ICES WKRED REPORT 2018

ICES ADVISORY COMMITTEE

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Report of the Benchmark Workshop on Redfish Stocks (WKREDFISH)

29 January –2 February 2018

Copenhagen, Denmark

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

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

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Executive summary

The ICES Benchmark Workshop on Redfish in Northeast Arctic waters (WKREDFISH) convened at two meetings, one data compilation workshop 21–23 November 2017 and the final benchmark meeting, 29 January – 2 February 2018. Both meetings took place at the ICES Headquarters in Copenhagen.

As part of the benchmark workshop a special request from Norway and Russia on HCR evaluation for redfish and by-catch limits of redfish in the Barents Sea shrimp fishery was addressed. WKREDFISH_2018 did not fully address the request but proposes a road map for setting bycatch limits for redfish. The HCR part of the request will be dealt with by a separate workshop before autumn 2018.

In WKREDFISH_2018 two stocks were benchmarked: Beaked redfish (*Sebastes mentella*) in subareas 1 and 2 (reb.27.1-2) and golden redfish (*Sebastes norvegicus*) in subareas 1 and 2 (reg.27.1-2). The most important conclusions for each stock were:

Beaked redfish in 1 and 2

No new information on stock id or sub-stock structure was presented during the benchmark. The assessment of beaked redfish has changed considerably since the last benchmark in 2012. The main points are that the model is now run in Template Model Builder (TMB) whereas in 2012 the implementation of the model was in ADMB. Autoregressive models are now implemented for recruitment and the annual component of fishing mortalities and selectivity in the demersal and pelagic fleets. Additionally, a right trapezoid population matrix is used, and older ages being aggregated into age blocks. Finally, data from the pelagic surveys in the Norwegian Sea were included in the assessment. These changes are considered an improvement and accepted by WKREDFISH_2018.

WKREDFISH_2018 proposes the following biomass reference points:

- B_{lim} as 324 000 tonnes. The stock-recruit scatterplot shows no clear evidence of relation between recruitment and spawning stock biomass but rather trends in recruitment and SSB over time. This can be classified as a type 1 stock and B_{lim} thus be approximated by the lowest observed SSB: 324 000 t. Result from the Schaefer biomass model for *S. mentella* in subareas 1 and 2, updated at the AFWG (2016) from previous benchmark assessment for the period 1952–2015 show no lower SSB prior to the assessment time-series.
- B_{pa} at 450 000 tonnes. B_{pa} can then be estimated from B_{lim} taking into account the uncertainty in estimating SSB in the most recent year: $B_{pa}=B_{lim}*e(1.645\times\sigma)$, with σ=0.2 (Note that the model output for SSB in 2016 gives σ=0.09 but this value is considered an under-estimate which doesn't account for sources of uncertainties external to the model, such as uncertainties in M or q).

As for fishing mortality reference points WKREDFISH_2018 proposes $F_{0.1}$ = 0.080 defined for ages 19 and older. As there is a request from Norway and Russia to evaluate harvest control rules for beaked redfish where F_{MGT} and other reference points will be evaluated, WKRED did not propose candidate F_{lim} and F_{pa} points.

Golden redfish in 1 and 2

No new information on stock id or sub-stock structure was presented during the benchmark. The assessment of golden redfish has changed considerably since the last benchmark in 2012.

The assessment model proposed by WKREDFISH_2018 is a modification of the existing Gadget model used for this stock (ICES, 2012).

The model is a single-stock, single-area model with an annual timestep, length range 1–80 cm+ in 1 cm size categories, age range 3–30+, which runs from 1986 to 2017. Two surveys are used for tuning: the winter survey (BS-NoRu-Q1) and the coastal survey (NOcoast-Aco-Q4). Neither of these gives good coverage of the larger fish, and thus the larger fish are only covered by the commercial catches. The modelled fleets are gilfleet, trawl (including the very minor handline catches) and longline. However, for practical reasons, the trawl and longline fleets are combined into a single fleet (trawl and longline) prior to 2009. Annual catches are considered exact, and each fleet has length distributions (in 1 cm categories from 1986) and age length data (from 2005, 5 cm length categories). Natural mortality is fixed at M=0.05. All fleets are modelled with asymmetric dome-shaped selectivity (in length), except for the longline fleet which has logistic selectivity. The main improvement in the model since WKRED-2012 is the use of annual, rather than quarterly, time-steps in the model and the splitting of trawl and longline catches. The model was considered suitable as basis for advice and was accepted by WKREDFISH_2018.

WKREDFISH_2018 proposed the following biomass reference points:

No stock recruitment relationship is presented for this stock. Within the model, recruitment is modelled as an annual recruitment value with no relationship to the SSB.

- B_{lim}: B_{lim} is based on the Lowest Observed Stock Size at which reasonable recruitment was observed. This is assumed to be the 2003 year class, at which time the SSB is estimated to be 44 000 tonnes.
- B_{pa}: Using the ICES default multiplier of 1.4 for B_{pa} gives a B_{pa} value of 61 600 tonnes.

The stock is currently well below the biomass limit reference point, and thus F_{MSY} is not recommended as the current fishing level. However, it was considered useful to try and estimate a candidate F_{MSY} reference point, which can be used to compare against management performance. Using yield per recruit analysis WKREDFISH_2018 proposes $F_{0.1}$(15+), estimated to be 0.0525, as a candidate F_{MSY}.

Future research and data requirements were identified, also by the external reviewers.

1 Introduction

A **Benchmark of Redfish in NorthEast Arctic waters** (WKREDFISH), chaired by External Chair Paul Spencer, US, and ICES Chair Gudmundur Thordarson, Iceland and attended by two invited external experts, Brian Linton, US and Michel Bertignac, France, will be established and meet for a three-day data evaluation meeting at ICES Headquarters, 21 – 23 November 2017 and at ICES Headquarters for a Benchmark meeting, 29 January – 2 February 2018 to:

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

   i. Stock identity and migration issues;

   ii. Life-history data;

   iii. Fishery-dependent and fishery-independent data;

   iv. Further inclusion of environmental drivers, multi-species information, and ecosystem impacts for stock dynamics in the assessments and outlook

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

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

c) Re-examine and update if appropriate necessary) MSY and PA reference points according to ICES guidelines (see Technical document on reference points);

d) Develop recommendations for future work to improve the assessment and data collection and processing;

e) As part of the evaluation:

   i) Conduct a 3 day data evaluation workshop (DEWK). Stakeholders are invited to contribute data (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality. As part of the data compilation workshop consider the quality of data including discard and estimates of misreporting of landings;

   ii) Following the DEWK, produce working documents to be reviewed during the Benchmark meeting at least 7 days prior to the meeting

STOCKS	STOCK LEADER
Beaked redfish (*Sebastes mentella*) in subareas 1 and 2 (Northeast Arctic)	Benjamin Planque
Golden redfish (*Sebastes norvegicus*) in subareas 1 and 2 (Northeast Arctic)	Daniel Howell

The Benchmark Workshop will report by 2 March 2018 for the attention of ACOM.

The following special request addressed by WKREDFISH_2018 from Norway and Russia was:

Background:

Norway and Russia share the management of redfish (*Sebastes mentalla* and *Sebastes norvegicus*) in ICES subareas 1 and 2. Currently a management plan is under development and ICES is therefore requested to evaluate HCRs for the redfish stocks. The HCRs to be evaluated will be based on the guidelines for such rules for this stock suggested by WKREDMP (ICES; 2014). The exact formulation of the rules to be evaluated will be communicated to ICES after the benchmark meeting for this stock (WKREDFISH) in February 2018.

Request:

a) ICES is requested to carry out an evaluation of harvest control rules for *Sebastes mentella* in ICES subareas 1 and 2.

b) ICES is also requested to evaluate the impact of by-catch regulations on the shrimp fisheries in the Barents Sea on the stocks of *Sebastes mentella* and *Sebastes norvegicus* in ICES subareas 1 and 2. This evaluation should be carried out for different levels of bycatch limitations and different levels of shrimp catch.

1.1 Adoption of the agenda

The following were dropped from the agenda:

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

In the special request from Norway and Russia it is stated that the evaluation is not to be a part of the Benchmark meeting and the exact formulation of the proposed HCR will take place at a meeting between Norway and Russia in March. Therefore WKREDFISH_2018 did not address the issue any further.

1.2 Description of the Benchmark Process

The ICES benchmark on redfish stocks in subareas 1 and 2 included the following steps:

1) A data call was issued 31 August 2017 for the redfish stocks in subareas 1 and 2 stocks to be benchmarked in WKREDFISH. The deadline of the data call was 20 October 2017.
2) On the 12 October an informal web meeting took place between the stock coordinators and the ICES chair to go through the issues list and to plan the work ahead.
3) A WebEx meeting with the reviewers and the stock coordinators took place on the 10 November 2017. The special request by Norway and Russia was also discussed.
4) Data compilation workshop 21–23 November 2017.

5) A WebEx meeting was held on 12 December 2017 to check on progress after the data workshop. Externals were invited to attend.

6) A WebEx meeting was held on 12 January 2018 to check on progress of the work on the *S. mentella* stock. Externals were invited to attend.

7) A WebEx meeting was held on 19 January 2018 to check on progress of the work on the *S. norvegicus* stock. Externals were invited to attend.

8) No deadline for working documents was set however most documents or drafts of them were available well before the meeting.

The data issues and subsequent working documents for *S. mentella* and *S. norvegicus* in subareas 1 and 2 are detailed below.

S. mentella and *S. norvegicus*

Title	Description	Contributors
1. Preparation of landings data	a) Landing statistics - compilation b) Catch-at-age	Tone Vollen Kjell Nedreaas
2. Survey indices	a) Barents Sea Winter Survey b) Barents Sea Ecosystem Survey c) Barents Sea Russian groundfish survey d) International Deep Pelagic Ecosystem Survey in th Norwegian Sea e) Norwegican Coastal and Fjord survey f) Barents Sea 0-group survey g) Norwegian Sea Slope surveys: Egga-Sør and Egga-Nor	Benjamin Planque Kjell Nedreaas Tone Vollen Anatoly Filin Elvar Hallfredsson Erik Berg Elena Eriksen
3. Gadget *norvegicus* model	a) Model settings b) Model runs	Daniel Howell
4. Statistical catch-at-age model for *S. mentella* in ICES subareas 1 and 2.	a) Model settings b) Model runs	Benjamin Planque Alf Harbitz Tor Arne Øigard
5. Bycatch of juvenile fish in the shrimp fishery in the Barents Sea	a) Special Request from Norway and Russia b) Real time closures in the shrimp fishery c) Bycatch of redfish	Bjarte Bogstad
6. Variation in consumption of redfish by cod in the Barents Sea during the period 1984–2016	a) Predation of cod on pre-recruit redfish	Bjarte Bogstad
7. *S. mentella* – consumption by cod and recruitment	a) Predation of cod on pre-recruit redfish	Bjarte Bogstad

The first two days of the benchmark were devoted to plenaries on the input data and the assessments. After each presentation, discussions were held and either a consensus was reached, or the reviewers asked for additional clarifications or further work. This process involved several iterations, where more work was completed on a topic until a consensus was reached.

2 Beaked redfish in subareas 1 and 2

This section relates to the beaked redfish (*S. mentella*) stock in subareas 1 and 2.

2.1 Stock ID and sub-stock structure

No results were presented on the stock ID during the benchmark. The perception of the stock structure is unchanged from the earlier benchmark. To date, there is no evidence of multiple stocks or sub-stocks of *S. mentella* in subareas 27.1 and 27.2. Recent work on the population structure of *S. mentella* across the North Atlantic Ocean supports this view (Saha *et al.*, 2016)

2.2 Issue list

Stock		***S. mentella* (reb.27.1-2) beaked redfish in ICES subareas 1 and 2**	
Stock coordinator		Name: Benjamin Planque	
Stock assessor		Name: Pavel Murashko	
Data contact		Name: Benjamin Planque	
Issue	**Problem/Aim**	**Work needed / possible direction of solution**	**Data needed to be able to do this: are these available / where should these come from?**
Weight-at-age in 19+ group	Poorly explained fluctuations in WAA lead to important variations in SSB	Re-analyse historical weight data from the fishery and from surveys	Data currently used by the WG, in disaggregated form
Weight-at-age in stock vs catches	The weight-at-age in the catch and stock may be different, but this is not currently considered	1) Re-analyse historical weight data from the fishery and from surveys, 2) allow the model to use 2 different datasets for WAA.	Data currently used by the WG, in disaggregated form
cohort tracking for older individuals	Bulk of the population is currently in the modelled 19+ group. Survey data cover only young individuals (<15y).	1) Expand the model to age groups older than 19 and 2) use data from surveys in the Norwegian Sea, which cover older ages.	New survey data, available from Norway
high number of model parameters	Model has 92 parameters and increases by 2 parameters every year.	Implement autoregressive recruitment function using random effects in the SCA model	No new data needed
age range for F	Current age range (12–18) is not representative of the fishing mortality experienced by the adult stock (mostly 19+)	Evaluate the impact of using different age range for F.	No new data needed
Sensitivity of model outputs to surveys	There is a need for a quantitative evaluation of the sensitivity of the model to current surveys and to inclusion of new surveys.	Run a sensitivity analysis by using different combination of surveys as model input.	Existing and new survey data (as described above).
Fleet selectivity	Change in regulation in 2014 led to change in the pelagic and demersal fleets. The possible consequence on fleet selectivity-at-age is unknown	Test the current SCA model with different fleet selectivity at age before and after 2014.	No new data needed.

2.3 Scorecard on data quality

A scorecard was not used for this benchmark.

2.4 Multispecies and mixed fisheries issues

2.4.1.1 Predation by cod on redfish.

WD6 summarizes information on predation by cod on redfish.

Key points:

Annual estimates of consumption of redfish by cod in the Barents Sea are available (ICES, 2017), based on stomach sampling by Norway and Russia. On average about 9000 cod stomachs are analysed annually.

Most of the redfish eaten by cod is in the 5–24 cm length range, corresponding to age range 1–8.

Most of the redfish consumed is believed to be *S. mentella*, reflecting the species distribution in the Barents Sea. The stomach data are not considered suitable for splitting the redfish consumption by species.

The trends in consumption of redfish by cod correspond well to the trends in abundance of young redfish, with very low values during the period of recruitment failure. The trends in size composition in the diet are also consistent with the trends in size consumption in the survey data.

The redfish consumption by cod was highest in the period 1984–1992 (200–350 thousand tonnes). The consumption figures after the period of recruitment failure are lower. This is probably due to higher geographical overlap between cod and redfish in the 1980s–1990s than in later years, which seems to more than outweigh the higher stock size in recent years. Changes in abundance of other prey may also have affected the consumption of redfish.

2.4.1.2 Relating data on predation by cod on redfish to other information on redfish abundance

In WD7, the cod consumption of redfish is compared to the *S. mentella* abundance at young ages and the removal of S. *mentella,* which corresponds to natural mortality, for ages 2–8. The biomass removed due to M (M-output-biomass, MOB, Bogstad *et al.* 2000; Hamre and Tjelmeland, 1982) was calculated in the following way:

$$MOB(y) = \sum_{amin}^{amax} \frac{N(a,y)M(a,y) * 0.5 * (w(a,y) + w(a+1,y+1)) * (1 - \exp(-Z(a,y))}{Z(a,y)}$$

To investigate how the stock history would look with a higher M, we investigated the following scenario. Assume that M decreases linearly from some given value (M02) at age 2 to 0.05 at age 9. M02 was set to 0.95 for the period 1984–1995 and 0.40 for the period 1996–2016. Then we kept the age 9 values from the WKREDFISH assessment and back-calculated to age 2 using Pope's formula. For the cohorts 2008–2014 (ages 2–8 in 2016) we similarly back-calculated them from 2016 values at age 2–8 set so that the strength of these year classes at age 2 relative to the other year classes was approximately the same as in the WKREDFISH assessment.

The split into two periods is based on the observed lower abundance of redfish in cod stomachs during the second part of the period 1984-present than the first part (see WD6). The timing of the split between the first and second period is somewhat arbitrary, as it comes during the period of low recruitment where the data available give little information on the choice of M value.

The main results of these comparisons were:

Higher mortality values on age 2-8 *S. mentella* gives values of abundance at age 2 which correspond better to abundance estimates from the 0-group survey and the winter survey than the abundance at age 2 from the WKREDFISH assessment.

The MOB estimates with higher M seems to be in a reasonable range compared to the consumption estimates (Figure 1), in contrast to the estimates with fixed M = 0.05 which seem way too low. Some of the consumption by cod is of redfish outside the age range 2–8, as well as of other redfish species. On the other hand, cod can not be the only source of mortality for young redfish. There are also other sources of mortality than predation by cod, other predators as well as by-catch in the shrimp fishery.

To conclude, estimates of consumption by cod indicate that M on young age groups of redfish may be considerably higher than 0.05. How much higher is very difficult to estimate, though some reasonable upper bound could probably be given. The assessment model could be changed to accommodate a variable M at young ages, and changes in M would affect calculations of effect of bycatch (special request) considerably. Further studies of redfish mortality at young age, including a scientific publication, should be carried out. These studies should also take into account historic estimates of bycatch.

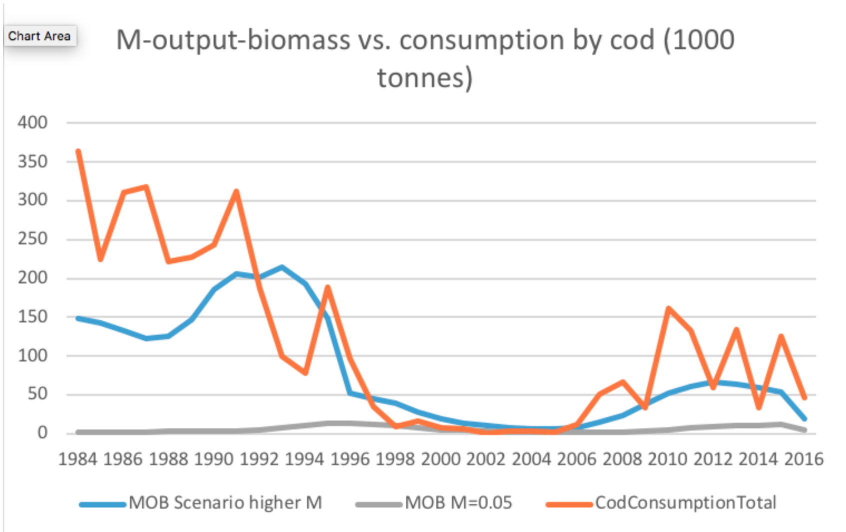

Figure 1: M-output-biomass from WKREDFISH assessment and high M scenario vs. consumption by cod

2.5 Ecosystem drivers

No new information was presented at the benchmark meeting. There have been large variations in the recruitment of *S. mentella* over the past four decades, but these cannot be attributed to particular environmental or ecosystem drivers.

2.6 Stock assessment

2.6.1 Catch: quality, misreporting, discards

The method for compiling catch data was presented at the benchmark. There are several challenges for compiling the catch data for beaked redfish. A detailed description of the process is given in WD-01 but the main steps are:

2.6.1.1 Step 1. Harmonizing trawl catches with logbooks (correction of time and area of catches)

Since 1986, the landing statistics from bottom trawlers have been harmonized with logbooks by using the distribution of catches by area and quarter from logbooks and raising them to the total quantity from the landings statistics.

2.6.1.2 Step 2. Species misidentification issues

The second step in the preparation of landings data takes into consideration species misidentification. Since 2000, the Norwegian landing statistics of redfish have been reported as *S. norvegicus* or *S. mentella*. Landings are regularly reported outside of the species distribution range, highlighting the difficulty of identifying these species correctly. Therefore, the species composition of the landings is checked and, if necessary, revised.

For *S. mentella* this is not considered a serious source of bias as the *S. mentella* stock is several orders of magnitude larger than the *S. norvegicus* stock in subareas 1 and 2.

2.6.1.3 Step 3. Norwegian landings in numbers-at-age-and-length

The Institute of Marine Research has long used a program scripted in SAS, in IMR named "the SAS biomass program", to calculate landings in numbers-at-age-and-length after matching national landings with all available samples in IMR's database. In the coming years it will be replaced by the IMR's new "Estimating Catch-at-Age (ECA) model. ECA is a model tool scripted in R, developed by the Norwegian Computing Center in cooperation with IMR.

2.6.1.4 Step 4. International landing statistics

Making the final tables of international landings for beaked redfish (*Sebastes mentella*) and golden redfish (*Sebastes norvegicus*) in ICES subareas 1 and 2 requires complex collation of data from many different sources and formats. Often the different data sources give vastly different estimates of catches by nations. The decision process each year is documented in the AFWG report. Often the different data sources give different estimates of catches by nations, and landings reported as *Sebastes* spp. needs to be allocated to species level.

2.6.2 Surveys

2.6.2.1 Research surveys

Information on abundance and biological parameters of *S. mentella* is available from seven surveys.

Barents Sea winter survey: BS-NoRu-Q1 (BTr)

The survey is a trawl and acoustic survey and only the trawl data is used for deriving indices of abundance-at-age and -length for both *S. mentella* and *S. norvegicus*. Abundance indices are calculated following a swept area estimate method. Until recently, the calculations were performed using the SAS program survey. The newly implemented StoX method is now in use for deriving the numbers-at-length for both redfish species in the Winter survey and the details of the method can be found in Mehl *et al*. (2016). StoX has not yet been implemented for estimating abundance-at-age for redfish and output from the SAS survey program are still used instead.

Indices in the form of numbers-at-age for *S. mentella* for the period 1992-2011 and for age groups 2-15y are used as tuning series in the assessment. After 2011, age readings are not available, and no data has been provided (otoliths are available for age determination). Abundance indices for individuals older than 15y are not provided. It is known that these migrate out of the Barents Sea and the survey is not considered adequate to derive reliable abundance estimates for these older age groups.

Barents Sea Ecosystem Survey: Eco-NoRu-Q3 (BTr)

The joint autumn ecosystem survey of the Barents Sea started in 2003 by combining five previous surveys into a single investigation. Combining the surveys enabled the whole ice-free Barents Sea to be covered by oceanographic, acoustic, pelagic trawl and demersal trawl investigations. Investigations on plankton, seabirds, marine mammals, marine pollution and benthos have also been carried out, but with various degrees of coverage. The survey is carried out in August and September each year.

The survey provides swept area abundance estimates for *S. mentella* and *S. norvegicus* in the Barents Sea during summer. In addition, the 0-group component of the survey is used to estimate the abundance of 0-group redfish for the two species combined.

Numbers-at-age for *S. mentella* for the period 1996-present and for age groups 2–15 y are used for tuning the assessment model. In 2010, no otoliths were collected, and no data is provided. The data for most recent years is often lagging, i.e. otoliths are available for age determination but have not been read by the time of the assessment working group. Abundance indices for individuals older than 15 years are not provided. It is known that these migrate out of the Barents Sea and the survey is not considered adequate to derive reliable abundance estimates for these older age groups.

Barents Sea Russian groundfish survey: RU- Q4 (BTr)

This survey is conducted from late-October to late-December. Its total duration is 40–50 days. Depths are surveyed from 50 to 900 m. The survey is performed by 2 or 3 vessels simultaneously. Sampling gear is a bottom trawl.

To calculate the indices of abundance-at-age of redfish total catch in each trawl are measured and the results of the redfish length measurements are combined with intervals of 2 cm. Age samples are selected from the redfish catches. After determining the age, an age-length key is compiled. To calculate the number of fish of a certain age in each catch, the size range of redfish in each catch are recalculated using the age-length key.

International Deep Pelagic Ecosystem Survey in the Norwegian Sea

The deep pelagic redfish surveys in the Norwegian Sea were initiated in 2007 following the onset of the pelagic fishery and the request by NEAFC to ICES to investigate the distribution and abundance of redfish in open (and international) waters of the Norwegian Sea. The survey uses the standard observation strategy based on hydroacoustic registrations at 38 kHz, sampling with a large pelagic trawl, and hydrographic measurements during trawling. Because of uncertainties in scrutinizing fish distribution at depths greater than 400 m and within the deep scattering layer, it is currently the trawl component of the survey that is used for deriving indices of abundance.

Trawl-base estimates of proportions-at-age for *S. mentella* in the northern part of the open Norwegian Sea for years 2008, 2009 and 2013 (2016 still to be read), ages from 7 to 75 years are used as tuning indices in the assessment model.

Norwegian Coastal and fjord survey (no ICES acronym)

The Norwegian Coastal and fjord survey is an acoustic survey designed to obtain indices of abundance and estimates of length and weight-at-age of saithe and coastal cod north of 62°N. It has been carried out annually in October-November, since 1985 for saithe and since 1995 for coastal cod. Redfish species are sampled as bycatch from the survey and the data has been used to derive abundance indices. Indices from the survey are not used in the assessment model.

Barents Sea 0-group survey: Eco-NoRu-Q3

The Barents Sea 0-group survey has been conducted since 1965. Since 2003 the 0-group survey has been a part of the Barents Sea Ecosystem Survey (see above). The survey is carried out annually during August-September.

The survey is used to derive estimates of abundance of 0-group juveniles in the Barents Sea from several commercial species, including redfish. Young-of-the-year redfish cannot be taxonomically identified down to the species level and the 0-group indices are available for *Sebastes* sp. Indices from the survey are not used in the analytical assessment model.

Norwegian northern autumn and southern spring slope surveys (NO-GH-Btr-Q3/no ICES acronym)

The Norwegian slope surveys in autumn (northern part) and spring (southern part) are combined trawl and acoustic surveys conducted alternatively and biennially along the continental slope in the Norwegian Sea. The southern spring slope survey covers the latitudinal range 62°–74°N and is conducted during spring, when adult redfishes of both species concentrate along the slope for larval extrusion. The northern autumn slope survey covers the latitudinal range 68°–80°N and is conducted in late summer and autumn when beaked redfish adults migrate back from summer migrations in the Norwegian Sea towards the slope. The southern spring slope survey was conducted in 2012, 2014 and 2016 while the northern autumn slope survey was conducted in 2011, 2013, 2015 and 2017.

Number-at-age/length for different depth and geographical strata have been estimated from these two surveys, but these have not been thoroughly evaluated and are not used in the assessment.

2.6.2.2 Catch and effort series

No new information was presented at the benchmark meeting.

2.6.3 Weights, growth, maturity, natural mortality

2.6.3.1 Weights and growth

No new information was presented at the benchmark meeting. Previous relevant documents on weight and growth include Working Document 19 from the earlier benchmark assessment (Aanes, 2012) and Working Document 3 from the Arctic Fisheries Working Group in 2015 (Planque, 2015). Weight-at-age data was prepared as in ICES (2017). Weight-at-age in the population and in the catches are identical in the assessment model.

2.6.3.2 Maturity

No new information was presented at the benchmark meeting. Maturity-at-age data was prepared as in ICES (2017). Maturity-at-age in the population and in the catches are identical in the assessment model.

2.6.3.3 Natural mortality

Mortality is assumed to be constant across ages and years with a value of $M = 0.05$. This value is derived from earlier calculations based on the Hoenig equation (Hoenig, 1983) which can be used to derive mortality from longevity. Thirty nine alternative mortality estimates were explored during the workshop (Annex 2), based on the review work by Kenchington (2014) and several additional papers published recently (Then *et al.*, 2014; Hamel, 2014; Charnov *et al.*, 2013). In addition, likelihood profiles and SSB profiles were performed to assess the sensitivity of model fit and results to alternative values of M.

The currently used natural mortality for *S. mentella* is within the range of mortalities estimated using 39 estimators. Most estimators are calculated as one value across the lifespan of the fish, whilst others are specific for age (Chen and Watanabe 1989), length (Gislason *et al.*, 2010) or weight (Lorenzen, 1996; Peterson and Wroblewski, 1984; Charnov *et al.*, 2013). The latter were calculated for the age range of 20 – 30 years and the corresponding lengths and weights. Griffiths and Harrod’s (2007) as well as Zhang and Megrey’s (2006) estimators differ for demersal and pelagic fish. As beaked redfish has demersal and pelagic life stages, these estimators are given as means between the two methods. Overall, the mode of the natural mortality estimates is 0.058 which departs only slightly from the original estimate of 0.050. WKREDFISH_2018 decided to continue using 0.050 as the value of M in the assessment model.

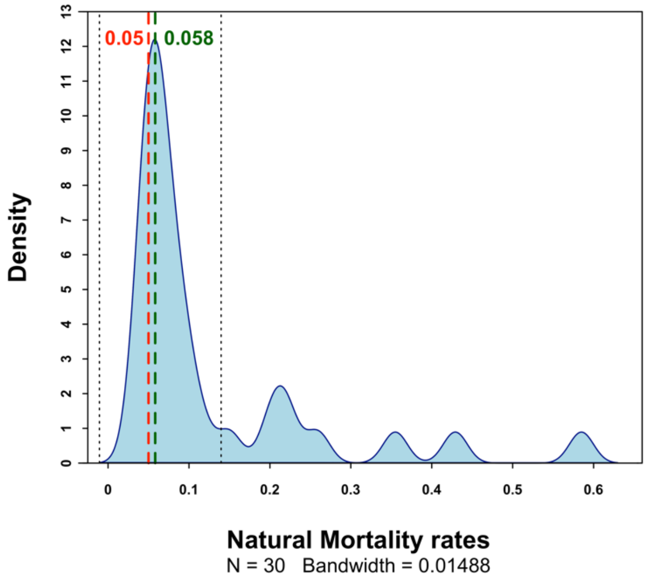

Figure 2: Density distribution of natural mortality rates calculated with 30 of the 39 methods listed in Annex 2. The excluded methods are those based on certain taxa or areas. The dashed red line indicates the value currently used; the broken green line the mode of the mortality estimates and the black dotted lines indicate the beginning and end of the distribution's peak.

2.6.4 Assessment model

2.6.4.1 Model structure

The assessment model used is a statistical catch-at-age model. The model runs for the period 1992–2016. A complete description of the model structure, equations, input data, parameters and options is provided in Working Document 4 of this workshop.

The model is similar to that used in prior assessments (2012–2016) with additional developments.

- Implementation in Template Model Builder. The 2012 version was implemented in ADMB,
- Autoregressive model for recruitment at age 2. In the 2012 version recruitment in individual years were estimated independently,
- Autoregressive model for the annual component of fishing mortalities in the pelagic and demersal fleets. In the 2012 version fishing mortalities in individual years were estimated independently,
- Autoregressive model to account for annual changes in demersal fleet selectivity-at-age. In the 2012 version selectivity of the demersal fleet was kept identical for all,
- Use of a *right trapezoid* population matrix. The 2012 version used a standard rectangular matrix with 19+ group,
- Coding of older ages into flexible predefined *age-blocks*. Older ages were not considered explicitly (only as +group) in the 2012 version,

- Use of data from the pelagic surveys in the Norwegian Sea. These data were not included in the earlier version.

2.6.4.2 Results of the baseline run

Detailed results of the baseline run are presented in WD4 (Planque *et al.*, 2018). The key outputs are summarised below:

- The baseline model has 53 parameters and optimises correctly
- Numbers-at-age in the first year (1992) show a quasi-exponential decline with age and the 19+ group constitute a large fraction of the population in that year.
- Recruitment was high (>400 millions age 2) earlier, then sharply decline in the late 1990's-early 2000's and returned to high values in the 2010's. Recent recruitment levels are uncertain
- Spawning-stock biomass has gradually increased from ~300 thousand tonnes in 1992 to over 1 million tonnes in 2007. It has slightly declined since then.
- Fishing mortality has remained below natural mortality. In 1992 *F* was around 0.04 and only the demersal fishery was operating. Recent changes in the fisheries (opening of the pelagic in 2006 and targeted pelagic in 2014) are reflected in fishing mortality trends. The current level is estimated to have returned to ~0.04 in 2016.
- The age structure of the population in 2016 indicate that the bulk of the biomass is over 20 years old and that there are incoming strong year classes of 13 y and younger fish.

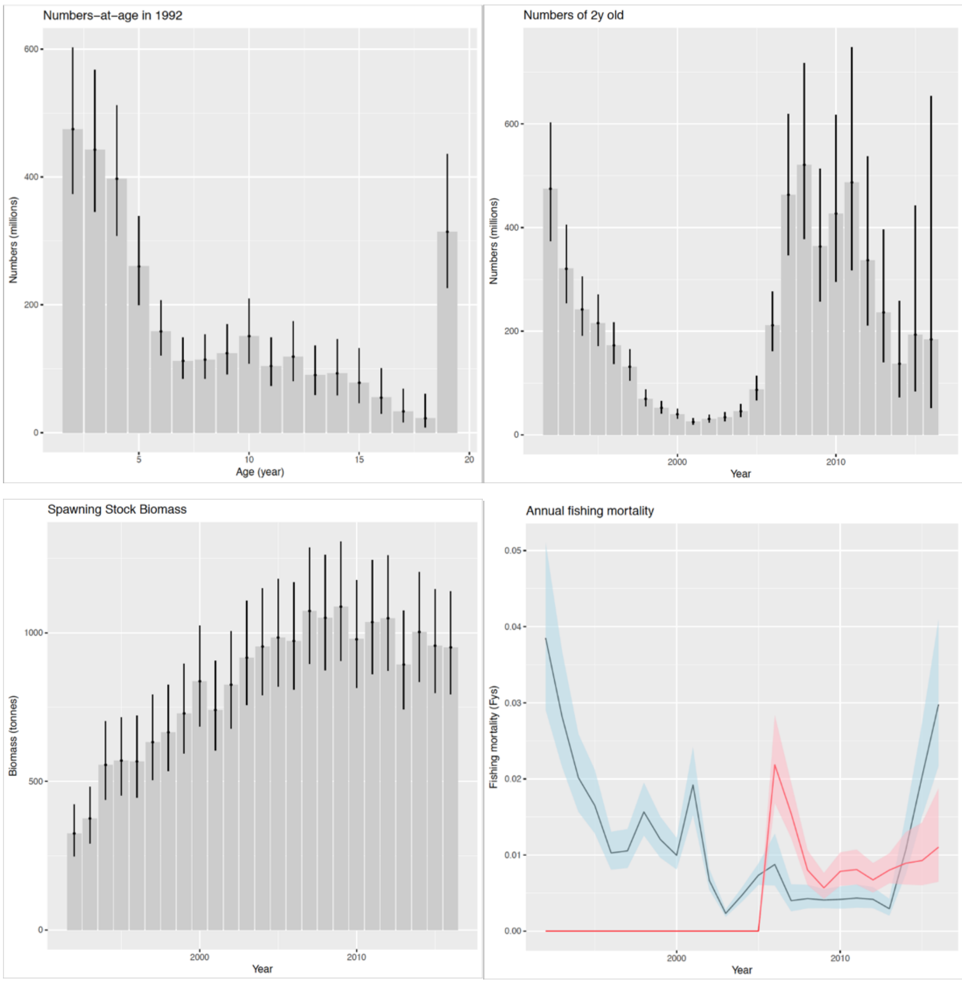

Figure 3: ***S. mentella*** **in ICES subareas 27.1 and 27.2. Results from the baseline run of the Statistical catch-at-age model. Top-left: numbers of individuals of age 2 to 19y+ in year 1992. Top-right: Numbers of individuals of age 2y, from 1992 to 2016. Bottom-left: Spawning-Stock Biomass from 1992 to 2016. Bottom-right: Annual component of the fishing mortality for the pelagic (red) and demersal (blue) fleets. Vertical black lines and translucent bands indicate 95% confidence limits.**

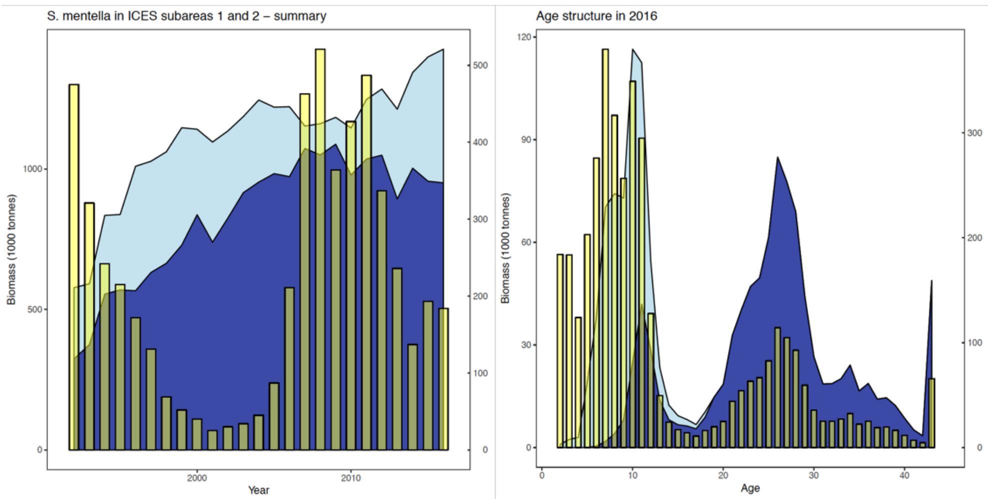

Figure 4: ***S. mentella*** **in ICES subareas 27.1 and 27.2. Results from the baseline run of the Statistical catch-at-age model. Left: summary of the stock development from 1992 to 2016 showing recruitment (yellow bars), spawning stock biomass (dark blue) and total stock biomass**

(light blue). Right: summary of the population structure in 2016 showing numbers-at-age (yellow bars), mature biomass-at-age (dark-blue) and total biomass-at-age (light blue).

Table 1. ***S. mentella*** **in ICES subareas 27.1 and 27.2. Results from the baseline run of the Statistical catch-at-age model. Estimated recruitment (million) at age 2y and 6y, Total Stock Biomass (TSB, tonnes), Spawning-Stock Biomass (SSB, tonnes), Fishing mortality for age 12–18y and 19y+ for the period 1992–2016.**

Year	Rec (Age 2)	Rec (age 6)	TSB	SSB	F12.18	F19+
1992	475	158	577 465	323 963	0.028	0.039
1993	321	245	591 153	374 544	0.027	0.028
1994	242	359	834 870	554 660	0.02	0.02
1995	215	381	837 864	569 467	0.016	0.017
1996	172	389	1 009 603	566 702	0.01	0.01
1997	131	263	1 027 540	631 585	0.011	0.011
1998	69	198	1 061 173	664 344	0.016	0.016
1999	52	176	1 146 896	728 892	0.012	0.012
2000	40	141	1 141 616	837 179	0.01	0.01
2001	25	107	1 095 915	739 307	0.019	0.019
2002	30	57	1 135 384	825 630	0.007	0.007
2003	34	42	1 186 570	915 726	0.002	0.002
2004	45	33	1 245 531	953 103	0.005	0.005
2005	87	21	1 219 978	983 409	0.007	0.007
2006	211	25	1 221 577	972 860	0.027	0.031
2007	463	28	1 152 735	1 073 223	0.016	0.019
2008	521	37	1 161 174	1 049 997	0.011	0.012
2009	364	71	1 183 678	1 088 167	0.009	0.01
2010	427	173	1 145 886	978 733	0.011	0.012
2011	487	380	1 247 650	1 035 483	0.011	0.012
2012	337	427	1 284 702	1 049 268	0.01	0.011
2013	236	298	1 212 818	893 394	0.009	0.011
2014	137	350	1 343 452	1 002 805	0.014	0.02
2015	193	399	1 399 088	956 331	0.018	0.03
2016	184	276	1 426 517	950 715	0.022	0.041

2.6.4.3 Model evaluation, profiling and alternative runs

Residual patterns were examined and are presented in detail in WD4 (Planque *et al.*, 2018). There were no strong residual patterns or departure from normality. The residual patterns for the demersal fleet are presented here as an example.

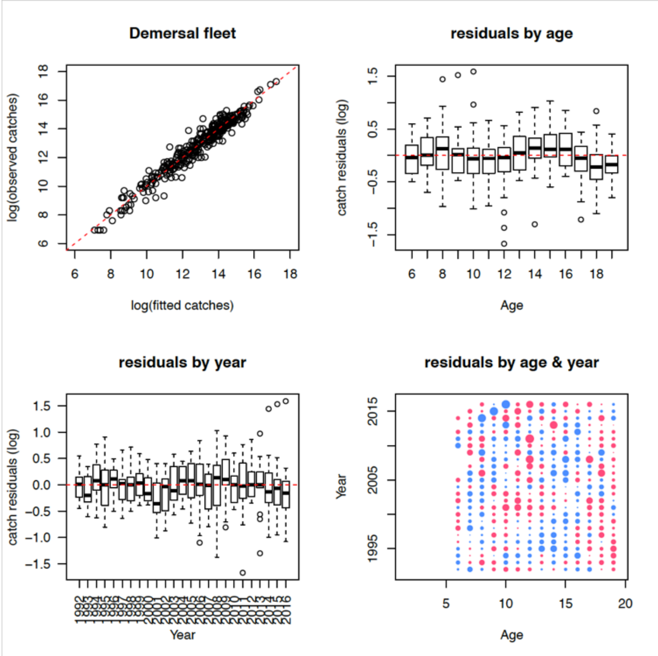

Figure 5. ***S. mentella*** **in ICES subareas 27.1 and 27.2. Diagnostic plots for the demersal fleet catch-at-age data. Top-left: scatterplot of observed vs. fitted indices, the dotted red line indicates 1:1 relationship. Top right: boxplot of residuals (observed-fitted) for each age. Bottom left: boxplot of residuals for each year. Bottom right: bubble plot of residuals for each age/year combination, bubble size is proportional to residuals, blue are positive and red are negative residuals.**

The sensitivity of the model to several hypotheses and parameters was assessed. This was done by profiling against a range of parameter values for *M* (natural mortality) and *q* (scaling coefficient for the Ecosystem survey) and by performing alternative runs in which new features of the models – that are included in the baseline run – were sequentially turned off.

Profiling of the negative log-likelihood against *M* shows that higher likelihood (*i.e.* lower nll) is found for lower values of *M*. However, the estimated 95% confidence interval of the nll estimate in the baseline run is ± 16 and all model runs with 0.00 < M < 0.75 have a nll in this interval. In terms of likelihood estimates, the model is therefore little sensitive to variations in M. On the other hand, changes in *M* values have a substantial impact on the stock abundance estimates and temporal dynamics. While the SSB in 2016 is around 1 million tonnes in the baseline run, it is estimated above 2 million tonnes when *M* = 0.005 and below 500 thousand tonnes when *M* = 0.1. These variations are associated with a stabilisation of SSB in recent years (baseline), a continuous increase in SSB (M = 0.005) or a decline in SSB (M = 0.1) during the same period.

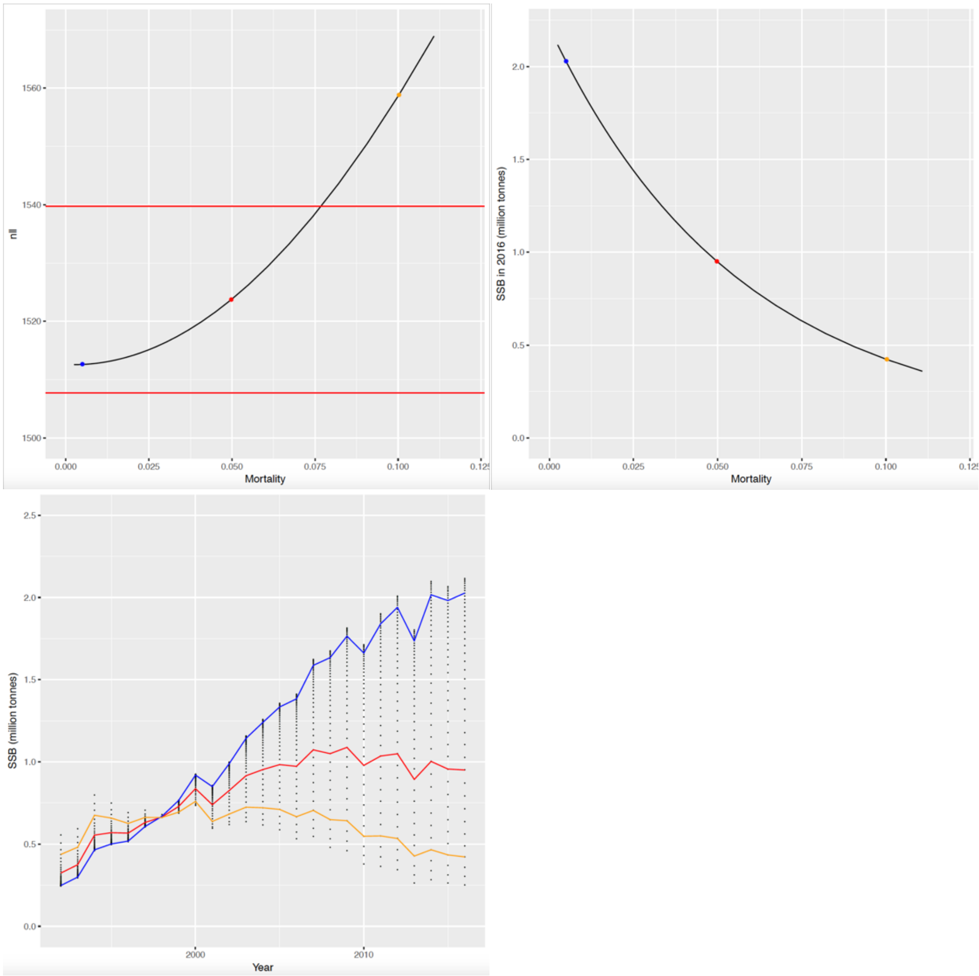

Figure 6. *S. mentella* in ICES subareas 27.1 and 27.2. Results from the profiling of the baseline run of Statistical catch-at-age model along *M*. Top-Left: changes in negative log-likelihood as a function of M. The horizontal lines mark the 95% confidence limits of the nll estimate for the baseline run. Top-right: changes in estimated SSB in 2016 as a function of *M*. Bottom: changes in SSB from 1992 to 2016 for 41 model runs with varying *M* values. Red dots/line indicate baseline run, blue dots/line indicate run with *M* = 0.005 and orange dots/line indicate run with *M* = 0.10.

Likelihood profiling of *q* values from 1e-5 to 7e-3 indicates that the highest likelihood (*i.e.* lowest nll) is found for low values of *q*. With *q* values between 1e-5 and 1e-3 the nll is within the 95% confidence interval of the baseline run. Because the likelihood profile is very flat for a wide range of low *q* values, it is not possible to estimate *q* directly from the model. As expected and observed in the previous benchmark, the biomass estimates are linearly related to the inverse of the scaling factor. For values around and lower to the baseline q, the relative SSB trajectory of the population is unchanged, but for high *q*'s, the model runs indicate a decline in SSB in recent years. WKREDFISH_2018 decided to continue using 1/3500 as the value of *q* for the Ecosystem survey in the assessment model.

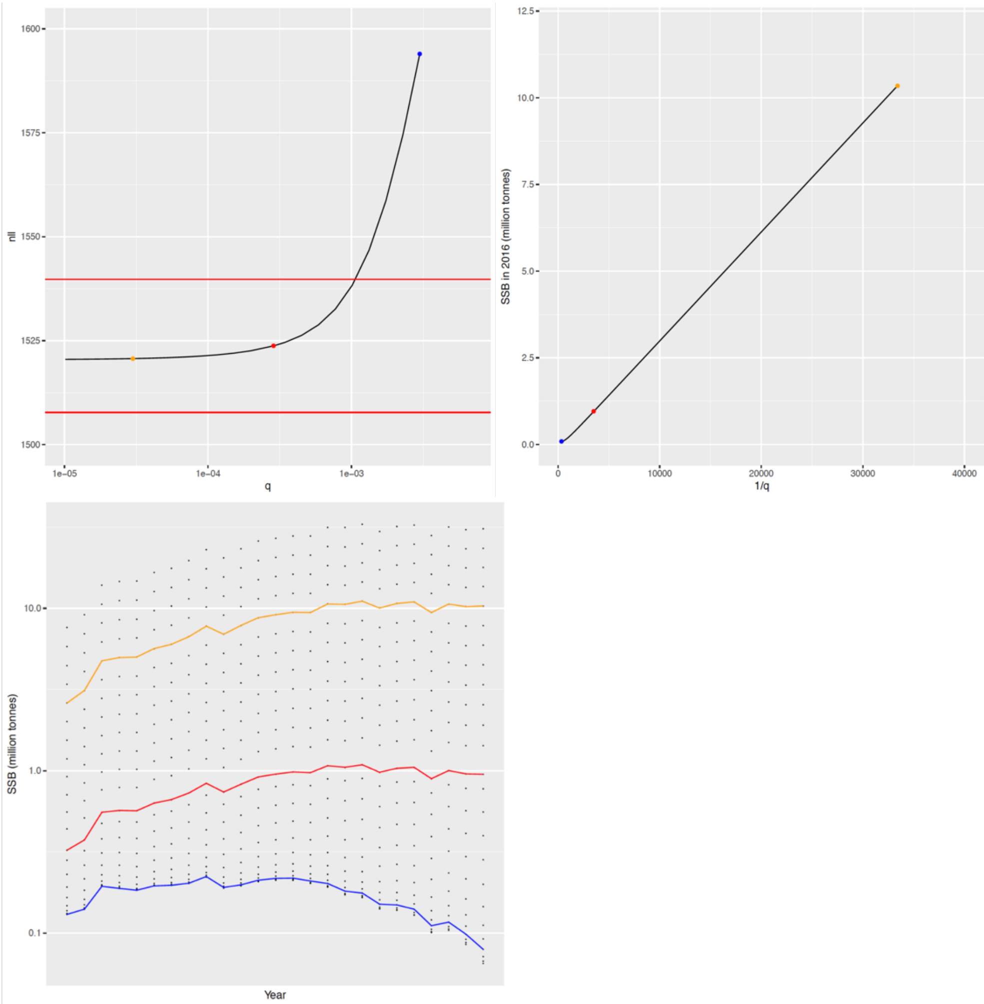

Figure 7. ***S. mentella*** **in ICES subareas 27.1 and 27.2. Results from the profiling of the baseline run of Statistical catch-at-age model along the scaling coefficient for the Ecosystem survey: q. Top-Left: changes in negative log-likelihood as a function of q. The horizontal lines mark the 95% confidence limits of the nll estimate for the baseline run. Top-right: changes in estimated SSB in 2016 as a function of 1/q. Bottom: changes in SSB (on a log scale) from 1992 to 2016 for 25 model runs with varying q values. Red dots/line indicate baseline run, blue dots/line indicate run with q=3e-3 and orange dots/line indicate run with q = 3e-5.**

The retrospective patterns for the period 2007–2016 show relatively stable SSB trajectories with possible deviations in the most recent years that have been mainly explained by changes in the calculation of the weight-at-age of the 19+ group (Planque, 2015). There is a significant difference between SSB trajectory in the baseline and that reported in the AFWG in 2017, with baseline estimates systematically higher than earlier ones. This is particularly evident in the earlier years of the time-series (1992–2006). In most recent years, the difference in SSB between the two models amounts to ~10% and is not significant.

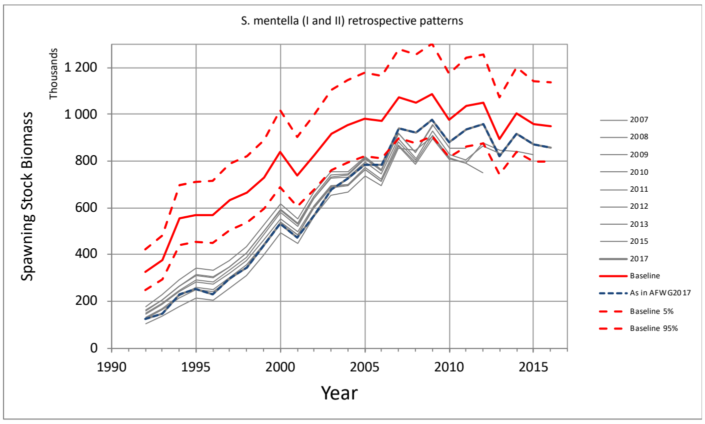

Figure 8: *S. mentella* in ICES subareas 27.1 and 27.2. Analytical (2007–2011) and historical (2012–2017) retrospective patterns of SSB. The output from the baseline run and the 95% confidence limits are indicated in red. When the new model is run with similar options to those used in AFWG 2017 (blue dashed line), the results are identical to those presented at the AFWG 2017 (thick grey line).

Eight model runs, alternative to the baseline run, were performed to quantify the contribution of different elements of the model design, implementation and data. These are as follow:

Run 1: baseline

Run 2: the annual component of the demersal fishing mortality is modelled as fixed effects for each year, rather than using random effects

Run 3: the annual component of the pelagic fishing mortality is modelled as fixed effects for each year, rather than using random effects

Run 4: the annual components of the pelagic and demersal fishing mortality are modelled as fixed effects for each year, rather than using random effects

Run 5: the demersal fleet selectivity-at-age does not vary between years

Run 6: the data from the Norwegian Sea survey (WGIDEEPS) is not included

Run 7: the data from the Russian groundfish survey is not included

Run 8: the data from the Winter survey is not included

Run 9: model set-up as in the AFWG in 2017 (ICES, 2017)

The SSB and recruitment trajectories for each of these runs are presented below. SSB trajectories in runs 2, 3, 4, 7 and 8 are similar to the baseline run.

Two features in the baseline model configuration explain the difference between the SSB in the baseline and AFWG2017 runs: the addition of new observations on old adults from the pelagic survey in the Norwegian Sea (WGIDEEPS, run 6) and the inclusion of a variable selectivity pattern for the demersal fleet (run 5). Adding these two features modifies the representation of the age structure in recent years, which affects abundance estimates at age in earlier years. Accounting for interannual variations in selectivity leads to a significant improvement of the model to fit catch-at-age data (WD4; Planque, 2018).

Recruitment trajectories are similar between the baseline and the AFWG2017 runs except for the period 2007–2009. The difference between the two is almost exclusively due to the inclusion of the variable demersal fleet selectivity in the baseline run. In recent years, most of the information about young individuals is derived from the Russian groundfish survey. When this survey is removed (run 7) recruitment estimates differ quite largely for the period 2007–2010.

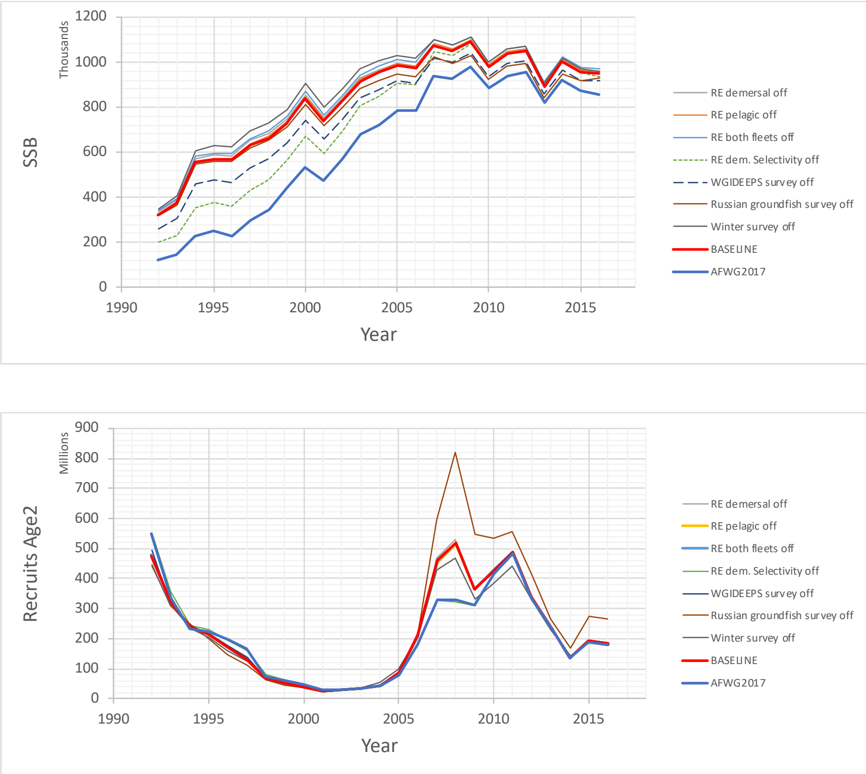

Figure 9: ***S. mentella*** **in ICES subareas 27.1 and 27.2. Output from the baseline, the 7 alternative runs and the run performed at the AFWG in 2017. Top: trajectory of the Spawning-Stock Biomass 1992–2016. Bottom: trajectory of the Recruitment at age 2 1992–2016.**

2.6.4.4 Medium and long-term projections

No specific projections were done during the benchmark assessment for *S. mentella*. Given the longevity of the species, the late age-at-maturity and the late age when entering the fishery, medium term projections can be considered up to 10 years into the future and long-term projections beyond this time horizon. For projection purpose, weight-at-age and maturity-at-age are considered identical to those in the last year of data available in the assessment. The fleet selectivity patterns are also considered identical to the last year of available data. Intermediate years assumptions include that catches will match the advice given by ICES. Variations in recruitment have little influence on TSB, SSB or catches over time horizons <10 years and even less so <5 years. Recruitment in future years is taken as the geometric mean of the last 5 years.

2.6.4.5 Key results from the new model implementation

The key results from the new implementation of the SCA model include:

- Natural mortality cannot be estimated. The current mortality rate (0.05) is based on life-history rational and model fits with lower mortality rates are not significantly different. Model fits with mortality rates >0.075 are significantly different.

- The scaling coefficient q for the ecosystem survey cannot be estimated reliably. The current value (1/3500) is based on sampling considerations, survey results and comparisons with other models in 2012. Model fits with lower q are not significantly different. Model fits with $q > 0.001$ are significantly different. SSB estimates are directly proportional to the inverse of this scaling coefficient.

