a Gadget model was run for the arctic *S. mentella*. Due to time constraints this model was used as a secondary model to compare against the SCAA model. One key difference between the models is that the Gadget model estimates stock levels without requiring any assumption about overall survey catchability, *q*. As a result the Gadget model can provide support for abundance estimates in the SCAA model.

The Gadget model for *S. mentella* is based on that for *S. marinus*, and is more fully described in Section 3.8. The differences between the two models are in the data used for tuning. All commercial catches are currently combined into two fleets, one for the pelagic and one for trawl fleet. Three surveys are also included: the winter, ecosystem and Russian surveys. However these only cover ages 3–15 (3–11 for the Russian survey). The fleets have age and age–length data up to age 30+ for the Norwegian sectors of the fleet; these data are used by the model as a proxy for covering the entire fleet.

As a result there is no direct information on the trends in the mature part of the stock. The commercial fleet and the surveys were each assigned exponential ("S-shaped) selectivity curves, with l_{50} and slope parameters to be estimated by fitting the model. During optimization it was found that for fish within the model (aged three and older), parameters were selected that gave flat selectivity curves for the ecosystem and winter surveys.

Possible future extensions to the model would include disaggregating the model in space into several areas, better reflecting the biology and structure of the fishery. Another possibility would be combining the model with the *Sebastes marinus* model used in the AFWG in order to examine the possible effects of misidentification between the two species.

4.8.1.2.2 Model results

Overall modelled stock biomass (Figure 4.17) rises from just under 500 thousand tonnes in 1990 to almost 1 million tonnes in 2000, and falls slowly thereafter until reaching 830 thousand tonnes in 2007 then rising slightly. The immature biomass initially rises from 250 thousand tonnes to 375 thousand tonnes in 1997, then falls to 150 thousand tonnes in 2005. Thereafter the immature biomass has risen in response to the improved recent recruitment (Figure 4.18). Recruitment, which had been high in the early 1990s was at a low level from the mid 1990s to the early 2000s, with several improved year classes thereafter, confirming the known very low recruitment for the year classes born over 1996–2003 (Planque *et al*., 2012). The mature biomass rises from an initial value of 250 thousand tonnes to around 750 thousand tonnes in 2004 as a result of maturing immature fish. However the decline in immature biomass from the late 1990s has begun to translate into a fall in mature biomass since 2004. This trend is likely to continue for some years, as the fish take over a decade to mature.

It should be emphasized that there are no survey data used for the model for fish older than 15 years, and the model results for the mature fish should thus be considered highly uncertain. Furthermore this lack of data makes modelling the overall biomass of the stock problematic. The model estimates stock levels directly from the input data, without any *ad hoc* assumptions about survey catchability. The estimated stock levels have a good lower bound (there must have been a certain population level to sustain the historically reported catches); however the upper bound is much less certain. Consequently the results here may be considered a minimum bound on the actual stock size. The stock dynamics and overall biomass levels produced in this model are similar to those in the SCAA model, and thus may be considered to support the conclusions from that model.

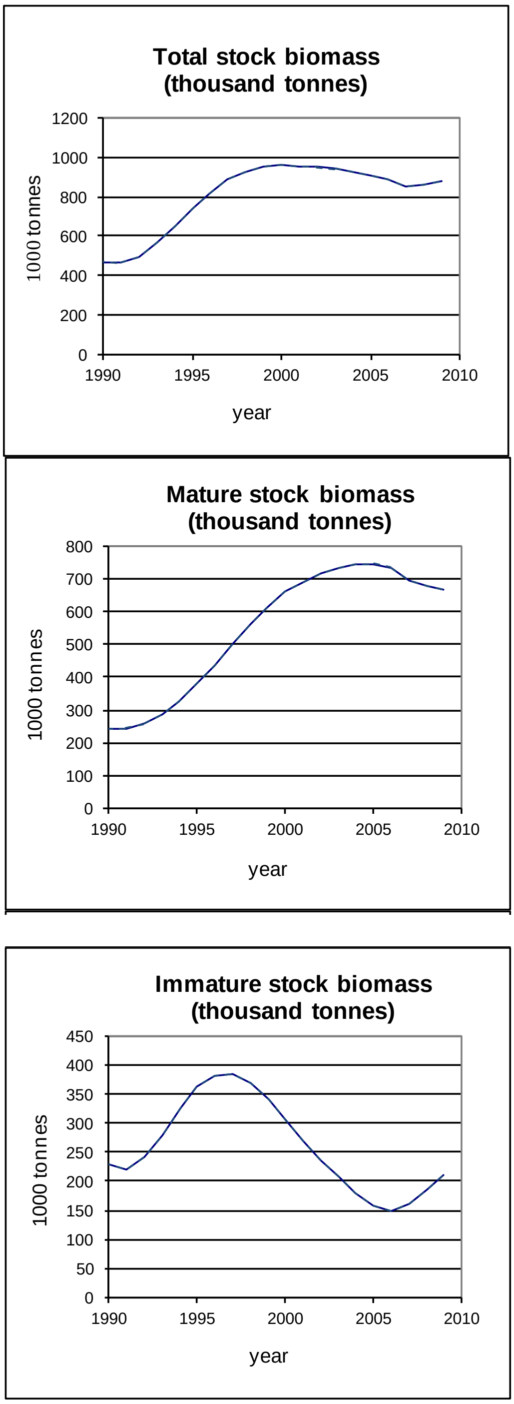


Figure 4.17. Stock, total and spawning–stock biomasses (in million tonnes) for the modelled *Sebastes mentella* population.

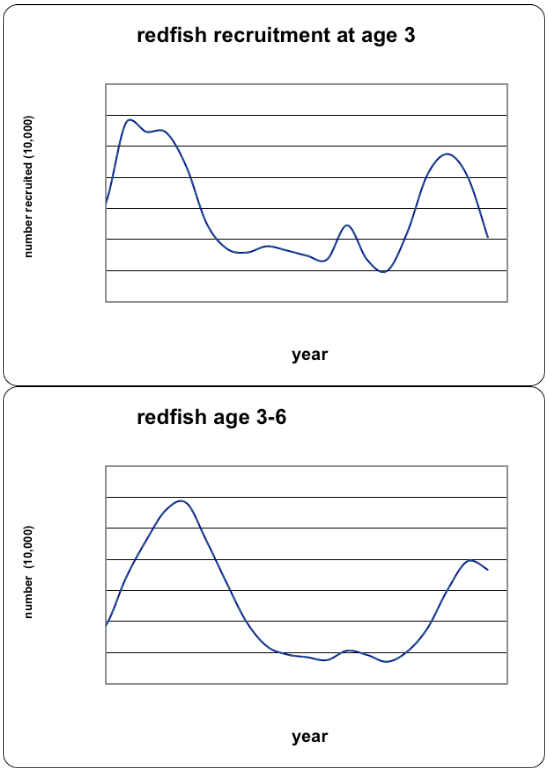
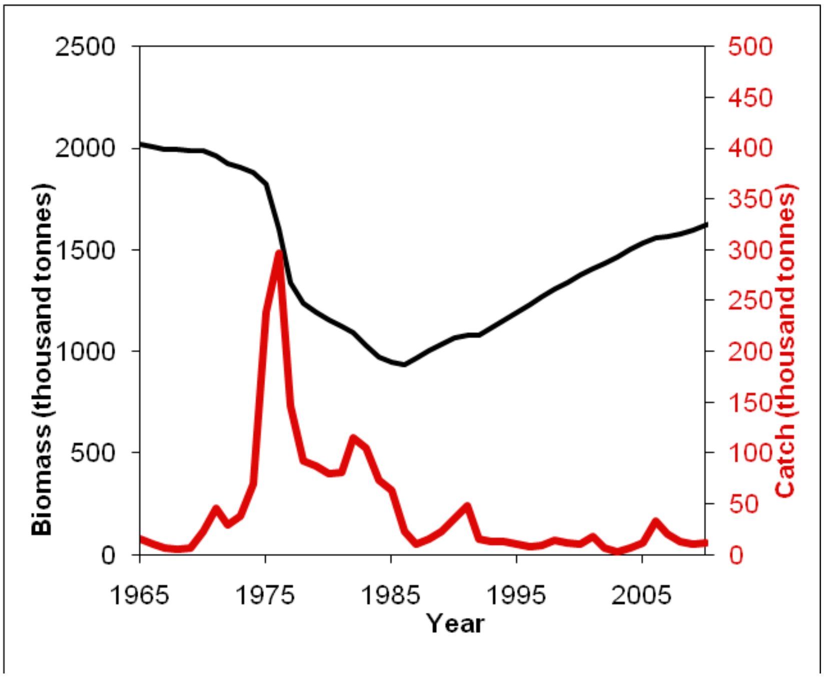


Figure 4.18. Number of recruits and fish age 3–6 in the model. Given poor age reading the "smoother" age3–6 are likely to be more realistic.

4.8.1.3 Biomass dynamics modelling

A Schaefer model was developed for the arctic *S. mentella* stock. The model rationale and structure are presented in Section 3.8.1.2. The model was coded and run during the workshop using ADMB. Runs were performed with different assumptions on *r* (intrinsic growth rate): 0.02, 0.05, 0.10 and 0.15. The value $r = 0.10$ was used as the base-case. This is consistent with estimates derived from longevity–mortality–growth relationships (see WD 25) and with the SCAA and Gadget model runs.

Schaefer model outputs can be used as reality checks for other models. The model indicates a general recovery trend from the early 1990s, followed by a slowdown in the mid-2000s (Figure 4.19). This pattern is also reproduced in the Gadget and SCAA model runs. The absolute biomass level of the Schaeffer model depends on the selected *r* value. The base case ($r = 0.10$) scenario results in an estimate of the carrying capacity of 2 million tonnes and current depletion of 0.8, i.e. a current biomass of 1.6 million tonnes. This is reasonably consistent with the base-case scenario for the SCAA model in which the total biomass in 2010 is estimated to be 1.3 million tonnes (SSB=1.2 million tonnes). However, the results from the Schaefer model must be interpreted with caution because the model makes the assumption that the survey data provided as an input for the recent years (1992 onwards) reflect annual variations in the overall population biomass. The winter and ecosystem survey data predominantly catch immature individuals whereas many of the mature individuals, which constitute the bulk of the adult population and of the fishable stock, are outside the area monitored by these surveys.



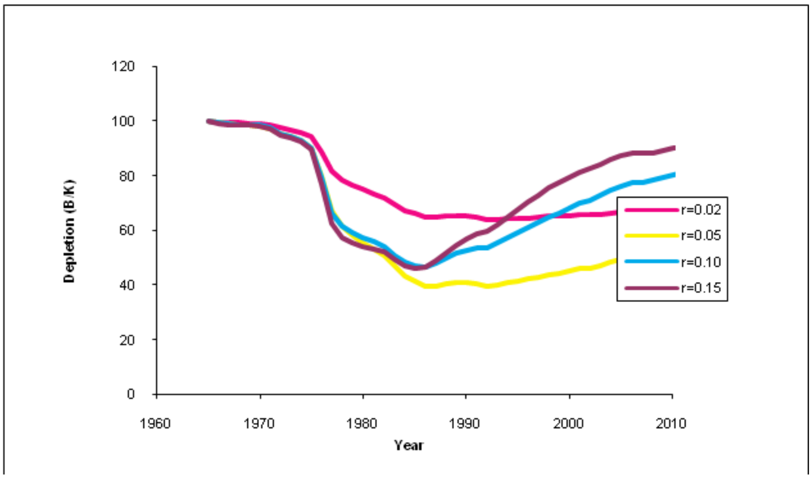


Figure 4.19. Top: The reported catches (red) and estimated stock biomass (black), in thousand tonnes, for the period 1965–2010 and for intrinsic growth rate *r* = 0.10. Bottom: the ratio of biomass (*B*) over carrying capacity (*K*) for the period 1965–2010 and four levels of intrinsic growth rate (*r*).

4.8.2 Sensitivity analysis

Sensitivity analysis was conducted for the biomass production (reported in Section 4.8.1.3) and the SCAA models. The SCAA model was run for several values of catchability for the ecosystem survey and two values of natural mortality (0.05 and 0.10). Setting different catchability values for the ecosystem survey results in near-proportional changes in the estimation of absolute numbers and biomass, without altering the model fitting performance appreciably. The base-case model provides an estimate average SSB of 1.1 million mt for the period 2006–2010. This is larger than the level estimated in the Gadget model (0.75 million mt). Natural mortality of 0.1 results in lower biomass estimates (close to 0.7 million mt) but much poorer fitting performance (change in nll=26). The two models with q=1/2.5 and q=1/4.0 provide a range of biomass between 0.8 and 1.3 million mt and will be considered for the projections as upper and lower bounds (Section 4.9). This is consistent with the estimate of 0.75 million mt from the Gadget model which can be considered a lower bound for SSB level in the stock (Section 4.8.1.2.2).

Table 4.5. Main configurations and output from several SCAA models used for sensitivity tests.

Model	M	Ecosystem scaling (adjusted for selectivity)	SSB (2006-2010)	Fpelagic(2006-2010)	Fdemersal (2006-2010)	nll
Base-Case q=1/3.5	0.05	1/4.9	1,167,080	0.013	0.004	1261
q=1/2.5	0.05	1/3.6	842,938	0.018	0.005	1263
q=1/4.0	0.05	1/5.6	1,330,770	0.011	0.003	1260
M=0.1 q=1/4.2	0.10	1/5.0	744,658	0.023	0.006	1287

4.8.3 Retrospective patterns

There was not sufficient time during the WKRED workshop to conduct a systematic analysis of the retrospective patterns using the SCAA and Gadget models. This will need to be investigated, presented and discussed at the assessment working group.

4.8.4 Evaluation of the models

4.8.4.1 Comparison with independent survey data

Both SCAA and Gadget give present SSB levels somewhat above the levels estimated by the pelagic surveys in the Norwegian Sea in 2008–2009 (400 000–550 000 tonnes). This indicates that the model results are plausible when related to the absolute values derived from that survey, which constitutes and independent data source, i.e. not included in the models.

4.8.4.2 Impact of predation on *S. mentella* stock dynamics

Natural mortality on young redfish may be considerably higher than the values of 0.05/0.10 y^{-1} suggested for older redfish (Bogstad, WD 27). Recruitment of redfish to the fishery might be influenced by variable and possibly high natural mortality on young redfish due to predation, mainly by cod. The cod stock is at a high level at present, a situation which is likely to continue (ICES, 2011). Recent changes in geographical distribution of cod indicate that overlap between the stocks has changed, cod has moved northwards (into areas where redfish previously was not subject to predation by cod) and towards the southeast (where there are no redfish). Whether the total overlap between the species has increased or decreased is not clear.

The calculated annual consumption by cod was compared to the biomass removed by natural mortality (M) in the SCAA and Gadget model runs (M-output-biomass or MOB, Hamre, 1994). The results are shown in Figure 4.20. Until 1995 and from 2005 onwards, the consumption by cod is an order of magnitude higher than the MOB, while over 1995–2005, they are at a comparable level, although the consumption estimates are rather uncertain when they are so low. As natural mortality may vary considerably, high survey indices at young ages do not necessarily mean similar high recruitment to the fishery (age 6), and this should be taken into account when making medium-term projections for stock development.

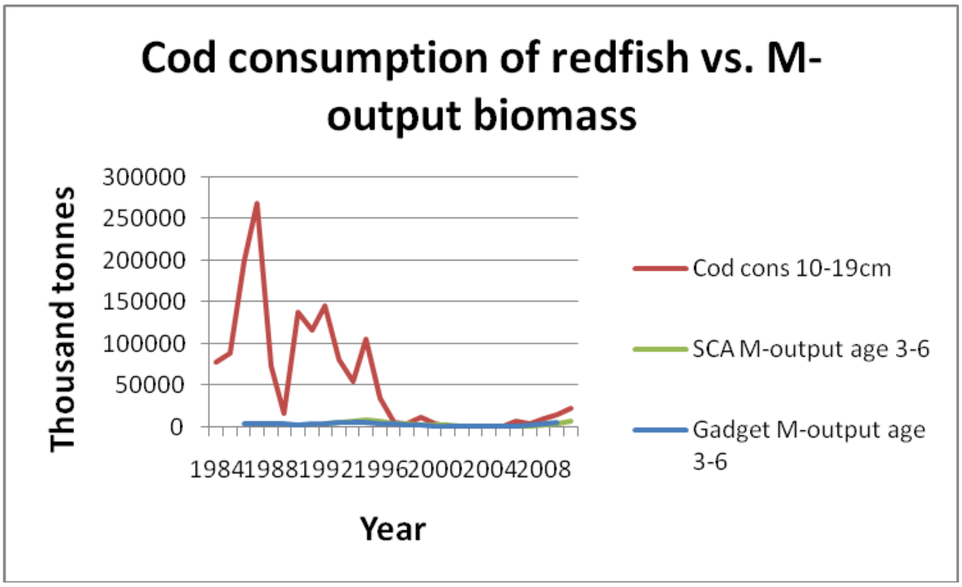


Figure 4.20. Cod consumption of 10–19 cm redfish in the Barents Sea compared to M-output biomass for *S. mentella* ages 3–6.

4.9 Medium- and long-term forecasts

Projections over a range of options for the major uncertainties in the SCAA assessment were conducted:

i) with the survey catchability coefficient set to 1/2.5 and 1/4.0; and

ii) with future recruitments at age 2 set equal to either the 25%- or 75%-ile of distributions of estimates for the Last Five Years (LFY: 2006–2010), or the mean recruitment over the preceding low recruitment period from 1998 to 2005.

Future catches were set equal to zero (as a bound), half, the same and double the average catch for the last five years (0, 0.5, 1.0 and 2.0 times LFY). The fisheries catch projections are based on the assumption that future catch proportions@age remains identical with the 2006–2010 situation. Projected natural mortality is fixed to 0.05 for all age groups.

The results suggest that under the first two scenarios for recruitment, the recent average catch (18 742 tonnes) could be maintained and possibly increased without leading to spawning–stock reduction in the longer term (Figures 4.21 and 4.22). Under the third recruitment scenario there would be reduction, but this would not be substantial over the next decade, and appropriate resource monitoring would allow such circumstances to be detected within this period, allowing for remedial action to be taken. This third scenario is in any case perhaps implausibly pessimistic and was intended only as a bound; though such low recruitments have occurred and may occur again in future, it is unlikely that they would persist over many decades, and the large numbers of cohorts in the populations serves as a buffer against recruitment failures over shorter periods. In medium-term projections (Figure 4.23), the fluctuations in SSB are mainly dependent on the catch scenario but are hardly sensitive to the recruitment scenario until 2015, i.e. five years into the future. The scenario of catch levels identical with the last five years projects into stable SSB levels over the next 5y.

Medium-term projections for management advice need to take into account that fishing mortality for the demersal (bycatch) fleet cannot be set to zero.

The Schaefer model indicates the depletion of this resource to be appreciably above 50% (Figure 4.19, MSY level in terms of this model) with a replacement yield (RY) in the vicinity of 30 thousand tons.

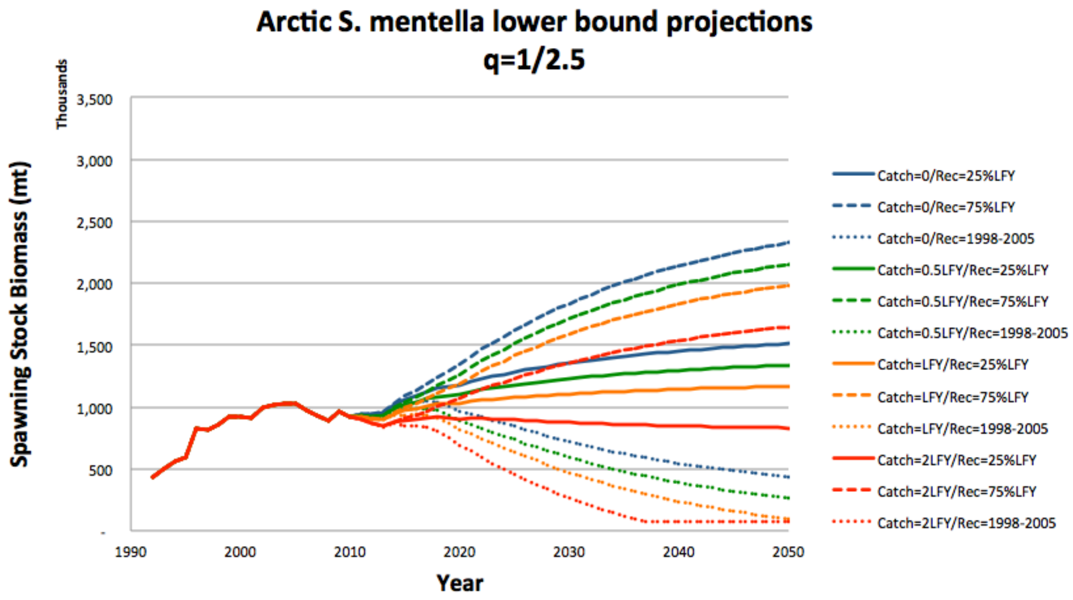


Figure 4.21. Long-term projections for the SSB of Arctic *S. mentella* with survey catchability coefficient q=1/2.5. Colours are indicative of catch level (blue: no catch, green: half of last five years, orange: last five years, red=twice last five years). Plain line: recruitment 25 percentile of the last five years, dashed line: 75 percentile of the last five years, dotted line: median for the 1998–2005 period.

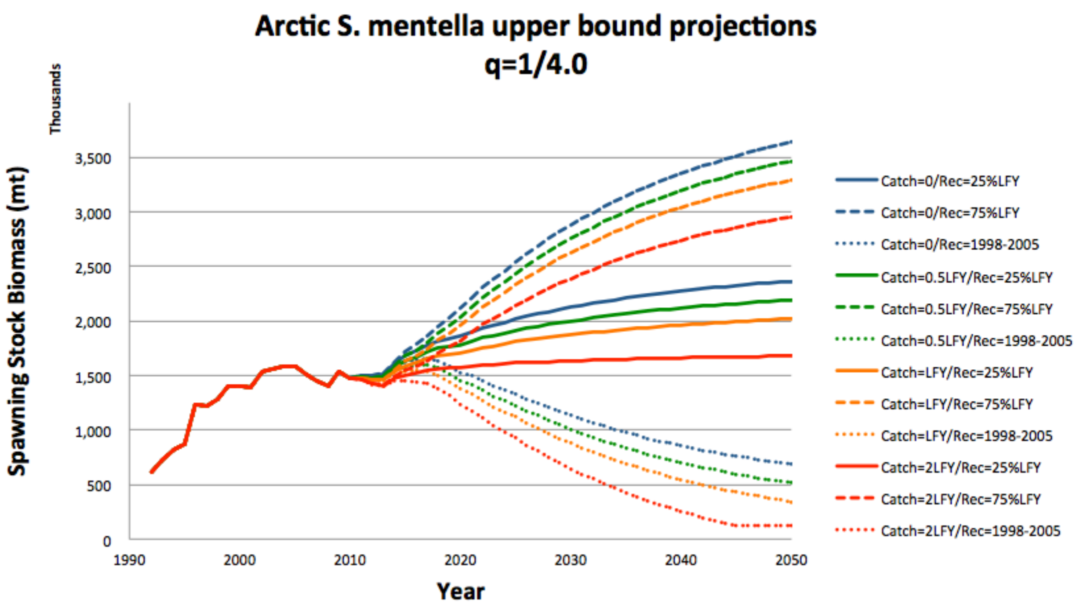


Figure 4.22. Long-term projections for the SSB of Arctic *S. mentella* with survey catchability coefficient q=1/4. See legend from Figure 4.21.

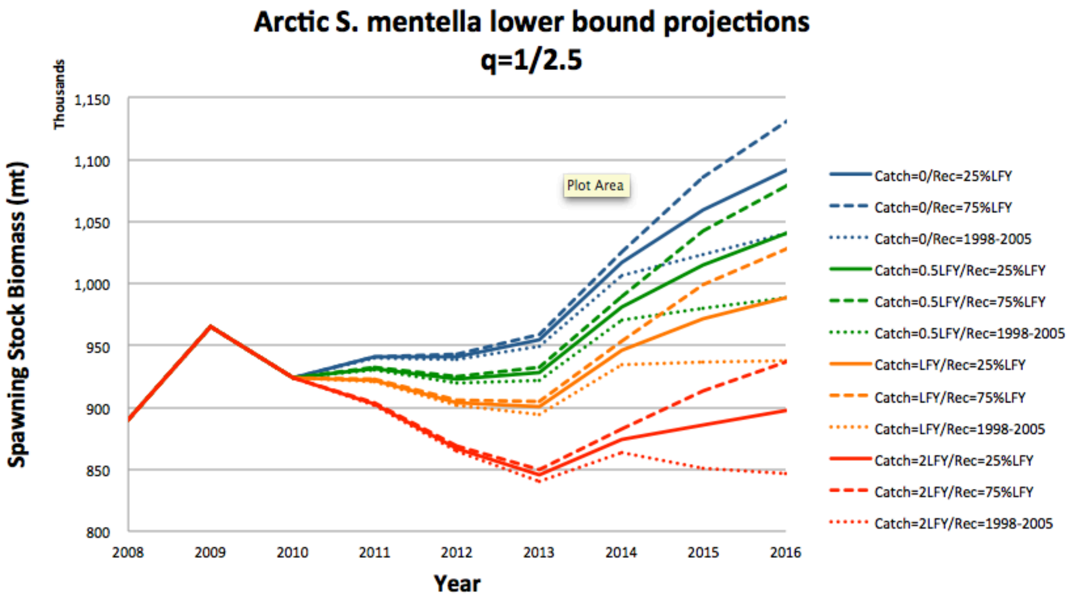


Figure 4.23. Medium-term projections for the SSB of Arctic *S. mentella* with survey catchability coefficient q=1/2.5. See legend from Figure 4.21.

4.9.1 Conclusions [why a given model and setting is chosen as final forecast, describe main changes from the last stock annex, the actual result should be in the stock annex itself]

None of the models presented have previously been described in the Stock Annex. The WG considers it appropriate to use the SCAA base case model with $M = 0.05$ for evaluation of population dynamics and current stock status of Arctic *S. mentella*, but for the time being the uncertainties in the absolute abundance level assumed for the surveys preclude the ability to estimate current stock levels directly. Additional information provided by the Gadget model and abundance estimates from recent surveys in the Norwegian Sea can, however, be used to approximate the stock biomass level. These can be used to validate the SCA.

In the absence of a clear stock–recruitment relationship, the SCAA can still be used to provide quantitative projections over five years. The SCAA model is, in principle, capable of estimating preliminary biological reference points and harvest control rules. However, a longer historical perspective may be necessary to ensure these estimates are realistic. This can possibly be achieved with a Schaefer biomass model, if the survey-series are representative of the biomass of the entire stock.

Currently, the survey-series used in the SCAA do not appropriately cover the geographical distribution of the adult population. Priority should be given to data collection over the slope and open Norwegian Sea regions, where the adult population is most abundant, and to including these new surveys in the analytical assessment in future.

4.10 Biological reference points

In the absence of long time-series of surveys on the mature stock and of model runs, it is difficult to establish reference points, although some attempts have been made (ICES, 2009; ICES, 2010; WD 25). However, in the present situation with low incoming recruitment to the spawning stock, a possible approach could be to advise on catch levels which give a low probability of decreasing the stock size.

4.11 Recommendations on the procedure for assessment updates and further work

4.11.1 Assessment updates

The WG considers that is appropriate to use the SCAA model presented here for evaluation of population dynamics and current stock status of *S. mentella* in Areas I and II, with Gadget and Schaefer models used as auxiliary models which may help validating the SCAA results. Data from the Norwegian Sea pelagic surveys should also be considered a reality check for the stock biomass level. The SCAA model should be further explored with regard to selectivity-at-age curves for the surveys and fleets and retrospective patterns should be explored.

Although the absolute stock level is uncertain, the recent recruitment pattern is fairly clear, with low recruitment (at age 2) in 1998–2005, followed by a period of better recruitment. Thus the recruitment to the spawning stock will be fairly low in the years to come. Medium-term projections (5–10 years) of SSB and total-stock biomass should be made annually.

Future assessment of the Arctic *S. mentella* stock status should be based on the trends and levels of SSB and recruitment (from the SCA) and on the demographic structure of the adult stock, derived from catches and survey in the Norwegian Sea.

4.11.2 Harvest control rules

In the absence of long time-series of surveys on the mature stock and of model runs, it is difficult to establish harvest control rules. However, in the present situation with low incoming recruitment to the spawning stock, a possible approach could be to advise on catch levels which give a low probability of decreasing the stock size. This approach could be maintained until improved recruitment to the spawning stock has been observed. If the stock level from the upcoming survey in the Norwegian Sea in 2012 is comparable to the results from 2008–2009, this will give a better foundation for the assessment of present SSB levels.

4.12 Implications for management (plans) [previous management plan evaluations, new ref. points]

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 and of model runs, it is difficult to establish reference points.

A dialogue with the managers about harvest control rules should be initiated as soon as possible. This is especially important as this stock is found both in the Barents Sea/Svalbard area (managed by the Joint Norwegian-Russian Fisheries Commission) and the International Waters in the Norwegian Sea (managed by NEAFC), and there are at the moment two distinct fisheries; a bycatch demersal trawl fishery in the Barents Sea/Svalbard area and a directed pelagic trawl fishery on adult fish in the International Waters. A trawl fishery on adult fish could also be carried out in the Barents Sea/Svalbard area.

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5 Golden redfish (*Sebastes marinus*) in Subareas V, VI and XIV

5.1 Current assessment and issues with data and assessment

Exploitation of golden redfish of the East-Greenland/Iceland/Faroe Islands stock (EGIF stock) started in the mid 1920s in Icelandic waters and in two other areas after the Second World War (Figure 5.1). Total annual landings gradually decreased by more than 70% from about 130 000 t in 1982 to about 43 000 t in 1994. Since then, these annual landings have varied between 33 500 and 51 000 t. The total landings in 2010 were 38 700 t, which is similar to 2009. The majority of the golden redfish catch is taken in ICES Division Va and in recent years contributes to about 94–98% of the total landings.

The basis for advice and the relative state of the stock has been based on projections derived from the analytical GADGET model (Björnsson and Sigurdsson, 2003; Begley and Howell, 2004) and survey index-series (ICES, 2011). The GADGET model used only catches and survey indices from Division Va. The survey index was the basis for estimating stock status and the GADGET model was the basis for providing advice on catch limits.

In 2011, the relative state of the stock was assessed through a survey biomass index-series (U) in Icelandic waters (Figure 5.2). The basis for the calculation of the U_{pa} was the Icelandic spring groundfish survey index-series starting in 1985. The indices used for assessing state of the stock were compiled differently from the indices used in the GADGET model. The main difference is that the some of the stations showing the most variability were excluded when compiling indices to assess the stock status. The reason was to avoid too much random variability inference on stock status for a species where the stock status changes slowly. The assessment model is on the other hand a lowpass filter, potentially able to handle this problem.

In the 1990s the average value of U was around half of U_{max}; the highest observed index in the time-series (276 thousand tonnes in 1987). Year classes in this period after the 1990 year class were all estimated relatively small in the late 1990s. A precautionary U_{pa} was therefore proposed at U_{max}*0.6, corresponding to the U's associated with the most recent strong year class, that is the 1990 year class. U is a reasonable proxy for SSB or represents the fishable biomass (this is the component of the biomass defined by a selection curve which rises from zero to full selectivity over the length range 34–36 cm). In Division Va in recent years the survey index (U) had fluctuated around U_{pa}, but in 2011 it was about 30% above U_{pa}.

The results from a number of analytical models have been presented (ICES 2011) and all of them indicated that fishing mortality has reduced in recent years and is now close to F_{MSY}=0.15. Total mortality estimated from catch curves from the commercial catch and the autumn survey give similar indications about total mortality. Spawning stock and fishable stock have been increasing in recent years and are now the highest since 1986. Recruitment in Va has been low since 1993 compared to the large 1985 and 1990 year classes, but there is an indication of stronger new year classes which have been observed as 9–14 years old fish in the October survey in 2010.

In Division XIVb (East Greenland) survey indices of both pre-fishery recruits and fishable size (fish 33 cm and larger) had increased in recent years. In Division Vb (Faroe Islands) the Faroese groundfish survey indicated that the abundance has been low and decreasing since 2001. No information was available on exploitation rates in Divisions Vb and XIVb.

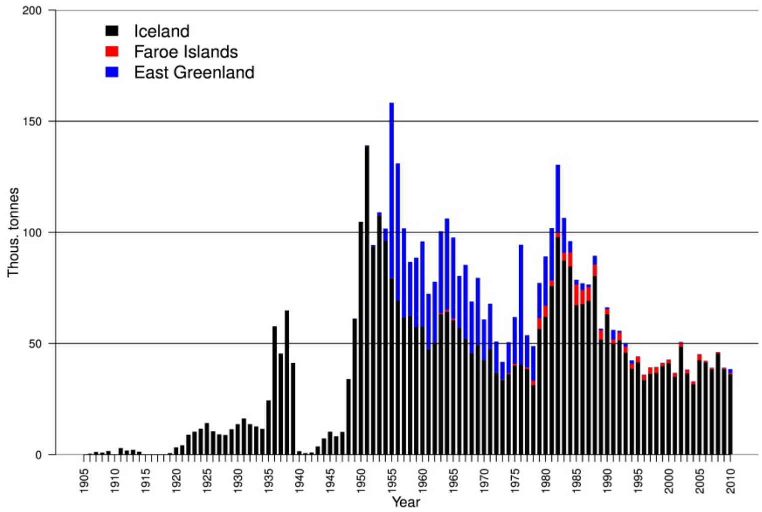

Figure 5.1. Nominal landings (in tonnes) of golden redfish from Icelandic waters (ICES Division Va), Faroes waters (ICES Division Vb) and East Greenland waters (ICES Division XIV) 1906–2010.

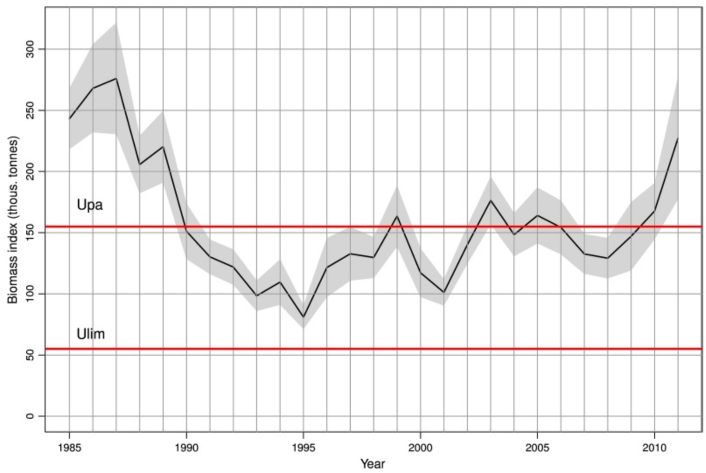

Figure 5.2. Index of fishable stock (this is the component of the biomass defined by a selection curve which rises from zero to full selectivity over the length range 34–36 cm) from the Icelandic groundfish survey in March 1985–2011 (left). The shaded area and the vertical bar show ±1 standard error of the estimate and the red lines show the U_{pa} and U_{lim} respectively.

5.2 Compilation of available data

5.2.1 Catch and landings data

Icelandic data on commercial catch in tonnes by month, area and gear are obtained from Statistical Iceland and the Directorate of Fisheries. The landings data are, however, recorded as redfish and not split between golden redfish and beaked redfish. Also, Icelandic authorities awarded a joint quota for golden redfish and Icelandic slope beaked redfish in ICES Division Va until the 2010/2011 season. Icelandic fishermen were, therefore, not required to divide the redfish catch into species. Since

1993, a so-called *split-catch* method has been used to split the Icelandic redfish catches between the two species, and is described in the Stock Annex for golden redfish. The method uses data from the logbooks and biological sampling from the fishery.

Landings of foreign fleets operating in Icelandic waters, which now are only Norwegian and Faroese vessels, are obtained by the Icelandic Coast Guard and reported to the Directorate of Fisheries.

The accuracy of the landings statistics from Iceland are considered reasonable with the main error coming from allocation of the catches to species, that is between golden redfish and Icelandic slope beaked redfish (see also Stock Annex).

Discarding of golden redfish in Icelandic waters, which has been estimated annually since 2001, is hardly detectable in that period (Pálsson *et al*., 2010).

Landings from Greenland are not divided by redfish species and the splitting is based on biological sampling of the catch.

Faroese data for commercial catches in tonnes by month, area and gear are obtained from Statistics Faroe Islands and the Directorate of Fisheries. The geographical distribution of catches is obtained from the logbooks, where location of each haul, effort (hours fished and trawling distance), the depth of trawling and total catch of redfish is recorded.

Landings statistics from the Faroe Islands are obtained from Faroese authorities. The redfish catches are, however, not split between the two redfish species. The splitting of the catches is based on biological sampling of the commercial catch.

5.2.2 Biological data

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) during trips 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.

Sampling of size composition from the Icelandic bottom-trawl fleet is available from 1956–1966 and 1970–2010, but sampling before 1976 was rather limited. Since 1999, 219–434 samples are taken annually and 35 000–74 000 lengths measured annually.

Sampling of age composition from the bottom-trawl fleet started only in 1995. Age reading has been since 1995. Few otoliths were read in 1995 and 1996. Since 2000 the annual numbers of samples are between 45 and 50 and ages are determined from1600–1800 otoliths are age determined. An overview of the biological sampling is given in Table 6.1. Figure 5.3 shows the growth of male and female golden redfish in Icelandic waters by age.

Table 6.1. Biological sampling from Division Va.

	Catch				Surveys	
Year	# of length measured	# of length samples	# of aged samples	# of aged fish	# of samples with aged fish	# of aged fish
1937	182	4	0	0	0	0
1939	221	33	0	0	0	0
1952	961	8	0	0	0	0
1953	2419	5	0	0	0	0
1954	63	2	0	0	0	0
1955	1733	3	0	0	0	0
1956	3461	6	0	0	0	0
1957	6931	16	0	0	0	0
1958	5273	19	0	0	0	0
1959	3763	12	0	0	0	0
1960	1576	6	0	0	0	0
1961	1787	10	0	0	0	0
1962	1332	6	0	0	0	0
1963	1444	8	0	0	0	0
1964	698	3	0	0	0	0
1965	2042	8	0	0	0	0
1966	451	4	0	0	0	0
1972	1204	6	0	0	0	0
1973	3676	17	0	0	0	0
1974	4001	19	0	0	0	0
1975	1792	18	0	0	0	0
1976	6200	36	0	0	0	0
1977	20 452	83	0	0	0	0
1978	17 748	93	0	0	0	0
1979	16 010	81	5	496	0	0
1980	8845	57	0	0	0	0
1981	19 787	93	0	0	0	0
1982	25 317	101	0	0	0	0
1983	44 767	162	16	1,500	1	120
1984	23 287	85	0	0	0	0
1985	14 771	54	0	0	0	0
1986	16 568	61	0	0	0	0
1987	10 602	42	0	0	0	0
1988	17 524	60	0	0	0	0
1989	13 836	53	0	0	0	0
1990	17 204	62	0	0	0	0
1991	9180	37	0	0	0	0
1992	13 533	51	0	0	0	0
1993	20 665	92	0	0	0	0
1994	33 516	154	0	0	0	0

	Catch				Surveys	
Year	# of length measured	# of length samples	# of aged samples	# of aged fish	# of samples with aged fish	# of aged fish
1995	33 461	151	7	598	0	0
1996	17 992	72	3	209	125	453
1997	39 585	170	23	1,436	155	815
1998	35 628	173	26	1,412	166	954
1999	53 462	250	37	1,228	177	1,007
2000	73 622	324	49	1,628	198	1,107
2001	47 726	254	46	1,630	219	1,372
2002	32 286	184	49	1,676	215	1,479
2003	21 161	147	49	1,736	224	1,528
2004	13 293	96	49	1,762	216	1,500
2005	19 459	165	44	1,669	218	1,428
2006	26 406	201	47	1,745	212	1,435
2007	23 132	145	46	1,746	217	1,405
2008	29 530	178	49	1,753	228	1,520
2009	31 982	193	52	1,848	210	1,392
2010	39 266	235	47	1,730	693	4,382
2011	37 114	192	48	1,719	0	0

From the other two areas, biological sampling is much more limited than in Icelandic waters. Length samples from the Faroese fleet are available from 2001 and there are a few samples from the early 1990s. Lengths are measured annually for between 1000 and 2000 golden redfish. Length samples are available from the German commercial fleet which operated in East Greenland waters in 1975–1991, 1999, 2002 and 2004. Few length samples are available from the Greenland fishery which commenced only recently.

Observations indicate that golden redfish become mature-at-age of about 8–13 years and at a length between 30 and 35 cm where males mature younger and smaller than females (Figure 5.4).

No estimates of natural mortality are available for golden redfish in V and XIV. In the GADGET model (see below) natural mortality is assumed to decrease gradually from 0.2 $year^{-1}$ for age 1 to 0.05 $year^{-1}$ for age 5 and older.

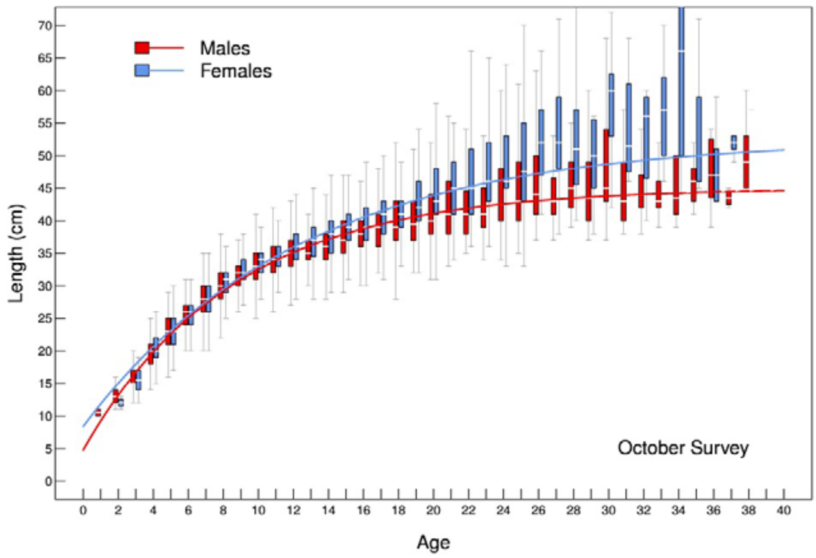

Figure 5.3. Length-at-age of golden redfish divided by sex (red are males and blue are females) as observed in the Autumn Survey 1996–2010 (boxplot, all data combined). The lines are the fitted von Bertalanffy growth model for each sex. Note that since there are no data for the youngest females, the model fits shown at those younger ages are extrapolations.

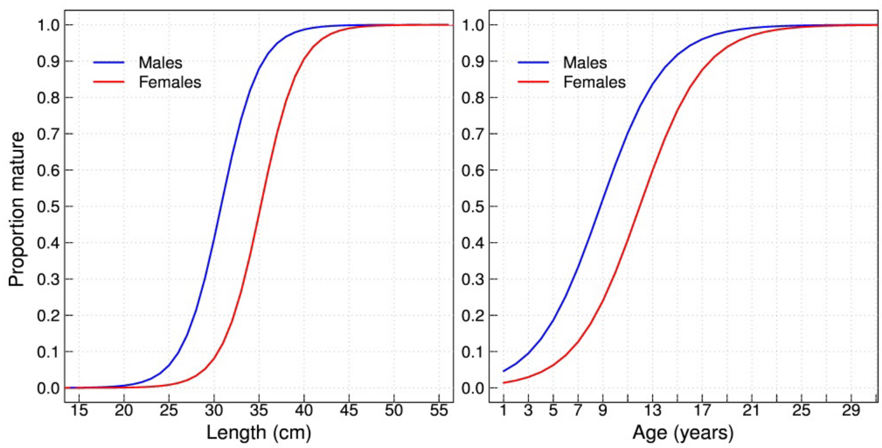

Figure 5.4. Maturity of male (blue line) and female (red line) of golden redfish in ICES Division Va by length (left) and age (right) in the Autumn Survey 1996–2010.

5.2.3 Survey data

Five bottom-trawl surveys conducted in Areas V and XIV are considered representative for golden redfish, although all of them were designed primarily for cod: one in Greenland waters, two in Icelandic waters and tow in Faroese waters.

The German Greenland groundfish survey (GER(GRL)-GFS-Q4) has been conducted annually in autumn on the continental shelf of Greenland since 1982. The survey was primarily designed for cod but covers the entire groundfish fauna down to 400 m. The design is 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 with equal weights.

The two annual bottom-trawl surveys conducted by the Marine Research Institute are the Spring (IS-SMB) and the Autumn Survey (IS-SMH). Both are stratified random bottom-trawl surveys. The Spring Survey has been conducted annually in March since 1985 on the continental shelf at depths shallower than 500 m, and has a relatively dense station-net (approximately 570 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 numbers of stations is about 380 and the density of stations considerably less than in IS-SMB. The main target species in the Autumn Survey are Greenland halibut (*Reinhardtius hippoglossoides*) and beaked redfish (*Sebastes mentella*).

The Faroese spring survey (FO-GFS-Q1) has been conducted annually in February–March since 1994 onwards. Each year 100 stations are sampled down to 500 m depth. The Faroese summer survey (FO-GFS-Q3) has been conducted annually in August–September since 1996. Each year 200 stations are sampled down to 500 m depth and half of the stations taken are the same taken in the spring survey.

Table 6.2 gives an overview of the surveys relevant to golden redfish in the area. A detailed description of the surveys and data sampling is given in the stock annex for golden redfish in V and XIV.

Table 6.2. Overview of the surveys relevant to golden redfish in the East Greenland/Iceland/Faroe Island area. All surveys are random stratified surveys.

Survey name	Acronym	Period	No. of stations	Depth range (m)
German survey	GER(GRL)-GFS-Q4	1982–2011	67–238	50–400
Icelandic spring survey	IS-SMB	1985–2011	550–600	50–500
Icelandic autumn survey	IS-SMH	1996–2010	290–380	50–1500
Faroes spring survey	FO-GFS-Q1	1994–2011	100	50–500
Faroes summer survey	FO-GFS-Q3	1996–2011	200	50–500

5.2.4 Commercial tuning data

Commercial cpue indices are not used for tuning in this assessment. The indices have been explored and the information contained in the logbooks on effort and on the spatial and temporal distribution of the fishery is of value. The indices were not considered for inclusion in stock assessment during the workshop, as trends in the cpue caused by improved fishing technology and constraints in the TAC system may be difficult to take into account. Furthermore, the fishery targets aggregating fish and in such cases cpue indices should be carefully evaluated in developing abundance indices. Effort may also be driven be market factors, quota shares in other species and oil prices.

5.2.5 Input from stakeholders/industry

No input from stakeholders was presented to the working group.

5.2.6 Environmental data

No environmental data were presented at the workshop.

5.3 Stock identity, distribution and migration issues

Golden redfish (*Sebastes marinus*) on the continental shelves of East Greenland, Iceland and the Faroe Islands (ICES Subareas V and Division XIVb) is considered one stock (Figure 5.5). 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).

Golden redfish is most abundant in Icelandic waters (ICES Division Va), which is 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 depth 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 located mainly 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). As they grow, the juveniles migrate along the north coast towards the most important fishing areas the off the west and southwest coast of Iceland, but also to the southeast fishing areas and to Faroese fishing grounds in ICES Division Vb. The migration between areas is though not well known.

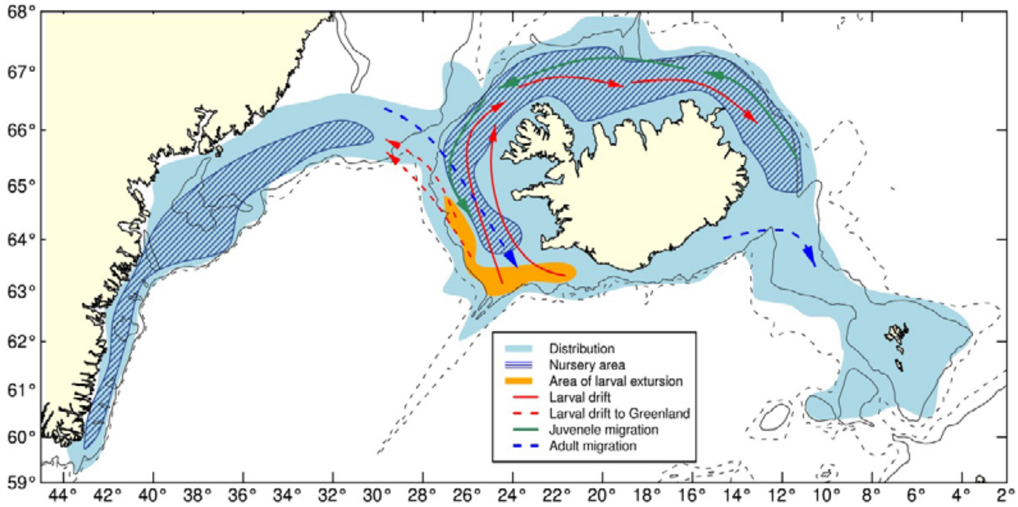

Figure 5.4. Geographical range of golden redfish (*Sebastes marinus*) in East Greenland, Icelandic and Faroese waters, area of larval extrusion, larval drift and possible migration routes. Based on various references (see text). The solid and dashed lines indicate the 500 m and 1000 m depth contours respectively.

5.4 Indirect influence of the fishery on stock dynamics

Direct influence of the fishery on stock demographics, for example on maturation and growth, of golden redfish in the East Greenland/Iceland/Faroe Islands region has not been investigated in any detail. There are indications that length at maturation of both males and females has decreased over time with both males and females maturing at smaller length than in the early 1980s (WD No. 3). It is not known whether or not these changes are related to the fishery.

Because of a rapid decline in abundance in the early 1990s, large areas west of Iceland were closed to the bottom-trawl fishery to protect juvenile redfish (Schopka, 2007). Small redfish around 5 cm below minimum landing size of 33 cm are common in those areas. Discards and possible mortality caused by mesh penetration were considered a potential problem when the areas were closed but at that time the 1985 year class was starting to recruit to the fishery while older year classes were severely depleted so the proportion of redfish just below minimum landing size was unusually high. These areas have been closed for almost two decades. At the same time sorting grids became mandatory in the shrimp fishery north of Iceland where large quantities of small redfish (especially the large year classes of 1985 and 1990) were killed in the fishery. The spatial and temporal closures seem to have direct effect by at least giving the fish better chances to aggregate.

5.5 Influence of environmental drivers on stock dynamics

No evidence of environmental drivers was presented at this benchmark workshop. Such patterns should be considered in future.

5.6 Role of multispecies interactions

5.6.1 Trophic interactions

No information about trophic interactions was presented and none were modelled in the assessment.

5.6.2 Fishery interactions

No fisheries interactions were included.

5.7 Impacts of the fishery on the ecosystem

No evidence was presented to indicate whether or not the fishery is impacting the marine environment.

5.8 Stock assessment methods

5.8.1 Models

At the meeting three different model approaches were presented, GADGET, TSA and a Schaefer implementation of a biomass dynamics model (Appendix 2).

GADGET is an age–length structured forward-simulation model, coupled with an extensive set of data comparison and optimization routines (Björnsson and Sigurdsson, 2003; Begley and Howell, 2004). 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 multiarea, multifleet model, capable of including predation and mixed fisheries issues; however it can also be used on a single-species basis. GADGET models can be both very data and very computationally intensive, with optimization in particular taking a large amount of time.

In the GADGET model for golden redfish in Division V and Subarea XIVb, 2 cm length groups are used and the year is divided into two equal time-steps (periods). The age range is 0 to 30 years, with the oldest age treated as a plus group. The length at recruitment (age 1) is estimated and mean growth is assumed to follow the von Bertalanffy growth function for which the parameters are estimated from the age data. Weight–length relationship is obtained from spring survey data. Natural mortality is set to 0.20 for the youngest age, decreasing gradually to 0.05 for age 5 and older. The commercial landings are modelled as three fleets (Greenland, Iceland and Faroe Islands), starting in 1970 each with their own selection patterns described by a logistic function and the total catch in tonnes specified for each six month period. The Spring Survey (IS-SMB) that serves as a tuning fleet is modelled as one fleet with constant effort and a nonparametric selection pattern that is estimated for each length group.

The main change to the model compared to the one presented at the NWWG-2011 (ICES, 2011) is the inclusion of catches from Greenland and the Faroe Islands and these catches being defined as separate fleets in the model. However, these changes did not alter terminal estimates very much because the catches from Greenland and Faroe have been relatively small in recent years. In contrast, estimates from the start of the time-series are substantially different due to the relatively large proportion (30–50%) of catches taken in Greenland waters in some of the years before 1980 (Figure 5.6).

The Benchmark Working Group noted, as NWWG before, the major problem evident in the application of GADGET to this stock is the poor fits to abundance indices of intermediate sized fish (30–40 cm). The problem is that there is no evidence of this intermediate sized abundance in the smaller length groups and subsequently they do not appear in the larger length groups (40+ cm). Therefore the model largely ignores this signal in the tuning data. One hypothesis for the changes in abundance of intermediate sized fish in the survey data is movement of these fish into the survey area. The reviewer panel suggested some approaches to address the problem including:

- A parametrization that allows changes in survey selectivity for these intermediate sizes over time. This would improve the residuals for the fit, but would not help in understanding the cause.
- A more realistic approach (which would however require more detailed data) in the form of a spatial model (possibly with two areas, Greenland and Iceland) that can account explicitly for possible ontogenetic movement patterns.
- Understanding the availability of redfish and other species in very dense groups to the survey gear.
- Evaluate how much unreported mortality could have reduced following the area closures west of Iceland.
- Identifying potential unreported mortality of small redfish in the shrimp fishery, which might improve the fit somewhat.

In response it was stated that these and related question have been answered for relatively few species worldwide. In age-structured models tuned with log ratios, observed and predicted biomass do not always match very well; two examples are Icelandic cod and haddock where the contrast in survey biomass is greater than in biomass estimates from the stock assessment. The basic assumption that catchability of a species in a survey is independent of the density of fish is most likely far from correct when the density becomes very high. That problem will though not be solved in the context of this redfish assessment but models used for assessment must have some internal check like that as the fish observed in the survey existed earlier and some of them show up later as older fish. Both GADGET and TSA have this internal check. The internal check might lead to poor residuals, but poor residuals are at least better than gross overestimation. Use of biomass models could be catastrophic in this case as they lack this internal consistency. They could though be useful if applied if one knows their limitation, something that applies to all models.

Using reiterative weighting of likelihood components, a relatively high weight is put on the age-structure data from both the commercial catches and the survey because they show a very clear signal in terms of strong cohorts going through the whole dataset. Therefore, the results of GADGET and TSA are very similar. Additionally it was pointed out during the meeting that surveys normally show higher variability than can be expected from the population in question and haddock in Va was offered as an example, where indices rose very fast and the models were not able to track the index for four years. Similar patterns have been observed for golden redfish, but due to the longevity of the species these positive blocks might be expected to persist for longer periods of time.