- Changes in selectivity pattern of the demersal fleet in recent years is important and must be explicitly incorporated in the assessment model. The alternative run with fixed selectivity have a significantly poorer fit (Δnll = 165).

- The implementation of the autoregressive processes for recruitment and fishing mortality leads to very similar outputs and fits to that of models with independent estimates, but with a much lower number of fixed parameters to estimates. In addition, using autoregressive process allows for the estimation of (random) parameters even in the case of missing observations (as is the case for recruitment at age 2 in 2016). It's recommended to keep the implementation of these autoregressive processes.

- Incorporation of data from the Norwegian Sea survey does not significantly impact model outputs or fit. In addition, the model predictions of the population structure for older age groups tracks closely the survey data. This is the only dataset in which the older component of the population is described by age (in the form of age blocks) rather than as a single +group. This indicates that earlier assessment model runs (which didn't include these data) tracked fairly well the cohorts in the old adult component of the stock despite lack of direct observations. This data series should be kept and updated in future runs of the model.

- Age data from the Winter and Ecosystem surveys is lacking (or lagging behind) in recent years. As a result, the recent population trajectory for younger age groups is mostly driven by information provided by the Russian groundfish survey.

2.6.5 Reference points prior to benchmark

$F_{0.1}$ for ages 12–18y has been used previously as a proxy for F[MSY], with $F_{0.1} = 0.039$.

Biomass reference points have not been reported by earlier assessment groups but were suggested by WKREDMP (ICES, 2014) with B_{lim} = 450 000 t and $B_{trigger}$ = 600 000 t.

2.6.6 Stock-recruitment relationship and new B_{lim} and B_{pa} reference points

The stock-recruit scatterplot shows no clear evidence of relation between recruitment and spawning stock biomass but rather trends in recruitment and SSB over time (Figure 10). This can be classified as a type 1 stock and B_{lim} thus be approximated by the lowest observed SSB: 324 000 t (95% CI = [250 000;420 000]). Result from the Schaefer biomass model for *S. mentella* in subareas 1 and 2, updated at the AFWG (ICES, 2016) from previous benchmark assessment for the period 1952–2015 show no lower SSB prior to the assessment times series.

B_{pa} can then be estimated from B_{lim} taking into account the uncertainty in estimating SSB in the most recent year: $B_{pa} = B_{lim}e^{(1.645\times\sigma)}$ = 450 000t, with $\sigma = 0.2$ (Note that the model output for SSB in 2016 gives $\sigma = 0.09$ but this value is considered an underestimate which doesn't account for sources of uncertainties external to the model, such as uncertainties in M or q).

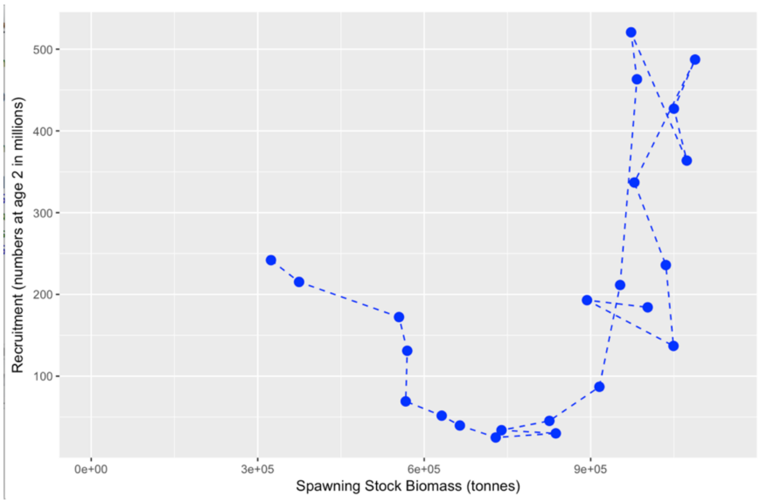

Figure 10. Recruitment at age 2y against Spawning-Stock Biomass for *S. mentella* in subareas 27.1 and 27.2 estimated by the SCA model. Dotted lines connect consecutive year classes (starting from left) from 1992–2014.

2.6.7 Methods and settings used to determine ranges for F_{MSY}

F_{MSY} is approximated by $F_{0.1}$ as previously proposed in the AFWG and explored in earlier workshop on management plan for redfish (ICES, 2014). Simulation based estimation of F_{MSY} were not performed during the benchmark since this work is expected to take place later in 2018 during a forthcoming ICES workshop on *S. mentella* management plan. The current estimate is therefore considered provisional.

Since the bulk of the biomass targeted by the fishery is older than 19y, the 19+ group is chosen as the age range over which $F_{0.1}$ is calculated, instead of the range 12–18y used previously. $F_{0.1}$ for age 12–18y is provided here for comparison with the earlier estimate. Change in yield-per-recruit as a function of F are illustrated in Figure 11.

$F_{0.1}$ (19+) = 0.080

$F_{0.1}$ (12–18 y) = 0.042

$F_{0.1}$ (12–18 y) from previous AFWG = 0.039

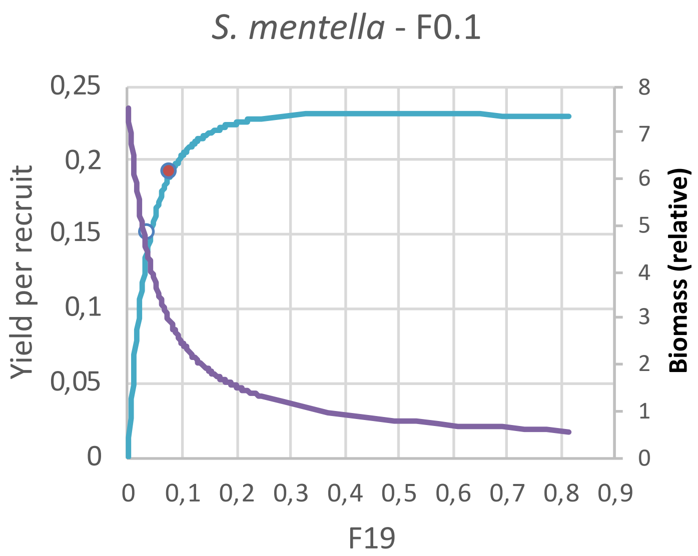

Figure 11. Blue line: yield-per-recruit against fishing mortality for the 19y+ group for *S. mentella* in subareas 27.1 and 27.2. The open white circle indicates the fishing mortality in 2016 estimated from the baseline run of the SCA model. The red circle indicates the fishing mortality at $F_{0.1}$. Relative biomass is indicated in purple.

2.6.8 Possible $B_{trigger}$ reference point

From the results of former simulations ICES have concluded that a biomass trigger of 600 kt seems to be a good starting point for future evaluations (Ch. 3.3.3.1 in ICES Advice 2014, Book 3). A biomass trigger point (preliminary set to 600 kt) has also been agreed by Russia and Norway, and when SSB is below this trigger point, F should be reduced linearly with the reduction in SSB.

During WKREDFISH_2018 the general level of the stock has been revised upwards, and it is hence expected that $B_{trigger}$ so should also be revised. WKREDFISH_2018 recommends that sufficient margins between B_{pa} and $B_{trigger}$ being considered before defining a $B_{trigger}$ in order to increase the possibility of good recruitment, and to maintain a maximum exploitation rate, and at the same time avoid increased variability of TAC between years. Considering the baseline model as a reference, a $B_{trigger}$ of 800 kt would not have led to recommendation for decreasing fishing mortality since 2002.

2.6.9 Proposed reference points

Reference point	Value
B_{lim}	324 000 t
B_{pa}	450 000 t
$F_{MSY} = F_{0.1}$(19y+)	0.080
$B_{trigger}$	*[600kt;800kt]*

2.7 Future research and data requirements

Further studies of redfish mortality at young age, including a scientific publication, should be carried out. These studies should also take into account historic estimates of bycatch. Variable *M* by age and possibly time period could then be incorporated in the assessment.

3 Golden redfish in subareas 1 and 2

This section relates to the golden redfish (*S. norvegicus*) stock in subareas 1 and 2.

3.1 Stock ID and substock structure

No results were presented on the stock ID during the benchmark.

3.2 Issue list

Stock		***S. norvegicus*** **, reg.27.1-2, golden redfish in ICES subareas 1 and 2**	
Stock coordinator		Name: Benjamin Planque	
Stock assessor		Name: Pavel Murashko	
Data contact		Name: Benjamin Planque	
Issue	**Problem/Aim**	**Work needed / possible direction of solution**	**Data needed to be able to do this: are these available / where should these come from?**
Choice of surveys for model tuning	Currently only one tuning survey series, which has poor coverage of adult fish.	Evaluate available survey datasets for utility as tuning series. Possibly suggest modifications to future survey design	New survey data, available from Norway
Evaluate winter survey in the assessment model	Survey is currently used in model tuning, but does not give good coverage of older fish	Evaluate which age or length ranges are appropriate to use in the model tuning	Data already available
age range for F	Current age range (12–19) is not representative of the fishing mortality experienced by the adult stock	Evaluate the impact of using different age range for F better covering older fish	No new data needed
Historical splitting of catches	Catches partially reported as "redfish", split post hoc into species	Evaluate the splitting procedure	Existing fisheries data
Assumed constancy of fleet selectivity	Change in regulation in 2015 removed the directed catch and reduced the bycatch	Evaluate length distributions in catches	No new data needed.
Reference points	Stock currently has generic F_{lim}/F_{pa} and no B_{lim}/B_{pa}	Need to agree on F and B limit reference points	No new data needed.

3.3 Scorecard on data quality

A scorecard was not used for this benchmark.

3.4 Multispecies and mixed fisheries issues

Predation by cod on redfish is addressed in the S. mentella section.

3.5 Ecosystem drivers

No new information was presented at the benchmark meeting.

3.6 Stock assessment

3.6.1 Catch: quality, misreporting, discards

The method for compiling catch data was presented at the benchmark. There are several challenges for compiling the catch data for golden redfish. A detailed description of the process is given in WD-01 but the main steps are:

3.6.1.1 Step 1. Harmonizing trawl catches with logbooks (correction of time and area of catches)

Since 1986, the landing statistics from bottom trawlers have been harmonized with logbooks by using the distribution of catches by area and quarter from logbooks and raising them to the total quantity from the landings statistics.

3.6.1.2 Step 2. Species misidentification issues

The second step in the preparation of landings data takes into consideration species misidentification. Since 2000, the Norwegian landing statistics of redfish have been reported as *S. norvegicus* or *S. mentella*. Landings are regularly reported outside of the species distribution range, highlighting the difficulty of identifying these species correctly. Therefore, the species composition of the landings is checked and, if necessary, revised.

For *S. mentella* this is not considered a serious source of bias as the *S. mentella* stock is several orders of magnitude larger than the *S. norvegicus* stock in subareas 1 and 2.

3.6.1.3 Step 3. Norwegian landings in numbers-at-age-and-length

The Institute of Marine Research has long used a program scripted in SAS, in IMR named “the SAS Biomass program”, to calculate landings in numbers-at-age-and-length after matching national landings with all available samples in IMR’s database. In the coming years it will be replaced by the IMR’s new “Estimating Catch-at-Age (ECA) model. ECA is a model tool scripted in R, developed by the Norwegian Computing Center in cooperation with IMR.

3.6.1.4 Step 4. International landing statistics

Making the final tables of international landings for beaked redfish (*Sebastes mentella*) and golden redfish (*Sebastes norvegicus*) in ICES subareas 1 and 2 requires complex collation of data from many different sources and formats. Often the different data sources give different estimates of catches by nations, and landings reported as *Sebastes* spp. needs to be allocated to species level.

3.6.2 Surveys

3.6.2.1 Research surveys

Information on abundance and biological parameters of *S. norvegicus* is available from seven surveys.

Barents Sea winter survey: BS-NoRu-Q1 (BTr)

The survey is a trawl and acoustic survey and only the trawl data is used for deriving indices of abundance-at-age and –length for both *S. mentella* and *S. norvegicus*. Abundance indices are calculated following a swept area estimate method. Until recently, the calculations were performed using "the IMR SAS Survey program". The newly implemented StoX method is now in use for deriving the numbers-at-length for both redfish species in the Winter survey and the details of the method can be found in Mehl *et al*. (2016). StoX has not yet been implemented for estimating abundance-at-age and output from the SAS survey program are therefore still used for both numbers-at-length and -age.

Numbers-at-age for *S. norvegicus* for the period 1990 – present and for age groups 1 – 36+, but with the two first years set equal to 1992. Age readings are not yet available for 2017. Numbers-at-length for *S. norvegicus* for the period 1990 – present and for length groups 2 – 58+ cm, by 2 cm length class.

Barents Sea Ecosystem Survey: *Eco-NoRu-Q3 (BTr)*

The joint autumn ecosystem survey of the Barents Sea started in 2003 by combining five previous surveys into a single investigation. Combining the surveys enabled the whole ice-free Barents Sea to be covered by oceanographic, acoustic, pelagic trawl and demersal trawl investigations. Investigations on plankton, seabirds, marine mammals, marine pollution and benthos have also been carried out, but with various degrees of coverage. The survey is carried out in August and September each year.

The survey provides swept area abundance estimates for *S. mentella* and *S. norvegicus* in the Barents Sea during summer. In addition, the 0-group component of the survey is used to estimate the abundance of 0-group redfish for the two species combined.

Indices from the Ecosystem survey is currently not used in the assessment model for *S. norvegicus*, as the Winter survey time series is much longer and is considered to cover the main distribution area for the species. The potential use of the Ecosystem survey, covering a wider geographical area, should be investigated in the future.

Barents Sea Russian groundfish survey*: RU- Q4 (BTr)* :

This survey is conducted from late-October to late-December. Its total duration is 40 – 50 days. Depths are surveyed from 50 to 900 m. The survey is performed by 2 or 3 vessels simultaneously. Sampling gear is a bottom trawl.

Indices from the survey are not used in the assessment model for *S. norvegicus*.

Norwegian Coastal and fjord survey: *NOcoast-Aco-Q4*

The Norwegian Coastal and fjord survey is an acoustic survey designed to obtain indices of abundance and estimates of length and weight at age of saithe and coastal cod north of 62°N. It has been carried out annually in October-November, since 1985 for saithe and since 1995 for coastal cod. Redfish species are sampled as bycatch from the survey and the data has been used to derive abundance indices.

Length distributions from the survey were at this meeting used in the assessment model for *S. norvegicus* for the first time. Abundance indices are too noisy to be useful, but length distributions show a consistent pattern between years.

Barents Sea 0-group survey: Eco-NoRu-Q3

The Barents Sea 0-group survey has been conducted since 1965. Since 2003 the 0-group survey has been a part of the Barents Sea Ecosystem Survey (see above). The survey is carried out annually during August-September.

The survey is used to derive estimates of abundance of 0-group juveniles in the Barents Sea from several commercial species, including redfish. Young-of-the-year redfish cannot be taxonomically identified down to the species level and the 0-group indices are available for *Sebastes spp*.

Indices from the survey are not used in the assessment model for *S. norvegicus*.

Norwegian northern autumn and southern spring slope surveys (NO-GH-Btr-Q3/no ICES acronym)

The Norwegian slope surveys in autumn (northern part) and spring (southern part) are combined trawl and acoustic surveys conducted alternatively and biennially along the continental slope in the Norwegian Sea. The southern spring slope survey covers the latitudinal range 62°–74°N and is conducted during spring, when adult redfishes of both species concentrate along the slope for larval extrusion. The northern autumn slope survey covers the latitudinal range 68°–8°0N and is conducted in late summer and autumn when beaked redfish adults migrate back from summer migrations in the Norwegian Sea towards the slope. The southern spring slope survey was conducted in 2012, 2014 and 2016 while the northern autumn slope survey was conducted in 2011, 2013, 2015 and 2017.

Indices from the surveys are not used in the assessment model for *S. norvegicus*. The potential use of the southern spring slope survey should be investigated in the future.

3.6.2.2 Catch and effort series

No new information was presented at the benchmark meeting.

3.6.3 Weights, growth, maturity, natural mortality

3.6.3.1 Weights and growth

No new information was presented at the benchmark meeting.

3.6.3.2 Maturity

No new information was presented at the benchmark meeting.

3.6.3.3 Natural mortality

Natural mortality is set within the model at 0.05 for all ages, following the discussions in the previous benchmark (ICES, 2012). Experiments profiling the likelihood surface for different values of M revealed very little contrast, indicating that the model does not have enough information to estimate M internally. As noted in Section 2.4.1.2 there is a possibility that cod predation imposes a large and variable mortality on the younger redfish (both *S. mentella* and *S. norvegicus*). This is not accounted for in the model, and including it would not influence the estimation of mature/fishable biomass, rather it would change the estimates of recruitment and numbers at the youngest ages.

This would be useful for future investigations of a possible SSB-recruitment relationship, and potentially for investigating the previously noted trend (ICES, 2016) to revise down signals of recruitment.

3.6.4 Assessment models

The assessment model proposed by the WG is a modification of the existing Gadget model used for this stock (ICES, 2012). A longer description of the model, together with justification for the chosen model structure, is in WD3.

The model is a single-stock, single-area model with an annual time step, length range 1–80 cm+ in 1 cm size categories, age range 3–30+, which runs from 1986 to 2017. However, there is limited tuning data prior to 1990, so the period 1986–1989 is treated as a burn in period. The estimates a constant Von Bertanlanffy growth curve (estimates are Linf = 72.66 cm, K = 0.05)

Two surveys are used for tuning: the winter survey (**BS-NoRu-Q1,** annual survey index, 1 cm length distributions and age-length keys length categories) and the coastal survey (**NOcoast-Aco-Q4**, only 1cm length distributions). Neither of these gives good coverage of the larger fish, and thus the larger fish are only covered by the commercial catches. The modelled fleets are gilfleet, trawl (including the very minor handline catches) and longline. However, for practical reasons, the trawl and longline fleets are combined into a single fleet (trawl and longline) prior to 2009. Annual catches are considered exact, and each fleet has length distributions (in 1 cm categories from 1986) and age length data (from 2005, 5 cm length categories). Natural mortality is fixed at M = 0.05 (following the work at the previous benchmark; ICES, 2012), but see WD3 for sensitivity tests on this. All fleets are modelled with asymmetric dome-shaped selectivity (in length), except for the longline fleet which has logistic selectivity (this is fleet that catches the largest fish, and ensures that all fish within the model are targeted by at least one fleet). Tuning datasets are weighted with an iterative approach ensuring that each dataset has approximately equal contribution to the final likelihood (misfit) score, except that the fleets which run 1986–2008 (combined trawl and longline) and 2009–2017 (trawl, longline) get half weights compared to the gilfleet (which runs from 1986 to 2017). Maturity data is taken from Norwegian commercial and survey data, and the model is tuned using a fit through the raw data (to avoid overfitting the very few data points on the oldest fish).

Dataset name	Description	Time range
lon.alkeys	Age length keys in longline fleet	2009–2017
lon.ldist	Length distribution in longline fleet	2009–2017
trawl.lon.alkeys	Age length keys in combined trawl and longline fleet	2005–2008
trawl.lon.ldist	Length distribution in combined trawl and longline fleet	1986–2008
trawl.alkeys	Age length keys in trawl fleet	2009–2017
trawl.ldist	Length distribution in trawl fleet	2009–2017

gil.alkeys	Age length keys in gill fleet	2005–2017
gil.ldist	Length distribution in gill fleet	1986–2017
alkeys_survey	Age length keys in winter survey	1990–2017
ldist_wintersur	Length distribution in winter survey	1990–2017
si_wintersur	Aggegate survey index in wintersur-vey	1990–2017
mature_at_age	Mature at age data, from Norwegian commercial and survey data	1986–2017
ldist_cstsur	Length distribution in longline	1998–2016

Table 2. tuning data in the assessment model

Results are shown in Figure 12. Fits to the data are described in WD3. The model confirms the previous trend of declining stock biomass since the early 1990s. The previously identified 2003 year class is now entering the fishery, and stabilizing and beginning to reverse the downward trend. SSB in 2017 is estimated (based on the provisional data employed here) at 21 000 tonnes. In the previous assessment model (ICES, 2016), there was a tendency for the model to consistently revise the SSB upwards each year. In comparison, the retrospective patterns in the present model are relatively unproblematic. There is tendency for the model to have over predicted the extent of the stock decline, which was revised upwards when data showing a slight upswing entered the model. In addition there is a continued trend to revise initial estimates of recruitment down over time until such time as the year class has entered the fishery and stabilized.

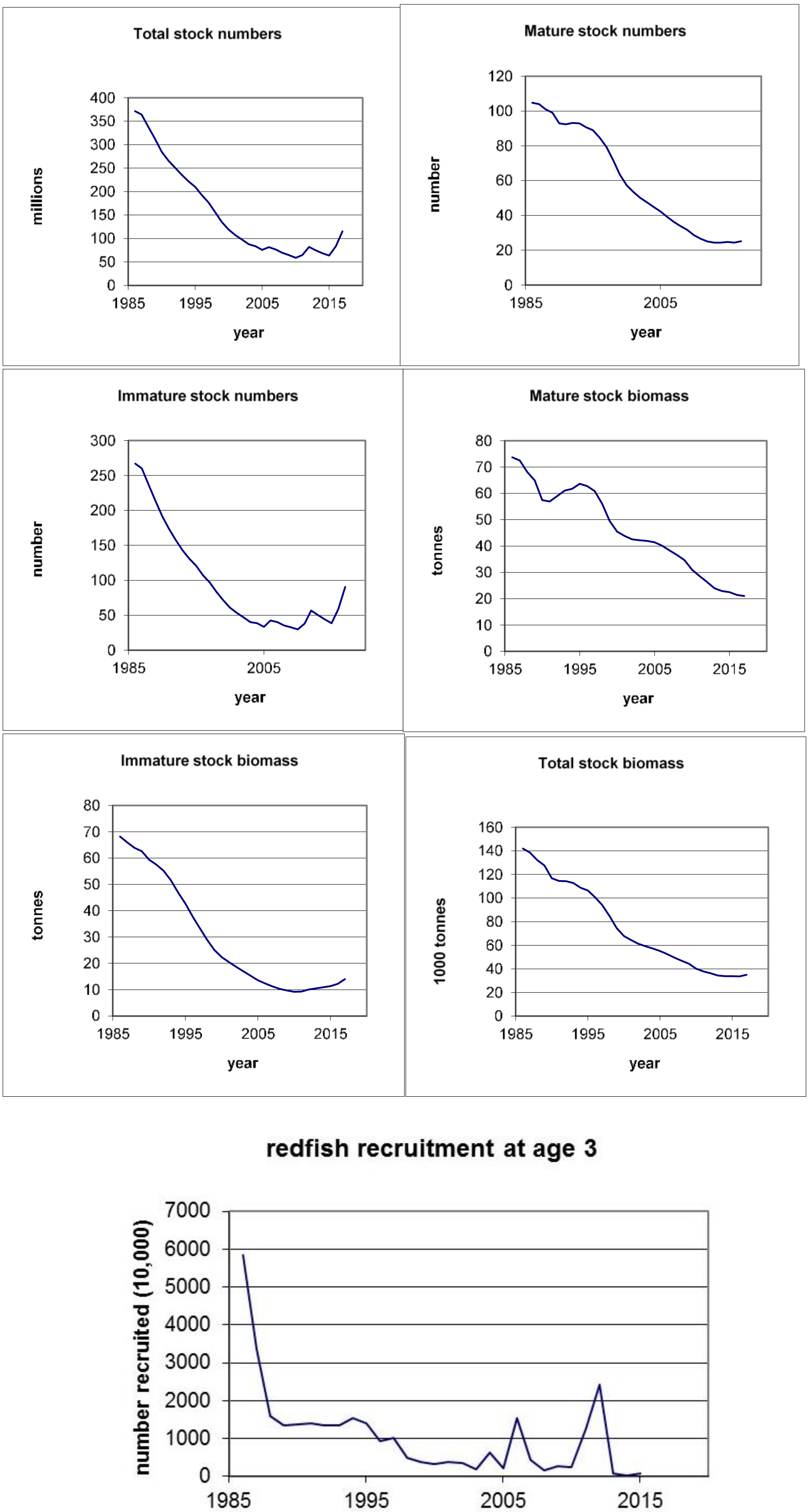

Figure 12. Modelled stock trends for *S. norvegicus*. Note that the model described here has been run using preliminary data for 2017. This will be updated prior to the 2018 AFWG, and thus the final point in the results shown here should be treated as provisional.

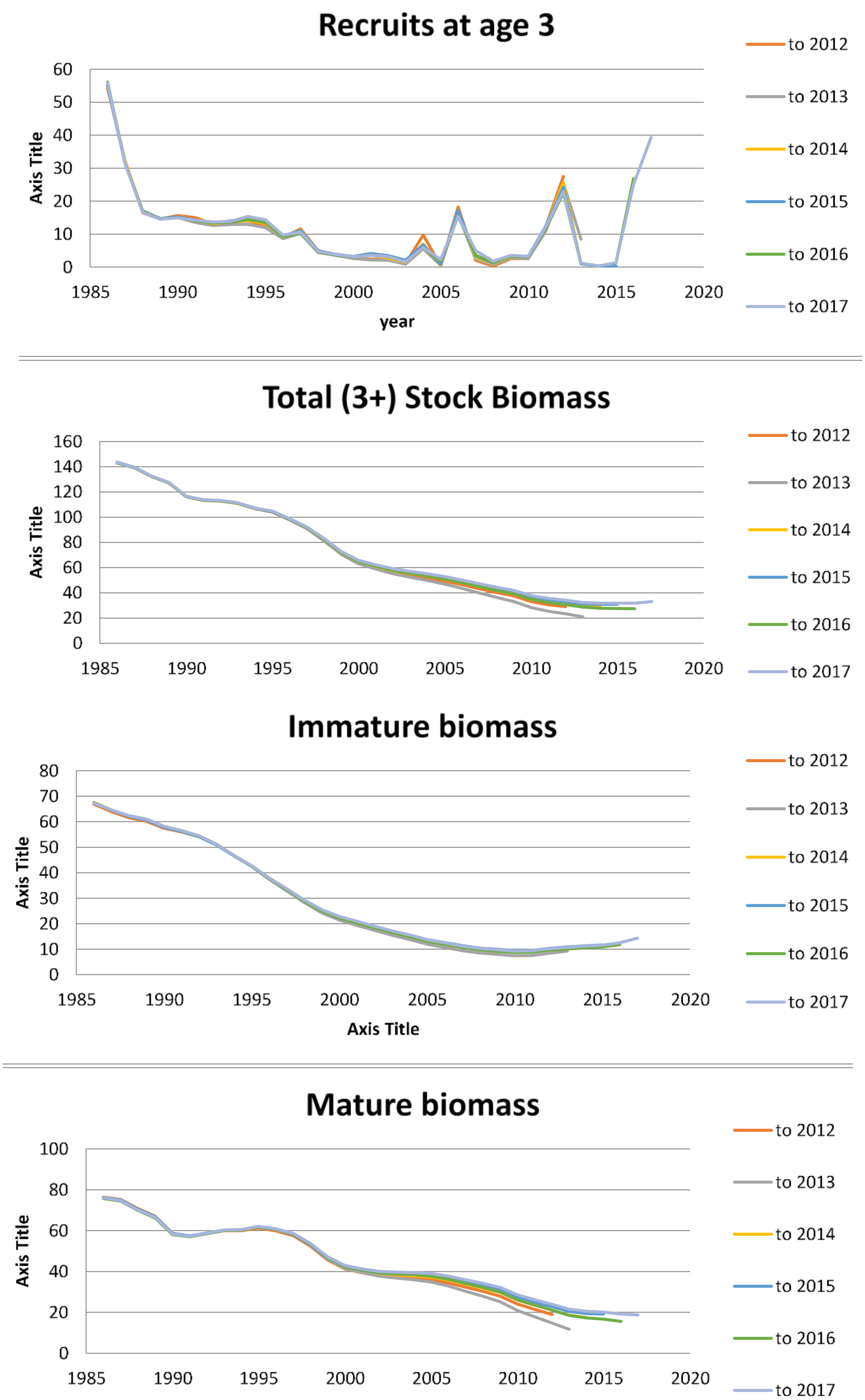

Figure 13. Retrospective trends 2012 to 2017, recruitment at age 3, total (3+) stock biomass, immature biomass and mature biomass.

3.6.5 Reference points prior to benchmark

No reference points were defined for this stock. Given the ongoing decline in the assessed SSB, and the absence of recent confirmed good recruitment, the stock was considered to be in a poor state, but no explicit reference points were calculated. It was considered that calculating these would be difficult and uncertain, given the uncertainty around the recruitment signals at the time, and not required given the collapsed nature of the stock.

3.6.6 Stock-recruitment relationship and new B_{lim} and B_{pa} reference points

No stock-recruitment relationship is presented for this stock. Within the model, recruitment is modelled as an annual recruitment value with no relationship to the SSB.

Given this, the biomass limit reference point is based on the Lowest Observed Stock Size at which reasonable recruitment was observed. This is the 2003 year class, at which time the SSB is estimated to be 44 000 tonnes. Note that there is a possible good year class in 2009 (corresponding to a SSB of 37 000 tonnes), but these fish have not yet entered the fishery, and the 2009 year class is thus considered uncertain, and is not used for the limit reference point. Using the ICES default multiplier of 1.4 for Bpa gives a Bpa value of 61 600 tonnes (the 2009 year class would give a provisional value of 51 800 tonnes).

3.6.7 Methods and settings used to determine ranges for F_{MSY}

The stock is currently well below the biomass limit reference point, and thus F_{MSY} is not recommended as the current fishing level. However, it was considered useful to try and estimate a F reference point, which can be used to compare against management performance.

Forecast runs were made to calculate the expected yield per recruit, and hence compute F reference points for this stock. All results here are quoted averaged over the 15+ age range, which approximates to the fishable biomass. Note that the is changed from the previous F range of 12-19, which is considered unsuitable given the increased importance of the oldest fish in the catches in the last decade. There is no Stock-Recruit relationship in the model, and hence the forecasts were made with a constant value for recruitment. The right-hand side of figure is therefore over-optimistic, since it does not account for a decline due to reduced recruitment at lower SSBs.

The analysis assumes that the selectivity of the different fleet components will remain unchanged, and the split of catches between the fleets will also remain unchanged. The split of catch between the fleets was based on the average split in 2014–2016 (the most recent years with reliable data), and is trawl 50%, gillnet 28% and longline 22%. If there is a change in these proportions this would equate to a selectivity change, which would alter the results presented here. The analysis is also based on a constant future recruitment pattern – in reality, appropriate F levels would be higher in a period of good recruitment and lower during periods of poor recruitment. Note that this value is also dependent on the choice of M in the model, a higher M would be expected to give a higher productivity and hence higher F reference points.

The results suggest $F_{0.1}$(15+) is estimated to be 0.0525, and F_{max} to be 0.08 (with the previously noted caveat about dependence on choice of M).

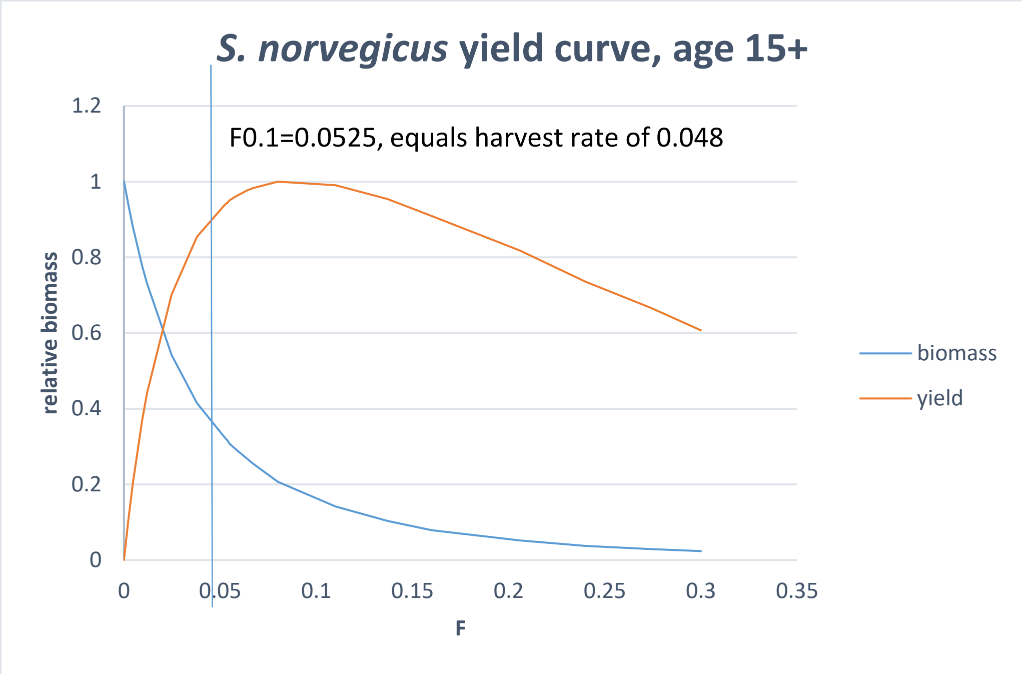

Figure 14. Yield per recruit analysis from the Gadget assessment model

3.6.8 Final Eqsim run

No Eqsim was conducted.

3.6.9 Sensitivity runs

3.6.10 Proposed MSY reference points

3.7 Future research and data requirements

Improved age data would be of great benefit for this stock, given the apparent noise in the current data. Of even greater benefit would be a survey index that covered the mature portion of the stock.

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Annex 1: List of participants

NAME	ADDRESS	EMAIL
Alf Harbitz	Institute of Marine Research NO-9294 Tromsø Norway	alf.harbitz@hi.no
Ana Leocádio	European Commission Directorate for Maritime Affairs and Fisheries B-1049 Brussels Belgium	ana.leocadio@ec.europa.eu
Anatolii Filin	Knipovich Polar Research Institute of Marine Fisheries and Oceanography(PINRO) Russian Federation	filin@pinro.ru
Benjamin Planque	Institute of Marine Research NO-9294 Tromsø Norway	benjamin.planque@hi.no
Bjarte Bogstad	Institute of Marine Research NO-5817 Bergen Norway	bjarte.bogstad@hi.no
Brian Linton	Northeast Fisheries Science Center 02543 Massachusetts USA	brian.linton@noaa.gov
Daniel Howell	Institute of Marine Research NO-5817 Bergen Norway	daniel.howell@hi.no
David Miller	International Council for the Exploration of the Sea (ICES) Denmark	david.miller@ices.dk
Gjert Endre Dingsør	Norwegian Fishermen's Association NO-7462 Trondheim Norway	gjert@fiskebat.no
Gudmundur Thordarson	Marine and Freshwater Research Institute. Reykjavík Iceland	gudmundur.thordarson@hafogvatn.is
Guro Gjelsvik	Fiskeridirektoratet Strandgaten 229 NO-5804 Bergen Norway	Guro.Gjelsvik@fiskeridir.no
Hannes Höffle	Institute of Marine Research NO-5817 Bergen Norway	hannes.hoffle@hi.no
Kjell Nedreaas	Institute of Marine Research NO-5817 Bergen Norway	kjell.nedreaas@hi.no
Martin Pastoors	Pelagic Freezer-Trawler Association 2280 AB Rijswijk Netherlands	mpastoors@pelagicfish.eu
Michel Bertignac	Ifremer Centre de Brest France	Michel.Bertignac@ifremer.fr
Paul Spencer (External Chair)	National Oceanic and Atmospheric Administration (NOAA) Alaska Fisheries Science Center Washington USA	Paul.Spencer@noaa.gov

NAME	ADDRESS	EMAIL
Sarah Millar	International Council for the Exploration of the Sea (ICES) Denmark	sarah-louise.millar@ices.dk
Tone Vollen	Institute of Marine Research NO-5817 Bergen Norway	tone.vollen@hi.no
Tor Arne Øigård	Norwegian computing Center PO Box 114 - 0314 Oslo Norway	oigard@nr.no
Yuri A. Kovalev	Knipovich Polar Research Institute of Marine Fisheries and Oceanography(PINRO) Russian Federation	kovalev@pinro.ru

Annex 2: Natural mortality estimates for *S. mentella*

Table 1: Natural Mortality (M) calculated as either point value applicable across the species lifespan or as mean over a range of ages, lengths, weights or life stages. Where the method is based on a specific taxon, group of taxa or a specific area, this is given under remarks as are assumed additional input values. Abbreviations: T_{max} = Maximum observed age, t_c = Minimum age considered, n_e = Sample size, Temp = Temperature, P = Proportion of fish surviving to T_{max}.

Estimator	Reference	M	Point/ Mean	Remarks
Alagaraja's	(Alagaraja, 1984)	0.034	Point	
Alverson & Carney's	(Alverson and Carney, 1975)	0.054	Point	
Bayliff's	(Bayliff, 1967)	0.085	Point	Engraulidae
Charnov's	(Charnov *et al.*, 2013)	0.047	Mean (weight)	
Charnov & Berrigan's	(Charnov and Berrigan 1990)	0.200	Point	
Chen & Watanabe's	(Chen and Watanabe, 1989)	0.052	Mean (age)	
Cubillos'	(Cubillos *et al.*, 1999)	0.079	Point	Chilenian Hake
Djabali's	(Djabali *et al.*, 1993)	0.132	Point	Mediterranean fish
Frisk's	(Frisk *et al.*, 2001)	0.116	Point	Elasmobranches
Gislason's 1st	(Gislason *et al.*, 2010)	0.045	Mean (length)	
Gislason's 2nd	(Gislason *et al.*, 2010)	0.049	Mean (length)	
Griffiths & Harrod's	(Griffiths and Harrod, 2007)	0.223	Mean (pelagic & demersal)	
Groeneveld's	(Groeneveld, 2000)	0.203	Point	Spiny lobster
Hamel's 1st	(Hamel, 2014)	0.072	Point	
Hamel's 2nd	(Hamel, 2014)	0.075	Point	
Hamel's 3rd	(Hamel, 2014)	0.055	Point	
Hoenig's	(Hoenig, 1983)	0.052	Point	
Jennings & Dulvy's	(Jennings and Dulvy, 2008)	0.585	Point	
Jensen's 1st	(Jensen, 1996)	0.150	Point	
Jensen's 2nd	(Jensen, 1996)	0.065	Point	
Jensen's 3rd	(Jensen, 2001)	0.259	Point	
Kenchington's	(Kenchington, 2014)	0.066	Point (calculated iteratively)	T_{max} = 75, t_c = 12, n_e = 500
Lorenzen's	(Lorenzen, 1996)	0.429	Mean (weight)	
Pauly's 1st	(Pauly, 1980)	0.092	Point	Temp = 5 °C
Peterson & Wroblewski's	(Peterson and Wroblewski, 1984)	0.355	Mean (weight)	
Ralston's 1st arithmetric	(Ralston, 1987)	0.107	Point	Snappers and Groupers
Ralston's 1st geometric	(Ralston, 1987)	0.042	Point	Snappers and Groupers
Ralston's 2nd	(Pauly and Binohlan, 1996)	-0.042	Point	Snappers and Groupers
Rikhter & Efanov's 1st	(Rikhter and Efanov, 1976)	0.057	Point	

Rikhter & Efanov's 2nd	(Rikhter and Efanov, 1976)	0.116	Point	
Roff's 1st	(Roff, 1984)	0.213	Point	
Roff's 2nd	(Roff, 1984)	0.054	Point	
Sekharan's	(Sekharan, 1974)	0.060	Point	Indian Oil Sardine
Tanaka's	(Tanaka, 1960)	0.040	Point	P = 0.05
Then's 1st	(Then *et al.*, 2014)	0.094	Point	
Then's 2nd	(Then *et al.*, 2014)	0.068	Point	
Then's 3rd	(Then *et al.*, 2014)	0.071	Point	
Ursin's	(Ursin, 1967)	0.097	Point	
Zhang & Megrey's	(Zhang and Megrey, 2006)	0.080	Mean (pelagic & demersal)	

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Annex 3: Comments from external reviewers

A panel of three external experts reviewed the *S. mentella* and *S. norvegicus* assessments: Paul Spencer, US (External Chair), Brian Linton, US, and Michel Bertignac, France. The external experts recognize the substantial work done by the assessment analysts and others to prepare the assessments that were presented at the benchmark workshop. For each assessment, we comment on the short term work that was done during the workshop to improve the assessments, and recommend long-term work to be completed after the workshop.

The panel considers the assessments appropriate for obtaining management advice. Additionally, appropriate biomass reference points were computed for each stock in a manner consistent with ICES guidelines.

Three issues common to the two assessments were identified at the workshop. First, there appears to be a general lack of age data in recent years. Age samples are collected, but resources are not available to process the samples. The *S. mentella* assessment is entirely dependent on age data, which, in recent years, is only provided by the Barents Sea Russian groundfish survey. The *S. norvegicus* assessment incorporates length data, but still requires the use of age-length key information to convert modeled ages to observed lengths. Therefore, we recommend that age samples from recent years be processed to improve the understanding of age structure for both species. Second, the workshop identified issues with uncertainty in age readings for older fish of both species. Therefore, we recommend that age error matrices be developed for both *S. mentella* and *S. norvegicus* for use in future assessments. Third, sensitivity of assessment results to different data weighting schemes in the negative log likelihood were not fully explored at the workshop. Therefore, w recommends that alternative weighting schemes be tested in the *S. mentella* and *S. norvegicus* assessment models for comparison purposes.

SEBASTES MENTELLA

Several issues associated with the assessment of beaked redfish (*Sebastes mentella*) in ICES areas 1 and 2 were investigated at WKREDFISH_2018. To address those issues, several modifications of the current statistical catch at age (SCA) model were presented to the review panel.

1) Data compilation

The procedures for data compilation is rather complex and would benefit from being standardized and automated. Furthermore, it appears that gaps in data are "filled" using observations from assumed similar gears, areas or time periods but that the process is rather cumbersome. However, statistical models such as the one used for beaked redfish allow for missing data, and we recommend that it would be better to limit as much as possible any data filling and use input data more directly related to observations rather than assumed similarities between gears, areas, and time periods. Currently, the model is directly fitted to catch and survey numbers at age matrices, which does not allow for such an approach. We recommend separating, in the fitting of the model, frequency data (in age and/or length) from the abundance and biomass data (i.e., survey indices and commercial catch in tonnes). This would also have the advantage of adding more control in the fitting procedure (i.e. more flexible weighting of the different data sources).

2) Inclusion of the Norwegian sea survey and right trapezoid population matrix

As little information on mature fish in comparison to juveniles is currently used in the assessment, an attempt to incorporate data from the Norwegian Sea survey which samples age groups above the current plus-group has been made. In the current version of the model, the plus group was set at age 19. To allow for the use of information provided by the Norwegian Sea survey, a right trapezoid population matrix has been developed which allows for an expansion of the population into older ages as more cohorts are recruited. As age determination for older fish is uncertain, a combination of age groups into blocks for age above 19 has also been carried out in the survey data and corresponding age blocks are used in the model to predict proportion at age. Furthermore, as the survey is not believed to produce estimates of abundance comparable between years, only the proportion at age are used to fit the model. The model fits the survey data reasonably well and that this provides a useful indication of the fact that the model with a 19+ group track fairly well the cohorts. It was found however that the addition of the survey does not significantly affect the model fit and output.

3) Autoregressive process in recruitment and fishing mortality

In order to reduce the number of parameters to estimate, a stochastic process has been implemented in which the annual estimates of age 2 recruitment and the fully-selected fishing mortality are modeled as random effects that follow an autoregressive model. These new features provide very similar results in terms of fits and model outputs, and should be retained as it reduces the number of parameters to be estimated without impairing the way the model fits the data.

4) Selectivity of the demersal fishery.

As it is believed that the selectivity of the demersal fishery may have changed over time (around 2014) because of changes in the national and international fisheries and associated regulations, it was proposed to implement an autoregressive model on that selectivity allowing for year to year variations. It was found that the inclusion of such flexibility in the model has led to an important improvement in model fits (the largest improvement among all alternative fits tested during the benchmark) and we agrees that this autoregressive process be included in the new model implementation.

5) Survey catchability and selectivity

The catchability (scaling) coefficients of surveys (q) cannot be estimated reliably for all surveys and at least one catchability coefficient needs to be set at a given value. This was already noted during the last benchmark in 2012 and led to setting the value of the ecosystem survey. The current value is based on sampling considerations, survey results and comparisons with the output of another assessment models. This year, another attempt was made to estimate this coefficient, which led to the same conclusions. A likelihood profile with a series of q values was produced. It shows that the model fits with lower values of q are not significantly different from the fits with q set at its 2012 value while values of q above 0.001 lead to significantly poorer fits. We considers that keeping the q value at its current level is a reasonable option. However, it would be advisable to reconsider on a regular basis the possibility to estimate this parameter as it affects the estimation of the size of the stock and the SSB. It must be noted that if, in future assessments, the value of q needed to be revised based on new available information or if q could be estimated, this could significantly affect the level of stock abundance and could have consequences on the level of biomass reference points.

Sensitivity runs were conducted dropping the Barents Sea Winter survey and Russian groundfish survey from the assessment, one at a time. We recommend that an additional sensitivity run be conducted, where the Barents Sea Ecosystem survey is dropped from the assessment. This sensitivity run would provide additional insight into model dynamics, and the influence of the different surveys on the model results. Catchability for one of the remaining surveys would need to be fixed for this analysis, which would require an external estimate of catchability for either the winter or Russian groundfish survey.

The assessment model currently assumes time-invariant selectivity for the three surveys. These selectivity curves represent both vulnerability and availability of fish to the gear. If redfish movement into and out of the surveys areas has changed over time, then fish availability and the resulting selectivity curves also may have changed. Therefore, we recommend that time-varying survey selectivity curves be explored in the *S. mentella* model.

6) Natural mortality, weight at age and age data

Values for natural mortality (*M*) were also considered during the workshop. This parameter is poorly known and a fixed value derived from a life-history analysis based on longevity has been set and accepted during the previous benchmark workshop held in 2012. This year, estimates of *M* made during the workshop very uncertain with very large confidence intervals. A likelihood profile analysis confirmed the difficulty to estimate that parameter and setting *M* at current value seems a reasonable option. The value of *M* has a strong impact on the model outputs and more particularly on the trend in biomass and SSB. Progress on this was made during the workshop using software for data-limited stocks that evaluate a series of external estimates of M based on life-history information, and this analysis indicated that a model of natural mortality estimates in the 0.05 to 0.10 range. However, we recommend conducting a more thorough review, carefully examining the methodologies and data underlying the various empirical estimates of *M*. In addition, we recommend that the results of this analysis be used to set a prior on the natural mortality parameter to attempt to estimate it within the SCA model.

Additionally, it seems that it would be reasonable to consider that *M* is not constant over age groups. For example, the predation of juvenile redfish by cod was discussed at the workshop. We recommend that methods be explored for incorporating the estimates of redfish consumption by cod presented at the Workshop (Bogstad 2018) into the SCA model. For example, cod predation could be modeled like a fishery, where an estimate of cod abundance could be used as a measure of cod "effort" targeting redfish (Spencer *et al.*, 2016).

Weight at age for all ages appeared to be relatively flat over time, apart from the first two years of the time series, when redfish ages were first estimated. Therefore, we recommend that time-invariant weight at age be used across all years, to reduce annual fluctuations in spawning stock biomass due to noise in the weight at age for the plus group. A time-invariant weight at age was evaluated in the previous *S. mentella* assessment, and was found to produce similar results to the model using time-varying weight at age. If the current assessment model results are found to be robust to the temporal assumptions regarding weight at age, then we recommend that the more parsimonious time-invariant weight at age model become the base model for *S. mentella*.

The lack of age data in the most recent years of the assessment was discussed at the workshop. If this issue persists, then we recommend that length data be incorporated directly into the assessment, to provide information on the current stock structure.

Length data could be incorporated by 1) modifying the existing SCA model to utilize length data (via data on length at age), or 2) migrating the *S. mentella* assessment to an off-the-shelf modeling platform that already utilizes length data.

7) Biological reference points

The stock–recruit scatterplot shows no clear evidence of relationship between recruitment and spawning stock biomass and following ICES guidelines to define biological reference points, Blim could be approximated by the lowest observed SSB (324,000t). Furthermore, F0.1 is proposed as a proxy for F_{MSY}. While, at this stage, this approach is considered adequate, it is noted that ICES, in its guidelines for setting MSY reference points, recommends approaches based on simulated long-term yield with stochasticity. Additionally, the reference points Flim and Fpa were not calculated at the benchmark workshop, as the preferred method for these rates is also based on simulation analyses. It is expected that Fmsy, Flim, and Fpa will be obtained during ICES workshop on *S. mentella* management conducted later this year.

SEBASTES NORVEGICUS

The stock of *Sebastes norvegicus* is modeled with the GADGET (Globally applicable Area Disaggregated General Ecosystem Toolbox) software, which was originally introduced and accepted at the 2012 redfish benchmark workshop. A substantial number of improvements in the model were made during the 2018 benchmark workshop. The time step for the model was changed from quarterly to an annual time step, which simplified the model, reduced the run times, and reduced the amount of noise in the input data. In previous assessments, the longline and trawl fleets had previously been combined into a single fleet, but length composition data from this combined fleet in recent years were not being fit well by the model. In this benchmark review, these two fleets were separated (from present to 2009). The proportion of large fish in the 60+ length bin for the gillnet fleet has been increasing in recent years, so the length bin plus group was expanded to 80+ cm. Additionally, the age plus group in the model was increased from 30+ to 40+, which improved the modeling of cohorts in the plus group (the plus group in the data was unchanged). The previous assessments had fixed the survey catchability coefficient at 1, whereas in this benchmark it was estimated. Finally, one selectivity curve (the longline fleet) was modeled as asymptotic, which ensured that older fish were being modeled as observed in at least one data component. Previously, all fleets and the survey allowed dome-shaped selectivity, although the longline selectivity curve was estimated as asymptotic when natural mortality (*M*) was fixed at 0.05. However, in doing a profile across *M*, the longline selectivity was estimated as sharply dome-shaped, which resulted low selectivity, and a large "hidden" abundance, of large fish. The cumulative result of these changes was that the strong retrospective pattern observed in previous assessments (in which the biomass was revised upward in successive assessments) was substantially reduced, although it appear to remain to a lesser extent. We are appreciative of the responsiveness of the assessment team in addressing these issues.

A set of long-term research recommendations are shown below.

We recommend that alternative statistical catch at age models, outside of the GADGET modeling framework, be developed. This recommendation is consistent with the external reviewer comments from the 2012 benchmark workshop (WKRED 2012): "*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.*" Several aspects of standard stock assessment models are either not possible or inefficient in GADGET, including estimation of error bounds on estimated parameters or derived quantities, Bayesian estimation, modeling of random effects, and modeling of aging error. Additionally, GADGET has modeling features, such as tracking the size distributions with age groups, that seem more appropriate for modeling interactions between multiple species (the original intent of GADGET) rather than stock assessment. An argument for using GADGET was that it allowed use of length composition data. However, this is a common feature of statistical catch at age models.

The weight given to different years of composition data within a data type (i.e., a fishing fleet or survey) should reflect differences in sampling intensity (i.e., the number of fish or hauls sampled); in contrast, it appears that all years within a data type are weighted equally. More generally, the degree to which the sampling intensity of length and otolith data varied between years should be documented (this effort could build from the information presented in Working Document 1 on the preparation of landings data). Finally, efforts should be conducted to ensure that the sampling of length and/or age composition of a given fleet are spatially representative of the catch of the fleet. If the sampling is spatially disproportionate to the catch, using weighted age/length compositions (i.e., the relative composition is each area is computed, and an average across areas, weighted by the catches in each area, is obtained) is a potential option.

The method for weighting the likelihood components ensures that each likelihood component contributes approximately equally to the overall likelihood. However, the numerical value of a likelihood component is dependent on the number of data points in the likelihood component as well as the numerical scale of the data. We recommend consideration of the data weighting procedures presented in Francis (2011, 2017) , in which the data weighting is a function of how well the model is fitting the data relative to the variance parameters of the likelihood distribution functions.

More generally, the assessment model methodology should be more thoroughly documented, including table of the list of likelihood functions used, and the population and observation model equations, and the equations used in the weighting of the likelihood components.

We recommend consideration of adding the ecosystem survey to the assessment model, as this could potentially give an alternative view of the stock dynamics. The utility of this survey is contingent on the adequate species identification of *S. novegicus*, as a small proportion of *S. mentella* misidentified as *S. norvegicus* could have a large effect on the *S. norvegicus* model.

Genetic research has indicated that *S. norvegicus* consists of three different crypic species (Saha *et al.*, 2017). Genetic testing should be conducted in order to provide information on a variety of topics, including: 1) the relative species composition across spatial areas in the Norwegian and Barents Seas; 2) quantifying errors in species identification; and 3) the degree of connectivity between spatial areas. The size at older ages appears to be bimodal and suggestive of different growth curves, and it should be investigated whether these data correspond to different species. Additionally, movement between different stocks may help resolve a retrospective pattern in the model, in which there is upward revision of mature fish (although this retrospective pattern was substantially reduced following the modeling changes conducted during the benchmark workshop).

The trawl and longline catch catches should be separated for the entire data series; this was partially accomplished during the workshop by separating these fisheries back to

2009. The estimated selectivities for these two fleet are substantially different, with the longline fishery showing high selectivity for old fish whereas the trawl fleet selectivity for old fish is reduced (i.e., a dome-shaped selectivity curve). The differences between the two fleets could reflect differences in the areas fished. It was reported that a survey dedicated to *S. norvegicus* has been considered. We recommend such a survey, as it would help resolve the areas occupied by the older portion of the population.

The aging error for older specimens of *S. norvegicus* is substantial, and efforts should be made to refine the aging protocols. It was reported during the meeting that thin sectioning of otoliths provided improves ages relative to the break and burn method, and higher resolution microscopes are also being evaluated. Additionally, an ageing error quantifying the between-reader variation in read ages should be constructed, and could be used within an age-structured assessment in order to interpret age composition data.

The uncertainty of the catch estimates should be evaluated, particularly in light of the uncertainties in species identification and any potential differences in sampling intensity between years. In particular, it should be evaluated whether the uncertainty in estimated catch has varied between years.

1) Management reference points

As with S. mentella, the value of Fmsy obtained from the benchmark workshop was based on a yield-per-recruit analysis, whereas the preferred method for computing Fmsy (and also Flim and Fpa) is to use simulation analyses that incorporates stochasticity. Time constraints prevented these calculations during the benchmark workshop, which partially reflected that these simulations are not straightforward under the current GADGET model. We recommend conducting simulation modeling to compute values of Fmsy, Flim, and Fpa for *S norvegicus*.

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Annex 4: Special request on bycatch regulations for redfish in the shrimp fishery in ICES subareas 1 and 2

The bycatch of juvenile fish can be a major problem in fisheries with small meshed trawls, such as fisheries for shrimp, *(Pandalus borealis)*. A sorting grid that effectively removes most of the undersized fish has been developed for shrimp trawls and it is not legal to fish for shrimp in the Barents Sea without the use of this sorting grid. Apart from this, the existing catch-regulation of shrimp fishery in the Barents Sea is closure of shrimp fisheries on fishing-grounds, where the bycatch of juvenile fish exceeds the criteria for allowable bycatch in numbers per ton of shrimp set by The Joint Norwegian - Russian Fishery Commission (JNRFC). The intention of such regulations is to reduce bycatch mortality of juvenile fish to a level which does not impair recruitment to the fish stocks.

WD 5 presents a suggested and improved procedure for how to decide on appropriate criteria that should avoid impairing the recruitment for the fish species, and that also takes into account the effort in the shrimp fishery, and regarding redfish, the mixing of *S. mentella* and *S. norvegicus*.

The WKREDFISH_2018 discussed the proposed methodology for such estimations, and will suggest the following procedure to be followed:

Method to calculate bycatch

- **Input data**
    - data on redfish recruitment, age 2, taken from the last ICES assessment (conducted every 3rd year by the Arctic Fisheries WG)
    - total International (incl. Norway) shrimp (*Pandalus borealis*) landings from ICES 1 and 2 from areas outside 12 nm and excl. redfish-absent-areas in the Russian EEZ (tonnes). Anticipating same distribution of international fishery in ICES 1 as the Norwegian fishery, if not other information from Russia
    - proportion (for sizes less than 20 cm) of *S. norvegicus* over combined *Sebastes* in scientific research hauls performed with shrimp trawls beyond the 12nm zone and north of 71°30′N. This is currently being quality checked by genetic analyses of *Sebastes* specimens collected from commercial shrimp trawlers fishing on different fields

- **Assumptions**
    - Assuming that the bycatch in the shrimp fishery is indiscriminately targeting 1, 2 and 3-year-old redfish individuals
    - Assuming a natural mortality rate of 0.05 for age 2 years and older as in the AFWG.
    - Assuming a natural mortality of 0.2 for age 1. The background knowledge for setting the M for especially age 1 is not particular solid and needs further investigation
    - Assuming that the total bycatch of redfish in numbers can be predicted my multiplying the bycatch criterion (numbers redfish per ton shrimp landings) with total international shrimp landings (in tonnes) excl. redfish-absent-areas. See chapter below for more information
    - Assuming recruitment (age 1–3) for the advice years to be equal to the average (or minimum or maximum) recruitment for an agreed number of recent assessment years (se chapter below). The Result-example

below is based on minimum, average and maximum recruitment during the ten years period 2007–2016 according to AFWG 2017

- Assuming that the same portion of the total international shrimp catch is taken in the "redfish-absent-areas" in the 3 advice years as the average portion in the last 3 assessment years

- **Example results**

The redfish bycatch criterion should be precautionary for both *Sebastes* species.

Bycatch mortality (%) of *S. mentella* juveniles (age 1–3) with different shrimp catches and bycatch limits (individuals per ton shrimp catch):

- In case of **minimum** recruitment age 1–3 = 438 millions during 2007–2016 (AFWG 2017)

	Total international catch of shrimps (in tonnes)		
Bycatch	17 000	20 000	30 000
300	1%	1%	2%
1 000	4%	5%	7%
1 500	6%	7%	10%
2 000	8%	9%	14%
3 000	12%	14%	21%
5 000	19%	23%	34%
10 000	39%	46%	68%
20 000	78%	91%	137%

- In case of **average** recruitment age 1-3 = 873 millions during 2007-2016 (AFWG 2017)

	Total international catch of shrimps (in tonnes)		
Bycatch	17 000	20 000	30 000
300	1%	1%	1%
1 000	2%	2%	3%
1 500	3%	3%	5%
2 000	4%	5%	7%
3 000	6%	7%	10%
5 000	10%	11%	17%
10 000	19%	23%	34%
20 000	39%	46%	69%

- In case of **maximum** recruitment age 1-3 = 1536 millions during 2007-2016 (AFWG 2017)

	Total international catch of shrimps (in tonnes)		
Bycatch	17 000	20 000	30 000
300	0%	0%	1%
1 000	1%	1%	2%
1 500	2%	2%	3%
2 000	2%	3%	4%
3 000	3%	4%	6%
5 000	6%	7%	10%
10 000	11%	13%	20%
20 000	22%	26%	39%

Given the slow life history (slow growth and late maturity) of redfish, the mortality imposed by the shrimp fishery should not exceed the natural mortality of 0.05 (5%). The example above with e.g., average recruitment allows for a maximum bycatch of about 1500 individuals per ton of shrimp with an expected shrimp catch of 20000 tons, or about 1000 individuals with a shrimp catch of 30000 tons.

The given mortality percentages take into account that only a portion of the total international shrimp landings are taken in redfish areas. It is suggested that the tables should present bycatch mortality percentages for the shrimp landing alternatives 20000, 30000, 40000, 50000, 60000 and 70000 tons.

- **Procedure to test different periods of averaging recruitment for calculating bycatch level of redfish in shrimp fishery.**

Until the AFWG meeting in April 2018, different periods of averaging recruitment for calculating bycatch level of redfish in the shrimp fishery should be tested following this procedure:

1. The method to calculate bycatch criteria should be applied for different periods for averaging redfish recruitment (for last 3, 5, 10 years as an example).
2. The certain level of shrimp catch should be assumed (20, 30, 50, 70 kt or actual observed catches of shrimp in historical time series as an example), taking into account only the proportion of the shrimp catch taken in areas where redfish are found
3. For each combination of shrimp catch level and period of averaging of redfish recruitment) "the retro run" could be done assuming that by-catch criteria calculated for every third year in historical time series of *mentella* recruitments are available using average (for certain period) redfish R (from current *mentella* assessment).
4. Then it is assumed that calculated criteria will be applied for next 3 years and "actual-according-to-model" percentage could be calculated based on recruitments from *mentella* assessment.
5. A comparison of "actual-according-to-model" bycatch with the level corresponding to catching 5% of the age 1-3 *mentella* could be done as well as a comparison of "actual-according-to-model" bycatch with real redfish bycatch calculated and presented at AFWG-2017 report (Figure 01 in ICES 2017).
6. The period providing the best correspondence between assumption of the method (5%) and calculations from the "retro run" should be chosen for practical use.

The work could be done before AFWG 2018 and presented there.

The same procedure should be followed for *S. norvegicus*, and the recommended redfish bycatch criterion should be precautionary for both *Sebastes* species.

- **Estimation and prediction of annual total bycatch of redfish juveniles**

Since bycatch of juvenile fish in the shrimp fishery is not recorded in the fishermen catch logbooks, bycatch needs to be estimated. Total discard estimates of cod, haddock and redfish juveniles in the commercial shrimp fishery in the Barents Sea have regularly been estimated and presented at the ICES Arctic Fisheries WG (e.g., ICES 2017) for the years 1983-2015. This has been a simple ratio procedure assuming that the observed bycatch ratios from observers on board commercial shrimp trawlers and from surveys are representative for the commercial bycatch ratios. The estimates have then been produced by scaling the ratios with the total commercial shrimp catch. More recently a prediction procedure based on a Bayesian hierarchical spatio-temporal bycatch model developed using historical bycatch data for the years 1994-2016 has been used (Breivik *et al.*, 2017). This model-based approach is thereby able to provide good realistic bycatch predictions (with uncertainty) even in areas and time periods with few or no inspected trawl hauls.

Prediction of total bycatch of redfish in numbers may be estimated by multiplying the bycatch criterion (numbers redfish per ton shrimp landings) with total international shrimp landings in tons excl. redfish-absent-areas.

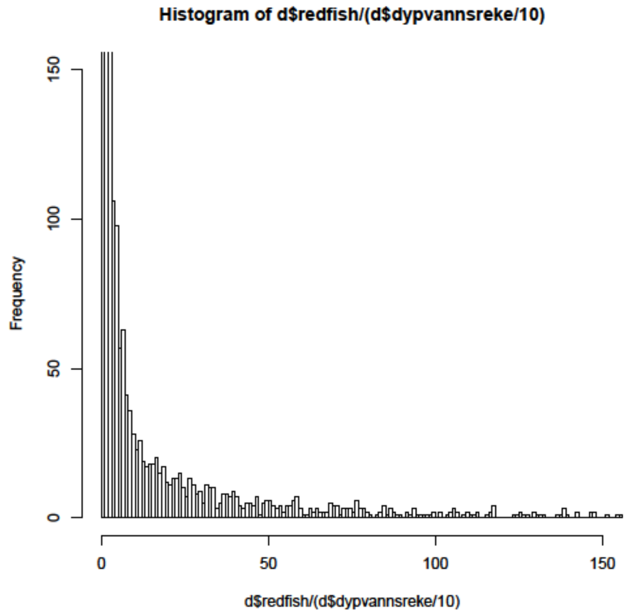

Figure: Distribution (number of hauls) of bycatch ratios (redfish individuals/10 kg shrimp). Data from Norwegian Surveillance Service in 2005–2015.

Estimates of redfish bycatch in 2014, 2015 and 2016 using the newly developed Bayesian hierarchical spatio-temporal bycatch model (Breivik *et al.*, 2017), amount to 278 specimens, 301 specimens and 1754 specimens, respectively, per ton shrimp catch (Table below). The reason for the high bycatch in 2016 may be explained by a delayed closure of problematic areas. One may argue that it is unlikely that the final bycatch per ton shrimp catch will be so close to the enforced criterion since so many shrimp hauls may contain zero or very small redfish bycatch, but Figure …. shows that we also have some hauls, although much fewer, with huge bycatch of redfish juveniles (up to 15 000 redfish per ton shrimp). WKREDFISH_2018 hence suggests predicting total bycatch of redfish in numbers by multiplying the bycatch criterion (numbers redfish per ton shrimp landings) with total international shrimp landings in tonnes excl. redfish-absent areas.

Table: Estimates of redfish bycatch in 2014, 2015 and 2016 using the Bayesian hierarchical spatio-temporal bycatch model. The corresponding shrimp catch, the bycatch rate and the agreed and enforced bycatch criteria are also shown.

	Bycatch (millions)	Shrimp catch (tons)	N per kg	N per 10 kg	N per ton	Agreed criterion per ton
2014	1.5	5390	0.28	3	278	300
2015	3.6	11947	0.30	3	301	300
2016	14.7	8379	1.75	18	1754	300

- **Monitoring of actual annual total bycatch and revision of the bycatch criterion**

In order to monitor the annual total bycatch of juvenile fish taken by the shrimp fishery it is of vital importance that observers are on board shrimp trawlers to collect data on bycatch to feed recent information into the model. In order to minimize the bycatch, the Norwegian and Russian surveillance services and coastguards must quickly close areas with bycatch-ratios above the agreed criteria.

In order to keep the mortality of the exposed redfish juveniles below agreed limits it is important that 0-group and juvenile surveys are annually and satisfactorily conducted. WKREDFISH_2018 suggests that the redfish bycatch criterion is revised every 3rd year in connection with the updated stock assessment, and recommends that the last year's 0-group index also been taken into account when the Joint Norwegian-Russian Fishery Commission sets the criterion for a new 3-year period.

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Annex 5: Working documents

WD1: Preparation of landings data

WD2: Scientific surveys

WD3: GADGET model for *S. norvegicus*

WD4: Statistical Catch_at_age model for *S. mentella*

WD5: Bycatch shrimp fishery

WD6: Cod consumption-redfish

WD7: Redfish consumption and recruitment.

Preparation of Norwegian and international landings data for beaked redfish (*Sebastes mentella*) and golden redfish (*Sebastes norvegicus*)

Working Document 1, ICES WKREDFISH Copenhagen 29 January – 2 February 2018

Tone Vollen and Kjell Nedreaas (Institute of Marine Research, Norway)

Norwegian landing statistics

The Norwegian national landings statistics are collected by the Norwegian Directorate of Fisheries, and are made available for the Institute of Marine Research at predefined dates throughout the year. The data used for the ICES AFWG are from the beginning of March the current year, and include preliminary data for the previous year and final data for earlier years.

The detailed landing statistics from the Directory of Fisheries are provided by vessel, gear, national statistical main- and sub-areas, gear and date, as well as other parameters. ICES division and/or sub-division may be extracted from national statistical areas (Figures 1 and 2). For our use, the data are summarized by national main area, quarter and gear groups. The nine gear groups used are; gillnet, longline, handline, purse seine, danish seine, shrimp trawl, demersal fish trawl, pelagic trawl and other gears.

The national landing statistics are precise with regards to quanta, but may contain errors on origin of the catches. The misidentification of *Sebastes* species is also a known issue. It is therefore necessary to manually check and correct the landings statistics.

Step 1. Harmonizing trawl catches with logbooks

The first step is correcting in which area the catches were taken. The fishery is often regulated through closed areas, highlighting the importance of having an accurate catch area resolution.

When landing, vessels should report the origin of their catches. This information is considered less accurate in space and time than entries in the vessel's logbook. Since 1986, the landing statistics from bottom trawlers has therefore been harmonized with logbooks by using the distribution of catches by area and quarter from logbooks and raising them to the total quantity from the landings statistics.

The harmonisation is done separately for beaked and golden redfish, and only for bottom trawlers, which holds most of the mixed fishery. Originally, paper logbooks needed to be digitized for daily catches per statistical sub-area. In 2010/2011, electronic logbooks (ERS) were introduced for all vessels over 15 m length, and the method could be considered for other gear groups as well.

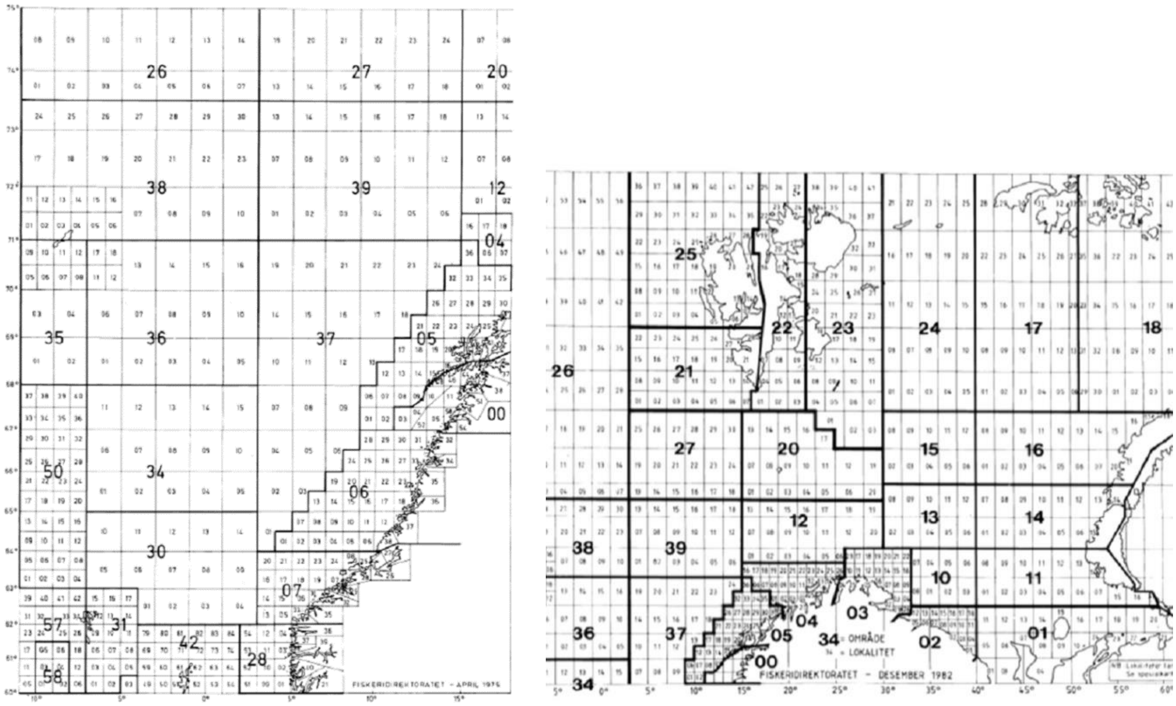

Figure 1. Norwegian statistical main- and sub-areas.

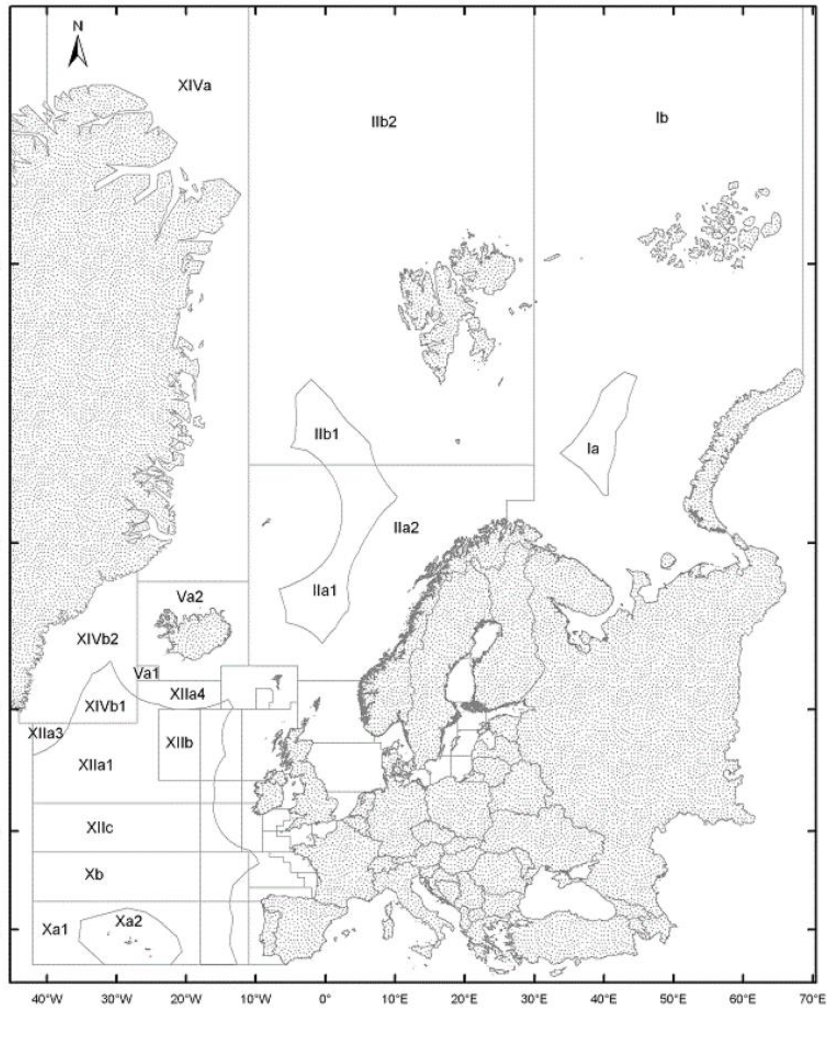

Figure 2. The ICES Statistical Areas delineates the divisions and subdivisions of FAO Major Fishing area 27.

Step 2. Species misidentification issues

The second step in the preparation of landings data takes into consideration species misidentification. Since 2000, the Norwegian landing statistics of redfish have been reported as *S. norvegicus* or *S. mentella*. Landings are regularly reported outside of the species distribution range, highlighting the difficulty of identifying these species correctly. Therefore, the species composition of the landings is checked and, if necessary, revised.

Species correction in bottom trawl landings

The species identification in bottom trawl landings is revised by summing landings of both species in a matrix by quarter and Norwegian statistical main area. An equivalent matrix with the proportion of *S. mentella* of each cell (here named “splitting ratios”) is then made. The matrix of splitting ratios used for 2016-landings for AFWG in 2017 is presented in Table 1. The splitting ratios for national main areas 3, 4, 5, 12 and 20 (the main fishing areas with mixed species) are revised every year from logbook data. The remaining ratios are constant between years and are only revised if there are changes in the fishery pattern or similar. They are originally based on area and depth.

For main areas 3, 4, 5, 12 and 20, the splitting ratio is calculated by multiplying logbook-catches for all sub-areas and quarters with an equivalent splitting-ratio matrix (Table 2). The numbers are then summed by species and quarter, providing a quarterly ratio for the main area. These five sub-area splitting ratio matrices do not change between years. They are based on sub-areas and depth.

For area 12 and 20, a second set of quarterly splitting ratios are made. These are the species ratios derived from reference fleet trawlers, expecting that they can separate the two species correctly. The decision on which ratios to use for area 12 and 20 is based on the quantity of data available. If both data-sources are poor, and ratios differ significantly from previous years’ values without any evident reason (such as changes in the fisheries), the previous year’s ratio may be used.

The method used for revising landings from bottom trawl needs to be checked from time to time as splitting ratios may change due to changes in the fishery or distributional changes of the redfish species. In the future this should be done by comparison with fishery-independent research survey data and by ensuring frequent training of the reference fleet crew.

Table 1. Splitting ratios for splitting landings of redfish from trawl. Red numbers (area 3, 4, 5, 12, and 20) are revised yearly.

MAIN AREA	Q1	Q2	Q3	Q4	MAIN AREA	Q1	Q2	Q3	Q4
1	0.500	0.500	0.500	0.500	7	0.000	0.000	0.000	0.000
2	0.500	0.500	0.500	0.500	30	1.000	1.000	1.000	1.000
3	0.614	0.019	0.006	0.139	34	1.000	1.000	1.000	1.000
10	0.500	0.500	0.500	0.500	35	1.000	1.000	1.000	1.000
11	0.500	0.500	0.500	0.500	36	1.000	1.000	1.000	1.000
13	0.500	0.500	0.500	0.500	37	0.990	0.990	0.990	0.990
14	0.500	0.500	0.500	0.500	38	1.000	1.000	1.000	1.000
15	0.500	0.500	0.500	0.500	39	1.000	1.000	1.000	1.000
16	0.500	0.500	0.500	0.500	50	1.000	1.000	1.000	1.000
17	1.000	1.000	1.000	1.000	20	1.000	0.991	0.794	0.999
18	1.000	1.000	1.000	1.000	21	1.000	1.000	1.000	1.000
24	1.000	1.000	1.000	1.000	22	1.000	1.000	1.000	1.000
4	0.660	0.624	0.237	0.170	23	1.000	1.000	1.000	1.000
12	0.607	0.990	0.830	0.362	25	1.000	1.000	1.000	1.000
0	0.000	0.000	0.000	0.000	26	1.000	1.000	1.000	1.000
5	0.842	0.702	0.483	0.880	27	1.000	1.000	1.000	1.000
6	0.000	0.000	0.000	0.000					

Table 2. Sub-area logbook ratios used for calculating splitting ratios for national main area 3,4,5,12 and 20. (For main areas 12 and 20, quarterly splitting ratios may be derived from the reference fleet trawlers, and the fixed splitting ratios in this table are then not used.)

Main area	Subarea	Proportion *S. mentella*
3	17-23	1
3	remaining subareas	0
4	6, 7, 16, 17	1
4	remaining subareas	0
5	6, 17, 27, 34	1
5	12	0.75
5	13, 18, 28, 35	0.50
5	remaining subareas	0
12	5, 6, 11, 12, 17, 20	0

12	remaining subareas	1
20	8	0
20	remaining subareas	1

Species correction in other gears

Normally, bottom trawl landings are a mix of the two species, pelagic trawl will catch only *S. mentella,* whereas other gears will primarily catch *S. norvegicus*. Revisions are done following the more detailed guidelines in Table 3.

Table 3. Rules for species reallocation of redfish landings.

Reported as	Gear	Comment	What is done
S. norvegicus	Gill nets	S. norvegicus	Keep as S. norvegicus
	Longline	S. norvegicus	Keep as S. norvegicus
	Pelagic trawl	Is S. mentella	Add to *S. mentella*, pelagic trawl
	Others	S. norvegicus	Keep as S. norvegicus
	Bottom trawl	Mix of S. norvegicus and S. mentella	Split based on area (depth), quarter and logbook information (1.3.1.)
S. mentella	Gill nets	Normally no *S. mentella*	Add to *S. norvegicus* gill nets
	Longline	S. mentella may occur	Keep as S. mentella
	Others	Normally no *S. mentella*	Add to *S. norvegicus* others
	Pelagic trawl	S. mentella	Keep as S. mentella
	Bottom trawl	Mix of S. norvegicus and S. mentella	Split based on area (depth), quarter and logbook information (1.3.1)

Norwegian landings in numbers-at-age-and-length

The Institute of Marine Research has long used a program scripted in SAS, in IMR named "the SAS biomass program", to calculate landings in numbers-at-age-and-length after matching national landings with all available samples in IMR's database. In the coming years it will be replaced by the IMR's new "Estimating Catch at Age (ECA) model. ECA is a model tool scripted in R, developed by the Norwegian Computing Center in cooperation with IMR. One feature that will simplify our work is the automatic matching of landings and samples (Table 4).

Figure 4. Example from ECA, showing the distribution of samples vs available samples. The data is for *S. norvegicus* in 2013. The table is a matrix of landings in tonnes by national main area groups (columns) and gear groups+quarters (rows). Numbers in red is the number of available samples (number of vessel sampling, number of stations/catches with age samples, number of stations/catches with length samples). The color code shows if there are sufficient samples (green), too few (yellow) or none (red). Grey cells have no landings.

Table 4. ECA test-run output for S. norvegicus, 2013.

age samples norvegicus 2013

Gear	Q '\' A	3	12	4	5	0	20	6
41	1	3.5 0, 0, 0	0 0, 0, 0	10.2 0, 0, 0	21.8 2, 5, 55	25 1, 1, 1	0 0, 0, 0	27.9 3, 11, 89
41	2	1 0, 0, 0	0 0, 0, 0	44.4 0, 0, 0	216.1 1, 1, 11	24.6 1, 1, 1	0 0, 0, 0	98.9 1, 9, 171
41	3	37.9 0, 0, 0	0 0, 0, 0	222.9 0, 0, 0	237.6 0, 0, 0	52 1, 2, 40	1.7 0, 0, 0	102.1 1, 8, 156
41	4	5.6 0, 0, 0	0 0, 0, 0	93.5 0, 0, 0	211.9 0, 0, 0	215.7 1, 16, 194	29.9 1, 4, 69	113.7 0, 0, 0
51	1	36.4 1, 1, 20	100.1 3, 4, 66	2 1, 2, 34	39.2 1, 1, 20	15.7 0, 0, 0	0 0, 0, 0	2.4 0, 0, 0
51	2	162.8 1, 2, 2	116.1 2, 5, 50	9.7 0, 0, 0	50.4 1, 1, 18	16.4 0, 0, 0	13.2 1, 2, 7	22.9 0, 0, 0
51	3	124 1, 6, 42	34.8 1, 1, 20	28.5 0, 0, 0	133 1, 1, 19	36.6 0, 0, 0	21.3 0, 0, 0	55.8 0, 0, 0
51	4	108.2 2, 3, 17	12.2 1, 1, 19	3.3 0, 0, 0	2.3 0, 0, 0	2.5 0, 0, 0	22.8 1, 4, 22	9.2 0, 0, 0
31	1	11.8 0, 0, 0	2.5 0, 0, 0	5.8 0, 0, 0	57.7 1, 1, 20	7.2 0, 0, 0	4.6 0, 0, 0	32.2 1, 1, 20
31	2	33 0, 0, 0	70.4 0, 0, 0	72.8 1, 1, 19	70.5 0, 0, 0	0.6 0, 0, 0	24.3 1, 1, 19	1 0, 0, 0
31	3	7.2 0, 0, 0	2.5 0, 0, 0	85.9 0, 0, 0	95.8 1, 1, 17	0 0, 0, 0	0 0, 0, 0	35.9 0, 0, 0
31	4	61.7 0, 0, 0	1.5 0, 0, 0	42 0, 0, 0	31.2 0, 0, 0	0 0, 0, 0	10.9 0, 0, 0	9 0, 0, 0
32	1	0 0, 0, 0	0 0, 0, 0	0 0, 0, 0	0 0, 0, 0	0 0, 0, 0	0 0, 0, 0	0 0, 0, 0
32	2	0 0, 0, 0	0 0, 0, 0	0 0, 0, 0	0 0, 0, 0	0 0, 0, 0	0 0, 0, 0	0 0, 0, 0
32	3	0 2, 9, 25	0 1, 4, 6	0 1, 4, 36	0 0, 0, 0	0 0, 0, 0	0 3, 19, 71	0 0, 0, 0
32	4	0 0, 0, 0	0 0, 0, 0	0 0, 0, 0	0 0, 0, 0	0 0, 0, 0	0 0, 0, 0	0 0, 0, 0

Total catch= 3757.7 #Boats sampled= 43
Sampled catch=2052(55)% #Serienr sampled= 133
Sampled catch required for DB estimation=1197.5(32)% #Fish sampled= 1376

IMR's "SAS biomass program"

The program is run separately for beaked and golden redfish.

Input data

Landings data: Corrected Norwegian landings (as prepared above). The landings are split by quarter, Norwegian statistical main area and gear nine groups (Gillnet, Longline, Handline, Seine, Danish seine, Bottom shrimp trawl, Bottom fish trawl, Pelagic trawl, Other gears)

Sample data: The biological samples come from surveys, port sampling, the Reference Fleet, the Directorate of fisheries' surveillance service, the Coast Guard, samples collected by national partners (e.g., Møre Research), and occasional samples from commercial pelagic catches. The samples are divided into three categories; (1) survey data, (2) port sampling data, and (3) data from on-board sampling (including the reference fleet), and split into quarter, Norwegian statistical main area and geargroup, in the same way as landings. In 2016, the institute collected a total of 1,641 age- and 11,414 length samples for *S. norvegicus.* For *S. mentella* the number of length samples collected in 2016 was 7138. Age reading of *S. mentella* has not been done yet for later years due to lack of otolith readers.

Length-weight relationship: an overall length-weight relationship calculated from all available biological samples the current year.

Allocation scheme: a list of which samples to use for each landing.

Allocation scheme

The allocation of samples to landings is done manually. Samples to use for length and age are specified independently. In practice, both landings and samples are listed by Norwegian statistical main area, gear group and quarter. The available samples are then allocated to landings following some basic guidelines, in prioritized order.

- Use samples from same gear, same area and same quarter,
- Use samples from same gear, same quarter, neighboring area or other area that is expected to be similar,
- Use samples from same gear, same area, neighboring quarter (NB! seasonal variation in growth, but is expected to be small in redfish),
- Use samples from gillnets for longline catches, or vice versa, from same area and quarter,
- If no appropriate samples are available, overall samples may be used.

Also, some guidelines on what not to do is provided:

- Do not use length samples from surveys unless they are known to be representative for landings. Age samples from surveys may in some cases be used,
- Do not use samples from areas closed for fishing,
- Do not use samples from gillnets or longlines for trawl catches, or vice versa,

Technical details

For a given landing with its corresponding allocated length samples, the numbers-at-length is calculated as follows: The mean weight of all individuals in the samples are calculated. Then, the total number of individuals landed is estimated (kg landed divided by mean individual weight of the samples). The total number of individuals in each length group in the catch is then calculated as the proportion of each length group multiplied by the total number in the landing. Finally, the total landed biomass of each length group is estimated by multiplying the number of fish landed in the length group by the mean weight of the length group. When there are no corresponding individual weights for a given length in the samples, the overall length-weight relationship is used.

The numbers-at-age is calculated for each landing using the age-length key of the allocated samples.

Output

The program outputs matrices of overall catch numbers-at-age-and-length by quarter as well as by area and gear group.

International landing statistics

Making the final tables of international landings for beaked redfish (*Sebastes mentella*) and golden redfish (*Sebastes norvegicus*) in ICES division 1 and 2 requires complex collation of data from many different sources and formats.

This document describes the preparation of the 2016 catch tables, prepared during AFWG 2017. Note that some details in the data preparation have been revised since AFWG 2017. The catch tables for earlier years have been made in a similar way, with the same methods and guidelines, but detailed reconstruction is not possible.

Data sources

Data are gathered from all the sources listed below. In addition, in case of obvious errors or missing data, the countries' representatives are contacted directly for supplementary information.

ICES official and preliminary statistics: ICES collects numbers on catches and landings from individual nations operating in EEZ and international waters. The statistics are aggregated annually and by ICES divisions/subdivisions.

InterCatch: ICES' InterCatch is a web-based system, to which fish stock coordinators and national data submitters from the North-East Atlantic can have access. In InterCatch national institutes can upload national fish catches per area per time period per fleet etc.

Data reported directly to the working group: Landings data that are revised or corrected compared to the ICES statistics.

NEAFC statistics: NEAFC provides monthly catches statistics from the fishery of *S. mentella* in international waters for the different regulatory areas under NEAFC jurisdiction. (Figure 2, ICES subdiv 2.a.1 and 2.b.1). It's recommended that NEAFC provide data from vessels reporting their logbook-catches at sea via their flag-state, but since 2015, this has unfortunately not been possible (see chapter 5 "Identifying pelagic catches of S. mentella in the NEAFC area").

Foreign vessels fishing in areas of Norwegian jurisdiction: When fishing in the Norwegian Economical Zone or Svalbard Fisheries Protection Zone (Figure 3), foreign vessels report their logbook catches to Norwegian authorities. However, Russia does not report fishing activity in the Svalbard Fisheries Protection Zone. They send COE/CAT (weekly catch)/COX and VMS when fishing in the territorial waters around Svalbard. Furthermore, UK and Ireland do not send VMS data from their fishing in the protection zone, but they report their catches electronically, ie, COE/DCA/COX.

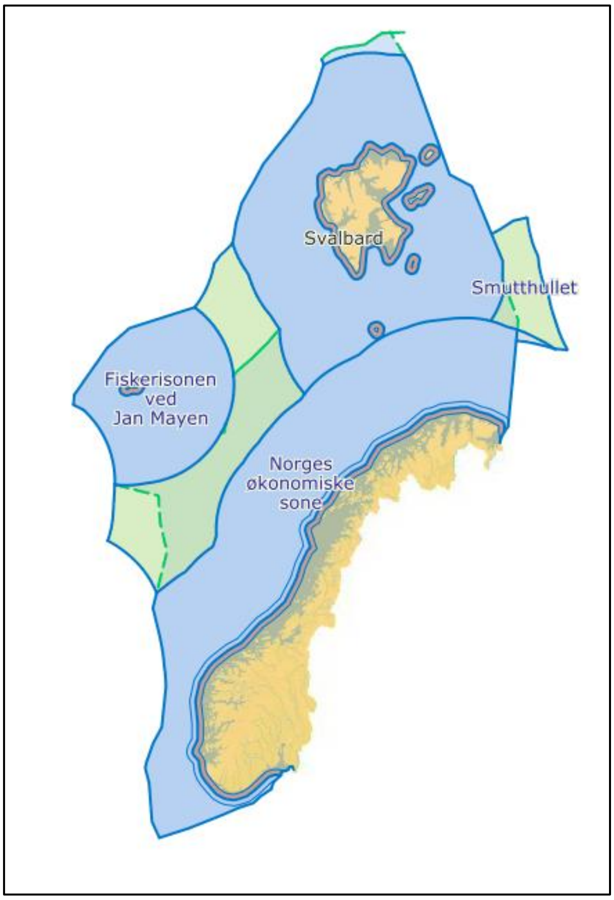

Figure 3. Norwegian Economical Zone, Jan Mayen Fisheries Zone and Svalbard Fisheries Protection Zone.

Data selection

Discrepancies between the different sources of data are frequent. In such cases, numbers reported directly to the working group are usually trusted more than other sources. In case of discrepancies between other sources, the higher number will often be used. If the discrepancies are abnormally high, the country's representative may be contacted.

Example: Data and data selection during AFWG 2016

During the AFWG 2017 all available data for 2016 were gathered. The data are presented in Appendix 1 (redo this in a more suitable format, with English text). The data were from the preliminary ICES statistics, NEAFC statistics, reported directly to the working group, or a combination of these sources.

Table 5 holds the collated landings data. The three left-hand tables list all the species specific landings and landings reported as "*Sebastes* spp" ("Redfish" in Table 2). The three right-hand tables contain data that uniquely identify pelagic catches (i.e. catches reported in ICES statistics in sub-division 2.a.1 and 2.a.2, information provided directly to AFWG, and NEAFC statistics). Data in the three right-hand tables may or may not be included in the data in the three left-hand tables. In all tables, the origin of the data is marked with colour codes (legend below Table 5). Where several data sources are available and do not match, the decision on which numbers to use is made following the guidelines above.

How discrepancies were handled in 2016:

Latvia, *S. mentella*: Latvia originally reported 158 080 tonnes in subdiv 2a, which was obviously an error. Latvian authorities were contacted, and the landings were corrected to 1243 tonnes.

Portugal, *S. mentella*: In agreement with R. Alpoim, the final numbers for Portugal used by the AFWG was a combination of the ICES preliminary statistics and information reported directly to the WD (Alpoim, 2016 WD).

Spain, *S. mentella*: The final numbers used by the AFWG for Spanish landings were a combination of data from the ICES preliminary statistics, information on Spanish pelagic fishery in international waters (Casas, 2016 WD) and reports to Norwegian authorities from Spanish vessels fishing in the Norwegian EEZ. The calculations were made in agreement with J. M. Casas.

Germany, *S. mentella*: M. Bernreuther informed that the German pelagic fishery in international waters summed to 272 t in 2016. (Personal communication, is not included in the "available data"-sheet).

EU, *S. mentella*: In the NEAFC statistics, the catch of all EU member states is aggregated (see section 4).

Species identification issues

Many countries do not provide species specific landings. The landings then need to be allocated to species by the AFWG. The allocation follows these guidelines unless other information is available;

- All redfish caught in the NEAFC area are *S. mentella*,
- All *Sebastes* spp. from ICES subdiv 2b are *S. mentella*,
- All *Sebastes* spp. from ICES div 1 are *S. norvegicus*,
- *Sebastes* spp. is split using the ratio from the country's own species-specific landings within the same ICES division,
- *Sebastes* spp. is split using the ratio from species-specific logbook-reports to Norwegian authorities,
- *Sebastes* spp. is split using ratios from earlier years for the same country and division,

Example: Allocating Sebastes spp. to species during AFWG 2016

The "Redfish" from Table 5 is split into *S. mentella* and *S. norvegicus*, resulting in the final species-specific landings tables shown in Table 6. Table 7 provides the rationale behind all the decisions made in the splitting process.

Table 5. Collated data for redfish, 2016, before splitting of data reported as "Sebastes spp.".

Splitting of Redfish into *S.norvegicus* and *S.mentella*.

Data year: 2016 Arctic Fisheries Working Group 2017

Numbers reported from different sources

Sebastes norvegicus

	1	2a	2b	TOT
EST				0
DEN			7	7
FAR				0
FRA				0
GER				0
GRL	9			9
IRE				0
ICE	51	20		71
LTU				0
LVA				0
NET				0
NOR	781	2280	1544	4 606
POL	2	8	11	22
POR				0
RUS	119	480	177	776
SPA				0
SWE				0
UK				0
EU				0
SUM	963	2 789	1 739	5 491

Sebastes mentella

	1	2a	2b	TOT
EST				0
DEN				0
FAR				0
FRA				0
GER				0
GRL				0
IRE				0
ICE		8		8
LTU		1 064		1 064
LVA		1 243		1 243
NET		0		0
NOR	176	9641	7814	17 631
POL	1	182	23	206
POR		1051	13	1 064
RUS	201	3 478	4 092	7 771
SPA	0	3102	8	3 110
SWE				0
UK				0
EU				0
SUM	378	19 770	11 950	32 097

Redfish

	1	2a	2b	TOT
EST				0
DEN				0
FAR	161	504	7	672
FRA	7	130	27	165
GER	4	493	0	497
GRL	65	74	14	153
IRE				0
ICE				0
LTU				0
LVA				0
NET				0
NOR				0
POL				0
POR		1	1	2
RUS	45	536	155	736
SPA	2	0	28	30
SWE				0
UK	60	87	50	197
EU				0
SUM	344	1 824	283	2 451

PELAGIC

ICES stats, ment+norv+spp
2a1+2b1=international waters

	2a1	2b1	TOT
EST			0
DEN			0
FAR			0
FRA			0
GER			0
GRL			0
IRE			0
ICE	8		8
LTU	1064		1 064
LVA	1243		1 243
NET			0
NOR	9		9
POL			0
POR	700		700
RUS			0
SPA	2467		2 467
SWE			0
UK			0
EU			0
SUM	5 491	0	5 491

PELAGIC

Info to AFWG on pelagic S. mentella
international waters

	2a	2b	TOT
EST			0
DEN			0
FAR			0
FRA	0		0
GER	272		272
GRL	0		0
IRE			0
ICE			0
LTU			0
LVA			0
NET			0
NOR			0
POL			0
POR	822		822
RUS			0
SPA	2862		2 862
SWE			0
UK	0		0
EU			0
SUM	3 956	0	3 956

PELAGIC

NEAFC, pelagic S. mentella

	REB/XNS
EST	
DEN	
FAR	393
FRA	
GER	
GRL	
IRE	
ICE	
LTU	
LVA	
NET	
NOR	3
POL	
POR	
RUS	512
SPA	
SWE	
UK	
EU	4481
SUM	5 389

27 Red numbers are according to reports to Norw. authorities.
27 Blue numbers are presented to the Working Group or set by the WG
27 Green numbers are official statistics to ICES
27 Brown numbers are reported in InterCatch
27 as reported to NEAFC

Table 6. Final numbers used by AFWG for *S. norvegicus* and *S. mentella*, as well as for *S. mentella* in the NEAFC area.

FINAL WORKING GROUP NUMBERS, SPLIT BY SPECIES

Sebastes norvegicus

	I	IIA	IIB	TOT
EST				0
DEN			7	7
FAR	161	29		190
FRA	7	65		72
GER	4	58		62
GRL	59			59
IRE				0
ICE	51	20		71
LTU				0
LVA				0
NET				0
NOR	781	2 280	1 544	4 606
POL	2	8	11	22
POR				0
RUS	136	545	183	864
SPA	2			2
SWE				0
UK	60	43		104
EU				0
SUM	1 264	3 050	1 746	6 060

Sebastes mentella

	I	IIA	IIB	TOT
EST				0
DEN				0
FAR		474	7	482
FRA		65	27	92
GER		434	0	434
GRL	15	74	14	102
IRE				0
ICE		8		8
LTU		1 064		1 064
LVA		1 243		1 243
NET		0		0
NOR	176	9 641	7 814	17 631
POL	1	182	23	206
POR		1 052	14	1 066
RUS	229	3 949	4 241	8 419
SPA		3 102	36	3 138
SWE				0
UK		43	50	94
EU				0
SUM	420	21 332	12 226	33 979

Pelagic S. mentella in international waters

	Pelagic
EST	
DEN	
FAR	393
FRA	
GER	272
GRL	
IRE	
ICE	8
LTU	1064
LVA	1243
NET	
NOR	9
POL	
POR	822
RUS	512
SPA	2862
SWE	
UK	
EU	
SUM	7 185
EU, recalculated	6 263
EU, NEAFC	4 481

Table 7. Splitting of *Sebastes* spp. landings (i.e. data in table “Redfish” in Table 5)

Country	ICES div/subdiv	Sebastes spp. landings (t)	Proportion S. mentella	Rationale
Faroe Islands	1	161	0.000	
Faroe Islands	2a	111*	0.735	Proportion from Faroese vessels’ reports to Norwegian authorities in 2015 *504 t minus 393 tonnes pelagic *S. mentella* reported to NEAFC.
Faroe Islands	2b	7	1.000	
France	1	7	0.000	
France	2a	130	0.500	No available information, using proportion from 2014
France	2b	27	1.000	
Germany	1	4	0.000	
Germany	2a	221*	0.741	Proportion from German vessels’ reports to Norwegian authorities in 2015 *493 t minus 272 t pelagic *S. mentella* reported to AFWG
Greenland	1	65	15/65	15 t added to *S. mentella* to match what was reported to Norwegian authorities: 102 t *S. mentella* and 56 t *S. norvegicus*
Greenland	2a	74	1.000	All added to *S. mentella* to match what was reported to Norwegian authorities: 102 t *S. mentella* and 56 t *S. norvegicus*
Greenland	2b	14	1.000	All added to *S. mentella* to match what was reported to Norwegian authorities: 102 t *S. mentella* and 56 t *S. norvegicus*
Portugal	2a	1	1.000	
Portugal	2b	1	1.000	
Russia	1	45	0.628	Proportion from Russias species specific landings in ICES preliminary statistics 2016
Russia	2a	536	0.879	Proportion from Russias species specific landings in ICES preliminary statistics 2016
Russia	2b	155	0.959	Proportion from Russias species specific landings in ICES preliminary statistics 2016
Spain	1	2	0.000	
Spain	2b	28	1.000	
UK	1	60	0.000	
UK	2a	87	0.500	No available information.
UK	2b	50	1.000	

Pelagic landings of *S. mentella* in the NEAFC area

To monitor the development of the pelagic fishery of *S. mentella* in the NEAFC area, landings from this fishery needs to be summarised from the general landings data. The primary source of information should be the NEAFC statistics, but it has some weaknesses. Prior to 2015, NEAFC reported tables of catches per active vessel as these vessels report their catches (logbooks) from the sea via their flag state to NEAFC. Unfortunately, since 2015, catches are no longer reported to NEAFC by vessels at sea. NEAFC now only provide landings data. In addition, the landings data are now aggregated for the following coastal states: EU, DFG Faroes, DFG Greenland, Iceland, Norway, Russian Federation.

Some information on the pelagic fishery can be extracted from the ICES statistics. Catches are reported at different geographical levels, illustrated in Figure 4. ICES subdivision 2.a.1 and 2.b.1 together make up the NEAFC regulatory area 2 (XNS/Banana hole), whereas subdivisions 27.2.a.2 and 27.2.b.2 are outside the NEAFC regulatory area. However, landings are also reported in subdivisions 27.2.a or 27.2.b, or simply division 27.2. These landings may or may not contain landings from the NEAFC regulatory area 2.

Finally, several countries report their landings in the NEAFC area directly to the AFWG. Some provide this in the form of Working Documents, whereas others report their catches through "personal communication". When these numbers differ from NEAFC and/or from ICES statistics, numbers presented directly to the AFWG are used.

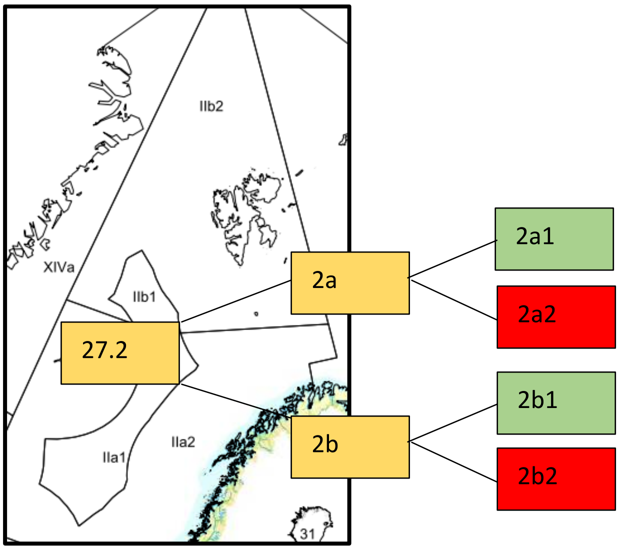

Figure 4. ICES statistical areas and how they relate to NEAFC regulatory area 2. Green = in NEAFC RA2, Red = not in NEAFC RA2. Yellow = may include catches from NEAFC RA 2.

Example: Pelagic landings, AFWG 2016

Table 8 shows reported landings for 2016 from different data sources (columns 1-4) and the final numbers used by the ICES assessment working group. The total landings reported in the NEAFC statistics for the EU at the end of 2016 is 4481 tonnes. For individual EU nations, national landings reported in the ICES statistics or directly to the AFWG add up to 6263 tonnes. This number is 40 % or 1782 tonnes higher than the number reported by NEAFC.

Table 5. Numbers from ICES AFWG 2017 (landings data for 2016)

Origin of statistics	ICES preliminary statistics	ICES preliminary statistics	NEAFC statistics	ICES AFWG	Final numbers used by the working group
What	Landings in Subarea 2 or Divisions 2a, 2b	landings in Divisions 2a1, 2b1	Catches in NEAFC area	Additional information provided to or by the working group	
Species	*S. mentella* or Sebastes spp.	All redfish species	Pelagic mentella	S. mentella	S. mentella
Comment	Inside or outside NEAFC area	NEAFC area	NEAFC area	NEAFC area	NEAFC area
Faroe Islands	256		393		393
Germany				272	272
United Kingdom	137			(Usually 0)	0
Iceland		8			8
Lithuania		1064			1064
Latvia		158080 (this is not a typo)		1243	1243
Norway		9 (6 reported as norvegicus)	3		9
Portugal		700		822	822
Russia	8261		512		512
Spain		2467		2862	2862
EU		-	4481	-	-
EU, recalculated					6263

References

Hirst, D., Aanes, S., Storvik, G., Aldrin, M., Huseby, R.B. 2005. Estimating catch-at-age by combining data from different sources. Can. J. Fish. Aquat. Sci. 62: 1377–1385.

Hirst, D., Storvik, G., Rognbakke, H., Aldrin, M., Aanes, S., Vølstad, J.H. 2012. A Bayesian modelling framework for the estimation of catch-at-age of commercially harvested fish species. Can. J. Fish. Aquat. Sci. 69: 2064-2076.

Vollen, T. and Nedreaas, K. 2017. Preparation of Norwegian landings data for beaked and golden redfish. WD XX, ICES WKREDFISH Copenhagen 29 January – 2 February 2018.

Appendix 1

All data for redfish available to the ICES AFWG 2016.

DATA FOR 2016

Utlendingers fiske 2016

Sum of Ru	Column Labels		
Row Labe	s mentella	s norvegicus	uer sp
N62N (TV =hovedsakelig I + IIa)			
DEU	6		217
DNK		3	0
ESP	240		23
FRA			85
FRO	72		27
GBR			152
GRL	102		56
ISL	6	19	0
POL	207	21	0
PRT	244		2
RUS	6807		1104
S62N (TV: utenfor ICES I og II)			
DNK	1	3	0
GBR			0
SWE			0
XSV (TV: hovedsakelig IIb)			
DEU	0		0
DNK		4	0
ESP	9		0
FRA			0
FRO	6		0
GBR			2
GRL	0		0
POL	2		0
PRT	0		0
RUS			2
Grand Tot	**7701**	**50**	1670

Ices prelim catches (v 6. april 2017)

Sum of Nominal Catches(TLW)

Row Label	27_1	27_2_A	27_2_B
Sebastes spp.			
DE	4	493	0
ES	2	2689	28
FO	161	504	7
FR	7	130	27
GB	60	87	50
GL	65	74	14
PT	0	1	1
RU	45	536	155
Sebastes mentella			
ES	0	13	8
IS	0	8	0
LT	0	1064	0
LV	0	1243	0
NL	0	0	0
NO	386	7976	9483
PL	1	182	23
PT	0	1045	13
RU	201	3478	4092
Sebastes norvegicus			
DK	0	0	7
GL	9	0	0
IS	51	20	0
NO	1055	2907	456
PL	2	8	11
RU	119	480	177

NEAFC (6. april 2017)

Aggregated Catch Statistics of pelagic ICES I & II Redfish (REB/XNS) for December 2015

Zone CPs	European Union	DFG Faroes	DFG Greenland	Iceland	Norway	Jan Mayen	Svalbard	Russian Fed.	NEAFC Reg.Area	CP Total
European Union							26		4481	4507
DFG Faroes									393	393
DFG Greenland										0
Iceland										0
Norway									3	3
Russian Fed.									512	512
Zone Total	0	0	0	0	0	0	1	0	5389	5415

Russian catch, provided by russians to B. Planque (same as in ICES prelim. catches

FAO Code	Latin Name	English Name	Fishing Area	Value	
REB	***Sebastes m***	**Beake**	**27**	**31371**	**окунь клювач**
REB	*Sebastes m*	Beake	27_1	201	
REB	*Sebastes m*	Beake	27_2_A	3478	
REB	*Sebastes m*	Beake	27_2_B	4092	
REB	*Sebastes m*	Beake	27_5_B	0	
REB	*Sebastes m*	Beake	27_12	1671	
REB	*Sebastes m*	Beake	27_14	21929	

SPAIN

Spanish catches reported to ICES

	1	**2a**	**2b**	**Total**
S. mentell	0	13	8	21
Sebastes	2	2689	28	2719
Total	2	2701	36	2739

From WD: Spanish catches of pelagic S mentella in international waters

	1	**2a**	**2b**	**Total**
S. mentella		2862		2862

Catches within Norwegian EEZ, reported to Norw gouvernment

	Norw EEZ
S. mentella	248
Sebastes sp.	23
Total	271

Final numbers used, as agreed with Casas

	1	**2a**	**2b**	**Total**
S. mentell	0	3102	8	3110
S. Sp	2		28	30
Total s. m	2	3102	36	3140

Utlendingers fiske 2016

Sum of Ru	Column Labels		
Land	Snabeluer	Uer (vanlig)	Uer
DEU	5.979		217
DNK		2.787	0
ESP	239.701		23
FRA			85
FRO	72		27
GBR			151.808
GRL	101.577		56.17
ISL	6.144	19.464	0
POL	206.646	20.53	0
PRT	243.642		1.661
RUS	6806.596		1104.03
DEU	0.24		0
DNK		3.952	0
ESP	8.653		0.039
FRA			0.335
FRO	6.143		0
GBR			1.69
GRL	0.316		0
POL	2.13		0
PRT	0.004		0
RUS			1.893

PIVOTTABELL, utlendingers fiske

	Data			
Land	mentella	norvegicus	sp	
DEU	6		217	
DNK		7	0	
ESP	248		23	**
FRA			85	
FRO	78		27	
GBR			153	
GRL	102		56	
ISL	6	19	0	
POL	209	21	0	*
PRT	244		2	*
RUS	6807		1106	
Grand Tota	7700	47	1670	

* POL and POR reportings to Norw authorities are 2-3 tonnes higher than ICES prelim landings. ICES prelim catches are still used.

** Spain has some discrepancies between ICES, Norw and WD numbers. Casas will look into this.

PORTUGAL

Portugese WD

catch in tonnes, s. mentella

I and IIa	244.8
IIa pelagic	821.6

Catches distributed on ICES area, as agreed with R. Alpoim by email

	ICES area			
	1	*2a**	*2b*	*SUM*
S mentella	0	1052	14	1066

* of this, 821.6 t are pelagic catches in international waters

Description of scientific surveys used for the assessment of beaked and golden redfishes in ICES subareas 27.1 and 27.2

Working Document2, ICES WKREDFISH Copenhagen 29 January-2 February 2018

Benjamin Planque, Kjell Nedreaas, Tone Vollen, Anatoly Filin, Elvar Hallfredsson, Erik Berg, Elena Eriksen

Survey considered in the assessments

1. Barents Sea Winter survey
2. Barents Sea Ecosystem survey
3. Barents Sea Russian groundfish survey
4. International Deep Pelagic Ecosystem Survey in the Norwegian Sea
5. Norwegian Coastal survey
6. Barents Sea 0-group survey
7. Norwegian Sea Slope surveys: Egga-Sør and Egga-Nor

Barents Sea winter survey: *BS-NoRu-Q1 (BTr)*

Description of the survey

The latest detailed description of the IMR-PINRO winter survey in the Barents Sea can be found in Working Document 3 of the Arctic Fisheries Working Group 2017. Some information from this document is reproduced below with additional information specific to redfish species.

The survey is a trawl and acoustic survey and only the trawl data is used for deriving indices of abundance-at-age and –length for both *S. mentella* and *S. norvegicus*. Abundance indices are calculated following a swept area estimate method. Until recently, the calculations were performed using the SAS program *survey*. The newly implemented StoX method is now in use for deriving the numbers-at-length for both redfish species in the Winter survey and the details of the method can be found in Mehl et al. (2016). StoX has not yet been implemented for estimating abundance-*at-age* and output from the SAS *survey* program are still used instead.

The stratasystem in use for deriving swept area estimates is presented in Figure 1. An important issue has been the change in survey coverage over time and the corresponding ad hoc revisions of the geographical area used for index calculations. From 1981 to 1992 the survey area was fixed (strata 1-12, main areas ABCD in Fig. 2.1). In 1993 and further in 1994 the survey area was extended to the north and east (strata 13-23, main areas D'ES) to obtain a more complete coverage of the younger age groups of cod, and since then the survey has aimed at covering the whole cod distribution area in open water. For the same reason the survey area was extended further northwards in the western part in 2014 (strata 24-26). In many years since 1997 Norwegian research vessels have had limited access to the Russian EEZ, and in 1997, 1998, 2007 and 2016 the vessels were not allowed to work in the Russian EEZ. In 1999 a rather unusually wide ice-extension partly limited the coverage. Since 2000, except in 2006, 2007 and 2017, Russian research vessels have participated in the survey and the coverage has been better, but for various reasons not complete in most years. In 2008-2015 Norwegian vessels had access to major parts of the Russian EEZ. The coverage was more complete in these years, especially in 2008, 2011 and 2014. Table 1 summarizes degree of coverage and main reasons for incomplete coverage in the Barents Sea winter 1981-2017.

Preparation of survey indices

At present, numbers-at-age and length are still derived from historical runs of the SAS *survey* program. It is not possible to easily trace back the exact stratasystem options chosen for each year without going through past working documents of the Arctic Fisheries Working Group. Hopefully, this will be solved when StoX swept area calculations are fully implemented, quality checked and documented for *Sebastes* species.

The yearly number of age and length samples for the *Sebastes* species available from the Winter survey is presented in Appendix 1.

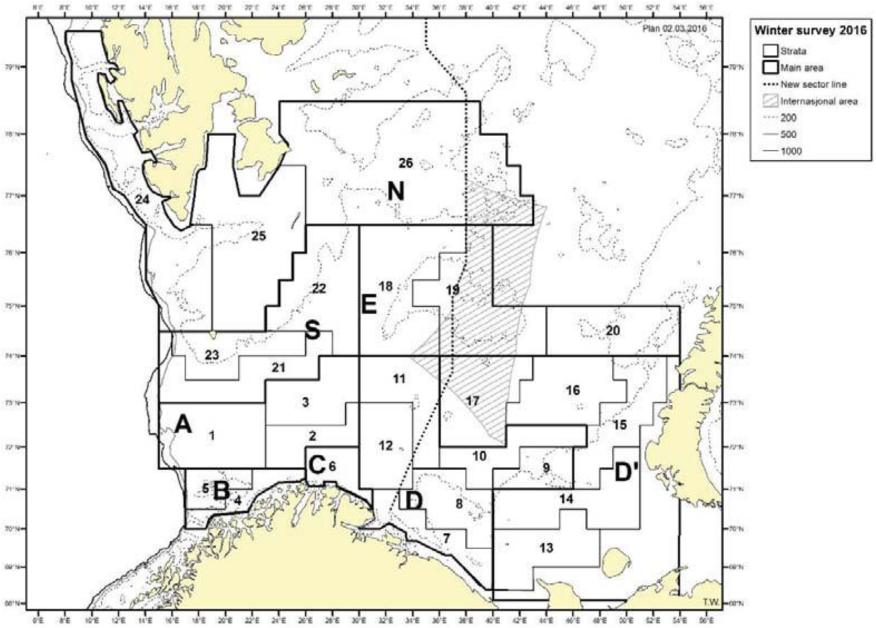

Figure 1. Strata (1-23) and main areas (A,B,C,D,D',E and S) used for swept area estimations estimations with StoX. Additional strata (24-26, main area N) are covered since 2014, but not included in the full-time series.

Table 1. Barents Sea winter surveys 1981-2017. Main Areas covered, and comments on incomplete coverage.