Part of the residual problem in GADGET seems to be caused by the prerecruits not being measured in the Icelandic surveys compared to the 1985–1992 year classes. Most likely this problem is caused by the recruits coming from other regions (most likely Greenland). A standard fix often used in stock assessment is to allow non-linear relationship between index and stock size without knowing what might be causing the non-linearity.

Taking notice of the discussions at WKRED, the 2012 assessment introduces two "improvements" of the GADGET model settings:

1) Let year classes recruit at age 5 and use only length groups 25 cm and larger for tuning.

2) Let each year class recruit in two parts, at age 1 and at age 8.

The results for the latter alternative were demonstrated at the meeting but not discussed much. Both alternatives reduce the residual pattern, but it does not disappear as here only one of the possible causes is taken into account. Letting year classes recruit at age 8 is rather late and reduces possibility for medium–long-term simulations. Year classes are though not fully recruited to the fishery until at age of 12–15 years so recruitment-at-age 8 can be used for advice and short-term prognosis. However alternative was used for the 2012 assessment as it was considered a more traditional configuration.

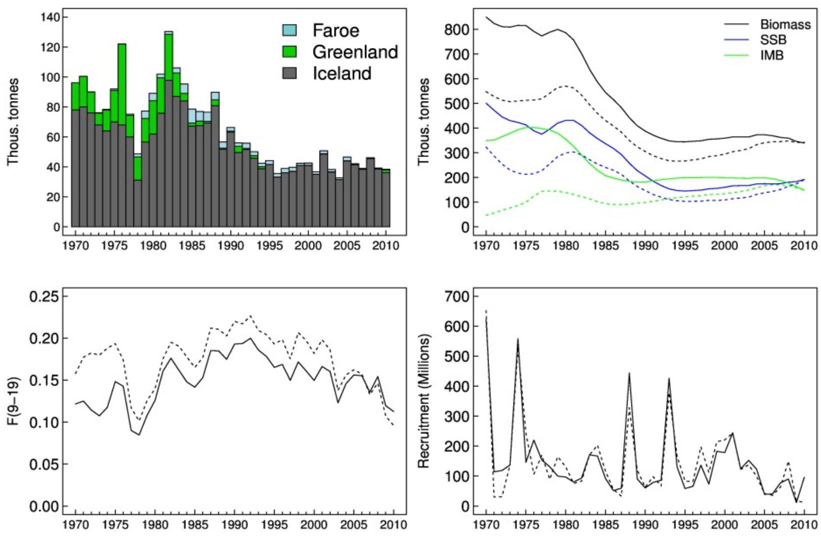

Figure 5.6. Golden redfish in Division Va and Subdivision XIVb. Commercial catches by country (fleets) (top left), estimates of biomass, spawning–stock biomass (SSB) and immature biomass (IMB) (top right). Estimates of fishing mortality (bottom left) and recruitment (bottom right). Solid lines represent the base GADGET model and broken lines the 2011 NWWG estimates.

TSA (Time-series Analysis) (Gudmundsson, 1994, 2004). The model is described in working document #9, both in the form of a model tuned with length disaggregated indices from IS-SMB and with age disaggregated indices from IS-SMH. The following is a short summary of the latter model, that is based on age disaggregated catches from 1996–2010 and age disaggregated abundance indices from the autumn survey over 1996–2010. Only Icelandic data are used.

The age range for the autumn survey is 3–17 years, but for the landings 9–19 years was selected by the assessor (GG) to avoid low values as residuals are log-ratios in the first years. The number of aged golden redfish from the landings has been approximately 1700 per year in recent years, allowing for fish older than 19 years to be used, but in the earlier years the number aged was less.

The selection function of the fishery is modelled by four polynomials with the first one being constant, second only the youngest age group, the third targeting of young fish and the fourth targeting of old fish. The polynomials except the second one are orthogonal (the second polynomial is though orthogonal to the constant) so if a parameter multiplying polynomials 1, 3 and 4 is estimated to be time varying, its values will not affect the factors affecting the other polynomials.

In the run for golden redfish only the year factor was estimated to be time-varying so the model became essentially a separable model in this case. The year factor is modelled by a time-series model including both random walk and transient changes.

Survey selection is modelled in a similar way. There a year factor, modelled as a time-series, is estimated. A random walk component in the changes to the survey selectivity was estimated to be important, something seen by looking at the age disaggregated data indices from the autumn survey and the same problem has been described as one in the GADGET model results that selection of the survey is changing. The polynomials used in TSA and the way one of the parameters can be used to model changed selectivity could be used as a template for other models.

Multiplicative measurement error in the survey is estimated to be large or close to 0.3 on log scale for the best observed age groups.

The Benchmark workshop did not have adequate time to scrutinize the TSA model thoroughly, but recommended further investigated as a candidate assessment model in future. It does also give confidence intervals on the results, something as yet missing for the GADGET model. With models as sophisticated as TSA, the Working Group considered that it is highly desirable to have the lead assessment scientist present at the meeting for clarification of details and to perform further iterations of the model with revised specifications.

The estimates of biomass (Figure 5.7), fishing mortality and recruitment were comparable between TSA and GADGET , though the level of comparability depends on the exact settings.

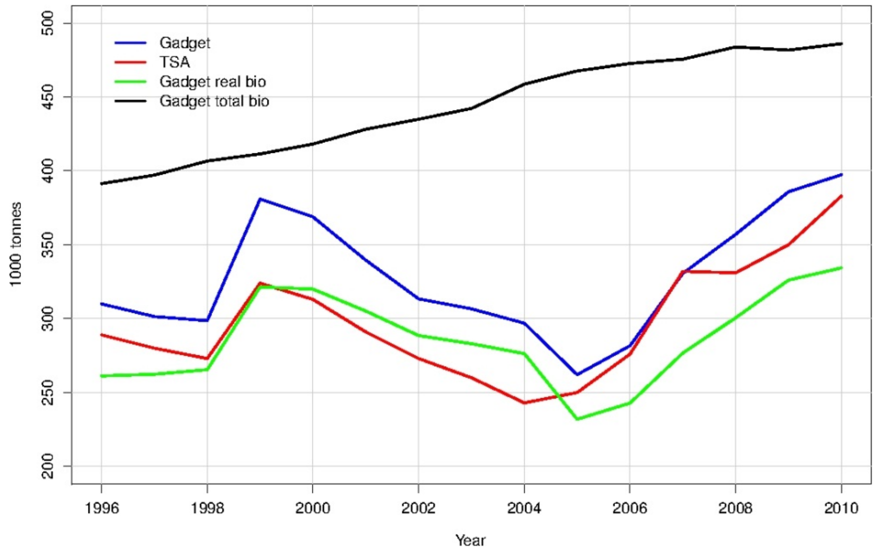

Figure 5.7. Golden redfish in Division Va and Subdivision XIVb. Trends in exploitable biomass (9–19 years old fish) according to GADGET and TSA (red line). The blue GADGET line uses the same weights-at-age as TSA and the same age range (9–19) they are therefore directly comparable. The green line describes the same age interval using the weights-at-age estimated by GADGET. Finally the black line is the total biomass (Age 0–30) as estimated by GADGET.

5.8.2 Sensitivity analysis

GADGET: Based on the suggestions made by the panel several different model variants were run during the meeting (Figures 5.8 and 5.9):

- **Scenario 1;** Tune the model to one aggregated abundance index in contrast to length-disaggregated abundance index;
- **Scenario 2;** Same as above but in addition assuming four different selection blocks in the survey (three selection curves);
- **Scenario 3;** Tuning the model with a re-calculated index that excludes the eight stations inside a protected area as the results from these stations are the main reason for the increase in recent years in intermediate sized fish (Scenario 3).

Sensitivity model runs were not explored in detail due to time constrains. Preliminary results indicate that these runs did not alleviate the problem. Scenario 1 fitted the index markedly better but the catch-at-age residuals showed clear non-random patterns, which were not observed in the base case. Scenario 2 did not fit the data well but the catch-at-age residuals were markedly better. The reason for this is that due to the reiterative weighting procedure, a very high weight is put on the age-structured data as they have the clearest and most consistent signal (two strong cohorts passing through the time-series).

Using a reworked index (excluding the closed area) (Scenario 3) did to some extent alleviate the problem but not entirely. Further work is needed to fully understand these features of the data.

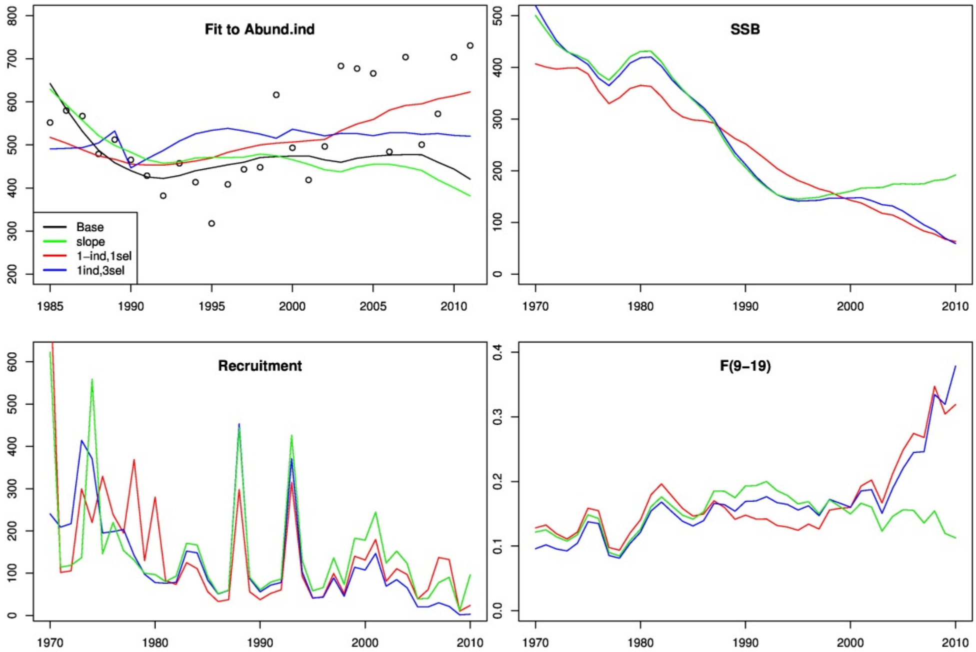

Figure 5.8. Golden redfish in Division Va and Subdivision XIVb. Fit to abundance index from four scenarios tested and estimates of biomass, recruitment and fishing mortality (See Section 5.8.2).

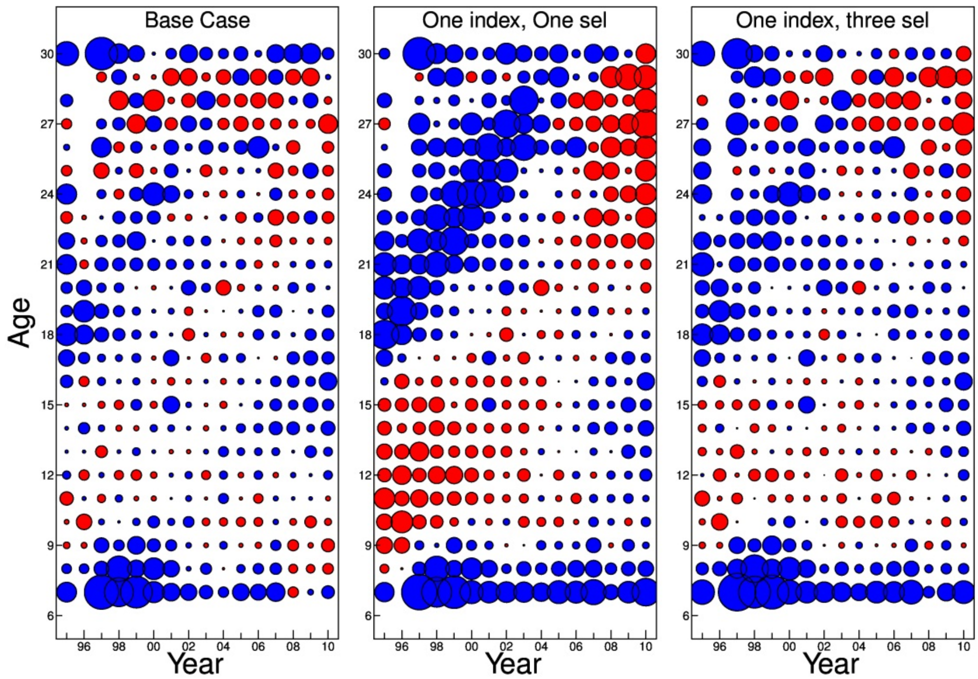

Figure 5.9. Golden redfish in Division Va and Subdivision XIVb. Catch-at-age residuals from the base model and Scenarios 1 and 2 (See Section 5.8.3). The red bubbles indicate positive residuals (model estimate less than data). The largest circle corresponds to log(obs/mod)=1.

5.8.3 Retrospective patterns

Due to time constraints no retrospective analysis was presented at the Workshop for the GADGET model.

Retrospective patterns in TSA model runs ending in 2010 show a downward trend of stock size with each new run. The time-series is short compared to the longevity of the species so part of this overestimation is getting the level of the stock right. The model returns standard deviations of biomass and fishing mortality. The estimate of the standard deviation in 2010 is 82 thousand tonnes or 22% of the estimated value. This is rather high but not unexpected.

5.8.4 Evaluation of the models

The Benchmark workshop spent considerable time evaluating the GADGET model but much less on the TSA model. The fundamental difficulty for the GADGET model is that it does not follow the trends in abundance indices for intermediate length groups. As stated above this issue was not resolved during the meeting, and therefore the review-panel could not accept this model as the official assessment model for adoption for the next inter-benchmark period.

Appreciable time was spent on running variants of a Schaefer stock production model which produced estimates of sustainable yield (Appendices 1 and 2) that are either similar to or higher than those from GADGET and TSA, depending upon the value input for the intrinsic growth rate *r* parameter. The full catch history was used for the Schaefer model, in contrast to the relatively short time period covered by the GADGET and TSA models compared to the exploitation history and longevity of the stock. The tuning data for the Schaefer model are IS-SMB biomass indices available since 1985. The Schaefer model run for the NW *marinus* stock fits well to the IS-SMB survey data, but as commented earlier this model is not subject internal consistency checks. Apart from random noise the tuning data have a positive second derivative all of the time, something ideal for a Schaefer model to give precise estimates.

5.8.5 Conclusions

The Benchmark workshop was not able to reach consensus regarding the golden redfish assessment. The external review panel concluded that because the GADGET model did not follow the increasing trend in the abundance indices for the intermediate length groups it could not be accepted as the model to be used routinely as basis for advice over the inter-benchmark period. The reasons for the inability of the current GADGET model to fit the survey data needs to be resolved and will likely require in-depth investigations. Others at the meeting supported the use of the current GADGET model without modification during the inter-benchmark period. However, a general consensus reached was that the results from the GADGET model were likely conservative. GADGET suggests catch levels of around 40 kt, and this could be used for formulating advice in the near term. The TSA model provided similar catch advice, though time was insufficient to examine this model in detail.

The external review panel considered the use of biomass dynamic (Schaefer) models that were specified to start at the beginning of the catch history as cross check on the GADGET model, due to the inability of the GADGET model to start at the beginning of the catch history. The goal was to use the biomass dynamic model results as a cross check on advice obtained from the GADGET model. Some meeting participants did not support the use of biomass dynamics models because they are age aggregated. The biomass dynamic model with *r* values fixed between 0.02 and 0.1 suggests stock depletion ranges between 39 to 67%, with RY in the range of about 39 to 61 thousand tons (Appendices 1 and 2). Note that some estimates from the Schaefer model generally manifest considerable uncertainty (e.g. CVs for depletion ranging between 0.12 and 0.35).

5.9 Short-term and medium-term forecasts

Short and medium-term forecasts can be developed using the current setup of the GADGET model and have been presented at the NWWG meetings. The input parameters for the short-term forecast are detailed in the Stock Annex. However, because the model formulation was not finalized at the Working Group meeting and also due to time constraints short and medium-term forecasts were not evaluated.

The GADGET model has been used for assessment of golden redfish since 2000 (Björnsson and Sigurdsson, 2003) and results for the initial years of the period assessed are comparable with those from current runs.

5.9.1 Input data

5.9.2 Model and software

5.9.3 Conclusions

5.10 Biological reference points

The GADGET model can be set up to estimate the reference points running with fixed effort and tracking the catches of one year class. To avoid problems with the year-class bookkeeping lost in the plus group all other year classes and initial numbers are set to zero. The simulation was run for 41 years or from 1970–2011 using estimated growth parameter and selection of the fisheries.

All results from the model are referred to F_{9-19} to facilitate comparison with TSA but F_{9-19} is considerably lower than F of fully recruited fish (Figure 5.9). Yield-per-recruit demonstrates a reasonably clear peak at age F_{9-19}=0.106 but traditional yield-per-recruit based on catch in numbers by age and mean weight in catch per age does not show similar peak as it does not take into account that removals of the largest individuals of the recruiting age groups reduces mean weight-at-age of the survivors (Björnsson and Sigurdsson, 2003).

Estimated reference points from the analysis are

F_{MAX}=0.106

$F_{0.1}$=0.063

$F_{ssb0.35}$ = 0.071

Maximum yield-per-recruit is 0.32 kg or 45 thousand tonnes if mean recruitment-at-age 3 is 142 million fish (as estimated in the base run for year classes 1975–2002).

Maximum spawning–stock per recruit is approximately 9 kg, of which 3 kg comes from the plus group (30+). This value is of course heavily dependent on assumptions regarding the plus group; here M=0.1 for all ages in the plus group.

Running the model from 1905 estimating one value for the initial biomass and one value for average recruitment from year classes 1905–1969 gives a low initial biomass but 154 million age 3 individuals (corresponding to 49.5 thousand tonnes at MSY, Figure 5.10). The average landings per year from 1945–1970 are 84 thousand tonnes per year or 70% more than the maximum sustainable under the estimated average recruitment. The division between initial biomass and recruitment is of course very uncertain as there are in addition recruitment period. But the maximum SSB of 1.3 million tonnes in 1945 can be compared to predictions from yield-per-recruit with estimated mean recruitment from 1970 (142 million individuals) and maximum SSB per recruit that is 8.82 kg.

If the future catches are based on F_{MAX} and average recruitment continues to be 142 million the predicted spawning stock will reach 300 thousand tonnes, not a high value in historical context.

The spawning stock recruit plot from the GADGET model runs (Figure 5.10) does not show any relationship, but the period is of course rather short. The plot does not indicate any autocorrelation of residuals but of course the reservations about short time do also apply here. Therefore, the lowest value of SSB or 160 thousand tonnes is suggested as a candidate for B_{lim}, something that a future HCR should avoid with high probability. This value of B_{lim} is considerably higher than the U_{lim} value used for inference of stock status in recent years (NWWG 2011) that is around 70% of U_{min}.

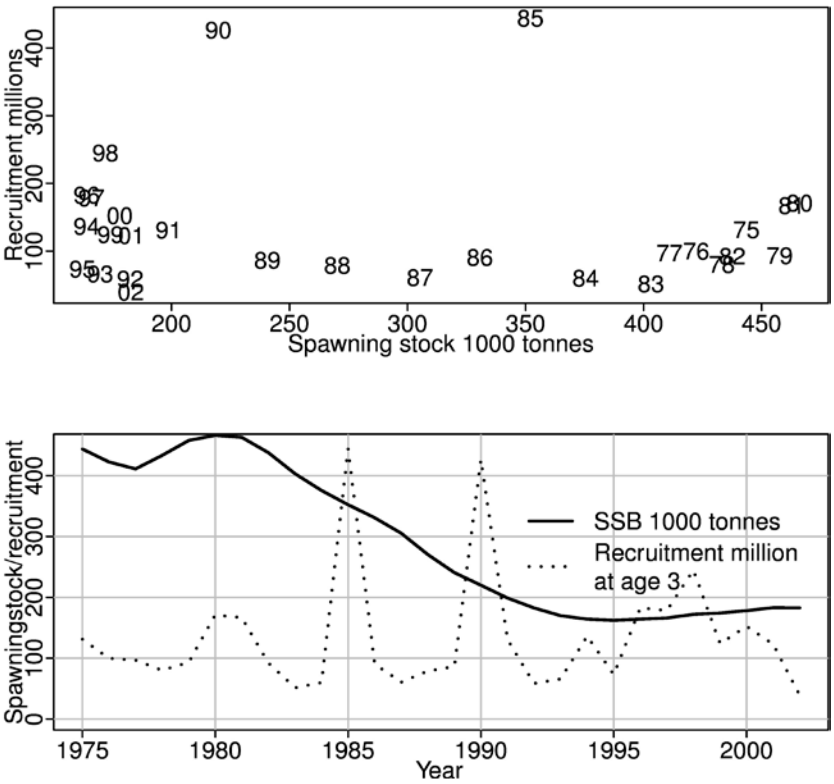

Figure 5.10. Recruitment and SSB of golden redfish in Icelandic waters 1975–2002.

5.11 Recommendations on the procedure for assessment updates and further work

The Benchmark workshop considered it appropriate to use the GADGET presented above for evaluation of population dynamics and current stock status of *S. marinus* in Areas V and XIV for the time being, pending resolution of issues identified above (particularly the lack of fit to recent intermediate length indices of abundance). There are indications at the moment that model results are rather conservative so they could probably be used for formulating advice in the near term, but in the longer run reasons for the discrepancy need to be understood. It is also important to identify where recruitment might be originating by trying to see if surveys in Greenland give useful recruitment signal. Other recommendations are:

- Estimate potential unreported mortality by the fisheries in the late 1980s and early 1990s.
- Investigate the areas with highest abundance of redfish in recent surveys, for example by acoustic measurements contemporary to the trawl surveys. One objective here is to investigate the extent of redfish schools and if the density of redfish near stations is representative of the whole area.
- Refine the current stock production models (Section 1.1).
- Try to include survey information from East Greenland (German groundfish survey) and Faroe Islands.
- Determine confidence intervals for the GADGET assessment results. This work is in process.

5.12 Implications for management (plans)

Current catch advice from the GADGET model is probably negatively biased and hence not likely to cause stock declines in the short term.

5.13 References

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6 Icelandic slope beaked redfish (*Sebastes mentella*) in Divisions Va, and XIVb

6.1 Current assessment and issues with data and assessment

The fishery of Icelandic slope beaked redfish started in the early 1950s (Figure 6.1). The annual catch 1950–1977 was on average 33 000 t. Annual landings gradually decreased from a record high of 57 000 t in 1994 to 17 000 t in 2001 t. Landings in 2003 increased to 28 500 t but have since then fluctuated between 16 000 t and 21 000 t. The fishery for the Icelandic slope beaked redfish is predominantly conducted by the Icelandic bottom-trawl fleet directed towards the species. Prior to 2000, between 10–40% of the total landings were taken by pelagic trawl. In general, the pelagic fishery has mainly been in the same areas as the bottom-trawl fishery, but usually in later months of the year. In 2001–2010, no pelagic fishery occurred or it was negligible except in 2003 and 2007.

The most important fishing grounds are southwest, west, and northwest (close to the Iceland-Greenland midline EEZ) of Iceland at depths from 450 to 800 m. A historically important fishing ground for the Icelandic slope stock is southeast of Iceland along the slope of the Iceland–Faroe Islands Ridge. Fishing in this area has, since 2000, gradually decreased and in recent years there has not been a directed fishery for Icelandic slope beaked redfish.

There is no analytical assessment carried out on this stock because of data uncertainties, short survey time-series and lack of reliable age data. Available survey biomass estimates indicate that in Division Va the biomass has been low without trend in recent years (Figure 6.2).

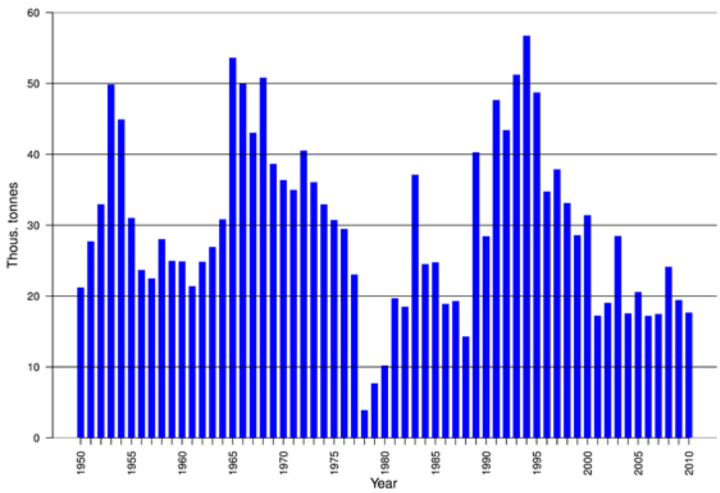

Figure 6.1. Nominal landings (in tonnes) of Icelandic slope beaked redfish from Icelandic waters (ICES Division Va) 1950–2010.

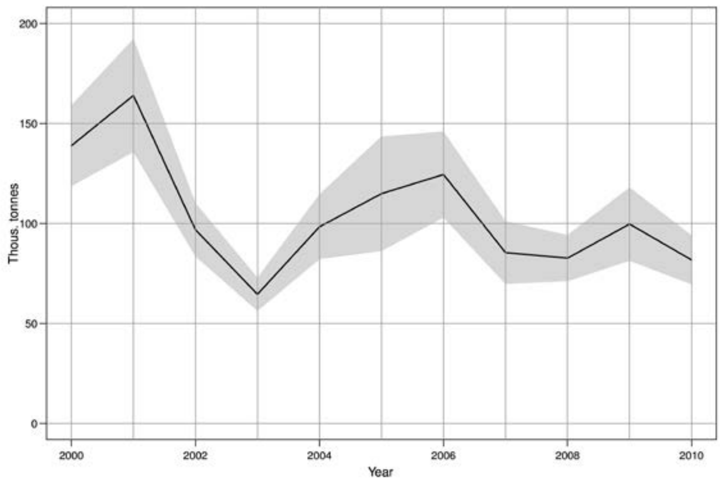

Figure 6.2. Total biomass index from the Autumn Survey 2000–2010.

6.2 Compilation of available data

6.2.1 Catch and landings data

Icelandic data of commercial catch in tonnes by month, area and gear are obtained from Statistical Iceland and the Directorate of Fisheries. The landings data are, however, recorded as redfish and not split between golden redfish and beaked redfish. Also, Icelandic authorities gave a joint quota for golden redfish and Icelandic slope beaked redfish in ICES Division Va until the 2010/2011. Icelandic fishermen were, therefore, not required to divide the redfish catch into species. Since 1993, a so-called *split-catch* method has been used to split the Icelandic redfish catches between the two species and is described in the Stock Annex for golden redfish. The method uses data from the logbooks and biological sampling from the fishery.

Landings of foreign fleet operating in Icelandic waters, which now are only Norwegian and Faroese vessels, are given by the Icelandic Coast Guard and reported to the Directorate of Fisheries.

The accuracy of the landings statistics from Iceland are considered reasonable although some bias is likely.

Although no direct measurements are available on discards, it is believed that there are no substantial discards of Icelandic slope *S. mentella* in the Icelandic redfish fishery.

6.2.2 Biological data

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) during trips 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.

Sampling of size composition from the Icelandic bottom-trawl fleet is available from 1991–2010. Since 1999, 95–260 samples are taken annually and 20 000–40 000 length measured annually.

Sampling of age composition from the bottom-trawl fleet is ongoing, but very little has been age read or only 405 from the years 2001 and 2002 (Figure 6.3).

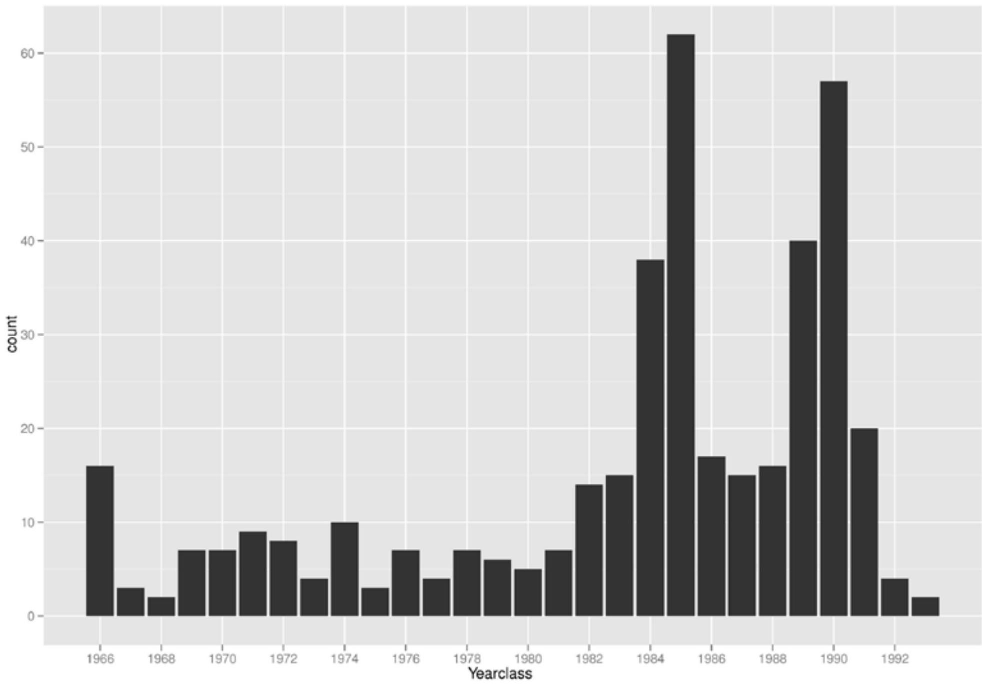

Figure 6.3. Year-class distribution of Icelandic slope deep-water redfish from the commercial catch in 2001 and 2002 (n = 405). The 1966-yearclass are the combined 1951–1966 year classes.

6.2.3 Survey data

One bottom-trawl survey, the Autumn Survey (IS-SMH), conducted in the area is considered representative for beaked redfish. A detailed description of the survey and data sampling is given in the stock annex for Icelandic slope beaked redfish.

The Icelandic Autumn Groundfish Survey has been conducted annually in October since 1996 by the Marine Research Institute (MRI). It is conducted on the continental shelf and slopes and extends to depths down to 1500 m. The numbers of stations are about 380. 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.

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 can be compared for Icelandic slope *S. mentella*. The survey was not conducted in 2011.

Annually, between 5000 and 8000 fish are length measured. Otoliths for age reading is extracted from between 1200 and 1500 fish and those fish are also length measured, and sex and maturity determined. Only otoliths from the 2000 survey have been age read (Figure 6.4).

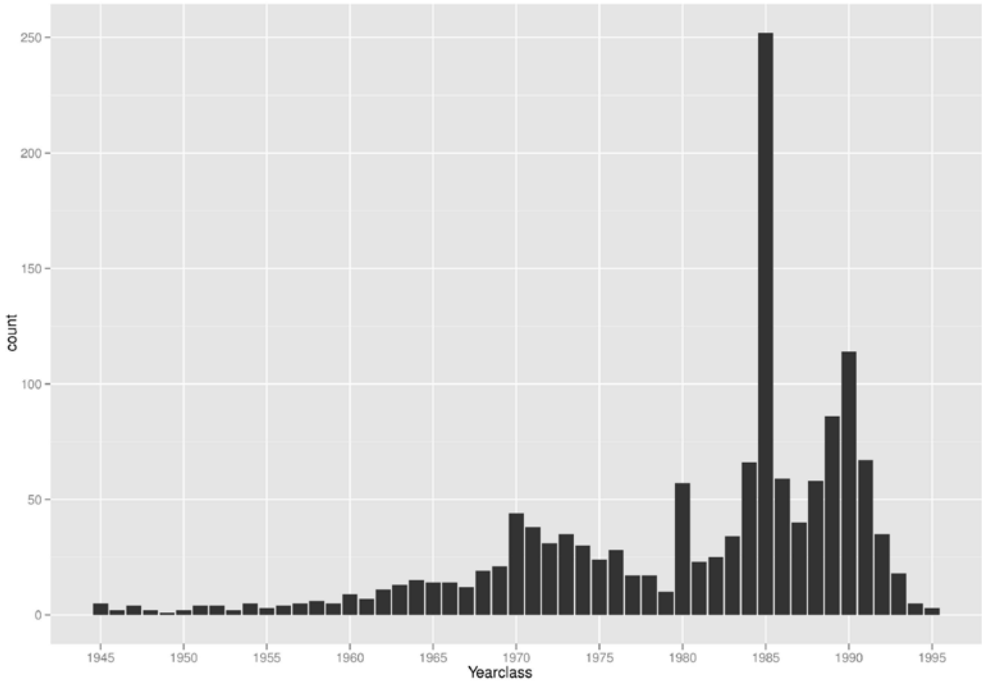

Figure 6.4. Year-class distribution of Icelandic slope beaked redfish from the Autumn Survey in 2000 (n = 1; 405). The year class of 1945 is the combined year classes of 1941–1945.

6.2.4 Commercial tuning data

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

6.2.5 Input from stakeholders/industry

No input from stakeholders was presented to the working group.

6.2.6 Environmental data

No environmental data were presented at the meeting.

6.3 Stock identity, distribution and migration issues

The "Workshop on Redfish Stock Structure" (WKREDS, 22–23 January 2009, Copenhagen, Denmark; ICES 2009) reviewed the stock structure of *Sebastes mentella* in the Irminger Sea and adjacent waters. ACOM concluded, based on the outcome of the WKREDS meeting, that there are three biological stocks of *S. mentella* in the Irminger Sea and adjacent waters:

1) 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;

2) 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;

3) an 'Icelandic Slope' stock (ICES Va, XIV) – primarily demersal habitats.

This conclusion is primarily based on genetic information, i.e. microsatellite information, and supported by analysis of allozymes, fatty acids and other biological information on stock structure, such as some parasite patterns.

The adult redfish on the Greenland shelf has traditionally been attributed to several stocks, and there remains the need to investigate the affinity of adult *S. mentella* in this region. The East Greenland shelf is most likely a common nursery area for the three biological stocks.

The Icelandic slope beaked redfish is treated as a separate management unit.

6.4 Influence of the fishery on stock dynamics

No information was available.

6.5 Influence of environmental drivers on stock dynamics

No evidence of environmental drivers was presented at this benchmark meeting. Such patterns should be considered in future.

6.6 Role of multispecies interactions

6.6.1 Trophic interactions

No information about trophic interactions was presented and none were modelled by the assessment.

6.6.2 Fishery interactions

No fisheries interactions were included.

6.7 Impacts of the fishery on the ecosystem

No evidence was presented to indicate whether or not the fishery is impacting the marine environment.

6.8 Stock assessment methods

Icelandic slope beaked redfish has previously been assessed based on trends in survey biomass indices from the Icelandic Autumn Survey in terms of ICES "trends-based assessment" approach. Supplementary data includes relevant information from the fishery and length distribution from the commercial catch and the Autumn Survey.

Some participants in the Working Group considered at the present analytical assessment cannot be conducted because, for example, of little age data and the relative shortness of the time-series available (the Autumn Survey index is only from 2000).

For Icelandic slope beaked redfish, alternative assessment methods (Schaefer stock production model) were compared to the current situation (trends based assessment). This is discussed in Section C in the Stock Annex and in Appendix 1. There was, however, disagreement regarding the use of the Schaefer model and those points are addressed as well in Section C in the Stock Annex.

6.8.1 Models

6.8.2 Sensitivity analysis

6.8.3 Retrospective patterns

6.8.4 Evaluation of the models

6.8.5 Conclusions

6.9 Short-term and medium-term forecasts

No short or medium-term forecast was presented at the meeting.

6.9.1 Input data

6.9.2 Model and software

6.9.3 Conclusions

6.10 Biological reference points

No suggestion for biological reference points was presented at the meeting.

6.11 Recommendations on the procedure for assessment updates and further work

Otoliths have been systematically sampled both from the commercial catch and the autumn survey, but it is important to start a systematic age reading. With more age data it will be possible to develop a statistical catch-at-age model or develop a length-based Gadget model.

During the meeting a harvest control rule method for the Icelandic slope redfish was presented (WD No. 12). This method is based on a proxy version of the standard MSY rule but developed where no formal assessment is conducted because of insufficient data.

It is also important to clarify the allocation of catches to different stocks, especially between the deep and Icelandic slope beaked redfish. Tagging experiments might be required.

6.12 Implications for management (plans)

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 and of model runs, it is difficult to establish reference points.

A dialogue with the managers about harvest control rules should be initiated as soon as possible.

6.13 References

Pálsson, Ó., Björnsson, H., Björnsson, E., Jóhannesson, G. and Ottesen Þ. 2010. Discards in demersal Icelandic fisheries 2009. Marine Research in Iceland 154.

7 Beaked redfish (*S. mentella*) in Subareas V, XII, XIV and NAFO Subareas 1 and 2 (Shallow pelagic stock)

7.1 Current assessment and issues with data and assessment

For 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 results of the international trawl-acoustic survey are given in Section 7.2.3. Given the high variability of the correlation between trawl and acoustic estimates as well as assumptions that need to be made about constant catchability across depth and areas, the uncertainty of these estimates is very high.

The reduction in biomass observed in the surveys in the hydroacoustic layer (about 2 mill. t in the last decade) cannot be explained by the reported removal by the fisheries (about 500 000 t in the entire depth range in 1995–2009) alone. A decreasing trend in the relative biomass indices in the acoustic layer, however, is visible since 1991 (Figure 7.4). It is not known to what extent cpue reflects changes in the stock status of pelagic *S. mentella*, since the fishery focuses on aggregations. Therefore, stable or increasing cpue series might not indicate or reflect actual trends in stock size, although decreasing cpue indices are likely to reflect a decreasing stock.

NEAFC set for 2011 a 0 TAC for Shallow Pelagic *S. mentella*. However, the Russian Federation filed a formal complaint announcing that they have decided on a unilateral quota of 29 480 t. This quota will be taken from both the Shallow and Deep pelagic stocks, since they do not agree on the division of the *S. mentella*. The Russian Federation compromised on catching no more than a 15% before the 10th of May 2011.

There is also an issue with the reporting of commercial catches. There are indications that reported effort (and consequently landings) could represent only around 80% of the real effort in certain years. Catch data are from many nations not divided by depth which is essential to divide the catches between the shallow and deep pelagic stocks. Splitting of the catches for various time periods are described in the Stock Annex for the species.

7.2 Compilation of available data

7.2.1 Catch and landings data

Iceland, Greenland, Faroe Islands, Norway, Germany and Russia are the nations providing the most complete databases, including detailed vessel and gear information, as well as catch data on a haul to haul basis. The rest of the countries supply catch in weight and the length composition of the catch.

The preliminary official landing data are provided by the ICES Secretariat, NEAFC and NAFO, and various national data are reported to the NWWG Group. The Group, however, repeatedly faces problems in obtaining reliable data due to unreported catches of pelagic redfish and lack of catch data disaggregated by depth from some countries. There are indications that reported effort (and consequently landings) could represent only around 80% of the real effort in certain years.

Russian trawlers started the pelagic *S. mentella* fishery in 1982, covering wide areas of the Irminger Sea. Vessels from Bulgaria, the former GDR and Poland joined in 1984. Annual landings for most of the period 1982–1995 ranged between 60 000 t and

100 000 t (Figure 7.1), declining to around 30 000 t between 1989 and 1991 when the East European countries reduced their effort. Fishing took place mainly from April to August. First, on prespawning and spawning aggregations from early April to mid-May, on post-spawning fish from late May to mid-June, and on feeding aggregations from mid-July to August. During this first period of the fishery, 1982–1991, all landings were registered as oceanic *S. mentella* because the main fishing area was in the central Irminger Sea from 59° to 62°N and between 30° and 35°W, corresponding to the ICES Divisions XII and XIV, beyond Greenland and Icelandic national jurisdictions and at depths between 80 and 500 m (Sigurðsson *et al*., 2006).

In the period 1992–1996, the fishery gradually shifted towards greater depths and developed a clear seasonal spatial pattern. Catches increased to 100 000 t as more nations joined the fishery and effort from Russia and Germany rose again. The fleets moved systematically to different areas and depths as the season progressed, fishing the shallow component in the southwestern Irminger Sea (57–58º30'N and 32–36ºW) later in the season, or from mid-June to October. Fishing is scarce between November and late March or early April.

In 1996, annual landings decreased to 41 000 t, a 60% decline in comparison with previous years, and they oscillated between 24 000 and 57 000 t (averaging 35 000 t) during the years 1997–2005. From 1997 onwards, logbook data from Russia, Iceland, Faroe Islands, Norway and Germany have been used to calculate landings by stock within each ICES division. It is assumed that catches by other nations have the same spatial distribution. However, the figures for total catch are probably underestimated due to incomplete reporting of catches. In 2006 there was another sharp decline in annual landings, which continue at very low levels, with 2000 t caught in 2008 and 2419 t caught in 2010 (Table 7.1). A large percentage of annual landings (50% on average) were taken in NAFO Area 1F in 2000–2008, but 81% of the 2009 landings were caught in ICES Division XIV. Since 1995, there is a decreasing trend in cpue.

In all 19 nations have taken part in this fishery since 1982, with a minimum of two nations in 1982 and a maximum of 17 in 1995. The total number of vessels from each country it is not known for the whole period, but during the years 1995–2009, their number ranged between 45 and 92. It should be noted that these are the same vessels that also participate in Deep Pelagic beaked redfish fishery. The fleets participating in this fishery keep updating their fishing technology, and most trawlers now use large pelagic trawls ("Gloria"-type) with vertical openings of 80–150 m.

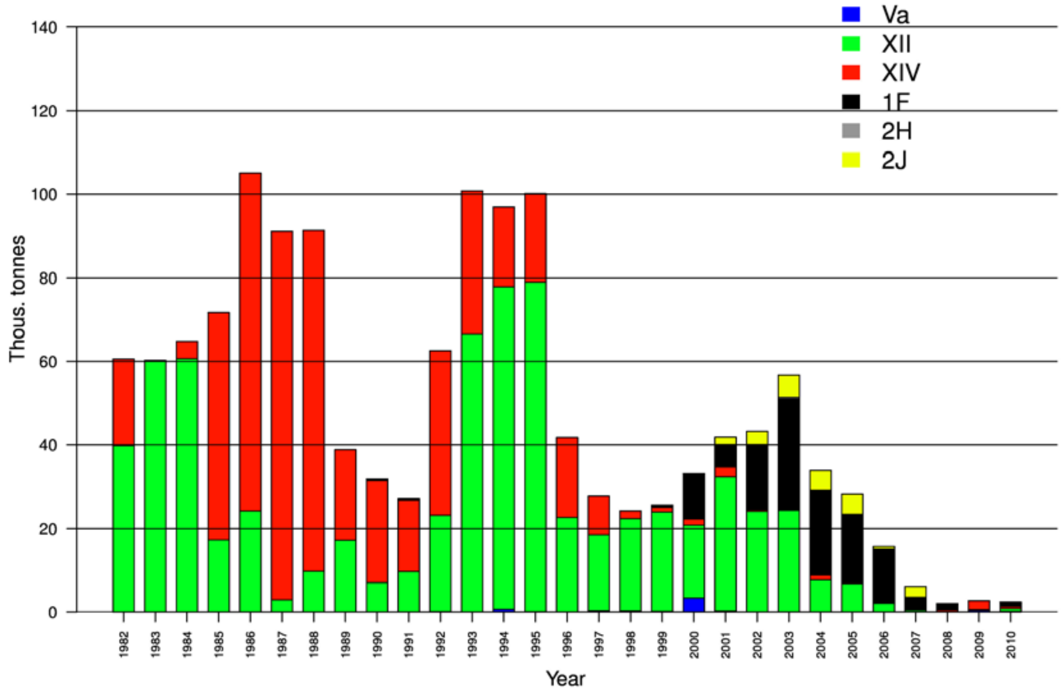

Figure 7.1. Landings of shallow pelagic *S. mentella* (NWWG estimates).

Table 7.1. Shallow pelagic *S. mentella* (stock unit <500 m). Catches (in tonnes) by area as used by the North Western Working Group (NWWG).

Year	Va	XII	XIV	NAFO 1F	NAFO 2J	NAFO 2H	Total
1982		39,783	20,798				60,581
1983		60,079	155				60,234
1984		60,643	4,189				64,832
1985		17,300	54,371				71,671
1986		24,131	80,976				105,107
1987		2,948	88,221				91,169
1988		9,772	81,647				91,419
1989		17,233	21,551				38,784
1990		7,039	24,477	385			31,901
1991		9,689	17,048	458			27,195
1992	106	22,976	38,709				62,564
1993	0	66,458	32,500				100,771
1994	665	77,174	18,679				96,869
1995	77	78,895	17,895				100,136
1996	16	22,474	18,566				41,770
1997	321	18,212	8,245				27,746
1998	284	21,976	1,598				24,150
1999	165	23,659	827	534			25,512
2000	3,375	17,491	687	11,052			33,216
2001	228	32,164	1,151	5,290	8	1,751	41,825
2002	10	24,004	222	15,702		3,143	43,216
2003	49	24,211	134	26,594	325	5,377	56,688
2004	10	7,669	1,051	20,336		4,778	33,951
2005	0	6,784	281	16,260	5	4,899	28,229
2006	0	2,094	94	12,692	260	593	15,734
2007	71	378	98	2,843	175	2,561	6,126
2008	32	25	422	1,580			2,059
2009	400	210	2,105				2,715
2010	160	686	498	1,074			2,419

1982-1991	All pelagic catches assumed to be of the shallow pelagic stock
1992-1996	Guesstimates based on different sources (see text)
1997-2010	Catches from calculations based on jointed catch database and total landings

7.2.2 Biological data

Biological information is collected since 1999 during the biennial international stock assessment survey targeting redfish (ICES 2011a,b), from the surveys conducted in 1991–1997, and from commercial catches (Iceland, Russia, Spain and other EU countries), consisting on length measurements, sex ratio, maturity stage, stomach contents and otolith collection. The 1999–2011 biennial surveys also recorded stomach fullness, parasite infestation, pigment patches and muscular melanosis, according to an approved method (Bakay and Karasev, 2001; ICES 2011).

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

- population age structure, with the need to validate and standardize the methods for age and maturity determination,
- species identification of young individuals,
- location of nursery and mating areas,
- estimation of natural mortality.

The length distributions for the period 1992–2011 of biological stocks survey data are shown in Figure 7.3. The length of the largest proportion of caught fish oscillates around 35–37 cm for the whole period. The sex ratio in the survey catches has constantly varied around 60% males and 40% females with largest proportion of females in 1992 with 44.7% and smallest proportion of 34.4% in 2009 (Table 7.2). From the length of 29 cm all sampled males were mature in the survey in 2011 while all females were with few exceptions mature from length 33 cm (Figure 7.2).

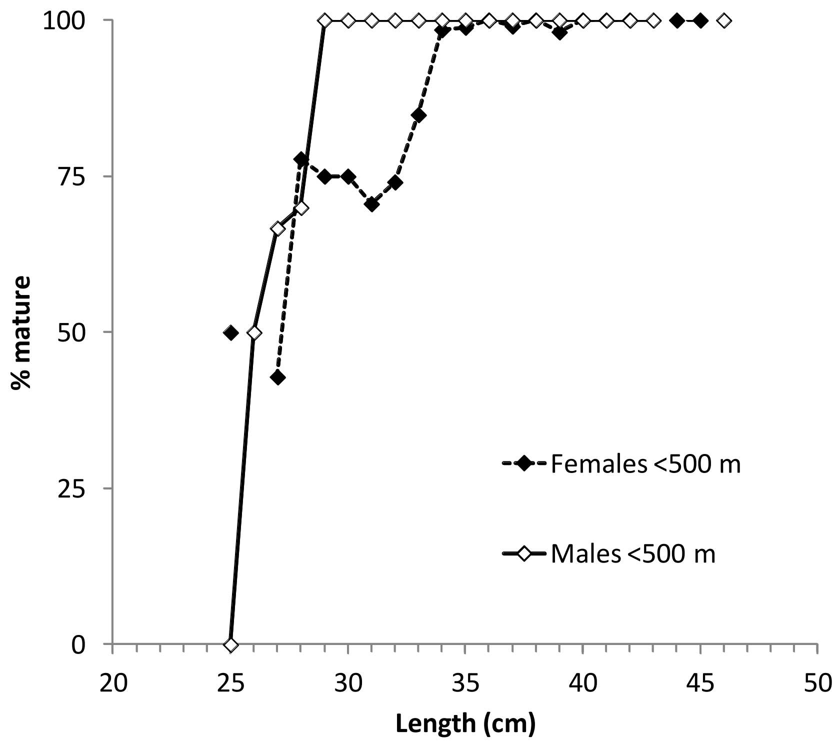

Figure 7.2. Maturity ogive (ICES scale) by sex as observed in the 2011 international trawl and acoustic survey in the Irminger Sea (ICES 2011b).

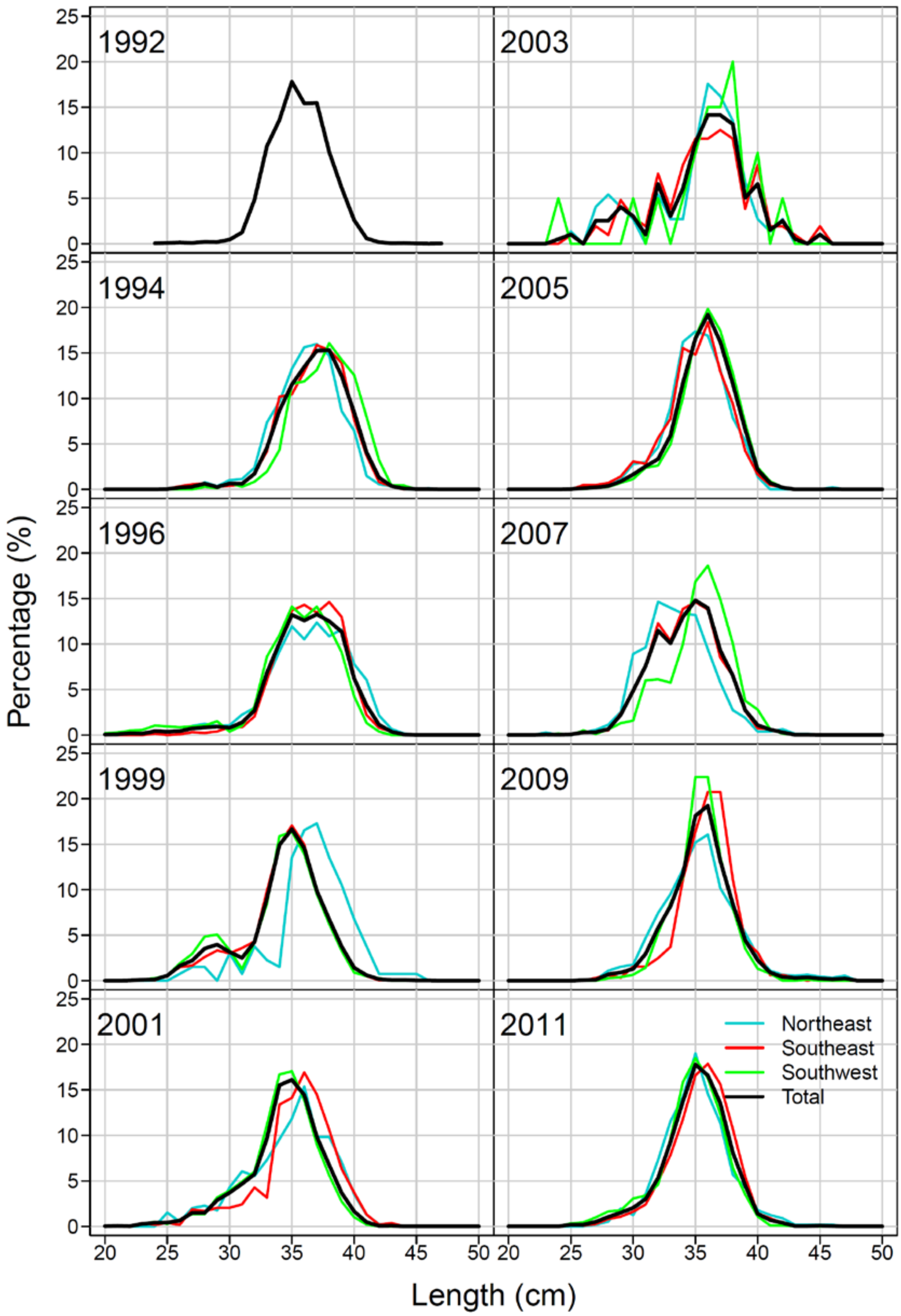

Figure 7.3. Length distribution from the International trawl and acoustic survey of shallow pelagic *S. mentella*.

Table 7.2. Sex ratio of shallow pelagic *S. mentella* in the surveys in the Irminger Sea and adjacent waters.

	Shallow Stock	
Year	Males	Females
1992	55.3	44.7
1994	58.3	41.7
1996	62.3	37.7
1999	63.2	36.8
2001	64.8	35.2
2003	63.1	36.9
2005	64.9	35.1
2007	60.1	39.9
2009	65.6	34.4
2011	61.0	39.0

7.2.3 Survey tuning data

Acoustic surveys have been conducted on pelagic redfish in the Irminger Sea and adjacent waters since 1982 (see Table 7.3). These surveys provide valuable information on the biology, distribution and relative abundance of oceanic redfish, as well as on the oceanographic conditions of the surveyed area. Many of them were undertaken by single nations, but after several joint surveys during the 1990s, an international trawl-acoustic survey has been conducted by Iceland, Germany and Russia (with Norway participating also in 2001) since 1999.

Until 1999, oceanic redfish was only 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; Sigurðsson 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).

Figure 7.4 indicates that the biomass index from the acoustic survey in 2011 has declined to less than 5% of the estimates at the beginning of the survey time-series in the early 1990s.

Table 7.3. Redfish surveys carried out in the Irminger Sea and adjacent waters (a.w.) since the beginning of the fishery. Thousand nm²; square nautical miles surveyed, Depth: depth stratum reached during survey, above or below 500 m depth.