Year	Coverage	Comments
1981-1992	ABCD	
1993-1996	ABCDD'ES	
1997	Norwegian EEZ (NEZ), S	Not allowed access to Russian EEZ (REZ)
1998	NEZ, S, minor part of REZ	Not allowed access to most of REZ
1999	ABCDD'ES	Partly limited coverage due to westerly ice extension
2000	ABCDD'ES	Russian participation starts
2001-2005	ABCDD'ES	Russian vessel covered where Norwegians had no access
2006	ABCDD'ES	No Russian vessel, not allowed access to Murman coast
2007	NEZ, S	No Russian vessel, not allowed access to REZ
2008	ABCDD'ES	Russian vessel covered where Norwegians had no access

2009	ABCDD'ES	Reduced Norwegian coverage of REZ due to catch handling
2010	ABCDD'ES	Reduced Norwegian coverage of REZ due to bad weather
2011	ABCDD'ES	Russian vessel covered where Norwegians had no access
2012	ABCDD'ES	No Norwegian coverage of REZ due to vessel problems
2013	ABCDD'ES	No Norwegian coverage of REZ due to vessel shortage
2014	ABCDD'ESN	Strata 24-26 (N) covered for the first time
2015	ABCDD'ESN	Slightly reduced/more open coverage due to bad weather
2016	ABCDD'ESN	No access to REZ, Russian vessel covered most of REZ
2017	ABCDD'ESN	No Russian vessel, not allowed access to southwestern REZ

Indices derived from the Winter survey that are included in current stock assessment models

Numbers-at-age for *S. mentella* for the period 1992-2011 and for age groups 2-15y. After 2011, age readings are not available and no data has been provided (otoliths are available for age determination). Abundance indices for individuals older than 15y are not provided. It is known that these migrate out of the Barents Sea and the survey is not considered adequate to derive reliable abundance estimates for these older age groups.

Numbers-at-age for *S. norvegicus* for the period 1992-present and for age groups 1-36+. Age readings are not yet available for 2017.

Numbers-at-length for *S. norvegicus* for the period 1990-present and for length groups 2 – 58+ cm, by 2 cm length class.

Numbers-at-age for *S. mentella* for the period 1992-present and for age groups 1-15+. Age readings are not available after 2011.

Indices derived from the Winter survey but not included in current stock assessment models

Numbers-at-length for *S. mentella* for the period 1986-present and for length groups 5 – 45+ cm, by 5cm length class.

Summary of known issues

Changes in the geographical extent of the survey is a known issue. There are several ways in which this can be handled to derive meaningful indices of abundance-at-age and the consequence of using one or the other approach have not been evaluated thoroughly.

The old 'SAS-survey program' is no longer in use and it is hard to retrieve original model implementation and datasets to reproduce what was done in previous years.

The implementation of StoX for numbers-at-age should make the data preparation from this survey more transparent and reproducible in the future.

Barents Sea Ecosystem Survey: *Eco-NoRu-Q3 (BTr)*

Description of the survey

The joint autumn ecosystem survey of the Barents Sea started in 2003 by combining five previous surveys into a single investigation. These five surveys comprised the joint Russian–Norwegian surveys for 0-group and capelin together with the Norwegian surveys for shrimp, Greenland halibut and redfish. Combining them enabled the whole ice-free Barents Sea to be covered by oceanographic, acoustic, pelagic trawl and demersal trawl investigations. Investigations on plankton, seabirds, marine mammals, marine pollution and benthos have also been carried out, but with various degrees of coverage. The survey is carried out in August and

September each year, with the aim of covering the whole area before the cod and haddock 0-group started to settle on the bottom. The survey data are also used as direct input to the capelin assessment, which is carried out in the first week of October. The survey is carried out during the period of minimum ice coverage, so the survey area has been in the order of 1.5 million square kilometres. The survey coverage and demersal trawl sampling is illustrated in Figure 2. Data from the earlier Norwegian Svalbard (Division 2.b) bottom trawl survey (August-September) are available annually since 1986 (incl.) in fishing depths of 100–500 m, disaggregated by age only since 1992. The earlier redfish and Greenland halibut survey covers the Norwegian Economic Zone (NEZ) and Svalbard including north and east of Spitsbergen during August down to 800 m depth.

The survey provides swept area abundance estimates for *S. mentella* and *S. norvegicus* in the Barents Sea during summer. In addition, the 0-group component of the survey is used to estimate the abundance of 0-group redfish for the two species combined.

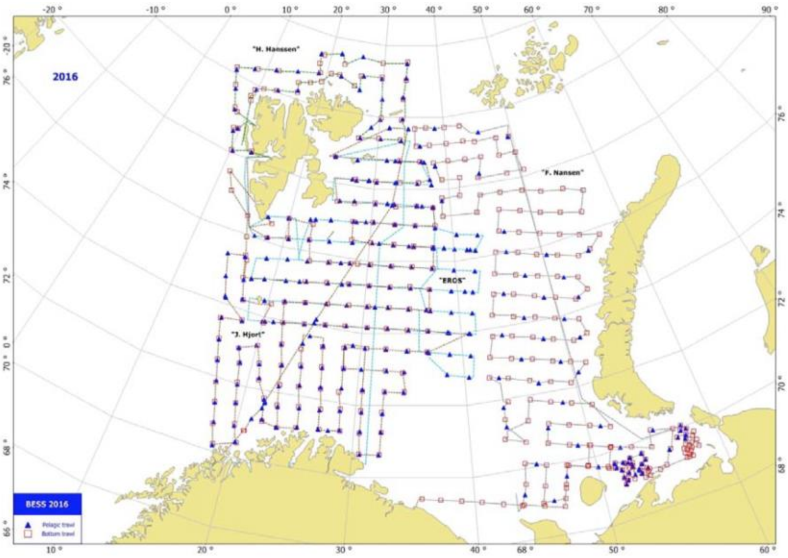

Figure 2. Ecosystem survey, August-October 2016. Research vessel tracks and trawl stations

Preparation of survey indices

At present, numbers-at-age and length are derived from historical runs of the SAS *survey* program. The strata system in use are a combination of geographical and bathymetrical coordinates (see below). This is scheduled to be updated using StoX which would then provide swept area calculations with uncertainty estimates *Sebastes* species. Three strata systems are currently in use, referred to as Arctic (strata system 15), Svalbard (strata system 31) and Barents (strata system 32) which correspond to different regions of the Barents Sea (Figure 3). In strata system 15, the depth intervals are 100-300 m, 300-500 m and deeper than 500 m. In strata system 31 and 32, the depth intervals are: 0-100 m, 100-200 m, 200-300 m, 300-400 m, and 400-500 m.

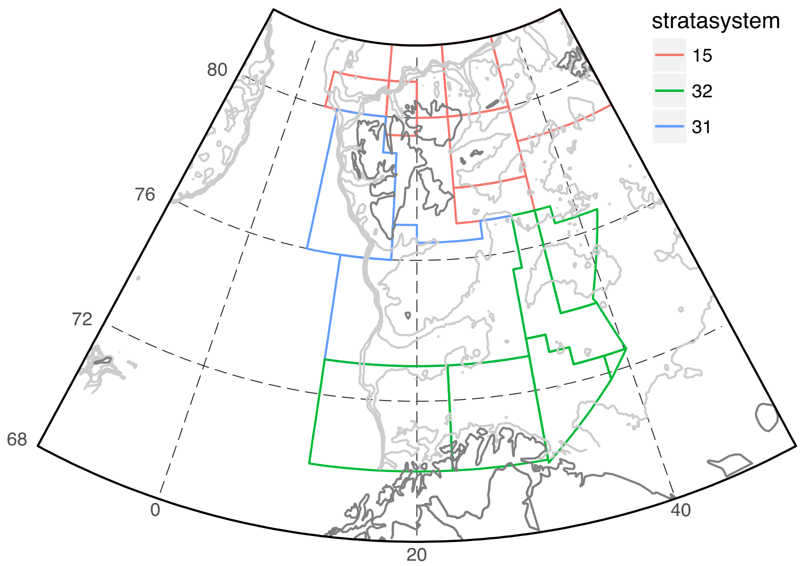

Figure 3. The stratasystems 15, 31 and 32 used for the Barents Sea ecosystem survey in summer. The strata are defined as a combination of geographical polygons (coloured lines) and depth ranges (grey lines).

Indices derived from the Ecosystem survey that are included in current stock assessment models

Numbers-at-age for *S. mentella* for the period 1996-present and for age groups 2-15y. In 2010, no otoliths were collected, and no data is provided. The data for most recent years is often lagging, i.e. otoliths are available for age determination but have not been read by the time of the assessment working group. The survey index is obtained by combining indices in the three stratasystems 15 (Arctic), 31 (Svalbard) and 32 (Barents).

Abundance indices for individuals older than 15y are not provided. It is known that these migrate out of the Barents Sea and the survey is not considered adequate to derive reliable abundance estimates for these older age groups.

Indices derived from the Ecosystem survey but not included in current stock assessment models

Numbers-at-age for *S. norvegicus* for the period 1992-present and for age groups 2-15y, for stratasystem 31 (Svalbard). Age readings are not available in 2009, 2010, 2011, 2014 and 2015, either because otoliths were not collected of because age determination wasn't performed.

Numbers-at-length for *S. norvegicus* for the period 1985-present and for length groups 5 – 45+ cm, by 5cm length class, for stratasystem 31 (Svalbard).

Numbers-at-length for *S. mentella* for the period 1986-present and for length groups 5 – 45+ cm, by 5cm length class, for the stratasystem 31 (Svalbard).

Summary of known issues

Lack (or lag) of age readings in recent years is the main issue.

The old 'SAS-survey program' is no longer in use and it is hard to retrieve original model implementation and datasets to reproduce what was done in previous years.

The implementation of StoX for numbers-at-age should make the data preparation from this survey more transparent and reproducible in the future.

Barents Sea Russian groundfish survey: *RU- Q4 (BTr)*

The detailed description of the PINRO winter survey in the Barents Sea and adjacent areas can be found in Shevelev et al. (1998). This survey is conducted from late-October to late-December. Its total duration is 40–50 days. Depths are surveyed from 50 to 900 m. MS TAS is carried out by a grid of hydroacoustic tracks, occupying trawl stations located with allowance for long-term mean distribution of commercial fish. Trawl stations are distributed with a mean density of about 1 station per 300 nm2. Each trawl station position is taken at random and is mainly determined by the necessity to have a complete and uniform coverage of the survey area.

The survey is performed by 2 or 3 vessels simultaneously. Sampling gear is a bottom trawl with the distance between wings about 30 m and 7.8–8.0 m opening height. A 16 mm inner mesh-size netting is installed into a trawl codend. The vessel speed is 3.2 knots and duration of trawling is 1 hr. Echo-integration of mid-water by layers is performed between trawl stations and during hauls.

Hydrological observations are done at each trawl station at all standard depths. Krill sampling is performed by attached net during the trawling. About 20 fish species along with the deep-water shrimp and benthic organisms occur in trawl catches. The survey is used to assess of relative abundance indices of juveniles of bottom fish simultaneously with assessment of their commercial stocks. Estimations of year-classes strength of the commercial species are done by comparing the mean abundance of a year-class in catch with the long-term mean in the survey time series.

To calculate the indices of abundance-at-age of redfish total catch in each trawl are measured and the results of the redfish length measurements are combined with intervals of 2 cm. Age samples are selected from the redfish catches. After determining the age, an age-length key are compiled. To calculate the number of fish of a certain age in each catch, the size range of redfish in each catch are recalculated using the age-length key.

Summary of known issues

Age determination is uncertain beyond maturity (~11y) and because of the use of an age-length key to determine age distribution, the numbers-at-age cannot be estimated for fish older than 11y when the growth curve starts to flatten.

International Deep Pelagic Ecosystem Survey in the Norwegian Sea: *no ICES acronym*

Description of the survey

The deep pelagic redfish surveys in the Norwegian Sea were initiated in 2007 following the onset of the pelagic fishery and the request by NEAFC to ICES to investigate the distribution and abundance of redfish in open (and international) waters of the Norwegian Sea. In 2008 the survey was first coordinated by ICES and conducted jointly by three nations: Norway, Russia and the Faroes. The survey has since then been coordinated at ICES (currently the working group on international deep pelagic ecosystem surveys: WGIDEEPS) in 2009, 2013 and 2016 but only Norway has conducted the survey which was therefore restricted to the northern area of the stock distribution. The survey used the standard observation strategy based on hydroacoustic registrations at 38 kHz, sampling with a large pelagic trawl, and hydrographic measurements during trawling. Because of uncertainties in scrutinizing fish distribution at depths greater than 400m and within the deep scattering layer, it is currently the trawl component of the survey that is used for deriving indices of abundance. The trawling is done on a quasi-regular grid (rather than being based on registration), using a multisampler that allows for sampling at three depths intervals within each trawl haul. The cruise track and location of trawl hauls in 2016 are illustrated in Figure 4.

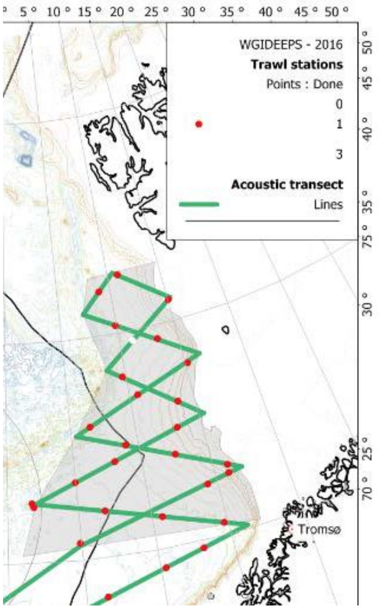

Figure 4. International Deep Pelagic Ecosystem Survey in the Norwegian Sea in August-October 2016. Research vessel tracks and trawl stations. The grey area shows the stratum used in 2016 for the calculation of the proportion-at-age.

Preparation of survey indices

Because the trawl model has changed between surveys (Gloria 2048 in 2008 and 2009, Gloria 2560 HO helix in 2013 and Gloria 1024 in 2016), the numbers-at-age indices derived from the survey are not comparable in absolute terms. Instead only the proportions-at-age are used.

These are estimated from trawl hauls only using StoX swept area estimates. The stratasystem for the Norwegian Sea consists of one geographical stratum only, as illustrated in Figure 4. However, data is split into three depth layers (150-300m, 300-600 and 600-800) in which it has been observed that beaked redfish have different age and size composition. The indices of abundance-at-age in each layer are added. From these, the proportion of fish in each age class is calculated.

Indices derived from the deep pelagic ecosystem survey that are included in current stock assessment models

Trawl-base estimates of proportions-at-age for *S. mentella* in the northern part of the open Norwegian Sea for years 2008, 2009 and 2013 (2016 still to be read), ages from 7 to 75y.

Indices derived from the deep pelagic ecosystem survey but not included in current stock assessment models

Acoustics abundance estimates by age, region and depth strata can be derived but are not yet extracted and included in the current model.

Summary of known issues

Survey coverage is incomplete, so abundance indices do not reflect population abundance.

Survey is only conducted every third year (since 2013) and current time series is short.

Acoustic estimates are highly uncertain due to the inadequacy of the methodology used in waters deeper than 400m.

Norwegian Coastal survey: *NOcoast-Aco-Q4*

Description of the survey

The Norwegian Coastal survey is an acoustic survey designed to obtain indices of abundance and estimates of length and weight at age of saithe and coastal cod north of 62ºN. It has been carried out annually in October-November, since 1985 for saithe and since 1995 for coastal cod. Redfish species are sampled as a 'by-catch' from the survey and the data has been used to derive abundance indices.

Preparation of survey indices

Survey indices are provided for *S. norvegicus* only. They consist of mean catch rates by 5cm length groups for the geographical area covered by the survey. The method used for deriving survey indices is described in Berg and Albert (2000) and summarised below:

Catch rates

Catch rates were calculated as numbers per 1 nautical mile (nm) trawling distance. The catch rate of length *i* of a species at trawl station *j* was estimated as:

$$n_{ij} = m_{ij} \cdot \frac{C_j}{M_j \cdot D_j}$$

where m_{ij} is number of fish of length i in length sample from station *j*, M_j is total number of fish in length sample from station *j*, C_j is catch of the species at station *j* in total number, and D_j is the towing distance of the trawl in nm. The mean catch rates are calculated separately for six geographical regions.

Area delimitation

The area-definition is based on the Official Norwegian Statistical Areas, which is a system of small sub-areas (usually a half latitude high and one longitude wide) grouped together in wider regions:

Area 00	Lofoten (Vestfjorden). 5542 NM^2
Area 03	Eastern part of Finnmark county. 4205 NM^2
Area 04	Western part of Finnmark county and northern part of Troms county. 7303 NM^2
Area 05	Southern part of Troms county and west of the Lofoten area. 9962 NM^2
Area 06	Nordland county and south to 64°N. 9316 NM^2
Area 07	Trøndelag and Møre counties south to 62°N. 7246 NM^2

The catch rate by length for the whole survey is finally calculated as the area-weighted mean of the catch rates in individual regions.

Indices derived from the Coastal and fjords survey but not included in current stock assessment models

The catch-rate-at-length index for *S. norvegicus* by 5cm for length ranging 0-65 cm was used in the GADGET assessment model for years 1995-2010, after which it was discontinued. The reason for the discontinuation was the very uneven catches of *S. norvegicus* in the survey with the majority of fish being caught in only very few trawl stations. The index was then considered unreliable and its use for assessment was stopped in 20**.

A new index series was calculated for consideration in the benchmark assessment for *S. norvegicus* and covers the period 1998-2017. The calculation is based on the same principles, with additional quality checks on historical data.

Summary of known issues

The sampling design is not optimal for species that have clustered spatial distribution (patches of high densities separated by large areas of low density). In some years, the length distributions were mainly driven by few trawl hauls only.

The calculation would need to be implemented in StoX to make the data preparation from this survey more transparent and reproducible.

Barents Sea 0-group survey: *Eco-NoRu-Q3*

Description of the survey

The Barents Sea 0-group survey has been conducted since 1965 by IMR, PINRO and U.K. (up until 1976). Since 2003 the 0-group survey has been a part of the Barents Sea Ecosystem Survey (see above). The survey is carried out annually during August-September. In 1980 a standard trawling procedure was recommended by ICES and has since been used on Norwegian and Russian vessels. The standard procedure consists of predetermined tows at three or more depths, each of 0.5 nautical mile, with the head-line at 0, 20 m, 40 m and so on.

Preparation of survey indices

The survey is used to derive estimates of abundance of 0-group juveniles in the Barents Sea from several commercial species, including redfishes. Young-of-the-year redfish cannot be taxonomically identified down to the species level and the 0-group indices are available for *Sebastes sp*. The method for the calculation of the 0-group indices was revised in 2009 and is presented in Eriksen et al.(2009).

Indices derived from the 0-group survey but not included in current stock assessment models

The 0-group abundance index for *Sebastes sp* is reported to the ICES assessment working group as an early indication of the strength of incoming year classes. This index is however not included in the input data for either the SCA or GADGET models. The geographical distribution of 0-group *Sebastes* in 2016 is illustrated in Figure 5.

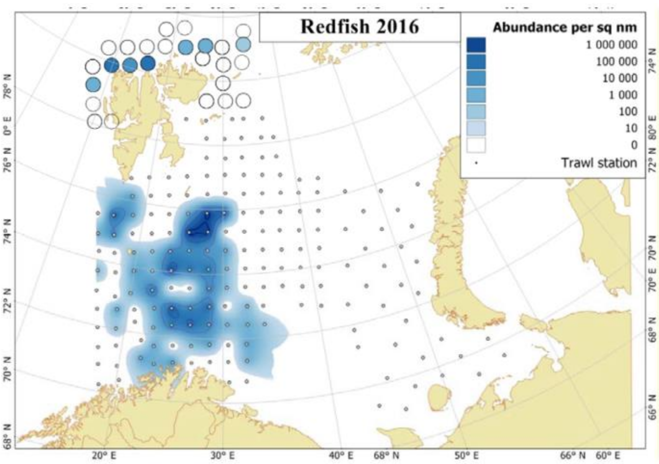

Figure 5. Distribution of 0-group redfishes (believed to be mostly *Sebastes mentella*), in August- October 2016.

Norwegian northern autumn and southern spring slope surveys: *NO-GH-Btr-Q3/no ICES acronym*

Description of the surveys

The Norwegian slope surveys in autumn (northern part) and spring (southern part) are combined trawl and acoustic surveys conducted alternatively and biennially along the continental slope in the Norwegian Sea. The southern spring slope survey covers the latitudinal range 62-74N and is conducted during spring, when adult redfishes of both species concentrate along the slope for larval extrusion. (Figure 6). The northern autumn slope survey covers the latitudinal range 68-80N and is conduct-ed in late summer and autumn when beaked redfish adults migrate back from summer migrations in the Norwegian Sea towards the slope. The southern spring slope survey was conducted in 2012, 2014 and 2016 while the northern autumn slope survey was conducted in 2011, 2013, 2015 and 2017.

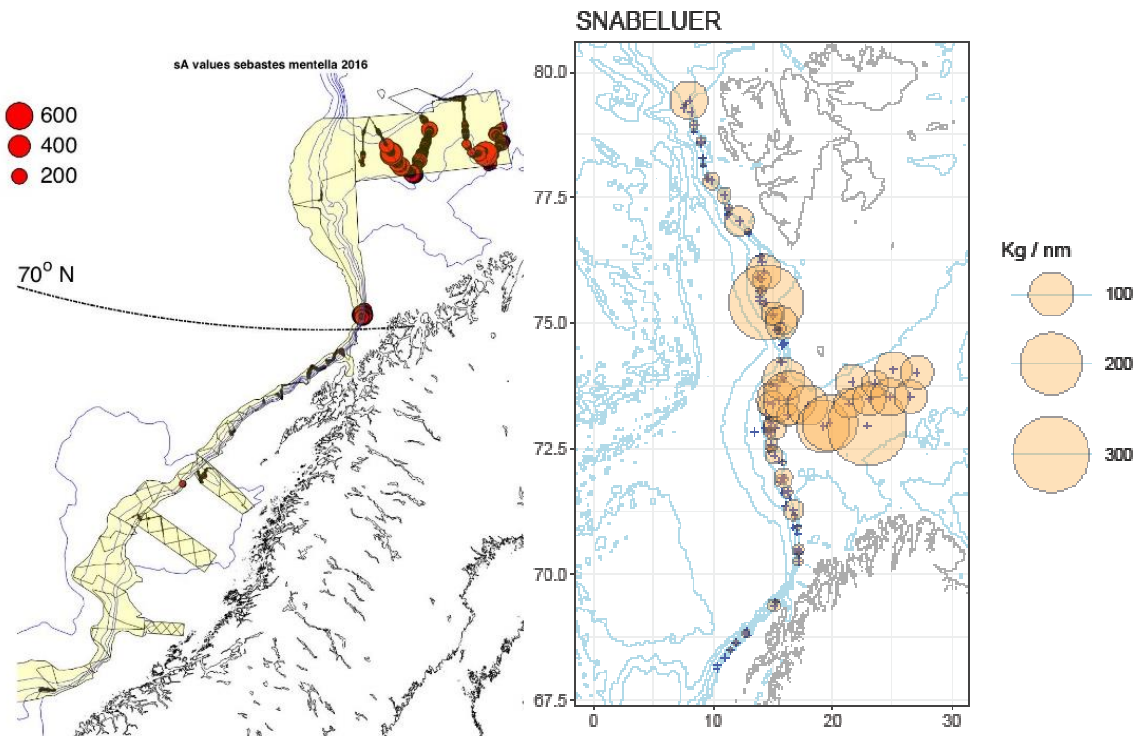

Figure 6. ***Sebastes mentella*** **in Subareas 1 and 2. Horizontal distribution of *S.mentella* hydroacoustic backscattering (sA) during the Norwegian southern spring slope survey in spring 2016 and northern autumn slope survey in 2017. The circles are proportional to the sA assigned to redfish along the vessel track (left) and to the trawl catch rates (right).**

Indices derived from the slope surveys but not included in current stock assessment models

Number-at-age/length for different depth and geographical strata have been estimated from these two surveys, but these have not been thoroughly evaluated and are not provided to the ICES assessment working group.

References

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Shevelev, M. S., Mamylov, V. S., Ratushny, S. V., and Gavrilov, E. N. 1998. Technique of Russian bottom trawl and acoustic surveys of the Barents Sea and how to improve them. NAFO Scientific Council Studies, 31: 13-19.

Appendix 1

Yearly number of age and length samples for *S. norvegicus* and *S. mentella* available from the Winter survey.

	S. norvegicus **samples**		***S. mentella*** **samples**	
Year	**Age**	**Length**	**Age**	**Length**
1981	0	3014	0	4129
1982	0	1402	0	9260
1983	0	7661	0	12979
1984	0	14620	0	14471
1985	0	x	0	x
1986	0	x	0	x
1987	0	2624	0	8159
1988	0	5477	0	20715
1989	0	2801	0	5332
1990	0	2701	0	8360
1991	0	3030	0	17088
1992	271	2220	415	11642
1993	170	2059	347	12710
1994	97	2384	95	12301
1995	238	2040	381	8935
1996	504	2354	1088	9637
1997	433	1436	943	10209
1998	399	1467	1336	9655
1999	225	1034	422	6635
2000	186	1106	660	8679
2001	351	1172	1258	7324
2002	342	954	1019	6512
2003	308	880	697	4495
2004	356	856	722	5378
2005	345	728	606	4118
2006	293	991	537	3369
2007	305	586	596	3557
2008	225	779	734	8534
2009	192	422	966	8898
2010	160	418	1354	8427
2011	115	284	1117	6483
2012	126	454	*not read*	5500
2013	156	479	*not read*	6024
2014	177	458	*not read*	9484
2015	174	310	*not read*	8676
2016	264	614	*not read*	12085
2017	*not read*	494	*not read*	11240

WD X.1. Gadget assessment model for S. norvegicus

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

Issues summary

There are several key issues around this stock, which both arise from *S. norvegicus* being a rather minor stock, with a much smaller biomass than the overlapping *S. mentella* stock. Firstly, there is a difficulty in identifying the species correctly. Because the *S. mentella* stock is so much larger, even a small amount of misidentified *S. mentella* will impact on the *S. norvegicus* assessment. The difficulty is most pronounced for the younger fish, which makes survey estimates for the younger fish potentially unreliable. However, although species identification becomes easier for larger fish, misidentification can still occur, and thus there is an external error in all of the data for both surveys and catches. Secondly, the relatively minor nature of the stock means that there is no dedicated survey that covers the whole population structure. The fish are mostly in the shelf area of the Barents Sea as juveniles, and are thus at least partially covered by the winter survey. However, mature individuals mostly move out of the area of this survey. The coastal survey also covers a fraction of the stock, however this is a minor portion of the distribution area and the fraction of the stock within the survey area may vary from year to year. Finally, as a minor stock, the number of age readings conducted is somewhat limited, and data is rather noisy. The stock has also suffered from a prolonged period of apparent recruitment failure, with some signs of one or two moderate yearclasses over the last several decades.

3.1 Current assessment and issues with data and assessment

The assessment model proposed here is a modified version based on the assessment model (GADGET) for *S. norvegicus* (golden redfish, previously reported within ICES as *S. marinus*) in Subareas I and II which has been run during the AFWG, as an experimental model since 2006 and as the assessment model following the WKRED benchmark in 2012 (ICES 2012, ICES 2017). This model allows the use of length data directly, which goes some way to mitigating the limitations of the age data. In brief, the model is a single-species, forward simulation, age–length structured model, split into mature and immature components. Following analysis at the meeting, the mode is run on an annual time step. There are three commercial fleets (a gillnet fleet, a longline fleet and a combined trawl and other gears fleet, but prior to 2009 the trawl and longline fleets are combined). All fleets are treated as having exact catch in tonnes value. There are two surveys (the winter survey and the coastal survey). The winter survey is treated as an index of abundance, no q is forced in the tuning, and no information on absolute abundance is given. A second survey (the coastal survey) was previously removed from the model due to erratic variations in the survey index. However, this survey is being considered for use in the present benchmark, though only the length distributions and not the overall index. Neither survey is directed at redfish, and both only give a highly partial view of the stock. Growth, natural mortality, and fishing selectivity are assumed constant over time (although see the experiments section), and recruitment is estimated on an annual basis (no SSB–recruit relationship). There are serious uncertainties around the stock identification, where a minor species misidentification of *S. mentella* individuals as *S. norvegicus* would have a large impact on the *S. norvegicus* assessment. This applies to overall biomass estimates, but especially to the younger fish making recent recruitment signals highly uncertain.

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 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 2016, with annual time-steps (n.b. the model is running until 2017, but using preliminary data for 2017 catches). 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. norvegicus* 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. norvegicus* was considered to have von Bertanlanffy growth, with estimated parameters of K=0.05, *L-inf*=72.6. The length–weight relationship W=0.000015*L3.0 (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 generally 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, based on evaluations at WKRED 2012. A profiling exercise was undertaken, which showed very little contrast in the likelihood score between M=.03 and M=0.1. It is likely that for both S.norvegicus and *S. mentella,* cod predation can impose a variable, but sometime high, mortality on young fish. If this is the case, then the model would employ a too low mortality for fish at the youngest ages. It should be noted that this underestimation would only be on the youngest ages, and underestimating the mortality would result in reduced estimate of recruitment rather than reduced fishable stock, since much of the data comes from the middle and large individuals. Thus, this lack of predation mortality would not affect the fishable biomass of the stock, but it can be expected to result in poor fit to the youngest ages in the surveys. If data were available to inform this predation level then the fit to the youngest ages in the survey might be improved.

Information on preparation of Norwegian landings data, including species identification issues, logbook harmonization and the “SAS biomass program”, is provided in WD 1 Preparation of Norwegian and international landings data for beaked redfish (Sebastes mentella) and golden redfish (Sebastes norvegicus) (WD Vollen and Nedreaas, 2018). Information on preparation of International landings data, including species identification issues, is also found here. The fishing was handled as three main fleets, plus one minor gear. The main fleets catching redfish are gillnet, trawl and longline, with a very minor catch by handline. The handline catches are included with the longline fleet within the model. For practical reasons it was not feasible to separate the trawl and longline data prior to 2009, and thus these are combined in the period 1986-2017. In addition to catch-in-tonnes, annual numbers caught at length, and age–length keys have been used. The length and age-length data are from Norwegian landings only. The age range is 5 years to 30+ years, whereas length range is 6 cm to 59+ cm (1990-2008) or 6 cm to 79+ cm (2009-2017).

The format of the selectivity (a logistic curve) was selected and assumed to remain constant over time for each fleet (although this constant assumption is relaxed in the experiments presented below). The predominance of the larger fish in both catches suggests that the fishing selectivity is not strongly dome shaped. 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.

Information on survey indices and the “SAS survey program” is provided in WD 2 Description of scientific surveys used for the assessment of beaked and golden redfishes in ICES subareas 27.1 and 27.2 (WD Planque et al., 2018). Two surveys are considered here. For the winter survey (BS-NoRu-Q1 (BTr)), data were used as age–length keys giving the age–length distribution within a single year, and as a purely length based survey index variations in numbers by length within each year, and as an overall aggregated survey index. The age-length data and the length distributions are only used as relative numbers within a given year, while the survey index gives year-to-year information. The winter survey largely covers the immature part of the stock, and we thus exclude data on fish older than 15, and assume that the aggregated survey index only relates to fish of age 15 and below. Prior to 1992 only length and weight data were recorded. In the absence of direct data, the age–length key for 1992 was also used as age–length key for 1990–1991. This is less than ideal, but aids in constraining the model estimates for the earliest period. Selectivity for the survey was set to be logistic. An experiment was run allowing asymmetric dome shaped selectivity, however the model selected parameters which resulted in the right hand part of the curve being flat.

For the coastal survey (NOcoast-Aco-Q4), only length distributions were employed. The aggregated survey index varies too much year-to-year to be driven by the population dynamics, but is probably a result of variable coverage (not surprising in using a coastal survey to monitor an ocean stock). The rationale for including the length distributions is discussed in the model fits section, below.

Dataset name	description	Time range
fleet.data	Total catch by fleet	1986-2017
lon.alkeys	Age length keys in longline fleet	2009-2017
lon.ldist	Length distribution in longline fleet	2009-2017
trawl.lon.alkeys	Age length keys in combined trawl and longline fleet	2005-2008
trawl.lon.ldist	Length distribution in combined trawl and longline fleet	1986-2008
trawl.alkeys	Age length keys in trawl fleet	2009-2017
trawl.ldist	Length distribution in trawl fleet	2009-2017
gil.alkeys	Age length keys in gill fleet	2005-2017
gil.ldist	Length distribution in gill fleet	1986-2017
alkeys_survey	Age length keys in winter survey	1990-2017
ldist_wintersur	Length distribution in winter survey	1990-2017
si_wintersur	Aggegate survey index in wintersurvey	1990-2017
mature_at_age	Mature at age data, from Norwegian commercial and survey data	1986-2017
ldist_cstsur	Length distribution in longline	1998-2016

Table 1. tuning data in the assessment model

Estimation

Estimation is conducted by minimizing a negative log quasi likelihood derived from a weighted sum of the negative log misfits for each of the available data-sets (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. There are no priors in the estimation, the initial parameter set should not influence the final optimised solution. The estimation process was iterated after convergence in order to improve confidence in the final solution. A jitter analysis was also conducted, 10 starting points chosen at random within the bounds all converged. However, the convergence time from such random starting values is rather lengthy, and during normal model development care is taken to have starting parameters which give a reasonable population to initialize the optimisation. Ranges were set for each estimable parameter; 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, with an estimated parameter on aits bounds being investigated further. Datasets were weighted via an iterative procedure, such that each dataset had an approximately equal contribution to the final likelihood score. If all the data are consistent with a common model solution, then this is equivalent to using the inverse of the score for each dataset as it's weight. However, if the data is inconsistent, then the procedure employed here effectively downweights outlying datasets.

Data Weighting

The data for this model is rather noisy, especially the age data, which is based on relatively limited sampling. However, the main sources of uncertainty lie outside the sampling of the data. None of the surveys used here were designed specifically for the *S. norvegicus* stock, and they each only have partial coverage of the stock. Furthermore, there are issues arising from the much larger population of S. mentella in the region. Small individuals are difficult to identify to species level, even by scientists, which there are uncertainties around the splitting of redfish catch into the correct species.

The model presented here uses a simple iterative weighting scheme to assign weights such that each dataset has approximately equal contribution to the final likelihood (mistfit) score. However, given that some fleets/surveys cover the whole time range, while others have been split in 2008/2009, an additional factor has been employed that halves the weight of the shorter time series fleets. If all dataseries were consistent in trends then this approach is essentially the same as fitting the model to each dataseries in turn, and inverting the residual misfit score to give a weight. This method optimized to all datasets at once to set weights, hence any datasets in disagreement with a consensus solution will be downweighted. The method thus represents a compromise between weighting by variance and disagreement in trends, and has the advantage of ensuring that all datasets contribute to the final fit, but none dominate.

Iterative weighting scheme.
*Set a weight so that each dataset has approximately equal contribution to the likelihood
*Re-optimise
*Repeat to convergence

Table 2. Weighting scheme

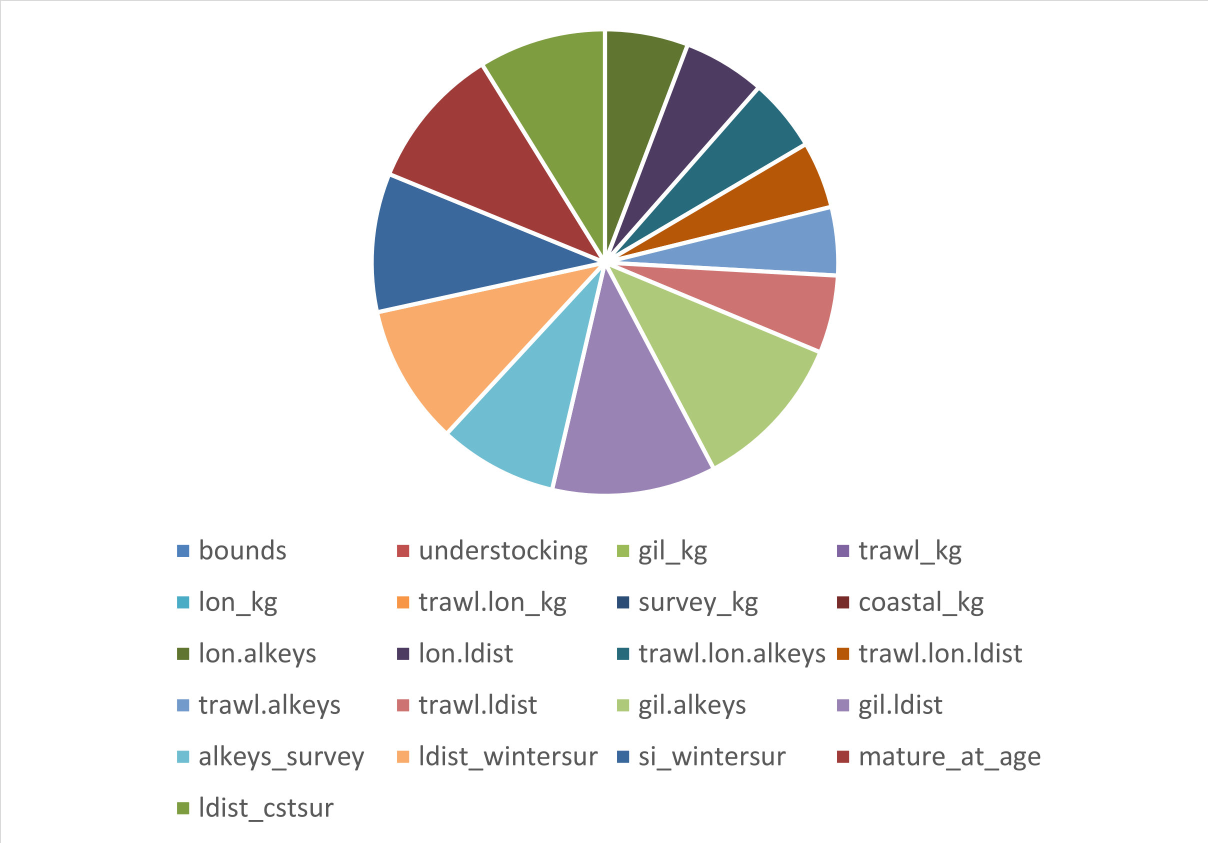


Figure 1. Contribution of likelihood components to overall score. Note that the first 8 components are technical ones for use in optimization, and should be (and are) zero in the final fit

Parameter list

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;

• Parameters governing commercial selectivity

Four for trawl&longline (1986-2008)

Four each for two periods in the gilfleet (1986-2008, 2009-2017)

Four the trawl fleet (2009-2017)

Two for the longline (2009-2017)

- Two parameters for selectivity of each survey;
- Initial population numbers at age 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, and experiments with changing fishing pattern are presented in the experiments section.

Data used for fitting the model are:

- Annual length distribution of the landings from the aggregated commercial fishing fleets;
- Annual age–length keys from the same fishing fleets;
- Length disaggregated length distributions and aggregated survey indices from the winter Norwegian Barents Sea bottom-trawl survey (February) from 1990 to present (joint with Russia since 2000);
- Age–length keys from the winter Barents Sea bottom-trawl survey;
- Length distributions for the Coastal survey are used in some of the runs presented here
- Maturity-at-age data
- Catch in tonnes is considered to be exact.

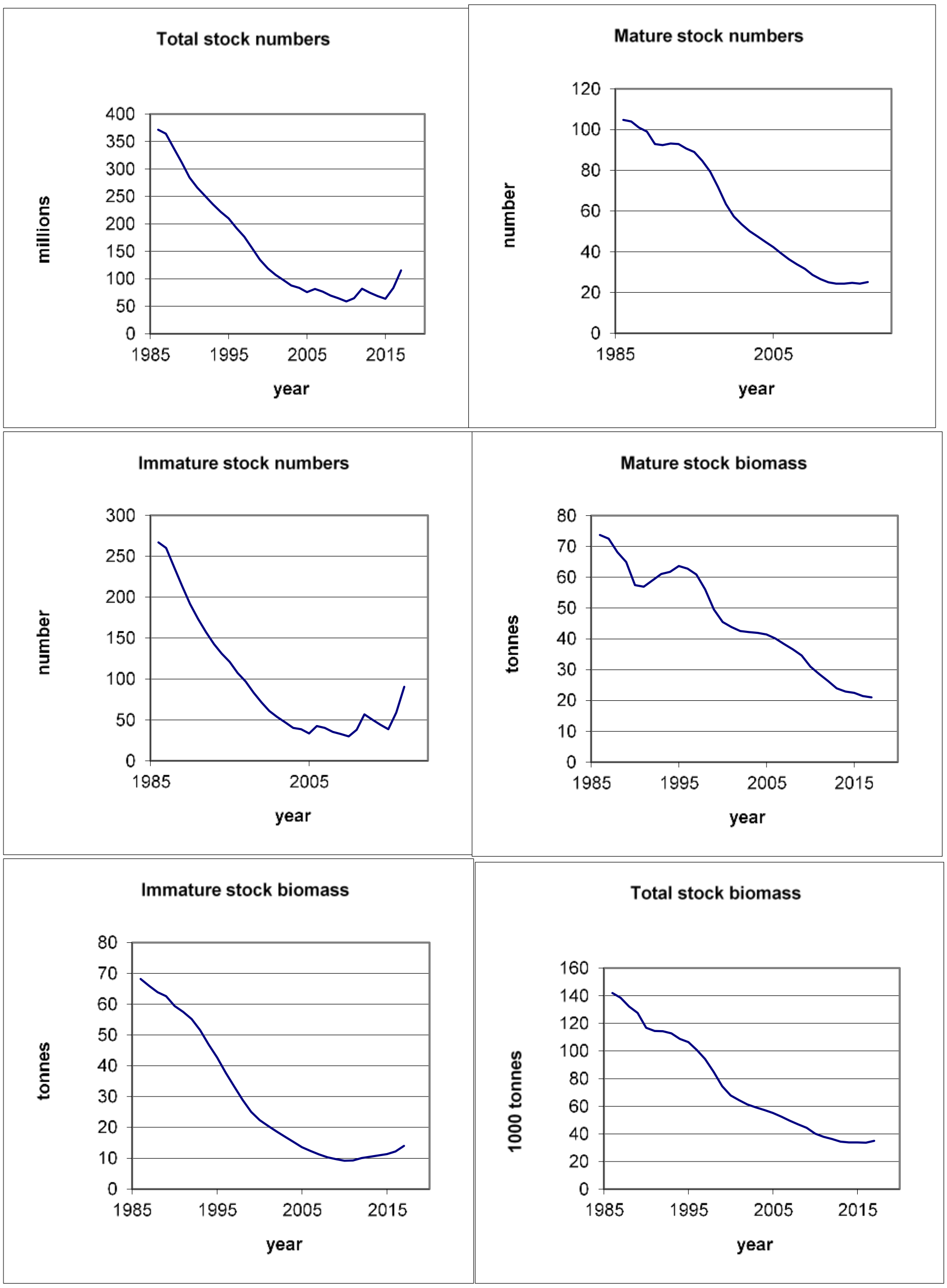
The model has been run to the end of 2017. It should be noted that the 2017 data is preliminary, and can be expected to be revised prior to the assessment at AFWG 2018. A relatively poor fit might be expected for this data, and we will therefore focus on the model fit up to the end of 2016.

Results

Base Case

The base case presented here uses the coastal survey length distributions, in 5cm bins, from 1998 to 2017. The fit to this survey is discussed in detail in section X.1. Based on the models ability to model the main features of the distribution, we propose that the dataset be included in the tuning series.

The results for the stock history (Figure 2) show the same broad trends as in the previous assessment model, with an overall declining stock, but with recent recruitment leading to an uptick in immature numbers and (later) immature biomass. This is now resulting in a flattening off of the mature stock numbers, indicating that these fish are now starting to mature. However, the newly maturing fish are still rather small, so the mature biomass is continuing to decline. Reassuringly, the signal of the maturing fish is now also showing up in the length distributions in the catch data (see “fits to data” section), indicating that this may be a genuine S. norvegicus recruitment event, not simply mis-identified small S. mentella.



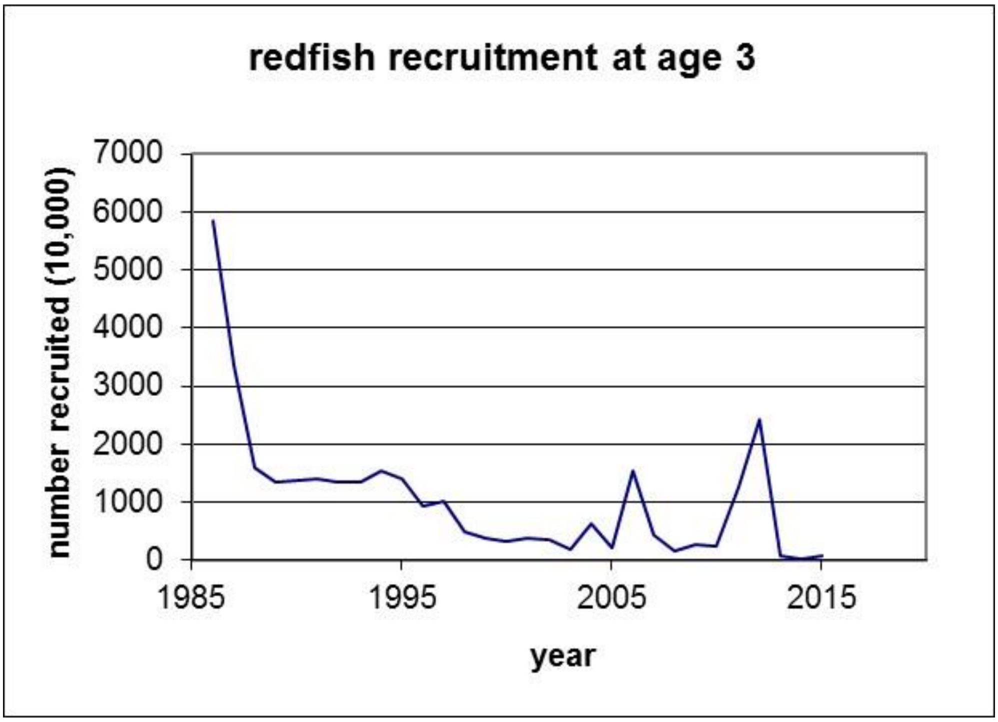


Figure 2. Modelled stock trends for S. norvegicus. Note that the model described here has been run using preliminary data for 2017. This will be updated prior to the 2018 AFWG, and thus the final point in the results shown here should be treated as provisional.

Fit to data

Fits to data are presented from 1990 to 2017. The model starts in 1985, with the earliest years treated as a "burn-in" period and are not presented. Also note that the 2017 catch data is preliminary, and fits to this should be treated with caution.

Length distributions in the catch

The fits to the length distributions in the catch are shown in Figures 3 to 6. Although there are year-to-year variations in the data which the model smooths out, the fit is generally good. The key misfit here is that there are fish in the data in the 60cm+ group of the combined trawl and longline fleet since 2001. This suggests that the fleets should be separated further back in time.

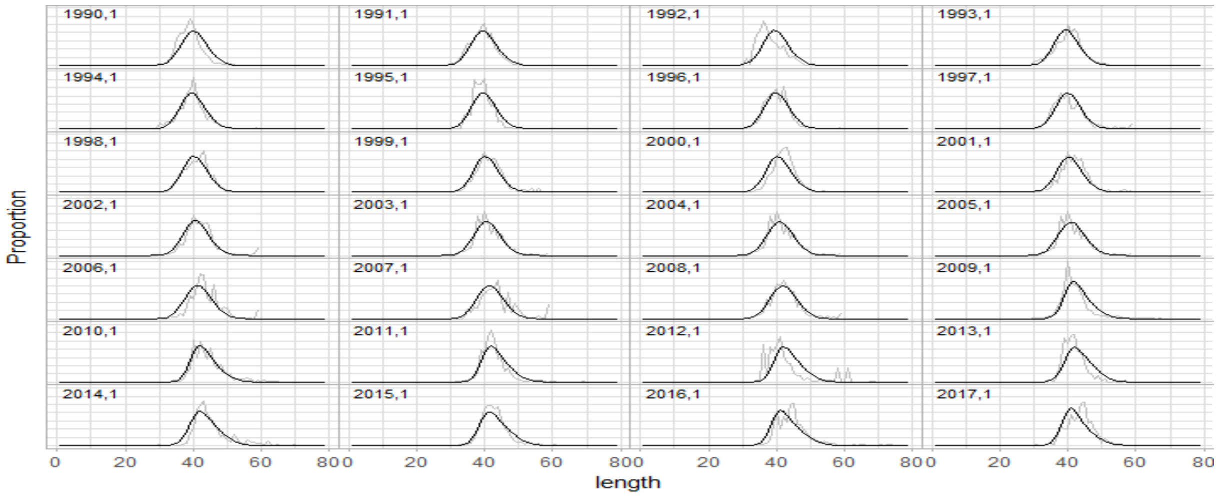


Figure 3. Length distributions in the gil fleet: solid is model, grey is data

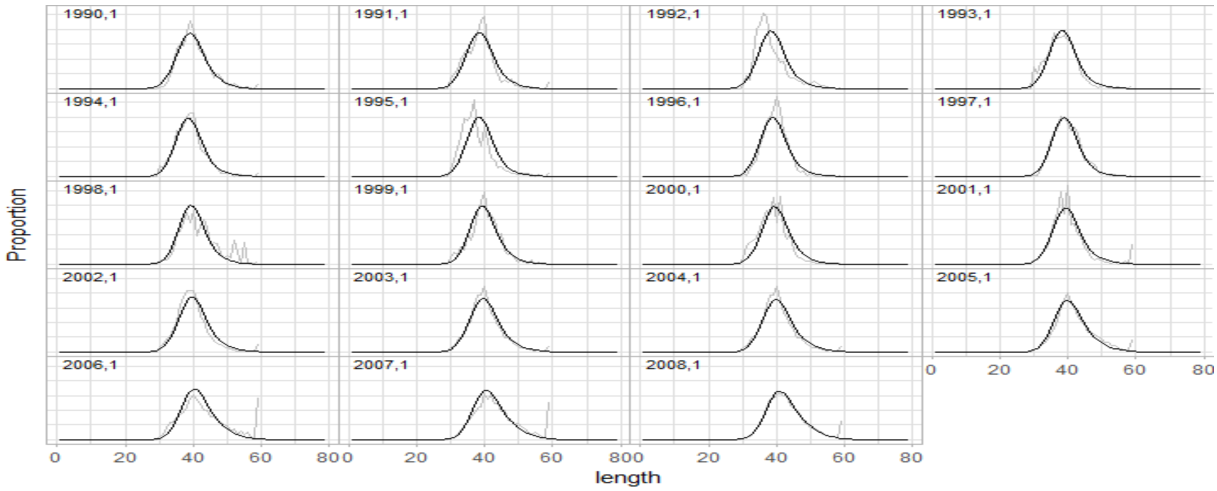


Figure 4. Length distributions in the combined trawl and longline fleet: solid is model, grey is data

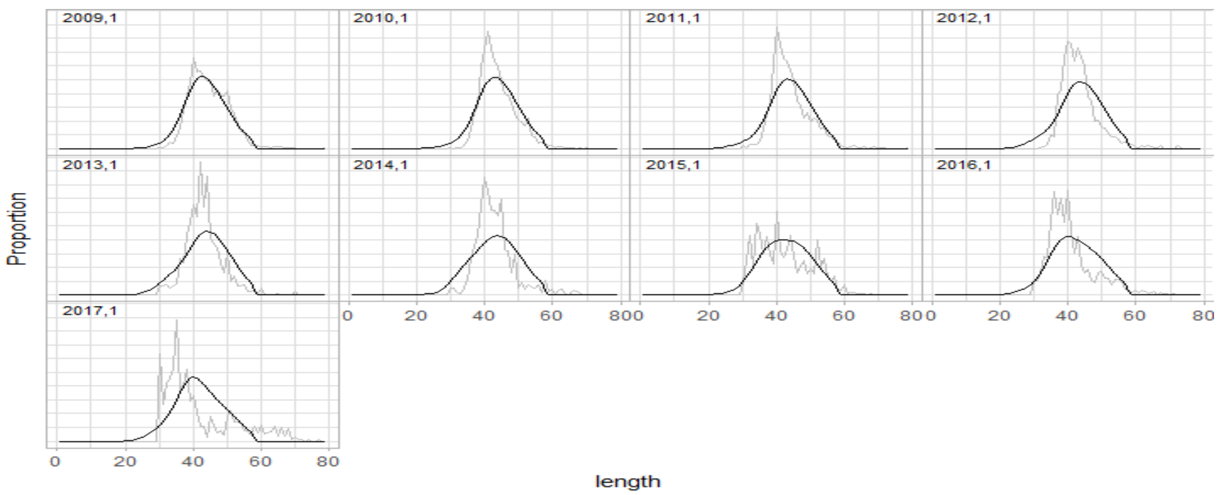


Figure 5. Length distributions in the trawl fleet: solid is model, grey is data

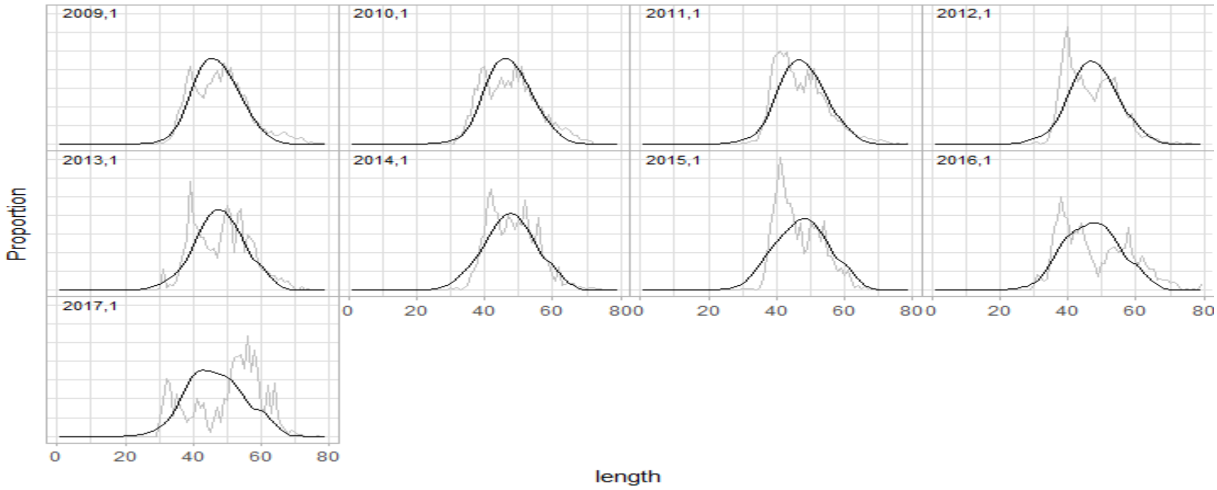


Figure 6. Length distributions in the combined longline fleet: solid is model, grey is data

Age fits to the catches

The model does not get any explicit age distribution data to fit to. However, it does use age-length matrices from the gilfleet, the trawl fleet and the wintersurvey. The sheer number of cells in this matrix for each timestep makes displaying the age-length fits problematic. We here show the fits to the age data (i.e fits to the age-length data aggregated into age groups), Figures 7-10. Note that since the model is not simply trying to fit the age data, one would expect a rather worse fit here than might be expected if age distributions were used as tuning data. Even given this, the fits are somewhat poor, suggesting noisy and difficult data. Experiments with upweighting the age-length data still resulted in rather poor fits, suggesting the difficulty lies within the age-length data, rather than in any inconsistency with other datasets. One point to note is that the model suggests that the gilfleet and trawlfleet should both be showing the 2003 yearclass entering the fishery, but this only shown in the data for the trawlfleet. It is therefore likely that there is an unaccounted change in selectivity in the last couple of years in the gilfleet, and as the time series is extended this should be re-examined and potentially included in the model. Note also that the longline fleet is showing signs of fish in the 30cm+ category in both the model and the data. This is the plus group in the data due to difficulties in age reading past age 30, but the model extends to age 40+. This ensures that the dynamics are modelled adequately in the model, albeit only tuned to the length data.