Year	Country	Region	Th nm2	Depth	Ref
1982–1991	URSS /RU	Irminger Sea & a.w.		< 500	Shibanov *et al.*, 1996 ICES, 1991
1991	IS	Icelandic waters	60	< 500	Magnússon *et al.*, 1992a
1992	IS/RU	Irminger Sea		< 500	Magnússon *et al.*, 1992b ICES, 1993
1993	RU IS	Irminger Sea Icelandic waters		< 500	Shibanov *et al.*, 1994 ICES, 1994a
1994	IS/NO	Irminger Sea	190	< 500	Magnússon *et al.*, 1994
1995	RU	Irminger Sea		< 500	Shibanov *et al.*, 1996a ICES, 1996
1996	IS/DE/ RU	Irminger Sea	250	< 500	Magnússon *et al.*, 1996
1997	RU	Irminger Sea		< 500	Melnikov *et al.*, 1998
1998	IS/DE/ RU	Irminger Sea & a.w.		< 500	Sigurðsson *et al.*, 1999
1999	IS/DE/ RU	Irminger Sea & a.w.		> 500	Sigurðsson *et al.*, 1999
2001	DE/IS/RU/NO	Irminger Sea & a.w.	420	> 500	ICES, 2002
2003	DE/IS/RU	Irminger Sea & a.w.	405	> 500	ICES, 2003b
2005	DE/IS/RU	Irminger Sea & a.w.	400	> 500	ICES, 2005b
2007	IS/RU	Irminger Sea & a.w.	350	> 500	ICES, 2007b
2009 2011	IS/DE IS/DE/RU	Irminger Sea & a.w. Irminger Sea & a.w.	360 343	> 500 > 500	ICES 2009b ICES 2011b

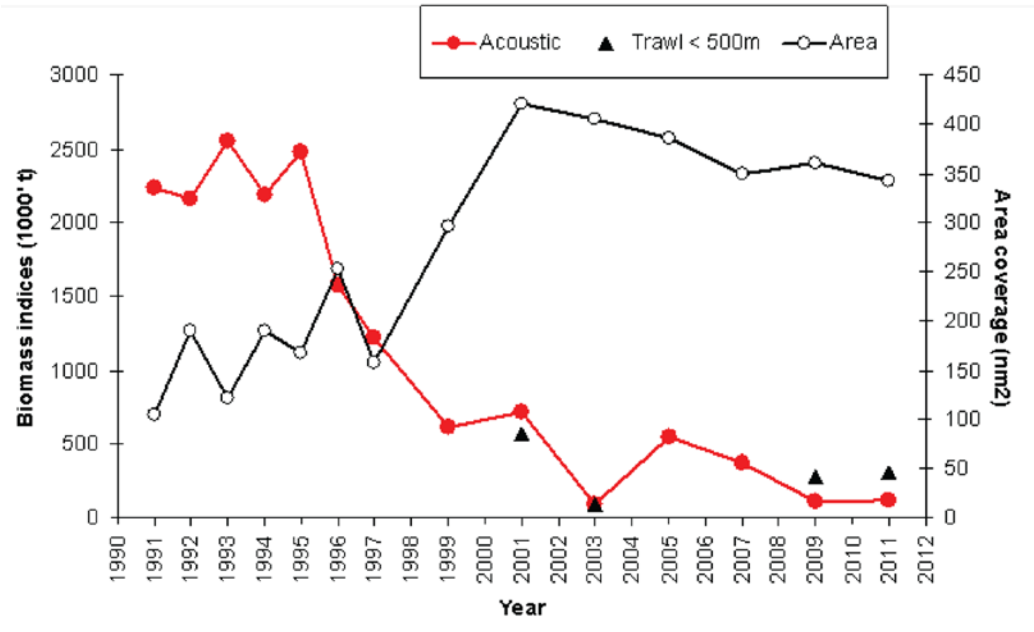

Figure 7.4. Shallow pelagic *S. mentella* stock. Overview of acoustic survey indices (´000 t) from above the deep scattering layer (red filled circle), trawl estimates within the deep scattering layer and shallower than 500 m (black triangle), and aerial coverage (NM²) of the survey (black open circle) in the Irminger Sea and adjacent water.

7.2.4 Commercial tuning data

It is not known to what extent cpue (Figure 7.4) reflects changes in the stock status of Shallow Pelagic *S. mentella*. Since the fishery focuses on aggregations, the cpue series might not indicate or reflect actual trends in stock size. The cpue data are not used in an assessment.

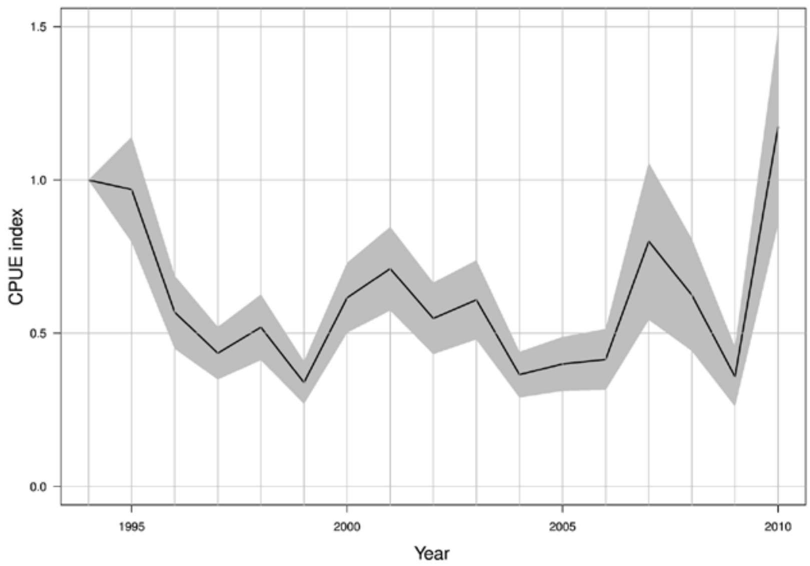

Figure 7.5. Trends in standardized cpue of the shallow pelagic *S. mentella* fishery in the Irminger Sea and adjacent waters, based on logbook data from Faroes, Iceland, Norway, and Greenland.

7.2.5 Industry/stakeholder data inputs

None.

7.2.6 Environmental data

Analysis of the oceanographic situation during the 2009 international survey and long-term data including 2003, allows the following conclusions:

Strong positive anomalies of temperature observed in the upper layer of the Irminger Sea with a maximum in 1998 are related to an overall warming of water in the Irminger Sea and adjacent areas in 1994–2003. These changes were also observed in the Irminger Current above the Reykjanes Ridge (Pedchenko, 2000), off Iceland (Malmberg *et al*., 2001) and in the Labrador Sea waters (Mortensen and Valdimarsson, 1999). Thus, temperature and salinity in the Irminger Current have increased since 1997 to the highest values seen for decades (ICES, 2001). The results of the 2003 survey were confirmed by the high temperature anomalies of the 0–200 m layer in the Irminger Sea and adjacent waters. In 200–500 m depth and deeper waters, positive anomalies in most parts of the observation area were observed, but increasing temperature as compared to the survey in June–July 2001 was obtained only north of 60° N in the flow of the Irminger Current above the Reykjanes Ridge and the northwestern part of the Irminger Sea. These changes in oceanographic conditions might have an effect on the seasonal distribution of redfish and its aggregations in the layer shallower than 500 m in the survey area (ICES, 2003b). In June/July 2005 and 2007, water temperature in the shallower layer (0–500 m) of the Irminger Sea was higher than normal (ICES, 2005b). As in the surveys 1999–2003, the redfish were aggregating in the southwestern part of the survey area, partly influenced by these hydrographic conditions. Favourable conditions for aggregation of redfish in an acoustic layer have been marked only in the southwestern part of the survey area with temperatures between 3.6–4.5°C, as confirmed by the survey results obtained in 2009.

7.3 Stock identity, distribution and migration issues

The shallow pelagic *Sebastes mentella* stock is found at depths <500 m in NAFO Areas 1 and 2 and ICES Divisions V, XII and XIV. It also extends to ICES Divisions I and II and includes demersal habitats east of the Faroe Islands. ACOM concluded in view of the results of the Workshop on Redfish Stock Structure (WKREDS, 22–23 January 2009, Copenhagen, Denmark; ICES, 2009a) and the RED-FISH project (Anon. 2004), that there are three biological stocks of *Sebastes mentella* present in the Irminger Sea and adjacent waters:

- Shallow pelagic stock;
- Deep pelagic stock;
- Icelandic slope stock.

The Workshop noted that the decision to classify pelagic redfish as two stocks rather than one stock was not unanimous among ACOM members, and was advised of Russia's position regarding the structure of the redfish stock in the Irminger Sea and adjacent waters remains unchanged, i.e. that there is a single-stock of *S. mentella* in that area (ICES, 2011).

The workshop noted that the stock structure of *Sebastes mentella* in the Irminger Sea and adjacent waters is informed by genetic information (i.e. microsatellite information), and by the analysis of allozymes, fatty acids and other biological information, such as some parasite patterns. Neither the connectivity, nor possible migration patterns are known. The stock in the shallow pelagic consists almost entirely of adult individuals. The recruitment pattern of juveniles into the adult stock is not known. The general perception is that the East Greenland shelf is the most important nursery area for this stock.

As it did not possess the necessary expertise, the Workshop did not review these data further. So as to develop discussions on stock assessment, it decided to use the ACOM conclusion of three stocks as a basis to proceed.

7.4 Influence of the fishery on stock dynamics

The fishery is targeting the adult part of the stock, so it is expected that the recruitment of juveniles is not negatively affected. However, the magnitude of the recruitment and the patterns are not known. It can be assumed that the intensive fishery (see Section 7.2.1) has had a negative impact on the stock dynamics of the shallow pelagic stock. However, the reduction in biomass observed in the surveys in the hydroacoustic layer (about 2 mill. t in the last decade) cannot be explained by the reported removal by the fisheries (about 500 000 t in the entire depth range in 1995–2009) alone. A decreasing trend in the relative biomass indices in the acoustic layer, however, is visible since 1991 (Figure 7.3). It is not known to what extent cpue reflects changes in the stock status of pelagic *S. mentella*, since the fishery focuses on aggregations. Therefore, stable or increasing cpue series might not indicate or reflect actual trends in stock size, although decreasing cpue indices are likely to reflect a decreasing stock.

7.5 Influence of environmental drivers on stock dynamics

An ICES workshop is currently investigating this topic (Workshop on Redfish and Oceanographic Conditions, WKREDOCE).

7.6 Role of multispecies interactions

7.6.1 Trophic interactions

Young redfish dwell at the bottom at different depths, the youngest ages preferring lesser depths than older fish. The juveniles are predominantly distributed on the continental shelf of West- and East Greenland. Age of recruitment to the fishery of both stocks is believed to be near maturity, maybe between ages 8 to 12 years. The causes for variability of recruitment are unknown. Adults are found in the open ocean (DEEPFISHMAN, WP2, 2010, unpublished report).

Little is known about the trophic interactions in the Irminger Sea. However a recent study by Petursdottir *et al*. (2008) shows that Euphausiids (*M. norwegica*) and *Calanus* spp. appear to play an important role in the diet of *S. mentella* in the pelagic ecosystem on the Reykjanes ridge. Pedersen and Riget (1993) investigated stomach content of *S. mentella* in W-Greenland waters and found planktonic crustaceans such as hyperiids, copepods and euphausiids to be the main food item in small redfish (5–19 cm). Among shallow stock adults, the diet includes mainly dominant plankton crustaceans such as Amphipods, Copepods and Euphausids. Cephalopods (small squids), shrimp (*P. borealis*) and small fish (including redfish) are also important food items (Pedersen and Riget, 1993; Magnusson and Magnusson, 1995).

Some seasonal, interannual and ontogenetic variability of the diet of *S. mentella* was observed in the Irminger Sea. (Dolgov *et al*., 2011). Ontogenetic changes in diet can reflect morphological changes occurring during fish growth and the availability of prey.

There are indications that *Sebastes* spp. play important role as a prey item for Greenland halibut (Orr and Bowering, 1997; Solmundsson, 2007) and adult harp and hooded seals during pelagic feeding (Haug *et al*., 2007; Tucker *et al*., 2009). The prey items in these studies were however not species-specific observations.

7.6.2 Fishery interactions

The fishery for pelagic *S. mentella* in the Irminger Sea is a highly directed fishery, catching mainly redfish .Hence, no known fishery interactions are being observed.

7.7 Impacts of the fishery on the ecosystem

The fisheries on pelagic redfish in the Irminger Sea and adjacent waters are generally regarded as having negligible impact on the habitat and other fish or invertebrate species due to very low bycatch and discard rates, characteristic of fisheries using pelagic gear.

7.8 Stock assessment methods

Shallow pelagic beaked redfish has previously been assessed based on trends in survey biomass indices from the international redfish survey since 1991 in terms of ICES "trends based assessment" approach. Supplementary data includes relevant information from the fishery and length distribution from the commercial catch and the surveys.

Some participants in the Working Group 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 put forward a Schaefer biomass dynamics model as an interim basis for assessment and the development of management advice (see Appendix 1).

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.

7.8.1 Models

7.8.2 Sensitivity analysis

7.8.3 Retrospective patterns

7.8.4 Evaluation of the models

7.8.5 Conclusions

7.9 Short-term and medium-term forecasts

For pelagic redfish in the Irminger Sea and adjacent waters, given the differing views expressed concerning the assessment no short or medium-term forecasts were calculated.

7.9.1 Input data [recruitment estimates, intermediate year assumptions, etc.]

7.9.2 Model and software

7.9.3 Conclusions

7.10 Biological reference points [see WKFRAME and WKFRAME2 reports]

For pelagic redfish in the Irminger Sea and adjacent waters, given the different views expressed concerning the assessment, no reference points are put forward.

7.11 Recommendations on the procedure for assessment updates and further work

Otoliths have been systematically sampled both from the commercial catch and the autumn survey, but it is important to start a systematic age reading.

7.12 Implications for management (plans) [previous management plans evaluations, new ref. points]

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.

A dialogue with the managers about harvest control rules should be initiated as soon as possible.

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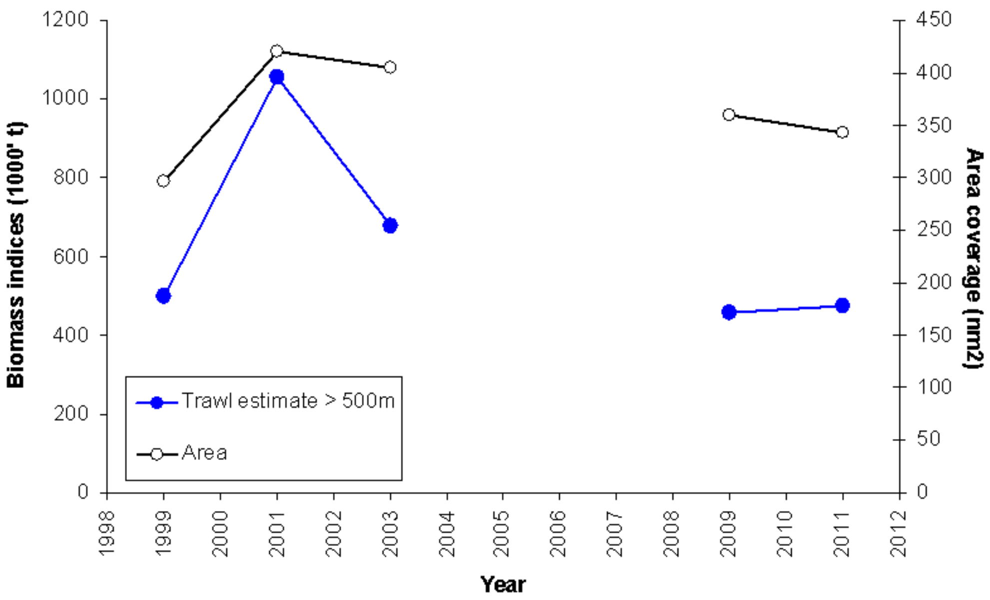
8 Deep *Sebastes mentella*

8.1 Current assessment and issues with data and assessment

For 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 (Figure 8.1). These indices in combination with a marked decrease in landings since 2004 suggest that the stock has been reduced in the past decade.


Biomass indices (1000' t)
Area coverage (nm2)
Year
Trawl estimate > 500m
Area
0
200
400
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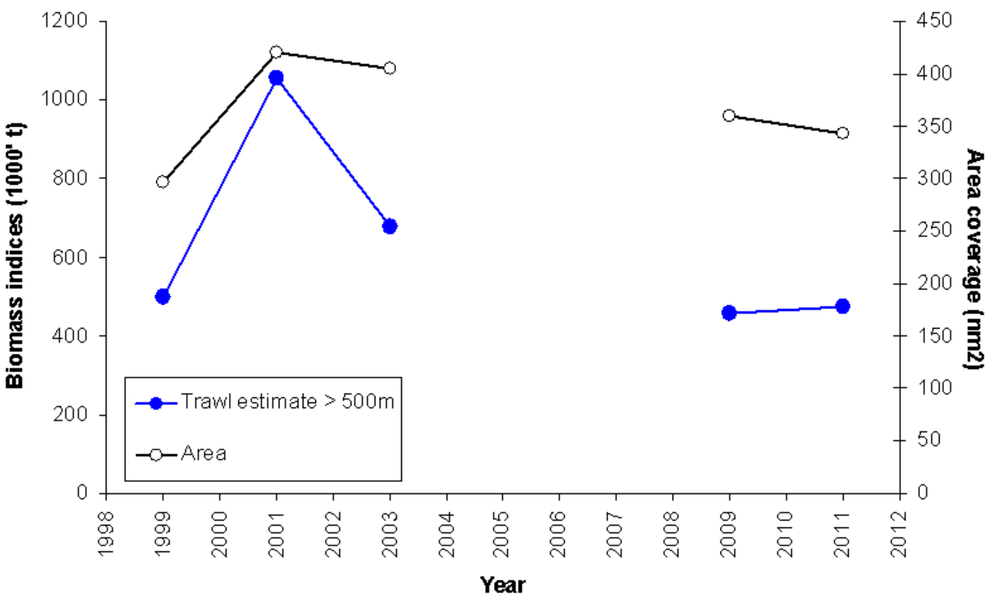
Biomass indices (1000' t)
Area coverage (nm2)
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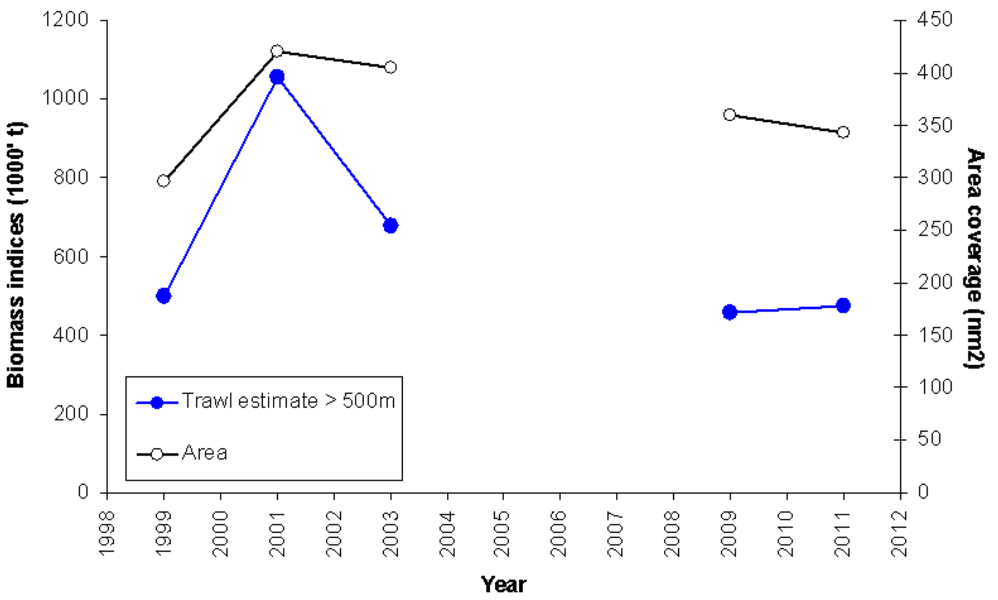


Figure 8.1. Deep pelagic beaked redfish. Overview of survey indices ('000 t) from trawl estimates deeper than 500 m (blue line) and aerial coverage (NM_2) of the survey (black line) in the Irminger Sea and adjacent waters 1999–2011. The surveys in 2005 and 2007 were conducted in different manner than in the other years and are therefore excluded.

8.2 Compilation of available data

8.2.1 Catch and landings data

Iceland, Greenland, Faroe Islands, Norway, Germany and Russia are the nations providing the most complete databases, including detailed vessel and gear information, as well as catch data on a haul to haul basis. The rest of the countries supply catch in weight and the length composition of the catch.

The preliminary official landing data are provided by the ICES Secretariat, NEAFC and NAFO, and various national data are reported to the North Western Working Group (NWWG). The Group, however, repeatedly faces problems in obtaining reliable data due to unreported catches of pelagic redfish and lack of catch data disaggregated by depth from some countries. Tables 8.1 and 8.2 show annual landings, as estimated by the NWWG disaggregated by ICES and NAFO regulatory areas and by country, respectively. Historical description of the fishery is given on the Stock Annex for the stock.

There is also an issue with the reporting of commercial catches. There are indications that reported effort (and consequently landings) could represent only around 80% of the real effort in certain years. Catch data are from many nations not divided by depth which is essential to divide the catches between the shallow and deep pelagic stocks. A description of the splitting of the catch between the stocks is given in the Stock Annex for the stock.

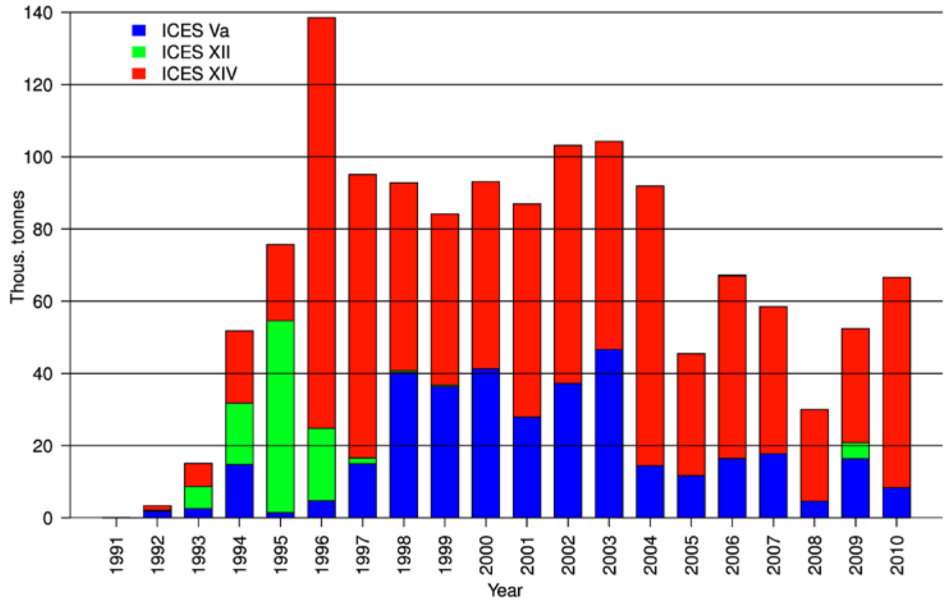


Figure 8.1. Nominal landings of deep pelagic beaked redfish 1991–2010 by ICES areas.

Table 8.1. Deep Pelagic *S. mentella* (stock unit > 500 m). Catches (in tonnes) by area as used by the NWWG.

Year	Va	XII	XIV	NAFO 1F	NAFO 2H	NAFO 2J	Total
1982		0	0				0
1983		0	0				0
1984		0	0				0
1985		0	0				0
1986		0	0				0
1987		0	0				0
1988		0	0				0
1989		0	0				0
1990		0	0	0			0
1991		7	52	0			59
1992	1,862	280	1,257				3,398
1993	2,603	6,068	6,393				15,064
1994	14,807	16,977	20,036				51,820
1995	1,466	53,141	21,100				75,707
1996	4,728	20,060	113,765				138,552
1997	14,980	1,615	78,485				95,079
1998	40,328	444	52,046				92,818
1999	36,359	373	47,421	0			84,153
2000	41,302	0	51,811	0			93,113
2001	27,920	0	59,073	0	0	0	86,993
2002	37,269	2	65,858	0		0	103,128
2003	46,627	21	57,648	0	0	0	104,296
2004	14,446	0	77,508	0		0	91,954
2005	11,726	0	33,759	0	0	0	45,485
2006	16,452	51	50,531	254	0	0	67,288
2007	17,769	0	40,748	0	0	0	58,516
2008	4,602	0	25,443	0			30,045
2009	16,428	4,417	31,609				52,454
2010	8,407	0	58,233	0			66,639

Table 8.2. Deep pelagic *S. mentella* catches (in tonnes) in ICES Div. Va, Subareas XII, XIV and NAFO Division 1F, 2H and 2J by countries used by the NWWG.

Year	Bulgaria	Canada	Estonia	Faroes	France	Germany	Greenland	Iceland	Japan	Latvia	Lithuania	Nederland	Norway	Poland	Portugal	Russia	Spain	UK	Ukraine	Total
1982														0		0				0
1983						0										0				0
1984	0					0								0		0				0
1985	0					0								0		0				0
1986	0			0		0								0		0				0
1987	0			0		0								0		0				0
1988	0			0		0										0				0
1989	0			0		0	0	0						0		0				0
1990	0					0		0					0			0				0
1991			0	0		0		59					0			0				59
1992	0		0	0	0	0	0	3,398		0	0		0			0				3,398
1993	0		0	310		1,135	0	12,741		0	0		878			0			0	15,064
1994	0		0	0	0	2,019		47,435		0	0		523		377	1,465			0	51,820
1995	1,140	181	5,056	1,572	68	8,271	1,579	25,898	396	1,501	6,868	4	3,169		2,955	15,868	227		956	75,707
1996	1,654	307	3,351	3,748		15,549	1,671	57,143	196	512	5,031		5,161		1,903	36,400	5,558	123	245	138,552
1997		9	315	435		11,200		36,830	3				2,849	0	3,307	33,237	6,895			95,079
1998			76	4,484		8,368	302	46,537	1		34		438	0	4,073	25,748	2,758			92,818
1999			53	3,466		8,218	3,271	40,261					3,337	0	4,240	11,419	9,885	5		84,153
2000			7,733	2,367		6,827	3,327	41,466			0		3,108		3,694	14,851	9,740			93,113
2001			878	3,377		5,914	2,360	27,727			7,515		4,275		2,488	23,810	8,649			86,993
2002			15	3,664		7,858	3,442	39,263		0	9,771		4,197	0	2,208	25,309	7,402			103,128
2003				3,938		7,028	3,403	44,620		0	0		5,185	0	2,109	28,638	9,374			104,296
2004				4,670		2,251	2,419	31,098		0	0		6,277	1,889	2,286	31,067	9,996			91,954
2005				1,800		1,836	1,431	12,919		0	1,027		3,950	1,240	1,088	16,323	3,871			45,485
2006				3,498		1,830	744	20,942		0	1,294		5,968	1,356	1,313	23,670	6,673			67,288
2007			0	2,902		1,110	1,961	18,097		575	1,394		4,628	636	2,067	21,337	3,810			58,516
2008				2,632			1,170	6,723			749		571	219	1,733	15,106	1,142			30,045
2009				3,206			1,519	15,125			2,613			178	1,596	25,309	2,907			52,454
2010				3,195			1,932	14,551		1,963	2,228		7,044	2,919	2,203	22,803	7,801			66,639

8.2.2 Biological data

Biological information is collected since 1999 during the biennial international stock assessment survey targeting redfish, but also from commercial catches (Iceland, Russia, Spain and other EU countries). In the surveys stomach fullness, parasite infestation, pigment patches and muscular melanosis, are also recorded according to an approved method (Bakay and Karasev, 2001).

This dataset consists of length measurements, sex ratio, maturity stage, stomach contents and otolith collection. The Group started to collate an international database with length distributions from the sampling of the fisheries on a spatially disaggregated level. Once complete, the horizontal and vertical differences in mean length by fishing areas can be illustrated as alternative to the portrayals by ICES/NAFO Divisions. The database includes data from Iceland, Greenland, Faroe Islands, Norway, Germany and Russia.

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

- population age structure, with the need to validate and standardize the methods for age and maturity determination,
- species identification of young individuals,
- location of nursery and mating areas,
- estimation of natural mortality.

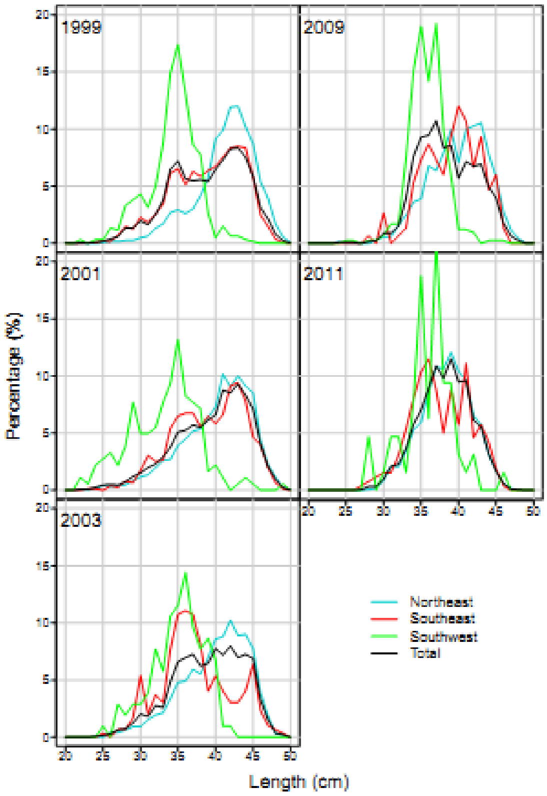
8.2.3 Survey tuning data

The surveys provide valuable information on the biology, distribution and relative abundance of oceanic redfish, as well as on the oceanographic conditions of the surveyed area. Until 1999, oceanic redfish was only 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; Sigurðsson 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). However, since the fishery had moved towards greater depths 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 pelagic *S. mentella* >500 m depth with so-called "trawl method", showing that the highest concentrations of redfish below 500 were associated with eddies and fronts. The surveys in 2005 and 2007 are not comparable with the other surveys due to changes in the depth range covered in the 2005 and 2007 surveys. It should be noted that the trawl data should be treated with great caution (ICES, 2002). Table 8.3gives an overview of the surveys conducted in the area.

Table 8.3. Redfish surveys carried out in the Irminger Sea and adjacent waters (a.w.) in both depth strata. Th. nm^2; square nautical miles surveyed, Depth: depth stratum reached during survey, above or below 500 m depth.

Year	Country	Region	Th nm2	Depth	Ref
1999	IS/DE/ RU	Irminger Sea & a.w.	296	> 500	Sigurðsson *et al*., 1999
2001	DE/IS/RU/NO	Irminger Sea & a.w.	420	> 500	ICES, 2002
2003	DE/IS/RU	Irminger Sea & a.w.	405	> 500	ICES, 2003b
2009	IS/DE	Irminger Sea & a.w.	360	> 500	ICES, 2009b
2011	DE/IS/RU	Irminger Sea & a.w.	343	> 500	ICES, 2011b

The Planning Group for Redfish Survey (PGRS) meets annually to organize and plan these international surveys and distribute survey area and time among the participants. The technical details and description of the equipment used are described in the Stock Annex for the stock and in ICES 2011a.



8.2.4 Commercial tuning data

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

8.2.5 Industry/stakeholder data inputs

There are no actual data inputs from any industry and stakeholders.

8.2.6 Environmental data

Analysis of the oceanographic situation during the international survey and long-term data including, allows the following conclusions:

Strong positive anomalies of temperature observed in the upper layer of the Irminger Sea with a maximum in 1998 are related to an overall warming of water in the Irminger Sea and adjacent areas in 1994–2003. These changes were also observed in the Irminger Current above the Reykjanes Ridge (Pedchenko, 2000), off Iceland (Malmberg *et al.*, 2001) and in the Labrador Sea waters (Mortensen and Valdimarsson, 1999). Thus, temperature and salinity in the Irminger Current have increased since 1997 to the highest values seen for decades (ICES, 2001).

The results of the 2003 survey were confirmed by the high temperature anomalies of the 0–200 m layer in the Irminger Sea and adjacent waters. In 200–500 m depth and deeper waters, positive anomalies in most parts of the observation area were observed, but increasing temperature as compared to the survey in June–July 2001 was obtained only north of 60°N in the flow of the Irminger Current above the Reykjanes Ridge and the northwestern part of the Irminger Sea. These changes in oceanographic conditions might have an effect on the seasonal distribution of redfish and its aggregations in the layer shallower than 500 m in the survey area (ICES, 2003b). The increasing of water temperature in the Irminger Sea may have an effect on spatial and vertical distributions of *S. mentella* in the feeding area (Pedchenko, 2005).

In June/July 2005 and 2007, water temperature in the shallower layer (0–500 m) of the Irminger Sea was higher than normal (ICES, 2005b). As in the surveys 1999–2003, the redfish were aggregating in the southwestern part of the survey area, partly influenced by these hydrographic conditions. Favourable conditions for aggregation of redfish in an acoustic layer have been marked only in the southwestern part of the survey area with temperatures between 3.6–4.5°C, as confirmed by the survey results obtained in 2009.

Hydrography surveys of June/July 2011 show that the increased temperature background is still in place in the survey area on the level specific for warm and moderately warm years. However as compared to the 2007 and 2009 surveys the heat capacity reduction trend is observed.

8.2.7 Stock identity, distribution and migration issues

The deep pelagic Sebastes mentella stock is distributed mostly in pelagic habitats within NAFO Divisions 1–2, and ICES Areas V, XII, XIV at depths >500 m, but it is also found in demersal habitats west of the Faroe Islands (NWWG, 2010).

ACOM concluded, in view of the results of the Workshop on Redfish Stock Structure (WKREDS, 22–23 January 2009, Copenhagen, Denmark; ICES, 2009a) and the REDFISH project (Anon. 2004), that there are three biological stocks of *Sebastes mentella* present in the Irminger Sea and adjacent waters:

- Shallow pelagic stock;
- Deep pelagic stock;
- Icelandic slope stock.

The Workshop noted that the decision to classify pelagic redfish as two stocks rather than one stock was not unanimous among ACOM members, and was advised of Russia's position regarding the structure of the redfish stock in the Irminger Sea and adjacent waters remains unchanged, i.e. that there is a single-stock of *S. mentella* in that area (ICES, 2011).

The workshop noted that the stock structure of *Sebastes mentella* in the Irminger Sea and adjacent waters is informed by genetic information (i.e. microsatellite information), and by the analysis of allozymes, fatty acids and other biological information, such as some parasite patterns. It has been suggested that the East Greenland shelf is most likely a common nursery area for the three biological stocks.

As it did not possess the necessary expertise, the Workshop did not review these data further. So as to develop discussions on stock assessment, it decided to use the ACOM conclusion of three stocks as a basis to proceed.

Based on this new stock identification information, ICES recommended in 2009 the use of three potential management units that are geographical proxies for the newly defined biological stocks, which are partly limited by depth and whose boundaries are based on the spatial distribution pattern of the fishery to minimize mixed-stock catches. Thus the newly described deep pelagic stock corresponds to the management unit in the northeast Irminger Sea: NAFO Areas 1 and 2, ICES Areas Vb, XII and XIV at depths greater than 500 m, including demersal habitats west of the Faroe Islands.

A schematic illustration of the relationship between the management units and biological stocks is given in Figure 8.4.

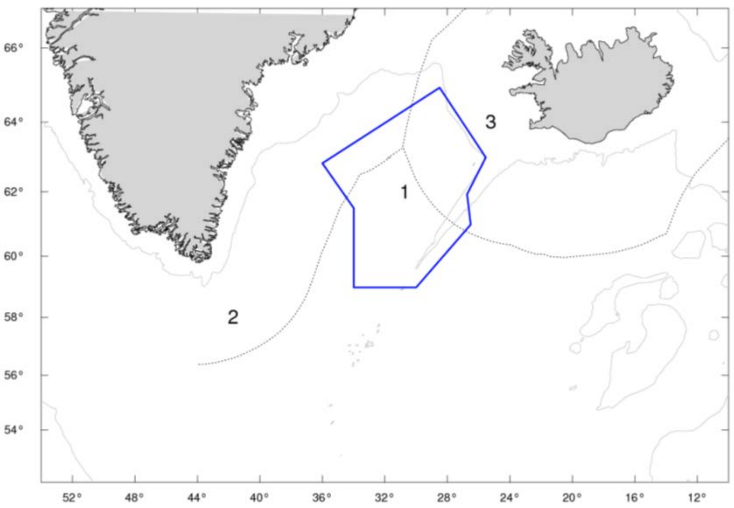


Figure 8.4. Proposed management unit boundaries for *S. mentella* in the Irminger Sea and adjacent waters. The polygon bounded by blue lines, i.e. 1, indicates the region for the 'deep pelagic' management unit in the northwest Irminger Sea, 2 is the "shallow pelagic" management unit in the southwest Irminger Sea, and 3 is the Icelandic slope management unit.

8.3 Influence of the fishery on stock dynamics

The fishery is targeting the adult part of the stock, so it is expected that the recruitment of juveniles is not negatively affected. However, the magnitude of the recruitment and the patterns are not known.

8.4 Influence of environmental drivers on stock dynamics

An ICES workshop is currently investigating this topic (Workshop on Redfish and Oceanographic Conditions, WKREDOCE).

8.5 Role of multispecies interactions

8.5.1 Trophic interactions

Little is known about the trophic interactions in the Irminger Sea. However a recent study by Petursdottir *et al*. (2008) shows that Euphausiids (*M. norwegica*) and *Calanus* spp. appear to play an important role in the diet of *S. mentella* in pelagic ecosystem on the Reykjanes ridge. Pedersen and Riget (1993) investigated stomach contents of *S. mentella* in W-Greenland waters and found planktoninc crustaceans such as hyperiids, copepods and euphausiids to be the main food items in small redfish (5–19 cm). Among shallow stock adults, the main food items are dominant plankton crustaceans such as Amphipods, Copepods and Euphausids. Cephalopods (small squids), shrimp (*P. borealis*) and small fish (redfish included) are also important food items (Pedersen and Riget, 1993; Magnusson and Magnusson, 1995; ICES, 1999; 2001).

Some seasonal, interannual and ontogenetic variability of the diet of *S. mentella* was observed in the Irminger Sea (Dolgov *et al*., 2011). Ontogenetic changes in diet can reflect morphological changes occurring during growth and the availability of prey.

There are indication that *Sebastes* spp. play important role as a prey item for Greenland halibut (Orr and Bowering, 1997; Solmundsson, 2007) and adult harp and hooded seals during pelagic feeding (Haug *et al*., 2007; Tucker *et al*., 2009). The prey items in these studies were however not species-specific observations.

8.5.2 Fishery interactions

The fishery for pelagic *S. mentella* in the Irminger Sea is a highly directed fishery, catching mainly redfish. Hence, no known fishery interactions are being observed.

8.6 Impacts of the fishery on the ecosystem

The fisheries on pelagic redfish in the Irminger Sea and adjacent waters are generally regarded as having negligible impact on the habitat and other fish or invertebrate species due to very low bycatch and discard rates, characteristic of fisheries using pelagic gear.

8.7 Stock assessment methods

Deep pelagic beaked redfish has previously been assessed based on trends in survey biomass indices from the biennial International Redfish Survey since 1999 in terms of ICES "trends based assessment" approach. Supplementary data includes relevant information from the fishery and length distribution from the commercial catch and the survey.

Some participants in the Working Group 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 put forward a Schaefer biomass dynamics model as an interim basis for assessment and the development of management advice (see Appendix 1).

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.

8.7.1 Models

Not yet.

8.7.2 Sensitivity analysis

8.7.3 Retrospective patterns

8.7.4 Evaluation of the models

8.7.5 Conclusions

8.8 Short-term and medium-term forecasts

For pelagic redfish in the Irminger Sea and adjacent waters, given the differing views expressed concerning the assessment no short-term forecasts were calculated.

8.8.1 Input data [recruitment estimates, intermediate year assumptions, etc.]

8.8.2 Model and software

8.8.3 Conclusions

8.9 Biological reference points [see WKFRAME and WKFRAME2 reports]

No suggestion for biological reference points was presented at the meeting.

8.10 Recommendations on the procedure for assessment updates and further work

Otoliths have been systematically sampled both from the commercial catch and the autumn survey, but it is important to start a systematic age reading. With more age data it will be possible to develop a statistical catch-at-age model or develop a length-based Gadget model.

During the meeting a potential harvest control rule method for the deep pelagic redfish was presented (WD No. 16). This method is based on a proxy version of the standard MSY rule but developed where no formal assessment is conducted because of insufficient data.

It is also important to clarify the allocation of catches to different stocks, especially between the deep and Icelandic slope beaked redfish. Tagging experiments might be required.

8.11 Implications for management (plans) [previous management plans evaluations, new ref. points]

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.

A dialogue with the managers about harvest control rules should be initiated as soon as possible.

8.12 References

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9 Beaked redfish (*S. mentella*) in Subarea XIV (demersal on Greenland slope)

9.1 Description of assessment methodology and main issues with data and methods

The main present problem for the Greenland *S. mentella* on the slope is stock identity, e.g. connectivity to the adjacent *S. mentella* stocks, the pelagic stocks in the Irminger Sea and the Iceland slope stock. The Greenland shelf is a potential nursery ground to both pelagic stocks (deep and shallow) and the Iceland slope stock. The extent of exchange with these other stocks is unknown. Ongoing genetic studies will help to clarify these issues in the near future. These issues should be further discussed at the upcoming North Western Working Group.

The stock is currently assessed by a qualitative assessment of two survey time-series (German and Greenlandic) and by use of catch rates from the fishery. The assessment is based on the ICES 'data poor stock' framework.

There are critical issues with both surveys. They are both designed for cod and shrimp, thereby ignoring the variance associated with *S. mentella* catch estimates in the allocation of stations (both are random stratified surveys). Furthermore, the German survey (1982–2011) covers depths from 0–400 m which does not cover the entire depth distribution of *S. mentella* (mainly 200–600 m) and generally estimates are associated with large uncertainties (CVs of approximately 50%).

The Greenland survey time-series only extends back to 2008 which limit its usefulness in the assessment of the long-lived *S. mentella*. In addition species identification (*S. marinus* vs. *S. mentella*) is uncertain and the biomass indices are associated with large uncertainties (CVs of approximately 35%).

Prior to the workshop there was doubt on the quality of landing statistics prior to 1999, concerning species split. Scrutinizing earlier NWWG reports this issue has now been clarified, and landings statistics should contain only *S. mentella* catches.

Logbooks on a haul-by-haul basis are available from 1992–2011 but have not previously been used in the assessment process. However, from 1992–1998 the data quality is poor due to incorrect species reporting and further does not contain all catches, consequently this time period is omitted from the data. From 1999–2011 the data are of a sufficient quality. The standardized cpue calculated from the redfish directed fishery has been evaluated, and is not proposed to be used in the assessment for several reasons: The fishery targets an aggregating species which may allow high cpue even at low stock size and further the fishery is currently in a very restricted area that may not be representative of the stock distribution.

A redfish bycatch cpue was instead calculated based on the Greenland halibut directed fishery. The rationale for using bycatch cpue is that a longer time-series is available and the fishery more dispersed thereby covering the stock distribution more appropriate. The index is based on hauls were Greenland halibut make up >50% of the catch by weight. This cut-off was based on the frequency distribution of redfish catches in all hauls, which typically made up either 0–20% (i.e. bycatch) or 90–100% (i.e. redfish directed fishery). Furthermore, all hauls at depths >1000 m were discarded as this is outside the depth range of *S. mentella*. This bycatch cpue covers a wider area on the Greenland slope than the redfish directed fishery, and since the

Greenland halibut fishery has been fairly stable in the past decade, the bycatch cpue was considered in future assessments. Regarding the bycatch cpue it should however be noted that bycatches are reported as "redfish" thus including both *S. mentella* and *S. marinus*, but the Greenland halibut fishery takes place at depths of 400 m and deeper, and from the Greenland survey it is observed that at these depths *S. mentella* constitutes at least 90%, and the confounding effect of the *S. marinus* contribution is assumed to be negligible.

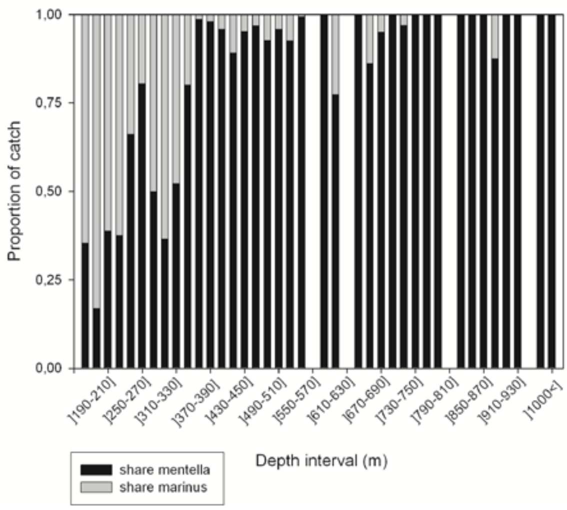


Figure 9.1. The relative contribution of *S. mentella* and *S. marinus* in the catches based on Greenlandic groundfish survey.

9.2 Compilation of available data

9.2.1 Catch and landings data

In recent years the fishery targets adult fish (>30 cm) but prior to 1999 juveniles were also caught. Catches have been limited by a TAC in 2009–2011, but prior to this period the TAC was not considered restrictive.

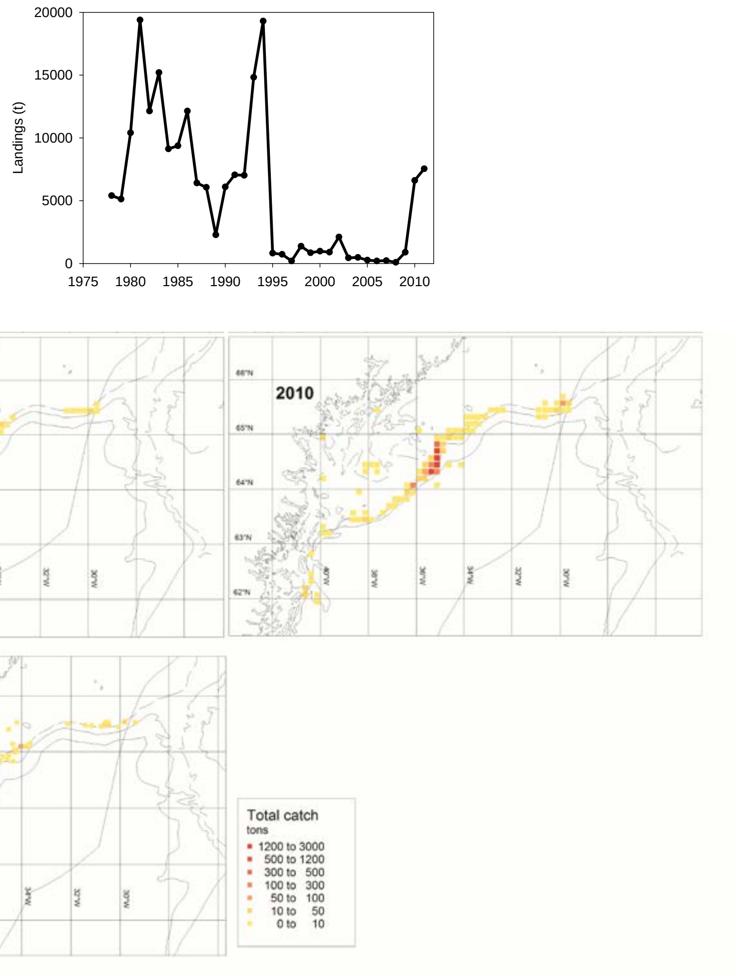


Figure 9.2.1. Landings of *S. mentella* (Greenland *mentella*) on the Greenland slope.

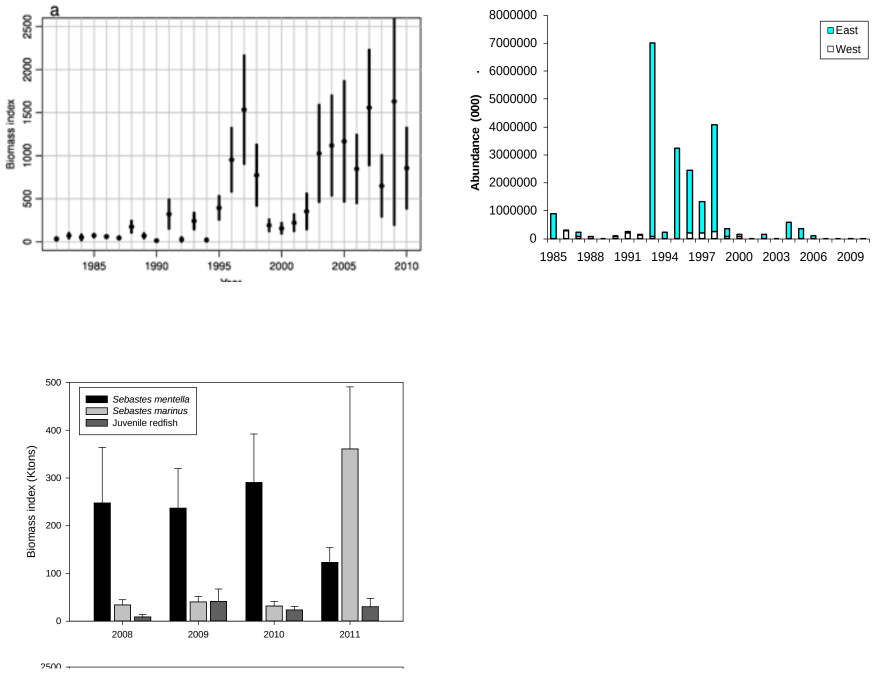
It is unknown in what area catches were taken prior to 1999. Recent catches have been taken in a relatively small area. The area seems to be contracting from 2009–2011. The condensed fishing area with high catches is confirmed by the survey.

9.2.2 Biological data

In addition to length and weight, few data have been sampled. Otoliths have been sampled occasionally but no age determinations have been initiated. No studies have been done on migration, maturity, spawning areas, feeding behaviour, larval drift, etc.

9.2.3 Survey tuning data

Indices from the German and the Greenland groundfish survey are displayed below. The German groundfish survey covers depths from 0 to 400 m, while the Greenland groundfish survey covers 0 to 600 m. Both surveys are late summer/early fall surveys. This season is associated with least problems such as bad weather and sea ice. Both surveys are random stratified bottom-trawl surveys targeting mainly cod and in the Greenland survey also shrimp.



Figures 9.2.3. Top left: biomass index of adult *S. mentella* (≥17 cm) from the German groundfish survey. Top right: abundance index of *S. mentella* juveniles (≤16 cm) in the German groundfish survey. Bottom left: biomass index of adult *S. mentella* (≥17 cm) in the Greenlandic groundfish survey. Error bars are CV's in all cases.

9.2.4 Commercial tuning data

No assessment model, but see landings.

9.2.5 Industry/stakeholder data inputs

None.

9.2.6 Environmental data

No environmental data has been presented. Generic information is available in NWWG reports.

9.3 Stock identity, distribution and migration issues

The stock identity is unknown and *S. mentella* on the East Greenland shelf is considered a provisional stock unit until further research has revealed its assignment. The Greenland *S. mentella* may be associated to Iceland *mentella*, shallow pelagic *mentella* and deep pelagic *mentella*, or any combination of these stocks, or it may be a separate stock that only mixes to a limited extend with other stock components. Indeed, the Greenland west coast stock (NAFO SA1) also has to be considered in this context, as does the problems with species identification.

The East Greenland shelf is considered a nursery area for more redfish species but the absolute proportion and importance of its contribution to the Greenland slope *mentella* is unknown.

9.4 Influence of the fishery on stock dynamics

Prior to 1999 the fishery targeted both adult and juvenile fish in unknown quantities and proportions, and the directed fishery stopped in 1995. The fishery reopened in 2009 after a decade of a catches being limited to bycatch in the Greenland halibut fishery. Due to contraction of the fishing grounds in the last three years and declining survey abundance indices it is plausible, that the stock is declining.

The shrimp fishery did prior to the mandatory use of sorting grids in 2002 catch significant numbers of juvenile redfish. This bycatch has been reported to be reduced markedly after the use of the grids.

9.5 Influence of environmental drivers on stock dynamics

Unknown.

9.6 Role of multispecies interactions

9.6.1 Trophic interactions

Unknown.

9.6.2 Fishery interactions

Vessels catching demersal redfish commonly have quotas for also cod and Greenland halibut and therefore often moves either shallower on the East Greenland slope for hauls directed for cod or deeper for hauls directed for Greenland halibut. The fishery in that sense is not a mixed fishery but the single vessel performs several directed fisheries under the same trip due to the close distance between the main distribution areas of the different targeted species.

9.7 Impacts of the fishery on the ecosystem

There is little bycatch in the redfish directed fishery, so direct impacts on other species are considered small. The fishery takes place in a narrow geographical area, so overall impacts on the ecosystem are most likely insubstantial. However, the indirect effects through species interactions are unknown.

9.8 Stock assessment methods

9.8.1 Models

This stock has previously been assessed based the ICES "trends based assessment" approach. Supplementary data includes relevant information from the fishery and length distribution from the commercial catch and the survey.

Some participants in the Working Group considered at the present analytical assessment cannot be conducted because, for example, of little age data and the relative shortness of the time-series available. However, alternative assessment methods (Schaefer stock production model) based on landings and the German survey index were compared to the current situation (trends based assessment). This is discussed in Section C in the Stock Annex and in Appendices 1 and 2. There was, however, disagreement regarding the use of the Schaefer model and those points are addressed in Section C of the Stock Annex as well as in Section 9.8.4 below.

9.8.2 Sensitivity analysis

Not relevant.

9.8.3 Retrospective patterns

Not relevant.

9.8.4 Assessment issues

ICES has only provided assessment for this stock since 2009, and there are no biological reference points available. The assessment is based on trends in two surveys (German and the Greenlandic) and trends in the landings. There are however several reservations regarding all of these time-series. The surveys biomass indices are both associated with high CV's. The German survey provides the longest time-series (1988–2011) but covers only shallow waters down to 400 m. The Greenland survey time-series is short (2008–2011) but coverage is appropriate with respect to stock distribution.

The cpue from the redfish directed fishery is not considered useful in the assessment of this stock. The bycatch cpue from the Greenland halibut directed fishery is a potential reliable biomass index to assess this stock (see elsewhere in this report) but has not previously been used.

Surveys have confirmed that abundance is narrowly concentrated to a location/few hauls and that there is a tendency of declining biomass estimates. Following a decade of very low catches the redfish directed fishery "reopened" in 2009, and can be considered a new fishery. Catches have increased from 1000 t in 2009 to around 7000 t in 2010 and 2011. The fishery has a relatively limited distribution, both regarding position and depth interval. This could indicate that there is potential for overexploitation of local populations of the stock, and that suitable fishing grounds are contracting.

As this stock is subject to a new fishery, and the assessment prior to this workshop has been based on trends only, ICES advice has been based on the framework for data poor stocks. Until the effect of the fishery on the stock can be evaluated, the advice is that the fishery should not expand beyond the 2009 level of initial fishery of 1000 t. This also entails that sensitivity analyses, retrospective analyses etc. are not possible for this stock.

During WKRED, Schaefer stock production model runs were performed to obtain MSY parameters using landings and the German survey input. For a range of r values (0.05–0.2) model parameters and associated uncertainties were estimated. The MSY and sustainable current yield estimates are robust for the range of r values (see table below).

Table 9.8.4.1. Estimates (Kt) of MSY, sustainable current yield (SCY) and current depletion based on Schaefer model runs.

MSY			SCY			Depletion		
r	mean	CV	r	mean	CV	r	mean	CV
0.05	7.21	1.63	0.05	3.44	0.03	0.05	0.86	0.31
0.1	6.14	0.52	0.1	3.76	0.12	0.1	0.81	0.19
0.15	6.47	0.31	0.15	3.64	0.17	0.15	0.83	0.12
0.2	6.94	0.25	0.2	3.46	0.14	0.2	0.85	0.08

However, several issues are of concern using the model to estimate MSY and current depletion. The German survey is considered a poor biomass indicator as coverage only are above depths of 400 m and *mentella* is mainly distributed down to 600 m. The CV's associated with the estimates model parameters are high. The model estimates the present stock size to be 80–90% of K, e.g. considerably higher than B_{MSY}. Given survey indices, cpues from the fishery and the very narrow fishing grounds/hot spots for survey compared to previous assumed dispersed fishery, this high biomass is uncertain.

9.8.5 Conclusions

There was disagreement regarding the use of the current "trends-based" assessment method and the Schaefer model and the individual best method for assessing this stock.

9.9 Short-term and medium-term forecasts

Not relevant.

9.9.1 Input data

9.9.2 Model and software

9.9.3 Conclusions

9.10 Biological reference points

No such exists.

9.11 Recommendations on the procedure for assessment updates and further work

Extending the survey time-series and further exploring the possible use of cpue (by-catch and directed fishery) would be helpful, as would taking nearby stock trends (Shallow and deep pelagic *mentella* and Iceland slope *mentella*) into consideration.

9.12 Implications for management (plans)

9.13 References

10 General recommendations

Time constraints/Need for preliminary workshops

The number of stocks and analytical models put forward for review during the Benchmark was demanding, leading to limited time to focus on the details of any one stock/model. Several of the assessments considered during this Benchmark could (and should) have been more fully developed prior to this workshop. Ideally reviewers would have model results, diagnostics, and sensitivity model runs available for review at least one week prior to workshop to allow them sufficient time to prepare. In addition, those with primary assessment responsibility for each stock should prepare updated stock annexes incorporating their proposals for any changes in advance; this is to facilitate ready focus during the Benchmark on the key issue of aspects of those annexes where the workshop, and the external panel in particular, may wish to consider (further) changes. Furthermore, a limited number of people were available to run models during the workshop which was problematic when multiple model runs for multiple stocks were requested. In some cases the results which were able to be presented during the workshop were rather limited, resulting in an inability to fully evaluate the reliability of the model input data and the results from the model fits to the data.

The issues above could be addressed via additional workshops (e.g. data and/or modelling) held prior to a final Benchmark workshop. A data workshop could provide an opportunity to evaluate potential model inputs (e.g. survey indices, catches, and corresponding length and age compositions), the precision of each data source, and to agree on which datasets should be considered during the stock assessment modelling. A modelling workshop could provide the chance for evaluation of preliminary model fits, the evaluation of candidate models, and the diagnosis of modelling problems (e.g. inability of the model to fit the data). Preliminary workshops can facilitate 1) early agreement on the common treatment of datasets between stocks and across alternative modelling platforms, and 2) communication between modellers working on similar models/stocks allowing for agreement on modelling conventions, the presentation of data, and the presentation of a common set of model outputs and diagnostics prior to the Benchmark workshop. These additional workshops would enhance the ability of the panel of external experts to evaluate the analyses for each stock and to request additional results from model sensitivities at the final Benchmark workshop. Ultimately, the external panel could either recommend one or more candidate models or come to consensus on legitimate concerns that may not have been considered during the process leading up to the final Benchmark workshop.

Cost considerations might preclude a sequence of three separate workshops as suggested above. If so, there would remain merit in combining the extra two workshops proposed into one prior to the benchmark workshop. A combined workshop would consider the issues identified above for the data and modelling workshops to the extent possible. In situations where (as in the case of most of these redfish stocks) the assessment models have not yet been fully developed, it would be useful to include at least some of the external panel members in this earlier meeting.

Future workshops

The workshop did not have time to investigate a number of topics thoroughly during the meeting. In future, workshops should be held to provide deep consideration of the following topics. Note that these generally involve issues of pertinence to more than redfish stocks alone, and so should have a broader remit in terms of species considered; some might be appropriately considered by other existing ICES working groups.

1) Harvest control rules, reference points, and management strategy evaluations (MSEs) for *S. marinus* and *S. mentella*. WDRED 2012 found it particularly difficult to investigate reference points given that the models presented at the workshop in the main included only limited portions of the most recent catch histories for *S. marinus* and *S. mentella* and these species are long-lived .
2) Data poor stock assessment methods for *S. marinus* and *S. mentella* that at least consider how to quantify information on stock productivity (e.g. the *r* parameter in the Schaefer models scrutinized here).
3) Methods for weighting component datasets in stock assessment models and how to weight each year of age/length composition data within individual datasets.
4) Independent review and acceptance of all modelling packages that are being presented and/or used at Benchmark workshops. Make detailed technical documentation available at a central location for all modelling software rather than referencing material from multiple sources. This is not to exclude innovative modelling (and hence software development/modification) during these workshops. However should recommendations related to management issues be based on such developments/modifications of code, arrangements would need to be made for validation of that code in the period between the end of the benchmark workshop and the consideration of the recommendations for implementation.
5) Independent review of survey methods and the provision of detailed technical documentation. WKRED 2012 took considerable time discussing survey data and methods for preparing the data for stock assessment. The Benchmark process would benefit from more deep independent external reviews of survey methods and data analyses, followed by documentation of accepted methods that can be referenced by the stock assessments.

Survey data standardization

The estimation of indices from surveys that have large infrequent catches (e.g. Norwegian coastal survey for Arctic *marinus*) or surveys that have had methodological changes over time (e.g. the winter survey) may be improved by using model-based methods. Annual indices can be estimated in such situations by application of, for example, Delta-GLM or hurdle models that control for spatial or temporal changes (e.g. Maunder and Punt, 2004). For species for which the survey abundance index is highly influenced by a few unusually large survey tows, mixture distribution models may outperform conventional log-linear models in predicting the positive catch rates (Thorson *et al.*, 2011). These statistical methods may yield estimates that have better precision and better reflect the trend in stock abundance than estimates that are based on the survey design alone.

Model run times and flexibility of stock assessment modelling platforms

The GADGET framework was developed with an age-and-length structure to provide maximum flexibility with respect to multispecies modelling that can consider size based predation; however this results in long run times to fit the models. Long run times for GADGET limit the feasibility of conducting model sensitivities, projections, and retrospectives in the time available during a Benchmark workshop. The Benchmark workshop was also hindered by a lack of flexibility in that the modelling platforms used were not able to consider sensitivity to alternative stock–recruitment assumptions (e.g. the inclusion of a stock–recruitment relationship) and the inclusion of the full catch history and cpue datasets that did not have age or length composition available (i.e. the separation of catches from age and length compositions so that all of these data could be considered). There were also concerns that the fundamental treatment length and age composition data both across and within time-steps does not account for differences in the number of observations, which is expected to influence the magnitude of the observation error.

The GADGET framework may be best suited for other purposes such as an operating model within a Management Strategy Evaluation for simulation work. The use of faster models built with AD Model Builder software (e.g. ASAP and SS3) merits consideration, as does the increased use of multicore computers. If GADGET continues to be applied as a stock assessment tool it appears the only practical alternative for a Benchmark workshop is that a final GADGET model run together with all but a few sensitivities and projections need to be completed before that workshop. However, the long times required for GADGET runs will still remain a limitation.

Standard model diagnostics

Valuable time during the Benchmark workshop was spent creating a set of standardized outputs requested by the external panel. A standard set of diagnostic plots and tables that can be used to evaluate the performance of the candidate assessment models needs to be defined. Of course, the requisite number and detail of these tables and figures would depend on the complexity of the model and there may be other figures and tables required which are specific to particular models.

Quantifying uncertainty

There is a general need for presentation of uncertainty estimates for both model inputs and outputs for these stocks. Variances of both annual aggregated and length (or age) disaggregated, indices need to be estimated and used in weighting inputs to the stock assessment models. The lack of estimates of uncertainty in derived quantities from GADGET model fits was particularly problematic. Note that such quantification is essential if moving to an MSE basis to evaluate the relative appropriateness of alternative candidate control rules, as the conditioned operating models used in the MSE simulation testing process need to properly incorporate the extent of this imprecision.

In situations where, as with these redfish stocks, information to quantify some important parameters such as productivity is limited for any one stock, it is important to also consider the stocks (and other similar stocks elsewhere) jointly to provide a basis (e.g. hierarchical modelling) for some penalty function (prior in a Bayesian assessment context) to be added to the model fitting criterion, as this can improve assessment precision. The Precautionary Approach requires that the greater the uncertainty, the lower that catch limits should be set. For this reason it is particularly important that measures of precision, such as standard errors, are evaluated for catch limit estimates. One possible approach for implementing the Precautionary Approach is to reduce the best (point) estimate for a catch limit by some multiple of the associated standard error.

Stocks without quantitative assessments

Biomass dynamics models were implemented for all stocks considered, including those brought to the Benchmark workshop without quantitative assessments. Extensions of these models (e.g. Age Structured Production Models) that can take account of other existing information, such as length or age data are recommended.

The terminology "trends-based assessment" is sometimes used in advocating an approach for stocks without an approved assessment model. The external panel had two difficulties with this:

1) The approach does not appear to be clearly defined in any ICES reference material. Certainly if an acceptable index of abundance is trending up or down, the appropriate recommendation would probably be an increase or decrease respectively in the allowable catch. However such advice would be incomplete without some indication of the magnitude of the change advocated, and no guidance appeared to be given on how this might (or should) be estimated.

2) For all of the redfish stocks considered, more data than simply an index of abundance were available. Assessments models are available that allow objective incorporation of such information, and these should be used rather than what seems to be no more than qualitative arguments as a basis for quantification.

Spatially structured stock assessment models

Multiple indices that cover only a limited portion of a stock's range along with apparent movement of fish between different portions of the stock range are potentially problematic for some current single area models (e.g. Northwestern *marinus*). Spatial modelling of stock dynamics can provide an approach for dealing with this issue and should be investigated.

Discards

Discard data were generally unavailable or considered in a limited fashion during this Benchmark workshop due to time constraints. However, the availability of discard data and the impact of including these data in the stock assessments should be investigated.

Commercial cpue data as tuning-series

The workshop agreed that commercial logbook data should be used with caution in developing abundance indices due to the fishery targeting of aggregations. In some instances bycatch of redfish in other fisheries (e.g. Greenland halibut) may produce more reliable indices of abundance for redfish.

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11 Data problems

Stock	Data Problem	How to be addressed	By whom
Stock name	Data problem identification	Describe data problem and recommend solution	Who should take care of the recommended solution and who should be notified on this data issue (e.g. a specific ICES member country, RCMs, PGCCDBS)
smr-arct	Limited availability of ecosystem survey data	The ecosystem survey data for Arctic Sebastes marinus are not currently easily available for this stock and should be prepared and made available to the stock assessment modellers.	Norway and Russia to make data available for assessment (e.g. AFWG)
smn-arct	Partial geographical coverage of the adult population	The survey time-series currently used in the assessment only cover the Barents Sea. There are no time-series for the deep slopes and Norwegian Sea where most adult fish are.	All countries involved in international fishery to support national and international efforts to establish regular surveys in the Norwegian Sea and continental slope (through ICES/WGRS)
smn-arct smr-arct	Limited availability of catch numbers-at-length.	Catch numbers-at-length are not reported by the AFWG.	Stock coordinators to report catch numbers-at-length to the AFWG.
All stocks	Availability of age data	Collect and age-read otoliths, including archived material.	All countries involved in fisheries and surveys on redfish to collect and age-read *S. marinus* and *S. mentella* otoliths, including archived material.
All stocks (except pelagic *S. mentella*)	Species identification	For demersal redfish in most areas, differentiation of *S. marinus* and *S. mentella* is problematic. The staff sampling redfish should be trained for species identification, aided by guidelines and photographs illustrating species ID features.	Germany, Greenland, Iceland, Norway and Russia to coordinate collation of descriptions and photos for a species identification key for redfish. This should be done as soon as possible.
smn-grl	Logbook data	Investigate the utility of the logbook cpue data from the Greenland fishery that took place during the 1990s.	Greenland and other countries fishing redfish on the East Greenland shelf to provide logbook data as far back in time as possible
smr-arct, smn-arct, smn-sp, smn-dp	Age data from Russian scale readings	Evaluate the utility of using age data based on scale readings from Russian surveys for use in the stock assessment modelling.	Russia, Norway and Iceland to investigate the use of Russian scale-reading age data in stock assessment.

Stock	Data Problem	How to be addressed	By whom
All stocks	Accuracy and precision of age data	Age validation should be completed for those stocks without validated ages. Estimates of ageing bias and variability should be produced and included in the stock assessment models.	All nations involved in fisheries and surveys on redfish to investigate possibilities for age validation. Estimates of bias and variability should be provided by those countries submitting age data. Stock assessment working groups to include the reported uncertainty of age data in stock assessments.
All stocks	Uncertainty estimates for survey and fisheries indices.	Produce annual estimates of uncertainty for all survey and fishery indices.	All nations involved in fisheries and surveys on redfish to provide uncertainty estimates for survey and fisheries indices.

Annex 1: Terms of Reference

2011/2/ACOM49 The **Benchmark Workshop on Redfish** (WKRED), chaired by External Chair Melissa Haltuch, USA, ICES Coordinator Christoph Stransky, Germany, and three Invited External Experts Doug Butterworth (South Africa), Tim Miller (USA) and Paul Spencer (USA) will be established and will meet at ICES Headquarters, 1–8 February 2012 to:

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

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

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

d) Evaluate the possible implications for biological reference points, when new standard analyses methods are proposed. Propose new MSY reference points taking into account the WKFRAME results and the introduction to the ICES Advice (Section 1.2);

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

f) As part of the evaluation:

- i) Conduct a one day data compilation workshop. Stakeholders shall be invited to contribute data (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality. As part of the data compilation workshop consider the quality of data including discard and estimates of misreporting of landings;
- ii) Consider further inclusion of environmental drivers, including multispecies interactions, and ecosystem impacts for stock dynamics in the assessments and outlook;
- iii) Evaluate the role of stock identity and migration.

	Stock	Assessment Lead
smr-arct	Golden redfish (*Sebastes marinus*) in Subareas I and II)	Benjamin Planque
Smn-arct	Beaked redfish (*S. mentella*) in Subareas I and II)	Konstantin Drevtnyak
Smr-5614	Golden redfish (*S. marinus*) in V, VI and XIV	
Smn-con	Beaked redfish (*S. mentella*) in division Va and Subarea XIV (Icelandic slope stock)	Kristjan Kristinsson
Smn-dp	Beaked redfish (*S. mentella*) in division V, XII, XIV and NAFO Subareas 1 and 2 (Deep Pelagic stock)	Kristjan Kristinsson
Smn-sp	Beaked redfish (*S. mentella*) in Division V, XII, XIV and NAFO Subareas 1 and 2 (Shallow Pelagic stock)	Kristjan Kristinsson
Smn-grl	Beaked redfish (*S. mentella*) in Subarea XIV (demersal on Greenland slope	

The Benchmark Workshop will report by 1 March 2012 for the attention of ACOM.

Annex 2: List of participants

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Annex 3: Comment by the Invited External Experts

Golden redfish (*Sebastes marinus*) in Subareas I and II

3.8.1

It is important to explain the lack of fit of the GADGET model to the full coastal survey time-series and why it will not currently be used to inform the assessment for this stock.

The GADGET model can inform stock trends and catch advice; however, it is not recommended as the sole source of information regarding stock trends and catch advice for the stock annex. More specifically, GADGET should not be the only tool used in the stock annex to assess the status of this stock. Results from the Schaefer surplus production model (WP 13) should also be considered as this incorporates the full catch history. The Schaefer model provides an analytical framework that can provide an estimate of stock depletion, although some prior information on realistic rates of production (r) is needed for this stock.

We recommend investigation of changes in availability of certain size classes of this stock to the survey and methods for dealing with this in future applications of GADGET or other assessment models to this stock.

When assessing this stock, there are potentially important impacts of errors in identification of redfish species (*S. mentella* and *S. marinus*) in commercial catches. The potential impacts are greater for this stock since it comprises a smaller proportion of the redfish stocks in the area, and there is evidence of its substantial depletion of this stock. Furthermore, the misidentification of *S. mentella* and *S. marinus* may be the source of some highly variable recruitment estimates in recent years. A coupled assessment model for both *S. mentella* and *S. marinus* that can take account of errors in catch identification may be a useful approach (e.g. Spencer and Ianelli, 2005).

Golden redfish (*S. marinus*) in V, VI and XIV [Kristján Kristinsson]

4.8.1

Describe GADGET model and sensitivity runs and TSA. Note that both models provide similar results.

Note that the benchmark investigated the difference in the survey data with the skipper selected and randomly selected tow and found no difference in trends.

The major limitation of the application of GADGET to this stock is the poor fits to recent trends in the survey and changes in abundance of the intermediate sized fish. One hypothesis for the changes in abundance of intermediate sized fish in the survey data is movement of these fish into the survey area. One potential model solution for this issue is a parametrization that allows changes in survey selectivity for these sizes over time. Another alternative that is more realistic (but would require detailed data) is a spatial model (possibly with three areas, Greenland, Iceland, and the Faroes) that can account for possible ontogenetic movement patterns. In any case, possible independent evidence of a disparate increase of intermediate sized fish in the closed area relative to the open area should be investigated. An investigation of whether there are similar differences for other species or stocks may also prove informative towards this end.

This benchmark did not have adequate time to scrutinize the TSA model thoroughly; we recommend that it is further investigated as a candidate assessment model in future. With such sophisticated models, it is highly valuable to have the lead assessment scientist present at the benchmark for clarification of details and to perform further iterations of the model with revised specifications.

Arctic *mentella*

4.8.1

Both a GADGET and a SCA model were presented, and provided similar results. The SCA model was preferred because run times were faster allowing for easier investigation of model diagnostics across a wider range of model sensitivity runs. Prior to this choice of SCA as the preferred modelling framework, the GADGET and SCA runs were specified to be as similar as possible.

4.8.5 and beyond

The Workshop discussed possible impacts of cod predation on *S. mentella*. While point estimates of cod predation on *S. mentella* were presented, uncertainty bounds from the predation study results were not available and should be provided in future. The stock assessment model could consider the impact of predation on the default assessment assumption that M is constant over time for the small fish that are subject to predation by cod by allowing for annual variation in M as a function of the predation estimates. Note that the predation impact may be difficult to predict in future from cod diet samples given that *S. mentella* constitute only about 10% of the cod diet while capelin make up a large proportion of the cod diet, so that changes in abundance of the latter could swamp any signal from changed redfish abundance.

Improve the data reliability for older age classes (19+) and expand the assessment model so that these older age classes from fish caught in the fishery can be used in the model, along with an older plus group (e.g. 30+).

The survey scaling factor for the Ecosystem survey is fixed in the SCA assessment. While sensitivity model runs with alternative scaling factors were completed an improved analysis of the uncertainty in the survey scaling factor is needed. For example, estimates of the scaling factor can be obtained by comparing trawl catch rates to acoustically derived abundance estimates expressed in absolute terms (this may be aided by investigating the possibility of using individual count data from acoustic surveys), and the horizontal and vertical distribution of fish should be investigated in order to estimate availability.

In the base model the ecosystem survey selectivity declines from age 2. However, residual patterns indicate that this selectivity may have a dome shape. The model needs more flexible options for dealing with a wider range of selectivity options (which vary both with age/length and with time). There is a need to look for independent evidence that might inform survey selectivity, and in particular could corroborate the existence of the cryptic fish implied by a selectivity that declines at larger age/length.

Extend the model back in time to include earlier catches (i.e. before surveys took place and/or catches were aged) to produce estimates of stock depletion that are more informative in a reference point context. (Many assessment packages provide examples of how to accommodate such information).

Explore the impact of treating the aggregate indices of abundance and biological data (age and length compositions) in the model in separate likelihood functions. This will allow for alternative variance structures for each dataset to be accommodated and explored.

Investigate the desirability of using an aggregate biomass index compared to an aggregate numbers index from surveys in fitting the assessment model (e.g. by determining which leads to lower variance estimates).

When assessing this stock, there are potentially important impacts of errors in identification of redfish species (*S. mentella* and *S. marinus*) in commercial catches. A coupled assessment model for both *S. mentella* and *S. marinus* that can account for error in catch identification may be a useful approach (e.g. Spencer *et al*., 2005).

Conduct a wider exploration of future recruitment scenarios for forecasts, including stochastic recruitment in forecasts.

Northwest *mentella* general

The workshop considered only assessment of stocks as defined by ICES, noting that these definitions arose from detailed consideration at an earlier workshop.

The Schaefer model approach provides robust estimates of the current depletion of these various stocks, but there is usually insufficient contrast in the survey trends for this model to be able to give precise estimates of quantities of importance for management, such as the current sustainable yield (sometimes known as "replacement yields".) However, both bias and precision of the current sustainable yields and reference points from a Schaefer model type approach can be improved in a number of ways:

- Develop and improved prior for Schaefer *r* based on estimates for other redfish populations and relationships with other demographic parameters. Extend this approach to provide a similar prior for natural mortality *M* as well.
- Change from the current age aggregated (Schaefer) to an age-structured production model (ASPM) with a deterministic stock–recruitment relationship; this avoids the bias in the Schaefer model estimates of biomass which may confound comparisons with, for example, estimates of abundance in absolute terms from acoustic surveys. A prior for the stock–recruitment steepness parameter *h* could be obtained from the RAM legacy database.
- Clarify what length-distribution data and otolith samples are available (from both surveys and commercial catches); if otoliths are archived then start collecting them to provide age data for these stocks. Then extend the ASPM to fit also to available length distribution and ageing data (i.e. extending it to a statistical catch-at-age model, and making allowance for variation about the stock–recruitment relationship if there are sufficient data to support such estimation).
- Identification to species of catches should be improved as the current allocation may be incorrect and bias estimates.

Annex 4: Score card results

WKACCU Scorecard *S. marinus* in ICES I and II

How to fill?	No bias	Potential bias	Confirmed bias	Comment
A. SPECIES IDENTIFICATION				
1. Species subject to confusion and trained staff		X		Measures introduced to reduce this
2. Species misreporting		X		Some misreporting (<10%) by fishermen,
		X		QC on species splitting could be improved
3. Taxonomic change	X			
4. Grouping statistics	X			Only 20% of the countries report by species
				This represent, however, 95% of the landings
5. Identification Key	X			
Final indicator		X		
B. LANDINGS WEIGHT				
Recall of bias indicator on species identification		X		
1. Missing part	X			
2. Area misreporting	X			
3. Quantity misreporting	X			
4. Population of vessels	X			
5. Source of information	X			
6. Conversion factor		X		Plan needed for checking the current factors
7. Percentage of mixed in the landings	X			
8. Damaged fish landed	X			
Final indicator		X		
C. DISCARDS WEIGHT				
Recall of bias indicator on species identification		X		
1. Sampling allocation scheme		X		No data on discard available
2. Raising variable		X		
3. Size of the catch effect		X		
4. Damaged fish discarded		X		
5. Non response rate		X		
6. Temporal coverage		X		
7. Spatial coverage		X		
8. High grading		X		
9. Slipping behaviour		X		
10. Management measures leading to discarding behaviour		X		
11. Working conditions		X		
12. Species replacement		X		
Final indicator		X		
D. EFFORT				
Recall of bias indicator on species identification		X		
1. Unit definition	X			
2. Area misreporting	X			
3. Effort misreporting	X			
4. Source of information	X			
Final indicator		X		

E. LENGTH STRUCTURE				
Recall of bias indicator on discards/landing weight				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Random sampling of boxes/trips				
5. Availability of all the landings/discards				
6. Non sampled strata				42% of the metiers-with-catch were covered with length samples
7. Raising to the trip				
8. Change in selectivity				
9. Sampled weight				
Final indicator				
F. AGE STRUCTURE				
Recall of bias indicator on length structure				
1. Quality insurance protocol				
2. Conventional/actual age validity				
3. Calibration workshop				
4. International exchange				
5. International reference set				
6. Species/stock reading easiness and trained staff				
7. Age reading method				
8. Statistical processing				
9. Temporal coverage				27% of the metiers-with-catch
10. Spatial coverage				were covered with age samples.
11. Plus group				Appropriate plus group (30+) and corresponding
12. Incomplete ALK				ALK should be established for catch & surveys
Final indicator				
G. MEAN WEIGHT				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Statistical processing				
5. Calibration equipment				
6. Working conditions				
7. Conversion factor				
8. Final indicator				
H. SEX RATIO				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Staff trained				
5.Size/maturity effect				
6. Catchability effect				
Final indicator				
I. MATURITY STAGE				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Appropriate time period				
3. Spatial coverage				
4. Staff trained				
5. International reference set				
6. Size/maturity effect				
7. Histological reference				
8. Skipped spawning				Skipped spawning is likely to happen in Sebastes. Only potential bias since several age groups in SSB, and effective reprod not used
Final indicator				
Final indicator				

WKACCU Scorecard *S. mentella* in ICES I and II

How to fill?	No bias	Potential bias	Confirmed bias	Comment
A. SPECIES IDENTIFICATION				
1. Species subject to confusion and trained staff		X		Measures introduced to reduce this
2. Species misreporting		X		Some misreporting (<10%) by fishermen,
		X		QC on species splitting could be improved
3. Taxonomic change	X			
4. Grouping statistics	X			Only 30% of the countries report by species
				This represent, however, 96% of the landings
5. Identification Key	X			
Final indicator		X		
B. LANDINGS WEIGHT				
Recall of bias indicator on species identification		X		
1. Missing part	X			
2. Area misreporting	X			
3. Quantity misreporting	X			Unreported bycatch in blue whiting fishery
4. Population of vessels	X			
5. Source of information	X			
6. Conversion factor		X		Plan needed for checking the current factors
7. Percentage of mixed in the landings	X			
8. Damaged fish landed	X			
Final indicator		X		
C. DISCARDS WEIGHT				
Recall of bias indicator on species identification		X		
1. Sampling allocation scheme		X		Data on discards are at present only available
2. Raising variable		X		from the Russian demersal fishery 1983-2002
3. Size of the catch effect		X		and from the Norwegian shrimp fishery
4. Damaged fish discarded		X		(scaled to international level) 1983-2002.
5. Non response rate		X		These data are currently, however, not used in
6. Temporal coverage		X		the assessments, and may hence be a
7. Spatial coverage		X		potential bias.
8. High grading		X		
9. Slipping behaviour		X		
10. Management measures leading to discarding behaviour		X		
11. Working conditions		X		
12. Species replacement		X		
Final indicator		X		

D. EFFORT				
Recall of bias indicator on species identification				
1. Unit definition				
2. Area misreporting				
3. Effort misreporting				
4. Source of information				
Final indicator				
E. LENGTH STRUCTURE				
Recall of bias indicator on discards/landing weight				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Random sampling of boxes/trips				
5. Availability of all the landings/discards				
6. Non sampled strata				The demersal bycatches (about 20% of the
				total catches) are poorly sampled
7. Raising to the trip				
8. Change in selectivity				
9. Sampled weight				
Final indicator				
F. AGE STRUCTURE				
Recall of bias indicator on length structure				
1. Quality insurance protocol				
2. Conventional/actual age validity				
3. Calibration workshop				
4. International exchange				Systematic difference in age readings
				between Russian readers and others
				(ref AFWG 2010/2011)
5. International reference set				related to fish older than 15–20 years
6. Species/stock reading easiness and trained staff				
7. Age reading method				Validated method not followed by all nations
8. Statistical processing				
9. Temporal coverage				The demersal bycatches (about 20% of the
10. Spatial coverage				total catches) are poorly sampled
11. Plus group				Appropriate plus group (30+) and corresponding
12. Incomplete ALK				ALK should be established for catch & surveys
Final indicator				
G. MEAN WEIGHT				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Statistical processing				
5. Calibration equipment				
6. Working conditions				
7. Conversion factor				
8. Final indicator				
H. SEX RATIO				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Staff trained				
5.Size/maturity effect				
6. Catchability effect				
Final indicator				
I. MATURITY STAGE				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Appropriate time period				
3. Spatial coverage				
4. Staff trained				
5. International reference set				
6. Size/maturity effect				
7. Histological reference				
8. Skipped spawning				Skipped spawning is likely to happen in
				Sebastes. Only potential bias since several
				age groups in SSB, and effective reprod
Final indicator				not used
Final indicator				

WKACCU Scorecard *S. marinus* in VXIVb

How to fill?	No bias	Potential bias	Confirmed bias	Comment
A. SPECIES IDENTIFICATION				
1. Species subject to confusion and trained staff		■		Iceland vs. Greenland
2. Species misreporting		■		Some misreporting (reported as redfish)
		■		
3. Taxonomic change	■			
4. Grouping statistics	■			
5. Identification Key	■			
Final indicator		■		
B. LANDINGS WEIGHT				
Recall of bias indicator on species identification				
1. Missing part	■			
2. Area misreporting	■			
3. Quantity misreporting	■			
4. Population of vessels	■			
5. Source of information	■			
6. Conversion factor	■			
7. Percentage of mixed in the landings	■			
8. Damaged fish landed	■			
Final indicator	■			
C. DISCARDS WEIGHT				
Recall of bias indicator on species identification		■		Little data available on discard.
1. Sampling allocation scheme		■		Some measurments done in Iceland but
2. Raising variable		■		little in other areas.
3. Size of the catch effect		■		
4. Damaged fish discarded		■		
5. Non response rate		■		
6. Temporal coverage		■		
7. Spatial coverage		■		
8. High grading		■		
9. Slipping behaviour		■		
10. Management measures leading to discarding behaviour		■		
11. Working conditions		■		
12. Species replacement		■		
Final indicator		■		
D. EFFORT				
Recall of bias indicator on species identification	■			
1. Unit definition	■			
2. Area misreporting	■			
3. Effort misreporting	■			
4. Source of information	■			
Final indicator	■			

E. LENGTH STRUCTURE				
Recall of bias indicator on discards/landing weight				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Random sampling of boxes/trips				
5. Availability of all the landings/discards				Not sampled from vessels where the species is caught as bycatch
6. Non sampled strata				
7. Raising to the trip				
8. Change in selectivity				
9. Sampled weight				
Final indicator				
F. AGE STRUCTURE				
Recall of bias indicator on length structure				Age data lacking from Greenland and Faroe Islands
1. Quality insurance protocol				
2. Conventional/actual age validity				
3. Calibration workshop				
4. International exchange				
5. International reference set				
6. Species/stock reading easiness and trained staff				
7. Age reading method				
8. Statistical processing				
9. Temporal coverage				
10. Spatial coverage				
11. Plus group				
12. Incomplete ALK				
Final indicator				
G. MEAN WEIGHT				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Statistical processing				
5. Calibration equipment				
6. Working conditions				
7. Conversion factor				
8. Final indicator				

H. SEX RATIO				
Recall of bias indicator on length/age structure				Data is lacking from the Faroe Islands and Greenland
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Staff trained				
5.Size/maturity effect				
6. Catchability effect				
Final indicator				
I. MATURITY STAGE				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Appropriate time period				
3. Spatial coverage				
4. Staff trained				
5. International reference set				
6. Size/maturity effect				
7. Histological reference				
8. Skipped spawning				Skipped spawning is likely to happen in
				Sebastes, especially for newly mature fish.
				Only potential bias since several
				age groups in SSB, and effective reprod
Final indicator				not used
Final indicator				

WKACCU Scorecard *S. mentella* in VXIVb

How to fill?	No bias	Potential bias	Confirmed bias	Comment
A. SPECIES IDENTIFICATION				
1. Species subject to confusion and trained staff	■			
2. Species misreporting		■		Some misreporting (reported as redfish)
		■		
3. Taxonomic change	■			
4. Grouping statistics	■			
5. Identification Key	■			
Final indicator		■		
B. LANDINGS WEIGHT				
Recall of bias indicator on species identification				
1. Missing part	■			
2. Area misreporting	■			
3. Quantity misreporting	■			
4. Population of vessels	■			
5. Source of information	■			
6. Conversion factor	■			
7. Percentage of mixed in the landings	■			
8. Damaged fish landed	■			
Final indicator	■			
C. DISCARDS WEIGHT				
Recall of bias indicator on species identification		■		No data available on discard.
1. Sampling allocation scheme		■		
2. Raising variable		■		
3. Size of the catch effect		■		
4. Damaged fish discarded		■		
5. Non response rate		■		
6. Temporal coverage		■		
7. Spatial coverage		■		
8. High grading		■		
9. Slipping behaviour		■		
10. Management measures leading to discarding behaviour		■		
11. Working conditions		■		
12. Species replacement		■		
Final indicator		■		
D. EFFORT				
Recall of bias indicator on species identification	■			
1. Unit definition	■			
2. Area misreporting	■			
3. Effort misreporting	■			
4. Source of information	■			
Final indicator	■			

E. LENGTH STRUCTURE				
Recall of bias indicator on discards/landing weight				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Random sampling of boxes/trips				
5. Availability of all the landings/discards				
6. Non sampled strata				
7. Raising to the trip				
8. Change in selectivity				
9. Sampled weight				
Final indicator				
F. AGE STRUCTURE				
Recall of bias indicator on length structure				Otoliths are sampled but little been age read
1. Quality insurance protocol				
2. Conventional/actual age validity				
3. Calibration workshop				
4. International exchange				
5. International reference set				
6. Species/stock reading easiness and trained staff				
7. Age reading method				
8. Statistical processing				
9. Temporal coverage				
10. Spatial coverage				
11. Plus group				
12. Incomplete ALK				
Final indicator				
G. MEAN WEIGHT				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Statistical processing				
5. Calibration equipment				
6. Working conditions				
7. Conversion factor				
8. Final indicator				
H. SEX RATIO				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Staff trained				
5.Size/maturity effect				
6. Catchability effect				
Final indicator				
I. MATURITY STAGE				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Appropriate time period				
3. Spatial coverage				
4. Staff trained				
5. International reference set				
6. Size/maturity effect				
7. Histological reference				
8. Skipped spawning				Skipped spawning is likely to happen in
				Sebastes, especially for newly mature fish.
				Only potential bias since several
				age groups in SSB, and effective reprod
Final indicator				not used
Final indicator				

WKRED WKACCU Scorecard Greenland slope *mentella*

How to fill?	No bias	Potential bias	Confirmed bias	Comment
A. SPECIES IDENTIFICATION				
1. Species subject to confusion and trained staff			■	
2. Species misreporting			■	
3. Taxonomic change	■			
4. Grouping statistics	■			
5. Identification Key		■		
Final indicator			■	Separation between *S. mentella* and *S. marinus* is problematic.
B. LANDINGS WEIGHT				
Recall of bias indicator on species identification				
1. Missing part				not possible
2. Area misreporting	■			
3. Quantity misreporting		■		not properly examined
4. Population of vessels		■		
5. Source of information	■			
6. Conversion factor	■			
7. Percentage of mixed in the landings		■		
8. Damaged fish landed	■			
Final indicator		■		Some vessels may catch cod and misreport.
C. DISCARDS WEIGHT				
Recall of bias indicator on species identification				
1. Sampling allocation scheme		■		
2. Raising variable		■		
3. Size of the catch effect				unknown
4. Damaged fish discarded	■			
5. Non response rate	■			
6. Temporal coverage		■		
7. Spatial coverage		■		
8. High grading	■			
9. Slipping behaviour	■			
10. Management measures leading to discarding behaviour				unknown
11. Working conditions	■			
12. Species replacement		■		
Final indicator		■		Discards are not well sampled due to few observers.
D. EFFORT				
Recall of bias indicator on species identification				
1. Unit definition			■	
2. Area misreporting				unknown
3. Effort misreporting				unknown
4. Source of information	■			
Final indicator		■		Potential biases linked to problems with species identification

E. LENGTH STRUCTURE				
Recall of bias indicator on discards/landing weight				Some vessels may catch cod and misreport.
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Random sampling of boxes/trips				
5. Availability of all the landings/discards				
6. Non sampled strata				
7. Raising to the trip				
8. Change in selectivity				
9. Sampled weight				unknown
Final indicator				Lake a of proper spatial and temporal
				sampling may give biased length structures.
F. AGE STRUCTURE				
Recall of bias indicator on length structure				Lake a of proper spatial and temporal
1. Quality insurance protocol				age not determined.
2. Conventional/actual age validity				
3. Calibration workshop				
4. International exchange				
5. International reference set				
6. Species/stock reading easiness and trained staff				
7. Age reading method				
8. Statistical processing				
9. Temporal coverage				
10. Spatial coverage				
11. Plus group				
12. Incomplete ALK				
Final indicator				
G. MEAN WEIGHT				
Recall of bias indicator on length/age structure				
1. Sampling protocol				same as for length structure
2. Temporal coverage				
3. Spatial coverage				
4. Statistical processing				
5. Calibration equipment				
6. Working conditions				
7. Conversion factor				
8. Final indicator				
H. SEX RATIO				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Staff trained				
5.Size/maturity effect				
6. Catchability effect				
Final indicator				
I. MATURITY STAGE				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Appropriate time period				
3. Spatial coverage				
4. Staff trained				
5. International reference set				
6. Size/maturity effect				
7. Histological reference				
8. Skipped spawning				
Final indicator				The lack of proper spatial and temporal sampling may well introduce bias. The staff is relatively new at determining maturity in redfish.
Final indicator				

Annex 5: Stock Annexes

Stock Annex: Golden redfish Subareas I and II

Stock	Golden redfish *Sebastes marinus* in ICES Subareas I and II
Working Group	Arctic Fisheries Working Group
Date	06.05.2010

A. General

A.0. Biology and ecology

Golden redfish is distributed in the Barents Sea from the northwest coast of Norway along the continental slope up to the Bear Island and further to the Spitsbergen slope, but more in the southern part of the Arctic Sea than beaked redfish.

Golden redfish is a long-lived and slow-growing fish. Longevity is greater than 50 years and maximum registered length is 122 cm. Fifty percent of individuals reach maturity by the age of 12 years.

Fertilization of eggs is internal and females release larvae several months after copulation took place. A schematic illustration of the distribution of the stock and of the areas of larval extrusion is given in Figure 1. Pelagic larvae of golden redfish drift after the extrusion with the warm Atlantic currents north to Barents Sea, to the Bear Island and Spitsbergen areas, and eastwards along the Norwegian and Murmansk coasts.

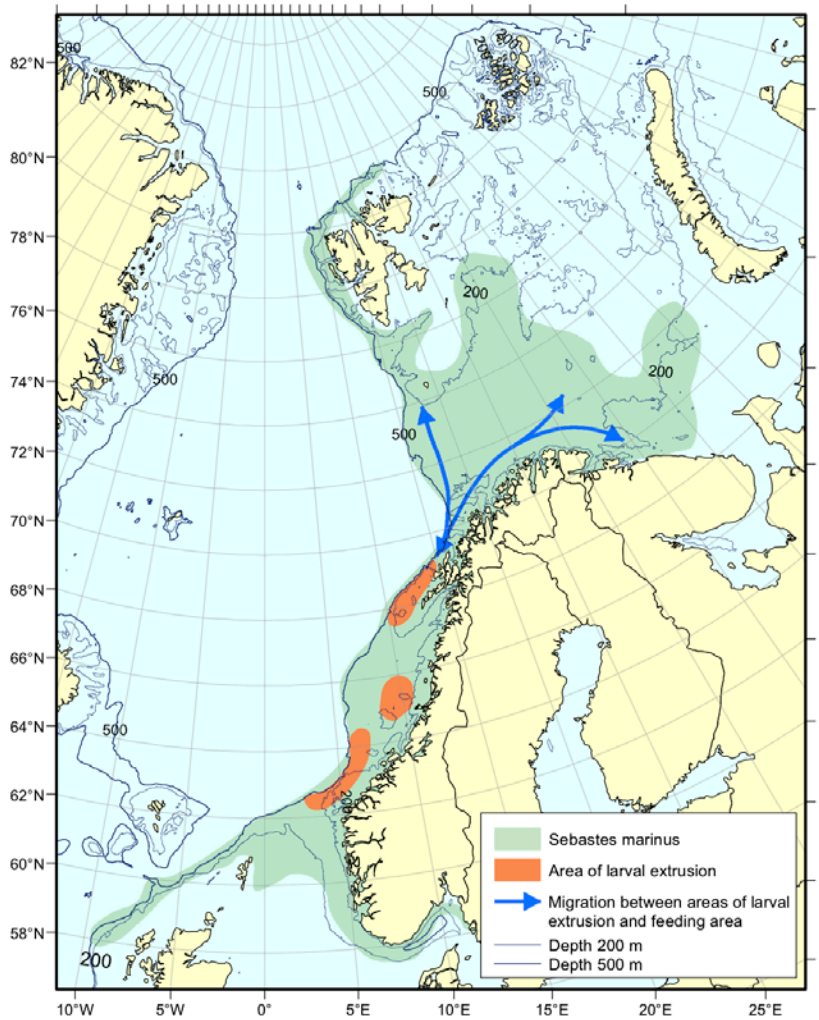

Figure 1. *Sebastes marinus* in ICES areas I and II. geographical distribution, areas of larval extrusion and migration routes. Reproduced from Drevetnyak *et al.* (2011).

A.1. Stock definition

The stock of *Sebastes marinus* (golden redfish) in ICES Subareas I and II is found in the northeast Arctic from 62°N in the south to north of Spitsbergen. The Barents Sea area is first of all a nursery area, and relatively few fish are distributed outside Spitsbergen. *S. marinus* are distributed all over the continental shelf southwards to beyond 62°N, and also along the coast and in the fjords. The main areas of larval extrusion are outside Vesterålen, on the Halten Bank area and on the banks outside Møre. The peak of larval extrusion takes place ca. one month later than *S. mentella*, i.e. during the beginning of May. Genetic studies have not revealed any hybridization with *S. marinus* or *S. viviparus* in the area.

A.2. Fishery

The fishery for *Sebastes marinus* (golden redfish) is mainly conducted by Norway which accounts for 80–90% of the total catch. Germany also has a long tradition of a trawl fishery for this species. The fish are caught mainly by trawl and gillnet, and to a lesser extent by longline and handline. The trawl and gillnet fishery have benefitted from the females concentrating on the “spawning” grounds during spring. Some of the catches, and most of the catches taken by other countries, are taken in mixed fisheries together with saithe and cod. Important fishing grounds are the Møre area (Svinøy), Halten Bank, the banks outside Lofoten and Vesterålen, and Sleppen outside Finnmark. Traditionally, *S. marinus* has been the most popular and highest priced redfish species.

Until 1 January 2003 there were no regulations particular for the *S. marinus* fishery, and the regulations aimed at *S. mentella* had only marginal effects on the *S. marinus* stock. After this date, all directed trawl fishery for redfish (both *S. marinus* and *S. mentella*) is forbidden in the Norwegian Economic Zone north of 62°N. During 2003 and 2004, when fishing for other species it was legal to have up to 20% redfish (both species together) in round weight as bycatch per haul and on board at any time. Since 1 January 2005 this percentage has been reduced to 15%.

A minimum legal catch size of 32 cm has been set for all fisheries (since 14 April 2004), with the allowance to have up to 10% undersized (i.e. less than 32 cm) specimens of *S. marinus* (in numbers) per haul.

Until April 2004 there were no regulations of the other gears/fleets than trawl fishing for *S. marinus*. Since then, different limited moratoriums have been enforced in all fisheries except trawl and handline vessels less than 11 meters. The moratorium has been from 1–31 May in 2004, 20 April–19 June in 2005 and during April–May and September in 2006. Since 2007 the moratorium has been during five months, i.e. March–June and September. When fishing for other species (also during the moratorium), it is allowed for these fleets to have up to 15% (in 2004, 20%) bycatch of redfish (in round weight) summarized during a week fishery from Monday to Sunday.

Since 1 January 2006 it is forbidden to use gillnets with mesh size less than 120 mm when fishing for redfish.

Since 1 January 2006, the maximum bycatch of redfish (both *S. mentella and S. marinus*) juveniles in the international shrimp fisheries in the northeast Arctic has been reduced from ten to three redfish per 10 kg shrimp.

A.3. Ecosystem aspects

B. Data

B.1. Commercial catch

The landings statistics used by the Arctic Fisheries Working Group (AFWG) are those officially reported to ICES. In cases where such reportings to ICES do not exist, reportings made directly to Norwegian authorities during the fishery have been used as preliminary figures. Norwegian commercial catch in tonnes by quarter, area and gear are derived from the sales notes statistics of The Directorate of Fisheries. Data from about 20 subareas are aggregated for the gears gillnet, longline, handline, Danish seine and bottom trawl. For bottom trawl the quarterly area distribution of the catches is area adjusted by logbook data from The Directorate of Fisheries. No discards are reported or accounted for. Reliable estimates of species breakdown (*S. mentella* vs. *S. marinus*) by area are available back to 1989. The national landings of redfish for Norway and Russia are split into species by the respective national laboratories. For other countries (and areas) the AFWG has split the landings into *S. mentella* and *S. marinus* based on reports from different fleets to the Norwegian fisheries authorities.

The Norwegian sampling strategy is to have age–length samples from all major gears in each area and quarter. There are at present no defined criteria on how to allocate samples of catch numbers, mean length and mean weight-at-age to unsampled catches, but the following general process has been applied: First look for samples from a neighbouring area if the fishery extends to this area in the same quarter. If there are no samples available in neighbouring areas, search in neighbouring quarters, first from the same gear in the same area, then from neighbouring areas and similar gears. The last option is to search for samples from other gears with the most similar selectivity in the same area or in neighbouring areas. For some gears, areas and quarters length samples taken by the coast guard are applied and combined with an ALK from a neighbouring area, gear or quarter. ALKs from research surveys (shrimp trawl) are also used to fill holes.

For Norway, weights-at-age in the catch are estimated according to the formula which gives the best fit to the length–weight data pairs collected during the year and applied to the mean length-at-age.

The text table below shows which country supplies which kind of data:

	Kind of data					
Country	Caton (catch in weight) on unidentified redfish	Caton (catch in weight) on *S. marinus*	Canum (catch-at-age in numbers)	Weca (weight-at-age in the catch)	Matprop (proportion mature by age)	Length composition in catch
Norway		x	x	x		x
Russia		x				x
Germany	x	x[2)				x
UK	x	1)				
France	x	1)				
Spain	x	1)				
Portugal	x	1)				
Ireland	x	1)				
Greenland	x	1)				
Faroe Islands[1)]						
Iceland	x	1)				

1) As reported to Norwegian authorities during the fishery (only for the Norwegian Economic Zone and Svalbard).

2) Irregularly.

The Norwegian and German input files are Excel spreadsheet files, while the Russian input data are supplied on paper and later punched into Excel spreadsheet files before aggregation to international data. The data should be found in the national laboratories and with the stock coordinator.

The national data have been aggregated to international data on Excel spreadsheet files. The Russian and German length composition has been applied on the Russian and German landings, respectively, using an age–length-key (ALK) and weight-at-age data from the Norwegian trawl landings. Catches from the other countries were assumed to have the same age composition and weight-at-age as the Norwegian trawl landings. In some years the final German and Russian numbers-at-age have been adjusted to remove SOP discrepancies before aggregation to international data. The Excel spreadsheet files used for age distribution, adjustments and aggregations can be found with the Norwegian stock coordinator and for the current and previous year in the ICES computer system under **w:\acfm\afwg\<year>\personal\name** (of stock coordinator).

The result files (FAD data) can be found at ICES and with the stock coordinator, either in the IFAP system as SAS datasets or as ASCII files on the Lowestoft format, either under **w:\acfm\afwg\<year>\data\smr-arct** or **w:\ifapdata\eximport\afwg\smr-arct**.

B.2. Biological

The total catch-at-age data back to 1991 are based on Norwegian otolith readings. In 1989–1990 it was a combination of the German scale readings on the German catches, and Norwegian otolith readings for the rest. In 1984–1989 only German scale readings were available; while in the years prior to 1984 Russian scale readings exist.

Weight-at-age in the stock is assumed to be the same as weight-at-age in the catch.

When an analytical assessment is made, a fixed natural mortality of 0.1 is used both in the assessment and the forecast.

Both the proportion of natural mortality before spawning (M_{prop}) and the proportion of fishing mortality before spawning (F_{prop}) are set to 0.

A knife-edge maturity-at-age 15 (age 15 as 100% mature) has been used for this stock. Since 2006 a maturity ogive has been modelled and estimated by the GADGET model.

B.3. Surveys

The results from the following research vessel survey series have annually been evaluated by the Working Group:

1) Norwegian Barents Sea bottom-trawl survey (February) from 1986–2009 in fishing depths of 100–500 m. Data are available on length for the years 1986–2009, and on age for the years 1992–2008. This survey covers important nursery areas for the stock;

2) Norwegian Svalbard (Division IIb) bottom-trawl survey (August–September) from 1985–2008 in fishing depths of 100–500 m. This survey covers the northernmost part of the species' distribution;

3) Data on length and age from both these surveys have been simply added together and used in the assessments;

4) Catch rates (numbers/nautical mile) and acoustic indices of *Sebastes marinus* from the Norwegian Coastal and Fjord survey in 1995–2008 from Finnmark to Møre. Since 2003, only catch rates are available.

A schematic illustration of these survey-series is given below in Figure 2.

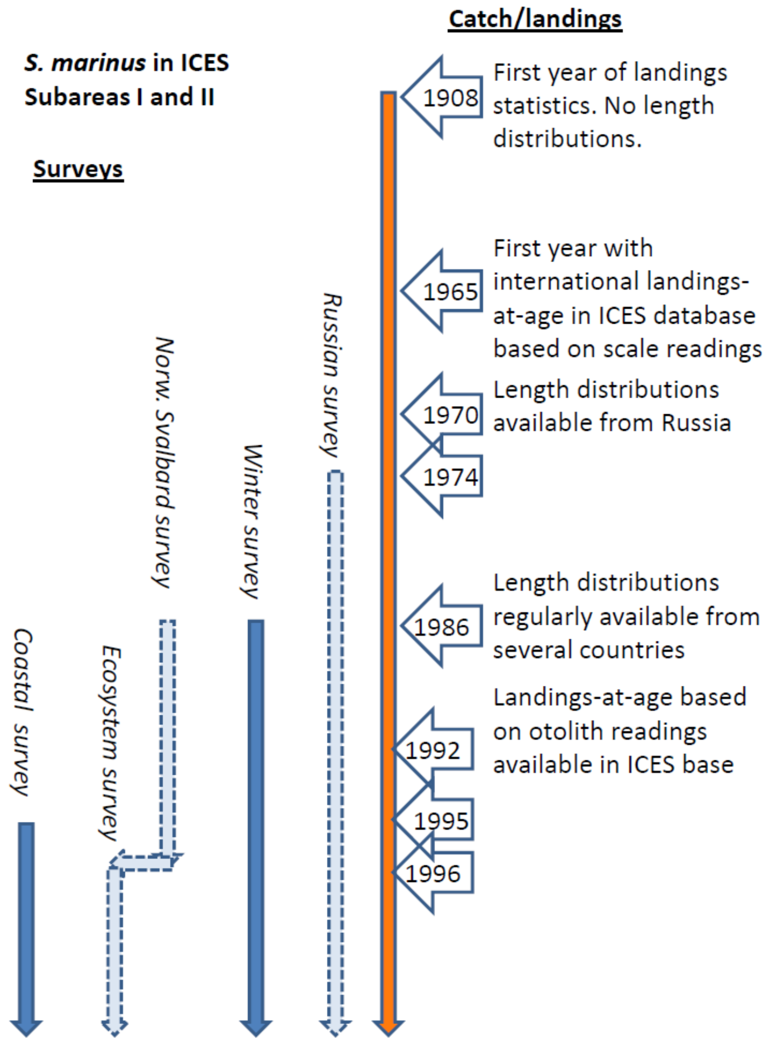

Figure 2. Illustration of the available time-series of surveys and catch/landings data. Solid blue arrows show the scientific surveys currently used in the Gadget model, while the dotted light blue arrows show available surveys currently not used.

B.4. Commercial cpue

The former (until 2002) cpue series for *S. marinus* from Norwegian 32–50 meter freezer trawlers has been improved (e.g. analysing the trawl data with regards to vessel length instead of vessel tonnage) and presented from 1992 onwards. Only data from days with more than 10% *S. marinus* in the catches (in weight) were included in the annual averages together with data on vessel days (i.e. effort) meeting the 10% criterion.

B.5. Other relevant data

None.

C. Historical stock development

The development of the stock has annually been discussed and evaluated based on the research survey-series, and information from the fishery.

In some years trial analytical XSA assessments have been made and discussed by the Working Group.

Since WG2005, experimental analytical assessments have been conducted on this stock using GADGET, and results presented for the years 1990–last year. This model has been evaluated at the WKRED Benchmark (2012), and it is recommended that this remain the basis for advice, with results from a Schaefer model being used to "sanity check" the results.

The GADGET model used for the assessment of *S. marinus* in Areas I and II is closely related to the GADGET model that currently is used by the ICES Northwestern WG on *S. marinus* (Björnsson and Sigurdsson, 2003). The functioning of a Gadget model, including parameter estimation, is described in Bogstad *et al*. (2004). The model used on this stock was for the first time presented to ACFM in 2005. The method was more thoroughly reviewed and described in AFWG report 2006. The main model period has been considered to be from 1990, with earlier years acting as a lead-in period to the model. *S. marinus* has been modelled with a single-species, single-area model, with mature and immature fish considered two population groups. The fish were modelled in 1 cm length categories. The age and length ranges were defined as 3–30+ and 1–59+ cm, respectively.

S. marinus was considered to have von Bertanlanffy growth (Nedreaas, 1990) with parameters estimated within the model. The length–weight relationship w=0.000015*l^3.0 (where w is in kilogramme and l in cm) was used and kept constant between seasons and years. There has been no cannibalism or modelled predation; mortality has been exclusively due to fishing and residual natural mortality was set initially at 0.1. Following the WKRED Benchmark meeting 2012, natural mortality within the model has been altered to 0.05. Recruitment was handled as a number of recruits estimated per year, and no attempt at closure of the life cycle was attempted. Maturity is explicitly modelled, allowing for a direct estimate of the spawning stock. Estimated parameters were: an L50 and slope parameters for the fleets, two growth parameters, annual recruitment, four parameters governing commercial selectivity (two per fleet), several parameters per survey governing selectivity (two per fleet), initial population numbers for mature and immature fish by age.

Data used for tuning are:

- Quarterly length distribution of the landings from two commercial fishing fleets;
- Quarterly age–length keys from the same fishing fleets;
- Length disaggregated survey indices from the Barents Sea (Division IIa) bottom-trawl survey (February) from 1990–2009 (Table D12a);
- Age–length keys from the same survey (Table D12b);
- Estimated maturity ogives for the population for 1993–2007.