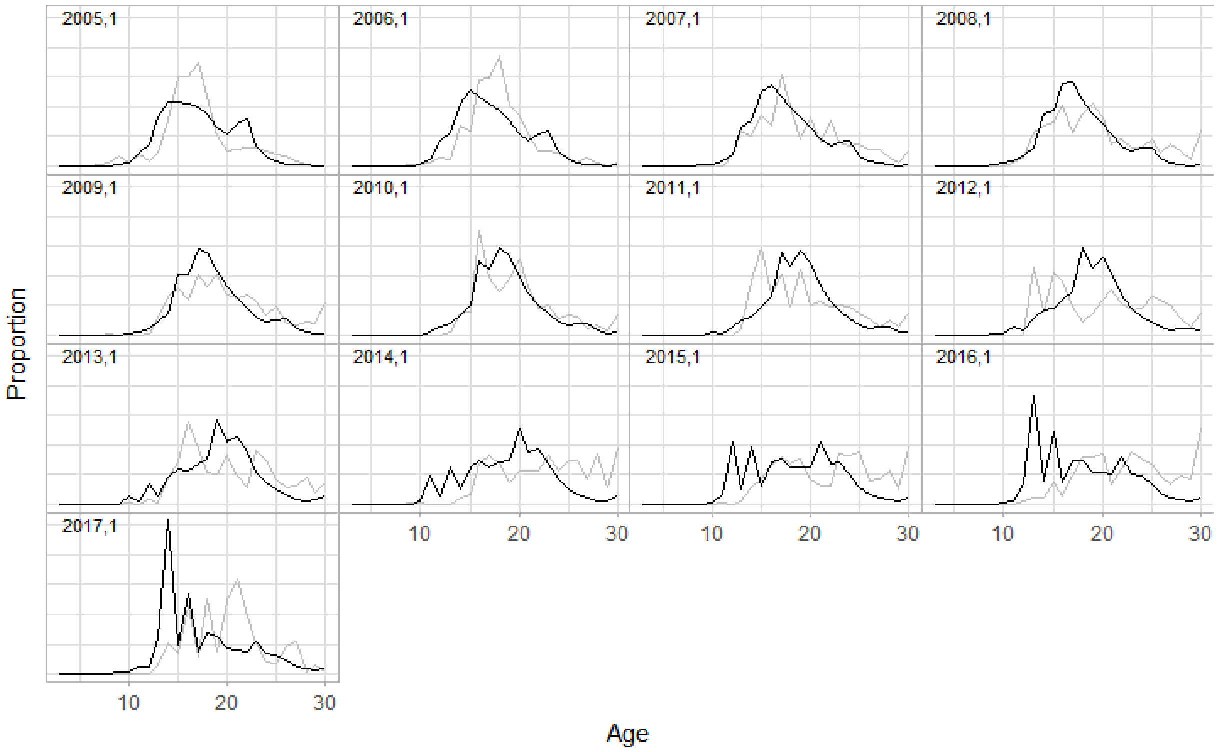


Figure 7. Age distributions in the gil fleet

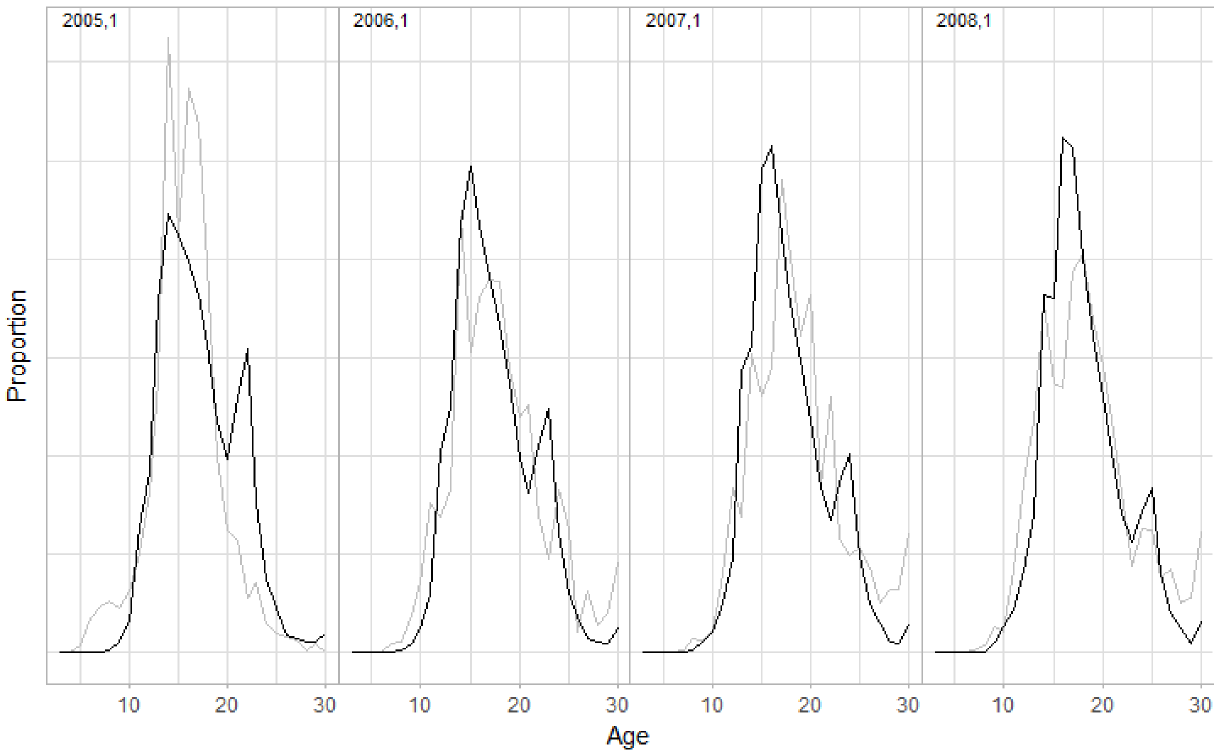


Figure 8. Age distributions in the combined trawl and longline fleet

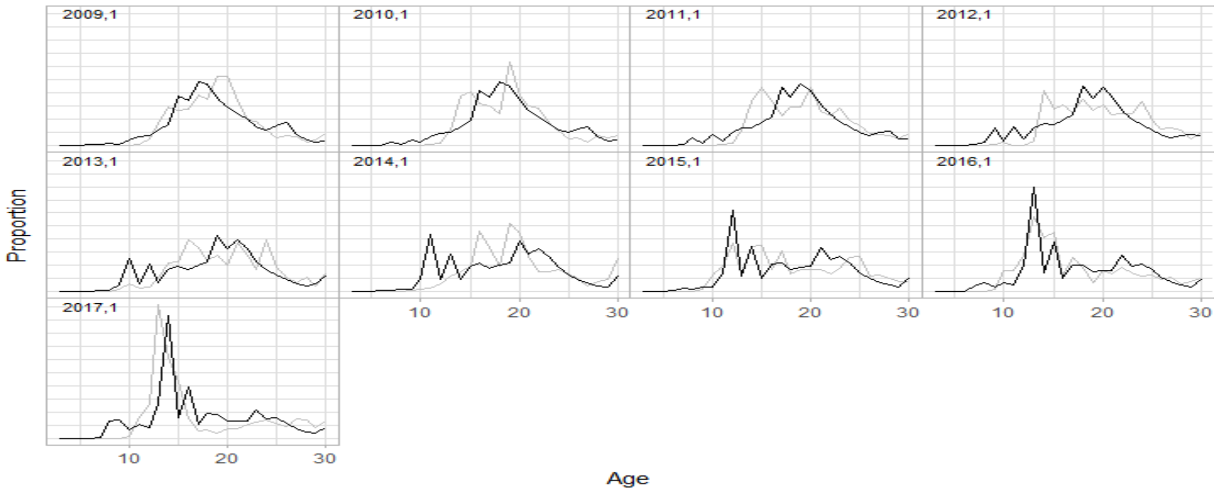


Figure 9. Age distributions in the trawl fleet

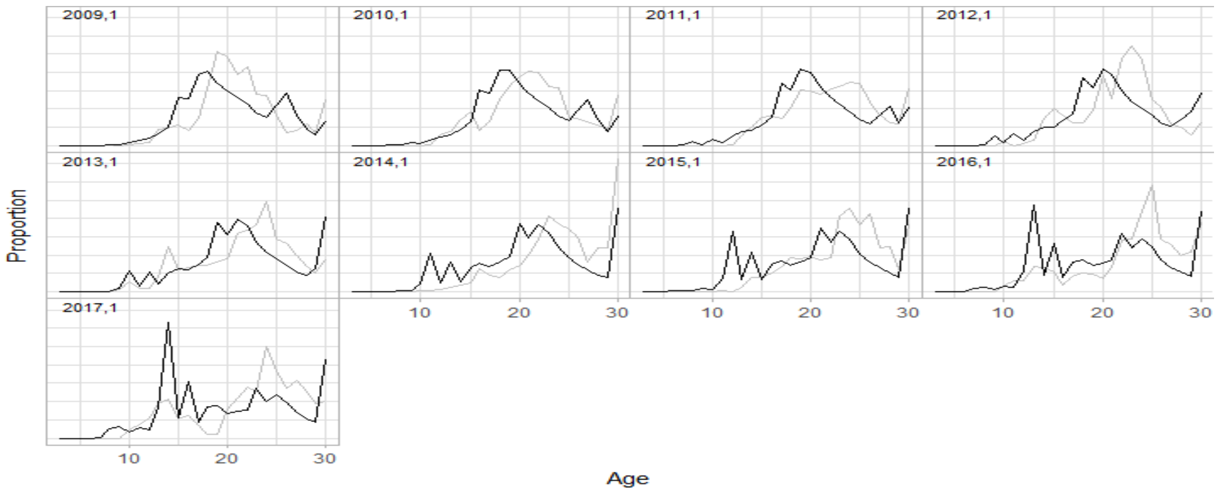


Figure 10. Age distributions in the longline fleet

Fits to the surveys

The fits to the surveys are shown in figures 11-14, below. The model tracks the trend in the wintersurvey index. Note that this index covers fish of age 1-15, which are mostly too small to be seen in the fishery. Thus, in the latest years the only information on the amount of these mostly immature fish comes from this dataset. It is therefore not surprising that the model tracks this series exactly in the most recent years.

The fits to the length distributions could, at best, be described as moderate. There are several potential problems with the data. One is simply noise, especially as these surveys are not designed as dedicated redfish surveys. A second issue for the smaller fish is that there is believed to be variable predation mortality from cod, which is not accounted for in the model. Since the model is fitting to data over the whole life span of the fish, a mis-specification in mortality for the youngest fish will manifest as incorrect estimates for numbers recruiting and in the youngest age classes. The model is thus not able to follow all of the details of either survey. However, the model does track the main trends of both surveys. Both surveys, and the model, all show an increasing amount of “medium” sized fish (<35) in the most recent years. In the wintersurvey, the fit is good up to 2011, and then struggles to match an incoming peak of small fish. Note that these are erratic in the survey, for example showing up in 2012 and 2014 but not 2013. The same signal of small fish shows up in the coastal survey, although the differing selectivity means that this does not show up until 2014. Note in the fit to the survey index, that this index covers mostly the unfished portion of the stock. This means that the good fit in recent years is because the fish are only found in the survey.

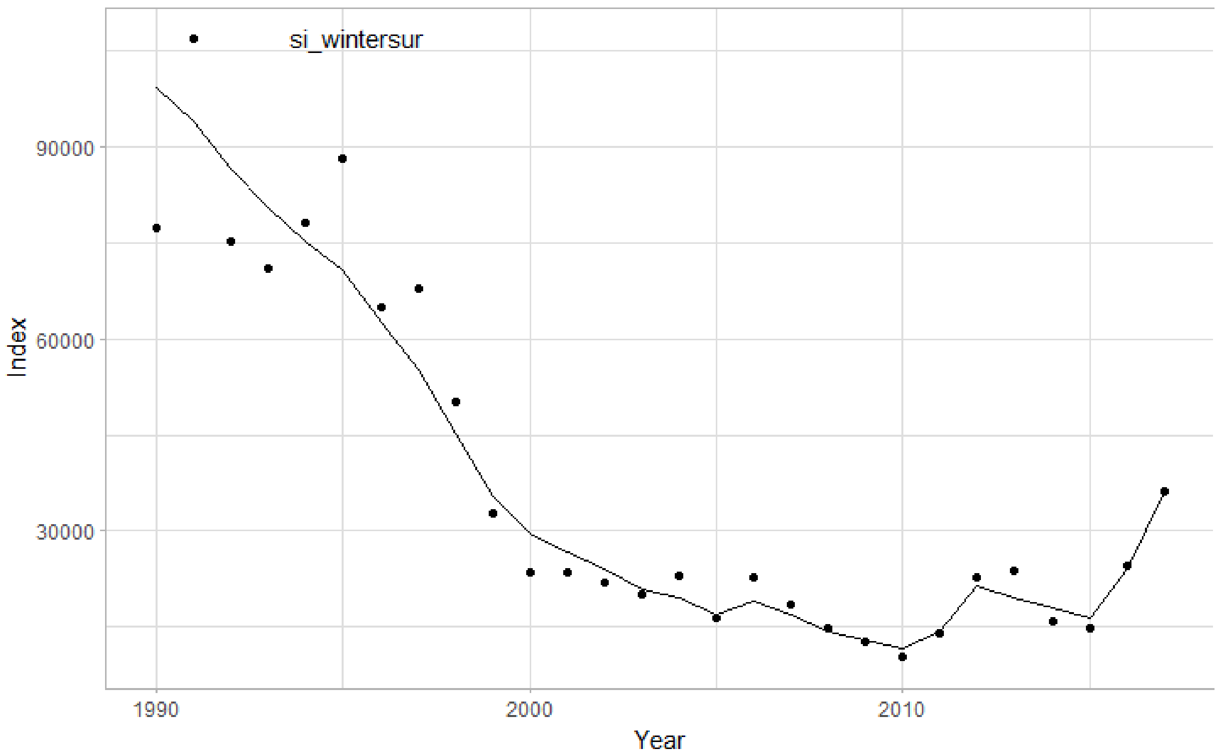


Figure 11. Fit to survey index in the wintersurvey

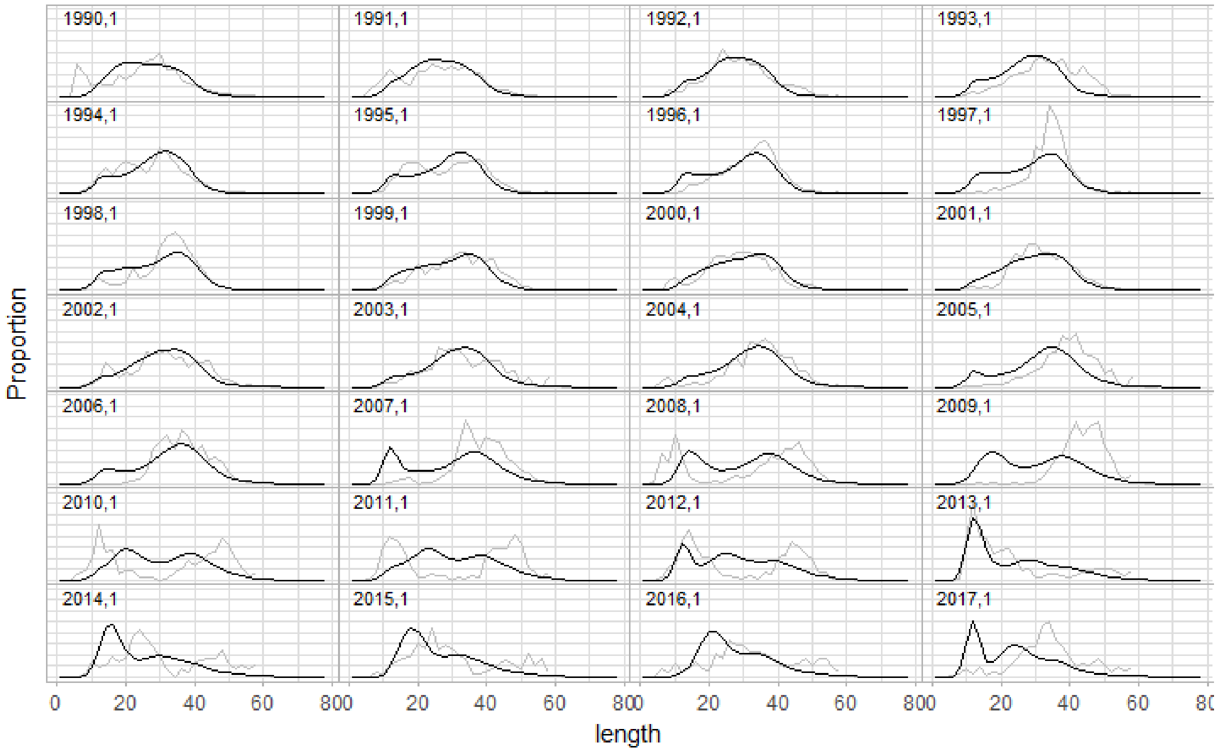


Figure 12. length distributions in the winter survey (pale line) and the model fit (heavy line)

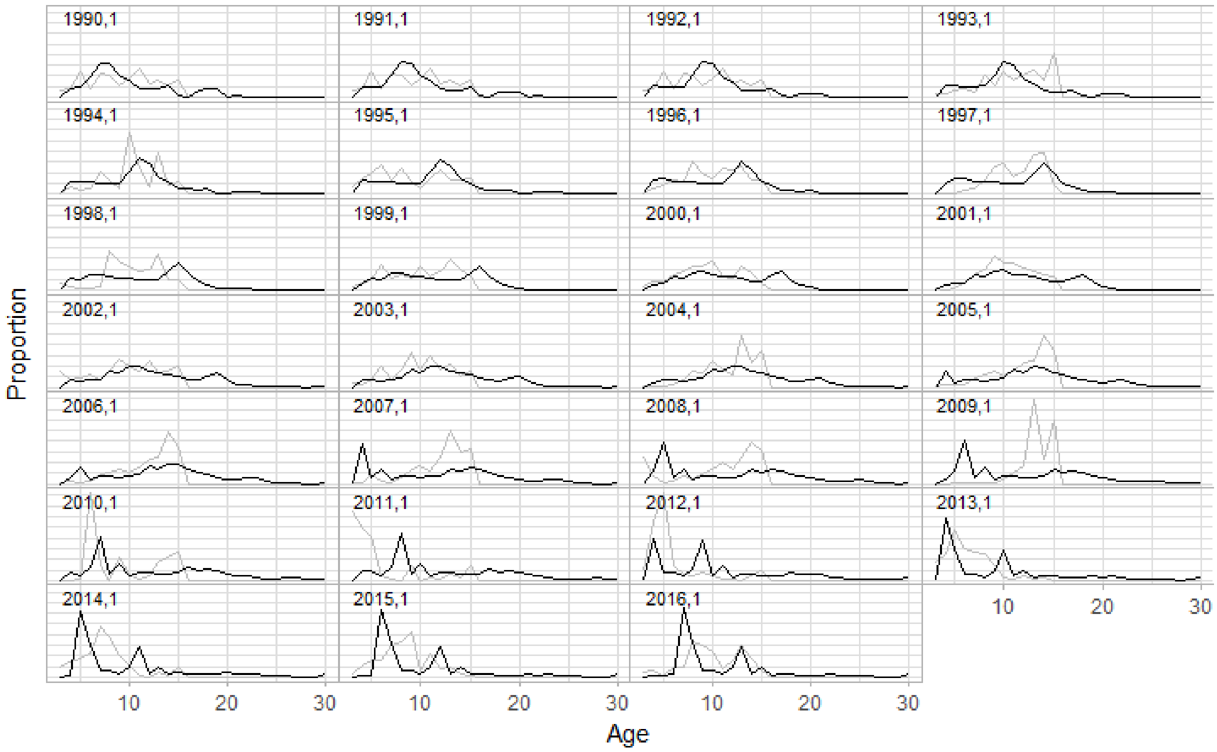


Figure 13. age distributions in the winter survey (pale line) and the model fit (heavy line)

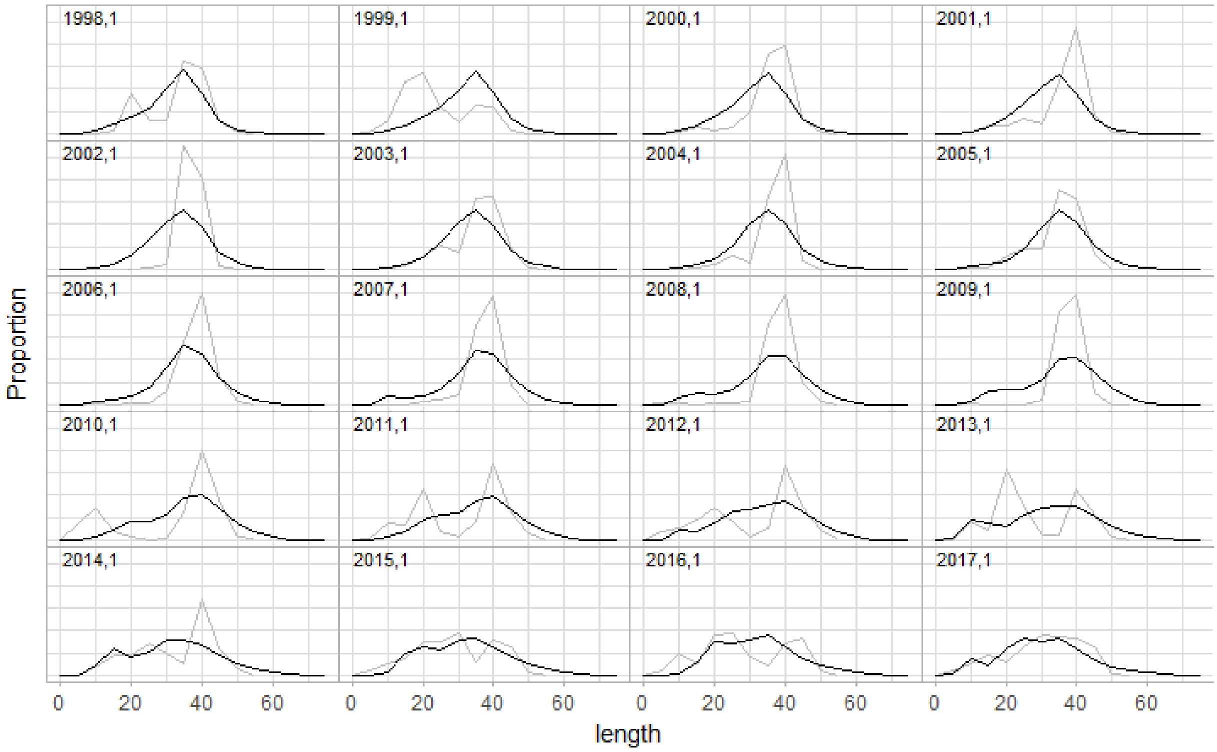


Figure 14. length distributions in the coastal survey (pale line) and the model fit (heavy line)

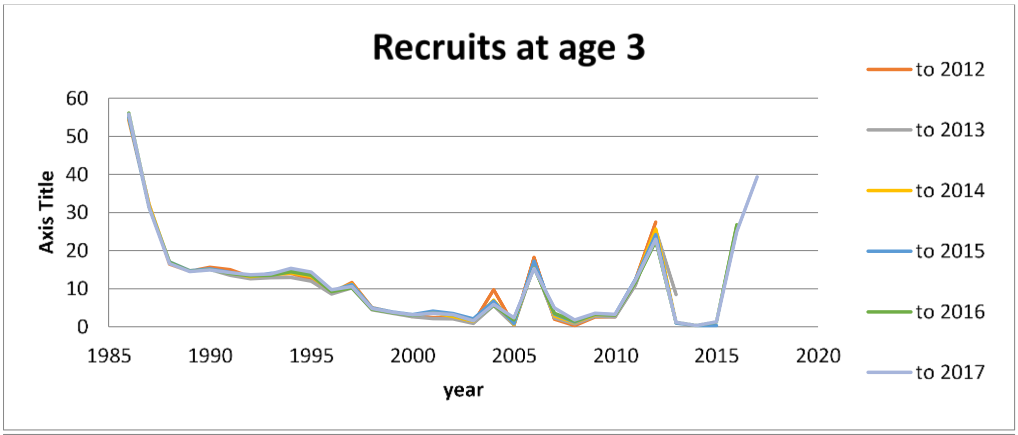
Retrospective

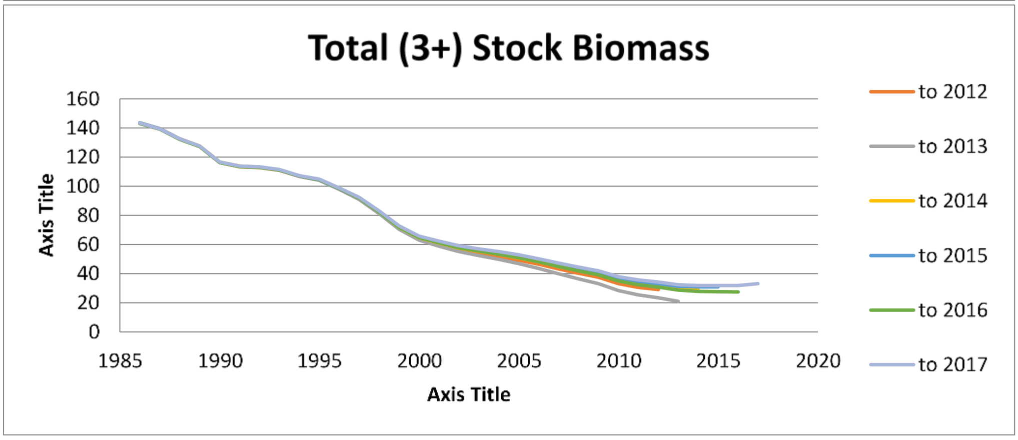
Again, note that although the model is run with 2017 data, this is preliminary.

The model had previously suffered from a consistent retrospective trend, where the mature biomass has been revised slightly upward each year (without affecting the overall downward trend). Associated with this is a slight upwards revision of the immature stock around 1990. It is likely that this is because the fishing has continued to catch the largest size categories of individuals, even though the medium size categories have disappeared from the catches and surveys. In order for the model to have sufficient large individuals to support this catch the population must be revised upwards. The present version of the model has reduced this trend, likely as a result of better modelling of the older individuals, better modelling of selectivity and how this has changes over time, and by having a slightly large mature stock within the model. Results are shown in Figure 15.

There is a notable upward revision in 2015. Such an upwards revision could be expected given that the data indicates that the previous downward trend has stabilized and is beginning to reverse. It is common for models to "overshoot" any turning point (either up or down), until enough new data is available to verify that such a turning point has been reached.

The trend in the retrospectives in the recruitment has been to consistently revise down the recent recruitments (since 2000). These had not, until now, been showing up in the fisheries data, and the revisions were based largely on the survey data (and the absence of these fish in the fishery). The 2003 yearclass (the 2006 point in the figure below) is now showing up in the fishery, and the model has revised this slightly upwards (although not to the original high estimate). The fact that the consistent downwards revision has gone is reassuring, and suggests that it may be possible to use this yearclass to calculate a limit reference point. The 2009 yearclass continues to be revised downwards, and we await it’s arrival in the fishery (likely in around 4-6 years) to confirm the size of this recruitment.





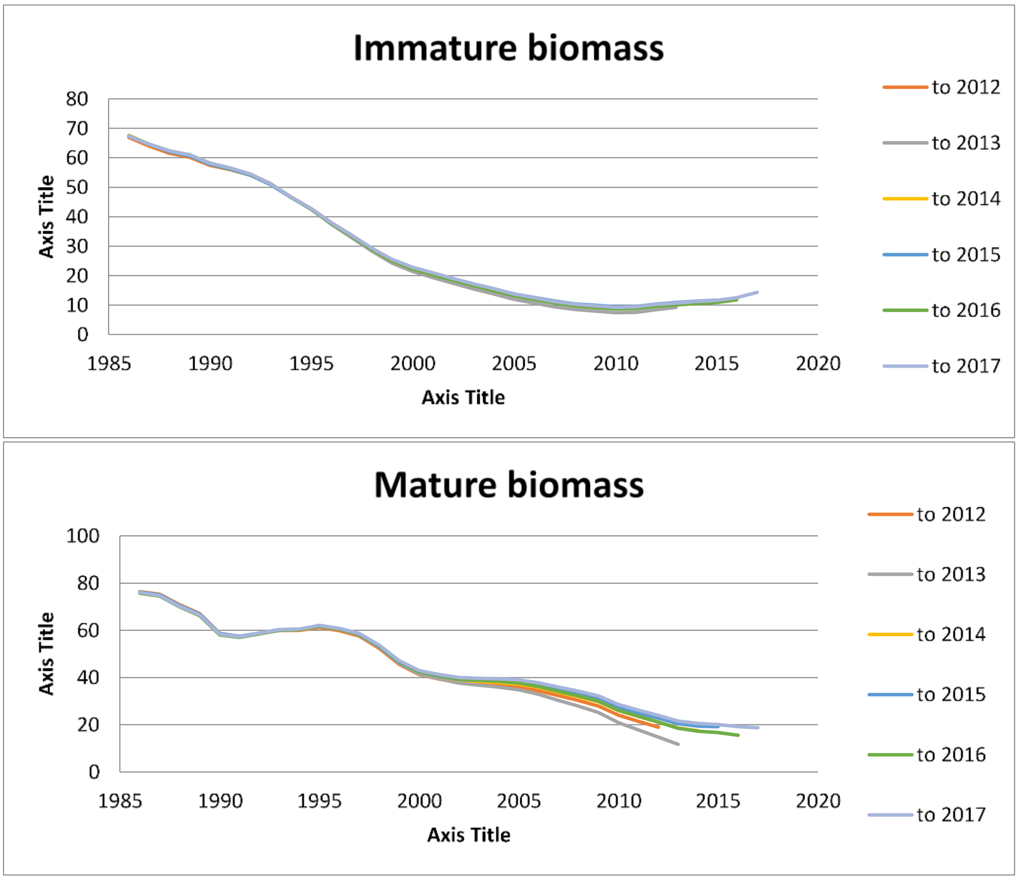
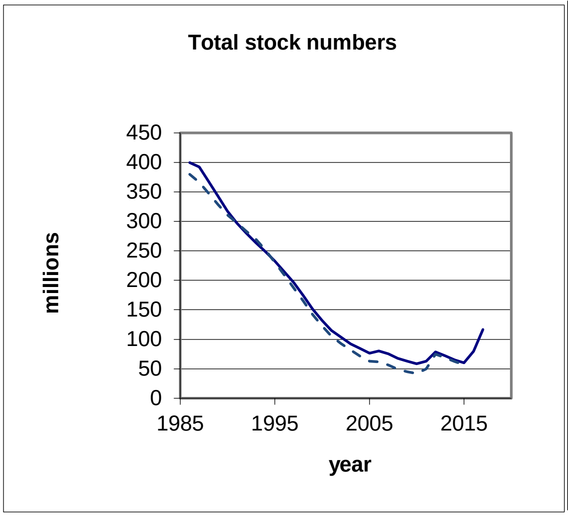
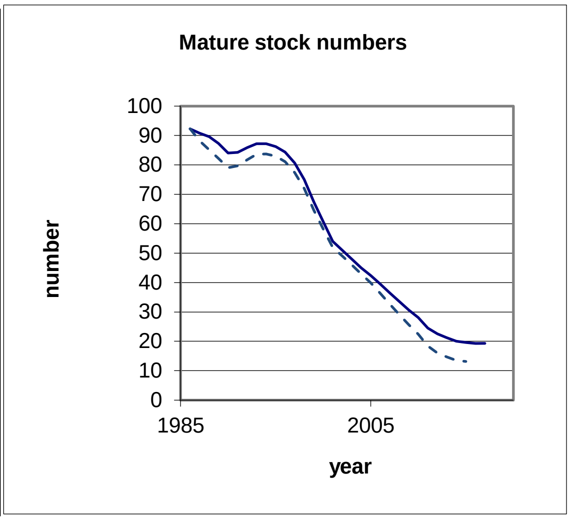


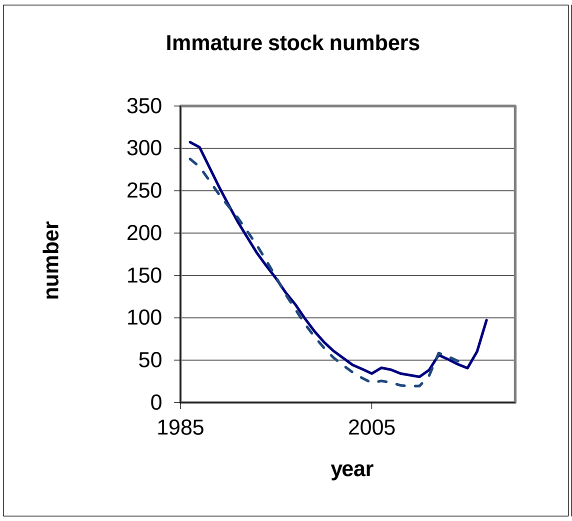
Figure 15. Retrospective trends 2012 to 2017, recruitment at age 3, total (3+) stock biomass, immature biomass and mature biomass.

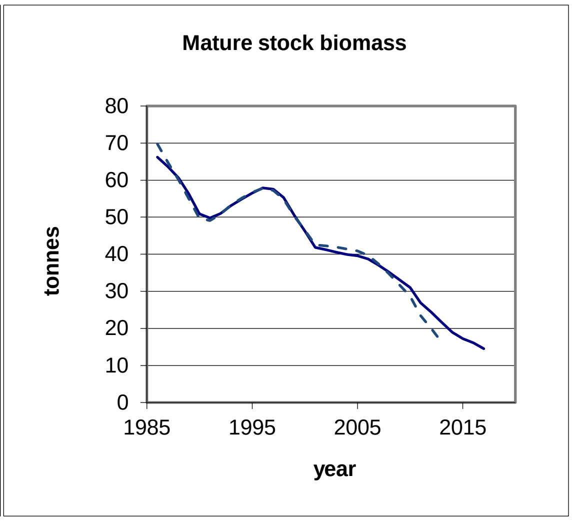
Compared to previous assessment

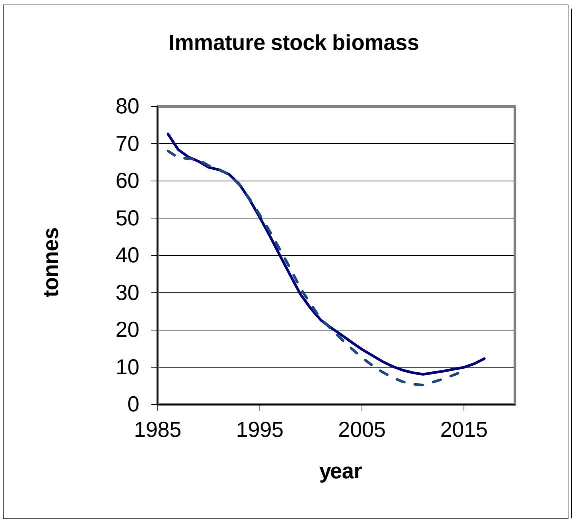
The previous assessment was run in 2016, using data to 2015. The model is now run with data for 2016 and (preliminary data) for 2017. These new data have, for the first time, shown the presence of newly maturing fish in the fisheries data. This would be expected to increase the mature biomass in the more recent years. In addition to two years of additional data, a number of changes have been made to the model. The coastal survey length distributions have been added, which gives additional confidence in the data on the fish from c. 20cm and up. The wintersurvey has also been reformulated to avoid possible errors in matching the survey age range to the model. The results of these changes have been to increase the biomass of the mature fish in recent years, with a smaller increase in the biomass of immature fish. Since the biomass is small compared to the catch, this has a relatively large impact on the estimated F (figure 16).

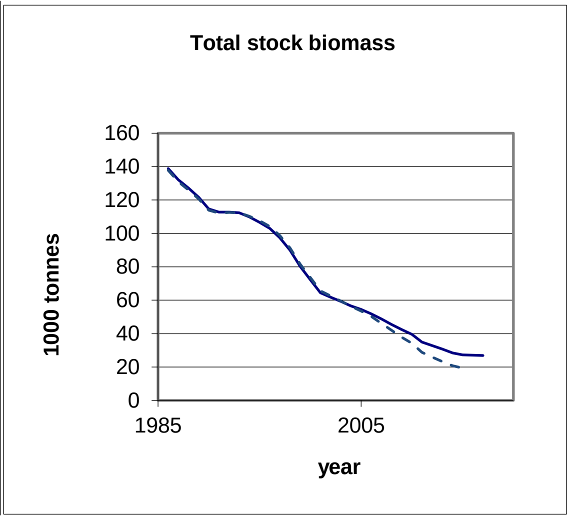

Total stock numbers
millions
450
400
350
300
250
200
150
100
50
0
1985
1995
2005
2015
year

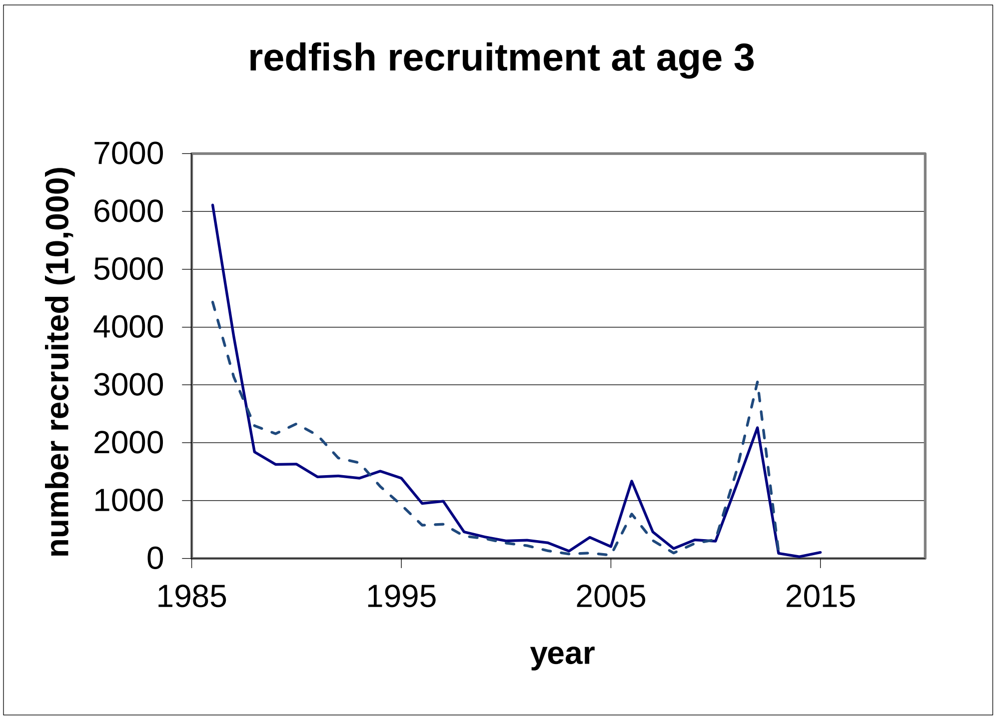

Mature stock numbers
number
100
90
80
70
60
50
40
30
20
10
0
1985
2005
year


Immature stock numbers
number
350
300
250
200
150
100
50
0
1985
2005
year


Mature stock biomass
tonnes
80
70
60
50
40
30
20
10
0
1985
1995
2005
2015
year


Immature stock biomass
tonnes
80
70
60
50
40
30
20
10
0
1985
1995
2005
2015
year


Total stock biomass
1000 tonnes
160
140
120
100
80
60
40
20
0
1985
2005
year



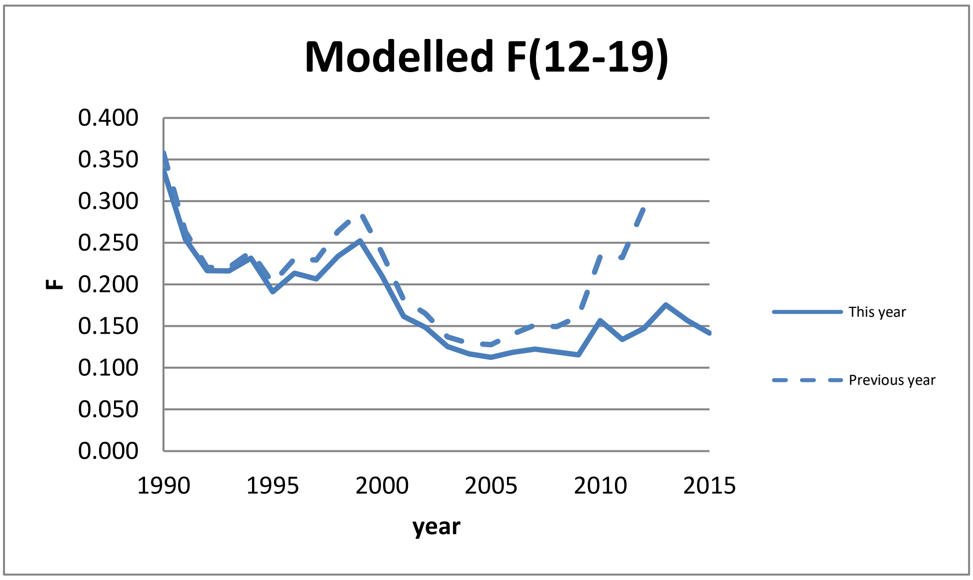


Figure 16. Model summary trends (solid blue line) compared with previous assessment model (dashed line)

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Statistical-catch-at-age model for *S. mentella* in ICES areas I and II

Working Document 4, ICES WKREDFISH Copenhagen 29 January-2 February 2018

Benjamin Planque[1], Alf Harbitz[1], Tor Arne Øigård[2]

[1]Institute of Marine Research, Norway

[2]Norwegian Computing Centre, Norway

1 Introduction

Statistical catch-at-age (SCA) is used to estimate abundance, recruitment and fishing mortality for many exploited fish stocks. In contrast to virtual population analysis (VPA), in SCA fishery catch-at-age data are assumed being measured with error. Under many conditions, SCA provides more accurate estimates of stock size and other important management quantities than other stock assessment techniques (Wilberg and Bence, 2006). An introduction to SCA can be found in Chapter 11.3 in Haddon (2001). SCA was applied for the first time for beaked redfish (*Sebastes mentella*) in ICES subareas 27.1 and 27.2 in 2012 (Planque, 2012) and has since been used as the main quantitative stock assessment model for this stock. This document reports on an update of this assessment model. The first implementation of SCA was done in AD Model Builder (ADMB Project, 2009).

The current implementation is done in Template Model Builder (TMB, Kristensen et al., 2016). Before new developments were initiated, the original version of the model was translated from ADMB to TMB during a workshop held in Lauklines (Norway) in February 2016. The TMB and ADMB versions delivered identical results.

Additional workshops took place in 2017 to implement several new features including: integrating a stochastic process model i) for recruitment at age 2, ii) for the annual component of fishing mortalities, and iii) to account for annual changes in fleet selectivities-at-age. In addition, iv) a *right trapezoid* population matrix, v) coding of older ages into flexible predefined *age-blocks*, and vi) integrating of data from pelagic surveys in the Norwegian Sea were implemented. The purpose of these new features was to reduce the number of parameters to estimate (i, ii), include new data on the older age fraction of the population (iv, v, vi) and account for possible temporal changes in selectivity linked to changes in the national and international fisheries and their regulations (iii).

2 Model

2.1 Population model

The basic equation SCA 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*):

(1) $$N_{y,a} = N_{y-1,a-1}e^{-Z_{y-1,a-1}}, a = 2, \dots, A.$$

Here *A* is the +group, i.e. the maximum age group containing fish of age *A* and older and set to 19 years, and $Z_{y,a}$ is the total mortality for year *y* and age *a*. In the special case of the +group the contribution of the +group in the previous year should be added:

(2) $$N_{y,A} = N_{y-1,A-1}e^{-Z_{y-1,A-1}} + N_{y-1,A}e^{-Z_{y-1,A}}$$

2.2 Mortality

$Z_{y,a}$ can be decomposed into 2 components: the natural mortality $M_{y,a}$ and the fishing mortality $F_{y,a}$. In SCA the fishing mortality is derived from two quantities: the fishing mortality in year *y*, F_y, and the fleet selectivity at age, $F_a \in [0,1]$. The simple multiplicative relation between F_y and F_a relies on the assumption that these are independent of each other. The resulting fishing mortality at age *a* in year *y* is given as $F_{y,a} = F_y F_a$. The resulting equation becomes:

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

Fitting the model requires estimating F_a's, F_y's, the number of fish in year 1, for all ages ($N_{1,.}$) and the number of fish of age 1 for all years ($N_{.,1}$). The natural mortality cannot be estimated for each year and age, since such estimates would be confounded with the fishing mortalities. However, it is in principle possible to estimate a fixed mortality term $M_{y,a} = M_0$ identical for all years and all ages.

2.3 Right trapezoid population matrix

Standard cohort population models use a *rectangular* population matrix of number-of-years times number-of-ages, the last age being the +group. It is however possible to expand the rectangular population matrix into a *right trapezoid* version in which the definition of the +group changes with time. In the case of *Sebastes mentella* in ICES subareas 27.1-2, observations start in 1992 and 18 year is the maximum single age observed so the +group consist of fish of 19 year and older. In 1993, we can calculate the number of fish at the single age 19 year based on the age 18 number from 1992 and applying Eq. (1). Correspondingly, by applying Eq. (1), we get a new 20+ group from the 19+ value in 1992. This relies on the assumption that fleet selectivity at age, F_a, for fish of ages 19 year and older is constant.

By iterating the procedure described above for 1994, we get a single value for fish of age 19 years by using fish of age 18 years from 1993 and we also get a population estimate for fish of age 20 years based on estimated number of fish at age 19 years from 1993. In addition, we get a new +group from fish of age 21 and older from estimated population of the *A* group obtained in 1993. Iterating year-by-year the original year-by-age matrix is now extended with a lower triangle with an increasing number of ages with time (Figure 1).

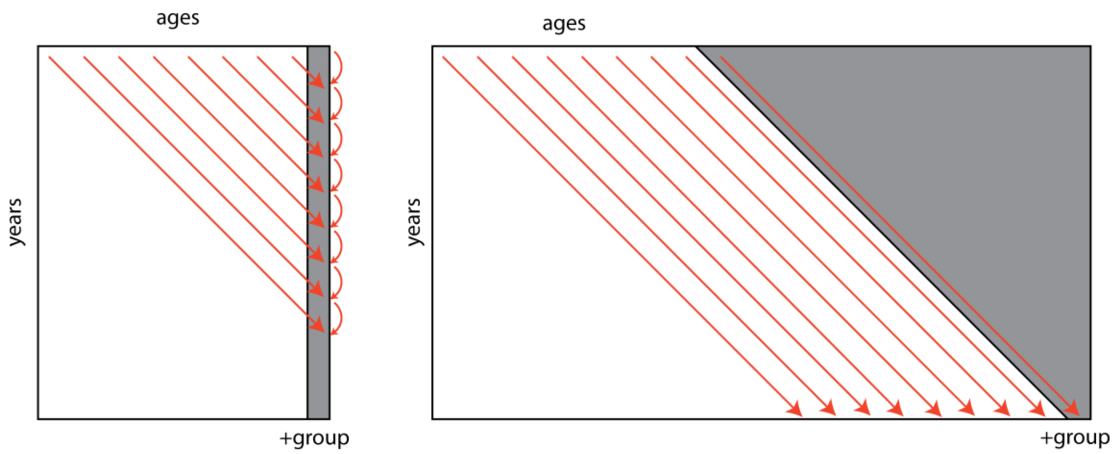


Figure 1. Left: the *rectangular* population matrix. Individual cohorts (red arrows) are followed until they merge into the +group. Right: the *right trapezoid* population matrix. Individual cohorts are followed throughout the modelling time period. The age of the +group increases with time.

2.4 Age blocks

Because age determination for older individuals is uncertain and because the number of individuals observed in older cohorts may be rather small, it is suggested that the older age groups can be combined into pre-defined age-blocks instead of being represented as individual ages. An age block is defined by a minimum and maximum age. When this is done, the data is reported as *numbers-at-age-block* rather than numbers-at-age. Similarly, although the population model operates on individual ages by year, the model output (and associated likelihood components) are provided for age blocks rather than for individual ages (Figure 2).

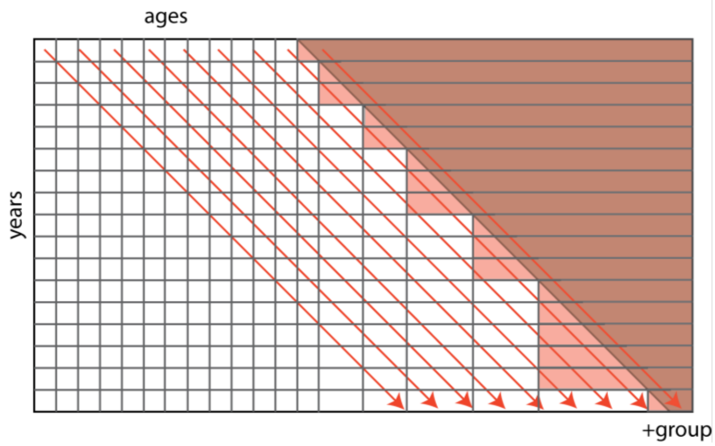


Figure 2. the *right trapezoid* population matrix with illustration of the age-blocks (vertical grey lines). In his example, age-blocks for young ages are individual years-of-age, but for older ages, numbers are grouped by block of several years-of-age. The +group in the data and model output follows the block structure (pink).

2.5 Recruitment

To estimate the temporal variation of the log recruitment, $\log(N_{y,1})$, a stochastic model for the log recruitment is integrated with the population model. Starting in year y_0 a first order auto-regressive (AR) process is used

(4) $$\log(N_{y,1}) = \upsilon_1 + \alpha_1 \log(N_{y-1,1}) + u_y^{(1)}.$$

Here α_1 is the AR parameter, υ_1 is the intercept and $u_y^{(1)}$ is a zero mean normally distributed random variable with standard deviation σ_1, i.e., $u_y^{(1)} \sim \mathcal{N}(0, \sigma_1)$. Instead of estimating the recruitment pointwise for each year the model estimates two parameters α_1 and σ_1, thus reducing the number of parameters to be estimated.

2.6 Fishing mortality

To estimate the temporal variation of the log-fishing mortality, log F_y, a stochastic model for the log fishing mortality was used, in the form of a first order auto-regressive process:

$$\text{(5)} \qquad \log F_y = \upsilon_2 + \alpha_2 \log F_{y-1,} + u_y^{(2)}.$$

Here α_2 is the AR parameter, υ_2 is the intercept, and $u_y^{(2)}$ is a zero mean normally distributed random variable with standard deviation σ_2, i.e., $u_y^{(2)} \sim \mathcal{N}(0, \sigma_2)$. Instead of estimating the log fishing mortality pointwise for each year the model estimates four parameters υ_2, α_2, σ_2, and the initial value of the log fishing mortality in year y_0, i.e. the $\log F_{y0}$, thus reducing the number of fixed parameters to be estimated.

2.7 Fleet selectivities

The selectivity of fleets F_a can be estimated for each individual age or can alternatively be approximated by a sigmoid function. The second option is chosen, as it significantly reduces the number of parameters needed to be estimated. The sigmoid is modelled following the Gompertz sigmoid equation:

$$\text{(6)} \qquad F_a = \frac{1}{2}\left(1 + tanh\left(\frac{(a - a50)}{w}\right)\right)$$

The use of selectivity functions significantly reduces the number of parameters to estimate. Here only two parameters need to be estimated: *a50* (the age of 50% selectivity) and *w* (smoothness/inverse slopes parameter).

Temporal change in fleet selectivity can occur due to changes in the national and international fisheries and their regulations (through changes in fishing gear, area, season or other fishing practices). In order to capture the potential temporal variations of fleet selectivity the age at 50% parameter, a_{50}, as well as the inverse slope parameter w are modelled as stochastic variables. A first order auto-regressive process is used in both cases, i.e.,

$$\text{(7)} \qquad a_{50,y} = \upsilon_3 + \alpha_3 a_{50,y-1} + u_y^{(3)}$$

and

(8) $w_y = \upsilon_4 + \alpha_4 w_{y-1} + u_y^{(4)}$,

where α_3 and α_4 are the AR parameters, υ_3 and υ_4 are the intercepts, and $u_y^{(3)}$ and $u_y^{(4)}$ are zero mean normally distributed random variables with standard deviations σ_3 and σ_4, respectively.

2.8 Catch model

Catch-at-age is modelled as:

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

where *f* is the fleet index. Two commercial fleets are considered. The by-catch fleet mostly operating in national waters are using bottom trawl, and the pelagic fleet operating in international waters and using very large pelagic trawls. The selectivity-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 only started to operate in 2006. Typically, the model is fitted on the log of the catch-at-age, log($C_{y,a,f}$), assuming a normal error distribution on the log-scale.

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

where $\varepsilon \sim \mathcal{N}(0, \sigma_5)$.

2.9 Survey models

2.9.1 Numbers-at-age

Survey indices, i.e. numbers-at-age in each survey, are modelled as:

(11) $\hat{I}_{y,a,s} = q_s \theta_{a,s} N_{y,a}$

where $\hat{I}_{y,a,s}$ is index for survey *s*, year *y* and age *a*, q_s is a survey scaling coefficient and $\theta_{a,s}$ is the survey selectivity-at-age. Note that θ_a not only contains gear selectivity, but also fish availability, being small if fish of a certain age is poorly presented at the fishing field though the gear selectivity is high. The above equation 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:

(12) $$\hat{I}_{y,a,s} = q_s \theta_{a,s} N_{y,a} e^{-\tau(M_{y,a}+F_{y,a})},$$

with τ the fraction of the year before the time of the survey, assuming stationary fishing activity throughout the year.

2.9.2 Proportions-at-age

In the Norwegian Sea, data from the pelagic survey (WGIDEEPS) is not believed to produce estimates of numbers-at-age that can be compared from year-to-year. However, the age distribution derived from this survey, i.e. proportions-at-age, is considered robust. The proportions at age are modelled as:

(13) $$\hat{P}_{y,a} = \frac{\theta_a N_{y,a}}{\sum_a \theta_a N_{y,a}} e^{-\tau(M_{y,a}+F_{y,a})}$$

Ages in the WGIDEEPS survey are reported beyond 19y and the data is provided in predefined age-blocks. The corresponding age-blocks are used in the model to predict proportions-at-age.

2.10 Survey selectivities

The selectivity of surveys (θ_a) can be estimated for each individual age or can alternatively be approximated by a function. Survey selectivity can increase or decrease with age due to a combination of gear-selectivity effects and ontogenetic migrations in/out of the survey area. The following piecewise polynomial function for survey selectivity is used:

(14) $$\log \theta_a = \begin{Bmatrix} \beta_1 a^2 + \beta_2 a + \gamma_1 \ if\ a < a_0 \\ \beta_1' a^2 + \beta_2' a + \gamma_2 if\ a \geq a_0 \end{Bmatrix},$$

where β's, and γ's are the polynomial parameters for the increasing and decreasing part of the selectivity curve. The two parts of the polynomial share the same inflexion point and the maximum value (at the inflexion point) of log(θ_a) is zero (so that maximum selectivity is unity). Therefore, only three parameters are required: a_0, b_1 and b_2 with:

$$(15) \qquad \begin{Bmatrix} \beta_1 = \frac{-b_1}{2a_0} \\ \beta_2 = b_1 \\ \gamma_1 = \frac{b_1^2}{4a_0} \end{Bmatrix} \text{ and } \begin{Bmatrix} \beta_1' = \frac{-b_2}{2a_0} \\ \beta_2' = b_2 \\ \gamma_2 = \frac{b_2^2}{4a_0} \end{Bmatrix},$$

where a_0 is the age at maximum selectivity and b_1, b_2 are the two slope parameters. For each survey, a set of selectivity parameters is estimated.

2.11 Likelihood components

Model parameters are estimated by maximizing the likelihood of the model given the data. There are up to nine likelihood components: Catch numbers-at-age, Survey numbers-at-age, Survey proportions-at-age, Total catch in weight and the likelihood components of the random effects (up to five).

2.11.1 Catch numbers-at-age

The negative log-likelihood component for the catch numbers-at-age in each fleet is given by:

$$(16) \qquad nll_C = \sum_i \left(\frac{1}{2}\log(2\pi) + \log(\sigma_f) + \frac{1}{2}\left(\frac{\log \hat{C}_i - \log C_i}{\sigma_f}\right)^2 \right),$$

where i is the observation index, σ_f is the standard deviation for the observation error of log-catches-at-age in fleet f, C_i is the observed catch-at-age and $\hat{C}_i$ is the predicted catch-at-age.

2.11.2 Survey numbers-at-age

The negative log-likelihood component for the numbers-at-age in each survey is given by:

$$(17) \qquad nll_n = \sum_i \left(\frac{1}{2}\log(2\pi) + \log(\sigma_s) + \frac{1}{2}\left(\frac{\log \hat{I}_i - \log I_i}{\sigma_s}\right)^2 \right),$$

where i is the observation index, σ_s is the standard deviation for the observation error of log-survey index in survey s, I_i is the observed survey index and $\hat{I}_i$ is the predicted survey index.

2.11.3 Survey proportions-at-age

The negative log-likelihood component for the survey proportions-at-age is given by:

(18) $$nll_p = \sum_i \left(\frac{1}{2}\log(2\pi) + \log(\sigma_p) + \frac{1}{2}\left(\frac{\text{logit}\,\hat{P}_i - \text{logit}\,P_i}{\sigma_p}\right)^2 \right),$$

where *i* is the observation index, σ_s is the standard deviation for the observation error of logit transformed proportions-at-age in survey, P_i is the observed proportion-at-age and $\hat{P}_i$ is the predicted proportion-at-age. Note that a survey can either be used to derived numbers-at-age or proportions-at-age but not both, so each survey only contributes to one likelihood component.

2.11.4 Total catch in weight

The negative log-likelihood component for the total catch in weight is given by:

(19) $$nll_{cw} = \sum_y \left(\frac{1}{2}\log(2\pi) + \log(\sigma_{CW}) + \frac{1}{2}\left(\frac{\log \widehat{CW}_y - \log CW_y}{\sigma_{CW}}\right)^2 \right),$$

where y is the year index, σ_{CW} is the standard deviation for the observation error of log-transformed catch-in-weight, CW_y is the observed catch-in-weight and $\widehat{CW}_y$ is the predicted catch-in-weight. The value of σ_{CW} can be estimated or set arbitrarily to a small value to ensure that the model tracks closely reported catches in tonnes.

2.11.5 Random effects

The negative log-likelihood estimators for the random effects given by:

$$nll_{RE,i} = \sum_y \left(\frac{1}{2}\log(2\pi) + \log(\sigma_i) + \frac{1}{2}\left(\frac{u_y^{(i)}}{\sigma_i}\right)^2 \right), i = 1, \dots, 4$$

where y is the year index, σ_i is the standard deviation for the random effect *i*.

3 Application to *Sebastes mentella*

A description of the fishery for *S. mentella* in subareas 27.1 and 27.2 is available from the Stock Annex.

3.1 Data

The data used for the SCA model consists of:

3.1.1 Catch data

Total catch-at-age as reported by the Arctic Fisheries Working Group (Table 6.6. in ICES 2017) for the period 1992-2016 and age groups 6-19+. This amounts to 450 observations.

Catch-at-age in the pelagic fleet as reported by the Arctic Fisheries Working Group (Table 6.8 in ICES 2017) for the period 2006-2016 and age groups 6-19+. This amounts to 198 observations.