The fishing was handled as two main, and two subsidiary fleets. The Norwegian trawl and gillnet fleets were both fully modelled, with estimated selectivity for each, accounting for about 70–80% of the total catch in tonnes. The amount fished in each time-step of one quarter of the year was input from catch data as a fixed amount. No account of possible errors in the catch-in-tons data was made. Two additional fleets have been considered; the international trawl fleet and a fleet made up by combining all other minor Norwegian fishing methods. Both these fleets have quarterly catch-in-tons specified, and have used the same selectivity as the Norwegian trawl fleet. In addition to catch-in-tons, quarterly catch in numbers-at-length and age–length keys have been used. The format of the selectivity (L50) was selected and assumed to remain constant over time for each fleet.

The Barents Sea survey data were used as age–length keys giving the distribution within a single year, and as a purely length based survey index giving year-to-year variations in numbers by length. Prior to 1992 only length and weight data were recorded; after that data on annual age readings (and hence age–length data) are also available. The time period 1990–2006 was used, and the age–length key for 1992 was also used as age–length key for 1990–1991.

D. Short-term projection

Model used: Visual inspection/analysis of survey results together with information from the fishery and Gadget model outputs. As a result of uncertainties surrounding the recruitment signal, no full analytical short-term projection has been made for this stock. However, Gadget model runs can be conducted to estimate the optimum yield-per-recruit, and the optimum catch from the stock if recent average recruitment were to continue.

E. Medium-term projections

Model used: Visual inspection/analysis of survey results together with information from the fishery and Gadget model outputs. As a result of uncertainties surrounding the recruitment signal, and the lack of a good SSB-recruitment relationship, no full analytical medium-term projection has been made for this stock. However, Gadget model runs can be conducted to estimate the optimum yield-per-recruit, and the optimum catch from the stock if recent average recruitment were to continue.

Uncertainty models used: None.

F. Long-term projections

Not done.

G. Biological reference points

Analysis at WKRED (2012) using a Schaefer model suggested that the stock is heavily depleted. Uncertainties over recent recruitment (from erratic signals in the survey data and concerns over species identification for young fish) and the absence of knowledge of productivity or SSB-recruitment relationships precludes medium–long-term projections of the stock.

Until an analytical assessment can be accepted and used as basis for reference points calculations for this stock, candidate reference points for the biomass could be set at the average biomass level, or at a certain percentage of this level, estimated by the Russian and Norwegian trawl surveys since 1986. ACFM is supporting this suggestion and states that U-type reference points could be developed provided that a sufficient long time-series demonstrating a dynamic range is available. Also the reference point should be expressed in biomass units (SSB or fishable stock), and work has hence been initiated to present the survey time-series also in biomass units (also as SSB and fishable stock).

A maximum exploitation rate of 5% has been suggested sustainable for long-lived species like *Sebastes* spp. when the stocks show no sign of reduced reproductive potential (ref. pelagic redfish in the Irminger Sea and for several rockfish in the Pacific). Based on the selection curves for the fleets, a reasonable classification of the fishable biomass would be the mature biomass. A corresponding 5% harvest of this would yield not more than 1500 tonnes. Work conducted at WKRED (2012) using GADGET suggested that a catch of around 1500 tonnes represented the optimum given current stock size and recruitment levels. This figure was similar to that obtained by a Schaefer model at the same meeting.

H. Other issues

A major source of uncertainty in the *S. marinus* stock is the level of recent recruitment. This is uncertain for two different reasons. Firstly, the recruitment signal in the winter survey has been erratic, with the small fish being observed intermittently between years. Secondly, the good year classes in the survey correspond to the years of known good recruitment in the much larger *S. mentella* stock in the region. Species identification is difficult for young fish of these species, and a species misidentification rate of less than 5% of *S. mentella* as *S. marinus* would completely account for the recent apparent recruitment of *S. marinus*. Until these fish enter the fishery caution is needed in the estimates of recent recruitment.

I. References

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Nedreaas, K. 1990. Age determination of Northeast Atlantic *Sebastes* species. J. Cons. int. Explor. Mer 47, 208–230.

WKRED. 2012. ICES CM 2012/ACOM:48.

Stock Annex: Beaked redfish Arctic *Sebastes mentella* in Subareas I and II

ACOM considers it not necessary to assess this stock every year since the status of the stock can clearly be deduced from the surveys. No analytical assessment has been carried out since 2003. A new analytical assessment was conducted in 2012.

Stock	Arctic *Sebastes mentella* (beaked Redfish) in Subareas I and II
Working Group	Arctic Fisheries Working Group (AFWG)
Date	01.03.12

A. General

A.1. Stock definition

The stock of *Sebastes mentella* (beaked redfish) in ICES Subareas I and II, also known as the Norwegian-Barents Sea stock, is found in the northeast Arctic from 62°N in the south to the Arctic ice north and east of Spitsbergen (Figure 1). The southwestern Barents Sea and the Spitsbergen areas are first of all nursery areas. Although some adult fish may be found in smaller subareas, the main behaviour of *S. mentella* is to migrate westwards and southwestwards towards the continental slope and out in the pelagic Norwegian Sea as it grows and becomes adult. In the Norwegian Sea and along the slope south of 70°N only few specimens less than 28 cm are observed, and on the shelf south of this latitude *S. mentella* are only found along the slope from about 450 m down to about 650 m depth. The southern limit of its distribution is not well defined but is believed to be somewhere on the slope northwest of Shetland. The stock boundary 62°N is therefore more for management purposes than a biological basis for stock separation, although the abundance of this species south of this latitude becomes less. The main areas of larval extrusion are along the slope from north of Shetland to west of Bear Island. The peak of larval extrusion takes place during the first half of April. Genetic studies have not revealed any hybridization with *S. marinus* or *S. viviparus* in the area. Recent genetic studies revealed no differentiation between *S. mentella* in the Norwegian Sea and the Barents Sea.

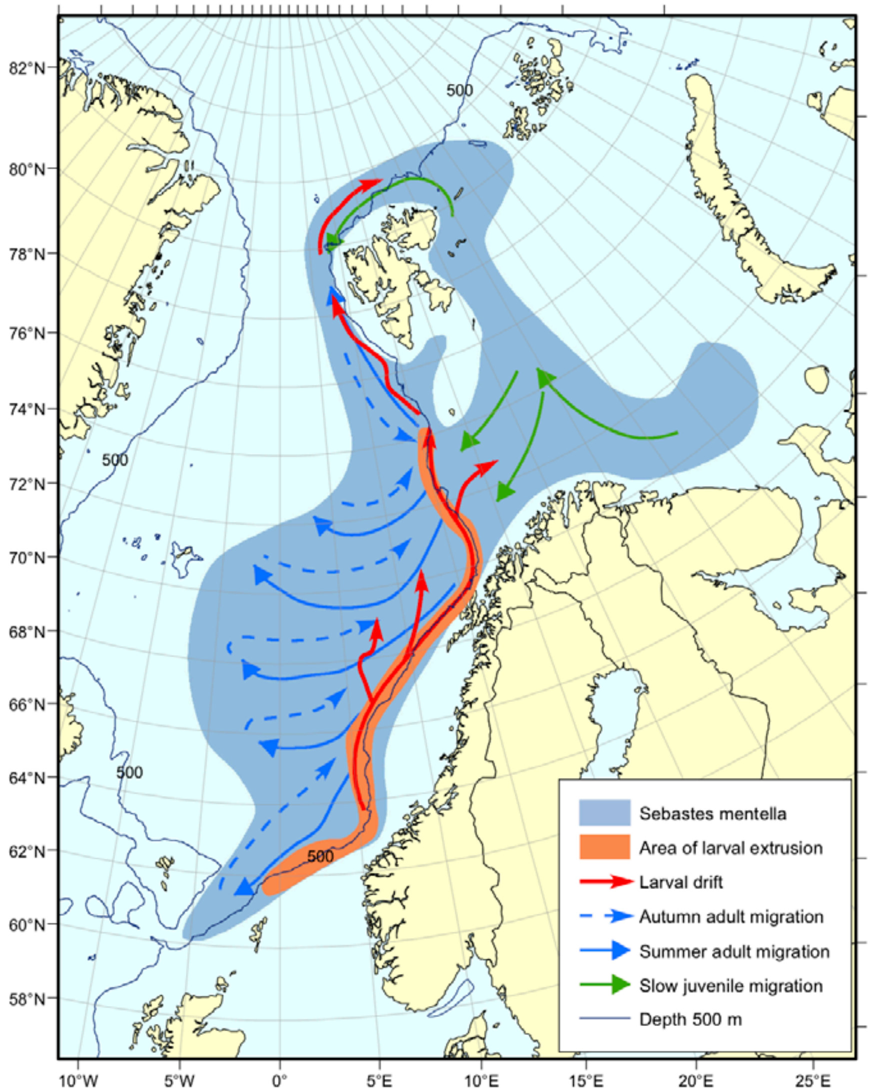

Figure 1. Beaked redfish distribution, area of larval extrusion larval drift and migration routes. Reproduced from Drevetnyak *et al*. (2011).

A.2. Fishery

The only directed fisheries for *Sebastes mentella* (deep-sea redfish) are trawl fisheries. Bycatches are taken in the cod fishery, occasionally also by longline, and as juveniles in the shrimp trawl fisheries. Traditionally, the fishery for *S. mentella* was conducted by Russia and other East European countries on grounds located south of Bear Island towards Spitsbergen. The highest landings of *S. mentella* were 293 000 t in 1976. This was followed by a rapid decline to about 80 000 t in 1979–1981, and a second peak of 114 000 t in 1982. The fishery in the Barents Sea decreased in the mid-1980s to the low level of 10 500 t in 1987. At this time Norwegian trawlers showed interest in fishing *S. mentella* and started fishing further south, along the continental slope at approximately 500 m depth. These grounds had never been harvested before and were inhabited primarily by mature redfish. After an increase to 49 000 t in 1991 due to this new fishery, landings have been at a level of 10 000–15 000 t, except in 1996–1997 when they dropped to 8000 t. Since 1991 the fishery has been dominated by Norway and Russia. Since 1997 ACFM has advised that there should be no directed fishery and that the bycatch should be reduced to the lowest possible level.

Strong regulations were enforced in the fishery in 1997. Since then it has been forbidden to fish redfish (both *S. marinus* and *S. mentella*) in the Norwegian EEZ north and west of straight lines through the positions:

1) N 7000′ E 0521′

2) N 7000′ E 1730′

3) N 7330′ E 1800′

4) N 7330′ E 3556′

and in the Svalbard area (Division IIb). When fishing for other species in these areas, a maximum 25% bycatch (in weight) of redfish in each trawl haul is allowed.

To provide additional protection of the adult *S. mentella* stock, two areas south of Lofoten have been closed for all trawl fishing since 1 March 2000. The two areas (A and B) are delineated by straight lines between the following positions:

A	B
1. N 6630′ E 0659′	1. N 6236′ E 0300′
2. N 6621′ E 0644′	2. N 6210′ E 0115′
3. N 6543′ E 0600′	3. N 6240′ E 0052′
4. N 6520′ E 0600′	4. N 6300′ E 0300′
5. N 6520′ E 0530′	
6. N 6600′ E 0530′	
7. N 6630′ E 0634.27′	

Area A has recently been enlarged to include the continental slope north to N 67°10′.

Since 1 January 2003 all directed trawl fishery for redfish (both *S. marinus* and *S. mentella*) is forbidden in the Norwegian Economic Zone north of 62°N. When fishing for other species it is legal to have up to 20% redfish (both species together) in round weight as bycatch per haul and on board at any time. Since 1 January 2005 the bycatch percentage has been reduced to 15% (both species together).

From 1 January 2000 until 31 December 2005 a maximum legal bycatch criterion of ten juvenile redfish (both *S. marinus*, *S. mentella* and *S. viviparus*) per 10 kg shrimp has been enforced in the shrimp fishery. Since 1 January 2006 this bycatch criterion has been reduced to three juvenile redfish (both *S. marinus*, *S. mentella* and *S. viviparus*) per 10 kg shrimp.

Landings of *S. mentella* taken in the pelagic fishery for blue whiting and herring in the Norwegian Sea have for some countries for some years been reported to the working group. In 2004–2006 this fishery developed further to become a directed and free fishery in 2006. Faroes and Russian vessels were the first to report large catches in 2004. Since 2007 NEAFC has decided on a TAC to be fished in an Olympic fishery starting in August each year. In 2008, seven countries and 31 trawlers were involved in this fishery. Although single specimens of *S. marinus* occasionally may be observed and caught, biological samples of the catches collected by observers and fishers show that the commercial catches are completely dominated by the deep-water redfish *S. mentella*.

Vinnichenko (WD 9, AFWG 2007) gives a good and comprehensive description of the previous abundance of pelagic *S. mentella* in the international waters of the Norwegian Sea, and how bycatches and exploratory fishing have developed during 1979–2006.

From the first years with a free pelagic fishery, i.e. 2005–2006, it is possible to observe the seasonality and migration pattern of this pelagic behaviour of the *S. mentella*. During summer small quantities of redfish were present regularly in catches from the blue whiting and herring fisheries in the international waters of the Norwegian Sea and the Bear Island-Spitsbergen area. Targeted redfish fishery began south of the Mohn Ridge (i.e. the ridge separating the Norwegian Sea into two main basins) in August. The fishery was conducted with gigantic "Gloria" trawls. The fishery finished at the beginning of November after the redfish dispersed and migrated eastwards into the Norwegian EEZ and the Svalbard fishery protection zone.

Some countries have only reported catches taken in Subarea IIa, without information whether the fish were caught pelagic or demersal. For these countries, the WG has considered all catches not reported to Norwegian authorities as being caught in international waters outside the EEZ.

Bycatch of herring could be a problem during daytime trawling in these waters at the time of the Olympic fishery (August–September). In some catches with the research survey trawl (40 mm mesh size in codend) up to 30% (in weight) herring was caught as bycatch when targeting the redfish. Even with a commercial trawl (100 mm mesh size in codend) reports from the fishery show that mixed catches of herring may occur. Even if some of the herring escape through the meshes, mortality through mesh selection may be high. During the 2007 Olympic fishery bycatches of blue whiting were small. Best catch-rates of *S. mentella* were usually achieved during daytime. According to the skippers they observed and obtained the best catch-rates of redfish about 50 meters deeper than last year, i.e. at about 400 m. Two tons redfish per trawl hour was considered a very good catch rate. With a common haul duration of 18 hours, catch rates of 30–40 tons/day were not uncommon. Even catch rates up to 70 tons/day were reported.

The redfish population in Subarea IV (North Sea) is believed to belong to the Northeast Arctic stock. Since this area is outside the traditional areas handled by this Working Group, the catches are tabulated but not included in the assessment. The landings from Subarea IV have been 1000–3000 t per year. Historically, these landings have been *S. marinus*, but since the mid-1980s trawlers have also caught *S. mentella* in Subarea IV along the northern slope of the North Sea. Approximately 80% of the Norwegian catches in Subarea IV are considered to be *S. mentella*.

A.3. Ecosystem aspect

As 0-group and juvenile fish, this stock is an important plankton eater in the Barents Sea, and when this stock was sound, 0-group fish have been observed in great abundance in the upper layers utilizing the plankton production. Especially during the first five–six years of life *S. mentella* is also preyed upon by other species, of which its contribution to the cod diet is well documented.

B. Data

B.1. Commercial catch

The landings statistics used by the Arctic Fisheries Working Group (AFWG) are those officially reported to ICES. In cases where such reports to ICES do not exist, reports made directly to Norwegian authorities during the fishery have been used as preliminary figures. Norwegian commercial catch in tonnes by quarter, area and gear are derived from the sales notes statistics of The Directorate of Fisheries. Data are aggregated on 17 areas for bottom trawl. Because of uncertainties in the geographical allocation of reported catches, the quarterly areal distributions of bottom-trawl catches are area adjusted on the basis of logbook data available from The Directorate of Fisheries. No discards are reported or taken into account. Reliable estimates of species breakdown (*S. mentella* vs. *S. marinus*) by area are available back to 1989. The national landings of redfish for Norway and Russia are split into species by the respective national laboratories. For other countries (and areas) the AFWG has split the landings into *S. mentella* and *S. marinus* based on reports from different fleets to the Norwegian fisheries authorities.

The Norwegian sampling strategy is to have age–length samples from all major gears in each area and quarter. There are at present no defined criteria on how to allocate samples of catch numbers, mean length and mean weight-at-age to unsampled catches, but the following general process has been applied. First look for samples from a neighbouring area if the fishery extends to this area in the same quarter. If there are no samples available in neighbouring areas, search in neighbouring quarters, first from the same gear in the same area, then from neighbouring areas and similar gears. The last option is to search for samples from other gears with the most similar selectivity in the same area or in neighbouring areas. For some gears, areas and quarters length samples taken by the coast guard are applied and combined with an ALK from a neighbouring area, gear or quarter. ALKs from research surveys (shrimp trawl) are also used to fill holes.

For Norway, weights-at-age in the catch are estimated from the length proportions-at-age in the catch combined with a length–weight equation of the for Weight = a*(Length)^b. The equation coefficients a and b are estimated annually from biological samples.

The text table below shows data types supplied by individual countries:

	Kind of data					
Country	Caton (catch in weight) of unidentified redfish	Caton (catch in weight) of *S. mentella*	Canum (catch-at-age in numbers)	Weca (weight-at-age in the catch)	Matprop (proportion mature by age)	Length composition in catch
Norway		x	x	x	x	X
Russia		x	x[2)]	x[2)]	X (1986–2001)	X
Germany	x	x[3)]				x[3)]
UK	x	[1)]				
France	x	[1)]				
Spain	x	[1)]				
Portugal	x	[1)]				x
Ireland	x	[1)]				
Greenland	x	[1)]				
Faroe Islands[1)]						
Iceland	x	[1)]				

[1)] As reported to Norwegian authorities during the fishery (only for the Norwegian Economic Zone and Svalbard).

[2)] For main fishing area until 2001.

[3)] Irregularly.

The Norwegian, Russian and German input files are Excel spreadsheet files. The data should be found in the national laboratories and also held by the stock coordinator. The data will soon be included in InterCatch.

The national data have been aggregated to international data on Excel spreadsheet files. The Russian and German length compositions have been assumed to apply to the Russian and German landings, respectively, using an annual age–length key (ALK) and weight-at-age data from the Norwegian trawl landings. Catches from the other countries were assumed to have the same age composition and weight-at-age as the Norwegian trawl landings. The Excel spreadsheet files used for age distribution, adjustments and aggregations can be found with the stock coordinator and for the current and previous year in the ICES AFWG SharePoint under 'Data'.

Historic result files (FAD data) can be found at ICES and with the stock coordinator, either in the IFAP system as SAS datasets or as ASCII files on the Lowestoft format, either under **w:\acfm\afwg\<year>\data\smn_arct** or **w:\ifapdata\eximport\afwg\smn_arct**.

B.2. Biological

Since 1991, the catch in numbers-at-age of *S. mentella* from Russia is based on otolith readings. The Norwegian catch-at-age is based on otoliths back to 1990. Before 1990, when the Norwegian catches of *S. mentella* were smaller, Russian scale-based age–length keys were used to convert the Norwegian length distribution to age.

As input to analytical assessments, the weight-at-age in the stock is assumed to be the same as the weight-at-age in the catch.

A fixed natural mortality of $0.05y^{-1}$ is used both in the assessment and the forecast.

Age-based maturity ogives for *S. mentella* (sexes combined) are available for 1986–1993, 1995 and 1997–2001 from Russian research vessel observations in spring and from 1992–present from Norwegian samples (surveys and commercial samples combined). In some years the maturity ogives are imprecise or unrealistic, mainly due to low sampling intensity. The approach taken is to model maturity-at-age with a double half Gompertz sigmoid[1], using mixed-effect models. In years of poor sampling intensity, the fixed ogive is used, while in years when more data are available, the random (i.e. annual) effects are incorporated.

B.3. Surveys

The results from the following research vessel survey-series have annually been presented to the AFWG:

1) The international 0-group survey (since 2004 part of the ecosystem survey) in the Svalbard and Barents Sea areas in August–September since 1980 (incl.).
2) The Russian bottom-trawl survey in the Svalbard and Barents Sea areas in October–December since 1978 (incl.) in fishing depths of 100–900 m.
3) The Norwegian Svalbard (Division IIb) bottom-trawl survey (August–September) since 1986 (incl.) in fishing depths of 100–500 m. Data disaggregated on age only since1992.

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[1] the double half sigmoid equation is of the form 0.5 * ((1+tanh(age- a50)/w1)) for age < a50 and 0.5 * ((1+tanh(age- a50)/w2)) for age > a50. a50 equals the age at 50% maturity.

4) The Winter Norwegian Barents Sea bottom-trawl survey (February) since 1986 (incl.) in fishing depths of 100–500 m. Data disaggregated on age only since 1992.

5) The Norwegian survey initially designed for redfish and Greenland halibut is now part of the ecosystem survey and covers the Norwegian Economic Zone (NEZ) and Svalbard including north and east of Spitsbergen during August 1996–2008 from less than 100 m to 800 m depth. This survey includes survey no. 3 above, and has been a joint survey with Russia since 2003, which since then has been known as the ecosystem survey.

6) The Russian acoustic survey in April-May since 1992 (except 1994, 1996 and 2002–2004) on spawning grounds in the western Barents Sea.

The international 0-group fish survey carried out in the Barents Sea in August–September since 1965 does not distinguish between the species of redfish but it is believed to be mostly *S. mentella*. The survey design has improved and the indices earlier than 1980 are not directly comparable with subsequent years.

Russian acoustic surveys which provide estimates of the commercially sized/mature part of the *S. mentella* stock have been conducted in April–May on the Malangen, Kopytov, and Bear Island Banks since 1986. In 1992 the area covered was extended, and data on age are available for 1992–1993, 1995 and 1997–2001. This is the only survey targeting commercially sized *S. mentella*, but for a limited part of its areal distribution only.

In order to investigate the distribution and abundance of pelagic *Sebastes mentella* in the Norwegian Sea the following surveys are/have been conducted:

i) The Norwegian part of the international ecosystem survey in the Nordic Seas in spring 2007–2009 (PGNAPES).

ii) The Norwegian trawl and acoustic survey in September 2007 and August 2009 and ICES coordinated international trawl and acoustic survey conducted by Norway, Russia and the Faroes in August 2008.

A schematic illustration of these survey-series is given below in Figure 2.

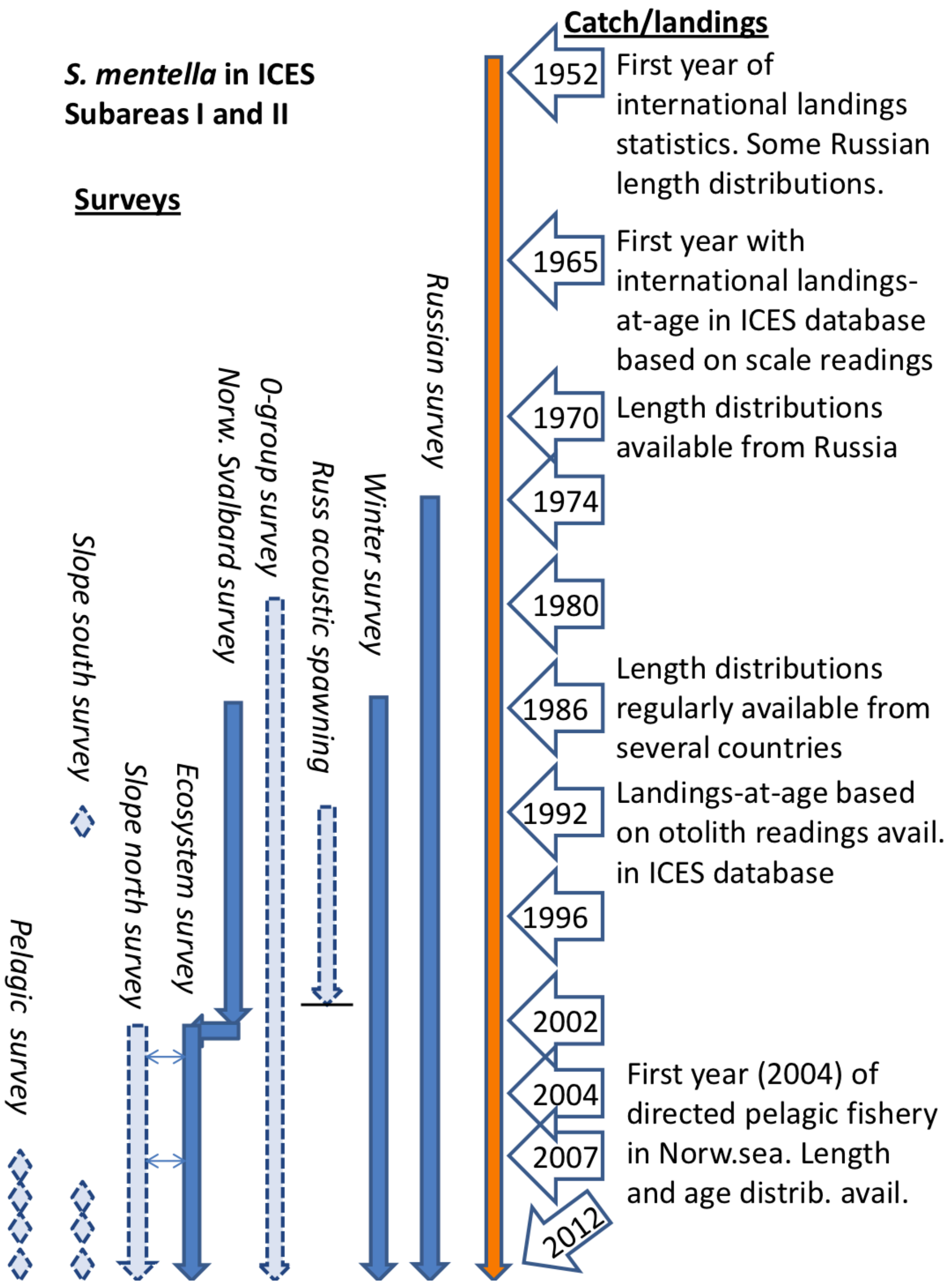

Figure 2. Illustration of the available time-series of surveys and catch/landings data. Solid blue arrows show the scientific surveys currently used in both the SCAA and Gadget models, while the dotted light blue arrows show available surveys for which data are available, but are currently not used as inputs to the assessment models.

B.4. Commercial cpue

Revised catch-per-hour-trawling data for the *S. mentella* fishery have been available from Russian PST- and BMRT-trawlers fishing in ICES Division IIa in March–May 1975–2002; these are representative of the directed Russian fishery which accounts for 60–80% of the total Russian catch. The Arctic Fisheries Working Group concluded that the Russian trawl cpue series do not reflect the trend in stock size but is more an indication of stock density in a localized area. This is because the fishery from which these data have been forthcoming since 1996 was carried out by one or two vessels only and on localized concentrations in the Kopytov area southwest of Bear Island. This is also reflected by the relative low fishing effort at present. Due to this change in fishing behaviour/effort, cpues have been presented for the period after 1991 only.

B.5. Other relevant data

Estimates of predation by cod on redfish juveniles in the Barents Sea, derived from the ecosystem survey, are provided to the assessment working group. The series covers the period 1984 to present.

C. Analytical assessment model

Model used: Statistical Catch-at-Age (SCAA).

Additional models: Gadget and Schaefer models used for validation.

Software used: R, ADMB and Gadget.

C.1. Statistical catch-at-age model structure

Statistical catch-at-age (SCAA) is used to estimate abundance, recruitment and fishing mortality for many exploited fish stocks. In contrast to virtual population analysis (VPA), in SCAA fishery catch-at-age data are assumed to be measured with error. Under many conditions, SCAA provides more accurate estimates of stock size and other important management quantities than other stock assessment techniques (Wilberg and Bence, 2006). An introduction to SCAA can be found for in Chapter 11.3 of Haddon (2001).

The basic equation SCAA relates numbers *N* in the population in year *y* and age *a* to numbers in the previous year (*y-1*) for the previous age (*a-1*):

$$N_{y,a} = N_{y-1,a-1}e^{-Z_{y-1,a-1}}$$

In the specific case of a +group, the contribution of the +group in the previous year should be added:

$$N_{y,a+} = N_{y-1,a-1}e^{-Z_{y-1,a-1}} + N_{y-1,a+}e^{-Z_{y-1,a+}}$$

where Z is the total mortality for year y and age a. $Z_{y,a}$ can be decomposed into two components: the natural mortality $M_{y,a}$ and the fishing mortality $F_{y,a}$. In SCAA the fishing mortality is derived from two quantities: the fishing mortality in year y, F_y, and the fleet selectivity at age, σ_a. The resulting fishing mortality-at-age a in year y is given as $F_{y,a} = \sigma_a F_y$. The resulting equation becomes:

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

Fitting the model requires estimating σ_a's, F_y's, the number of fish in year 1, for all ages ($N_{1,\cdot}$) and the number of fish of age 1 for all years ($N_{\cdot,1}$). The natural mortality cannot be estimated for each year and age, since such estimates would be confounded with the fishing mortalities. However, it is possible to estimate a fixed mortality term $M_{\cdot,\cdot}$ identical for all years and all ages.

The model is fitted to catch-at-age data, where predicted catch-at-age is given as:

$$\hat{C}_{y,a,f} = \frac{F_{y,a,f}}{M_{y,a} + F_{y,a,\cdot}} N_{y,a} \left(1 - e^{-(M_{y,a,\cdot} + F_{y,a,\cdot})}\right)$$

with *f* the fleet index. Two commercial fleets are considered. The bycatch fleet, mostly operating in national waters, is using bottom trawl, and the pelagic fleet operating in international waters is using very large pelagic trawls. The selectivities-at-age of the two fleets are different (due to differences in gear and in the geographical distribution of age groups of redfish). The fishing mortality for each year is also different, and the pelagic fleet started to operate only in 2006. Typically, the model is fitted to the log of the catch-at-age, $logC_{y,a,f}$, assuming normal error distribution.

In addition, the model can be fitted to auxiliary data such as survey indices, with:

$$\hat{I}_{y,a} = q\theta_a N_{y,a}$$

where *I* is the survey index, *q* a survey scaling coefficient and θ_a is the survey selectivity at age. The equation above is valid if the survey is conducted at the beginning of the year; when this is not the case the equation must account for mortality prior to the survey:

$$\hat{I}_{y,a} = q\theta_a N_{y,a} e^{-\tau(M_{y,a} + F_{y,a})}$$

with τ the fraction of the year before the time of the survey.

Typically, the model is fitted to the log of the survey indices, $logI_{y,a}$, assuming normal error distribution.

Optimization is carried out by minimizing the negative loglikelihood on observations (logcatches and logsurvey indices):

$$nll = \sum \left(\frac{1}{2} \log(2\pi\sigma_s) + \left(\frac{\widehat{\text{LogO}}_i - \text{LogO}_i}{\sigma_s} \right)^2 \right)$$

where $LogO_i$ are the logobservations (catches and survey indices), *i* is the observation index (from 1 to the total number of observations) and *s* is the index, which relates to a fleet or a survey, from which an individual observation originates. An additional loglikelihood component is calculated for the total catch in tonnes in each year (following the same equation as above, where C_y – catch in year *y* – substitute the O_i's).

The selectivity of fleets (σ_a) can be estimated for each individual age or can alternatively be approximated by a sigmoid function. The second option was chosen, and the sigmoid was modelled by the Gompertz sigmoid equation:

$$\sigma_a = \frac{1}{2} + tanh\left(\frac{(a - a50)}{w}\right)$$

The use of selectivity functions appreciably reduces the number of parameters to estimate. Here there only two parameters need to be estimated: *a50* (the age of 50% selectivity) and *w* (the slope of the sigmoid).

For the survey selectivity, several functions should be tested, including the sigmoid equation above, exponential declines or dome-shaped functions (e.g. exponential parabola). The shape selected for the assessment will depend on the results of these investigations.

C.2. Gadget and Schaefer models

These models are used for quality check and the detailed structured is not presented in the stock annex, although the model configurations are provided in the section below.

Model options chosen:

	SCAA	Gadget	Schaefer
Year span	1992–2010	(1986) 1990–2009	1965–2010
Population characteristics			
Maximum age	19+	30+	-
Genders	1	1	-
Number of maturity stages	2	2	-
Population lengths (cm)	N/A	1–60+	-
Summary biomass (mt)	Immature/SSB/Total	Immature/SSB/Total	Total
Data characteristics			
Data lengths	N/A	1–60+	-
Data ages	2–19+	2–19+	-
First mature age	From fitted annual ogives	Estimated age-based maturation	-
Starting year of estimated recruitment	1992	1986	-
Fishery characteristics			
Fishery timing	Annual	Quarterly	Annual
Fishery ages	6–19+	6–30+	-
Winter survey timing (year fraction or quarter)	0.12	Q1	Annual
Winter survey ages	2–15	3–15	-
Ecosystem survey timing	0.75	Q3	Annual
Ecosystem survey ages	2–15	3–15	-
Russian survey timing	0.90	Q4	Not included
Russian survey ages	2–11	3–11	-
Fishing mortality	Separable, age x year	Match reported catches (no selectivity)	Total catches
Fishery selectivity	Gompertz sigmoid	Exponential	-
Winter & ecosystem survey selectivities	Exponential decline	Exponential	-
Russian groundfish survey selectivity	Gompertz sigmoid	Exponential	-

For the SCAA, the catchability coefficient for the Ecosystem survey needs to be fixed. After comparisons with the output from the Gadget model, it was agreed to set the value $q = 1/3.5$, so that the absolute biomass levels in SCAA are consistent with those in Gadget.

C.3 Data sources

Fisheries data sources:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Total catch in tonnes	1992–2010	NA	yes
Canum1	Catch-at-age in numbers for the demersal fleet	1992–2010	6–19+	yes
Canum2	Catch-at-age in numbers for the pelagic fleet	2006–2010	6–19+	yes
Weca	Weight-at-age in the commercial catch	1992–2010	6–19+	yes
Matprop	Proportion mature at age	1992–2010	6–19+	yes
Natmor	Natural mortality	1965–2008	6–19+	Constant=0.05

Numbers-at-age from surveys:

Type	Name	Year range	Age range
Tuning fleet 1	Winter survey	1992–2010	2–15
Tuning fleet 2	Ecosystem survey	1996–2009	2–15
Tuning fleet 3	Russian survey	1992–2010	2–11

D. Short-term projection (<5 years)

Model used: projection with SCAA model output

Software used: Excel/ADMB

Initial stock size: 1150 thousand tonnes (SSB) in 2010

Natural mortality: 0.05

Maturity: as in 2010

F and M before spawning: $M = 0.05$, F varies with age

Weight-at-age in the stock: as in 2010

Weight-at-age in the catch: as in 2010

Exploitation pattern: as in 2010, i.e. sigmoid with 50% selectivity at 11 years (demersal) and 14 years (pelagic)

Intermediate year assumptions: constant recruitment, weight-at-age, maturity-at-age, exploitation patterns

Stock–recruitment model used: N/A. Recruits do not contribute to the fishery before age 6.

Procedures used for splitting projected catches: Projected catches are allocated to fleets according to the proportions in the last year of assessment (2010).

E. Medium and long-term projections(>5 years)

Model used: projection with SCAA model output and different scenarios for recruitment.

Software used: Excel/ADMB

Initial stock size: as of last year of assessment

Natural mortality: 0.05

Maturity: as in 2010, sigmoid with 50% maturity-at-age 11

F and M before spawning: $M = 0.05$. F varies with age, as in last year of assessment (2010)

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

Weight-at-age in the catch: as in last year of assessment

Exploitation pattern: as in 2010, i.e. sigmoid with 50% selectivity at 11 years (demersal) and 14 years (pelagic)

Intermediate year assumptions: constant recruitment, weight-at-age, maturity-at-age, exploitation patterns

Stock–recruitment model used: Recruitment (age 2) scenarios with different levels: average of the last five years and average of the recruitment failure period (1998–2005).

Catch scenario: Future catches were set equal to zero (as a bound), half, the same and double the average catch for the last five years

Uncertainty models used:

1) Initial stock size: Distribution from ADMB MCMC
2) Natural mortality: fixed
3) Maturity: fixed
4) F and M before spawning: M fixed, initial F distribution from ADMB MCMC
5) Weight-at-age in the stock: fixed
6) Weight-at-age in the catch: fixed
7) Exploitation pattern: Distribution from ADMB MCMC
8) Intermediate year assumptions:
9) Stock–recruitment model used: scenarios

G. Biological reference points

Biological reference points could be defined based upon SCAA and Gadget model results but this has yet to be done.

The Schaefer model (see WKRED report, Appendix 1 and 2) the estimates of MSY for $r = 0.05$ and 0.10 are respectively 27 (SE 9) and 30 (SE 12) thousand tonnes respectively.

The Schaefer model indicates the abundance of this resource to be appreciably above 50% (MSY level in terms of this model) over a wide range of r values (see WKRED report, Appendix 1 and 2). It should be noted that this model does not take explicit account of recent low recruitments.

H. Other issues

The bulk of the population biomass of arctic *S. mentella* is constituted by individuals of age 19 and older. The assessment of the status of Arctic *S. mentella* stock should therefore explicitly consider the demographic structure of the adult stock, beyond 19 years, but this is not the case in the current assessment models used (SCAA and Gadget). It must be emphasized that even if these models can be configured to include more age groups, the survey-series currently used in these models do not provide adequate data for the older age groups. The winter, ecosystem and Russian groundfish surveys are restricted to the Barents Sea where juveniles and young adults predominate, but a large fraction of older mature individuals migrate into the Norwegian Sea. Therefore, these surveys do not appropriately cover the demographic distribution of the adult population and are only considered for individuals up to age 11 years (Russian survey) and 15 years (Winter and Ecosystem surveys). Priority should be given to data collection over the slope and open Norwegian Sea regions, where the adult population is most abundant, and to including these new surveys in the analytical assessment in future.

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Stock Annex: Golden redfish (Subareas V and XIV)

Stock	Golden redfish (*Sebastes marinus*) in ICES Subareas V and XIV
Working Group	WKRED
Date	February 2012
Revised by	Kristján Kristinsson, Guðmundur Þórðarson, 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 depth 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 the 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 but in the two other areas after the Second World War (Figure A.2.1). The EGIF stock is most abundant in Icelandic waters and where most of the commercial catches have been taken.

The landings from the EGIF stock peaked in 1955 to 160 000 t (Figure A.2.1.), 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 has been around 40 000 t and 95–98% have 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 was little until late 1930s when annual landings started to increase (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. Little redfish fishery was conducted in Icelandic waters 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 varied 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 varied between 32 000 and 49 000 t. Average annual landings in 2000–2010 have been around 40 000 tonnes.

The fishery for golden redfish in Icelandic waters is predominantly conducted by the Icelandic bottom-trawl fleet directed towards the species, and which accounts for more than 90% of the total catch. The remains are partly caught as bycatch in gillnet, longline, and lobster fishery. The most important fishing grounds are southwest and west of Iceland at depths from 200–400 m.

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 early 1950s and annual landings have been more variable than in the other areas (Figure A.2.1). The fishery until early 1980s 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 varied between 8000 and 41 000 t during the period 1957 to 1975 or 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 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 it was in early 1990s. This increase is mainly due to increased directed redfish fishery in the area.

Faroe Islands

Directed fishery for golden redfish in Faroes 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 has since then been between 460 to 690 t. Annual landings has not been observed below 1000 t since 1978.

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 management of the Icelandic fisheries, including the golden redfish fishery, and implementation of the legislation in the Icelandic Exclusive Economic Zone (EEZ). The Ministry issues regulations for commercial fishing for each fishing year (starts on September 1 and ends on August 31 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 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 individual company as well as among different companies. The latter can be done via temporary or permanent transfer of quota. In addition, some flexibility is allowed by individual boats with regard to transfer 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 2010/211 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 from the beginning. Icelandic authorities gave a joint quota for these two species until the fishing year 2010/2011, although 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 1994/1995 fishing year, the total annual landings of golden redfish has been in most years exceeded the recommended TAC.

Regulations

With some minor exceptions, it is required by law to land all catches. Consequently, no minimum landing size is in force. No formal harvest control rule exists for this stock. 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 golden redfish is 33 cm for all fleets, with allowance to have up to 20% undersized (i.e. less than 33 cm) specimens of golden redfish (in numbers) in each haul. If the number of redfish smaller than 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 with the objective 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, in a given area, there are several consecutive quick closures the Minister of Fisheries can with regulations close the area for longer time 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 protection of juveniles. Figure 1 shows map of such area closures that was in force in 2006. Some of them are temporarily closed, but others have been closed for fishery for decades.

Temporary area closures: The major spawning grounds of cod, plaice and wolfish are closed during the main spawning period of these species. The general objectives of these measures, which were in part initiated by the fishermen, are to reduce fishing during the spawning activity of these species.

Since 1991, when the first redfish closure took place, in all 68 quick closures on golden redfish have taken place (Table A.2.1 and Figure A.2.2). Few quick closures have been on small redfish since 2001 or on average three every year. The reason for few quick closures on small golden redfish is because large areas southwest and west of Iceland are closed permanently or temporarily for trawling to protect juvenile golden redfish (Figure A.2.3). These areas were closed partly because of frequent quick closures on redfish fisheries in 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 have 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 depth of fishing 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 the fisheries regulations. 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.

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 have 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

A.3. Ecosystem aspects

Golden redfish is an ovoviviparous, in which 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 fish species. 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, Calanoida, and Euphausids (Pálsson, 1983).

B. Data

B.1. Commercial catch

The text table below shows which data from landings are 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 data of commercial catch 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 is recorded.

B.1.1.1. Splitting the redfish catch 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:

1) 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).

2) Information on landed products from Icelandic factory (freezer) trawlers.

3) Biological samples from the Icelandic fresh-fish trawlers sampled by MRI and Icelandic Catch Supervision (ICS) personnel.

4) Landing statistics from Germany and UK if available.

5) Landing statistics from foreign vessels fishing in Icelandic waters.

6) 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 first found. 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 unsplit 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 found 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 up to maximum five years before a given year. If no samples were available in this five years 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 the last criteria.
3) The split into species of redfish landings in Germany and UK (containers or fresh landings) are based on landings reports and are 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*. This is 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* and
- 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 are a mixture of *S. marinus* and *S. mentella*. All surveys report that *S. men-*

tella is dominating the catches. On background of the surveys 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 substantial catches (e.g. 1986) but it remains uncertain what have been done through the years with low catches.

B.1.3. Faroe Islands

Faroese data of commercial catch in tonnes by month, area and gear are obtained from 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 is recorded.

Since 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 was caught of redfish).

For the catches by 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) during trips 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 fish: 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 of size composition from the bottom-trawl fleet is available from 1956–1966 and 1970–2010 but sampling before 1976 was rather limited. Since 1999, 219–434 samples are taken annually and 35 000–74 000 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 has been since 1995. Few age read in 1995 and 1996. Since 2000 the annual number of samples are 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 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 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 has a relatively dense station-net (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). Where applicable the emphasis has been put on golden redfish. 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

From the commencing of the Spring Survey the stated aim has been to estimate 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 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.

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 in 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 that data it made sense to conduct the survey in March.

The total number of stations was decided to be 600 (Figure B.3.1). The reason of having so many stations was to decrease variance in indices but was inside 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 10 strata, four in the south and six in the north.

Stratification in the survey and the allocation of stations was based on pre-estimated cod density patterns in different "statistical squares" (Palsson *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 the size of the square. Within statistical squares, stations were divided equally between fishermen and fishery scientists at the MRI for decisions of location. There are up to 16 stations in each statistical square in the Northern area and up to seven in the Southern are. The captains were asked to decide the towing direction for all of the stations.

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), the hull extended by several meters, larger engines, and some other minor alterations. These alterations have most likely changed the qualities of the ships but it is very difficult to quantify these changes.

The trawlers are now considered old and it is likely that they will soon disappear from the Icelandic fleet. Some search for replacements is ongoing. 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 was divided between the two areas. Of them, 150 stations were allocated to the shallow-water area and randomly selected from the Spring Survey station list. In the deep-water area, half of the 280 stations were randomly positioned in the area. The other half were randomly chosen from logbooks of the commercial bottom-trawl fleet fishing for Greenland halibut and deep-water redfish in 1991–1995. The locations of those stations were, therefore, based on distribution and pre-estimated density of the species.

Because MRI was not able to finance a project 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 can be compared for Icelandic slope *S. mentella*.

The number of stations in the deep-water area was therefore reduced to 150. In all 100 stations were randomly positioned in the area. The remaining stations were located on important Greenland halibut fishing grounds west, north and east of Iceland and randomly selected from a logbook database of the bottom-trawl fleet fishing for Greenland halibut 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. In all 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, twelve stations were added in 1999 in the shallow-water area, making total 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 twelve 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 66.6m" 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 4 (Spring Survey) or 5 (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 has 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 on board.

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 fish 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 estimates 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 region with relatively long interval between stations and holes in the station net 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 cause's great diurnal variation in the catch rates of golden redfish in both spring and autumn bottom-trawl surveys conducted in Icelandic waters and has great 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 large part of the total catches of golden redfish and inter-annual 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 as 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 taken 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 1982–2010. The survey was primarily designed for the assessment of cod, but covers the entire groundfish fauna 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 both according to 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. These were carried out by the research vessel (RV) Anton Dohrn and since 1994, by RV Walther Herwig III.

Calculations of abundance and biomass indices were based on the 'swept-area' method where the width of the trawl is assumed to be 22 m and towing time of 30 min. In order to reduce the error of abundance estimates, the subdivision of shelf areas and the continental slope into different geographical and depth strata was required due to a pronounced heterogeneity of fish distribution. The survey area was thus split into seven geographical strata (strata 1–4 off West-Greenland and strata 5–7 off East Greenland, Figure B.3.12). Each stratum was itself subdivided into two depth strata covering the 0–200 m and 201–400 m zones. Only strata off East Greenland area considered (strata 5–7). Figure B.3.12 indicate the names of the strata. The inner limit of all strata was the 3 mile offshore line.

The applied strategy was to distribute the sampling effort according both to the stratum areas and to cod abundance. Consequently, fifty percent of the hauls were allocated proportionally to strata by stratum area while the other fifty percent were apportioned on the basis of a review of the historical mean cod abundance/NM^2, all hauls being randomly distributed within trawlable areas of the various strata. Non-trawlable areas were mainly located inshore.

Apart from stratum 7.1 (Dohrn Bank), East Greenland strata were not covered adequately in 1984, 1992 and 1994 due to technical problems. Stratum 7.1 has a very low area and therefore never been covered. Since 1996, the entire survey area was considered to be almost completely covered.

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. Hauls which received net damage or became hung up after less than 15 minutes were rejected.

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 10 minutes because of the expected large cod catches as observed from echosounder traces.

Stratified abundance estimates were calculated from catch-per-tow data using the stratum areas as weighting factor (Cochran, 1977; Saville, 1977). All hauls were included and strata with less than five valid sets per year were also calculated.

The coefficient of catchability was set at 1.0, implying that estimates are merely indices of abundance and biomass. Respective confidence intervals (CI) were determined at the 95% significance level of the stratified mean. The length frequency distributions (LFDs) were compiled by stratum and year and raised to the respective abundance.

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.

B.4. Commercial cpue

Iceland

Catch per unit of effort are 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 Bertanlanffy 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

$$\sum ip_{il} = \mu_i$$

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:

$$CPUE_{\text{mod}} = \sum_{prey} \sum_{l} S_{prey,l} N_{prey,l} W_{prey,l}$$

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:

$$C_{prey,l} = C \frac{S_{prey,l} N_{prey,l} W_{prey,l}}{CPUE_{\text{mod}}}$$

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:

$$C = E \times CPUE_{\text{mod}}$$

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 date directly means that the model can be used for stocks such as golden redfish where age data are sparse or considered unreliable (given 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 gradientbased, 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 optima 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 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 parametrization. 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 data-points, 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 data-points (df*) in 3) is used as a proxy for the degrees of freedom determined from the number of non-zero data-points. 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

Golden redfish is a long-lived species, reaching 30 to 40 years of age in Division V and Subdivision XIVb, so it takes a cohort a long time to pass through the fishery.

In the assessment 1 cm length groups are used and the year is divided into two time-steps. The age range is 5 to 30 years, with the oldest age 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. Weight–length relationship is obtained from spring survey data. Before spring 2012, age range in the model was 0–30 years old but the youngest age groups were excluded from the model as distribution of recruits have changed.

Natural mortality for this long-lived species is probably low but has to be guessed like for most other stock. Since spring 2012, M of all age groups, except the plus group, is 0.05 but 0.1 for the plus group. Before spring 2012 M for 0 years old was 0.20 reducing gradually to 0.05 for age 5. M for age 5–29 was 0.05 but 0.1 for the plus group (30+). The reason for higher natural mortality on age 0–5 is not clear but these age groups are not caught by the fisheries so the value selected for M does not matter. A good choice is to use M=0 for all prerecruits making the number in stock comparable for different age groups. The philosophy precautionary in selection of M has been rather to use too low than to high value leading to conservative reference points.

The model starts in 1970 and the time-step is six months and the simulation period 42 years. 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.

The commercial landings are since 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. The survey (1985–onwards) is modelled as one fleet with constant effort and a nonparametric selection pattern that is estimated for each length group.

Data/constraints used in the objective function to be minimized are as follows:

- Length distributions from the commercial catches (Greenland, Iceland and the Faroese) and survey (IS-SMB) using multinomial likelihood functions.
- Age–length keys from surveys and commercial catches (Icelandic) using multinomial likelihood functions.
- Length disaggregated survey indices in 2 cm length groups using log-normal errors.
- 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. Weights for the various log-likelihood components are assigned according to the procedure described above.

The parameters estimated are:

- The number of fish when simulation starts.
- Recruitment each year.
- Parameters of the growth equation.
- Parameter β of the beta-binomial distribution controlling the spread of the length distributions.
- The selection pattern of the commercial catches.
- Size and standard deviation of recruitment size.

The estimation can be difficult because of some or some groups of parameters are correlated, and therefore the possibility of multiple optima cannot be excluded.

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 lead to consistent underestimation of recruiting year classes in recent years.

In addition development of the model has been ongoing. Among the things developed in 2011–2012 is the likelihood weighting that has been changed somewhat in the first quarter of 2012.

Data used for tuning are:

- Length disaggregated survey indices (2 cm length increments, 4 cm for 5–8 cm fish) from the Icelandic groundfish surveys in March (IS-SMB): 1985–recent year.
- Length distributions from the Icelandic, German (in Greenland waters) and Faroese commercial catches: since 1970.
- Landings data by six month period.
- Age–length keys and mean length-at-age from the Icelandic groundfish survey in October (IS-SMH): 1996–recent year.
- Age–length keys and mean length-at-age from the Icelandic commercial catch 1995–recent year.

Description	period	Half-year	area	Likelihood component
Length distribution of landings	1970+	YES	Iceland Germany Faroese	ldist.catch
Length distribution of IS-SMB	1985+	-	Iceland	ldist.survey
Abundace index of IS-SMB of 5–10 cm individuals	1985+	-	Iceland	Si510
Abundace index of Icelandic IS-SMB of 11–24 cm individuals	1985+	-	Iceland	Si1124
Abundace index of IS-SMB of 25–54 cm individuals	1985+	-	Iceland	Si2554
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	1995–2010	-	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.

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 0 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

Exploitation pattern:

Landings: logistic selection parameters estimated by GADGET.

Intermediate year assumptions: F = last assessment year F

Stock recruitment model used:

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: 1 year class of 1 million individuals

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

Exploitation pattern:

Landings: logistic selection parameters estimated by GADGET.

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 in 1970 of million fish for 41 years through the fisheries calculating total yield from the year class as function of fishing mortality of fully recruited fish. 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

The biological reference points based on the GADGET model were not fully evaluated by the Group.

In 1998 the reference points were defined based on the index of fishable biomass index $U_{lim} = U_{max} /5$ and U_{pa} = 60% of U_{max} (ICES 2011). U_{pa} corresponds to the fishable biomass associated with the last strong year class (1990). Use of these reference points in advice has not been well defined except the fishery should close below U_{lim}.

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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	No. Of Cluosures
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 Vessel name	No.Stations	Deep waters Vessel name	No.Stations	Total stations
1996	r/v Bjarni Sæmundsson	146	Múlaberg ÓF32	144	290
1997	r/v Bjarni Sæmundsson	150	Brettingur NS50	149	299
1998	r/v Bjarni Sæmundsson	153	Brettingur NS50	144	297
1999	r/v Bjarni Sæmundsson	166	Brettingur NS50	149	315
2000	r/v Bjarni Sæmundsson	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

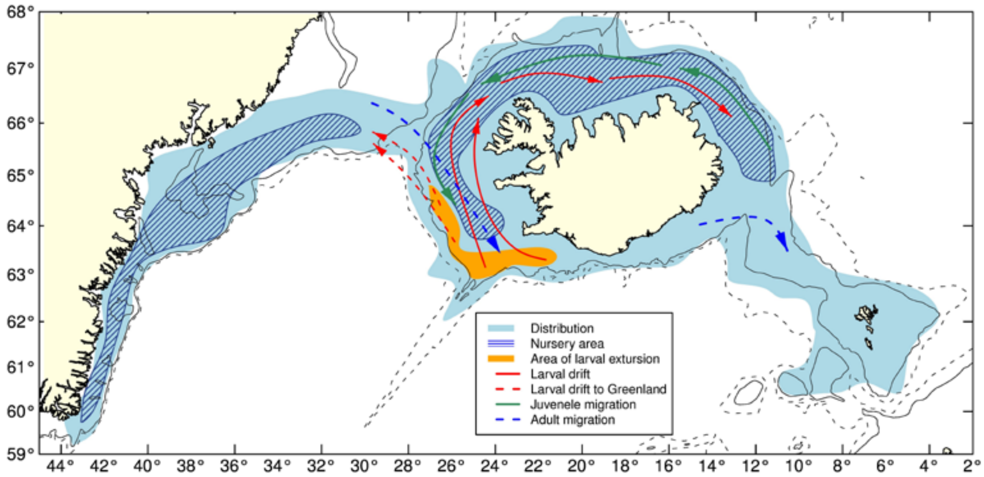

Figure A.1.1. Geographical range of golden redfish (*Sebastes marinus*) in East Greenland, Icelandic and Faroese waters, area of larval extrusion, larval drift and possible migration routes. The solid and dashed lines indicate the 500 m and 1000 m depth contour respectively.

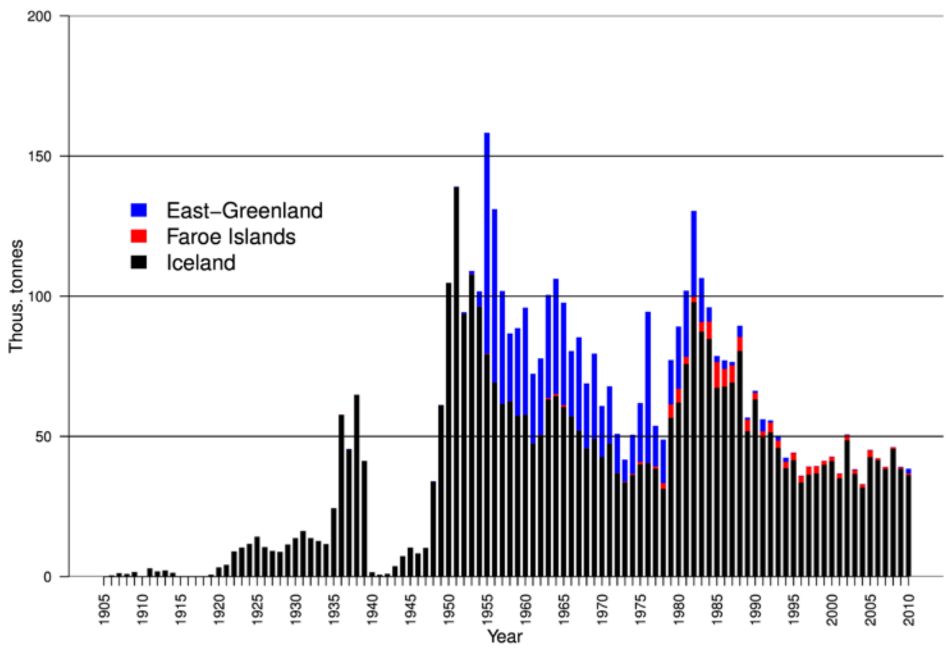

Figure A.2.1. Nominal landings (in tonnes) of golden redfish from Icelandic waters (ICES Division Va), Faroes waters (ICES Division Vb) and East-Greenland waters (ICES Division XIV) 1906–2010.

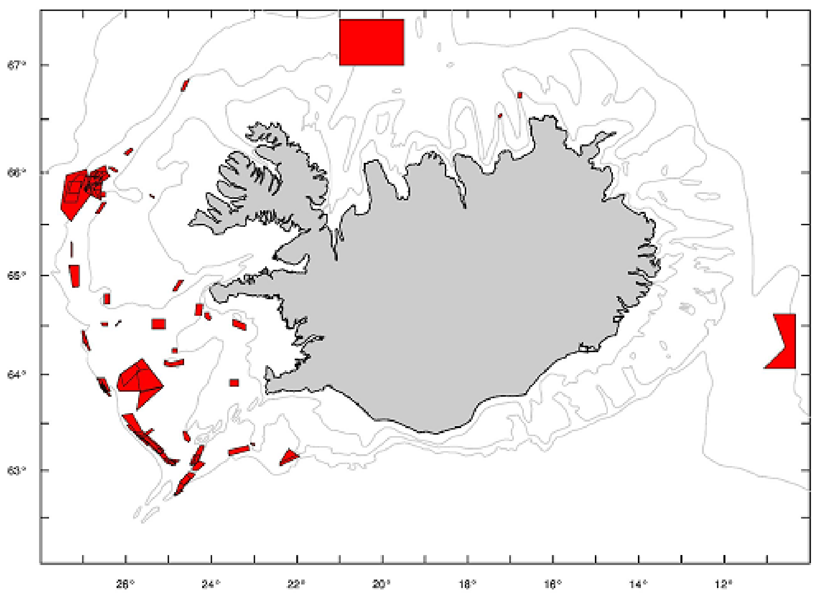

Figure A.2.2. Schematic overview of quick closures on golden redfish in Icelandic waters (ICES Division Va) 1991–2011.

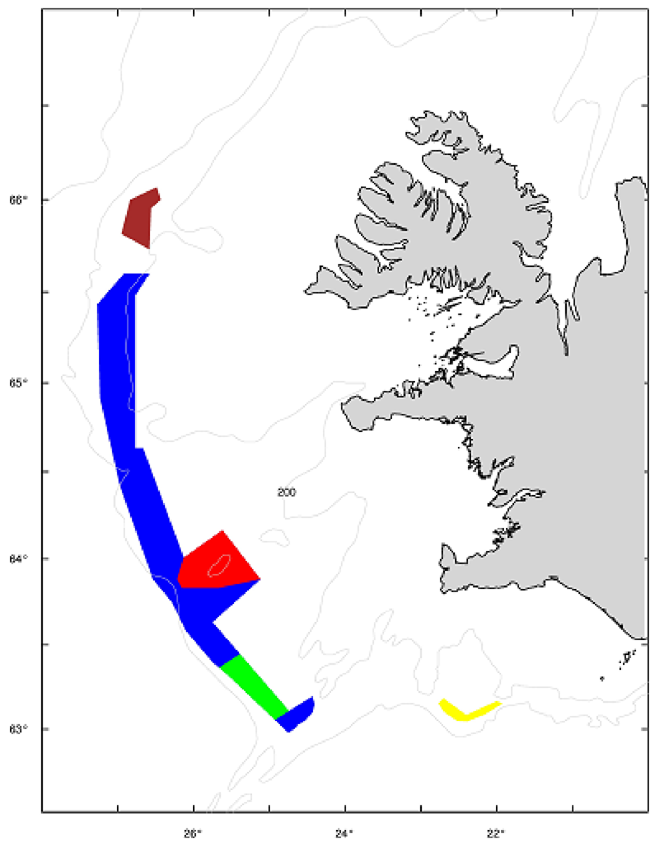

Figure A.2.3. Schematic overview of closed areas for protection of juvenile *S. marinus* in Icelandic waters (ICES Division Va). These areas are either closed permanently or temporarily. During closure bottom trawling is prohibited. The blue area is closed all year long; the red area is only open during 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.

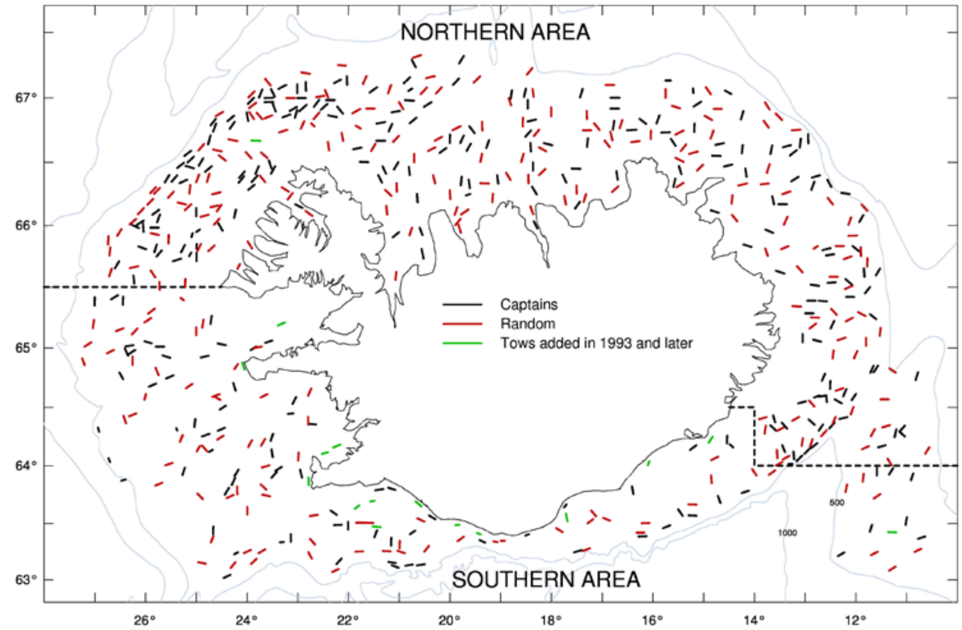

Figure B.3.1. Stations in the Spring Survey in March. Black lines indicate the tow-stations selected by captains of commercial trawlers, red lines are the tow-stations selected randomly, and green lines are the tow-stations that were added in 1993 or later. The broken black lines indicate the original division of the study area into Northern and Southern area. The 500 and 1000 m depth contours are shown.

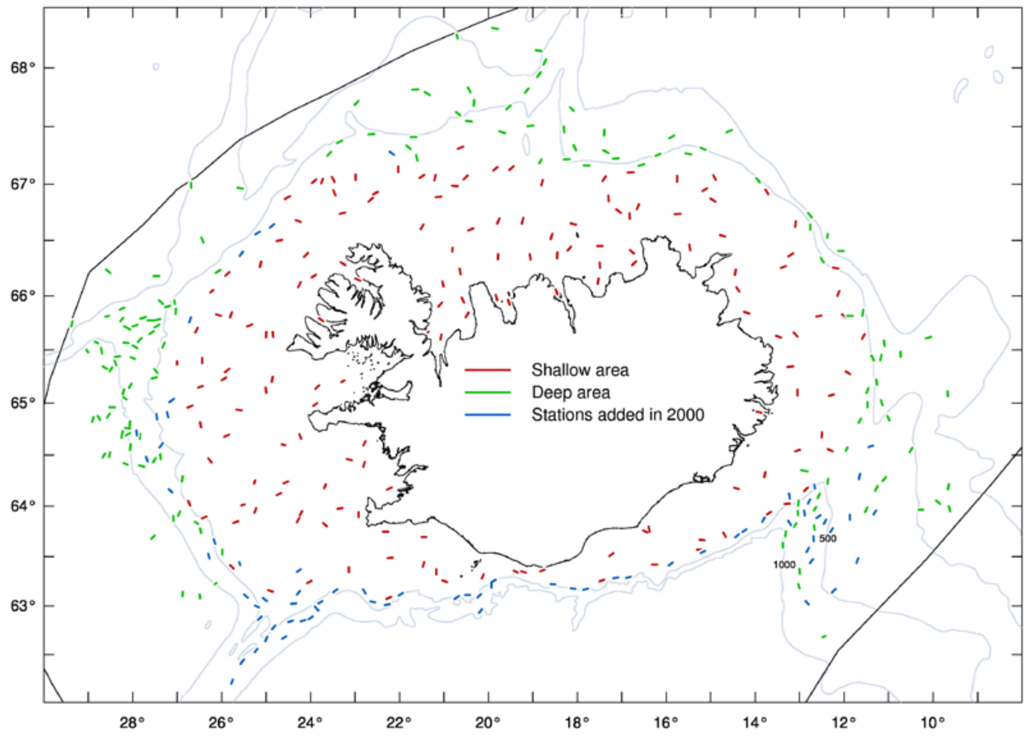

Figure B.3.2. Stations in the Autumn Groundfish Survey (AGS). RV "Bjarni Sæmundsson" takes stations in the shallow-water area (red lines) and RV "Árni Friðriksson" takes stations in the deep-water areas (green lines), the blue lines are stations added in 2000.

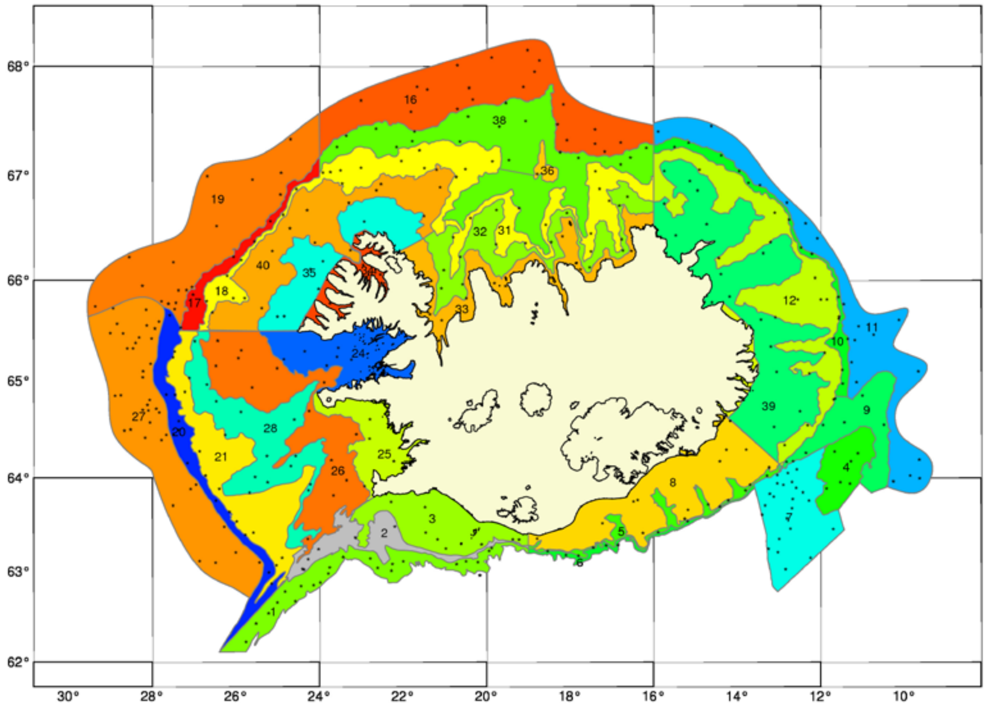

Figure B.3.3. Subareas or strata used for calculation of survey indices for golden redfish from the Autumn Survey in Icelandic waters. This stratification was applied in 2008.

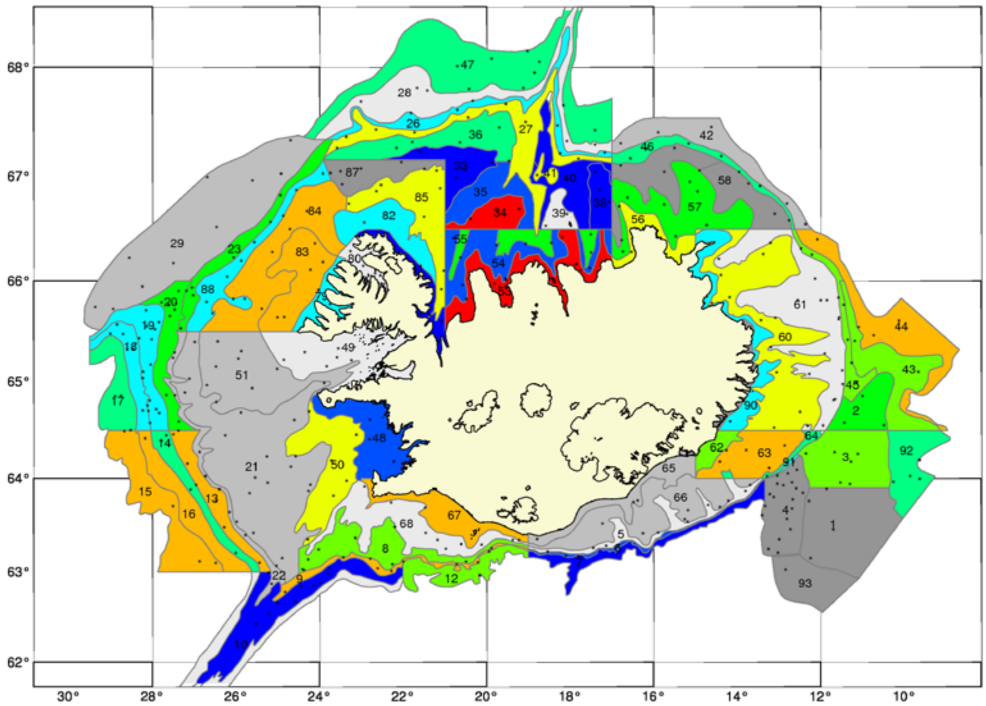

Figure B.3.4. The old stratification (before 2008) that was used for calculation of golden redfish indices from the Autumn Survey in Icelandic waters.

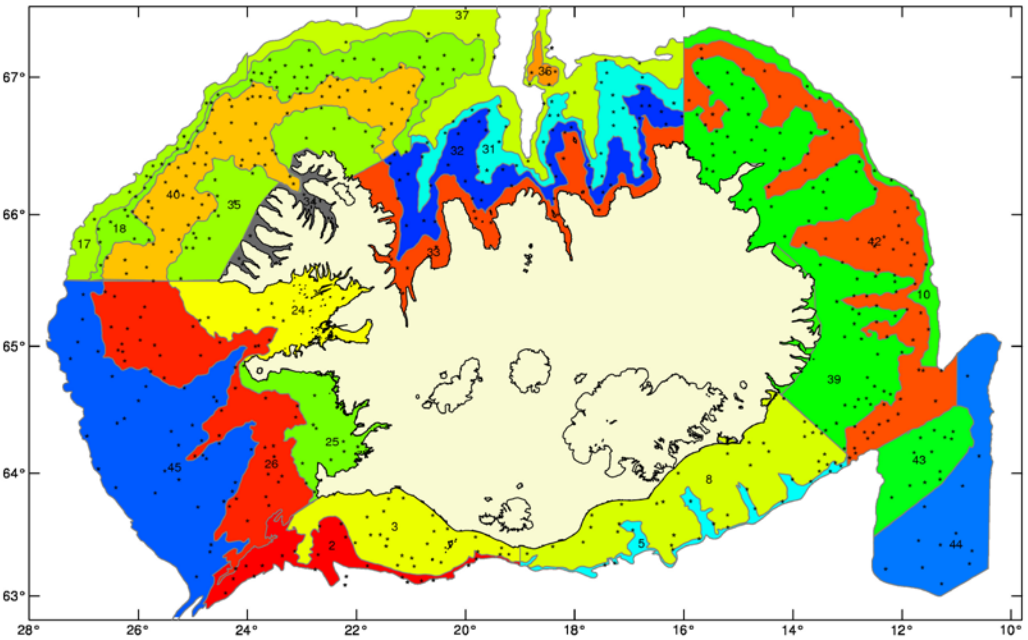

Figure B.3.5. Subareas or strata used for calculation of survey indices for golden redfish from the Spring Survey in Icelandic waters. This stratification was applied in 2011.

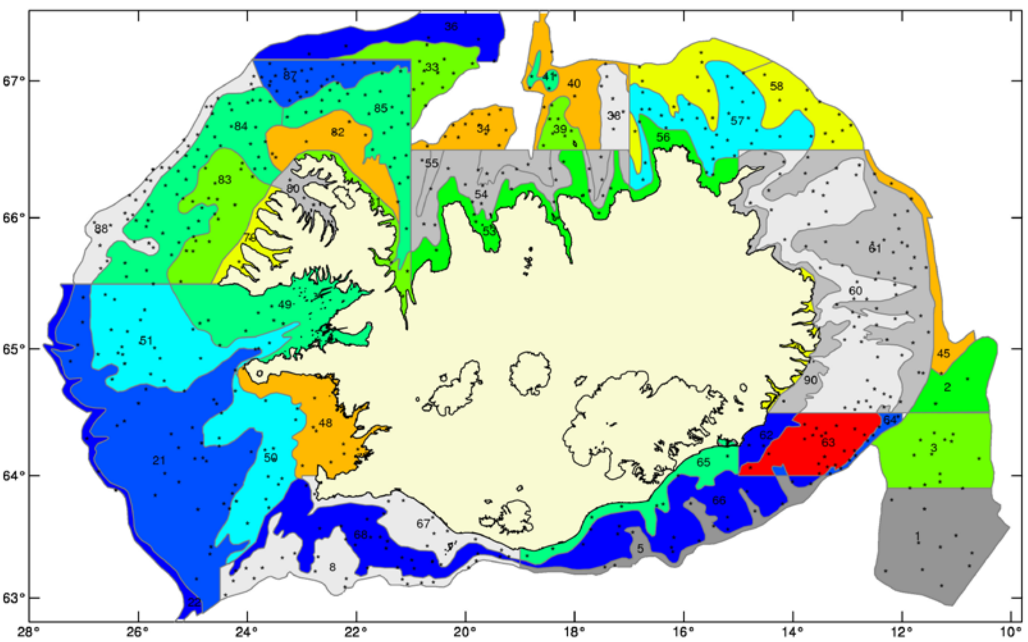

Figure B.3.6. The old stratification (before 2011) that was used for calculation of golden redfish indices from the Spring Survey in Icelandic waters.

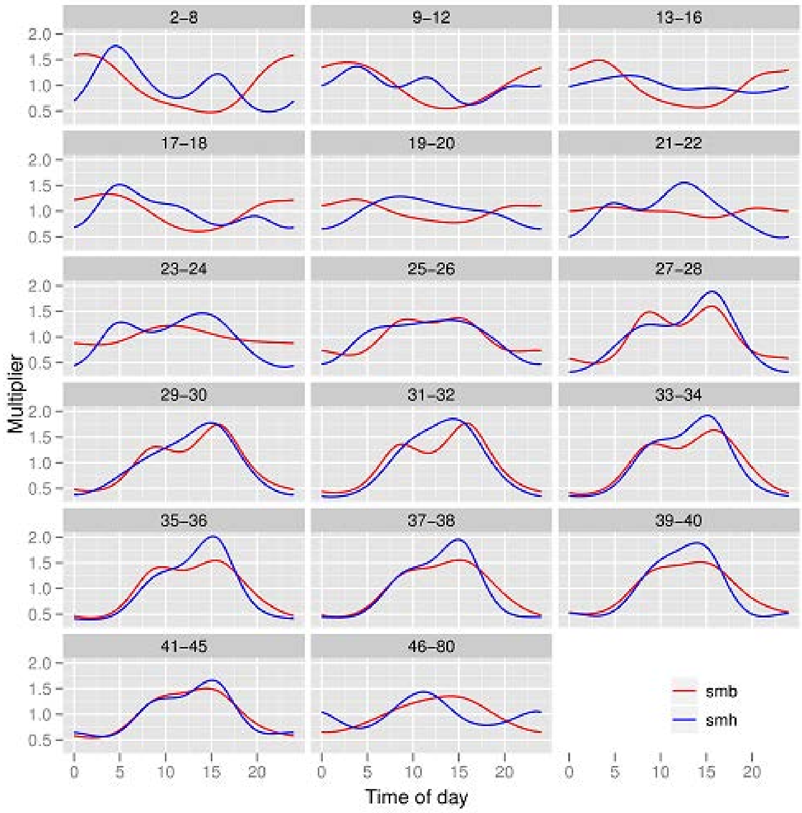

Figure B.3.7. Scaled multiplier for each length group in the Spring Survey (smb - red line) and the Autumn Survey (smh - blue line) based on the glm model with smoother applied to each length group.

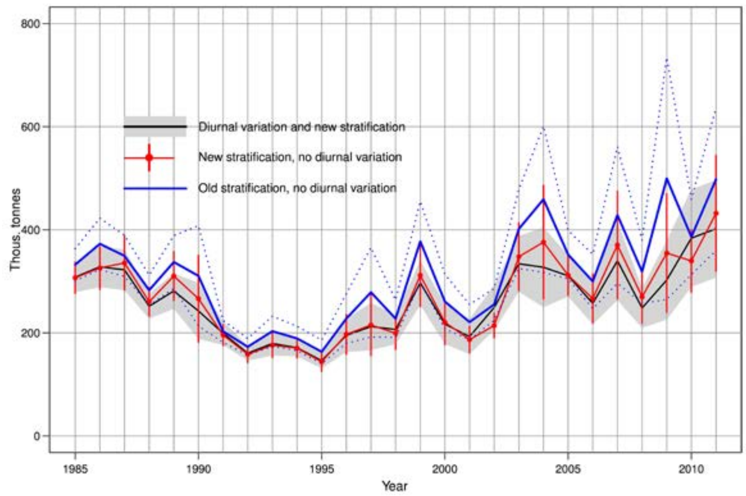

Figure B.3.8. Comparison in survey indices of golden redfish in the Spring Survey 1985–2011, calculated using the new stratification scheme (Figure 3) with and without diurnal vertical migration, and the old stratification scheme (Figure 4).

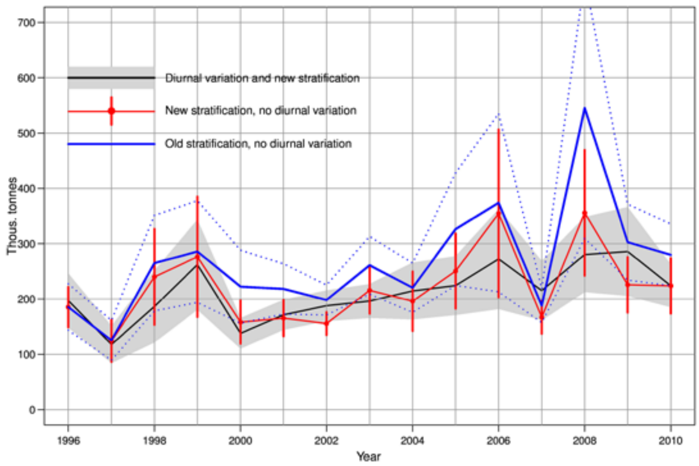

Figure B.3.9. Comparison in survey indices of golden redfish in the Autumn Survey 1996–2010, calculated using the new stratification scheme (Figure 3) with and without diurnal vertical migration, and the old stratification scheme (Figure 4).

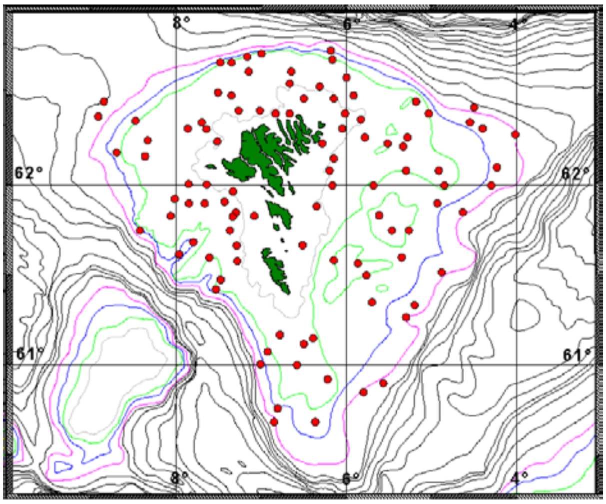

Figure B.3.10. Stations in the Spring Survey on the Faroe Plateau in March 2011.

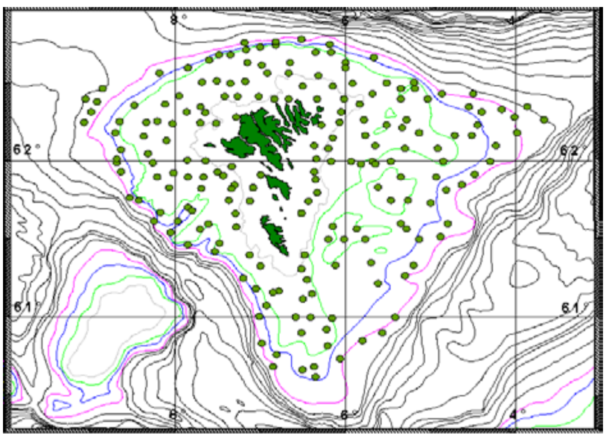

Figure B.3.11. Stations in the Summer Survey on the Faroe Plateau in August 2011.

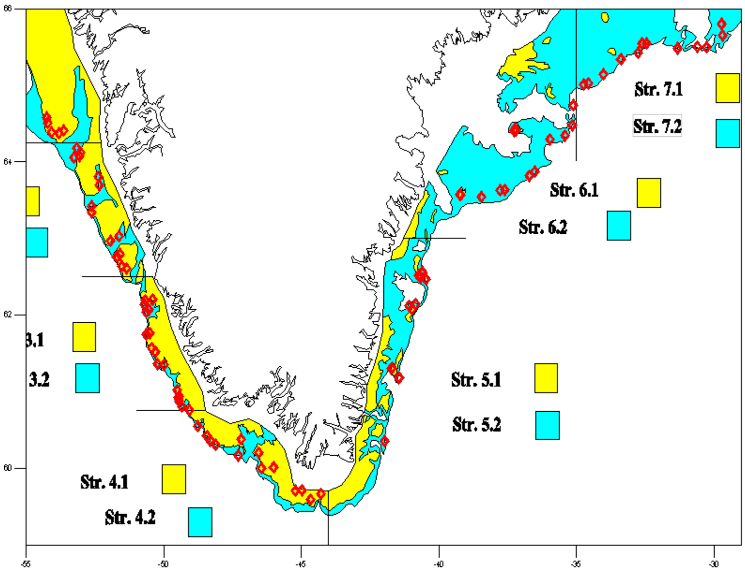

Figure B.3.12. Subareas or strata used for calculation of golden redfish survey indices of the German groundfish survey conducted on the Greenland shelf. Only strata off the East Greenland were used (strata 5–7). Also shown are the stations taken in 2007.

Stock Annex: Icelandic slope beaked redfish (*Sebastes mentella*) Divisions Va and XIVb

Stock	Icelandic slope beaked redfish (*Sebastes mentella*) in Divisions Va and XIVb
Working Group	WKRED
Date	February 2012
Revised by	Kristján Kristinsson.

A. General

A.1. Stock definition

The "Workshop on Redfish Stock Structure" (WKREDS, 22–23 January 2009, Copenhagen, Denmark; ICES 2009) reviewed the stock structure of beaked redfish (*Sebastes mentella*) in the Irminger Sea and adjacent waters. ACOM concluded, based on the outcome of the WKREDS meeting, that there are three biological stocks of beaked redfish 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, XIVb) – primarily demersal habitats.**

This conclusion is primarily based on genetic information, i.e. microsatellite information, and supported by analysis of allozymes, fatty acids and other biological information on stock structure, such as some parasite patterns.

The adult redfish on the Greenland shelf has traditionally been attributed to several stocks, and there remains the need to investigate the affinity of adult beaked redfish in this region. The East-Greenland shelf is most likely a common nursery area for the three biological stocks.

The Icelandic slope beaked redfish is treated as a separate management unit.

A.2. Fishery

Annual landings and spatial and temporal distribution of catches

The fishery of Icelandic slope beaked redfish started in the early 1950s (Figure A.2.1). The annual catch 1950–1977 was on average 33 000 t. Annual landings gradually decreased from a record high of 57 000 t in 1994 to 17 000 t in 2001 t. Landings in 2003 increased to 28 500 t but have since then fluctuated between 16 000 t and 21 000 t.

The fishery for beaked redfish in Icelandic waters is predominantly conducted by the Icelandic bottom-trawl fleet directed towards the species. Prior to 2000, between 10–40% of the total landings were taken by pelagic trawl. In general, the pelagic fishery has mainly been in the same areas as the bottom-trawl fishery, but usually in later months of the year. In 2001–2010, no pelagic fishery occurred or it was negligible except in 2003 and 2007.

The catch pattern was different in 2003 and in 2007 than in other years. The catches peaked in July in 2003 and in June 2007, which was unusual. This pattern is associated with the deep pelagic beaked redfish stock fishery within the Icelandic EEZ. The deep pelagic beaked redfish fishery has in some years moved further north, and in 2003 and 2007 it merged with the Icelandic slope beaked redfish fishery on the redfish line (a line defined by Icelandic authorities in 1993 to separate catches of pelagic and Icelandic slope beaked redfish) in July. When the deep pelagic beaked redfish crossed the redfish line to the east, it was recorded as Icelandic slope beaked redfish and caught either with pelagic or bottom trawls. This explains the pelagic catches of Icelandic slope beaked redfish in those two years.

The most important fishing grounds are southwest, west, and northwest (close to the Iceland–Greenland midline EEZ) of Iceland at depths from 450 to 800 m. A historically important fishing ground for the Icelandic slope beaked redfish stock is southeast of Iceland along the slope of the Iceland–Faroe Islands Ridge. Fishing in this area has, since 2000, gradually decreased and in recent years there has not been a directed fishery for Icelandic slope beaked redfish.

Although no direct measurements are available on discards, it is believed that there are no substantial discards of Icelandic slope beaked redfish.

Fleet composition

The fishing fleet operating in Icelandic waters consists of diverse boat types and sizes, operating various types of gear. The majority of the Icelandic slope beaked redfish catches are taken by trawlers larger than 40 BRT using bottom trawls. The remainder of the catch comes from vessels targeting Greenland halibut (*Reinhardtius hippoglossoides*) and in recent years, greater silver smelt (*Argentina silus*). Most of the vessels that target Icelandic slope beaked redfish are the same vessels that fish the pelagic beaked redfish stocks and the majority of the golden redfish (*S. marinus*) catch.

Management

The Ministry of Fisheries and Agriculture is responsible for management of the Icelandic fisheries, including the Icelandic slope beaked redfish fishery, and for the implementation of the legislation in the Icelandic Exclusive Economic Zone (EEZ). There is, however, no explicit management plan for Icelandic slope beaked redfish.

The Ministry issues regulations for commercial fishing for each fishing year (starts on September 1 and ends on August 31 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 feature of the management system with emphasis on Icelandic slope beaked 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 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 individual company as well as among different companies. The latter can be done via temporary or permanent transfer of quota. In addition, some flexibility is allowed by individual boats with regard to transfer 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 2010/211 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 landing is stored in a centralized database maintained by the Directorate and is available in real time on the Internet (www.fiskistofa.is). Up to 10% of the amount of the Icelandic slope *S. mentella* 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.

With some minor exceptions it is required by law to land all catches. Consequently, no minimum landing size is in force. No formal harvest control rule exists for this stock. 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.

Redfish (golden redfish and Icelandic slope beaked redfish) has been within the ITQ system from the beginning. Icelandic authorities gave, however, until the 2010/2011 fishing year a joint quota for these two species. MRI has since 1994 provided a separate advice for the species. The separation of quotas was implemented in the fishing year that started September 1, 2010.

A.3. Ecosystem aspects

Beaked redfish is an ovoviviparous fish species, in which 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. Beaked redfish produce many, small larvae (40–400 thousand larvae) that are extruded soon after they hatch from eggs and disperse widely as zooplankton 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 Icelandic slope beaked redfish reproduction is very scarce.

Little is known about the geographical location and timing of fertilization (mating grounds where copulations occur) and extrusion of larvae (larval extrusion grounds) of Icelandic slope beaked redfish, but it is similar to those for the pelagic beaked redfish stocks (Magnusson and Magnusson, 1995). It is known that mating and copulation takes place in autumn (September–November), but the exact location of copulation is not known (most likely southwest and south of Iceland). The fertilization of eggs occurs in winter (February–March). The extrusion of larvae occurs in spring (April–June), but its exact location of the extrusion area is unknown. The extrusion areas of the pelagic beaked redfish stocks and the Icelandic stocks may merge to some extent, and they are in the open seas in the Irminger Sea, southwest of Iceland (Magnusson and Magnusson, 1995). The extrusion takes place mainly at 500–700 m depth in waters with temperature around 6°C.

Larvae drift to the continental shelf of East Greenland and to some extent to West Greenland, where they settle to the bottom. They are difficult to distinguish from their sibling species golden redfish (*S. marinus*), which has the same nursery areas.

Only the fishable stock of Icelandic slope beaked redfish is found in Icelandic waters, i.e. mainly fish larger than 30 cm. The East Greenland shelf is most likely the main nursery area for the Icelandic slope stock. The nursery areas of both pelagic and the stock found on the continental shelf of Iceland are believed to be on the continental shelf of East Greenland at depths of 200–400 m and reach the shelf off West-Greenland. The proportion of juveniles recruiting to each stock is not known.

Growth and maturity

Icelandic slope beaked redfish is like the pelagic beaked redfish and golden redfish are long-lived, slow-growing and late-maturing fish species.

Diet

The food consists of dominant plankton crustaceans such as Amphipods, Copepods and Euphausids. Small fish and Cephalopods (small squids) can also be important food items in certain areas.

B. Data

B.1. Commercial catch

Sampling from the Icelandic fleet

	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

Icelandic commercial catch in tonnes by month, area and gear are obtained from Statistical Iceland and Directorate of Fisheries. The geographical distribution of catches (since 1991) is obtained from logbook statistic where location of each haul, effort, depth of trawling and total catch of Icelandic slope beaked redfish is given.

B.1.1. Splitting the redfish catch between golden redfish and Icelandic slope beaked redfish in Icelandic waters

Until the 2010/2011 fishing season, Icelandic authorities gave a joint quota for golden redfish and Icelandic slope beaked redfish in Icelandic waters. 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.1.1.2. Data

The following data were used:

1) 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).

2) Information on landed products from Icelandic factory (freezer) trawlers.

3) Biological samples from the Icelandic fresh-fish trawlers sampled by MRI and Icelandic Catch Supervision (ICS) personnel.

4) Landing statistics from Germany and UK if available.

5) Landing statistics from foreign vessels fishing in Icelandic waters.

6) Official landings by gear type provided by Directorate of Fisheries in Iceland.

B.1.1.3. Splitting the redfish catch from freezer trawlers

The redfish landings statistics of the freezer fleet is 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. According to logbooks, the redfish caught with pelagic trawl was Icelandic slope beaked redfish.

To get reliable species composition of the bottom-trawl catch, the total catch of the freezer trawler for each species was first found. If, for a given year, redfish was caught with pelagic trawl (total catch was based on logbooks) the catch was subtracted from the total beaked redfish catch.

B.1.1.4. 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 golden redfish/beaked redfish observed in biological samples from each strata. Each stratum is a rectangle measuring 15 minutes Latitude by 30 minutes Longitude.

1) **For each year:** The redfish catch from each year was divided into strata and scaled to the total unsplit catch of the two species for each rectangle. It is assumed that the distribution of catch not reported in logbooks was the same as for the reported catch. Catch taken by other gears was included (usually 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 found 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 up to maximum five years before a given year. If no samples were available in this five years 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 the last criteria.

3) The split into species of redfish landings in Germany and UK (containers or fresh landings) are based on landings reports and are considered reliable.

4) For other nations operating in Icelandic waters, the catches are split according to information given by those nations. In recent years, only Faroe Islands and Norway have operated in ICES Division Va.

B.1.1.5. 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 golden redfish. This is because boats using these gear types mainly operate in shallow waters were beaked redfish is not found.

B.1.2. Biological data from the commercial catch

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) during trips by personnel of the Directorate of Fisheries in Iceland. The biological data collected are length (to the nearest cm), sex, maturity stage, weight, and otoliths for age reading. Age reading has so far been very limited.

The general process of the sampling strategy is to take one sample of Icelandic slope beaked redfish for every 500 tonnes landed. Each sample consists of 200 fish: 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.

The data are stored in a database at the Marine Research Institute.

B.2. Biological

B.3. The 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 and Icelandic slope beaked redfish. This is because the Spring Survey conducted annually in March since 1985 does not cover the distribution of these deep-water species. The secondary aim of the survey is to have another fisheries-independent estimate on abundance, biomass and biology of demersal species, such as cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and golden redfish, in order to improve the precision of stock assessment.

The text in the following description of the surveys is mostly a translation from Björnsson *et al*. (2007). Where applicable the emphasis has been put on golden redfish. 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. 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 Icelandic slope beaked 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. Preparation and later alterations to the survey

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

Because MRI was not able to finance a project of this magnitude, it was decided to focus the deep-water part of the survey on the Greenland halibut main distributional area. Important Icelandic slope beaked 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 can be compared for Icelandic slope beaked redfish.

The number of stations in the deep-water area was therefore reduced to 150. In all 100 stations were randomly positioned in the area. The remaining stations were located on important Greenland halibut fishing grounds west, north and east of Iceland and randomly selected from a logbook database of the bottom-trawl fleet fishing for Greenland halibut 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 Icelandic slope beaked redfish and the location of the stations selected in a similar manner as for Greenland halibut. In all 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.3.1).

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, increasing the total number of stations in the shallow-water area to 162. 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 Icelandic slope beaked redfish, were omitted southeast of Iceland. The rest or 12 stations were omitted west and northwest of Iceland, these were stations originally aimed at Greenland halibut.

B3.3. Vessels

The RV "Bjarni Sæmundsson" has been used in the shallow-water area from the beginning of the survey. For the deep-water area, the MRI rented one commercial trawler 1996–1999, which was replaced in 2000 by the RV "Árni Friðriksson" (Table B.3.1).

B3.4. 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 from the moment 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, the majority of them, including Icelandic slope beaked redfish, 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 five times the length interval of deep-water redfish. Example: If the continuous length distribution of beaked 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 beaked 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.

Each beaked redfish that is length measured is both sex and maturity determined.

B.3.5.2. Otolith sampling

For beaked redfish, a minimum of one and a maximum of 25 otoliths are collected in the Autumn Survey. Otoliths are sampled at a ten fish interval, so that if in total 200 deep-water redfish are caught in a single haul, 20 otoliths are sampled.

Each beaked redfish taken in the otolith sampling is sex and maturity determined, weighed ungutted, and the stomach content is analysed on board.

Only otoliths from the Autumn Survey in 2000 have been age-read.

B.3.5.3. Information on tow, gear and environmental factors

At each station/haul, relevant information on the haul and environmental factors is recorded 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, Sub-square, 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 estimates 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 NM^2 and A_{tow} is the size of the area surveyed in a single tow in NM^2.

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

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 Icelandic slope beaked redfish in the Autumn Survey are shown in Figure B.3.2. The stratification is in general based on depth stratification and similar oceanographic conditions within each stratum.

The stratification for the Autumn Survey was revised in 2008. This was because the majority of the total catch of species, such as golden redfish, comes in a few but large tows leading to high uncertainties in the estimates of the biomass/abundance indices (high CV). The aim of this revision was, therefore, to reduce the weight of certain tows (the few but large tows that account for the bulk of the total catch) and to reduce the area weight. The number of strata was reduced from 74 to 33. Figure B.3.3 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.

Comparison of total biomass index for Icelandic slope beaked redfish based on the old and new stratification is shown in Figure B.3.4. In general, the measurement errors of the indices based on the new stratification are lower than the ones based on the old one. The indices are similar and show the same trend (except for 2010).

B.4. Commercial cpue

Catch per unit of effort are routinely calculated during the annual assessment process. Data used to estimate cpue for Icelandic slope *S. mentella* in Division Va since 1978 were obtained from logbooks of the Icelandic bottom-trawl fleet. Only those hauls taken below 450 m depth (combined golden redfish and Icelandic slope *S. mentella*) and that were comprised of at least 50% Icelandic slope *S. mentella* (assumed to be the directed fishery towards the species; between 70–90% of the total annual catch were from those hauls) were used. Non-standardized cpue and effort are 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)

Icelandic slope beaked redfish in ICES Division Va has previously been assessed based on trends in survey biomass indices from the Icelandic Autumn 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 Autumn Survey.

At the meeting working document (# 12) was presented where the trend in survey indices for the Icelandic slope beaked redfish was estimated as well as F_{proxy} (catch divided by index for the same stock). The trend in the survey indices was estimated to be around 5% per year (uncertain estimate) so assuming F=M 10% reduction in total mortality was required to stop the trend and 20% to reverse it. If F > M, which is considered a likely hypotheses considering the state of the stock, less than 20% reduction in F is needed to get the intended 10% reduction in Z. The only data available to support that F and M are similar are results from limited age-readings that indicate Z to be around 0.1 and M "is known" to be 0.05. The approach in the working document #12 makes no special reference to the status of the stock which is considered difficult to assess. Similar ideas are put forward in working document #16 for the deep pelagic beaked redfish in the Irminger Sea.

The method proposed in working document #12 has three major shortcomings.

1) The survey data are noisy and the trend is not clear;
2) The survey-series are short (11 years) compared to the lifespan of the species. One year class can take more than five years to recruit to the stock so the survey period might be characterized by abnormally high or low recruitment leading to trend in indices reflecting recruitment anomaly rather than deviations from sustainable fishing effort.
3) Catches may not be correctly allocated to stocks. Spatial distribution of the catches west of Iceland in some years indicate that part of the catch for deep-sea pelagic beaked redfish could be Icelandic slope beaked redfish and vice versa.

The external panel rejected the approaches of working documents #12 and #16 as they did not make any reference to the state of the stock and depended on the assumption F=M. In response it was stated that most likely F > M and therefore the method is if anything conservative.

Some participants in the Working Group considered that at present analytical assessments cannot be conducted because, for example, of little age data and the relative shortness of the time-series available.

The external panel considered that although the biomass dynamic model (specifically the Schaefer form off this approach; see Appendix 1 is preliminary and should be improved, it is possible to use this approach to initially assess stock status and current replacement yield (RY, being the annual catch estimated to maintain abundance at its present level) based on information on past catches, the autumn survey, and external information used to inform on the likely range of the value for stock productivity parameter. For the values of stock productivity parameter considered the most realistic (r = 0.05 to r = 0.10), this approach provides estimates of the current depletion (the present to pre-exploitation abundance ratio) of this resource to be from 46–49% with CVs between 47% and 48%. Estimates of RY range from about 26 (SE 10) to 39 (SE 14) thousand tons, by comparison with an average annual catch over the 2000 to 2010 period of about 72 thousand tons. Although the precision of these RY estimates is poor, the panel draws attention to the approach suggested in the general recommendations section whereby the requirements of the precautionary approach can be addressed by decreasing catch limit estimates by some multiple of the associated SE estimate. The panel does not suggest that the Schaefer model approach used here is to be final; to the contrary it is offered as a first step (from which interim management advice might be formulated) while the assessment is extended to an Age Structured Production Model framework which could, for example, also take account of the commercial catch-at-length and limited ageing data available for this resource. While the projection and reference point computations referenced below are possible within this Schaefer model framework, the panel did not consider it appropriate to report them at this stage, given the interim and intermediate nature of this approach. The difficulties found by the panel with the "trends based assessment" approach are set out in the general recommendations section.

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1978–2010		
Canum	Catch-at-age in numbers			
Weca	Weight-at-age in the commercial catch			
West	Weight-at-age of the spawning–stock at spawning time.			
Mprop	Proportion of natural mortality before spawning			
Fprop	Proportion of fishing mortality before spawning			
Matprop	Proportion mature at age			
Natmor	Natural mortality			

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1	Autumn Survey	2000–2010	Not available
Tuning fleet 2			
Tuning fleet 3			

D. Short-term projection

No short-term predictions are performed.

E. Medium-term projections

No medium-term predictions are performed.

F. Long-term projections

No long-term predictions are performed.

G. Biological reference points

No biological reference points are defined for Icelandic slope beaked redfish in Division Va.

I. References

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Marine Research Institute. 2010. Manuals for the Icelandic bottom-trawl surveys in spring and autumn (*edt.* Jón Sólmundsson and Kristján Kristinsson). Marine Research in Iceland, Report Series no. 156.

Pálsson, Ó. K., Björnsson H., Björnsson E., Jóhannesson G., and Ottesen, Þ. 2010. Discards in demersal Icelandic fisheries 2010. Marine Research Institute, Report series no. 154.

Table B.3.1. Vessels used in the Autumn Groundfish Survey in ICES Division Va, their survey area, and the number of stations 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

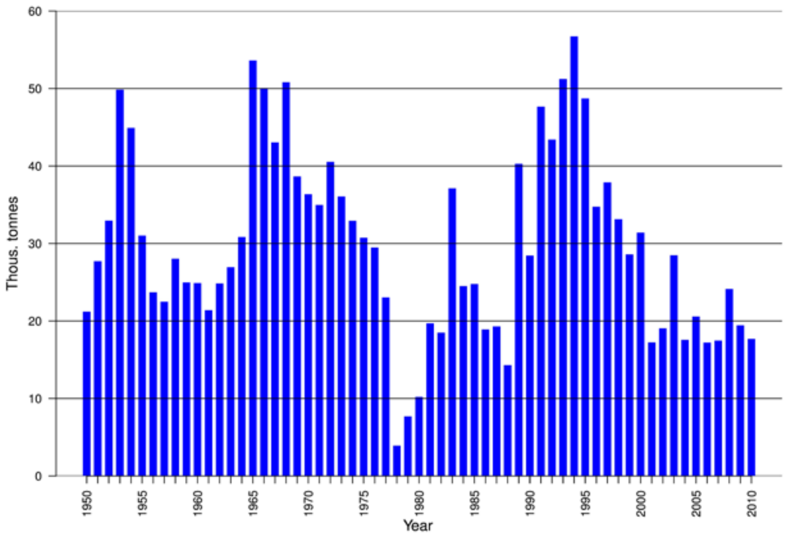

Figure A.2.1. Nominal landings (in tonnes) of beaked redfish (*S. mentella*) from Icelandic waters (ICES Divisions Va and XIVb) 1950–2010.

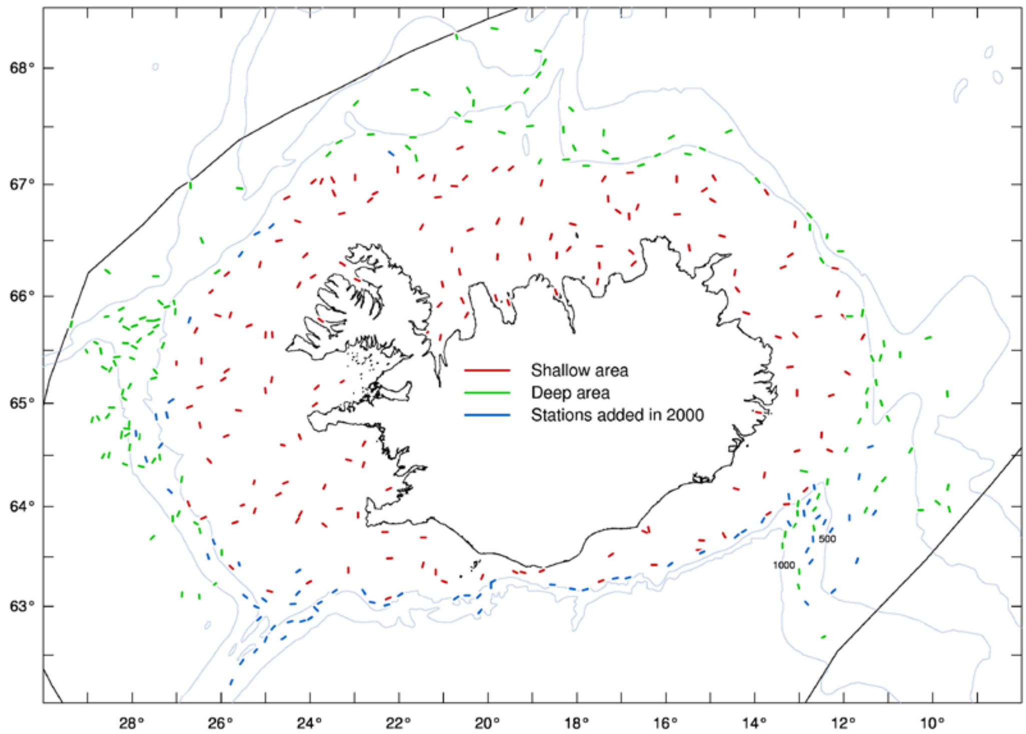

Figure B.3.1. Stations in the Autumn Groundfish Survey (AGS). RV "Bjarni Sæmundsson" takes stations in the shallow-water area (red lines) and RV "Árni Friðriksson" takes stations in the deep-water areas (green lines), the blue lines are stations added in 2000.

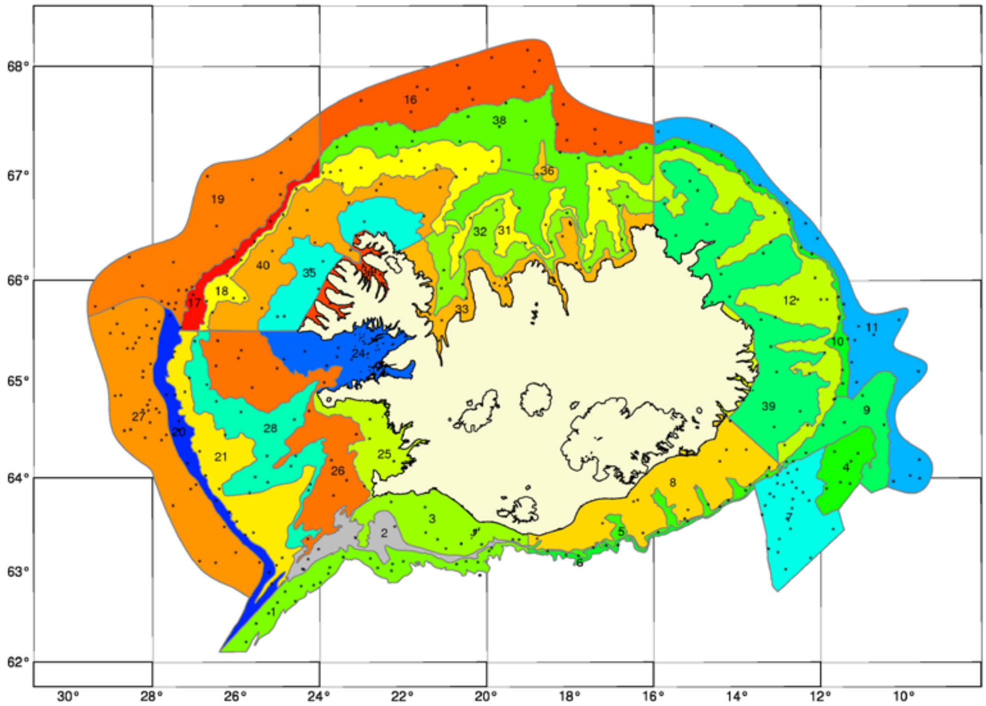

Figure B.3.2. Subareas or strata used for calculation of survey indices for Icelandic slope *S. mentella* from the Autumn Survey in Icelandic waters. This stratification has been applied since 2008.

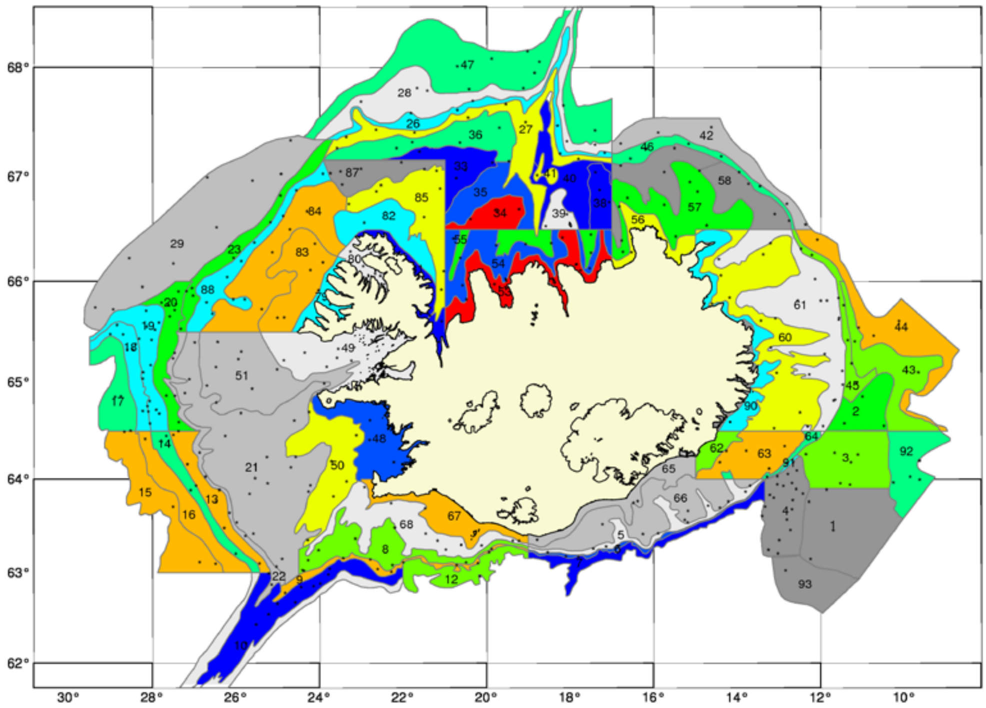

Figure B.3.3. The old stratification (before 2008) that was used for calculation of Icelandic slope *S. mentella* indices from the Autumn Survey in Icelandic waters.