Total catches in tonnes 1992-2016 (Table 6.1 in ICES 2017) and catches in tonnes from the Pelagic (international waters) fishery (Table 6.5 in ICES 2017). This amounts to 36 observations.

3.1.2 Survey data

Numbers-at-age from the winter survey, years 1992-2011, ages 2-15 (Table 6.16b in ICES 2017). This amounts to 280 observations.

Numbers-at-age from the ecosystem survey, years 1992-2015 (2010 missing), ages 2-15 (Table 6.15b in ICES 2017). This amounts to 322 observations.

Numbers-at-age from the Russian groundfish survey, years 1979-2013, ages 2-11 (Table 6.14 in ICES 2017). This amounts to 240 observations.

Proportions-at-age from the International Deep Pelagic Ecosystem Survey (Table 6.6 in ICES, 2011) for years 2008, 2009 and 2013, ages 7-75 (not reported in ICES, 2017). This amounts to 45 positive observations, when the data is grouped into age blocks (see section 3.3.2 below).

Additional data from the 0-group survey are reported but not used because the survey has high observation error, is poorly related to the following year-class strength and the mortalities between age 0 and 2 are unknown and probably highly variable between years(Table 6.6 in ICES, 2011).

Additional data (numbers-at-age or proportions-at-age) from the Egga-Sør and Egga-Nor surveys that take place along the continental slope in spring and autumn are not yet used in the model but are considered as potential candidates.

3.1.3 Maturity-at-age

Maturity-at-age is assumed to be identical in the stock and in the catches. Maturity-at-age is estimated for each individual year based on Norwegian data, years 1992-2016, ages 6-19+ (surveys and catches, Table 6.19 in ICES 2017). Individuals less than 6y are considered immature. This amounts to 350 observations.

3.1.4 Weight-at-age

Weight-at-age is assumed to be identical in the stock and in the catches. Weight-at-age is estimated for each individual year based on Norwegian data years 1992-2016, ages 6-19+ (surveys and catches, Table 6.7 in ICES 2017). Weight-at-age for ages 0-5 are set constant across years. This amounts to 350 observations.

3.2 Survey input parameters:

The parameter τ (timing of the survey) is set to 0.12, 0.75, 0.90 and 0,67 for the winter, ecosystem, Russian groundfish and WGIDEEPS surveys respectively.

The survey scaling factor is fixed for ecosystem survey in order to scale the model estimates. Considering that 1) the survey covers the entire distribution area of the stock (for ages 2-15), 2) only 20% (1/5th) of the biomass is caught by demersal trawling and 3) the survey index is reported in 1000's individuals the scaling factor was set to 1/5000. This ratio is corrected to account for the fact that the average selectivity for fish aged 2-15 in the ecosystem survey is around 0.7, and becomes 1/3500 (= 1/(5000*0.7)). With such correction, it is assumed that the ecosystem survey provides an absolute abundance estimate of the beaked redfish population.

Details of the preparation for individual datasets are provided in working documents numbered 1 and 2 of the ICES-WKREDFISH benchmark assessment 2018.

3.3 Model configuration

3.3.1 Time period and age groups:

The model is implemented for the period 1992-2016. The population model covers the age range 2-19+ in the starting year (1992). Using a *triangular* population matrix, the +group is increased by one year for every new year in the model. In the last year, 2016, the +group is a 43+ group (19+2016-1992 = 43).

3.3.2 Age-blocks

The selection of age blocks is set in an input data file and can be modified. The baseline model uses the following age blocks:

Block num	Min age	Max age	Block num	Min age	Max age	Block num	Min age	Max age
1	2	2	10	11	11	19	21	22
2	3	3	11	12	12	20	23	24
3	4	4	12	13	13	21	25	26
4	5	5	13	14	14	22	27	28
5	6	6	14	15	15	23	29	30
6	7	7	15	16	16	24	31	35
7	8	8	16	17	17	25	36	40
8	9	9	17	18	18	26	41	50
9	10	10	18	19	20	27	51	100

Age blocks are used when fitting the model with the data from the WGIDEEPS survey, in which numbers-at-age are reported beyond age 19.

3.3.3 Switches

All surveys, except the ecosystem survey, can be switched on/off in the model. The ecosystem survey must be included because this survey is used to set the absolute level in the model.

Recruitment (numbers-at-age 2y) can be estimated with parameter estimates for each individual year or by using random effects to model an AR(1) process. The random effect can be switched on/off. Note that when numbers-at-age 2y are not available for the last year(s), only the model with random effects can be used.

The annual components of the fishing mortalities (F_y) for the pelagic (international waters) and demersal (Exclusive Economic Zones) can be estimated with parameter estimates for each individual year or by using random effects to model an AR(1) process. The random effect can be switched on/off.

Fleet selectivities can be estimated as being fixed over time (same fleet selectivity every year) or as varying between years. This is done by using random effects to model an AR(1) process on the two parameters of the fleet selectivity curve. The random effect can be switched on/off.

3.4 Model parameters

The following parameters are estimated:

- The number of fishes for age groups 2-19+ in the first year (1992): 18
- The number of 2y old fishes for the period 1993-2016
  - Without random effects: 24
  - With random effects: 2[a] (baseline)
- The natural mortality is set to 0.05: 0
- The demersal fleet fishing mortality for the period 1992-2016:
  - Without random effects: 25
  - With random effects: 4 (baseline)
- The demersal fleet selectivity-at-age coefficients: 2
  - Without random effect: 2
  - With random effects: 7[b] (baseline)
- The pelagic fleet fishing mortality for the period 2006-2016:
  - Without random effects: 11
  - With random effects: 4 (baseline)
- The pelagic fleet selectivity-at-age coefficients: 2
- The survey selectivity coefficients for the surveys in numbers: 9 (6, baseline)[c]

---

[a] The intercept parameter for number of 2y old fishes was found to be non-significantly different from zero on a 5% level and hence was left out, reducing the number of fixed parameters from 3 to 2.

[b] The intercept parameter for the inflection point was found to be non-significantly different from zero on a 5% level and hence was left out, reducing the number of fixed parameters for the demersal fleet selectivity with random effects from 8 to 7.

[c] In practice the selectivity of the Norwegian surveys are high (close to unity) for all young age groups and decrease for older ages which are less abundant in the Barents Sea as they migrate to the Norwegian Sea. Only two parameters are estimated for each survey: age at maximum selectivity (a_0) and declining slope (b_2). For younger ages the selectivity is assumed to be one and the first slope parameter (b_1) is set to zero. the Russian surveys does not decline with older age groups because only individuals up to age 11y are preported. Only two parameters are estimated for each survey: age at maximum selectivity (a_0) and increasing slope (b_1). For older ages the selectivity is assumed to be one and the second slope parameter (b_2) is set to zero.

- The survey selectivity coefficients for the surveys in proportion: 2
- The survey scaling coefficients:
  - 0 to 2 (baseline), depending on which surveys are switched on
- The observation variance for the demersal and pelagic catches: 2
- The observation variance for the surveys:
  - 0 to 4 (baseline), depending on which surveys are switched on

The total number of fixed parameters to estimate varies between 45 and 107, depending on which switches are *on* or *off*. In the baseline run, all switches are turned ‘on’ and the total number of parameters to estimate is 53. It is possible to revert to the earlier version of the SCA model used at the benchmark assessment in 2012 by turning all switches ‘off’.

There is a total of 2,271 observations (see data section above). Observations with null abundances are removed since these cannot be included in any multiplicative model. The likelihood functions are evaluated against 1,308 observations: 777 number@age survey indices, 45 proportion@age survey indices, 341 catch@age from the demersal fleet, 109 catch@age from the pelagic fleet, 25 catch-in-tonnes and 11 pelagic catch-in-tonnes.

3.4.1 Parameter transformations

For optimization purpose, not all model parameters are estimated directly. When model parameter values are known to be bounded, it is a transformed version of the parameter, which ranges ±∝, that is estimated instead. Log transformations are used for strictly positive parameters and logit transformations for parameters that are bounded on both sides (e.g. between 0 and 1).

Model parameter	Estimated parameter
NY1: numbers-at-age in year 1	Log(NY1)
alogNA1: alpha parameter of the random walk process for the log-recruitment at age 2y	Logit(alogNA1)
SigmalogNA1: variance of the random walk process for the log-recruitment at age 2y	Log(SigmalogNA1)

DemFYinit and PelFYinit: fishing mortality in the demersal/Pelagic fleet in the first year	Log(DemFYinit) and Log(PelFYinit)
aDemlogFY and aPellogFY: alpha parameter of the random walk process for the fishing log(mortality) in the demersal/pelagic fleet	Logit(aDemlogFY) and Logit(aPellogFY)
SigmaDemlogFY and SigmaPellogFY: standard deviation of the random walk process for the fishing log(mortality) in the demersal/pelagic fleet	Log(SigmaDemlogFY) and Log(SigmaPellogFY)
Dema50Init and DemwInit: age at 50% selectivity and selectivity smoothness (inverse slope) parameter for the demersal fleet in the first year	Logit(Dema50Init), these are bounded between 6 and 19 Log(DemwInit)
apDema50 and aDemlogw: alpha parameters of the random walk process for the logit of the age at 50% selectivity and the smoothness parameter in the demersal fleet	Logit(apDema50) and Logit(aDemlogw)
SigmaDema50 and SigmaDemlogw: variance of the random walk process for the logit-transformed age at 50% selectivity and the smoothness parameter in the demersal fleet	Log(SigmaDema50) and Log(SigmaDemlogw)
Pela50 and Pelw: age at 50% selectivity and selectivity smoothness (inverse slope) parameter for the pelagic fleet	Logit(Pela50) and Log(Pelw)
Propa50 and Propw: age at 50% selectivity and selectivity smoothness (inverse slope) parameter for the survey in proportions	Logit(Propa50) and Log(Propw)
DemVarLogC, PelVarLogC, VarLogI and VarLogIProp: Observation variance of the log-catches in the demersal/pelagic fleet and of the log-abundance/proportion indices in the surveys.	Log(DemVarLogC), log(PelVarLogC), log(VarLogI) and log(VarLogIProp)
QSurvey: survey scaling factors	Log(Qsurvey)

a0, b1, b2: survey selectivities parameters	Logit(a0), Log(b1), Log(b2)

The model is fitted using Template Model Builder. Data preparation, data plots, model building, result plots and projections are coded in R.

4 Results

4.1 Baseline run

4.1.1 Data

The catch and survey input data are summarised in Figure 3.

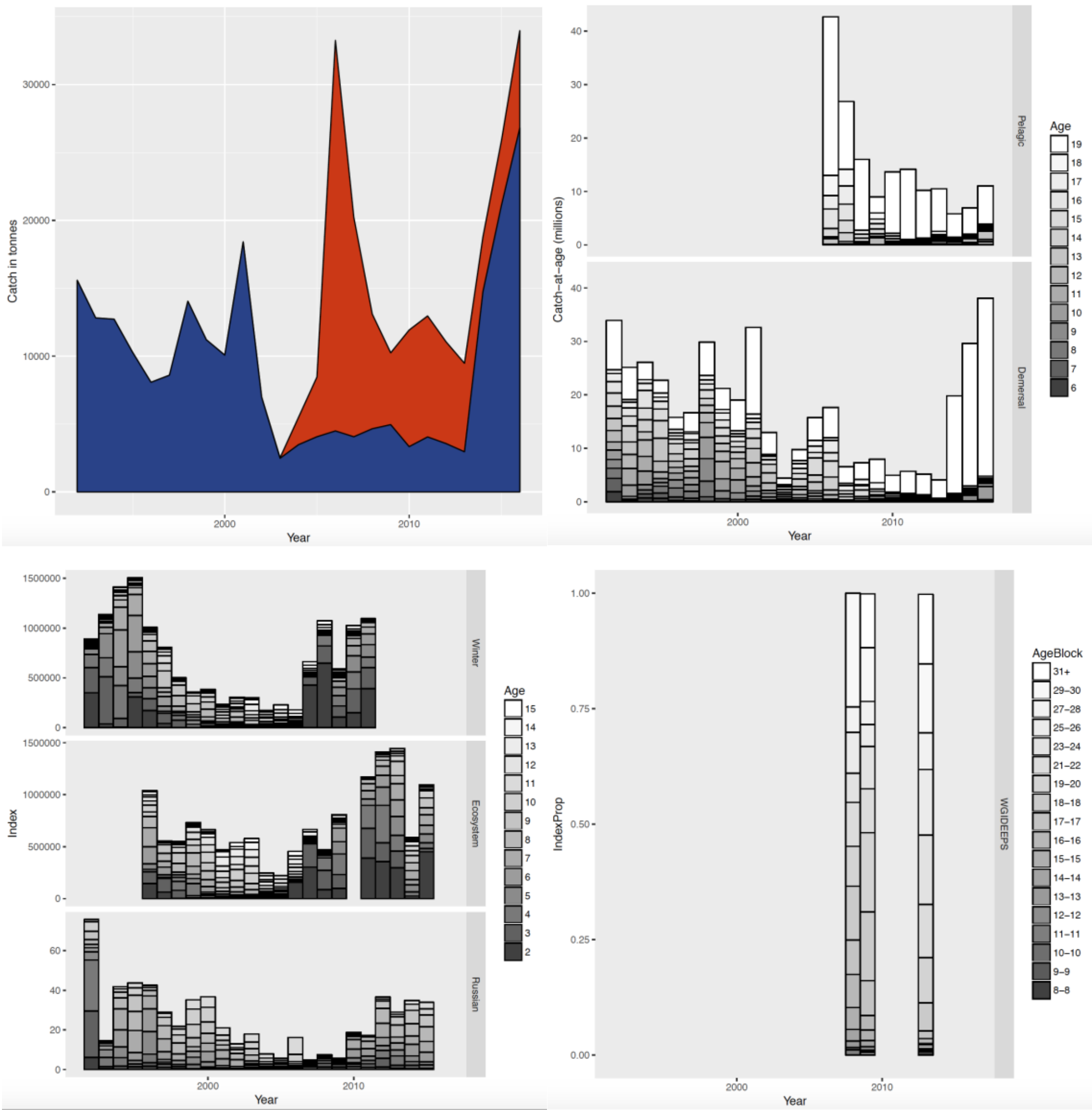


Figure 3: *S. mentella* in ICES subareas 27.1 and 27.2. Catch and survey data used as input to the SCA model. Top-left: total catch in tonnes for the demersal (blue) and pelagic (red) fisheries. Top-right: Catch numbers-at-age from the demersal and pelagic fleets. Bottom-left: Numbers-at-age from the Winter, Ecosystem and Russian groundfish surveys. Bottom-right: Proportions-at-age from the WGIDEEPS survey.

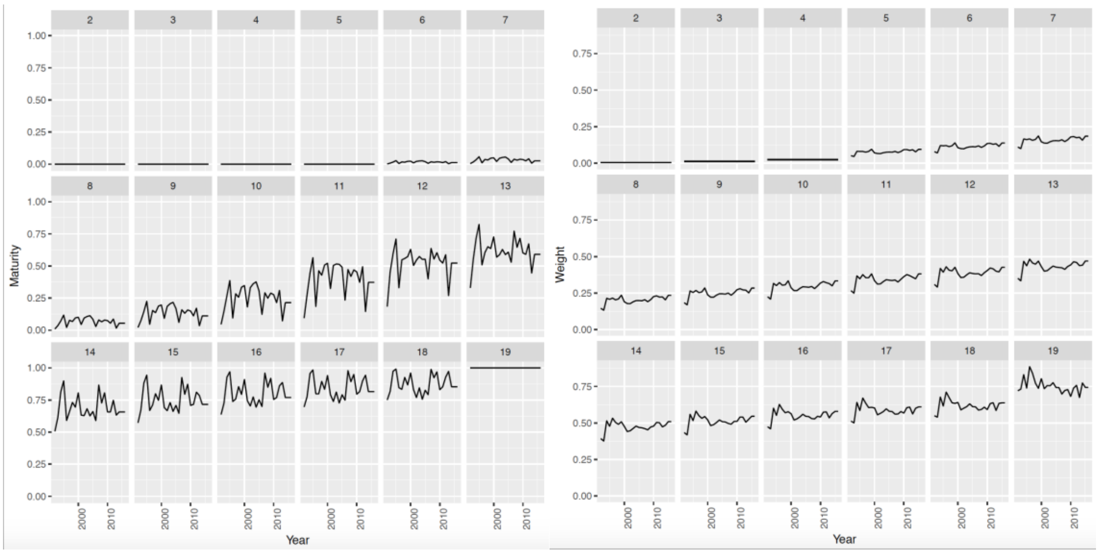


Figure 4: *S. mentella* in ICES subareas 27.1 and 27.2. Left: Proportion mature for ages 2-19+ and years 1992-2016. Right: mean weight for ages 2-19+ and years 1992-2016

4.1.2 Parameter estimates

The estimated values and standard deviations for the 53 parameters of the baseline run are reported below:

Parameter name	Estimate	Std. Error	Parameter description
logNY1	19.978	0.119	log-abundance age 2 in 1992
logNY1	19.908	0.124	log-abundance age 3 in 1992
logNY1	19.800	0.127	log-abundance age 4 in 1992
logNY1	19.377	0.132	log-abundance age 5 in 1992
logNY1	18.879	0.135	log-abundance age 6 in 1992
logNY1	18.535	0.142	log-abundance age 7 in 1992
logNY1	18.552	0.149	log-abundance age 8 in 1992
logNY1	18.639	0.156	log-abundance age 9 in 1992
logNY1	18.830	0.165	log-abundance age 10 in 1992
logNY1	18.463	0.177	log-abundance age 11 in 1992
logNY1	18.591	0.193	log-abundance age 12 in 1992
logNY1	18.314	0.207	log-abundance age 13 in 1992
logNY1	18.344	0.228	log-abundance age 14 in 1992
logNY1	18.175	0.262	log-abundance age 15 in 1992
logNY1	17.822	0.303	log-abundance age 16 in 1992
logNY1	17.321	0.361	log-abundance age 17 in 1992
logNY1	16.916	0.500	log-abundance age 18 in 1992
logNY1	19.566	0.163	log-abundance age 19 in 1992
DemlogFYinit	-3.257	0.140	initial value of the random process of the log fishing mortality for the demersal fleet in 1992

DemlogFYIntercept	-1.464	0.683	intercept of the random process on log fishing mortality for the demersal fleet
logSigmaDemlogFY	-0.680	0.152	log-transformed standard deviation of the random variable of the random process on log fishing mortality for the demersal fleet
paDemlogFY	0.858	0.274	logit-transformed alpha parameter of the random process on log fishing mortality for the demersal fleet
PellogFYinit	-3.823	0.130	initial value of the log fishing mortality for the pelagic fleet in 2006
PellogFYIntercept	-2.741	0.932	intercept of the random process on log fishing mortality for the pelagic fleet
logSigmaPellogFY	-1.455	0.315	log-transformed standard deviation of the random variable of the random process on log fishing mortality for the pelagic fleet
paPellogFY	0.460	0.241	logit-transformed alpha parameter of the random process on log fishing mortality for the pelagic fleet
pDema50Init	-0.805	0.413	logit-transformed initial value of the random process of the a50 parameter for the selectivity function of the demersal fleet
papDema50	1.838	0.776	logit-transformed alpha parameter of the random process of the a50 parameter for the selectivity function of the demersal fleet
logSigmaDema50	-0.983	0.228	log-transformed stantard deviation of the random variable of the random process of the a50 parameter for the selectivity function of the demersal fleet
DemlogwInit	2.230	0.440	logit-transformed initial value of the random process of the scale parameter for the selectivity function of the demersal fleet
DemlogwIntercept	0.433	0.159	intercept of the random process of the scale parameter for the selectivity function of the demersal fleet
paDemlogw	0.287	0.224	logit-transformed alpha parameter of the random process of the scale parameter for the selectivity function of the demersal fleet
logSigmaDemlogw	-0.950	0.184	log-transformed stantard deviation of the random variable of the random process of the scale parameter for the selectivity function of the demersal fleet
pPela50	-0.037	0.110	logit-transformed a50 parameter for the selectivity function of the pelagic fleet
Pellogw	0.640	0.126	log-transformed scale parameter for the selectivity function of the pelagic fleet
pPropa50	0.487	0.224	logit-transformed a50 parameter for the selectivity function of the survey in proportion
Proplogw	1.793	0.173	log-transformed scale parameter for the selectivity function of the survey in proportion
logVarLogIProp	-1.317	0.229	log-transformed standard deviation of the survey in proportion
DemlogVarLogC	-0.739	0.046	log-transformed standard deviation of the demeral fleet log-catches-at-age

PellogVarLogC	-0.184	0.146	log-transformed standard deviation of the pelagic fleet log-catches-at-age
logVarLogI	0.060	0.087	log-transformed standard deviation of the Winter survey log-indices-at-age
logVarLogI	-0.155	0.089	log-transformed standard deviation of the Ecosystem survey log-indices-at-age
logVarLogI	-0.647	0.097	log-transformed standard deviation of the Russian survey log-indices-at-age
logQSurvey	-8.465	0.106	log-transformed scaling coefficient for the Winter survey
logQSurvey	-17.773	0.098	log-transformed scaling coefficient for the Russian survey
pa0	-0.421	0.595	logit-transformed a0 coefficient for the Winter survey selectivity-at-age
pa0	0.237	0.410	logit-transformed a0 coefficient for the Ecosystem survey selectivity-at-age
pa0	0.772	0.323	logit-transformed a0 coefficient for the Russian survey selectivity-at-age
logb1	-0.220	0.155	log-transformed b1 coefficient for the Russian survey selectivity-at-age
logb2	-1.659	0.799	log-transformed b2 coefficient for the Winter survey selectivity-at-age
logb2	-0.766	0.680	log-transformed b2 coefficient for the Ecosystem survey selectivity-at-age
palogNA1	3.355	1.052	logit-transformed alpha parameter of the random process on recruitment (age 2)
logSigmalogNA1	-0.792	0.171	log-transformed standard deviation of the random variable of the random process on recruitment (age 2)

4.1.3 Derived quantities

In addition to the parameter estimates, several quantities are provided as an output from the model runs. These are as follows:

- ulogNA1: the values of the random effect parameter $u_y^{(1)}$ for recruitment (eq. 4)
- uDemlogFY: the values of the random effect parameter $u_y^{(2)}$ for demersal fishing mortality (eq. 5)
- uPellogFY: the values of the random effect parameter $u_y^{(2)}$ for pelagic fishing mortality (eq. 5)
- uDema50: the values of the random effect parameter $u_y^{(3)}$ for a50 parameter of the demersal fleet selectivity function (eq. 7)
- uDemlogw: the values of the random effect parameter $u_y^{(4)}$ for scale parameter of the demersal fleet selectivity function (eq. 8)
- logSSB: the spawning stock biomasses for each individual year

- PredTotalCatches: the predicted total catches in tonnes for each individual year
- logNA1: the time series of recruits at age 2y
- RecAge6: the time series of recruits at age 6y
- DemlogFYRE: The time series of log-fishing mortality for the demersal fleet
- PellogFYRE: The time series of log-fishing mortality for the pelagic fleet
- logitDemFARE: The logit-selectivities-at-age for the demersal fleet
- logitPelFA: The logit-selectivities-at-age for the demersal fleet
- SA: The selectivities-at-age for the surveys
- SAProp: The selectivities-at-age for the survey in proportion
- M2: The natural mortality
- nll1: The likelihood component for the catch in numbers-at age
- nll2: The likelihood component for the surveys in numbers-at-age
- nll3: The likelihood component for the total catch in tonnes
- nll4: The likelihood component for the surveys in proportion-at-age
- nll5: The likelihood component for the random effects on recruits
- nll6: The likelihood component for the random effects on demersal fishing mortality
- nll7: The likelihood component for the random effects on pelagic fishing mortality
- nll8: The likelihood component for the random effects on the scaling coefficient of the demersal fleet selectivity
- nll9: The likelihood component for the random effects on the a50 coefficient of the demersal fleet selectivity
- nll: The sum of the above nine likelihood components
- logTriN: The population matrix in trapezoid form (section 2.3)
- IndexProp: The predicted proportions-at-age in the survey

4.1.4 Development of the population and fishery

The estimated numbers-at-age in the first year of the model run (1992) show an exponential-like decline from age 2 to 18y. It is noticeable that the 19+group comprises a large number of individuals and therefore contribute significantly to the stock biomass in that year.

The recruitment time series is marked by a continuous decline in the early years towards a recruitment collapse (year-classes 1998-2005), followed by a sharp recovery to peak recruitment in 2008. Since then, recruitment has been variable and recent years show a decline although estimates are highly uncertain.

The spawning stock biomass has increased almost continuously between 1992 and 2007, followed by a stabilisation and slight decline in recent years.

The fishing mortality patterns are marked by a large decline in mortality between 1992 and 2006, when the pelagic fishery in international waters starts. This fishery contributed most to fishing mortality after that date until 2014 when the fishery in the Norwegian EZ was reopened. The latter dominates fisheries mortality today. It is assumed that the pelagic fleet selectivity-at-age has remained stable since 2006. The selectivity of demersal fishery in the Norwegian EZ has dramatically changed in 2014 when it changed from a by-catch to a targeted fishery. It now targets larger/older individuals.

The selectivity patterns for the Russian groundfish survey in the Barents Sea indicate an increased selectivity with age from 2-9y which reflect gear selectivity. Note that fish are only reported up to age 11 from this survey. The selectivity patterns for the Winter and Ecosystem surveys in the Barents Sea indicate an decreased selectivity with age from 8-15y which reflects the migration of individuals out of the Barents Sea, towards the Norwegian Sea, as they reach maturity (age at 50% maturity ≈ 11y).

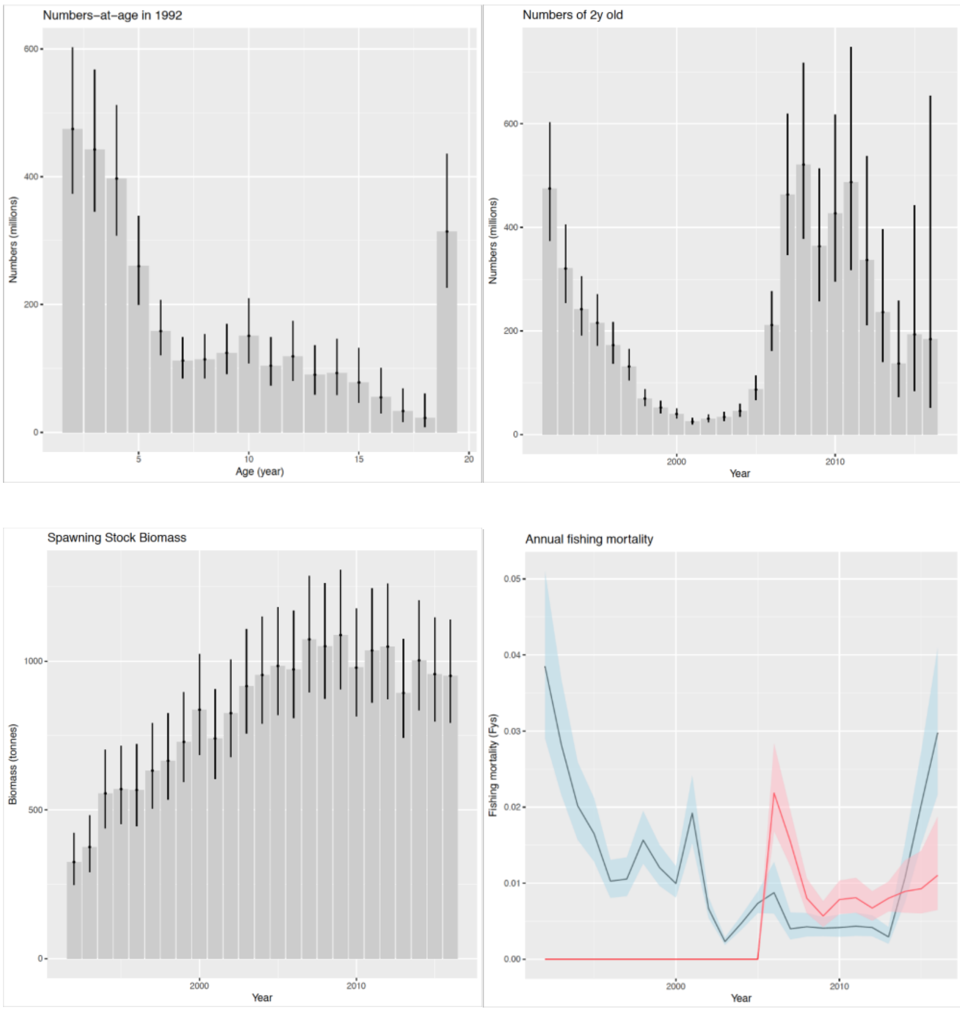


Figure 5: *S. mentella* in ICES subareas 27.1 and 27.2. Results from the baseline run of the Statistical catch-at-age model. Top-left: numbers of individuals of age 2 to 19y+ in year 1992. Top-right: Numbers of individuals of age 2y, from 1992 to 2016. Bottom-left: Spawning Stock Biomass from 1992 to 2016. Bottom-right: Annual component of the fishing mortality for the pelagic (red) and demersal (blue) fleets.

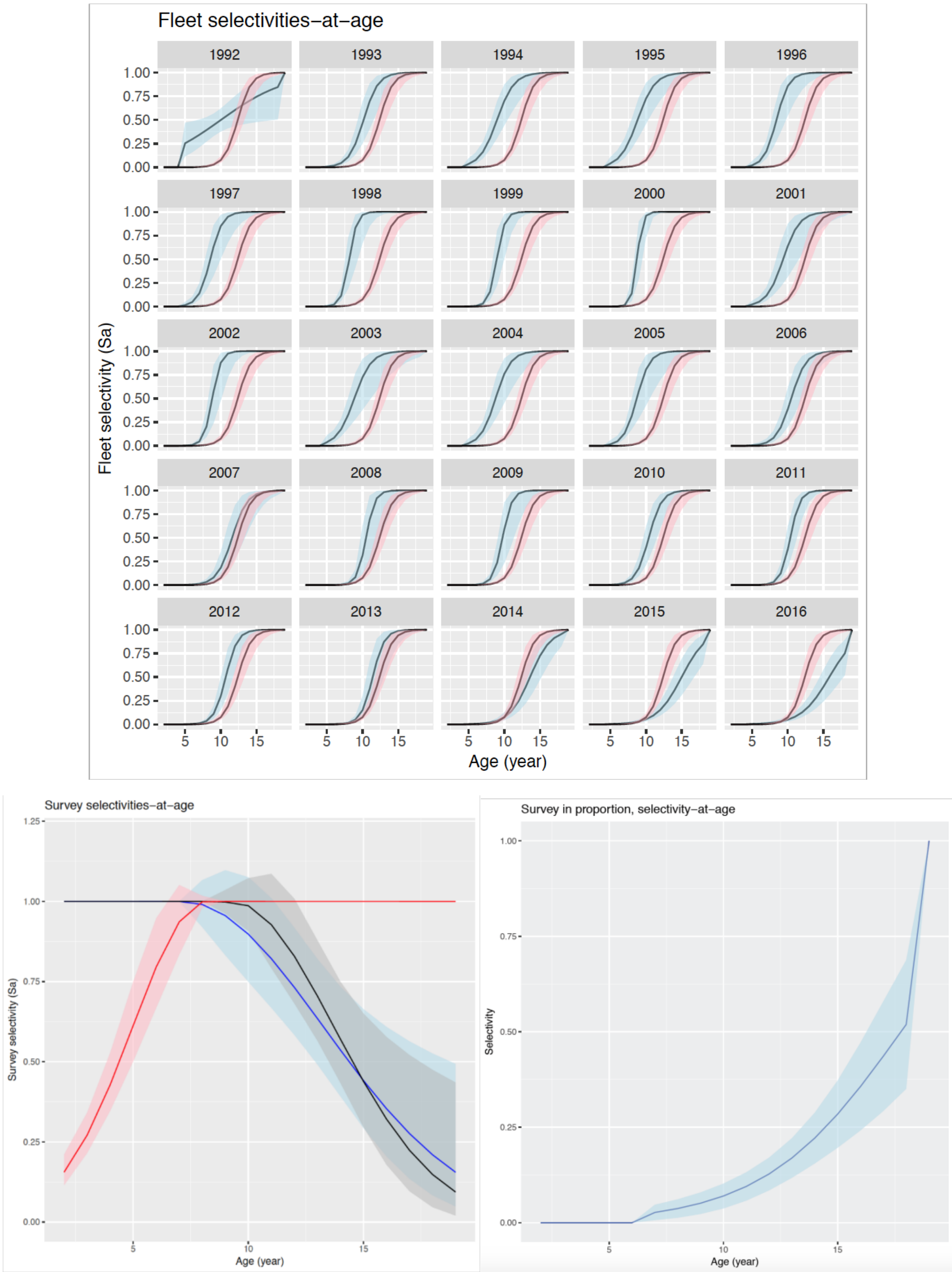


Figure 6: *S. mentella* in ICES subareas 27.1 and 27.2. Results from the baseline run of the Statistical catch-at-age model. Top: selectivity curves for the pelagic (red) and demersal (fleet), note that pelagic selectivity does not vary between years. Bottom-left: selectivity curves for the Winter (blue), Ecosystem (black) and Russian groundfish (red) surveys in the Barents Sea. Bottom-right: selectivity curve for the WGIDEEPS survey. Translucent bands indicate 95% confidence limits.

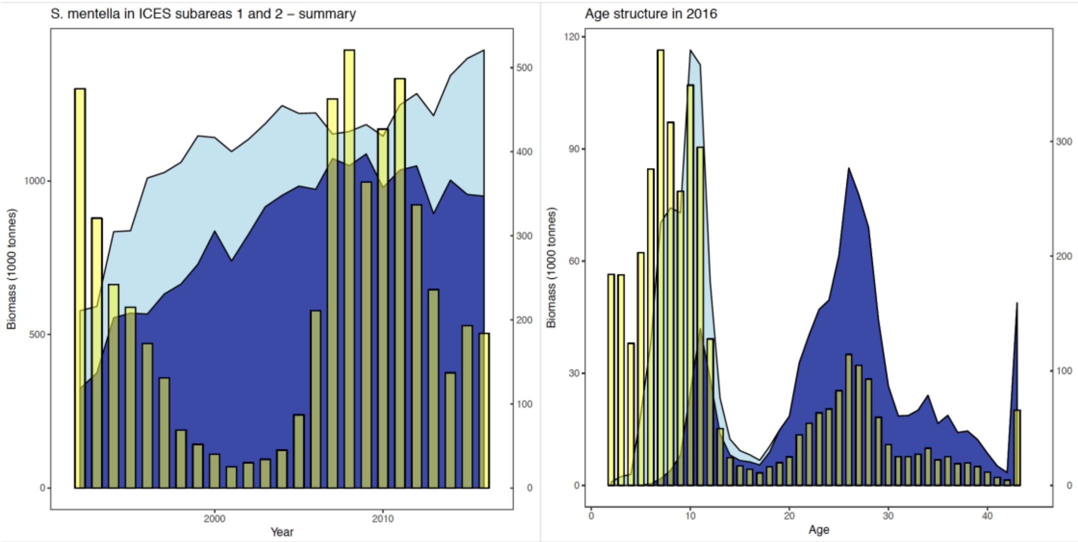


Figure 7: *S. mentella* in ICES subareas 27.1 and 27.2. Results from the baseline run of the Statistical catch-at-age model. Left: summary of the stock development from 1992 to 2016 showing recruitment (yellow bars), spaning stock biomass (dark blue) and total stock biomass (light blue). Right: summary of the population structure in 2016 showing numbers-at-age (yellow bars), mature biomass-at-age (dark-blue) and total biomass-at-age (light blue).

4.1.5 Residuals

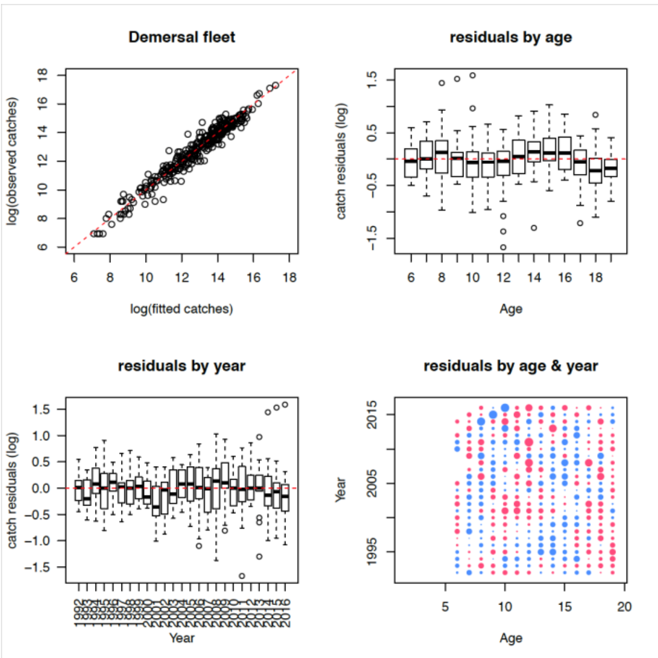


Figure 8. *S. mentella* in ICES subareas 27.1 and 27.2. Diagnostic plots for the demersal fleet catch-at-age data. Top-left: scatterplot of observed vs. fitted indices, the dotted red line indicates 1:1 relationship. Top right: boxplot of residuals (observed-fitted) for each age. Bottom left: boxplot of residuals for each year. Bottom right: bubble plot of residuals for each age/year combination, bubble size is proportional to residuals, blue are positive and red are negative residuals.

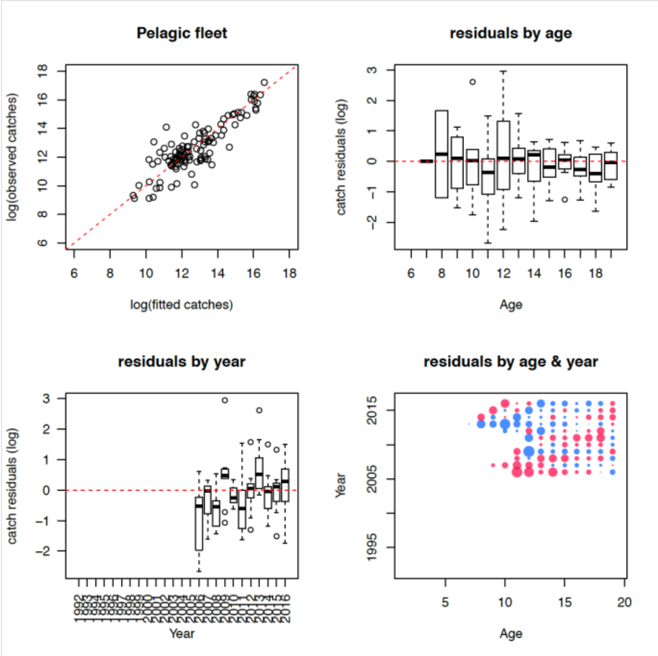


Figure 9. *S. mentella* in ICES subareas 27.1 and 27.2. Same as Fig. 8 for the pelagic fishery catches.

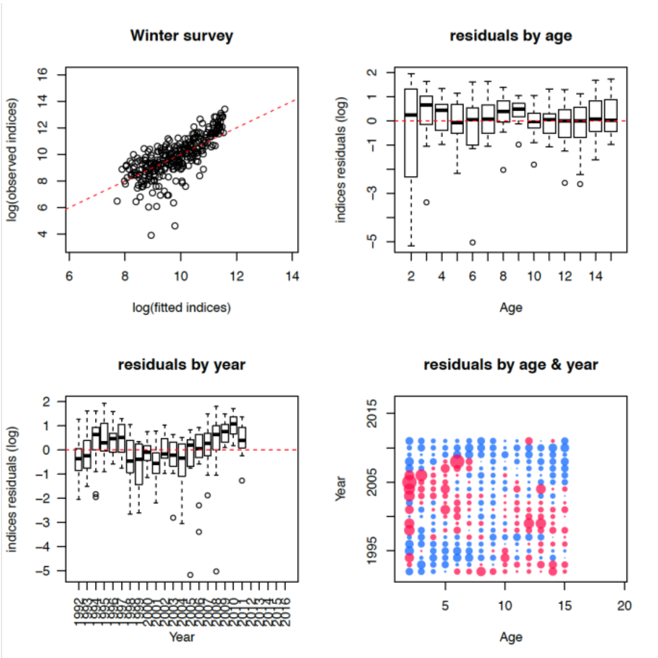


Figure 10. *S. mentella* in ICES subareas 27.1 and 27.2. Same as Fig. 8 for the Winter survey.

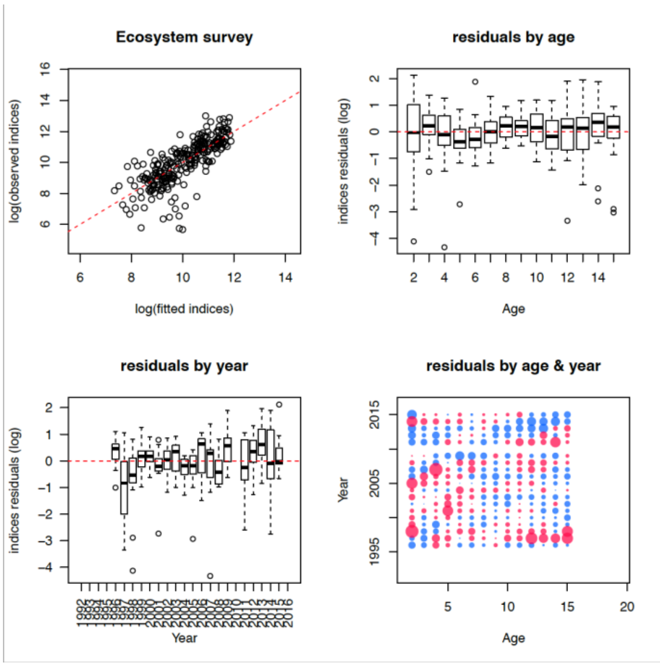


Figure 11. *S. mentella* in ICES subareas 27.1 and 27.2. Same as Fig. 8 for the Ecosystem survey.

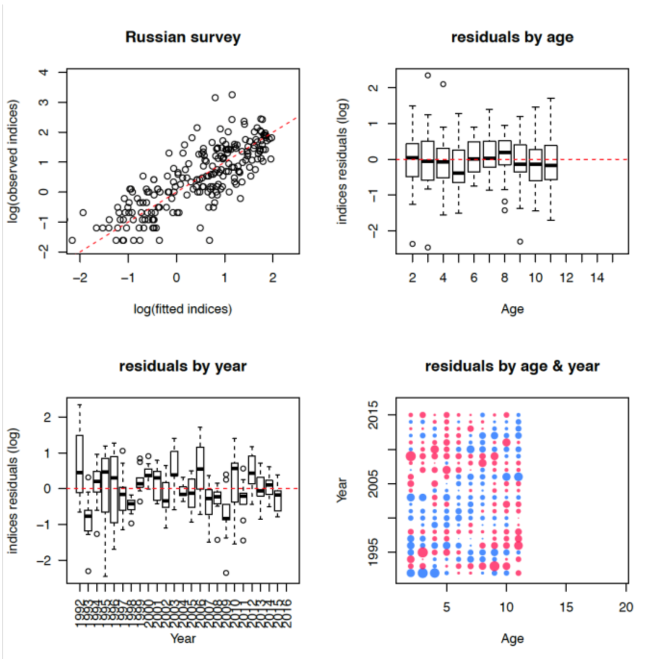


Figure 12. *S. mentella* in ICES subareas 27.1 and 27.2. Same as Fig. 8 for the Russian groundfish survey.

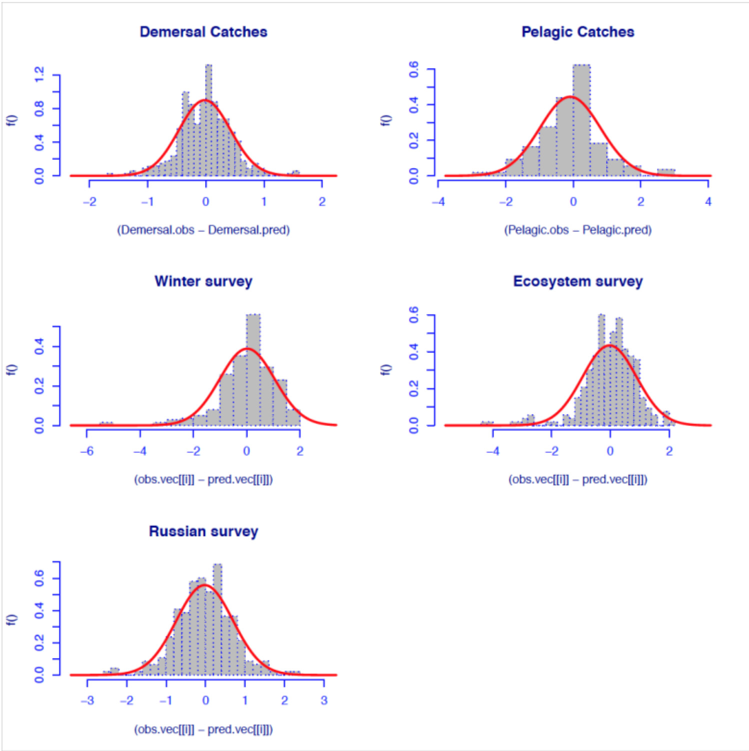


Figure 13. *S. mentella* in ICES subareas 27.1 and 27.2. Empirical (bars) and fitted (red lines) statistical distributions of the residuals log-catches and log-survey indices.

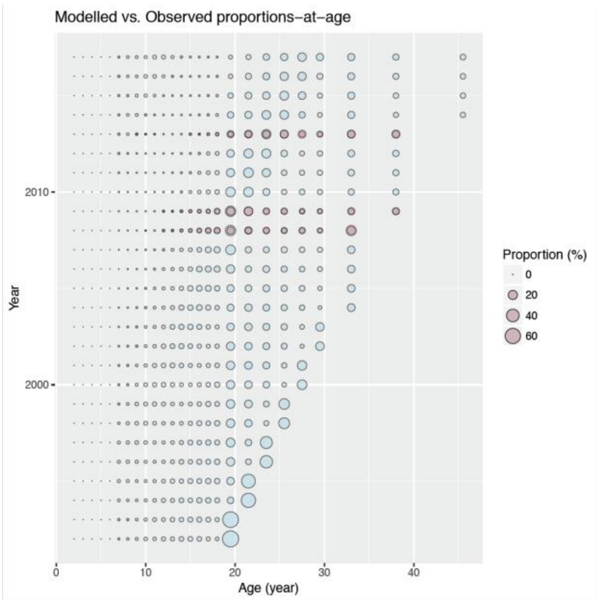


Figure 14. *S. mentella* in ICES subareas 27.1 and 27.2. Comparison of the proportions at age observed during the Norwegian Sea pelagic surveys (red) and predicted by the SCA model (blue).

4.1.6 Natural mortality

In the baseline model, natural mortality (*M*) is set to 0.05 for all ages and all years. This is done following the choice made in the earlier development of the model and approved at the previous benchmark in 2012. At the time the value was primarily derived from the estimated longevity of 75y and the equation proposed by (Hoenig, 1983) which relates natural mortality (*M*) to longevity (*Ls*): log(*M*)=1.46 - 1.01*log(*Ls*). There are a number of alternative ways to derive natural mortality, although not all of them are robust enough to be used in assessment (see e.g.Kenchington, 2014; Hoenig et al., 2016). We performed an extra run of the model in which log(*M*) was set as a free parameter. The estimate of log(M) is very low: -6.4, which corresponds to *M*=0.0017. However, the estimate is also very uncertain with standard error of 6 which gives a 95% confidence interval of log(*M*) = -6.4 ± 11.8, i.e. $M \in$[1.2e-8 , 221]. Clearly, *M* cannot be estimated and must be set. We explored the sensitivity of the model to natural mortality by profiling the likelihood and the spawning stock biomass trajectories along a range of *M* values from 0.0025 to 0.135. Profiling of the negative log-likelihood against M shows that higher likelihood (i.e. lower nll) is found for lower values of M. However, the estimated 95% confidence interval of the nll estimate in the baseline run is ±16 and all model runs with 0.00<M<0.75 have a nll in this interval. In terms of likelihood estimates, the model is therefore little sensitive to variations in M. On the other hand, changes in M values have a substantial impact on the stock abundance estimates and temporal dynamics. While the SSB in 2016 is around 1 million tonnes in the baseline run, it is estimated above 2 million tonnes when *M*=0.005 and below 500 thousand tonnes when *M*=0.1. These variations are associated with a stabilisation of SSB in recent years (baseline), a continuous increase in SSB (M=0.005) or a decline in SSB (M=0.1) during the same period.

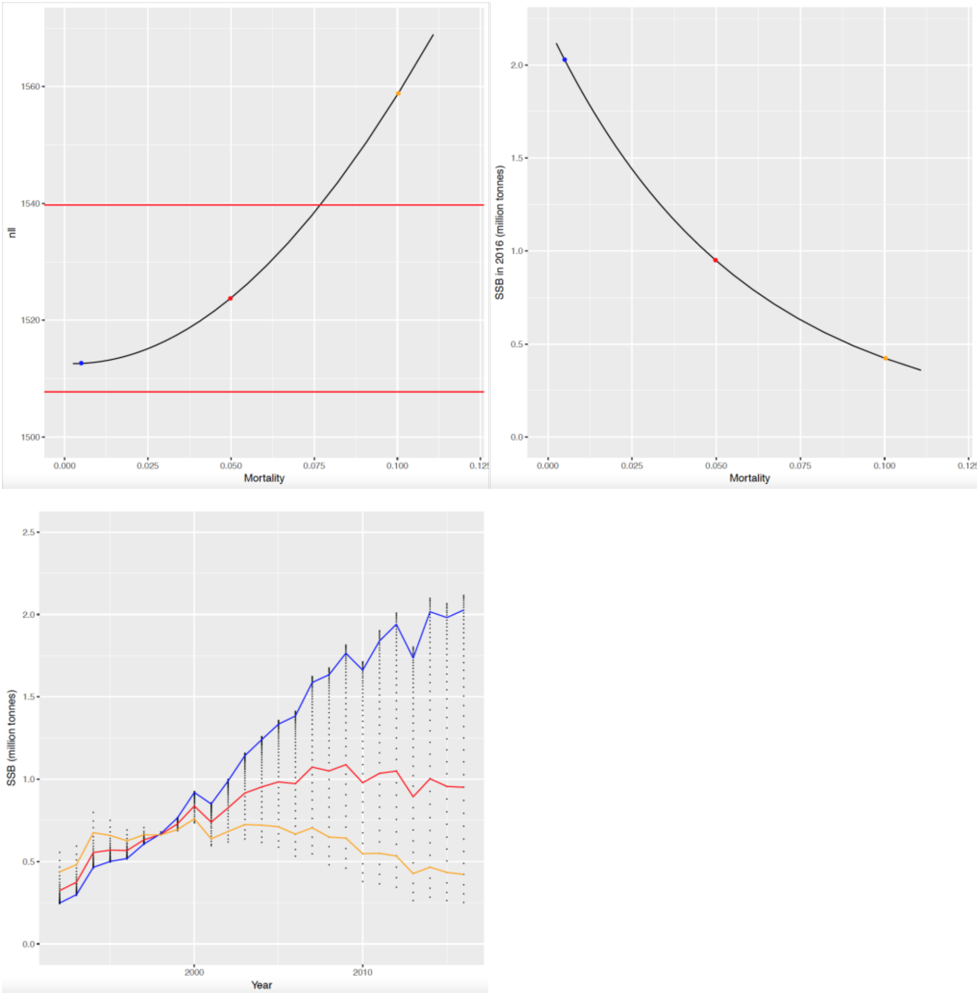


Figure 15. *S. mentella* in ICES subareas 27.1 and 27.2. Results from the profiling of the baseline run of Statistical catch-at-age model along *M*. Top-Left: changes in negative log-likelihood as a function of M. The horizontal lines mark the 95% confidence limits of the nll estimate for the baseline run. Top-right: changes in estimated SSB in 2016 as a function of *M*. Bottom: changes in SSB from 1992 to 2016 for 41 model runs with varying *M* values. Red dots/line indicate baseline run, blue dots/line indicate run with *M*=0.005 and orange dots/line indicate run with *M*=0.10.

4.1.7 Survey scaling factor

In the baseline model, the index scaling factor for the ecosystem survey (q) is not estimated but has been set to a fixed value: 1/3500 (3e-4). It is assumed that the ecosystem survey provides an absolute abundance estimate of the beaked redfish population. The rational for choosing this value in 2012 included i) consideration about the vertical distribution of *S. mentella* and the accessibility of the population to bottom trawling, ii) results from the abundance estimates derived from the Norwegian Sea survey in 2008 and 2009, iii) comparison with results from a GADGET model implementation and a biomass production model.

Here, we have explored the sensitivity of the model to the ecosystem survey scaling parameter by profiling the likelihood and the spawning stock biomass trajectories along a range of *q* values from 1e-5 to 7e-3. The likelihood profile indicates that the highest likelihood (i.e. lowest nll) is found for low values of *q*. With *q* values between 1e-5 and 1e-3 the nll is within the 95% confidence interval of the baseline run. Because the likelihood profile is very flat for a wide range of low q values, it is not possible to estimate *q* directly from the model. As expected and observed in the previous benchmark, the biomass estimates are linearly related to the inverse of the scaling factor. For values around and lower to the baseline q, the relative SSB trajectory of the population is unchanged, but for high *q*'s, the model runs indicate a decline in SSB in recent years.

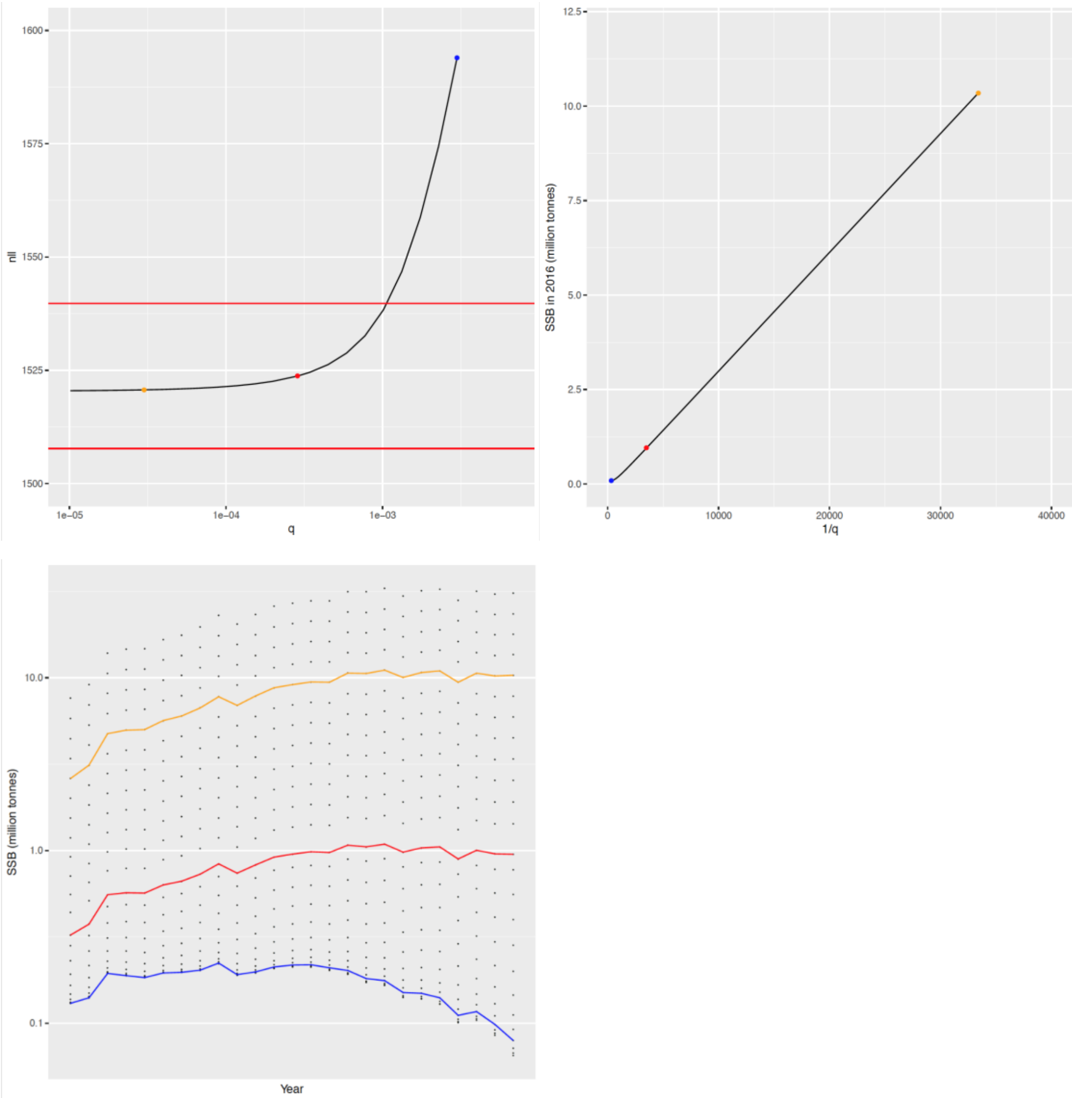


Figure 16. *S. mentella* in ICES subareas 27.1 and 27.2. Results from the profiling of the baseline run of Statistical catch-at-age model along the scaling coefficient for the Ecosystem survey: *q*. Top-Left: changes in negative log-likelihood as a function of *q*. The horizontal lines mark the 95% confidence limits of the nll estimate for the baseline run. Top-right: changes in estimated SSB in 2016 as a function of 1/*q*. Bottom: changes in SSB (on a log scale) from 1992 to 2016 for 25 model runs with varying *q* values. Red dots/line indicate baseline run, blue dots/line indicate run with *q*=3e-3 and orange dots/line indicate run with *q*=3e-5.

4.2 Alternative runs

4.2.1 Selection of runs

Seven model runs, alternative to the baseline run, were performed to quantify the contribution of different elements of the model design, implementation and data. These are as follow:

Run 1: baseline

Run 2: the annual component of the demersal fishing mortality is modelled as fixed effects for each year, rather than using random effects

Run 3: the annual component of the pelagic fishing mortality is modelled as fixed effects for each year, rather than using random effects

Run 4: the annual components of the pelagic and demersal fishing mortality are modelled as fixed effects for each year, rather than using random effects

Run 5: the demersal fleet selectivity-at-age does not vary between years

Run 6: the data from the Norwegian Sea survey (WGIDEEPS) is not included

Run 7: the data from the Russian groundfish survey is not included

Run 8: the data from the Winter survey is not included

For each run, we looked specifically at the value of the model nll components for the catch-at-age, total catch in tonnes and survey indices-at-age (in numbers or proportion). We also report the estimated recruitment (age 2 and 6), biomass (total and spawning) and fishing mortality (ages 12-18 and 19y) in the last year (2016)

4.2.2 Results

All model runs fit relatively similarly to the catch-at-age data with the notable exception of run 5 where selectivity of the demersal fleet was held constant. The difference in nll in >150 which indicates a very significant improvement of the model to fit catch-at-age data when interannual variations in selectivity are accounted for. This is not surprising given the recent change in the demersal fleet fishing patterns following the 2014 change in regulation. Runs 7 an 8 have a slightly better fit to catch-at-age data indicating that when surveys monitoring juveniles are removed the model can slightly better track catches-at-age on the mature part of the population. This is to be expected.

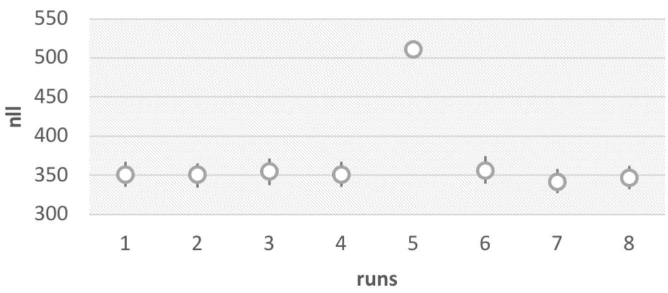


Figure 17: *S. mentella* in ICES subareas 27.1 and 27.2. Nll component for the catch-at-age. Vertical bars indicate the 95% confidence intervals. Run characteristics are defined in section 4.2.1

The model is heavily constrained to track interannual variations in total catch in tonnes. It does so regardless of the run and the nlls for the 8 runs are almost identical.

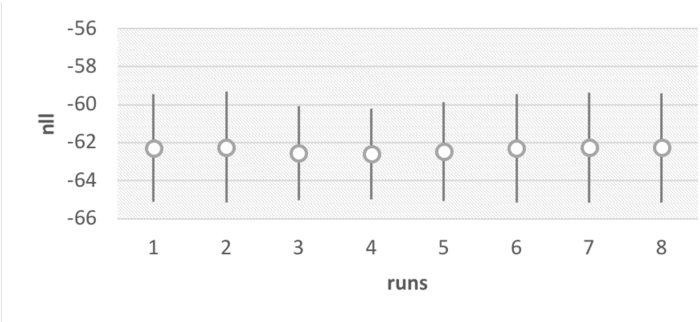


Figure 18: *S. mentella* in ICES subareas 27.1 and 27.2. Nll component for the total catch in tonnes

The survey indices in numbers are tracked in a similar way in runs 1(baseline) and 2, 3, 4. However the model performs slightly better (at fitting survey indices) when the demersal fleet selectivity is set constant across years (run 5) or when the Norwegian Sea survey is left out (run 6). This simply reflects that when less weight is given to the mature part of the population (caught by the fleet and monitored by the Norwegian Sea survey), the models better tracks the juvenile component monitored by the Barents Sea survey.

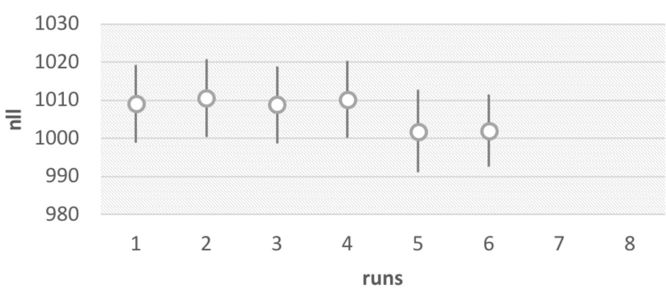


Figure 19: *S. mentella* in ICES subareas 27.1 and 27.2. Nll component for survey indices-at-age in numbers

The survey indices in proportion are tracked in a similar way in all runs except when the demersal fleet selectivity is set constant across years (run 5). The direct relationship between demersal fleet selectivity and model tracking of the adult population in the Norwegian Sea is not clear. There is a slight improvement in likelihood when the Barents Sea surveys are not included (runs 7 and 8) which again reflects that when less weight is given to the juvenile component in the Barents Sea the model track better the mature component in the Norwegian Sea.

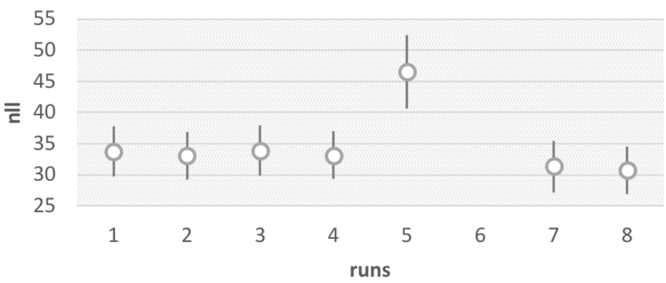


Figure 20: *S. mentella* in ICES subareas 27.1 and 27.2. Nll component for survey indices in proportions

Estimated recruits in numbers, at age 2 and 6 in 2016 vary little between runs with the notable exception of run 7, when the Russian groundfish survey is not included. This could reflect the difference in trends between the Russian survey indices and those from the winter and ecosystem surveys. Alternatively, it may simply reflect the lack of age readings in recent years from the two latter surveys, in which case recruitment estimated in the most recent years are little informed when the Russian survey is removed. This is supported by the much wider 95% confidence interval on recruits in run 7 in comparison with other runs.

Estimates of SSB in the last year vary little between runs (915 to 968 thousand tonnes) but estimates of TSB are more variable, reflecting variations in the estimates of juvenile numbers. These are sensitive to removal of any of the surveys (runs 6-8) and the switching to fixed selectivity for the demersal fishing fleet (run 5).

Fishing mortality estimates are somehow stable with the exception of runs 4 and 5. When the annual components of the mortality estimates are estimated as individual fixed effects for each year for both surveys (run 4) mortality at age 12-18 increase while it decreases slightly for age 19+, in comparison with the baseline run. This suggests that the random process in the baseline run could be too constraining to allow for recent rapid changes in fishing mortality. Similar changes in fishing mortality are observed when the fishing selectivity of the demersal fleet is held constant, in which case it should be excepted that mortality on younger age groups is over-estimated and mortality on 19+ group is underestimated in recent years.

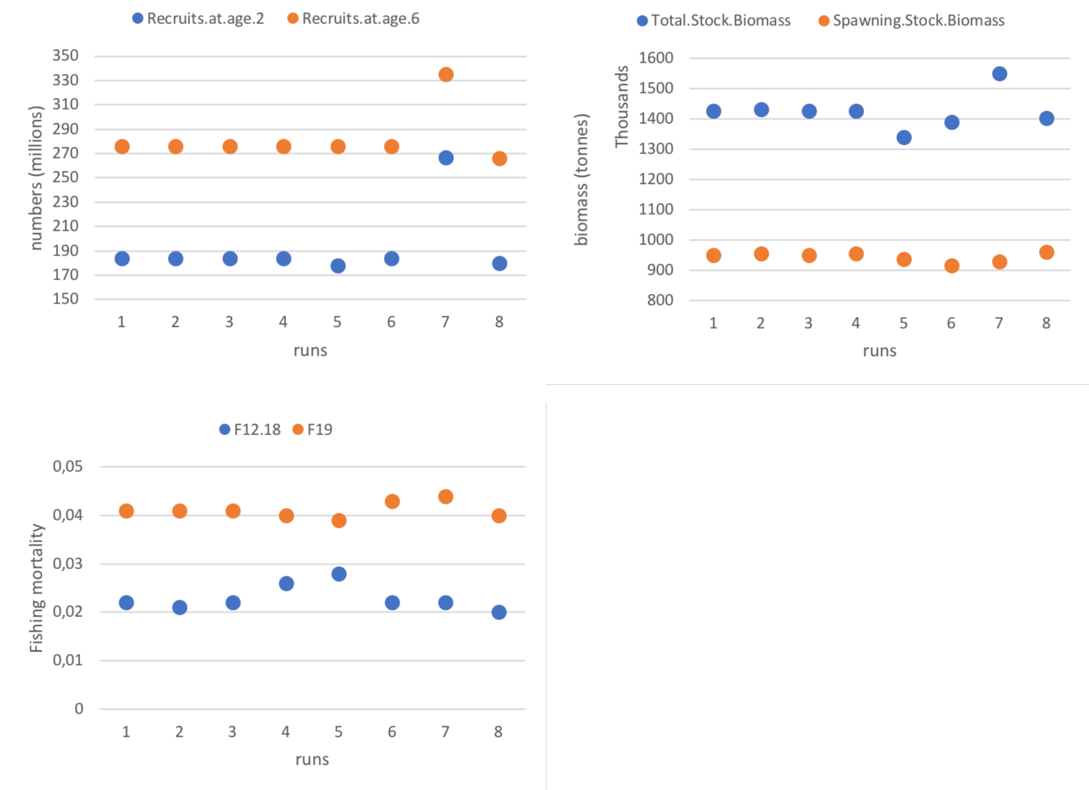
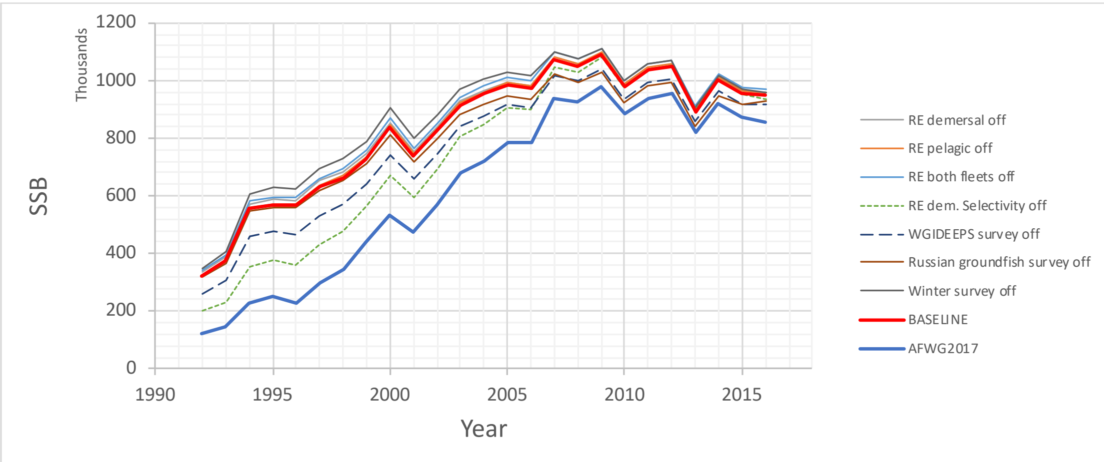


Figure 21: *S. mentella* in ICES subareas 27.1 and 27.2. Output from the baseline and 7 alternative runs. Top left: numbers of recruits at age 2 and 6 in 2016. Top-right: Total stock biomass and spawning stock biomass in 2016, Bottom-left: fishing mortality for ages 12-18 and 19+ in year 2016. Run characteristics are defined in section 4.2.1

SSB estimates from 1992 to 2016 in the baseline run are generally higher that those reported in the lasted Arctic Fisheries Working Group (AFWG 2017). This is particularly true for earlier years, i.e. until 2005. The increase in SSB in the early period mainly result from the implementation of the flexible selectivity for the demersal fleet and to a lesser extent from the incorporation of new data from the Norwegian Sea survey. Both options modify the perception of the stock for older age groups and feed-back into biomass estimates earlier in the time series.

The recruitment time series are also rather similar between runs and with the results from AFWG 2017, except for the period 2006-2009 (year classes 2004-2007). The difference is mainly explained by the implementation of the flexible demersal fleet selectivity-at-age with modifies the perception of the young adults (9-12y) cohorts and feed back into recruit estimates for these years. Removing the data from the Russian groundfish survey also leads to modified recruitment in recent years, since this survey is the most informative on recent year classes (no age readings in recent years from the other surveys).



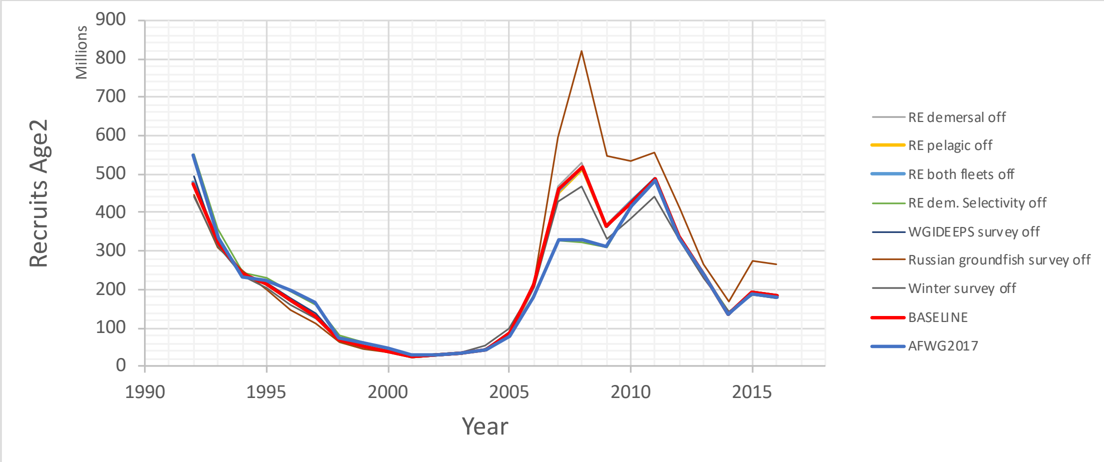


Figure 22: *S. mentella* in ICES subareas 27.1 and 27.2. Output from the baseline, the 7 alternative runs and the run performed at the AFWG in 2017. Top: trajectory of the Spawning Stock Biomass 1992-2016. Bottom: trajectory of the Recruitment at age 2 1992-2016.

5 Conclusion

The Statistical Catch at Age model presented here is based on the model presented in the benchmark in 2012. The model has been further developed along the following lines:

- Implementation in Template Model Builder. The 2012 version was implemented in ADMB),
- Autoregressive model for recruitment at age 2. In the 2012 version recruitment in individual years were estimated independently,
- Autoregressive model for the annual component of fishing mortalities in the pelagic and demersal fleets. In the 2012 version fishing mortalities in individual years were estimated independently,
- Autoregressive model to account for annual changes in demersal fleet selectivity-at-age. In the 2012 version selectivity of the demersal fleet was kept identical for all,
- Use of a *right trapezoid* population matrix. The 2012 version used a standard rectangular matrix,
- coding of older ages into flexible predefined *age-blocks*. Older ages were not considered explicitly (only as +group) in the 2012 version,
- Use of data from the pelagic surveys in the Norwegian Sea (WGIDEEPS). These data were not included in the earlier version.

Key results:

- Mortality cannot be estimated. The current mortality rate (0.05) is based on life-history rational and model fits with lower mortality rates are not significantly different. Model fits with mortality rates > 0.075 are significantly different.
- The scaling coefficient *q* for the ecosystem survey cannot be estimated reliably. The current value (1/3500) is based on sampling considerations, survey results and comparisons with other models in 2012. Model fits with lower *q* are not significantly different. Model fits with *q* > 0.001 are significantly different. SSB estimates are directly proportional to the inverse of this scaling coefficient.
- Changes in selectivity pattern of the demersal fleet in recent years is important and must be explicitly incorporated in the assessment model. The alternative run with fixed selectivity have a significantly poorer fit (Δnll=165).
- The implementation of the autoregressive processes for recruitment and fishing mortality leads to very similar outputs and fits to that of models with independent estimates, but with a much lower number of fixed parameters to estimates. In addition, using autoregressive process allows for the estimation of (random) parameters even in the case of missing observations (as is the case for recruitment at age 2 in 2016). It's recommended to keep the implementation of these autoregressive processes.
- Incorporation of data from the Norwegian Sea survey does not significantly impact model fit. The model predictions of the population structure for older age groups tracks closely the survey data. This is the only dataset in which the older component of the population is described by age (in the form of age blocks) rather than as a single +group. This indicates that earlier assessment model runs (which didn't include these data) tracked fairly well the cohorts in the old adult component of the stock despite lack of direct observations. This data series should be kept and updated in future runs of the model.
- Age data from the Winter and Ecosystem surveys is lacking (or lagging behind) in recent years. As a result, the recent population trajectory for younger age groups is mostly driven by information provided by the Russian groundfish survey.

- The updated baseline run leads to higher estimates for the SSB in particular for the earlier years of simulations (1992-2005). This change results from the implementation of the flexible demersal selectivity and the inclusion of new data from the Norwegian Sea.

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Bycatch of juvenile fish in the shrimp fishery in the Barents Sea

WD to ICES WKREDFISH, 29 January-2 February 2018

Bjarte Bogstad, Kjell Nedreaas and Benjamin Planque (IMR, Norway)
Anne Kjos Veim and Hanne Østgård (Directorate of Fisheries, Norway)

Introduction

Norway and Russia has sent the following request to ICES, which WKREDFISH will answer:

"Background:

Norway and Russia share the management of redfish (Sebastes mentella and Sebastes norvegicus) in ICES areas 1 and 2. Currently a management plan is under development and ICES is therefore requested to evaluate HCRs for the redfish stocks. The HCRs to be evaluated will be based on the guidelines for such rules for this stock suggested by ICES WKREDMP in 2014. The exact formulation of the rules to be evaluated will be communicated to ICES after the benchmark meeting for this stock (WKREDFISH) in February 2018.

Request:

a) ICES is requested to carry out an evaluation of harvest control rules for Sebastes mentella in ICES areas 1 and 2.

b) ICES is also requested to evaluate the impact of by-catch regulations on the shrimp fisheries in the Barents Sea on the stocks of Sebastes mentella and Sebastes norvegicus in ICES areas 1 and 2. This evaluation should be carried out for different levels of by-catch limitations and different levels of shrimp catch."

This WD provides background for part b) of the request.

The bycatch of juvenile fish can be a major problem in fisheries with small meshed trawls, such as fisheries for shrimp, *(Pandalus borealis)*. A sorting grid that effectively removes most of the undersized fish has been developed for shrimp trawls and it is not legal to fish for shrimp in the Barents Sea without the use of this sorting grid. Apart from this, the existing catch-regulation of shrimp fishery in the Barents Sea is closure of shrimp fisheries on fishing-grounds, where the bycatch of juvenile fish exceeds the criteria for allowable bycatch in numbers per ton of shrimp set by The Joint Norwegian - Russian Fishery Commission (JNRFC). The intention of such regulations is to reduce bycatch mortality of juvenile fish to a level which does not impair recruitment to the fish stocks.

In the protocol from the March meeting between IMR and PINRO in 2017 it is stated:

"Criteria for bycatches of juvenile fish in shrimp fishery

In accordance with Appendix 10 to the protocol of the 2016 JNRFC meeting criteria for bycatches of juveniles of redfish, cod, haddock and Greenland halibut in shrimp fishery presented by Norwegian scientists were considered and discussed. The proposal to review and change if needed criteria for bycatches of juvenile fish in shrimp fishery once each 5 years was considered to be useful and acceptable. Species-specific criteria (same type as currently used) as different species has their own specific stock dynamics and spatial distribution as well as fluctuating year class abundance over years is preferable. Combined (weighted) criteria for the 4 species would need further research of group of specialists with all data available. Proposals for exact values of criteria for bycatches of juvenile redfish (and possibly other species) in shrimp fishery will be presented to the WG on joint technical regulations in May 2017 after the AFWG updated assessment of the status of stocks in ICES area 1 and 2."

The present document focuses on revised bycatch criteria for redfish in the shrimp fishery in the Barents Sea, and suggest an improved procedure for how to decide on appropriate criteria that should avoid impairing the recruitment for the fish species, and that also takes into account the effort in the shrimp fishery, and regarding redfish, the mixing of *S. mentella and S. norvegicus.*

The redfish stock numbers used in this WD are based on the assessments made in 2017 (*S. mentella)* and 2016 *(S. norvegicus).* Although the methodology could be evaluated at the start of WKREDFISH, the conclusions need to be updated based on revisions to the assessments made during the benchmark.

History

- Current rules for bycatch in shrimp fishery are: Maximum 800 cod, 2000 haddock, 300 redfish and 300 Greenland halibut specimens per ton of shrimp
- Current rules decided on at JNRFC 2005 (first such rules introduced in 1983)
- At that time the redfish and G. halibut stocks were considered to be in a bad state. Stock situation for *Sebastes mentella* and G. halibut is now good, and it is timely to reconsider these criteria. However, the *S. norvegicus* is depleted and in poor condition.

Thus, strict criteria were in 2005 set for redfish and Greenland halibut, while a bio-economic approach was taken for cod and haddock. The main concept in the bio-economic approach is that if the expected future economic value of the bycatch exceeds the value of the shrimp catches, the shrimp fishery should be closed (Veim et al.1994)[1]. This bio-economic approach could be an alternative to the existing biological approach for redfish when it with reasonable certainty does not impair the redfish recruitment. The shrimp/fish price ratio has increased since 2005, which means that the bio-economic approach would lead to a higher bycatch criterion now

Background

[1] Veim et al., ICES CM 1994

- Bycatch of juvenile fish in the shrimp fishery is at present mainly an issue in NEZ and the Svalbard zone, although shrimp distribution has moved eastwards in the last decade
- The redfish criterion has caused most of the temporary area closures in recent years.
- Most of the juvenile redfish is in NEZ and the Svalbard zone, but also in the Loop hole (international waters) and the northwestern REZ
- Temporary area closures, but some areas, e.g., the area east of Nordaustlandet, between White Island and King Charles' Land, have been closed over long time (since 2000), and may hence be considered being a permanent area closure
- Changing criteria may also affect the closed areas that can be considered permanently closed.
- Work ongoing on calculation methodology tool for estimation of bycatch and to aid real-time monitoring of shrimp areas (Breivik et al. 2016[2], 2017[3]; Breivik is now employed at Norwegian Computing Centre)
- Work ongoing on improvement of sorting system to avoid catch of smallest fish and shrimp

Information on geographical distribution and fisheries

The closed areas are shown in Fig. 1 (2000-2011) and Fig. 2 (2017), while Fig. 3 shows the geographical distribution of Norwegian shrimp catches from logbooks. Fig. 4 and 5 shows shrimp catches by country and area, as well as advised catch. Fig. 6 and 7 show the geographical distribution of shrimp and redfish (all size groups combined), while Fig. 8 shows the distribution of relevant size groups for redfish bycatch, i.e., redfish less than 18 cm. Above this length, most of the redfish are sorted out by the sorting grid.

[2] Breivik, O. N., Storvik, G., and Nedreaas, K. (2016). Latent Gaussian models to decide on spatial closures for bycatch management in the Barents Sea shrimp fishery. Canadian Journal of Fisheries and Aquatic Sciences, 73(8): 1271-1280

[3] Breivik, O. N., Storvik, G., and Nedreaas, K. (2017). Latent Gaussian models to predict historical bycatch in commercial fishery. Fisheries Research, 185: 62-72.

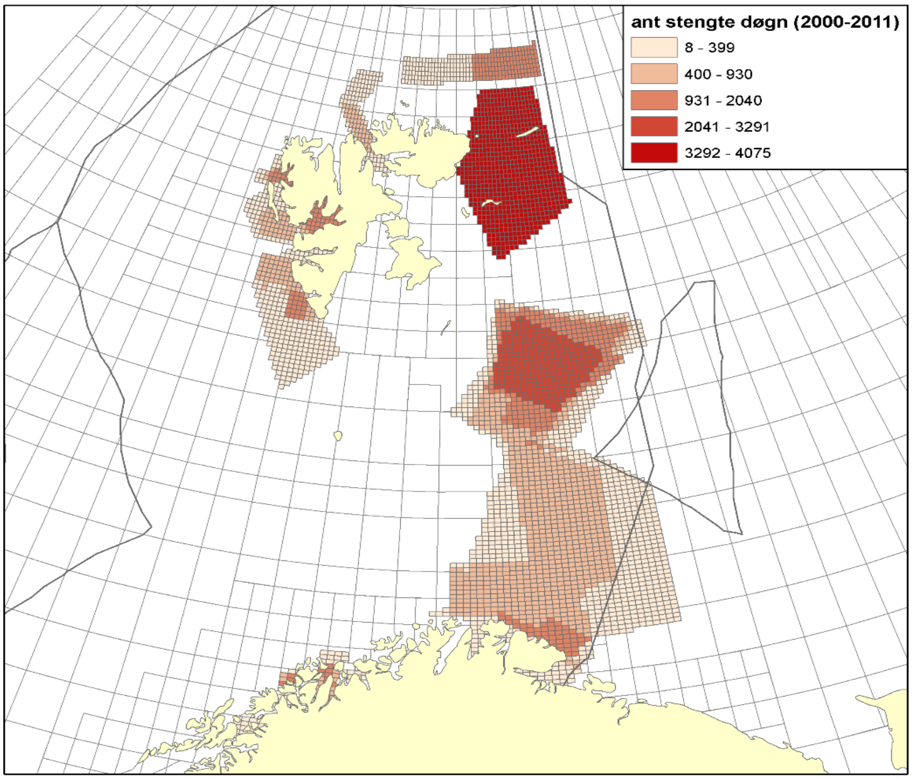


Fig. 1. Closed areas (days) during the period 2000-2011.

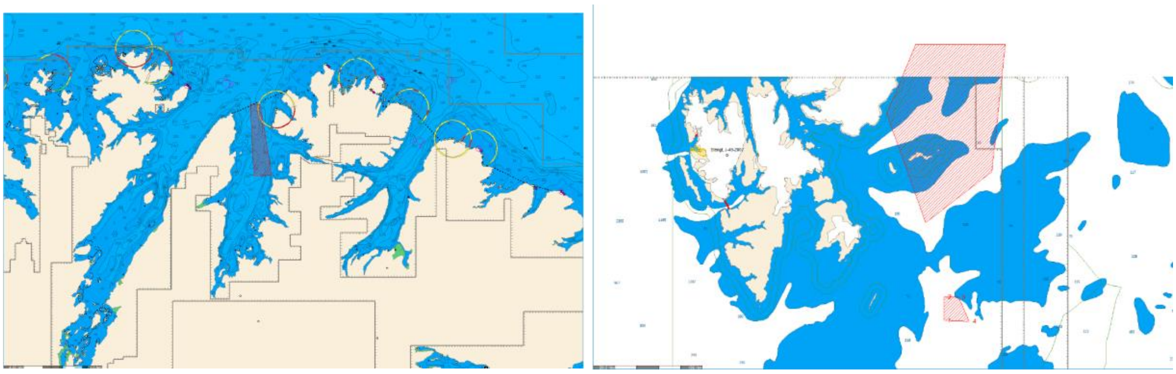


Fig. 2 Closed areas as of 4 July 2017 for the coastal shrimp fishery (left) and as of 23 June 2017 for the Barents Sea/Svalbard (Spitsbergen) shrimp fisheries (right). The areas inside the red lines at West-Spitsbergen are closed due to undersized shrimp (Norwegian regulations, minimum size 6 cm total length, 10% (by weight) of undersized shrimp allowed).

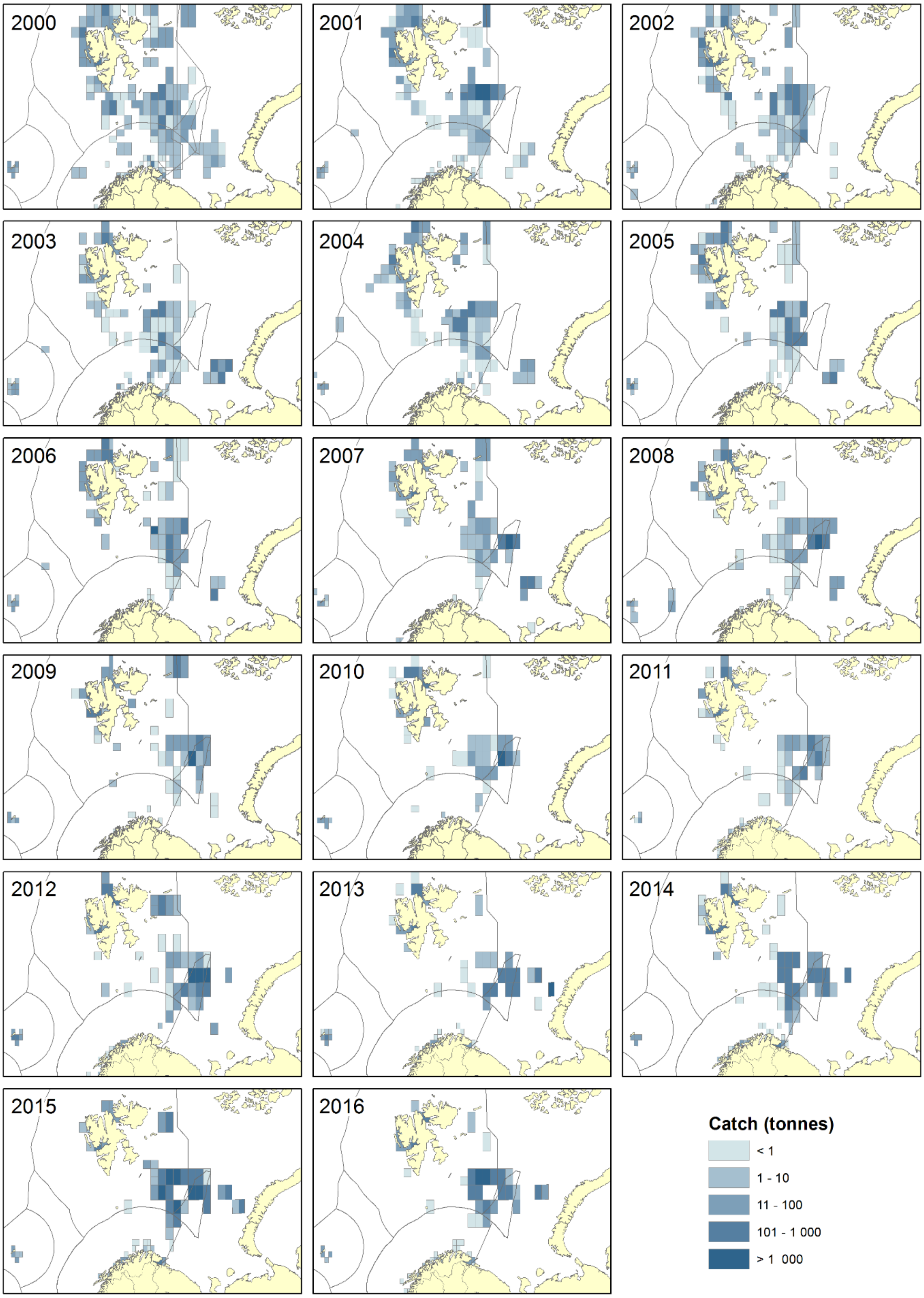


Fig. 3 Distribution of Norwegian shrimp catches (from logbooks) (ICES 2017)

Shrimp catches by country and area

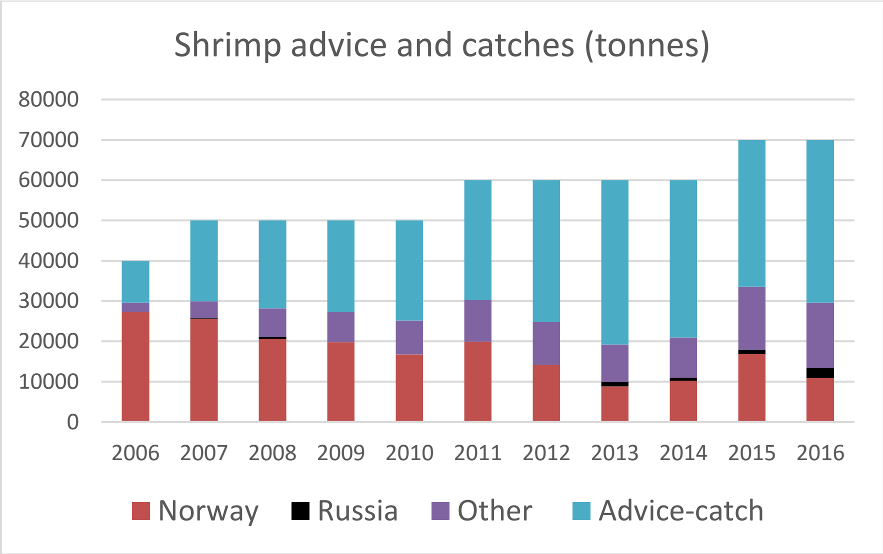


Fig. 4 Shrimp catches by country and advised catch (ICES 2017). The advice for 2017 and 2018 was equal to that for 2016 – 70 000 tonnes.

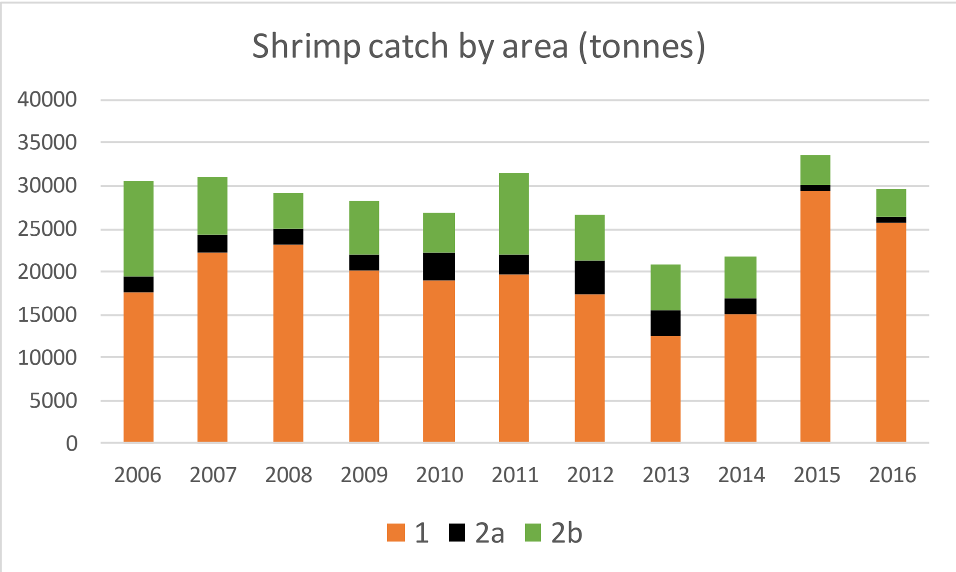


Fig.5 Shrimp catches by ICES areas (ICES 2017[4]).

[4]ICES 2017. NAFO/ICES Pandalus Assessment Group Meeting, 7–14 September 2016. ICES CM 2017/ACOM:09. 84 pp.

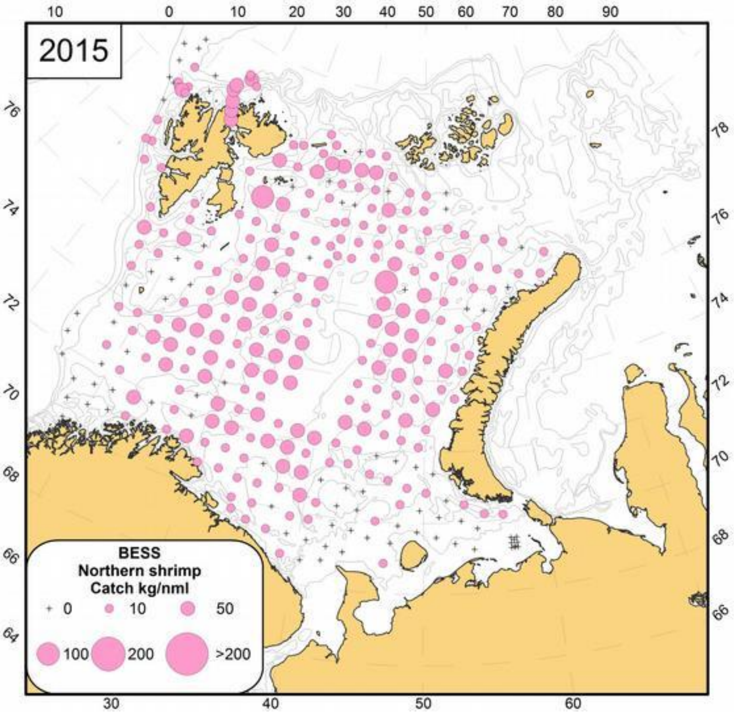


Fig. 6 Geographical distribution of shrimp catches during the ecosystem survey 2015

Geographical distribution of Sebastes mentella and S. norvegicus

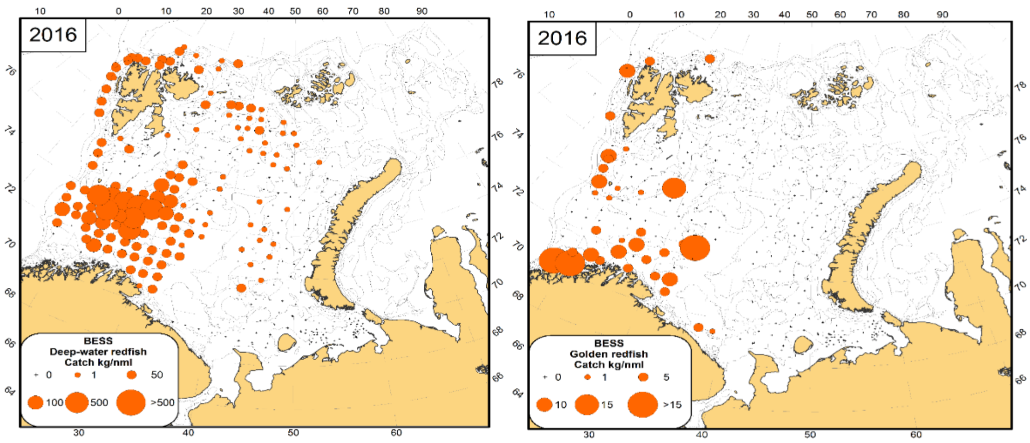


Fig 7. Geographical distribution of *S. mentella* (left) and *S. norvegicus* (right) during the ecosystem survey 2016. All fish sizes combined.

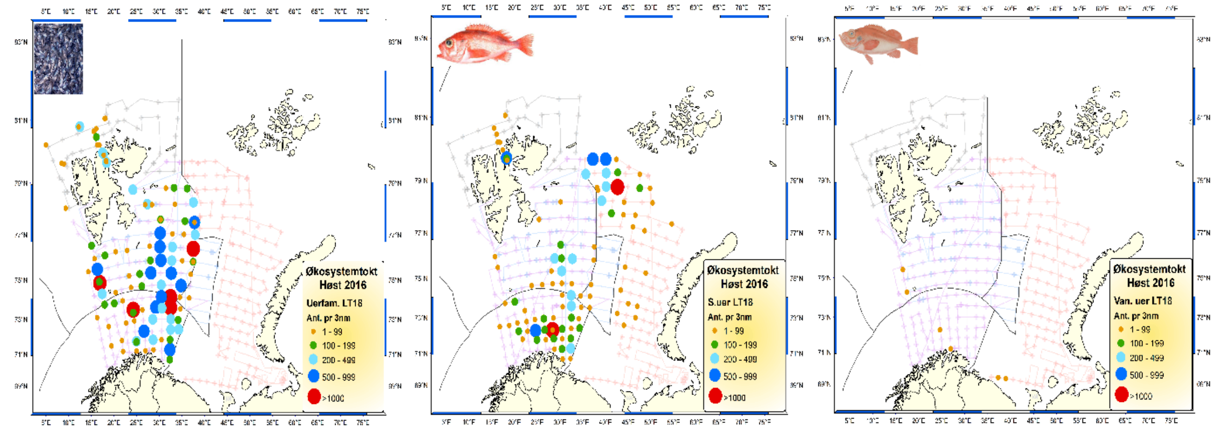


Fig. 8. Geographical distribution of small redfish, *S. mentella* and *S. norvegicus*, during the ecosystem survey 2016 (numbers per 3 nm trawling). The left panel shows small unspecified redfish mostly less than 10 cm, the two other panels show *S.mentella* and *S. norvegicus*, respectively, less than 18 cm.

Which proportion of shrimp catches are taken in areas where redfish is found?

The precision of our analysis increases if we only scale or raise the bycatch ratio to account for the shrimp catch caught in "redfish" areas. That means that we exclude coastal areas inside 12 nm which mainly contain shrimp fields in the fjords with mostly *S. norvegicus* as redfish bycatch, and shrimp fished in large areas of the Russian EEZ where redfish juveniles are nearly absent. Each Norwegian fisheries statistical area has been classified as a 'redfish' or 'non-redfish' area. 'Redfish' or 'non-redfish' shrimp areas may also be defined by comparing Fig. 3 (shrimp commercial catches) with Fig. 8 (distribution of small redfish). The results are shown in Table 1:

Year	Norw. total shrimp landings from ICES 1 and 2 (tonnes)	Norw. shrimp landings from ICES 1 and 2 from areas outside 12 nm and excl. redfish absent areas in the Russian EEZ (tonnes)	Total International (incl Norway) shrimp landings from ICES 1 and 2 (tonnes)	Total International (incl. Norway) shrimp landings from ICES 1 and 2 from areas outside 12 nm and excl. redfish-absent-areas in the Russian EEZ (tonnes). Anticipating same distribution of international fishery in ICES 1 as the Norwegian fishery.
2014	10234	6600	20964	**16099**
2015	16750	12676	33624	**25904**
2016	10897	8560	29610	**24313**

Table 1. Shrimp landings 2014-2016 – total and for 'redfish areas' only

Bycatch information

Fig. 9 shows the distribution of bycatch ratios (number of hauls with various ratios). Fig. 10 shows how much different bycatch ratios contributed (in %) to the total bycatch based on the data from the Norwegian Surveillance Service (Overvåkningstjenesten- OVT) in 2005-2015. These plots provide further information on the effect of changing the criteria.

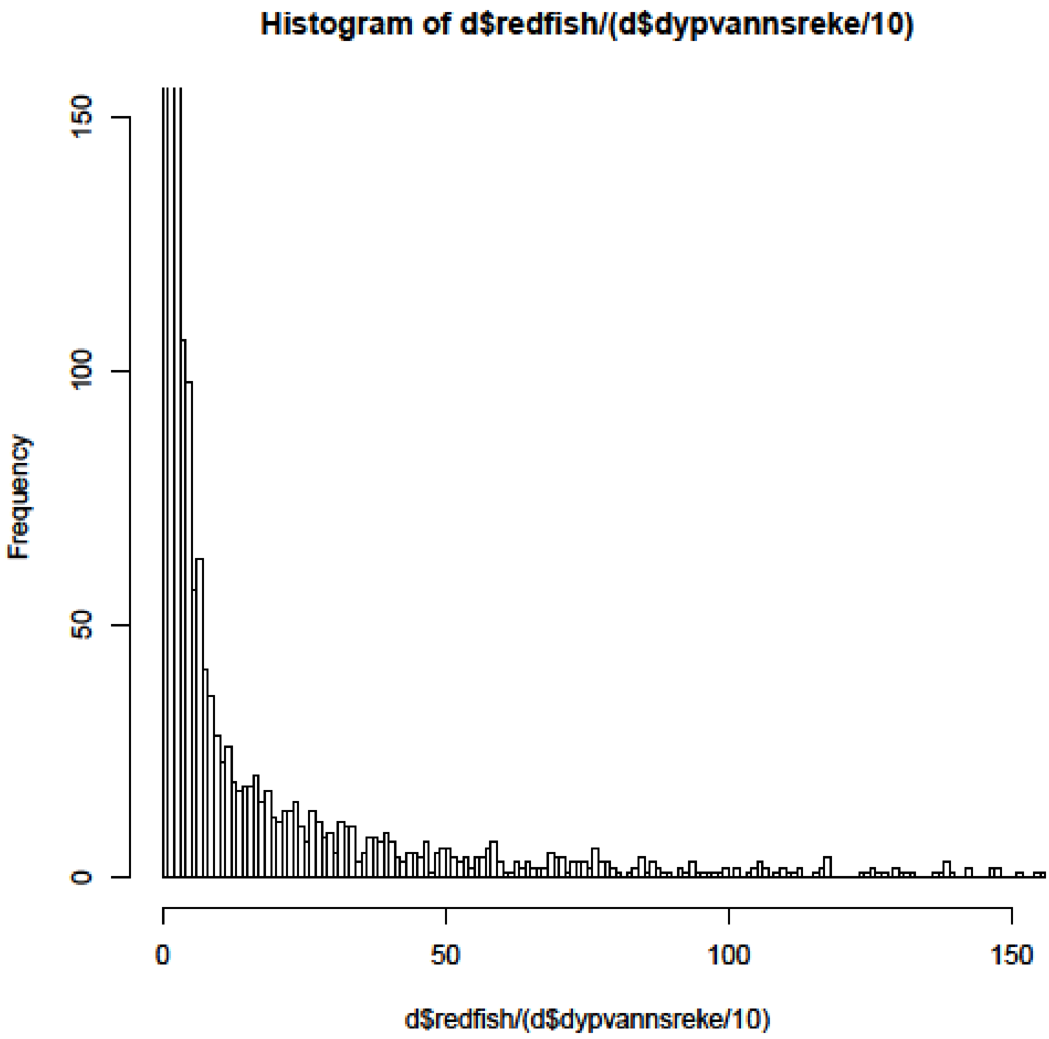


Fig. 9. Distribution (number of hauls) of bycatch ratios (redfish individuals/10 kg shrimp). Data from Norwegian Surveillance Service (Overvåkningstjenesten- OVT) in 2005-2015.

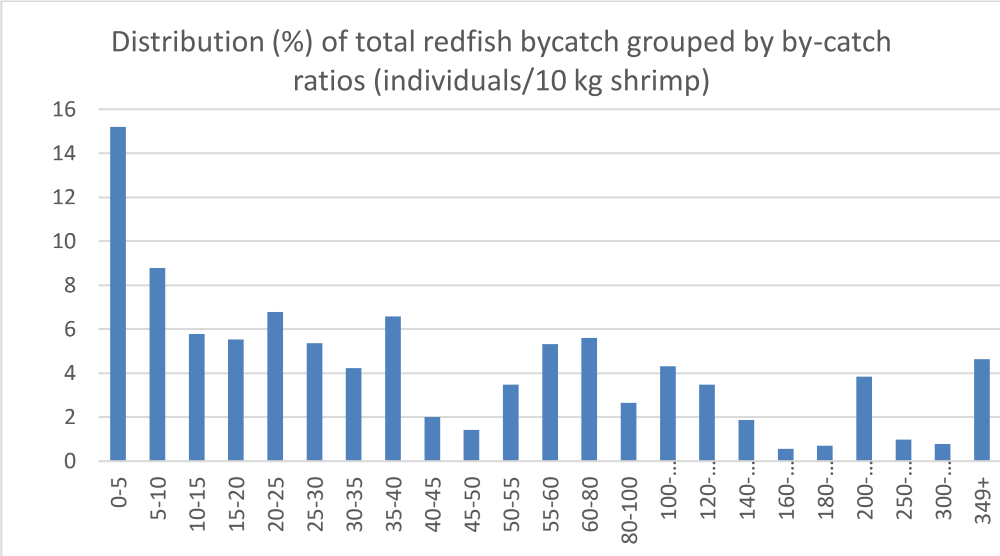


Fig. 10. Distribution (%) of total redfish bycatch grouped by bycatch ratio (individuals/10 kg shrimp). Data from Norwegian Surveillance Service (Overvåkningstjenesten- OVT) in 2005-2015. Note that the width of bycatch ratio categories varies within Fig. 10, a plot with equally wide (eg width 5) categories can be made if desired.

Bycatch scenarios

We look at scenarios with total shrimp catch of 17, 20 and 30 thousand tonnes, our conclusions will however partly be based on interpolations corresponding to the 2016 catch of 24 thousand tonnes in the 'redfish areas' (text table above). We look at bycatch acceptance of 300, 1000, 1500, 2000, 5000, 10000 and 20000 individuals/tonnes shrimp. We assume that the bycatch in the shrimp fishery is indiscriminately targeting 1, 2 and 3 year old redfish individuals.

Recruitment information

We assume a recruitment of 275 million redfish individuals at age 2 (geometric mean of the last 10 years: 2007-2016, updated by figures from ICES AFWG 2017, see Table 2). Also for comparison, calculations with maximum and minimum observed values of recruitment were made. We assume a natural mortality rate of 0.05 for age 2 years and older as in the AFWG. This is a compromise between low estimates of total mortality from cohort tracking (Planque et al. 2012[5], see figure 11 below) and higher mortality rates derived from consumption rates by cod (AFWG[6]). Natural mortality at age 1 year is possibly greater, although there is no estimate for it. We assume a mortality of 0.2 for this age group.

[5] Planque, B., Johannesen, E., Drevetnyak, K. V., and Nedreaas, K. 2012. Historical variations in the year-class strength of beaked redfish (*Sebastes mentella*) in the Barents Sea. ICES Journal of Marine Science, 69: 547-552.

[6] ICES 2017c. Report of the Arctic Fisheries Working Group, Copenhagen, 19-25 April 2017. ICES C.M. 2017/ACOM:06,486 pp. Figure 6.15, page 335, shows the estimated consumption rate of juvenile redfish by cod.

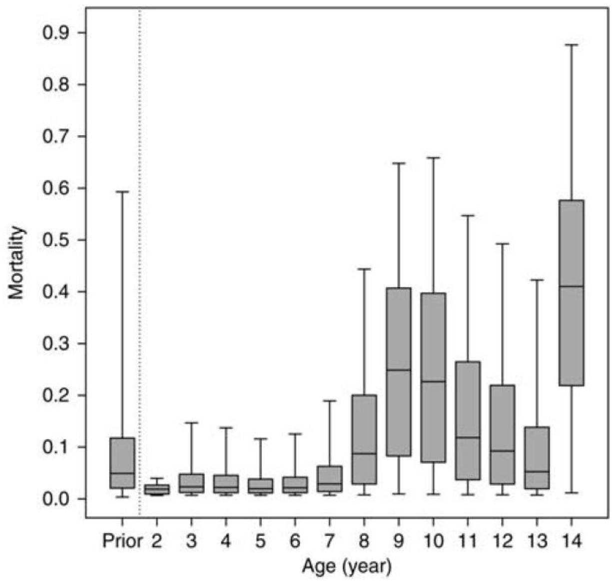


Figure 11. Modelled total-mortality-at-age for ages 2-14. The median estimate is indicated by the horizontal line in each box. Box edges outline the 25 and 75% distribution percentiles and whiskers show the 2.5 and 97.5% percentiles. The first box on the left shows the prior distribution of total mortality (Planque et al. 2012).

Table 2. Redfish recruitment in millions (AFWG 2017)

	S. mentella (age 2)	*S. norvegicus* (age 3)
2006	*222*	0.77
2007	330	0.31
2008	329	0.09
2009	313	0.26
2010	417	0.32
2011	484	1.52
2012	335	3.05
2013	236	0.13
2014	138	0.03
2015	188	0.03
2016	178	*No update available*
geo.mean 07-16 (norv. 06-15)	275	0.25
min	138	0.03
max	484	3.05
mean 07-16 (norvegicus 06-15)	295	0.65

Case 1:Assuming that the bycatch only concerns S. mentella.

Calculation:

Age 1: The number of individuals aged 1y is 275/exp(-0.2) = 336 millions.

If minimum recruitment, then the number is 138/exp(-0.2) = 169 millions, and if maximum recruitment then the number is 484/exp(-0.2) = 591 millions.

Age 2: The number of individuals aged 2y is 275 millions (geometric mean of past recruitment).

The corresponding minimum and maximum numbers of individuals are 138 millions and 484 millions, respectively.

Age 3: The number of individuals aged 3y is 275*exp(-0.05) = 262 millions.

If minimum recruitment, then the number of individuals aged 3y is 138*exp(-0.05) = 131 millions, and if maximum recruitment, then 484*exp(-0.05) = 460 millions.

Age 1-3: The total number of individuals for ages 1, 2 and 3y combined is 873 millions.

The corresponding minimum and maximum numbers of individuals are 438 millions and 1535 millions, respectively.

Estimates of redfish bycatch in 2014 and 2015, when Norway caught about 10,000 tonnes and 17,000 tonnes of shrimp, respectively, resulted in a bycatch of redfish juveniles of about 12 and 31 millions, respectively for these years (ICES 2016). This corresponds to an average of 1200 and 1800 redfish per tonnes shrimp catch. The values for 2016 have not yet been estimated.
Assuming a catch of 17 thousand tonnes and an effective bycatch (equal to the current bycatch limit) of 300 individuals per ton gives a total of 300*17,000 = 5.1 millions.
This corresponds to a mortality ratio of 5.1/873 = 0.6% for average recruitment, 5.1/438= 1.2% for minimum recruitment, and 5.1/1535 = 0.3% for maximum redfish recruitment of the age groups caught by the fishery. The same calculation is done for a range of bycatch and shrimp catch scenarios and levels of redfish recruitment (figures are rounded to the nearest %).

Table 3. Bycatch mortality (%) of S. mentella juveniles with different shrimp catches and bycatch limits

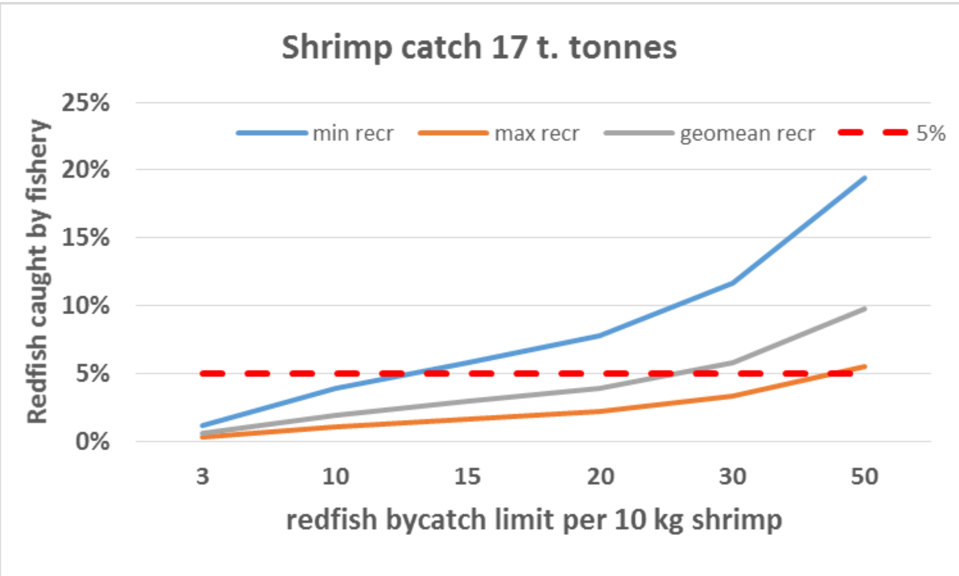
	Catch of shrimps (in tonnes) (in case of geo mean recr age 1-3 = 873 million)		
bycatch (ind/ton)	17 000	20 000	30 000
300	1%	1%	1%
1000	2%	2%	3%
1500	3%	3%	5%
2000	4%	5%	7%
3000	6%	7%	10%
5000	10%	11%	17%
10000	19%	23%	34%
20000	39%	46%	69%

Catch of shrimps (in tonnes) (in case of min recr age 1-3 = 438 million)

bycatch (ind/ton)	17 000	20 000	30 000
300	1%	1%	2%
1000	4%	5%	7%
1500	6%	7%	10%
2000	8%	9%	14%
3000	12%	14%	21%
5000	19%	23%	34%
10000	39%	46%	68%
20000	78%	91%	137%

Catch of shrimps (in tonnes) (in case of max recr age 1-3 = 1536 million)

bycatch (ind/ton)	17 000	20 000	30 000
300	0%	0%	1%
1000	1%	1%	2%
1500	2%	2%	3%
2000	2%	3%	4%
3000	3%	4%	6%
5000	6%	7%	10%
10000	11%	13%	20%
20000	22%	26%	39%



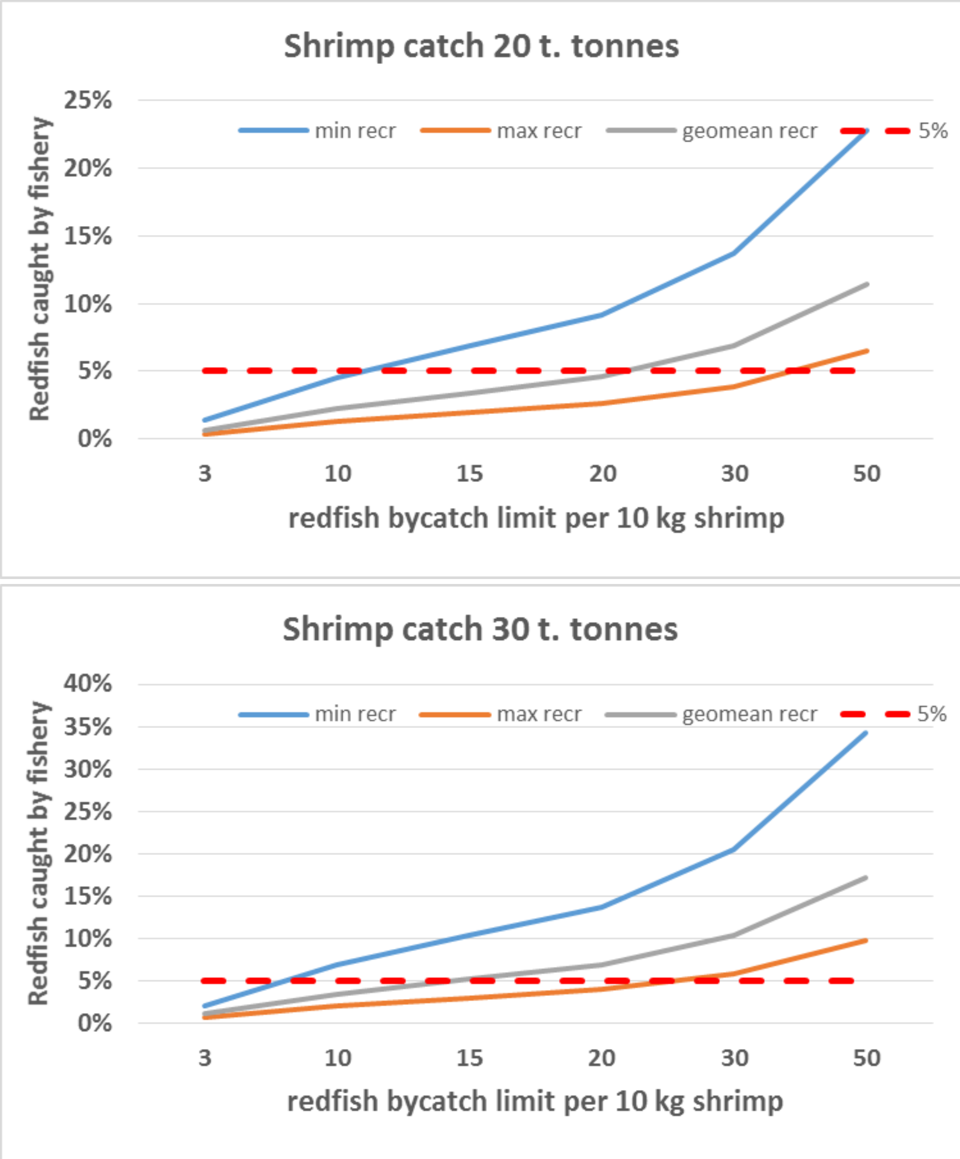


Fig.12. Ratio of redfish juveniles caught by shrimp fishery with different scenarios (ref. Table 3).