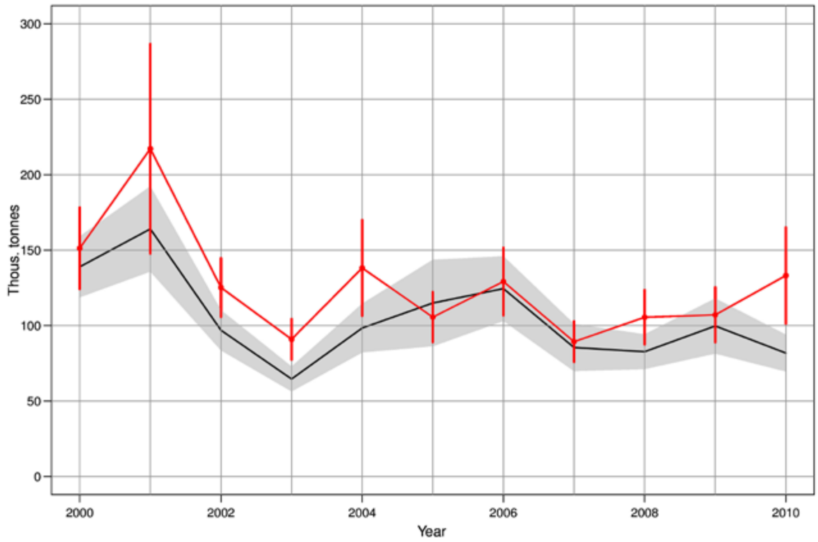

Figure B.3.4. Comparison of survey indices of Icelandic slope *S. mentella* in the Autumn Survey in ICES Division Va based on the new stratification (black line and shaded area, see Figure B.3.2) and the old stratification (red dots and lines, see Figure B.3.3).

Stock Annex: Shallow pelagic beaked redfish (*Sebastes mentella*)

Stock	Shallow pelagic beaked redfish (*Sebastes mentella*)
Working Group	WKRED
Date	February 2012
Revised by	Kristján Kristinsson

A. General

A.1. Stock definition

The deep pelagic beaked redfish (*Sebastes mentella*) stock is distributed mostly in pelagic habitats within NAFO Divisions 1–2, and ICES Areas V, XII, XIV at depths >500 m, but it is also found in demersal habitats west of the Faroe Islands (ICES, 2010).

The Workshop on Redfish Stock Structure (WKREDS) reviewed the stock structure of beaked redfish in the Irminger Sea and adjacent waters (ICES, 2009a). 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 workshop reviewed the stock structure of *Sebastes mentella* in the Irminger Sea and adjacent waters, using genetic information (i.e. microsatellite information), supported by analysis of allozymes, fatty acids and other biological information on stock structure, such as some parasite patterns.

The adult redfish on the Greenland shelf has traditionally been attributed to several stocks, and there remains the need to investigate the affinity of adult *S. mentella* in this region. WKREDS also suggested that the East Greenland shelf is most likely a common nursery area for the three biological stocks they distinguished.

Based on this new stock identification information, ICES recommended in 2009 the use of three potential management units that are geographical proxies for the newly defined biological stocks, which are partly limited by depth and whose boundaries are based on the spatial distribution pattern of the fishery to minimize mixed-stock catches. Thus the newly described deep pelagic stock corresponds to the management unit in the northeast Irminger Sea: NAFO Areas 1 and 2, ICES Areas Vb, XII and XIV at depths greater than 500 m, including demersal habitats west of the Faroe Islands.

A.2. Fishery

The historic development of the fisheries by nation is described in detail in the 2007 NWWG Report, and resumed here. Russian trawlers started the shallow pelagic beaked redfish fishery in 1982, covering wide areas of the Irminger Sea. Vessels from Bulgaria, the former GDR and Poland joined in 1984. Annual landings for most of the period 1982–1995 ranged between 60 000 t and 100 000 t, declining to around 30 000 t between 1989 and 1991 when the East European countries reduced their effort. Fishing took place mainly from April to August. First, on prespawning and spawning aggregations from early April to mid-May, on post-spawning fish from late May to mid-June, and on feeding aggregations from mid-July to August. During this first period of the fishery, 1982–1991, all landings were registered as oceanic *S. mentella* because the main fishing area was in the central Irminger Sea from 59°N to 62°N and between 30°W and 35°W, corresponding to the ICES Divisions XII and XIV, beyond Greenland and Icelandic national jurisdictions and at depths between 80 and 500 m (Sigurðsson *et al.*, 2006).

In the period 1992–1996, the fishery gradually shifted towards greater depths and developed a clear seasonal spatial pattern. Catches increased to 100 000 t as more nations joined the fishery and effort from Russia and Germany rose again. The fleets moved systematically to different areas and depths as the season progressed, fishing the shallow component in the southwest Irminger Sea (57–58°30′N and 32–36°W) later in the season, or from mid-June to October. Fishing is scarce between November and late March or early April.

In 1996, annual landings decreased to 41 000 t, a 60% decline compared with previous years, and they oscillated between 24 000 and 57 000 t (averaging 35 000 t) during the years 1997–2005. From 1997 onwards, logbook data from Russia, Iceland, Faroe Islands, Norway and Germany have been used to calculate landings by stock within each ICES division. It is assumed that catches by other nations have the same spatial distribution. However, the figures for total catch are probably underestimated due to incomplete reporting of catches. In 2006 there was another sharp decline in annual landings, which continue at very low levels, with 2000 t caught in 2008 and 4000 t caught in 2009. A large percentage of annual landings (50% on average) were taken in NAFO Area 1F in 2000–2008, but 81% of the 2009 landings were caught in ICES Division XIV. Since 1995, there is a decreasing trend in cpue.

In all 19 nations have taken part in this fishery since 1982, with a minimum of two nations in 1982 and a maximum of 17 in 1995. The total number of vessels from each country it is not known for the whole period, but during the years 1995–2009, their number ranged between 45 and 92.The fleets participating in this fishery keep updating their fishing technology, and most trawlers now use large pelagic trawls ("Gloria"-type) with vertical openings of 80–150 m.

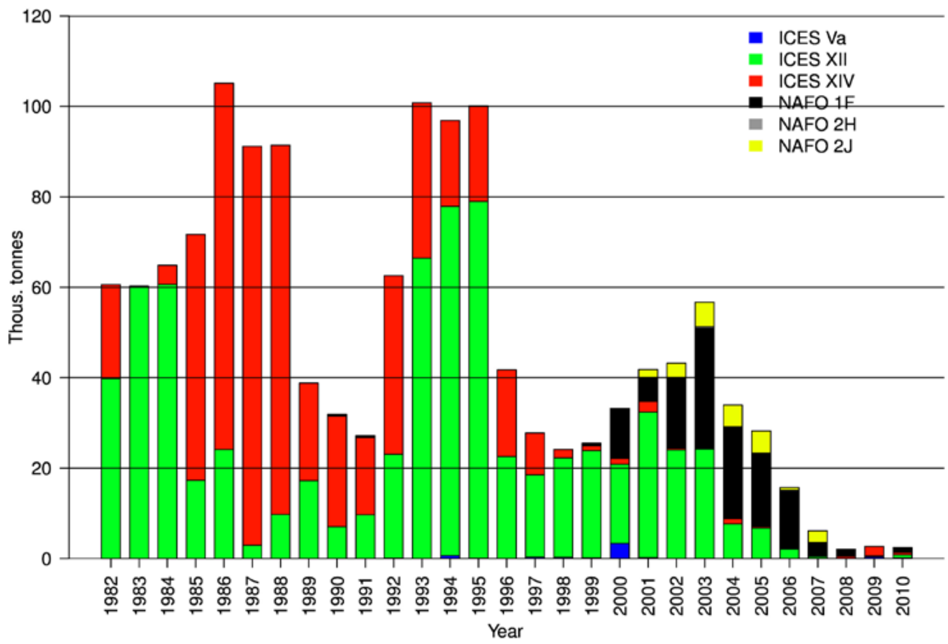

Figure A.2.1. Nominal landings (in thousand tonnes) of shallow pelagic beaked redfish 1982–2010 by ICES areas.

A.3. Ecosystem aspects

Beaked redfish is an ovoviviparous fish species, in which 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 spring. Females are thought to have a determinate fecundity. Beaked redfish produce many, small larvae that are extruded soon after they hatch from eggs and disperse widely as zooplankton. The extrusion of larvae may take place over several days or weeks in a number of batches. It occurs in large areas of the Irminger Sea during April and May, peaking in late April and early May. The main area of extrusion is found south of 65°N and east of 32°W. The location of the mating grounds is unknown, but mating adults are found in the slopes. Knowledge of the biology, behaviour and dynamics of redfish reproduction is very scarce (Magnusson and Magnusson, 1995).

After the larvae extrusion, the adults of the shallow pelagic stock move westwards towards Greenland for feeding and copulation. In the late summer the main concentration is found south and southwest of Greenland and it is the target of the international pelagic fishery.

Early life-history stages are described in Magnusson and Magnusson (1995). The larvae are pelagic and drift northwards in the surface layer and to the continental slope of West and East Greenland. The nursery areas are believed to be on the continental shelf off East Greenland, and to some extent off West Greenland. The identification of beaked redfish and its sibling species golden redfish (*S. marinus*) occupying the same nursery areas is very difficult. It is unknown to what extent beaked redfish juveniles recruit to the different stocks.

Young redfish dwell at the bottom at different depths, the youngest ages preferring lesser depths than older fish. The juveniles are predominantly distributed on the continental shelf of West and East Greenland. Age of recruitment to the fishery of both stocks is believed to be near maturity, maybe between ages 8 to 12 years. The causes for variability of recruitment are unknown. Adults are found in the open ocean.

Little is known about the trophic interactions in the Irminger Sea. However a recent study by Petursdottir *et al*. (2008) shows that Euphausiids (*M. norwegica*) and *Calanus* spp. appear to play an important role in the diet of *S. mentella* in the pelagic ecosystem on the Reykjanes ridge. Pedersen and Riget (1993) investigated stomach content of *S. mentella* in West Greenland waters and found planktonic crustaceans such as hyperiids, copepods and euphausiids to be the main food item in small redfish (5–19 cm). Among shallow stock adults, the diet includes mainly dominant plankton crustaceans such as Amphipods, Copepods and Euphausids. Cephalopods (small squids), shrimp (*P. borealis*) and small fish (including redfish) are also important food items (Pedersen and Riget, 1993; Magnusson and Magnusson, 1995).

There are indications that *Sebastes* spp. play important role as a prey item for Greenland halibut (Orr and Bowering, 1997; Solmundsson, 2007) and adult harp and hooded seals during pelagic feeding (Haug *et al*., 2007; Tucker *et al*., 2009). The prey items in these studies were however not species-specific observations.

Research is needed to get a better understanding of the following issues:

- migrations and locations of the different life stages,
- recruitment success,
- determination of population age structure,
- species identification for young specimens,
- standardization of maturity determination,
- natural mortality.

There has already been some effort conducted to validate and harmonize the methodologies used for age determination at an international level (ICES, 2006 and 2009b). This should however be pursued, since there are still non-standard methodologies used by some Russian teams which forbids data compilation at an international level.

A maturity scale has been agreed at an international level (ICES) but there is a requirement for workshops to be conducted in order to guarantee that this scale is well understood and used in a standardized fashion across nation and research laboratories.

Regarding impact of the fishery on shallow pelagic redfish in the Irminger Sea and adjacent waters, it is generally regarded as having negligible impact on other fish or invertebrate species due to the very low bycatch and discard rates characteristic of pelagic fishing gear.

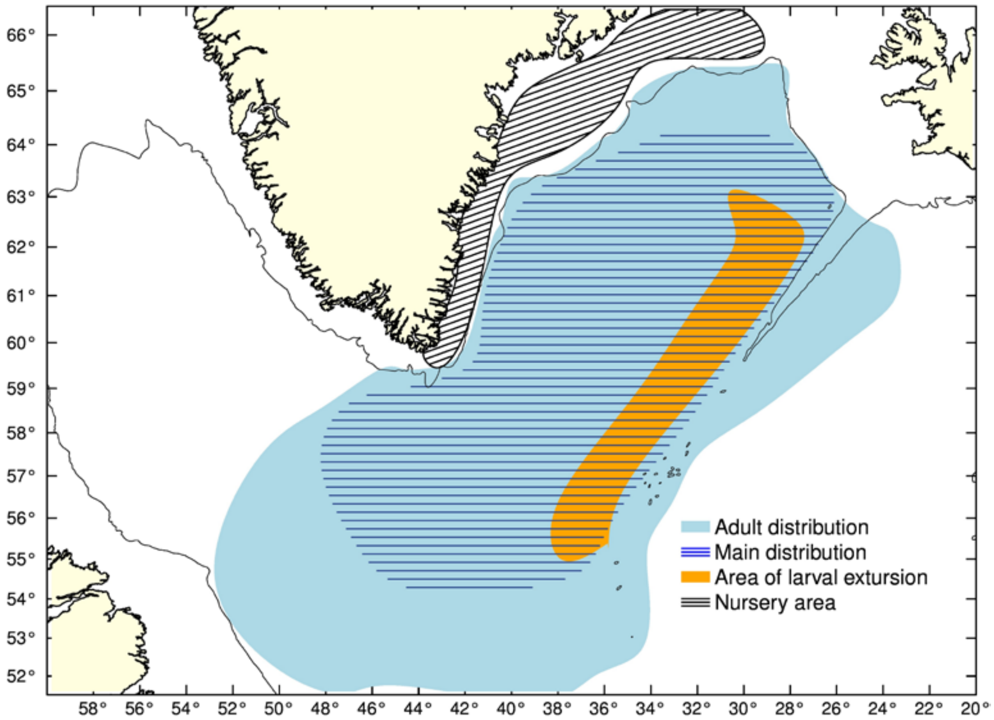

Figure A.3.1. Distribution of both pelagic redfish stocks (shallow and deep) in the Irminger Sea and adjacent waters at different stages of the life cycle.

A.4. Management

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 (minimum mesh size in the trawls is set at 100 mm).

No harvest control rule exists for the stock and there has been no agreement on stock structure (see A.1), the TAC and allocation key between contracting parties in NEAFC for several years, and some countries had set autonomous quotas. This has led in to total annual catches far above the NEAFC TAC.

In March 2011 NEAFC agreed on interim measures for the shallow pelagic beaked redfish fisheries until the end of 2014. These measures were agreed by all members of NEAFC except Russia.

Catches in the shallow pelagic fishery in the Irminger Sea and adjacent waters should take place outside Area 1 shown in Figure A.4.1 (Area 2 in the figure) of this measure. In accordance with the latest advice from ICES and in the absence of any agreed recovery plan, there shall be no fishery during 2011 in the NEAFC Regulatory Area. NAFO shall be informed of this prohibition. Fisheries for 2012 to 2014 will depend upon the establishment of a recovery plan for the shallow redfish in the Irminger Sea and adjacent waters, as well as on any new scientific advice.

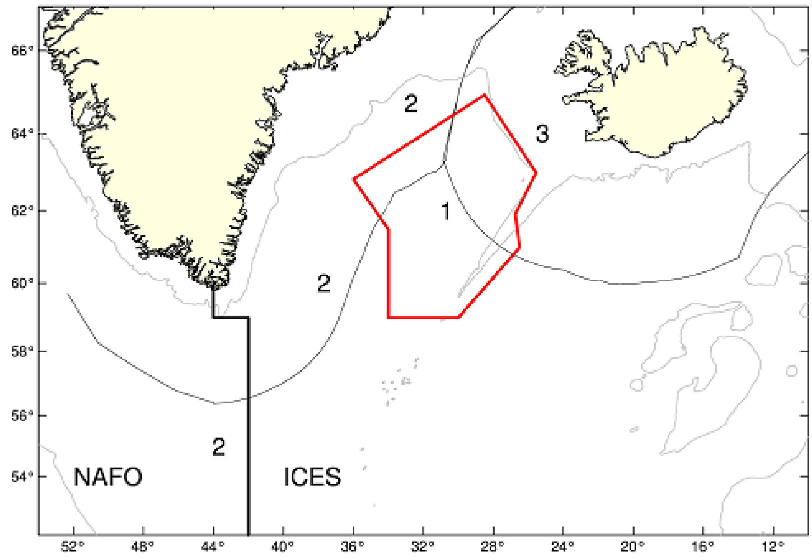

Figure A.4.1. Management unit boundaries for beaked redfish (*S. mentella*) in the Irminger Sea and adjacent waters. The polygon bounded by red lines, i.e. 1, indicates the region of the deep-pelagic management unit in the northwest Irminger Sea, 2 is the shallow-pelagic management unit in the Irminger Sea and adjacent waters including within the NAFO Convention areas, and 3 is the Icelandic slope management unit which is within the Icelandic EEZ.

B. Data

B.1. Commercial catch

Iceland, Greenland, Faroe Islands, Norway, Germany and Russia are the nations providing the most complete databases, including detailed vessel and gear information, as well as catch data on a haul to haul basis. The rest of the countries supply catch in weight and the length composition of the catch.

The preliminary official landing data are provided by the ICES Secretariat, NEAFC and NAFO, and various national data are reported to the Group. The Group, however, repeatedly faces problems in obtaining reliable data due to unreported catches of pelagic redfish and lack of catch data disaggregated by depth from some countries. There are indications that reported effort (and consequently landings) could represent only around 80% of the real effort in certain years (see Chapter 19.3.3 in the 2008 NWWG report). No new data in IUU have been available since 2008.

Splitting of catches: In the period 1992–1996, the fishery gradually shifted towards greater depths and developed a clear seasonal spatial pattern. The fleets fished first the deep stock and moved to the southwestern Irminger Sea (south of 60°N and west of about 32°W) from mid-June to October to fish the shallow stock. Landings from these years have been assigned to the different biological stocks according to several criteria, such as landings by ICES statistical areas, ICES divisions, by nation, and logbook data. When a nation lacked data, the average from the other nations was used instead. Landing data disaggregated by biological stock from this period are considered to be the most unreliable and must be regarded as the WGs best estimates (guesstimates). This task was carried out according to the NWWG meeting celebrated in 2004, Bergen.

B.2. Biological

Biological information is collected from commercial catches (Iceland, Russia, Spain and other EU countries). For Iceland, the data consist of length measurements, weight, sex, maturity stage, and otolith collection. Otoliths have not been age read.

The Group started to collate an international database with length distributions from the sampling of the fisheries on a spatially disaggregated level. Once complete, the horizontal and vertical differences in mean length by fishing areas can be illustrated as alternative to the portrayals by ICES/NAFO divisions. The database includes data from Iceland, Greenland, Faroe Islands, Norway, Germany and Russia.

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

- population age structure, with the need to validate and standardize the methods for age and maturity determination,
- species identification of young individuals,
- location of nursery and mating areas,
- estimation of natural mortality.

There has already been some effort conducted to validate and harmonize the methodologies used for age determination at an international level (ICES, 2006 and 2009b). This should however be pursued, since there are still non-standard methodologies used by some Russian teams which forbids data compilation at an international level.

A maturity scale has been agreed at an international level (ICES) but there is a requirement for workshops to be conducted in order to guarantee that this scale is well understood and used in a standardized fashion across nation and research laboratories.

B.3. Surveys

Acoustic surveys have been conducted on pelagic redfish in the Irminger Sea and adjacent waters since 1982 (Table B.3.1). These surveys provide valuable information on the biology, distribution and relative abundance of oceanic redfish, as well as on the oceanographic conditions of the surveyed area. Many of them were undertaken by single nations, but after several joint surveys during the 1990s, an international trawl-acoustic survey has been conducted by Iceland, Germany and Russia (with Norway participating also in 2001) since 1999.

The Working Group for Redfish Survey (WGRS, formerly as SGRS then PGRS) has organized and planned these international surveys since 1999 and distribute survey area and time among the participants.

Technical description

The technical details and description of the equipment used are described in (ICES, 2011a). Here, a brief summary of the sampling methodology of the surveys 1999–2011 is given.

Acoustics

In the 2011 survey, 38 kHz Simrad EK60 split-beam echosounder was used for the acoustic data collection on RV "Árni Friðriksson" and RV "Vilnyus" whereas on RV "Walther Herwig III" an EK500 was used, also equipped with a 38 kHz split-beam transducer. The settings of the acoustic equipment used during the survey are given in Table 2 in ICES (2011b). During the survey on board of the Icelandic and German vessels the post-processing system (EchoView V4.9, Myriax) was used for scrutinising the echograms, whereas FAMAS (a post-processing program developed by TINRO) was used in the Russian vessel. Mean integration values of redfish per 5 NM were used for the calculations.

The integration threshold of 80–84 dB/m^3 was used. A length based target

TS = 20logL – 71.3 dB

has been used for the estimation of the number of pelagic redfish in the survey area.

Earlier investigations (Magnússon *et al.*, 1994; Magnússon *et al.*, 1996; Reynisson and Sigurðsson, 1996) have demonstrated that the acoustic values obtained from oceanic redfish exhibit a clear diurnal variation, due to a different degree of mixing with smaller scatter and to changes in target strength. In order to compensate for these effects, the acoustic data obtained when mixing is most pronounced (i.e. during the darkest hours of the night), are discarded and the values within the missing sections are estimated by interpolation.

In further data processing, the number of fish is calculated for statistical rectangles measuring 1°latitude x 2°longitude. Changes in the length range of redfish in the past acoustic surveys are taken into account by changing the length-based target strength formula accordingly (Reynisson, 1992; ICES, 2011 for details). The total number of fish within the Subareas A–F in which the survey area is divided (Figure B.3.1) is then obtained by summation of the individual rectangles. The acoustic results were further divided into the number of individuals and biomass based on the biological samples representative for each subarea.

For the entire survey area, single-fish echoes from redfish are expected to be detectable down to 350 m. In order to include all echoes of interest, a low integration threshold is chosen (i.e. -80 dB//m^3 for the 2011 survey). Based on the depth distribution of redfish observed during the survey and the expected target strength distribution, the method outlined by Reynisson (1996) is used to estimate the expected bias due to thresholding. The results of the biomass calculations were adjusted accordingly.

The measurements of echosounders can be disturbed by noise (from the ambient and the vessel) and reverberation (echoes reflected from unwanted targets). Because the amplitude of the signal decreases with depth whereas the amplitude of noise increases due to time varied gain, very small noise can prevent the measurements. Thus, to improve the signal to noise ratio, a threshold is usually applied (Bethke, 2004).

When the redfish appears mixed with other deep-sea species, or the weather is bad and disturbs the measurements, echo counting is preferred over echo integration, as described in Bethke (2004). The counting procedure is based on the fact that fish are recognized as single targets according to the parameter settings of the echosounder. However, if redfish is found in dense aggregations, echo integration is more accurate. Switching between methods may be necessary during the survey (ICES, 2011).

To get biological information on the redfish acoustically identified trawling for 4 NM is done. The net used on RV "Árni Friðriksson" and RV "Walther Herwig III" was a Gloria type #1024, with a vertical opening of approximately 50 m. The net used on RV "Vilnyus" was a Russian pelagic trawl (design 75/448) with a circumference of 448 m and a vertical opening of 47–50 m. Russia was using a mesh opening of 40 mm in the codend, while Iceland and Germany were using a mesh opening of 23 mm in the codends. The trawls used on RV "Árni Friðriksson" and RV "Walther Herwig III" were fitted with multiple codend sampling device: the 'multisampler' (Engås *et al.*, 1997). This allowed for successive sampling at three distinct depth zones within one trawl haul and without 'contamination' from one depth to the next and no sampling during shooting or heaving of the trawl.

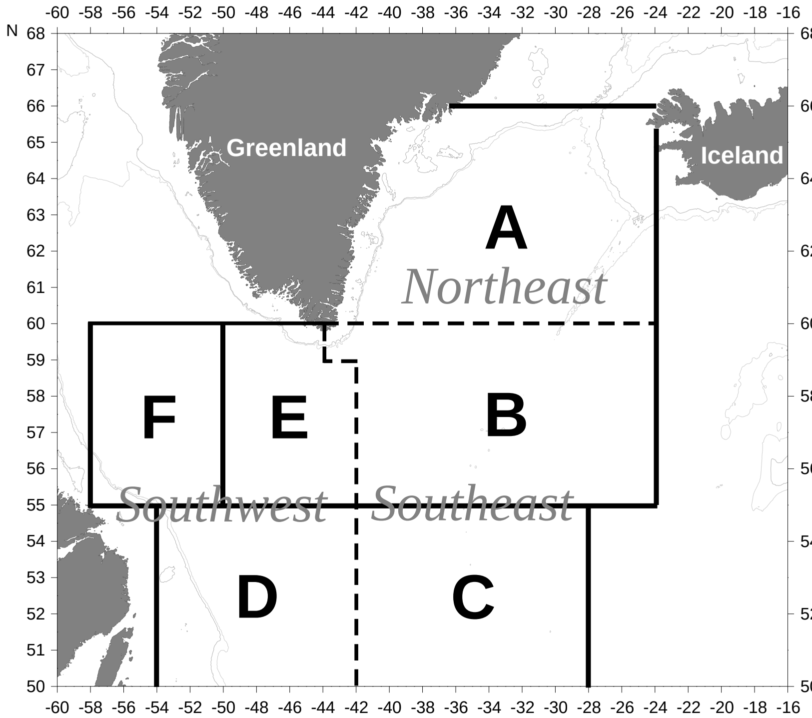

Figure B.3.1. Subareas A–F used on international surveys for redfish in the Irminger Sea and adjacent waters and divisions for biological data (Northeast, Southwest and Southeast; boundaries marked by broken lines).

Table B.3.1. Summary of trawl-acoustic surveys conducted in the Irminger Sea and adjacent waters 1982–2011. The surveys 1982–1997 were acoustic surveys, whereas the surveys 1999–2011 were both acoustic and trawl surveys. In all surveys CTD station were taken down to 1000 m. AC=Acoustic survey; TR/AC=Trawl-acoustic survey; RUS=Russia; ICE=Iceland; GER=Germany; NOR=Norway.

Year	Time	Type	Area surveyed NM2	Depth (m)	Nation	Reference
1982		AC	40		RUS	Pavlov and Mamylov, 1989.
1983		AC	50		RUS	Pavlov and Mamylov, 1989.
1984		AC	55		RUS	Pavlov and Mamylov, 1989.
1985		AC	71		RUS	Pavlov and Mamylov, 1989.
1986		AC	117		RUS	Pavlov and Mamylov, 1989.
1987		AC	215		RUS	Pavlov and Mamylov, 1989.
1988		AC	163		RUS	Pavlov and Mamylov, 1989.
1989	June/July	AC	148		RUS	Shibanov *et al*., 1996a.
1990	June/July	AC	73		RUS	Shibanov *et al*., 1996a.
1991	June/July	AC	105		RUS	Shibanov *et al*., 1996a.
1991	June	AC	60	0–500	ICE	Magnússon *et al*., 1992a.
1992	May/July	AC	190	0–500	ICE/RUS	Magnússon *et al*., 1992b.
1993	June/July	AC	121		RUS	Shibanov *et al*., 1996a.
1994	June/July	AC	190	0–500	ICE/NOR	Magnússon *et al*., 1994.
1995	June/July	AC	168	0–500	RUS	Shibanov *et al*., 1996b.
1996	June/July	AC	253	0–500	GER/ICE/RUS	Magnússon *et al*., 1996.
1997	June/July	AC	158	0–500	RUS	Melnikov *et al*., 1998.
1999	June/July	TR/AC	296	0–950	GER/ICE/RUS	Sigurdsson *et al*., 1999
2001	June/July	TR/AC	420	0–950	GER/ICE/RUS/NOR	ICES, 2002.
2003	May/June	TR/AC	405	0–950	GER/ICE/RUS	ICES, 2003
2005	June/July	TR/AC	386	0–950	GER/ICE/RUS	ICES, 2005
2007	June/July	TR/AC	349	0–950	ICE/RUS	ICES, 2007b
2009	June/July	TR/AC	360	0–950	GER/ICE	ICES, 2009c
2011	June/July	TR/AC	343	0–950	GER/ICE/RUS	ICES, 2011b

Biological sampling

Catch weight and number of all species will be recorded for each haul. The individual biological sampling of deep-water redfish was done in following way (taken from ICES (2011a)):

1) The total length (cm below), individual weight, sex and stage of maturity should be measured on at least 300 redfish from each haul type.

2) Otolith sampling was carried out at each station. Sampling was conducted on 50 individuals following a random sampling procedure (i.e. not stratified by length).

3) Observations on the stomach fullness, the location and size of skin/muscular pigments as well as infestation with *Sphyrion lumpi* and its remnants was investigated on at least 50 randomly sampled fish (usually collected on individual fish for which otoliths are sampled).

B.4. Commercial cpue

It is not known to what extent cpue reflects changes in the stock status of pelagic *S. mentella*. Since the fishery focuses on aggregations, the cpue series might not indicate or reflect actual trends in stock size.

B.5. Other relevant data

C. Historical stock development

Model used: Some participants in the Working Group considered that no model was suitable and that, the assessment of pelagic redfish in the Irminger Sea and adjacent waters should be based on survey indices, catches, cpue and biological data.

The external panel noted that a concern with any assessment of this resource is possible violation of the assumption of a closed population. There may have been a distributional shift out of area covered by the survey due to environmental changes; this will be addressed in upcoming meeting on oceanographic drivers of stock distribution. A change in distribution has been observed in the surveys over time and will be the topic of that workshop.

However if the survey results are accepted as an index of population abundance, then the external panel considered that although the biomass dynamic models (the Schaefer model, and the aggregated model assuming very poor recruitment; see Appendix 1 for details on the methodology) are preliminary and should be improved, it is possible to use the former to initially assess stock status and current replacement yield (RY, being the annual catch estimated to maintain abundance at its present level) based on information from past catches, the acoustic-trawl survey, and external information used to inform on the likely range of the value for stock productivity parameter r. The poor recruitment model can (like the Schaefer model) be used to provide an estimate of the current depletion (the present to pre-exploitation abundance ratio), though naturally that model implies no sustainable yield for as long as such poor recruitment might continue. For the values of stock productivity parameter considered the most realistic ($r = 0.05$ to $r = 0.10$), the Schaefer model approach provides estimates of the current depletion (the present to pre-exploitation abundance ratio) of this resource to be about 4% with CVs of about 50%; these compare with estimates from the poor recruitment model (which provides a better fit to the data) of about 1% to 4%, depending upon the level of natural mortality (M) and survey catchability (q). Estimates of RY from the Schaefer model range from about 2 (SE 1) to 4 (SE 2) thousand tons, by comparison with an average annual catch over the 2000 to 2010 period of about 24 thousand tons. Although the precision of these RY estimates is poor, the panel draws attention to the approach suggested in the general recommendations section whereby the requirements of the precautionary approach can be addressed by decreasing catch limit estimates by some multiple of the associated SE estimate. The panel does not suggest that either the Schaefer or poor recruitment model approaches used here should be final; to the contrary they are offered as a first step (from which interim management advice might be formulated) while the assessment is extended to an Age Structured Production Model framework which could, for example, also take account of the commercial catch-at-length and ageing data available for this resource. While the projection and reference point computations referenced below are possible within the Schaefer model framework, the panel did not consider it appropriate to report them at this stage, given the interim and intermediate nature of this approach. The difficulties found by the panel with the "trends based assessment" approach are set out in the general recommendations section.

Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	Since 1982		Yes
Canum	Catch-at-age in numbers			
Weca	Weight-at-age in the commercial catch			
West	Weight-at-age of the spawning–stock at spawning time.			
Mprop	Proportion of natural mortality before spawning			
Fprop	Proportion of fishing mortality before spawning			
Matprop	Proportion mature at age			
Natmor	Natural mortality			

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1			
Tuning fleet 2			
Tuning fleet 3			
….			

D. Short-term projection

Model used:

Software used:

Initial stock size:

Maturity:

F and M before spawning:

Weight-at-age in the stock:

Weight-at-age in the catch:

Exploitation pattern:

Intermediate year assumptions:

Stock–recruitment model used:

Procedures used for splitting projected catches:

E. Medium-term projections

Model used:

Software used:

Initial stock size:

Natural mortality:

Maturity:

F and M before spawning:

Weight-at-age in the stock:

Weight-at-age in the catch:

Exploitation pattern:

Intermediate year assumptions:

Stock–recruitment model used:

Uncertainty models used:

1) Initial stock size:
2) Natural mortality:
3) Maturity:
4) F and M before spawning:
5) Weight-at-age in the stock:
6) Weight-at-age in the catch:
7) Exploitation pattern:
8) Intermediate year assumptions:
9) Stock–recruitment model used:

F. Long-term projections

Model used:

Software used*:*

Maturity:

F and M before spawning:

Weight-at-age in the stock:

Weight-at-age in the catch:

Exploitation pattern:

Procedures used for splitting projected catches:

G. Biological reference points

For 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. Thus, no reference points can be derived.

H. Other issues

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Stock Annex: Deep pelagic beaked redfish (*Sebastes mentella*) in ICES

Stock	Deep pelagic *Sebastes mentella*
Working Group	WKRED
Date	February 2012
Revised by	Kristján Kristinsson

A. General

A.1. Stock definition

The deep pelagic beaked redfish (*Sebastes mentella*) stock is distributed mostly in pelagic habitats within NAFO Divisions 1–2, and ICES Areas V, XII, XIV at depths >500 m, but it is also found in demersal habitats west of the Faroe Islands (ICES, 2010).

The Workshop on Redfish Stock Structure (WKREDS) reviewed the stock structure of beaked redfish in the Irminger Sea and adjacent waters (ICES, 2009a). 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 workshop reviewed the stock structure of *Sebastes mentella* in the Irminger Sea and adjacent waters, using genetic information (i.e. microsatellite information), supported by analysis of allozymes, fatty acids and other biological information on stock structure, such as some parasite patterns.

The adult redfish on the Greenland shelf has traditionally been attributed to several stocks, and there remains the need to investigate the affinity of adult *S. mentella* in this region. WKREDS also suggested that the East Greenland shelf is most likely a common nursery area for the three biological stocks they distinguished.

Based on this new stock identification information, ICES recommended in 2009 the use of three potential management units that are geographical proxies for the newly defined biological stocks, which are partly limited by depth and whose boundaries are based on the spatial distribution pattern of the fishery to minimize mixed-stock catches. Thus the newly described deep pelagic stock corresponds to the management unit in the northeast Irminger Sea: NAFO Areas 1 and 2, ICES Areas Vb, XII and XIV at depths greater than 500 m, including demersal habitats west of the Faroe Islands.

The decision to classify pelagic redfish as two stocks rather than one stock was not unanimous among ACOM members. Russia's position regarding the structure of the redfish stock in the Irminger Sea and adjacent waters remains unchanged, i.e. that there is a single-stock of *S. mentella* in that area (ICES, 2011).

A.2. Fishery

The fishery for deep pelagic redfish started in the early 1990s and grew quickly, with vessels from Iceland, Faroese, Germany, Norway, Portugal and Russia (Sigurðsson *et al.*, 2006). In 1995, 17 nations participated in the fishery, but nine of them retired soon or have participated occasionally.

In the period 1992–1996, the fishery gradually shifted from the traditional fishing grounds towards greater depths, developing a clear seasonal spatial pattern. The fleets moved systematically to different areas and depths as the season progressed, fishing the deep component in the northeastern Irminger Sea (north of 61°N and east of 32°W) during the first months of the fishing season, or from April to mid-June, and moving to the shallow fishing grounds later in the season. Fishing is scarce between November and late March or early April.

As more nations joined the fishery, annual landings increased quickly from 59 tonnes in 1991 to nearly 140 000 t in 1996, stabilizing at 85 000–105 000 t during the period 1997–2004, when some countries ceased fishing (Figure A.2.1). From 2005 onwards, annual landings have declined, being in the range 30 000–68 000 t. From 1997 onwards, logbook data from Russia, Iceland, Faroe Islands, Norway and Germany have been used to calculate landings by stock within each ICES division. It is assumed that catches by other nations have the same spatial distribution. However, the figures for total catch are probably underestimated due to incomplete reporting of catches. A large percentage of annual landings (63% on average) were taken in ICES Division XIV in 1991–2009.

The fleets participating in this fishery keep updating their fishing technology, and most trawlers now use large pelagic trawls ("Gloria"-type) with vertical openings of 80–150 m.

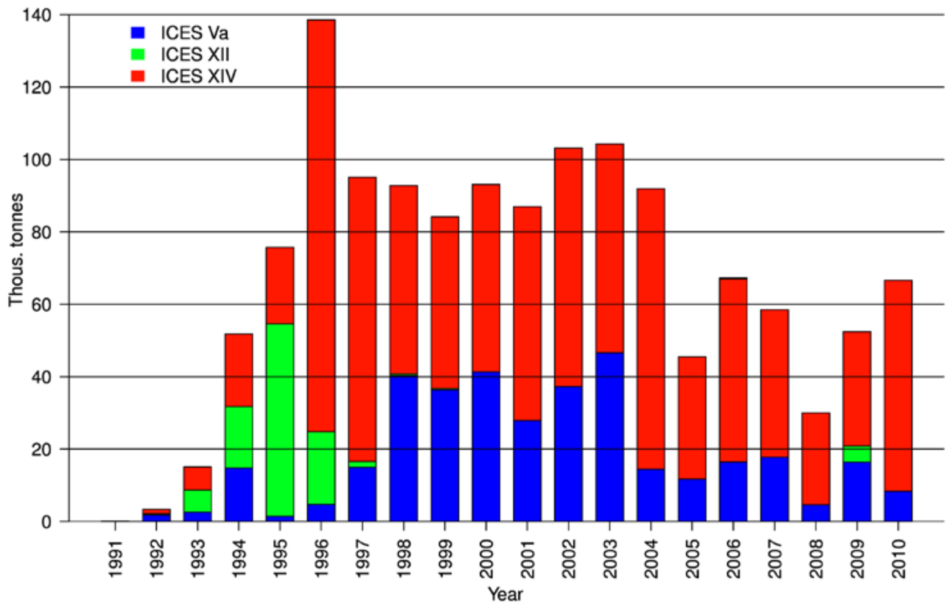

Figure A.2.1. Nominal landings of deep pelagic beaked redfish 1991–2010 by ICES areas.

A.3. Ecosystem aspects

Beaked redfish is an ovoviviparous fish species, in which 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 spring. Females are thought to have a determinate fecundity. Beaked redfish produce many small larvae that are extruded soon after they hatch from eggs and disperse widely as zooplankton. The extrusion of larvae may take place over several days or weeks in a number of batches. It occurs in large areas of the Irminger Sea during April and May, peaking in late April and early May. The main area of extrusion is found south of 65°N and east of 32°W. The location of the mating grounds is unknown, but mating adults are found in the slopes. Knowledge of the biology, behaviour and dynamics of redfish reproduction is very scarce (Magnusson and Magnusson, 1995).

The adults of the deep pelagic stock move northwards and are found in May–July close to and within the Icelandic EEZ and to the continental shelf of Iceland. The international fishing fleet targets this adult population, with the main fishing areas being both close to the Icelandic–Greenland EEZ's and within Icelandic waters.

The larvae are pelagic and drift northward in the surface layer and to the continental slope of West and East Greenland. The nursery areas are believed to be on the continental shelf of East Greenland and to some extent of West Greenland. It is unknown to what extend juveniles recruit to the different stocks.

Early life-history stages are described in Magnusson and Magnusson (1995). Larvae drift to the continental shelf of East Greenland and to some extent to West Greenland, where they settle to the bottom. It is difficult to distinguish from the sibling species golden redfish (*S. marinus*), which occupies the same nursery areas.

Young redfish dwell at the bottom at different depths, the youngest ages preferring lesser depths than older fish. The juveniles are predominantly distributed on the continental shelf of West and East Greenland. Adults are found in the open ocean.

Age of recruitment to the fishery of both stocks is believed to be near maturity, maybe between ages 8 to 12 years. The causes for variability of recruitment are unknown.

Little is known about the trophic interactions in the Irminger Sea. However a recent study by Petursdottir *et al*. (2008) shows that Euphausiids (*M. norwegica*) and *Calanus* spp. appear to play an important role in the diet of beaked redfish in pelagic ecosystem on the Reykjanes ridge. Pedersen and Riget (1993) investigated stomach contents of beaked redfish in W-Greenland waters and found planktonic crustaceans such as hyperiids, copepods and euphausiids to be the main food items in small redfish (5–19 cm). Among shallow stock adults, the main food items are dominant plankton crustaceans such as Amphipods, Copepods and Euphausids. Cephalopods (small squids), shrimp (*P. borealis*) and small fish (redfish included) are also important food items (Pedersen and Riget, 1993; Magnusson and Magnusson 1995).

There are indication that *Sebastes* spp. play important role as a prey item for Greenland halibut (Orr and Bowering, 1997; Solmundsson, 2007) and adult harp and hooded seals during pelagic feeding (Haug *et al*., 2007; Tucker *et al*., 2009). The prey items in these studies were however not species-specific observations.

Research is needed to get a better understanding of the following issues:

- migrations and locations of the different life stages,

- recruitment success,
- determination of population age structure,
- species identification for young specimens,
- standardization of maturity determination,
- natural mortality.

There has already been some effort conducted to validate and harmonize the methodologies used for age determination at an international level (ICES, 2006, 2009b). This should however be pursued, since there are still non-standard methodologies used by some Russian teams which forbids data compilation at an international level.

A maturity scale has been agreed at an international level but there is a requirement for workshops to be conducted in order to guarantee that this scale is well understood and used in a standardized fashion across nation and research laboratories.

Regarding the impact of the fishery on pelagic redfish in the Irminger Sea and adjacent waters, it is generally regarded as having negligible impact on the habitat and other fish or invertebrate species due to very low bycatch and discard rates, characteristic of fisheries using pelagic gear.

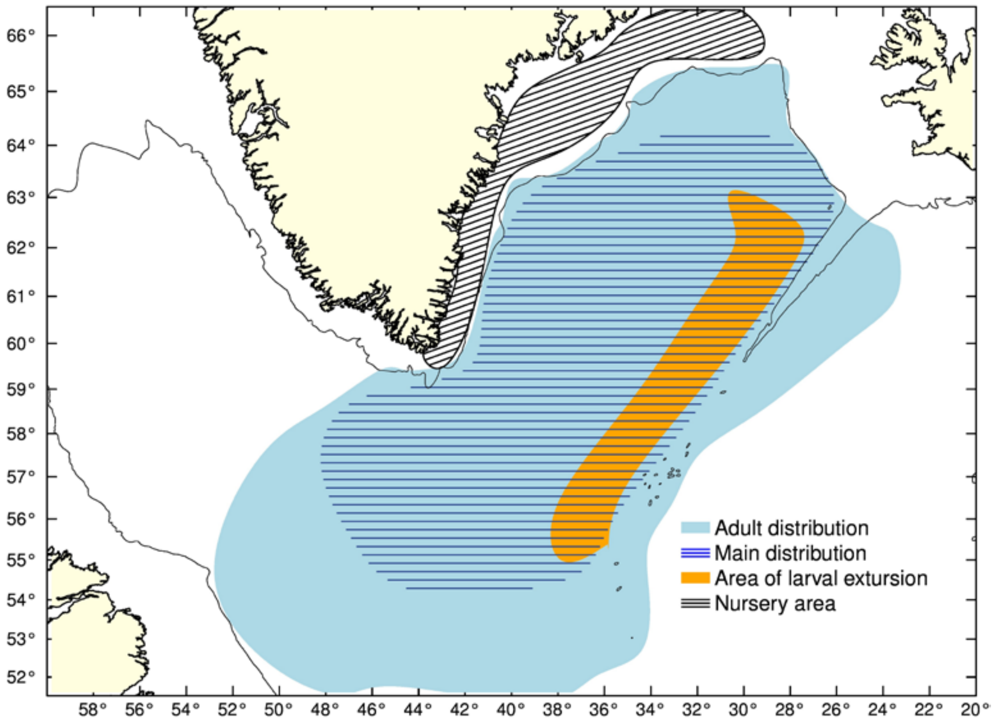

Figure A.3.1. Distribution of both pelagic redfish stocks (shallow and deep) in the Irminger Sea and adjacent waters at different stages of the life cycle.

A.4. Management

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 (see A.1), the TAC and allocation key between contracting parties in

NEAFC for several years, and some countries had set autonomous quotas. This has led in 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. It is therefore expected that the total catch will exceed the TACs set by NEAFC. The objective of these measures is to gradually decrease the catches to the ICES advice and in the long term to establish harvest control rule.

The main measures that apply in 2011–2104 are (see detailed agreement on http://www.neafc.org/system/files/postalvote_redfish_Irmingersea_april2011.pdf):

1) TAC and quota allocation between Contracting Parties for the deep pelagic beaked redfish fishery in the Irminger Sea and adjacent waters 2011–2014 is fixed as follows: in 2011 TAC was 38 000 tonnes, in 2012 it will be 32 000 tonnes, in 2013 26 000 tonnes, and in 2014 TAC will be 20 000. Additional quotas may be allocated to non-Contracting Parties for each year.

2) The level of the TACs for 2012 to 2014 may be adjusted in the light of new scientific advice from ICES.

3) The Contracting Parties are allocated the following quota shares of the established TACs for the period 2011 to 2014. These percentage shares are agreed on an *ad hoc* basis for the period 2011 to 2014 and do not prejudice quota allocation schemes for subsequent periods.

3.1)	Denmark, in respect of the Faroe Islands and Greenland	28.98%
3.2)	European Union	15.45%
3.3)	Iceland	31.02%
3.4)	Norway	3.85%
3.5)	Russian Federation	20.70%

4) From 2011, each Party may transfer to the following year unutilized quantities of up to 5% of the quota allocated to that Party for the initial year. The quantity transferred shall be in addition to the quota allocated to the Party concerned in the following year. This quantity cannot be transferred further to the quotas for subsequent years. No transfers may be made from unfished quantities of quotas established for 2010 or for any earlier fishing seasons.

5) Each Party may authorize fishing by its vessels of up to 5% beyond the quota allocated to that Party in any one year. All quantities fished beyond the allocated quota for one year shall be deducted from that Party's quota allocated for the following year.

6) The fisheries shall not commence prior to 10 May each year to enhance the protection of areas of larval extrusion.

7) Catches in the deep pelagic fishery in the Irminger Sea and adjacent waters referred to in paragraph 1 shall be conducted from 2011 to 2014 within an area bounded by the lines joining the following coordinates (Area 1 in Figure A.4.1).

Point no.	Latitude	Longitude
1	64° 45' N	28° 30' W
2	62° 50' N	25° 45' W
3	61° 55' N	26° 45' W
4	61° 00' N	26° 30' W
5	59° 00' N	30° 00' W
6	59° 00' N	34° 00' W
7	61° 30' N	34° 00' W
8	62° 50' N	36° 00' W
9	64° 45' N	28° 30' W

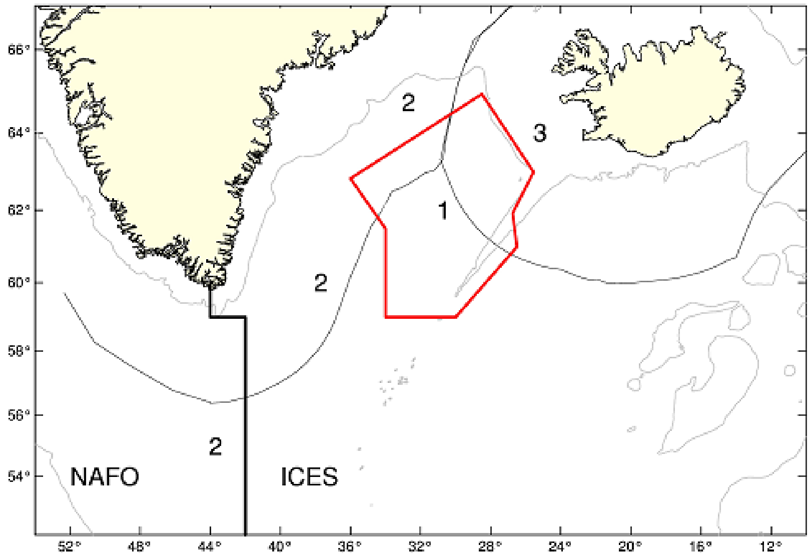

Figure A.4.1. Management unit boundaries for beaked redfish (*S. mentella*) in the Irminger Sea and adjacent waters. The polygon bounded by red lines, i.e. 1, indicates the region of the deep pelagic management unit in the northwest Irminger Sea, 2 is the shallow pelagic management unit in the Irminger Sea and adjacent waters including within the NAFO Convention areas, and 3 is the Icelandic slope management unit which is within the Icelandic EEZ.

8) Among reporting requirements are that masters of fishing vessels shall record the fishing depth in their fishing logbooks. Also, that Contracting Parties shall report to the Secretariat on a weekly basis the catches landed by their vessels. This information shall be made available to Contracting Parties and to the inspectors on the secure site of the NEAFC website.

9) The minimum mesh size of the trawl is 100 mm.

10) Finally, NEAFC will seek to establish a long-term management plan for redfish in the Irminger Sea and adjacent waters during the period of implementation of these interim management measures. This includes appropriate harvest control rule.

The objective of any such management plan shall be to establish such levels of catches and fishing effort, which will result in the sustainable exploitation of pelagic redfish in the Irminger Sea and adjacent waters. This long-term management plan should take due account of the interim management measures as set out in this recommendation.

B. Data

B.1. Commercial catch

Iceland, Greenland, Faroe Islands, Norway, Germany and Russia are the nations providing the most complete databases, including detailed vessel and gear information, as well as catch data on a haul to haul basis. The rest of the countries supply catch in weight and the length composition of the catch.

The preliminary official landing data are provided by the ICES Secretariat, NEAFC and NAFO, and various national data are reported to the Group. The Group, however, repeatedly faces problems in obtaining reliable data due to unreported catches of pelagic redfish and lack of catch data disaggregated by depth from some countries. There are indications that reported effort (and consequently landings) could represent only around 80% of the real effort in certain years (see Chapter 19.3.3 in the 2008 NWWG report). No new data in IUU have been available since 2008.

Splitting of catches: In the period 1992–1996, the fishery gradually shifted towards greater depths and developed a clear seasonal spatial pattern. The fleets fished first the deep stock and moved to the southwestern Irminger Sea (south of 60°N and west of about 32°W) from mid June to October to fish the shallow stock. Landings from these years have been assigned to the different biological stocks according to several criteria, such as landings by ICES statistical areas, ICES Divisions, by nation, and logbook data. When a nation lacked data, the average from the other nations was used instead. Landings data disaggregated by biological stock from this period are considered to be the most unreliable and must be regarded as the WG's best estimates (guesstimates). This task was carried out according to the NWWG meeting celebrated in 2004, Bergen (ICES, 2004).

B.2. Biological

Biological information is collected from commercial catches (Iceland, Russia, Spain and other EU countries). For Iceland, the data consist of length measurements, weight, sex, maturity stage, and otolith collection. Otoliths have not been age read.

The Group started to collate an international database with length distributions from the sampling of the fisheries on a spatially disaggregated level. Once complete, the horizontal and vertical differences in mean length by fishing areas can be illustrated as alternative to the portrayals by ICES/NAFO Divisions. The database includes data from Iceland, Greenland, Faroe Islands, Norway, Germany and Russia.

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

- population age structure,
- species identification of young individuals,
- location of nursery and mating areas,
- estimation of natural mortality.

There has already been some effort conducted to validate and harmonize the methodologies used for age determination at an international level (ICES, 2006, 2009b). This should however be pursued, since there are still non-standard methodologies used by some Russian teams which forbids data compilation at an international level.

A maturity scale has been agreed at an international level but there is a requirement for workshops to be conducted in order to guarantee that this scale is well understood and used in a standardized fashion across nation and research laboratories.

B.3. Surveys

The surveys provide valuable information on the biology, distribution and relative abundance of oceanic redfish, as well as on the oceanographic conditions of the surveyed area. Until 1999, oceanic redfish was only 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; Sigurðsson 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). However, since the fishery had moved towards greater depths 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 *S. mentella* deeper than 500 m depth, showing that the highest concentrations of redfish below 500 were associated with eddies and fronts.

Since 1999, an international trawl-acoustic survey has been conducted biennially by Iceland, Germany and Russia (with Norway participating in 2001) with two to five research vessels (ICES 2002, 2003, 2005, 2007b, 2009c, 2011b; Sigurdsson *et al*., 1999). In this survey, the deep pelagic beaked redfish stock is measured with so-called "trawl method". The surveys in 2005 and 2007 are not comparable with the other surveys due to changes in the depth range covered in the 2005 and 2007 surveys. However, it was agreed that the trawl data should be treated with great caution (ICES, 2002).

The Working Group for Redfish Survey (WGRS, formerly as SGRS then PGRS) has organized and planned these international surveys since 1999 and distribute survey area and time among the participants.

Table 1. Deep pelagic redfish surveys carried out in the Irminger Sea and adjacent waters. Th. NM^2; thousand square nautical miles surveyed, Depth: depth stratum reached during survey, above or below 500 m depth, Country: GER=Germany, ICE=Iceland, NOR=Norway, RUS=Russia.

Year	Country	# of vessles	Th. NM2	Depth	Ref
1999	GER/ICE/ RUS	3	296	> 500	Sigurðsson *et al*., 1999
2001	GER/ICE/RUS/NOR	5	420	> 500	ICES, 2002
2003	GER/ICE/ RUS	3	405	> 500	ICES, 2003
2009	GER/ICE	2	360	> 500	ICES, 2009c
2011	GER/ICE/ RUS	3	343	> 500	ICES, 2011b

Technical description

The technical details and description of the equipment used are described in (ICES, 2011a). Here, a brief summary of the sampling methodology of the surveys 1999–2011 is given.

Acoustics

In the 2011 survey, 38 kHz Simrad EK60 split-beam echosounder was used for the acoustic data collection on RV "Árni Friðriksson" and RV "Vilnyus" whereas on RV "Walther Herwig III" an EK500 was used, also equipped with a 38 kHz split-beam transducer. The settings of the acoustic equipment used during the survey are given in Table 2 in ICES (2011a). During the survey on board of the Icelandic and German vessels the post-processing system (EchoView V4.9, Myriax) was used for scrutinising the echograms, whereas FAMAS (a post-processing program developed by TINRO) was used in the Russian vessel. Mean integration values of redfish per 5 NM were used for the calculations.

The integration threshold of 80–84 dB/m³ was used. A length based target

TS = 20logL – 71.3 dB

has been used for the estimation of the number of pelagic redfish in the survey area.