Given the slow life history (slow growth and late maturity) of redfish, 5% mortality is commonly accepted as a rule of thumb for the maximum acceptable mortality for this genus. The mortality rates recommended by ICES (for the older age groups which are targeted by the adult fishery) are always lower than 5%.

For individual cohorts, of average recruitment strength, to suffer less than 5% mortality on average, it is necessary to maintain the bycatch allowance at a maximum of <1800 individuals per ton with the same shrimp catch in the 'redfish areas' as in 2016, i.e., 24 thousand tonnes (interpolating in Table 3).

If the total catch of shrimp in the 'redfish areas' increases to 30 thousand tonnes, this number should be brought down to <1500 ind/ton. If recruitment of redfish returns to the low levels observed in the early 2000's this should be further reduced to < 1000 ind/ton (see Fig. 12).

Case 2: Assuming that the bycatch concerns both S. mentella and S. norvegicus

IMR data back to 1992 can be used to map the distribution of redfish in the Barents Sea. Individuals may have been identified down to species levels (*Sebastes marinus/norvegicus, S. mentella, S. viviparus*) or only to genus level (*Sebastes*).
The distribution maps of *Sebastes norvegicus* and combined *S. norvegicus, S. mentella* and undetermined *Sebastes* species illustrate the broad distribution of the species in the Barents Sea (see Figs. 7 and 8).
We estimate the proportion (all sizes) of *S. norvegicus* over combined *Sebastes* in the hauls performed with shrimp trawls. As a proxy for the Barents Sea and Svalbard (Spitsbergen) areas beyond the 12nm zone, we only consider observations north of 71°30'N. Over the period 2005-2016, the mean ratio is 3.7% of *S. norvegicus* in the redfish catches.

Over the period 2006-2015, the geometric mean of the number *S. norvegicus* aged 3y is 0.25 millions (Table 2). Assuming the same mortality pattern as for *S. mentella* leads to an estimate of 0.26 millions 2y old *S. norvegicus*, 0.32 millions 1y old, and a total of 1-2-3y olds of 0.83 millions.
Assuming a catch of 17 thousand tonnes and a bycatch of 3 individuals per 10 kg gives a total of 3*17,000,000/10 = 5.1 millions, of which 3.7% are *S. norvegicus* = 189 thousand. This correspond to 0.189/0.83 = 23% of the age groups being caught by the fishery. With low recruitment (a total of 1-2-3y olds of 0.1 millions), all fishes may theoretically be caught. Even with highest observed recruitment (10.2 millions), nearly 2% may be caught of *S. norvegicus* juveniles (Table 4).
This is likely to be an over-estimate and will hence be carefully assessed based on the exact proportions of juveniles of the two *Sebastes* species in recent years and their bycatch by the shrimp fishery. Table 4 shows that it also is very unlikely to get three years in row with maximum recruitment (3.05 millions at age 3). At present it is more likely to get three subsequent years with minimum/low recruitment. Comparing the geographical distribution maps of *S. mentella and S. norvegicus* less than 18 cm in Fig. 8 indicates that the ratio S. *norvegicus/S.mentella* may be less than 3.7% on the shrimp fields, and this is now further investigated with more precise analyses of the research survey data combined with genetics.

Table 4 Bycatches of *S. norvegicus* juveniles with different recruitment levels

	y1	y2	y3	total	% of year-class caught
geomean R	0.374	0.306	0.250	0.93	20%
high R	3.916	3.210	3.05	10.18	2%
low R	0.039	0.032	0.030	0.10	189%

However, it indicates that the impact of the shrimp fishery on *S. norvegicus* might be very substantial, even if it only occurs outside the 12nm zone. Unrealistic levels (more than 100%

of catches) indicates high uncertainty in calculations. The ratio *S. norvegicus/S. mentella* should, however, in first instance be re-calculated based on only small redfish less than 18 (20) cm in the ecosystem survey. Genetic analyses of juvenile redfish bycatch on the shrimp fields have been conducted in 2017 to estimate more precisely the redfish species ratios in areas where the shrimp fishery is going on. The results of those analyses are not yet available.

In accordance with precautionary approach (PA) "States shall be more cautious when information is uncertain, unreliable or inadequate. The absence of adequate scientific information shall not be used as a reason for postponing or failing to take conservation and management measures." In this case management decisions with lowest risk should be applied. It is also planned to continue to use 300 specimen/tonnes shrimp as the criterion in some areas outside 12nm where the contribution of *S. norvegicus* is known to be higher, e.g., Mehamnleira and Ingøydjupet.

Variation in consumption of redfish by cod in the Barents Sea during the period 1984-2016

Bjarte Bogstad, Institute of Marine Research, Bergen, Norway

WD to WKREDFISH, ICES 29 January- 2 February 2018

Introduction

In this document we describe the calculation of consumption of redfish by cod in the Barents Sea, and try to explain the observed variability during the period 1984-2016.

Material and methods

The consumption by cod of redfish and other prey species has been calculated annually back to 1984 (ICES, 2017), based on data from the joint Norwegian-Russian stomach content data base (Dolgov et al. 2007) and the methodology described by Bogstad and Mehl (1997). On average about 9000 stomachs are analysed. Most of the data are from surveys, but some data are also from commercial vessels. The coverage of samples ins generally poorest in the second quarter of the year. The consumption is calculated separately for cod ages 1-11+, three areas in the Barents Sea (west, east, north) and the first and second half of the year separately. The redfish has been separated into 5 length groups: 0-4 cm, 5-9 cm, 10-14 cm, 15-19 cm and 20 cm and larger. Most of the redfish eaten is between 5 and 25 cm, as seen from Fig. 1 (taken from Holt et al. in review). Only a minor part of the redfish found in cod stomachs is identified to species, and in these calculations all redfish species have been pooled. Most of the redfish found is believed to be *S. mentella*, which is the dominant species in the Barents Sea. *S. norvegicus* and *S. viviparus* are also found in cod stomachs

Fig.2 shows the consumption by year and redfish length group, while Fig. 3 and 4 show the consumption per cod (redfish biomass consumed divided by biomass of age 3 and older cod) compared to *S. mentella* winter survey indices (ICES AFWG tab. 6.16a) for length groups 5-14 and 15-24 cm. Fig.5 shows the cod abundance during the period.

Some observations:

The strong decline in abundance of young redfish from mid-1990s onwards due to the weak 1996-2003 year classes is reflected in the same way in the winter survey and in cod stomachs.

As could be expected, it is the smallest redfish length groups which first disappears from the stomachs and also the smallest length groups which first appear again after the period of recruitment failure.

The consumption of redfish by cod in the period after the recruitment failure is lower than before the recruitment failure, although the cod stock generally was higher during the latter

period. This is probably related to the large change in cod distribution area during the period, which has led to less overlap between cod and redfish after than before the recruitment failure, and possibly also higher abundance of alternative prey in the period after the recruitment failure. This is illustrated by Figs 6-7, showing:
Cod ((> 50 cm) and redfish distributions during the winter surveys 1994 and 2016
Cod and redfish distribution during the ecosystem surveys 2004 and 2015.

It should also be noted that the survey estimates prior to 1994 may be underestimates compared to later estimates due to changes in survey methodology. The gear was changed from bobbins to rockhopper in 1989, and in 1994 an inner net in the trawl was introduced (Jakobsen et al. 1997). Both of these changes are likely to increase the survey indices.

Conclusion

The high but variable consumption of redfish by cod indicates that it is important to take this into account in assessment of young redfish, especially in order to describe recruitment variability.

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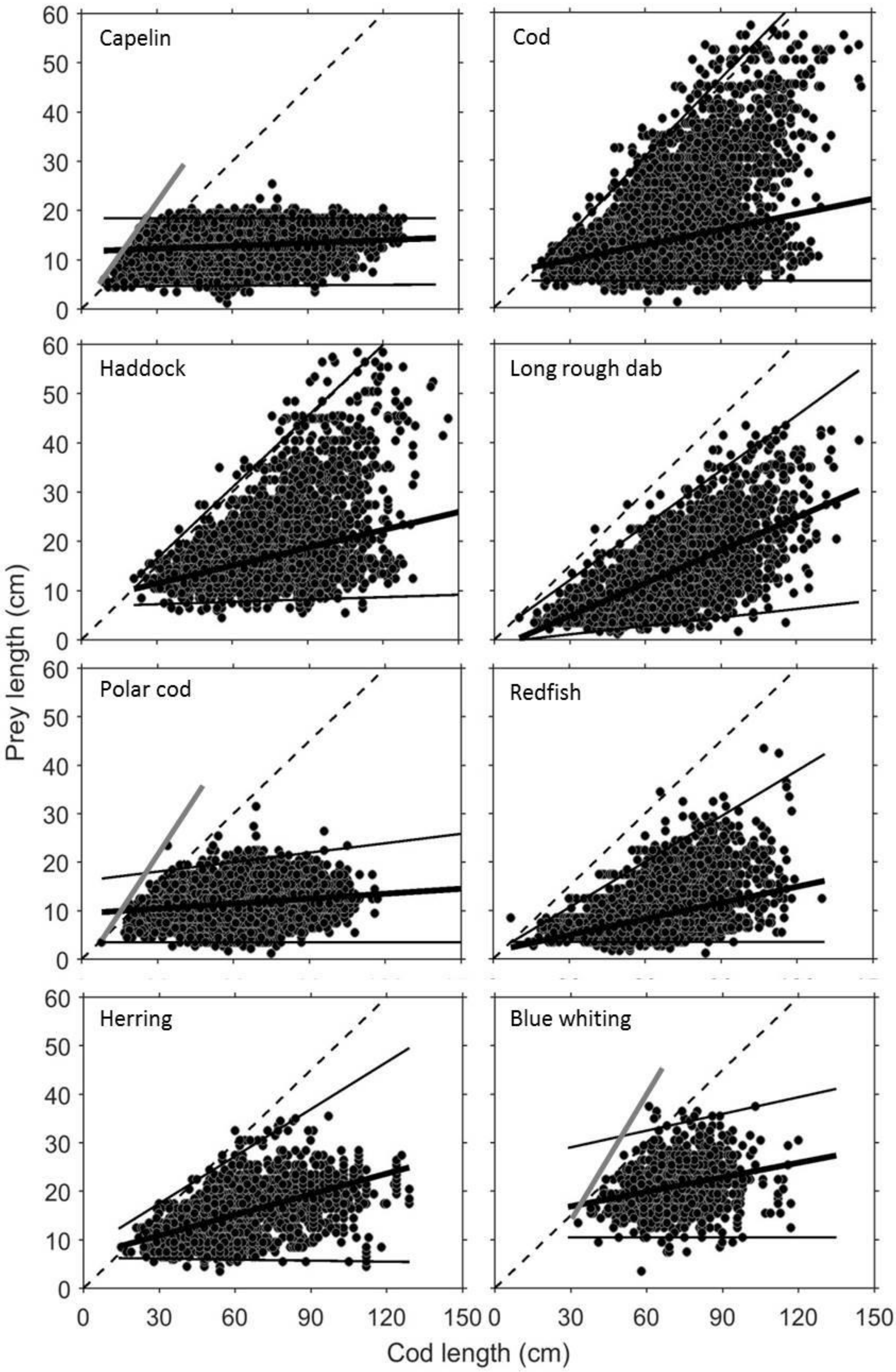


Figure 1. Cod lengths vs prey lengths, data for 1984-2016. Quantile regression lines: median regressions (thick black) and upper and lower bound regressions (thin black). Black dashed lines indicate the maximum prey size eaten by cod. Thick grey lines for capelin, polar cod and blue whiting illustrate the increasing size of prey eaten.

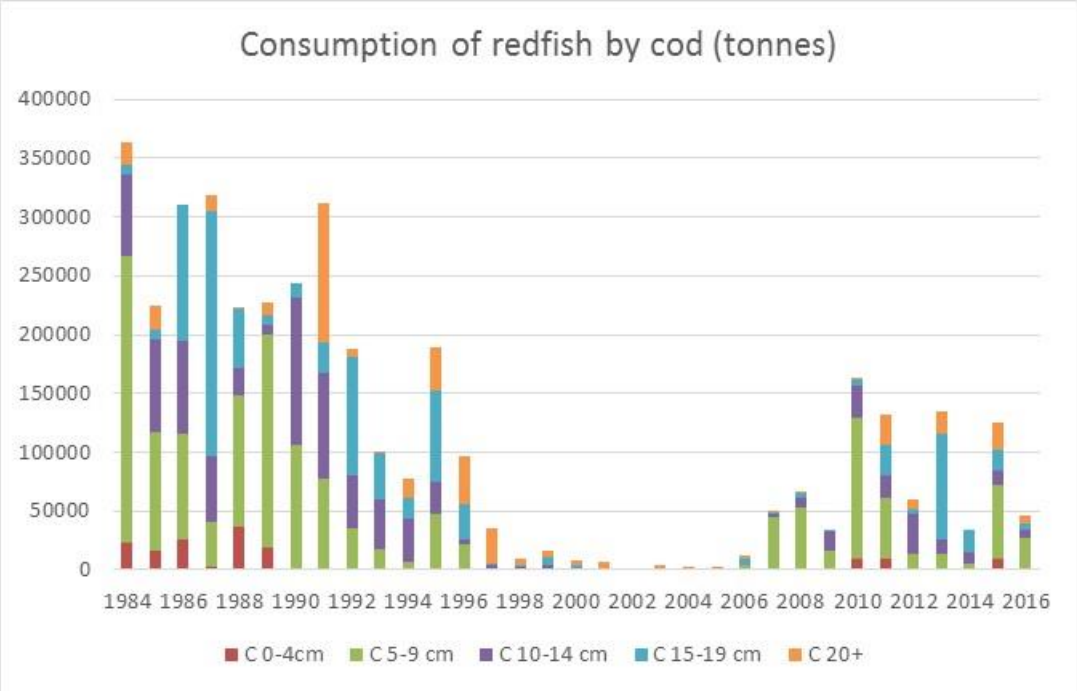


Fig. 2. Cod consumption of redfish, by year and redfish length group

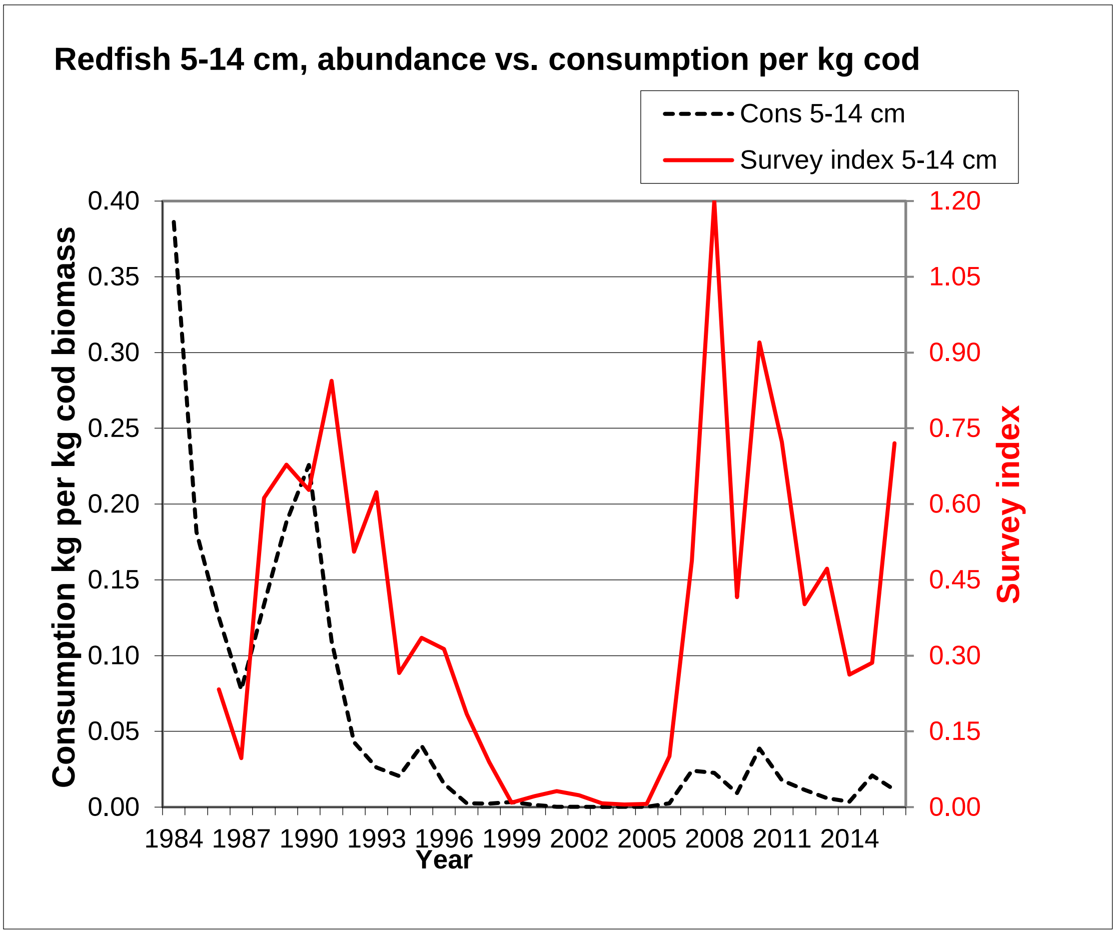


Fig 3. Redfish survey abundance (winter survey) vs. redfish consumption per cod for length group 5-14 cm

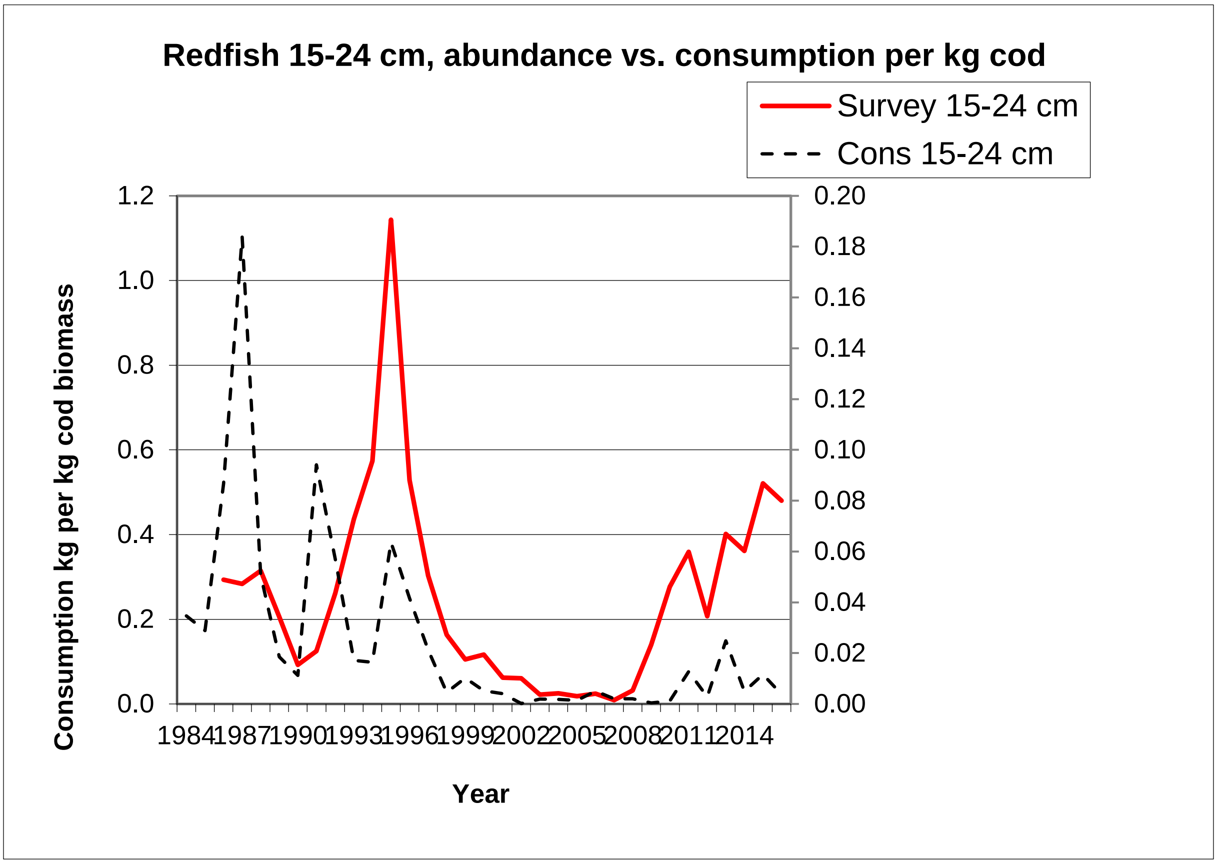


Fig 4. Redfish survey abundance (winter survey) vs. redfish consumption per cod for length group 15-24 cm

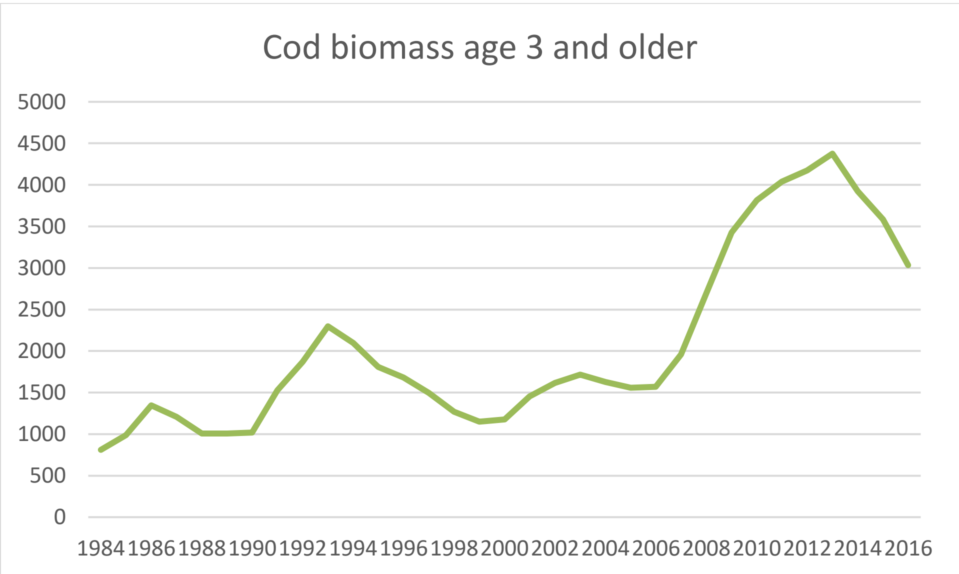


Fig. 5 Cod biomass (age 3+) 1984-2016

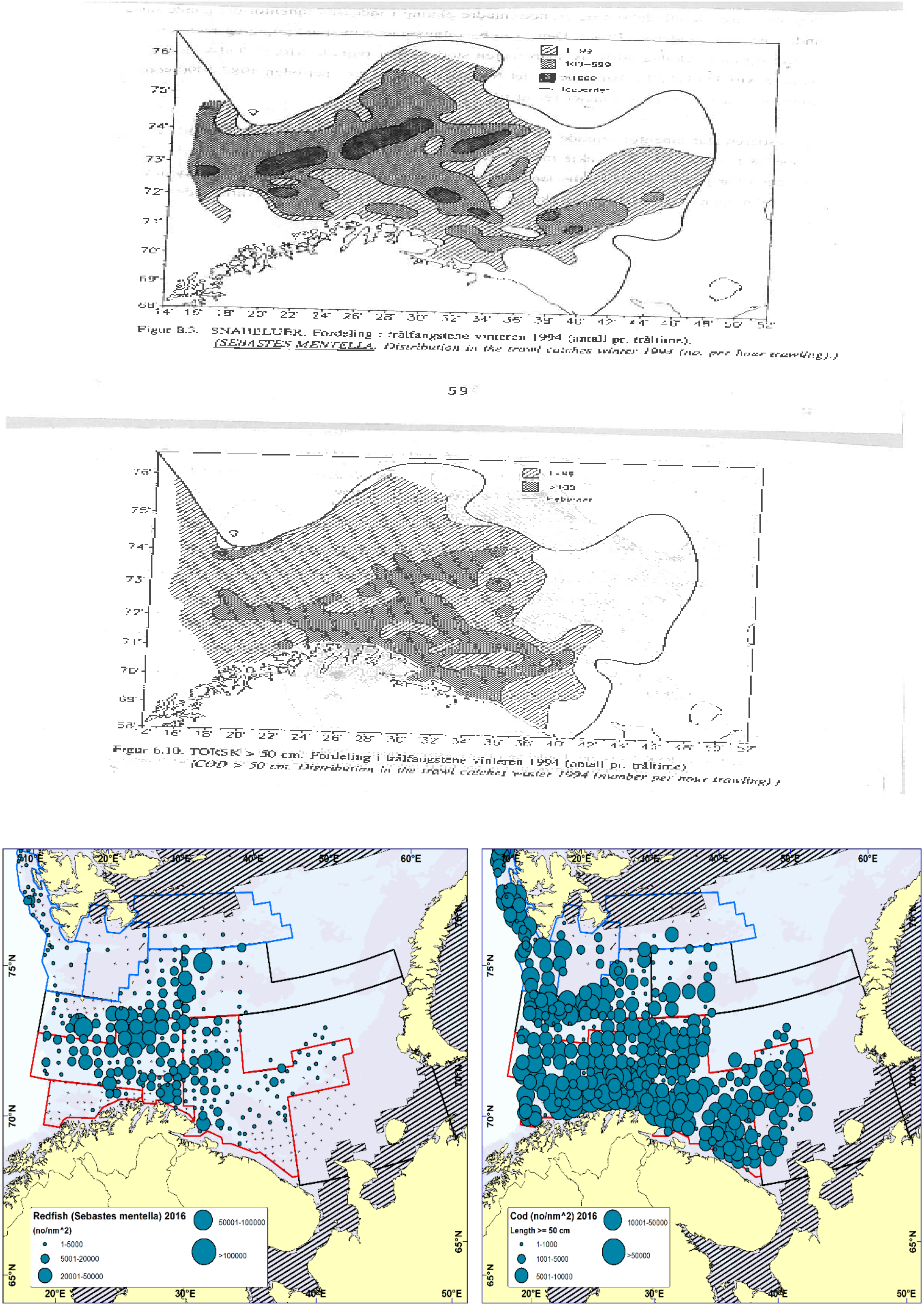


Fig. 6. Cod (>= 50 cm) and *S. mentella* distributions during the winter surveys 1994 (top) and 2016

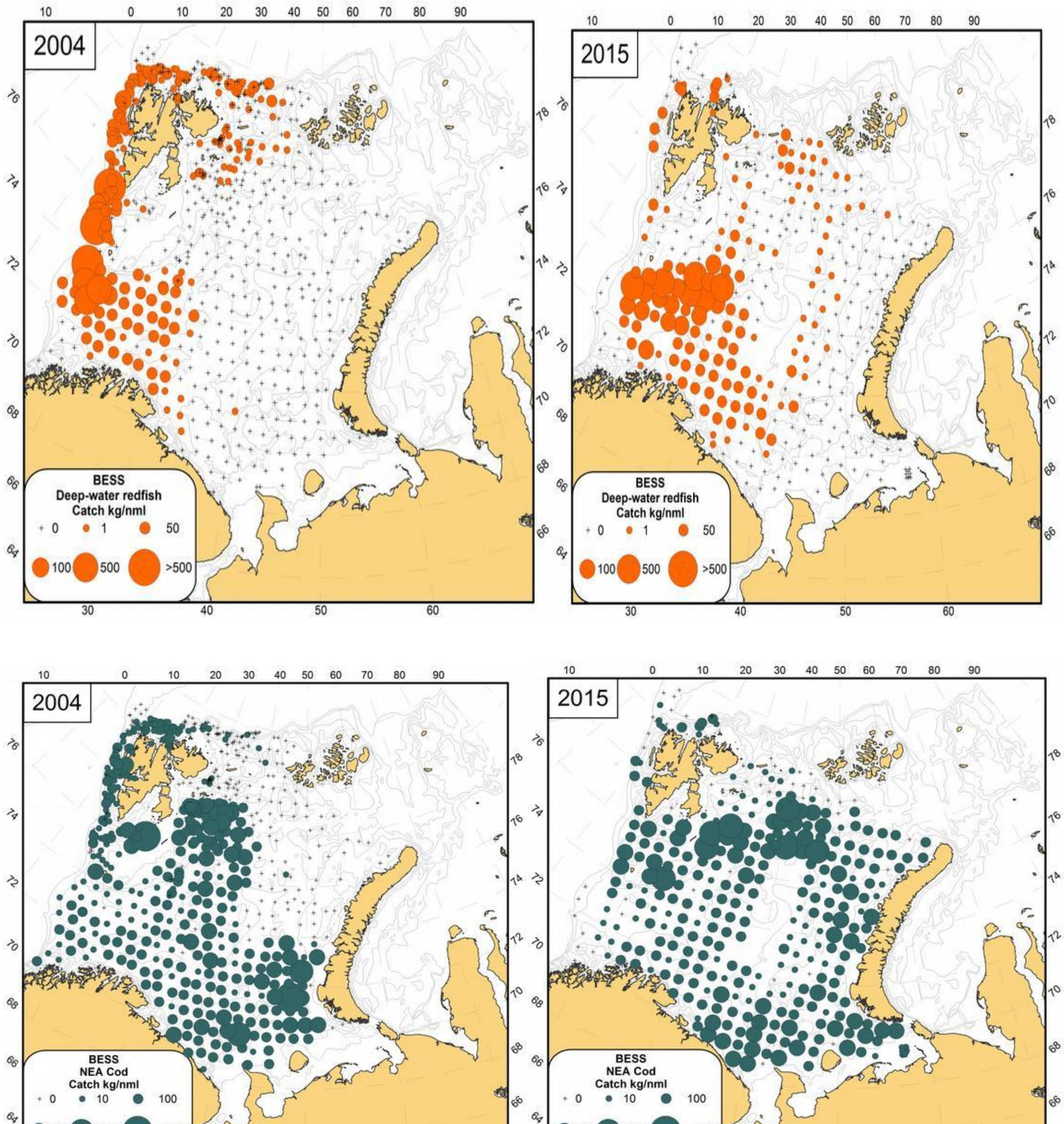


Fig 7. Geographical distribution of *S. mentella* (top) and cod (bottom) during the ecosystem surveys in 2004 and 2015. All size groups combined.

S. mentella – consumption by cod and recruitment

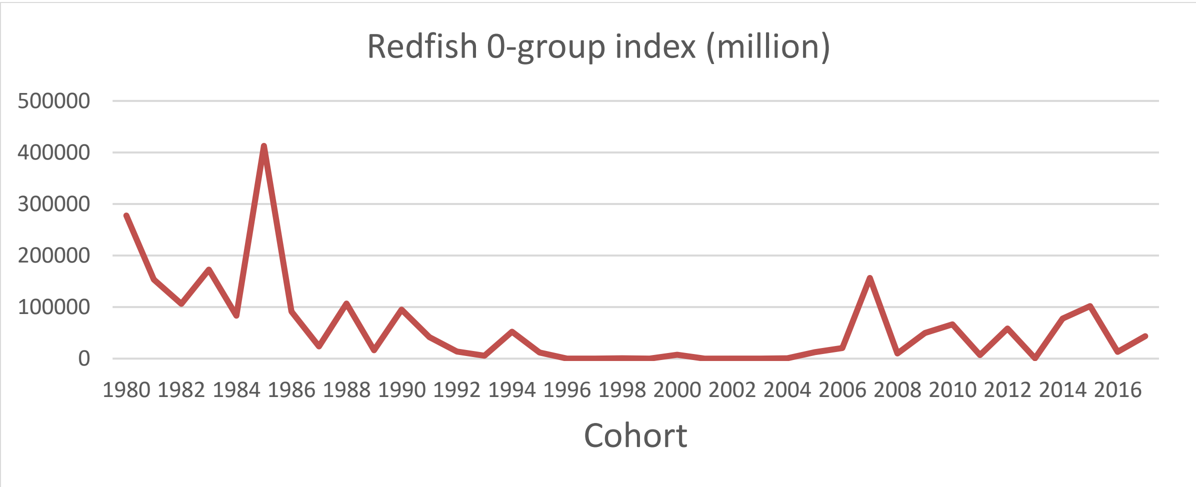
WD 7, WKREDFISH 2018. Bjarte Bogstad, IMR, Bergen, Norway

Introduction

The abundance estimates from 0-group indices (1980-present) and estimates of consumption of redfish by cod (1984-present) do not match the abundance at age for younger age groups in the most recent stock assessment for *S. mentella* (ICES, 2018) very well. We present an alternative stock history scenario which gives better fit to those data, by changing natural mortality on younger age groups. There are considerable differences (almost an order of magnitude for age 2 abundance) between the stock history from this scenario and the most recent stock assessment. The estimates of the fishable stock are hardly affected by these new data sources, but changes in recruitment dynamics may influence both reference points and analyses of the effect of by-catch of redfish in the shrimp fishery.

0-group abundance

Fig. 1 shows the 0-group indices for the cohorts 1980-present (ICES, 2017, Table 1.1, note that the 2012 value is now corrected) The 0-group survey is known to be quite noisy for redfish due to a very patchy distribution. However, the overall level of abundance viewed over several years should give an indication of the abundance at age 0. It should be noted that no correction for length-dependent catchability in the trawl has been applied to the number of 0-group redfish shown here. For other species (gadoids, herring, capelin), such correction factors have been applied (Eriksen et al. 2009; Prozorkevitch and Sunnanå 2017). As for the other species, the 0-group estimates without correction for length-dependent catchability for redfish are likely to be underestimates of abundance. The mean length of 0-group redfish is about 4 cm, less than for several of the other species except capelin. A correction (scaling) factor of 4 has been suggested as a reasonable overall (not length-dependent) factor to use for redfish (E. Eriksen, IMR, pers. comm.) Redfish 0-group is not identified to species, but it is strongly believed that most of it is *S. mentella*.



Consumption by cod

The consumption by cod of redfish and other prey species has been calculated annually back to 1984 (ICES, 2017), for details see WD6. The consumption estimates seem in the correct range compared to growth rates (Bogstad and Mehl 1997), and no particular bias towards over or underestimating the proportion of redfish in the diet is known. Most of the redfish found in cod stomachs is between 5 and 25 cm. We assume that redfish > 25 cm corresponds to age 9 and older redfish and calculate the biomass removed due to M (M-output-biomass, MOB, Bogstad et al. 2000, Hamre and Tjelmeland 1982) for ages 2-8.
The formula for calculation of MOB is given below:

$$MOB(y) = \sum_{amin}^{amax} \frac{N(a,y)M(a,y) * 0.5 * (w(a,y) + w(a+1,y+1)) * (1 - \exp(-Z(a,y))}{Z(a,y)}$$

Extending the age 2 winter survey series

For the winter survey, age 2 estimates are only available for the years 1992-2011 while estimates of 5-9 cm fish are available from 1986-present. We found a high correlation between abundance of 5-9cm fish and abundance at age 2 in this survey, as shown in Fig. 2. Fig 3 shows the age 2 and 5-9cm abundance by year, as well as the abundance by year obtained by the regression shown in Fig. 2. The age 2 values from the regression for the years 1986-1991 and 2012-2016 are used for comparisons with 0-group indices and age 2 abundance from assessments and scenarios later in this paper.

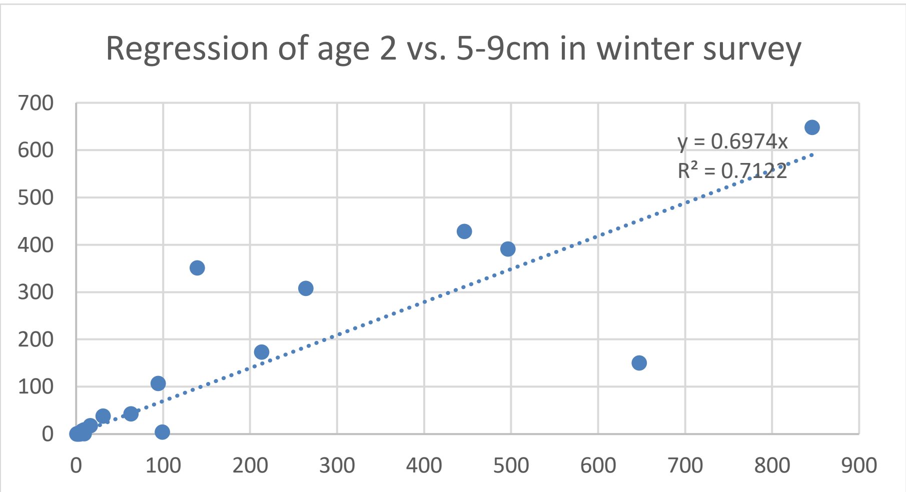


Fig. 2 Regression of age 2 vs 5-9 cm fish abundance in the winter survey. Years 1992-2011.

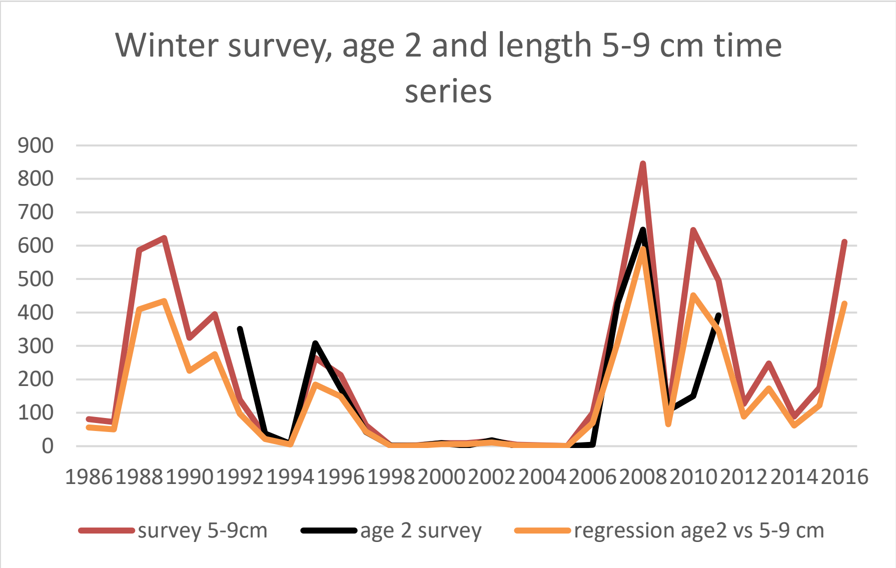


Fig 3. Time series of 5-9cm fish and age 2 fish from the winter survey as well as time series of age 2 fish based on the regression in Fig. 2.

Scenario with higher M

To investigate how the stock history would look with a higher M, we investigated the following scenario. Assume that M decreases linearly from some given value (M02) at age 2 to 0.05 at age 9. M02 was set to 0.75 for the period 1984-1995 and 0.40 for the period 1996-2016. Then we kept the age 9 values from the WKREDFISH assessment and back-calculated to age 2 using Pope's formula. For the cohorts 2008-2014 (ages 2-8 in 2016) we similarly back-calculated them from 2016 values at age 2-8 set so that the strength of these year classes at age 2 relative to the other year classes was approximately the same as in the WKREDFISH assessment.

The split into two periods is based on the observed lower abundance of redfish in cod stomachs during the second part of the period 1984-present than the first part (see WD6). The timing of the split between the first and second period is somewhat arbitrary, as it comes during the period of low recruitment where the data available give little information on the choice of M value.

Comparison of scenario with higher M to WKREDFISH

In order to compare the WKREDFISH assessment and the scenario with higher M, we calculated and compared the following quantities:

0-group index (left axis), age 2 from winter survey and age 2 from assessment and scenario (Fig 4)

Mortality 0-group survey to age 2 from assessment and scenario (Fig. 5)

Winter survey catchability at age from assessment and scenario (Fig. 6 and 7)

MOB vs. consumption by cod from assessment and scenario (Fig. 8)

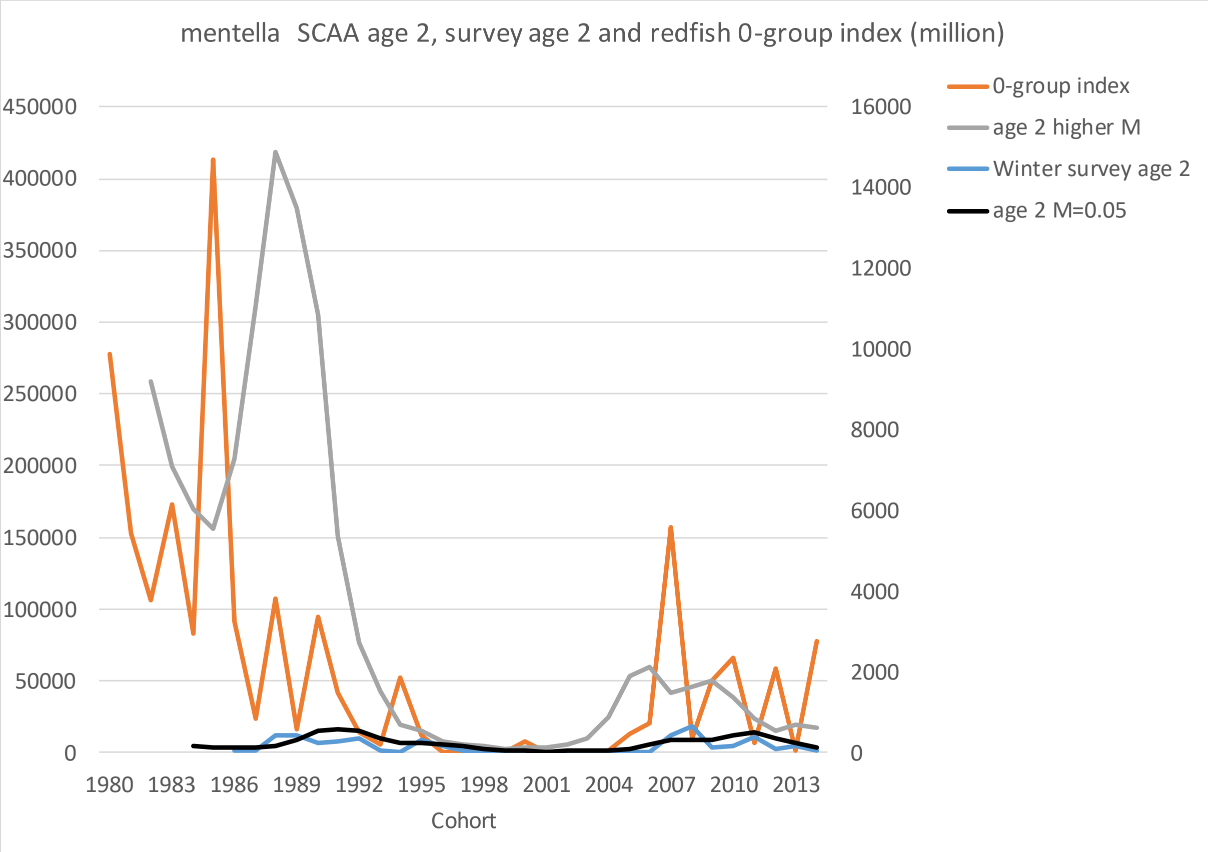


Fig. 4. 0-group index (left axis), age 2 from winter survey and age 2 from assessment and scenario (all right axis)

Fig 4. shows that for the weak cohorts 1996-2003, the 0-group index was also very low. Further, the winter survey estimates at age 2 are somewhat lower, but mostly in the same range as the age 2 estimates from the 2017 assessment. The age 2 estimates from the scenario are, however, much higher than the winter survey estimates. Considering that up to 80% of the young redfish may be in the pelagic layer and thus not accessible to the bottom trawl (Nedreaas, check reference), and that there is some gear selectivity for such small fish (cf. relationship between winter survey indices and stock abundance for young cod, Bogstad et al. 2016) the scenario estimates are not unreasonable. The peaks in abundance for age 2 is slightly shifted between the two sets of M values because in the high M scenario the M is variable between the periods 1984-1995 and 1996-2016.

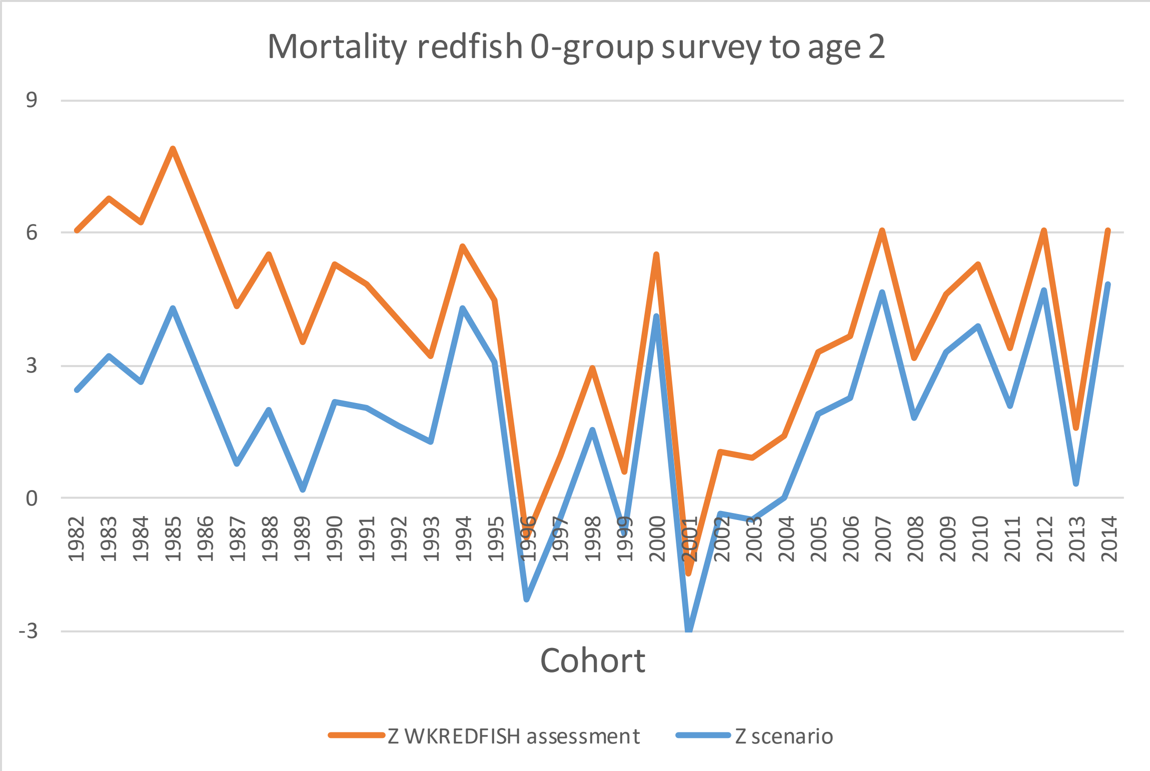


Fig. 5 Mortality from 0-group survey to age 2 from assessment and scenario.

As for what is reasonable mortality levels for young fish, Bogstad et al. (2016) compared the abundance of cod at different life stages, and found that the mean abundance of 0-group (corrected for length dependence) and age 3 (VPA), indicates a mortality of 4.9 from 0-group to age 3 (corresponding to cod lengths of about 7 and 30 cm, respectively). Note that the applying suggested scaling factor of 4 for 0-group redfish means an additional mortality of approximately 1.4! The very noisy mortality estimates for the very weak cohorts 1996-2003 should not be given much consideration.

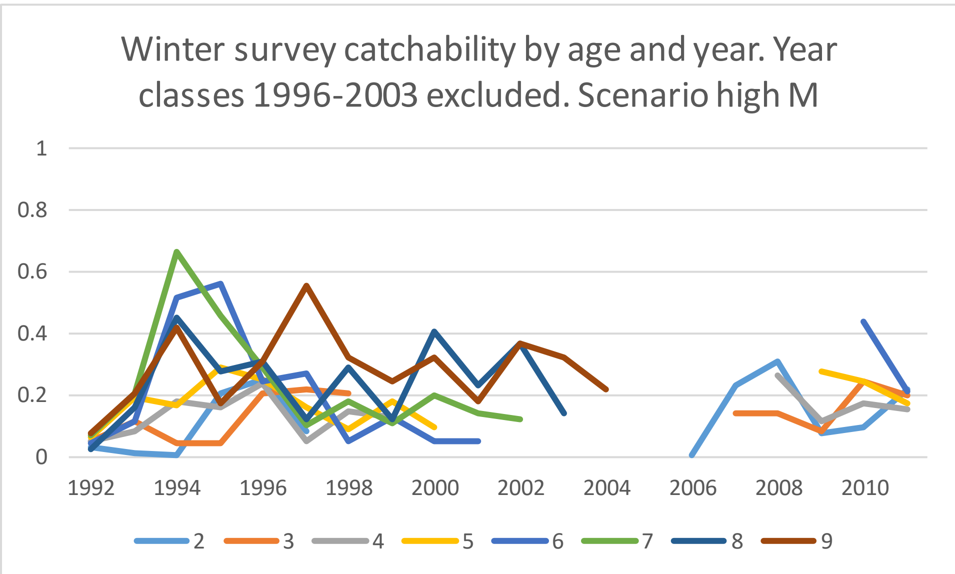


Fig. 6a,b. Winter survey catchability by year and age from assessment (upper) and scenario (lower)). Weak cohorts excluded.

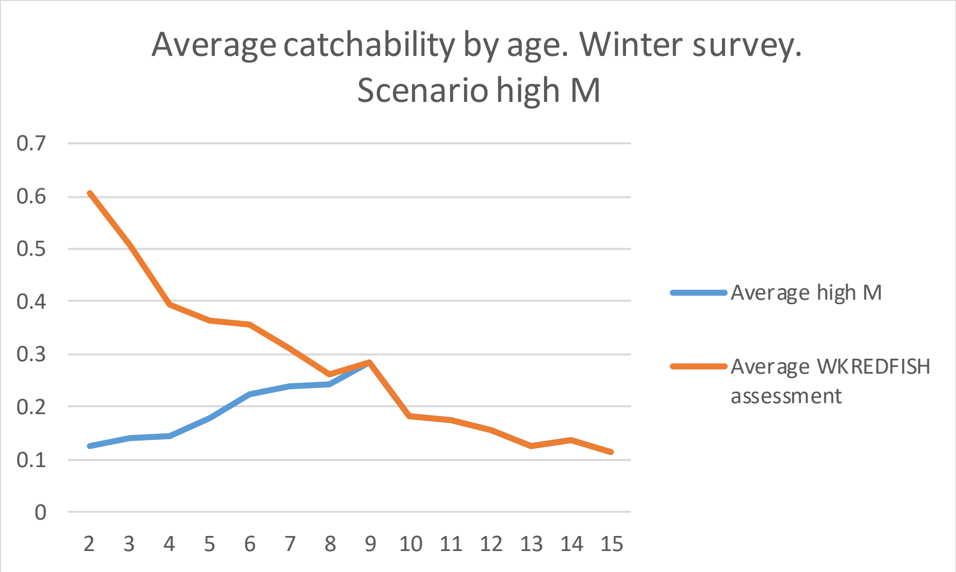


Fig. 7. Winter survey catchability by age, average over year. Weak cohorts excluded.

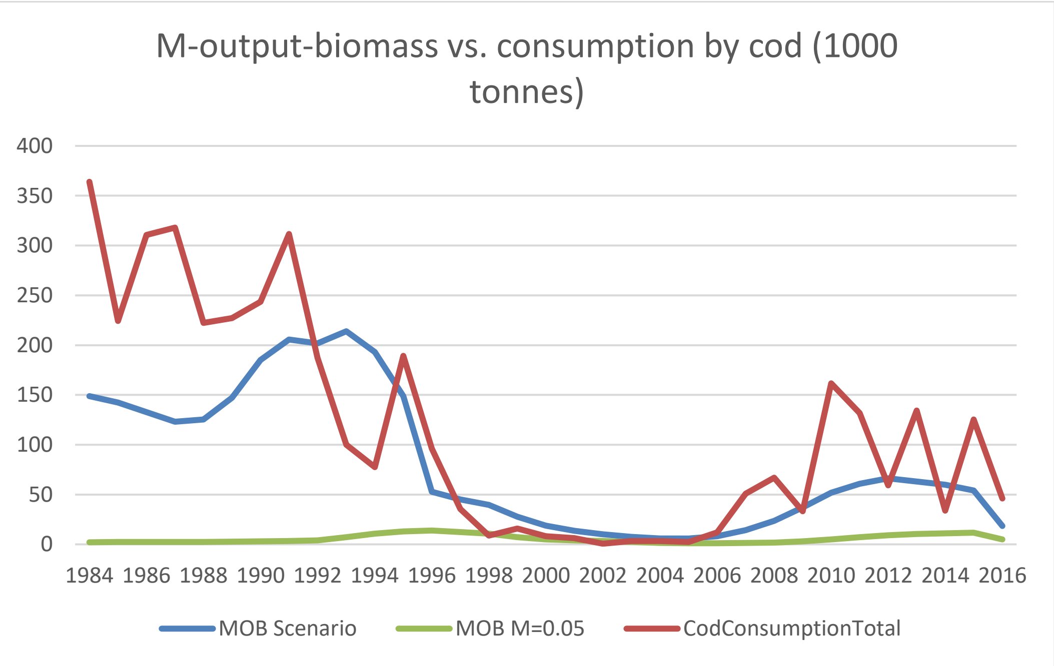


Fig. 8. MOB vs. consumption by cod from assessment and scenario

Note that:

This shows an order of magnitude difference between the consumption and MOB estimates with M=0.05, with the MOB estimates being much lower. The MOB estimates with higher M seems to be in a reasonable range compared to the consumption estimates. Some of the consumption by cod is of redfish outside the age range 2-8, as well as of other redfish species. However, cod can not be the only source of mortality for young redfish. There are also other sources of mortality than predation by cod, other predators as well as by-catch in the shrimp fishery.

Some points

Estimates of consumption by cod indicate that M on young age groups of redfish may be considerably higher than 0.05. How much higher is very difficult to estimate, though some reasonable upper bound could probably be given.

Age 2 abundance estimates obtained by back-calculation from age 9 using a higher M give more reasonable mortalities from age 0 to 2 as well as more reasonable catchability values for the

A higher M on younger fish implies dome-shaped selectivity for the winter survey (lowest on youngest fish), which sounds reasonable in view of gear selectivity and migration out of the area at ages around age at first maturation.

The higher values of M suggested from the scenario presented here are in conflict with the values of M around 0.05 estimated by Planque et al. (2012) and also in profiling of overall M values made before this meeting.

A comparison of consumption of redfish by cod to historic by-catches of redfish in the shrimp fishery should also be made in connection with evaluating the special request on by-catch in the shrimp fishery.

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