Earlier investigations (Magnússon *et al*., 1994; Magnússon *et al*., 1996; Reynisson and Sigurðsson, 1996) have demonstrated that the acoustic values obtained from oceanic redfish exhibit a clear diurnal variation, due to a different degree of mixing with smaller scatter and to changes in target strength. In order to compensate for these effects, the acoustic data obtained when mixing is most pronounced (i.e. during the darkest hours of the night), are discarded and the values within the missing sections are estimated by interpolation.

In further data processing, the number of fish is calculated for statistical rectangles measuring 1°latitude x 2°longitude. Changes in the length range of redfish in the past acoustic surveys are taken into account by changing the length-based target strength formula accordingly (Reynisson, 1992; ICES, 2011a for details). The total number of fish within the Subareas A–F in which the survey area is divided (Figure B.3.1) is then obtained by summation of the individual rectangles. The acoustic results were further divided into the number of individuals and biomass based on the biological samples representative for each subarea.

For the entire survey area, single-fish echoes from redfish are expected to be detectable down to 350 m. In order to include all echoes of interest, a low integration threshold is chosen (i.e. -80 dB//m³ for the 2011 survey). Based on the depth distribution of redfish observed during the survey and the expected target strength distribution, the method outlined by Reynisson (1996) is used to estimate the expected bias due to thresholding. The results of the biomass calculations were adjusted accordingly.

The measurements of echosounders can be disturbed by noise (from the ambient and the vessel) and reverberation (echoes reflected from unwanted targets). Because the amplitude of the signal decreases with depth whereas the amplitude of noise increases due to time varied gain, very small noise can prevent the measurements. Thus, to improve the signal to noise ratio, a threshold is usually applied (Bethke, 2004).

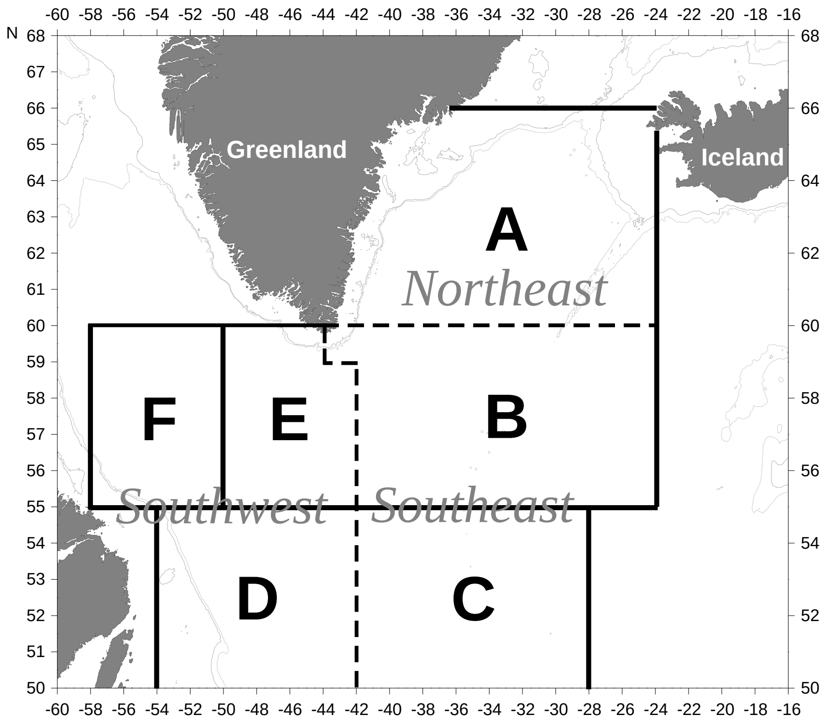

Figure B.3.1. Subareas A–F used on international surveys for redfish in the Irminger Sea and adjacent waters and divisions for biological data (Northeast, Southwest and Southeast; boundaries marked by broken lines).

When the redfish appears mixed with other deep-sea species, or the weather is bad and disturbs the measurements, echo counting is preferred over echo integration, as described in Bethke (2004). The counting procedure is based on the fact that fish are recognized as single targets according to the parameter settings of the echosounder. However, if redfish is found in dense aggregations, echo integration is more accurate. Switching between methods may be necessary during the survey (ICES, 2011a).

Trawling

The classic method of continuous echo integration deeper than 350 m (within and deeper than DSL) is applicable only under very specific conditions. The need for the vertical expansion of the survey led to the use of the trawl method since 1999. This method is based on a combination of standardized survey catches and the acoustic data, where the correlation between catch and acoustic values during trawling in the layer shallower than the DSL is used to obtain acoustic values for the deeper layer. There are three types of trawls (ICES, 2011a):

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

2) The depth shallower than 500 m depth, where acoustic redfish registration is hampered by the DSL: from the top of the DSL down to 450 m. Trawling distance is 2 NM in each depth layer.

3) The depth zones deeper than 500 m depth, trawling at different depth layers. The deep identification covered the following three depth layers: 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, 2007b) 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 stocks were sampled simultaneously, and have been excluded in the analysis.

The net used on RV "Árni Friðriksson" and RV "Walther Herwig III" was a Gloria type #1024, with a vertical opening of approximately 50 m. The net used on RV "Vilnyus" was a Russian pelagic trawl (design 75/448) with a circumference of 448 m and a vertical opening of 47–50 m. Russia was using a mesh opening of 40 mm in the codend, while Iceland and Germany were using a mesh opening of 23 mm in the codends. The trawls used on RV "Árni Friðriksson" and RV "Walther Herwig III" were fitted with multiple codend sampling device: the 'multisampler' (Engås *et al.*, 1997). This allowed for successive sampling at three distinct depth zones within one trawl haul and without 'contamination' from one depth to the next and no sampling during shooting or heaving of the trawl. The catches were standardized by 1 NM and converted into acoustic values using a linear regression model between catches and acoustic values at depths shallower than the DSL.

A linear regression model between the acoustic values and catches (in kg/NM) of type 1 trawls (shallower than the DSL) was applied to predict the acoustic values (S_A) for trawls type 2 and 3. 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:

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

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 and K_H is the width of the depth range towed defined as:

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

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.

Based on the regressions, confidence limits for the estimates are 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 dB) and the same algorithm as used for the acoustic estimation. The area coverage was considered to be the same as for the acoustic results and applied to all subareas.

Biological sampling

Catch weight and number of all species will be recorded for each haul. The individual biological sampling of deep-water redfish was done in following way (taken from ICES (2011a)):

1) The total length (cm below), individual weight, sex and stage of maturity should be measured on at least 300 redfish from each haul type.

2) Otolith sampling was carried out at each station. Sampling was conducted on 50 individuals following a random sampling procedure (i.e. not stratified by length).

3) Observations on the stomach fullness, the location and size of skin/muscular pigments as well as infestation with *Sphyrion lumpi* and its

remnants was investigated on at least 50 randomly sampled fish (usually collected on individual fish for which otoliths are sampled).

B.4. Commercial cpue

It is not known to what extent cpue reflect changes in the stock status of pelagic *S. mentella*. Since the fishery focuses on aggregations, the cpue series might not indicate or reflect actual trends in stock size.

B.5. Other relevant data

C. Historical stock development

Deep pelagic beaked redfish in the Irminger Sea and adjacent waters has previously 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.

At the meeting working document (# 16) was presented where the trend in survey indices for the deep pelagic beaked redfish was estimated as well as F_{proxy} (catch divided by index for the same stock). The trend in the survey indices was estimated to be around 5% per year (uncertain estimate) so assuming F=M 10% reduction in total mortality was required to stop the trend and 20% to reverse it. If F > M, which is considered a likely hypotheses considering the state of the stock, less than 20% reduction in F is needed to get the intended 10% reduction in Z. The only data available to support that F and M are similar are results from limited age-readings that indicate Z to be around 0.1 and M "is known" to be 0.05. The approach in the working document #16 makes no special reference to the status of the stock which is considered difficult to assess. Similar ideas are put forward in working document #12 for the Icelandic slope beaked redfish.

The method proposed in working document #16 has three major shortcomings.

1) The survey data are noisy and the trend is not clear;

2) The survey-series are short (11 years) compared to the lifespan of the species. One year class can take more than five years to recruit to the stock so the survey period might be characterized by abnormally high or low recruitment leading to trend in indices reflecting recruitment anomaly rather than deviations from sustainable fishing effort;

3) Catches may not be correctly allocated to stocks. Spatial distribution of the catches west of Iceland in some years indicate that part of the catch for deep-sea pelagic beaked redfish could be Icelandic slope beaked redfish and vice versa.

The external panel rejected the approaches of working documents #12 and #16 as they did not make any reference to the state of the stock and depended on the assumption F=M. In response it was stated that most likely F > M and therefore the method is if anything conservative.

Some participants in the Working Group considered that at present analytical assessments cannot be conducted because, for example, of little age data and the relative shortness of the time-series available.

The external panel considered that although the biomass dynamic model (specifically the Schaefer form off this approach; see Appendix 1) is preliminary and should be improved, it is possible to use this approach to initially assess stock status and current replacement yield (RY, being the annual catch estimated to maintain abundance at its present level) based on information on past catches, the autumn survey, and external information used to inform on the likely range of the value for stock productivity parameter. For the values of stock productivity parameter considered the most realistic ($r = 0.05$ to $r = 0.10$), this approach provides estimates of the current depletion (the present to pre-exploitation abundance ratio) of this resource to be from 18–19% with CVs between 40% and 50%. Estimates of RY range from about 10 (SE 4) to 13 (SE 4) thousand tons, by comparison with an average annual catch over the 2000 to 2010 period of about 21 thousand tons. Although the precision of these RY estimates is poor, the panel draws attention to the approach suggested in the general recommendations section whereby the requirements of the precautionary approach can be addressed by decreasing catch limit estimates by some multiple of the associated SE estimate. The panel does not suggest that the Schaefer model approach used here is to be final; to the contrary it is offered as a first step (from which interim management advice might be formulated) while the assessment is extended to an Age Structured Production Model framework which could, for example, also take account of the commercial catch-at-length and limited ageing data available for this resource. While the projection and reference point computations referenced below are possible within this Schaefer model framework, the panel did not consider it appropriate to report them at this stage, given the interim and intermediate nature of this approach. The difficulties found by the panel with the "trends based assessment" approach are set out in the general recommendations section.

Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1982–		
Canum	Catch-at-age in numbers			
Weca	Weight-at-age in the commercial catch			
West	Weight-at-age of the spawning–stock at spawning time.			
Mprop	Proportion of natural mortality before spawning			
Fprop	Proportion of fishing mortality before spawning			
Matprop	Proportion mature-at-age			
Natmor	Natural mortality			

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1			
Tuning fleet 2			
Tuning fleet 3			
….			

D. Short-term projection

Model used:

Software used:

Initial stock size:

Maturity:

F and M before spawning:

Weight-at-age in the stock:

Weight-at-age in the catch:

Exploitation pattern:

Intermediate year assumptions:

Stock–recruitment model used:

Procedures used for splitting projected catches:

E. Medium-term projections

Model used:

Software used:

Initial stock size:

Natural mortality:

Maturity:

F and M before spawning:

Weight-at-age in the stock:

Weight-at-age in the catch:

Exploitation pattern:

Intermediate year assumptions:

Stock–recruitment model used:

Uncertainty models used:

1) Initial stock size:
2) Natural mortality:
3) Maturity:
4) F and M before spawning:
5) Weight-at-age in the stock:
6) Weight-at-age in the catch:
7) Exploitation pattern:
8) Intermediate year assumptions:
9) Stock–recruitment model used:

F. Long-term projections

Model used:

Software used*:*

Maturity:

F and M before spawning:

Weight-at-age in the stock:

Weight-at-age in the catch:

Exploitation pattern:

Procedures used for splitting projected catches:

G. Biological reference points

H. Other issues

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Stock Annex: East Greenland slope *Sebastes mentalla*

Stock	East Greenland slope *Sebastes mentella*
Working Group	North Western Working Group
Date	February 2012
Revised by	Rasmus Hedeholm/Jesper Boje

A. General

A.1. Stock definition

ICES concluded in February 2009 that *S. mentella* in the northwest is to be divided into three biological stocks and that the *S. mentella* on the Icelandic continental shelf and slope should be treated as a separate biological stock and management unit. This separation of the stocks did not include the adult *S. mentella* on the Greenland continental slope. ICES therefore decided that NWWG will conduct a separate assessment of *S. mentella* in Subarea XIVb until further information is available to assign stock origin.

Although not recognized as a separate stock area, WKREDS suggested that the Greenland shelf (East and West) is a common nursery ground for all of the *S. mentella* stocks in the Northwest Atlantic.

A.2. Fishery

The fishery for *S. mentella* on the Greenland slope is conducted almost exclusively with bottom trawl. In the 1980s and 1990s the fishery had catches as high as 19 000 tonnes (1981 and 1994) and catches ranged from 5000 to 15 000 tonnes. The fishery declined rapidly in 1995 to 819 tonnes. Since then catches have been below 1000 tonnes in most years. The fishery has been dominated by British, Faroese, Norwegian and Greenlandic vessels and in some years German vessels (ICES 2011). Since 2009 a directed fishery began for demersal *S. mentella*, and in 2010 produced catches of 6613 tonnes with the majority being taken by Greenland and Norwegian vessels (95%). For further details on the historical development of the fishery see ICES (2011).

The directed fishery towards *S. mentella* in recent years has taken place in a limited geographical area at 64°N 36°W and just northeast from here at 64° 30′ N-65°N and 35°W on depths between 400 and 500 meters. In the years prior to this new directed fishery, *S. mentella* has been caught as bycatch in the Greenland halibut fishery, and consequently at greater depths (ICES, 2011).

The redfish fishery on the East Greenland slope is influenced by the proximity of Greenland halibut (*Reinhardtius hippoglossoides*), Atlantic cod (*Gadus morhua*) fishing grounds. Hence, some by catch of cod is expected in the redfish fishery and in 2010 this amounted to 400 tonnes (5% of total catches).

Sorting grids are mandatory in the shrimp fishery since 2002 due to high historical bycatches of juvenile redfish. Since this implementation bycatches of redfish have been reported to be insubstantial.

A.3. Ecosystem aspects

S. mentella is a ovoviviparous species. The female carries sperm and eggs for months, and extrude larvae in April–May in the Irminger Sea (Cadrin *et al*., 2010) but the exact mating site of the different stocks is unknown. The larvae are planktonic and drift to the nursery areas on the Greenland slope were they settle on the bottom (Magnússon and Magnússon, 1995). In this area they mix with juveniles of the very similar *Sebastes marinus*. Both species recruit to the fishery at ages 8 to 12 years.

S. mentella feeding was investigated on the West Greenland slope and it was found that planktonic crustaceans (i.e. hyperiids, copepods and euohausiids) dominated the diet in smaller fish (5–19 cm, Pedersen and Riget, 1993). In adult fish (31–33 cm.) from the Reykjanes ridge Petursdottir *et al*. (2008) found indications that *S. mentella* fed heavily on the euphausiid *M. norvegica*. In the Greenland slope area adult feeding on amphipods, copepods, cephalopods, shrimps and fish (including cannibalism) are probably also important (Pedersen and Riget, 1993).

Redfish spp. have been revealed to comprise a substantial part of the diet in both harp and hooded seals (Haug *et al*., 2007; Tucker *et al*., 2009). Greenland halibut feeding on *S. mentella* has been documented in Iceland waters (Solmundsson, 2007) but data from the West Greenland shelf does not indicate that *Sebastes* spp. is an important prey item (Greenland Institute of Natural Resources, Unpublished data).

B. Data

B.1. Commercial catch

The information on catches in ICES XIVb is available from the Greenland Fisheries Licence Control (GFLK) who provide haul-by-haul information from logbooks. These logbooks cover three types of Redfish quota uptake that all contribute to the total catches of demersal *S. mentella*:

- Fish caught by bottom trawl and longlines on the bottom are named *S. marinus*.
- Fish caught pelagic in the Irminger Sea are named *S. mentella*.
- Fish caught as bycatch in the shrimp fishery are named *Sebastes* sp.

Until 2011 catches reported as *S. marinus* were used to distinguish between Greenland slope demersal *S. mentella* catches and pelagic *S. mentella* catches in the Irminger Sea. Starting in 2011 the catches were split based on a line following the outside the 1000 meter depth curve (Table I, Figure 1) as it will be in 2012. This is done to avoid the situation seen in 2010, were some vessels fished on their pelagic quota on the shelf (2179 tons, ICES, 2011). Both survey results and analyses of commercial catches demonstrates that *S. mentella* dominates the catch on the slope, and the catches have historically been split into species based a best estimate of species proportions. Hence, in 2010 these were set at 80/20, but it is uncertain how the catches were separated in earlier years.

Table 1. Positions (decimal degrees and degrees) used to separate the fish found demersal on the slope at East Greenland and the pelagic stocks in the Irminger area. See Figure 1.

Point	Latitude (N)	Longitude (W)	Latitude (N)	Longitude (W)
1	59.25	-54.43	59°15'	54°26'
2	59.25	-44.00	59°15'	44°00'
3	59.50	-42.75	59°30'	42°45'
4	60.00	-42.00	60°00'	42°00'
5	62.00	-40.50	62°00'	40°30'
6	62.00	-40.00	62°00'	40°00'
7	62.67	-40.25	62°40'	40°15'
8	63.15	-39.67	63°09'	39°40'
9	63.50	-37.25	63°30'	37°15'
10	64.33	-35.00	64°20'	35°00'
11	65.25	-32.50	65°15'	32°30'
12	65.25	-29.84	65°15'	29°50'

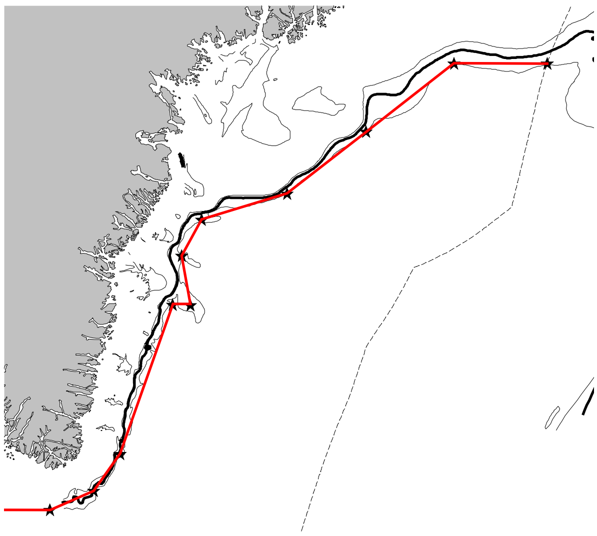

Figure 1. The red line following the outside the 1000 meter depth curve delimits the shelf area where ICES gives separate advice from the pelagic stocks. 500, 1000 and 1500 m depth curves are on the map with the 1000 meter depth curve being bold. The dashed line is the 200 nm fishery zone line.

B.2. Biological

Sampling for further information on stock structure based on DNA is taking place under the European Commission's Fifth Framework Programme (1998–2002). This includes samples from surveys and commercial catches in ICES Areas V, XII and XIV as well as NAFO 1.

B.3. Surveys

There are currently three surveys in XIVb. A German survey directed towards cod in Greenland waters (0–400m.), the Greenland deep-water survey (400–1500 m.) targeting Greenland halibut and a Greenland shallow-water survey (0–600 meters) targeting mainly cod.

The German survey

The survey commenced in 1982 and was designed for the assessment of cod. The surveyed area is the 0–400 m depth zone that is divided into seven geographical strata and two depth zones (1–200 m; 201–400 m, Table II, Figure 2). The numbers of hauls were initially ca. 200 per year but were reduced from the early 1990s to 80–100 per year.

The surveys were carried out by the research vessel (RV) Walther Herwig (II) in 1982–1993 (except 1984 when RV Anton Dohrn was used) and since 1994 by RV Walther Herwig III. 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 meshliner (10 mm) was used inside the codend. The horizontal distance between wingends is 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.

For historical reasons strata with less than five hauls were not included in the annual stock calculations op to 2008. From 2009 all valid hauls have been included and the entire time-series have been corrected. 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.

Table 2. The survey area (nm^2) in the German groundfish survey in Greenland.

Strata	Depth (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

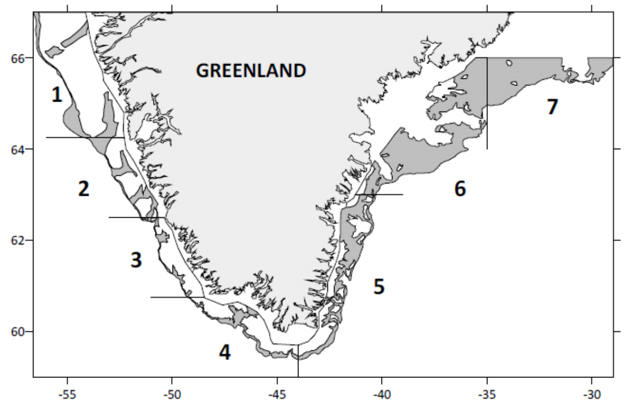

Figure 2. The stratification areas used in the German groundfish survey. Each stratum is divided into two depth zones (1–200 m and 201–400 m).

The East Greenland deep-water survey

The East Greenland deep-water survey is a stratified random survey. From 1989–1996 the Greenland Institute of Natural Resources conducted annual shrimp trawl surveys with RV Paamiut (722 GRT) at East Greenland (Anon., 1997), but the surveys only covered depths down to 600 m with a poor coverage of depths >400 m. In 1998 a bottom-trawl survey-series with RV Paamiut, which has been rigged for deep-sea trawling, was initiated. The survey was not conducted at East Greenland in 2001. Until 2008 the survey was conducted in June, but suffered in most years under the ice coverage found at the east coast of Greenland during early summer. Therefore the surveys from 2008 and onwards, have taken place in August/September where the ice induced problems have mostly vanished.

The stratification was changed in 2004 in order to reduce the variance on the biomass estimate of Greenland halibut and to get larger strata. The purpose of larger strata was to reduce the number of strata and thereby avoid strata without observations caused by bad weather or ice, etc. The "old" stratum Q1 was divided into two strata. The northern, shallow part of the stratum has been separated from the rest of the stratum primarily because the fish fauna here is different and because Greenland halibut is generally smaller in this area than on the shelf. This northern shallow area is now stratum Q1. The remaining part of the old Q1 has been combined with Q2 as there was no difference in the catches of Greenland halibut in the two areas. The depth strata 1001–1200 m, 1201–1400 m and 1401–1500 m have been combined to one stratum as Greenland halibut catches generally have been small in these strata. In Q5, the two small depth strata 801–1000 and 1001–1200 were combined as catches of Greenland halibut have been at the same level in the two strata throughout the years.

The Greenland shallow-water survey

The Greenland shallow-water survey has been conducted since 2007 in combination with the Greenland deep-water survey. However, logistical problems entailed that few valid hauls were conducted in 2007, and furthermore no species distinction was made with regard to redfish. Hence, species-specific results are only available from 2008. The survey covers the Greenlandic coast east of 44˚00W and north to 67˚00N and is delimited by the 3 mile limit and the 600 m depth contour. The region is stratified into six areas (Q1–Q6) which are further stratified into three depth strata: 0–200 m, 201–400 m and 401–600 m (Table III, Figure 3). Within each area strata, stations are allocated randomly from known trawlable sites, as Greenland East Coast bottom topography severely limits the number of trawlable areas.

Table 3. Areas (km²) of the different area and depth strata surveyed in the East Greenland shallow-water survey.

		Depth strata (m)		
Area strata	Area (km²)	0–200	201–400	401–600
Q1	42 637	217	35 445	6975
Q2	8996	93	7657	1246
Q3	35 740	3363	22 547	9830
Q4	11 161	1337	7770	2054
Q5	5073	469	2785	1819
Q6	14 500	6307	6130	2063
Total	118 107	11 786	82 334	23 987

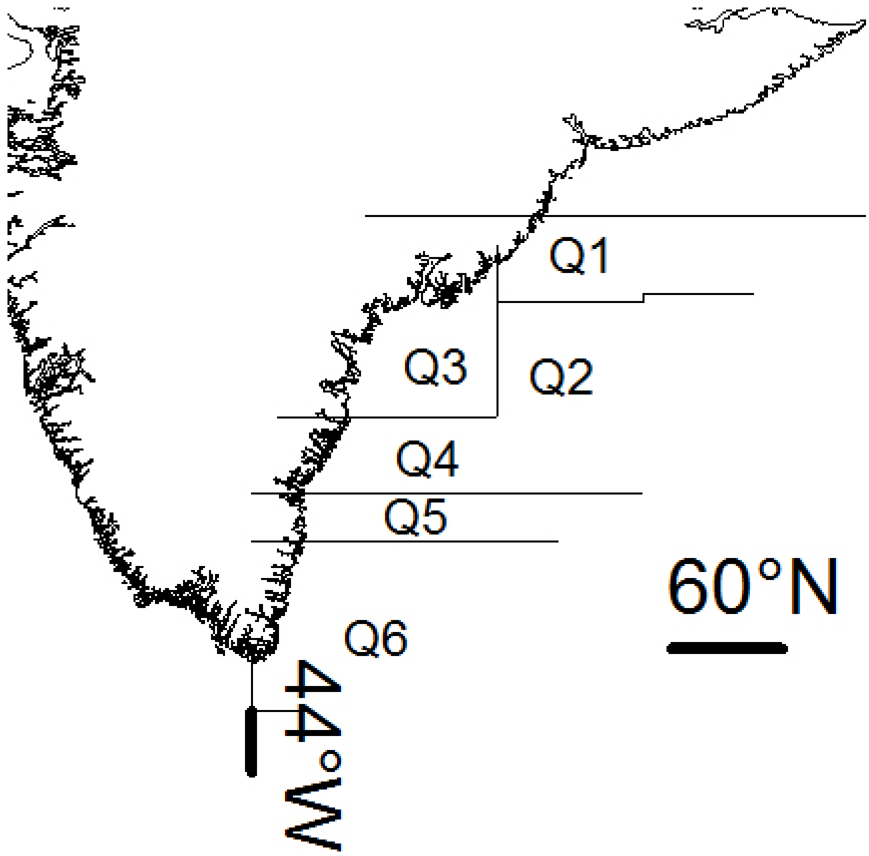

Figure 3. The East Greenland shallow-water survey area strata.

The survey is conducted using a "Cosmos" trouser trawl with 20 mm codend. The standard towing time at 2.5 knots has in all years been 15 minutes, but shorter tows are included in the calculations if they are deemed valid. All hauls were performed at daytime. A temperature sensor (Seamon, 0.1˚C) is mounted on a trawl door and a bottom temperature is noted for each haul. If a depth stratum in a given year was not successfully trawled, the area was joined with the neighbouring depth stratum to allow for abundance and biomass estimation.

B.4. Commercial cpue

Logbooks on a haul-by-haul basis are available from 1992–2011 but have not previously been used in the assessment process. However, from 1992–1998 the data quality is poor due to incorrect species reporting and further does not cover the entire catches, consequently this time period is omitted from the data. From 1999–2011 the data are of a sufficient quality. The standardized cpue calculated from the redfish directed fishery has been evaluated, and is not proposed to be used in the assessment for several reasons. The fishery targets an aggregating species and further the fishery is currently in a very restricted area. This means large catches in short hauls and eventual searching time is unknown, implying little correlation between recorded effort and landings.

A redfish bycatch cpue calculated based on the Greenland halibut directed fishery is available. The rationale for using bycatch cpue is that a longer time-series is available and the fishery more dispersed thereby covering the stock distribution more appropriate. The index is based on hauls were Greenland halibut make up >50% of the catch by weight. This cut-off was based on the distribution of redfish catches in all hauls, which typically made up either 0–20% (i.e. bycatch) or 90–100% (i.e. redfish directed fishery). Furthermore, all hauls at depths >1000 m were discarded as this is outside the depth range of *S. mentella*. This bycatch cpue covers a wider area on the Greenland slope than the redfish directed fishery, and since the Greenland halibut fishery has been fairly stable in the past decade, the bycatch cpue could possibly considered in future assessments. Regarding the bycatch cpue it should however be noted that bycatches are reported as "redfish" thus including both *S. mentella* and *S. marinus*, but the Greenland halibut fishery takes place at depths of 400 m and deeper, and from the Greenland survey it is observed that at these depths *S. mentella* constitutes at least 90%, and the confounding effect of the *S. marinus* contribution is probably negligible.

B.5. Other relevant data

C. Assessment: data and method

Otoliths are not sampled and no age-based assessment is therefore possible. The qualitative assessment is based on survey indices and catch information.

The external panel considered that although the biomass dynamic model (specifically the Schaefer model – see Appendix 1 for details on the methodology) is preliminary and should be improved, it is possible to use this approach to initially assess stock status and current replacement yield (RY, being the annual catch estimated to maintain abundance at its present level) based on information on past catches, the German shallow-water trawl survey, and external information used to inform on the likely range of the value for the stock productivity parameter r. For the values of stock productivity parameter considered the most realistic (r = 0.05 to r = 0.10), this approach provides estimates of the current depletion (the present to pre-exploitation abundance ratio) of this resource to be from 81–86% with CVs ranging from 31 to 19% correspondingly. Estimates of RY range from about 3.4 (SE 0.1) to 3.8 (SE 0.5) thousand tons, by comparison with an average annual catch over the 2000 to 2010 period of about 1.2 thousand tons. As status is estimated relatively close to pristine, catch advice might be better based on the Schaefer maximum sustainable yield estimates. These are 7 and 6 thousand tons for r = 0.05 and 0.10, respectively, but with high CVs of about 160% and 50%, respectively. Until further data allow improved precision, an

RY basis for management might still therefore be best at the present time. Although the precision of these RY estimates is reasonably good, the panel still draws attention to the approach suggested in the general recommendations section whereby the requirements of the precautionary approach can be addressed by decreasing catch limit estimates by some multiple of the associated SE estimate. The panel does not suggest that the Schaefer model approach used here is to be final; to the contrary it is offered as a first step (from which interim management advice might be formulated) while the assessment is extended to an Age Structured Production Model framework which could, for example, also take account of the commercial catch-at-length and limited ageing data should these become available for this resource. While the projection and reference point computations referenced below are possible within this Schaefer model framework, the panel did not consider it appropriate to report them at this stage, given the interim and intermediate nature of this approach. The difficulties found by the panel with the "trends based assessment" approach are set out in the general recommendations section.

Some members of the workshop thought that the stock production model approach has a questionable use for advice purposes in terms of absolute numbers, although the estimates seem robust. Sustainable current yields of approximately 3500 t from the model vs. an arbitrary number of 1000 t (present advice) derived from 2009 catches (when fishery started again) are not from comparable approaches and both numbers are therefore candidates for advice.

G. Biological reference points

I. References

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Annex 6: List of Working Documents

WD 1: Kristinsson, K., Fock, H. and Reinert, J.: Golden redfish (*Sebastes marinus*) in ICES Subarea V and Division XIVb as observed in groundfish surveys.

WD 2: Björnsson, H. and Kristinsson, K.: Diurnal vertical migration of golden redfish (*Sebastes marinus*) in the Icelandic groundfish surveys.

WD 3: Kristinsson, K.: Growth and maturity of golden redfish (*Sebastes marinus*) in ICES Division Va.

WD 4: Kristinsson, K.: Fishery of Golden Redfish (*Sebastes marinus*) in Icelandic, Faroes and East Greenland waters (ICES Divisions Va, Vb, and XIVb).

WD 5: Kristinsson, K.: Splitting the redfish catch between golden redfish (*Sebastes marinus*) and Icelandic slope deep-water redfish (*S. mentella*) in ICES Division Va.

WD 6: Thordarson, G., Björnsson, H. and Kristinsson, K.: Golden redfish (*Sebastes marinus*) in Subarea V and Division XIVb, assessed using the GADGET framework.

(no WD 7 and 8 existing)

WD 9: Gudmundsson, G.: Time-series assessment of Icelandic golden redfish.

WD 10: Kristinsson, K.: Icelandic Slope Deep-Water Redfish (*Sebastes mentella*) in ICES Division Va as Observed in the Icelandic Autumn Survey 2000–2010.

WD 11: Kristinsson, K.: The fishery of Icelandic slope deep-water redfish (*Sebastes mentella*) in ICES Division Va.

WD 12: Björnsson, H.: MSY Harvest Control Rule for Icelandic Slope Deep-water Redfish (*Sebastes mentella*) in ICES Division Va.

WD 13: Magnusson, Á.: Exploratory biomass model assessment of the Icelandic slope redfish (*Sebastes mentella*).

WD 14: Kristinsson, K.: Deep-water redfish (*Sebastes mentella*) surveys in the Irminger Sea and adjacent waters.

WD 15: Kristinsson, K.: Age-reading of deep-water redfish (*Sebastes mentella*) from the Irminger Sea and the Icelandic slope.

WD16: Björnsson, H.: MSY Harvest Control Rule for Deep Pelagic Deep-water Redfish (*Sebastes mentella*) in the Irminger Sea and adjacent waters.

WD17: Hedeholm, R. and Boje, J.: Exploratory analysis on survey and commercial catch data from the Greenland slope *Sebastes mentella* and *Sebastes marinus* stocks.

WD18: Drevetnyak, K., Nedreaas, K. and Planque, B.: Scientific surveys used for redfish (*Sebastes mentella* and *S. marinus*) research and stock assessment in ICES Subareas I and II.

WD 19: Aanes, S.: Empirical analysis of growth of *Sebastes marinus* and *S. mentella* in ICES Subareas I and II.

WD 20: Nedreaas, K.: Fisheries regulations related to redfish in ICES Subareas I and II.

WD 21: Nedreaas, K. and Drevetnyak, K.: Fisheries data preparation - *Sebastes mentella* and *S. marinus* in ICES Subareas I and II.

WD 22: Planque, B., Vollen, T., Nedreaas, K., Aglen, A., Drevetnyak, K.: Data preparation for the assessment of redfish stocks (*S. marinus* and *S. mentella*) in ICES Subareas I and II: Survey data.

WD 23: Howell, D.: Barents Sea *Sebastes marinus* GADGET model.

WD 24: Planque, B.: A Statistical-catch-at-age model for *S. mentella* in ICES Areas I and II.

WD 25: Planque, B., Bogstad, B., Nedreaas, K. and Howell, D.: Biological reference points for *Sebastes mentella* and *S. marinus* in ICES Areas I and II.

WD 26: Howell, D. and Planque, B.: *Sebastes mentella* Gadget model description.

WD 27: Bogstad, B.: Biomass levels of *S. mentella* in ICES Subarea I and II calculated using a VPA approach.

WD 28: Bogstad, B.: Predation on redfish in the Barents Sea.

WD 29: Yaragina, N.A. and Dolgov, A.V.: Long-term fluctuations of redfish frequency of occurrence in cod diet in the Barents Sea.

Appendix 1: Estimation of *Sebastes* population productivity and natural mortality from longevity

The Schaefer biomass dynamic model was applied to seven redfish stocks in the WKRED in order to assess the trends on stock biomass and relative level of depletion (i.e. the stock size relative to an unfished stock). A key parameter in the Schaefer model is the maximum per capita (i.e. "intrinsic") growth rate (r), which determines the rate of population production and thus the rates of sustainable fishing mortality. This parameter, as expected given the often short series of abundance indices, was found to be poorly estimated from the available data for the seven stocks examined, particularly for stocks in which only a declining trend in the abundance index is observed (i.e. the "one way trip"). Thus, the sensitivity of Schaefer model results to r values ranging from 0.02 to 0.15 was examined. The purpose of this Appendix is to attempt to assess which of these values of r are most plausible based upon redfish life-history considerations.

For the Schaefer model, the fishing mortality corresponding to maximum sustainable yield (F_{msy}) is $r/2$. Additionally, F_{msy} is generally related to the instantaneous rate of natural mortality (M). Thus, information on the rate of natural mortality can be used to infer the Schaefer model r parameter.

Estimation of natural mortality for redfish

A number of methods exist that allow estimation of natural mortality from information on biological and/or demographic characteristics such as growth or longevity. Here we apply one approach by way of example, and a fuller analysis would examine other methods as well.

Hoenig (1983) developed regression equations that related instantaneous mortality from unexploited populations to the maximum age observed (t_{max}). The regression equation obtained for fish species (n = 84) was

$$\ln M = 1.46 - 1.01 \ln t_{\max} \qquad \text{Eq. 1}$$

The regression equation obtained for all species examined, including fish, cetaceans, and molluscs (n=134), was

$$\ln M = 1.44 - 0.982 \ln t_{\max} \qquad \text{Eq. 2}$$

The regression equation for all species has a wider range of t_{max} (1–123) than that observed from the fish species, and results from the high t_{max} values for the cetacean species. The regression lines are nevertheless similar to each other, and Hoenig (1983) recommends using the regression line obtained from all species for estimating natural mortality. This advice seems particularly relevant to *Sebastes* species, which can have longevities similar to the cetacean species examined by Hoenig (1983).

Values of t_{max} of approximately 70 years have been reported for the redfish considered in the WKRED. Because values of t_{max} are typically for the single oldest observed age, and thus can be subject to high variance especially if the sample size is small, it is useful to evaluate the sensitivity of M estimates various values of t_{max}. The following table shows estimates of M from the two equations above for t_{max} values of 50, 70, and 90 years.

	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

The estimated natural mortality ranges from 0.046 to 0.091 for the two equations and three values of t_{max}, which is broadly consistent with M values within the range of 0.05 to 0.10.

Relation between natural mortality and F_{msy}

A common fishing rate reference point applied in data-limited situations is $F_{msy} = M$ (Gulland, 1971), which is derived from the notion that the optimal rate of fishing should be comparable to natural mortality. Gulland (1971) used yield-per-recruit calculations to conclude that an F=M strategy would reasonably approximate maximum sustainable yield (MSY); however, Beddington and Cooke (1983) further noted that with low values of age-at-recruitment, the MSY is lower than that implied by F_{msy} =M. In simulation modelling incorporating stock–recruitment relationships, F_{msy} was often less than M for a variety of parameter combinations (Mace, 1994), and Williams and Shertzer (2003) found that the ratio of F_{msy} /M was highly sensitive to life-history parameters. For these reasons, M is typically considered an upper bound to F_{msy} and an approximation of $F_{msy} = M/2$ seems more appropriate. As noted above, F_{msy} for the Schaefer model is $r/2$; thus, we can use estimates of M to approximate the Schaefer r parameter. In broad terms therefore, r for the redfish stocks examined in the WKRED would be expected to range between 0.05 and 0.10.

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Appendix 2: Description of biomass dynamics modelling methodology

The biomass dynamics modelling approach was introduced to WKRED in Working Document (WD) 13 (Magnusson) as a method for estimating biomass and depletion levels for the Icelandic slope beaked redfish (*S. mentella*) stock for which only catch and indices of abundance (e.g. from surveys) are available. Biomass dynamics models view interannual changes in biomass as the difference between biomass production and catch. Various formulations can be specified to model biomass surplus production, with the Schaefer model being a form commonly assumed. During the WKRED, participants recognized the utility of applying biomass dynamics modelling to the other redfish stocks. Magnusson was unable to attend the workshop but did provide both the computer spreadsheet from which the model is fit to data, and a summary of results of the Schaefer surplus production model applied to the seven stocks considered by the workshop. During the workshop, a modified version of the spreadsheet was developed to fit to data in order to generate graphs of depletion of biomass relative to its pre-exploitation level and fits to survey indices. The Schaefer surplus production model was also coded in the ADMB modelling language during the workshop, and applied in order to evaluate the uncertainty in key estimates such as current year depletion and sustainable yield. Results from both the modified spreadsheet and the ADMB program were compared to Magnuson's original model runs to ensure consistency.

The text below describes the general approach for fitting biomass dynamics models to survey index data, followed by description of the Schafer surplus production model and a "poor recruitment" model (also of the biomass dynamics type).

1 General approach

The biomass in the first year is an estimated parameter B_{init}. In subsequent years:

$$B_{t+1} = B_t + g(B_t) - C_t$$

where $g(B_t)$ is a surplus production function (see next subsection) and C_t is the catch in year *i*.

The biomass index is predicted by:

$$\hat{I}_t = qB_t$$

where q is a catchability coefficient.

Assuming a lognormal distribution for the survey observation errors, the objective function (negative log-likelihood) is given by:

$$-\ln L = 0.5n\ln(2\pi) + \sum \ln\sigma_t + \sum \frac{(\ln I_t - \ln\hat{I}_t)^2}{2\sigma_t^2}$$

where σ is the log-scale standard deviation of the biomass index, which can be approximated by the coefficient of variation (CV) of index. These CVs are not input as the absolute σ_t values provided by survey sampling variance computations in the objective function, but rather as relative coefficients ε_t that are multiplied with an estimated scalar τ to predict σ_t (which includes contributions to the variance in addition to survey sampling error):

$$\sigma_t = \varepsilon_t \tau$$

2 Schaefer model

In the Schaefer (1954) model, annual surplus production is a function of two parameters:

$$g(B) = rB_t\left(1 - \frac{B_t}{K}\right)$$

where r maximum per capita growth rate (i.e. the intrinsic growth rate) and K is the carrying capacity.

In application to the redfish stocks, the population is assumed to be at carrying capacity in the first year:

$$B_{init} = K$$

resulting in four estimable parameters: r, K, q, τ.

The maximum growth rate *r* was expected to be poorly estimated from the available data, particularly for stocks with declining survey index series (the "one way trip"). Thus, model fits were evaluated for fixed levels of *r* over a range viewed as plausible for redfish (see separate Appendix on developing Bayesian priors for *r* and natural mortality for *Sebastes* spp.). The spreadsheet version of the Schaefer model was applied to the seven stocks, with *r* fixed at values of 0.02, 0.05, 0.10, and 0.15. For the four northwest *S. mentella* stocks, an additional model run with $r = 0.20$ was conducted, which was motivated by the support for a higher level of *r* for the Greenland slope *S. mentella* stock. For all stocks, the ADMB version of the model was applied to in order to evaluate the uncertainty (variance) in estimates of maximum sustainable yield (MSY), depletion (the estimate of current biomass (B_{curr}) divided by *K*), and current sustainable yield (i.e. $g(B_{curr})$) (Table 1). Estimates of variance were obtained from the Hessian approximation to the likelihood surface. The catch time-series, estimated depletion, and fits to survey biomass are shown in Figure 1 for the four northwest *S. mentella* stocks, and in Figure 2 for the Arctic *S. mentella* and *S. marinus* stocks and the northwest *S. marinus* stock.

3 Poor recruitment model

The shallow pelagic *S. mentella* stock has demonstrated a sharp decline in survey biomass index since 1980, consistent with an exponential decline over time due to fishing and natural mortality during a period of poor recruitment. In this case, the biomass at each time-step is modelled as:

$$B_{t+1} = (B_t - C_t)e^{-M}$$

where *M* is the instantaneous rate of natural mortality. This model assumes that there is no positive surplus production which could cause the biomass to increase, only depletion, and was run as a comparison to the Schaefer model above. Note that that this model can be considered an extension of the classic Leslie depletion estimator (Leslie and Davis, 1939) which is typically applied over short time periods in which natural mortality is negligible. The parameters estimated for this model are B_{init}, M, q, and τ.

Four models were considered. Two models estimated *M* and fixed *q* at either 1 or 2, based upon the expected range of *q* from the acoustic sampling methods. These values for *q* were determined by considering the range of target strength values that were consistent with available survey data. A second set of two models estimated *q* and fixed *M* at either 0.0 or 0.1. Estimates of current depletion, initial biomass, *M*, and *q* are shown in Table 2.

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Table 1. Estimated value, standard deviation (SD), and coefficient of variation (CV) of maximum sustained yield (MSY), sustainable current yield, and current depletion obtained from Schaefer models applies to the seven redfish stocks examined in the WKRED workshop. Biomass units are kilotons (kt).

		Negative	MSY (kt)			Sustainable current yield (kt)			Current Depletion		
Stock	r	ln likelihood	mean	SD	CV	mean	SD	CV	mean	SD	CV
Deep pelagic S. mentella	0.02	0.56	12.68	5.55	0.44	12.68	5.45	0.43	0.50	0.23	0.46
Deep pelagic S. mentella	0.05	0.62	26.10	9.81	0.38	26.09	10.40	0.40	0.49	0.23	0.47
Deep pelagic S. mentella	0.10	0.70	39.53	10.78	0.27	39.22	13.73	0.35	0.46	0.22	0.48
Deep pelagic S. mentella	0.15	0.78	47.34	8.86	0.19	46.29	14.34	0.31	0.43	0.20	0.47
Deep pelagic S. mentella	0.20	0.84	52.69	6.61	0.13	50.50	14.17	0.28	0.40	0.18	0.46
Greenland S. mentella	0.02	35.05	422580.00	661620000.00	1565.67	2.49	0.00	0.00	1.00	0.00	0.00
Greenland S. mentella	0.05	34.93	7.21	11.79	1.63	3.44	0.11	0.03	0.86	0.26	0.31
Greenland S. mentella	0.10	34.47	6.14	3.18	0.52	3.76	0.46	0.12	0.81	0.16	0.19
Greenland S. mentella	0.15	34.15	6.47	2.03	0.31	3.64	0.62	0.17	0.83	0.10	0.12
Greenland S. mentella	0.20	34.10	6.94	1.70	0.25	3.46	0.49	0.14	0.85	0.07	0.08
Iceland S. mentalla	0.02	0.45	8.83	0.92	0.10	5.77	3.01	0.52	0.21	0.12	0.56
Iceland S. mentalla	0.05	0.52	16.10	0.80	0.05	9.88	4.15	0.42	0.19	0.09	0.48
Iceland S. mentalla	0.10	0.64	22.12	0.40	0.02	12.85	4.38	0.34	0.18	0.07	0.41
Iceland S. mentalla	0.15	0.76	25.21	0.20	0.01	14.26	4.35	0.30	0.17	0.06	0.37
Iceland S. mentalla	0.20	0.88	27.11	0.11	0.00	15.08	4.35	0.29	0.17	0.06	0.36
Shallow pelagic S. mentella	0.02	12.87	6.63	0.09	0.01	0.91	0.45	0.50	0.04	0.02	0.50
Shallow pelagic S. mentella	0.05	13.13	14.77	0.14	0.01	2.11	1.07	0.51	0.04	0.02	0.52
Shallow pelagic S. mentella	0.10	13.55	24.97	0.14	0.01	3.77	1.99	0.53	0.04	0.02	0.55
Shallow pelagic S. mentella	0.15	13.93	32.41	0.10	0.00	5.15	2.86	0.55	0.04	0.02	0.58
Shallow pelagic S. mentella	0.20	14.27	38.06	0.07	0.00	6.32	3.68	0.58	0.04	0.03	0.61
Arctic S. mentella	0.02	15.86	20.80	20.33	0.98	18.46	7.14	0.39	0.67	0.39	0.58
Arctic S. mentella	0.05	14.78	27.49	8.77	0.32	27.44	7.24	0.26	0.52	0.32	0.62
Arctic S. mentella	0.10	14.53	50.48	12.17	0.24	30.65	6.83	0.22	0.81	0.11	0.14
Arctic S. mentella	0.15	14.55	64.10	11.33	0.18	21.71	4.46	0.21	0.91	0.04	0.04
Arctic S. marinus	0.02	9.30	7.16	0.07	0.01	1.63	0.43	0.26	0.06	0.02	0.27
Arctic S. marinus	0.05	9.03	13.42	0.06	0.00	3.13	0.76	0.24	0.06	0.02	0.26
Arctic S. marinus	0.10	8.78	18.82	0.02	0.00	4.57	1.06	0.23	0.06	0.02	0.25
Arctic S. marinus	0.15	8.76	21.70	0.01	0.00	5.45	1.26	0.23	0.07	0.02	0.25
NW marinus	0.02	5.11	44.74	27.00	0.60	39.27	8.74	0.22	0.67	0.24	0.35
NW marinus	0.05	2.51	48.85	4.93	0.10	48.81	5.64	0.12	0.48	0.12	0.24
NW marinus	0.10	-2.90	58.36	0.92	0.02	56.18	3.80	0.07	0.40	0.06	0.16
NW marinus	0.15	-8.06	65.21	0.22	0.00	61.78	3.06	0.05	0.39	0.05	0.12

Table 2. Estimates of current depletion, initial biomass, survey *q*, and *M* from the "poor recruitment" model applied to the shallow pelagic *S. mentella* stock. Biomass units are kilotons (kt).

Model	Current	Negative		Initial	
Description	Depletion	ln likelihood	q	Biomass (kt)	M
q= 2, estimate *M*	0.02	12.04	2	2869.74	0.05
q = 1, estimate *M*	0.01	11.27	1	8437.49	0.11
Estimate *q*, *M*=0	0.04	12.70	2.71	1440.99	0.0
Estimate *q*, *M*=0.1	0.02	11.34	1.04	7086.71	0.1

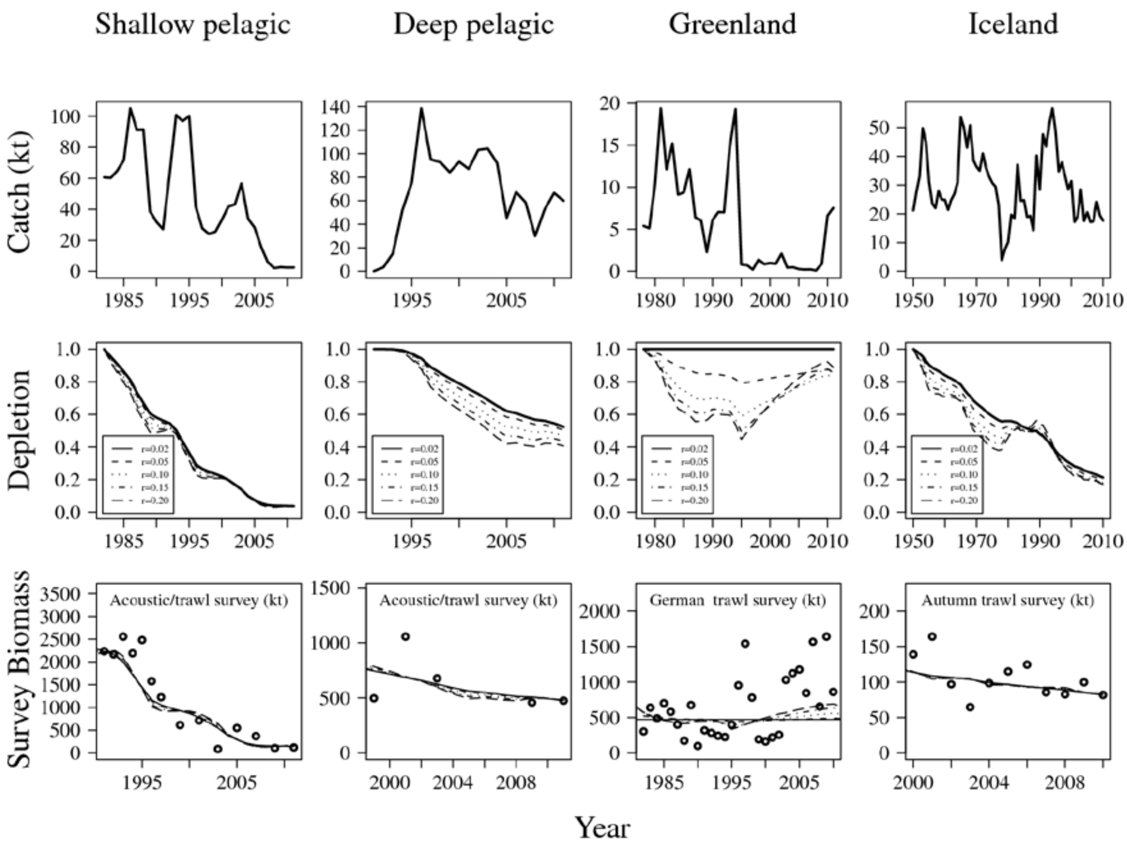

Figure 1. Catch, estimated depletion, and fits to survey biomass from Schaefer models applied to four stocks of *Sebastes mentalla* in the northwest area.

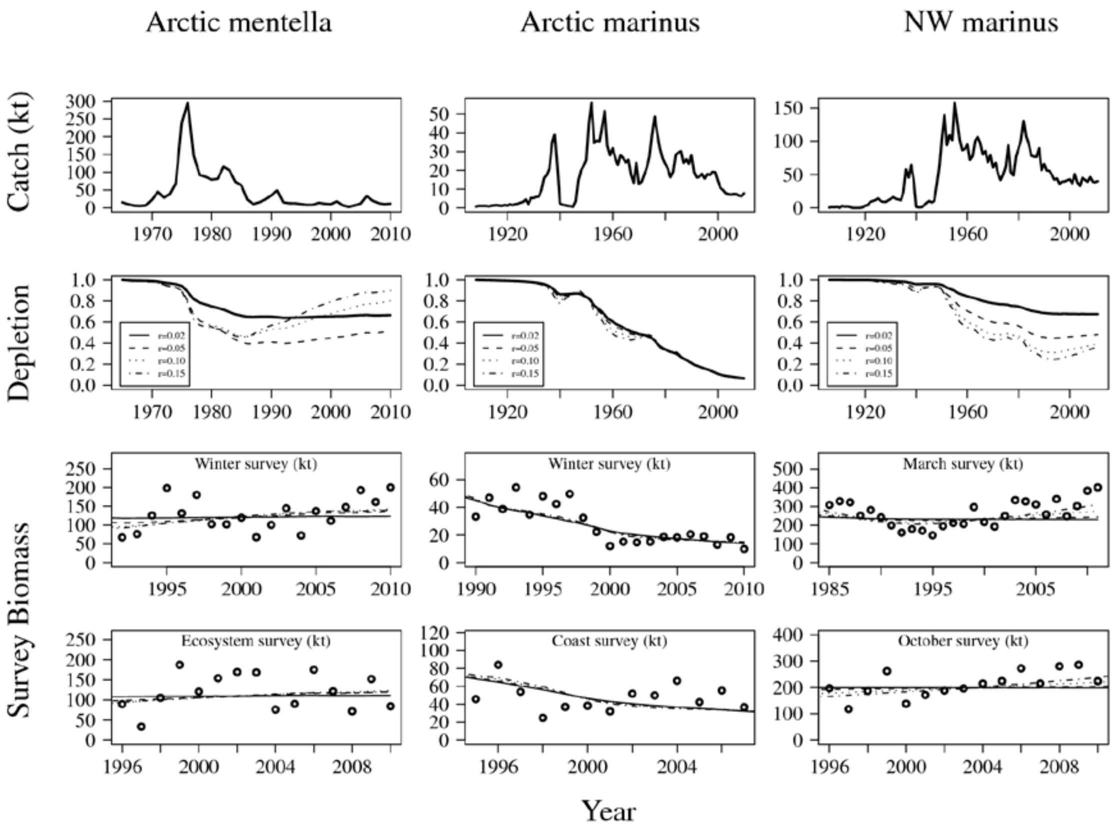

Figure 2. Catch, estimated depletion, and fits to survey biomass from Schaefer models applied to *Sebastes marinus* in the Arctic and northwest areas, and *Sebastes mentalla* in the Arctic area.